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NEW ENGLAND NOTE

DECEMBER LEAF OUT OF *FRANGULA ALNUS* (RHAMNACEAE) IN EASTERN MASSACHUSETTS

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Frangula alnus Mill. (glossy buckthorn; hereafter "buckthorn") is an invasive shrub that has become widespread across the northeastern US and southeastern Canada over the last century. Buckthorn is native to Europe, and genetic analyses suggest that populations in the northeastern US likely originated in western Europe (De Kort et al. 2016). Buckthorn rapidly forms dense thickets, reducing light availability and thus inhibiting regeneration of native species (e.g., Fagan and Peart 2004; Frappier et al. 2003a). Given the potential impact of buckthorn on forest composition and stand dynamics, a number of studies have examined its ecology and management (e.g., Burnham and Lee 2010; Catling and Porebski 1994; Converse 1984; Cunard and Lee 2009; Frappier et al. 2003b, 2004; Hamelin et al. 2015, 2017; Koning and Singleton 2013; Lee and Thompson 2012; McDonald et al. 2008).

In early December of 2015 I observed buckthorn plants leafing out over a span of several weeks in eastern Massachusetts. A strong El Niño contributed to record-breaking warmth across much of the northeastern US (NOAA 2016), with Boston experiencing many days in December with daily high temperatures 5-10°C warmer than normal (Figure 1). That observation prompted this opportunistic study in which I paired continued field observations with a laboratory experiment. The objectives of the study were to investigate why leaf out occurred at this time and to evaluate whether leafing out in December had lasting consequences for buckthorn. The findings provide new insights and raise new questions about (1) the causes and costs of off-season leaf out, (2) the ecology of buckthorn, and (3) the dynamics of nonnative species and climatic variability.

The study site is located in the northwestern part of the Middlesex Fells Reservation (hereafter "the Fells") in the town of Winchester, ~10 km northwest of Boston. The buckthorns observed in this study

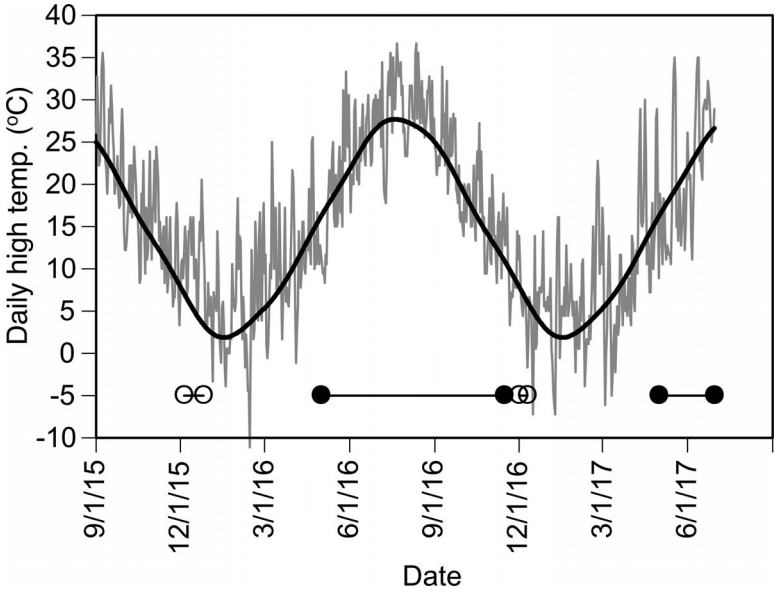

Figure 1. Daily high temperature values for Boston, MA; thin gray line represents values for September 15, 2015 through June 30, 2017, thick black line represents average values for 1981-2010 (http://www.usclimatedata.com). Circles and lines represent periods when leaves were present on glossy buckthorns in the Middlesex Fells Reservation, Winchester, MA; closed circles represent the normal growing season, open circles represent off-season leaf out.

occur along a 20-m segment of the Skyline Trail on the western side of Money Hill, a rocky outcrop with thin soils, just north of North Reservoir (42.467°N, -71.117°W, 60 m). In addition to buckthorn, the forest surrounding the study site features *Quercus rubra* L. (northern red oak), *Pinus strobus* L. (white pine), *Acer rubrum* P.Watson (red maple), *Carya ovata* (Mill.) K.Koch (shagbark hickory), *Fraxinus americana* L. (white ash), *Hamamelis virginiana* L. (American witch hazel), *Smilax rotundifolia* L. (roundleaf greenbrier), *Viburnum acerifolium* L. (mapleleaf viburnum), *Toxicodendron radicans* (L.) Kuntze (eastern poison ivy), and *Celastrus scandens* L. (American bittersweet).

In early December of 2015 I observed newly leafed-out buckthorns at several locations in the northwestern part of the Fells. I also noticed buckthorn leafing out in Boxford State Forest in the town of Boxford, ~20 km northeast of the Fells. Buckthorns did not leaf out at this time at the Harvard Forest in north-central Massachusetts (A. Barker

Table 1. Characteristics of glossy buckthorns in the Middlesex Fells Reservation, Winchester, MA monitored after off-season leaf out in December 2015.

Plant	Height (m)	Diameter (cm)	Total Leaf Weight (g)	Number of Leaves	Mean Leaf Length (cm)	% Yellow Leaves	Status 6/30/2017
A	2.4	1.5	2.1	121	3.2	12.4	dead, 3 sprouts
B	2.7	2.5	0.9	65	2.9	10.8	live
C	2.1	1.5	2.8	162	3.1	17.9	dead, 2 sprouts
D	3.3	3.0	0.8	75	2.3	97.3	live
E	3.2	3.0	1.1	119	2.0	83.2	upper half dead

Plotkin, Harvard Forest, pers. comm.). I did not observe other species leafing out at this time. I placed tags on the stems of five leafed-out buckthorns in the Fells study site so that they could be identified for future analysis. Those plants ranged in height from 2.1 to 3.3 m, and their diameters varied from 1.5 to 3 cm (Table 1). I returned to the study site regularly throughout the month of December 2015 and continued to observe leaves on the buckthorns.

To assess the cost of off-season leaf out to the buckthorns, I attempted to quantify their investment in leaves. On December 27, 2015, with cold temperatures forecast for the following day, I removed all leaves from the five tagged buckthorns. Temperatures fell below 0°C for the next three days, killing the leaves of all other leafed-out buckthorns near the study site. I obtained digital images of the harvested leaves using a flatbed scanner, then measured the length of each leaf using ImageJ software (https://imagej.net/ImageJ). I then measured the total mass of the leaves for each of the five plants after drying them overnight in a warm (90°C) oven.

I continued to observe the tagged buckthorns regularly (every 1-2 months) between December 2015 and June 2017, visiting them weekly in April of 2016 and 2017. I noted that the buckthorns experienced springtime leaf out during the last week of April in both of those years (Figure 1). I also observed newly leafed-out buckthorns, including one of the tagged plants, in the northwestern Fells during the first week of December 2016. I compared the timing of springtime and winter buckthorn leaf out with meteorological data from Boston (https://www.wunderground.com/history/airport/KBOS).

In addition to the observational study, I carried out a laboratory experiment, following the methods of Polgar et al. (2013), to test the chilling requirement of buckthorn relative to two other species: American witch hazel and American bittersweet. I collected 10 dormant twigs from each of these three species near the study site on January 7-13 and March 11, 2016. The twigs were approximately 40 cm in length. After each collection, the twigs were brought to a laboratory, placed in containers filled with tap water, and exposed to a grow light for 14 hours per day. The laboratory was maintained at 22°C, and each week I changed the water in the containers and re-cut the base of each stem to enable the twigs to keep taking up water. I calculated the time between collection and leaf-out dates for each of the three species for both collection periods.

The laboratory experiment and field observations indicate that buckthorn has little to no chilling requirement. For American witch hazel and American bittersweet the time to leaf out between the January and March collection dates differed by at least two weeks (33-35 days in January, 19 days for both in March), but in the case of buckthorn the time to leaf out was nearly identical (27 days in January, 26 days in March; Figure 2). This finding is consistent with the observed leaf out of some buckthorns in early December 2015 and 2016 (Figure 1). It appears that leaf out is triggered by temperatures of around 15°C for a period of 2-4 weeks.

The leaf-out event of December 2015 represents a substantial resource investment by the buckthorn plants. The number of leaves produced by the buckthorns that I sampled in late December ranged from 65 to 162 per plant, and the total leaf mass per plant varied from 0.8 to 2.8 g (Table 1). The leaves were quite small (averaging 2-4 cm in length) compared with the size typically achieved in summer (generally 9-10 cm long). Some leaves had changed from green to yellow by the time of collection, indicating break down of chlorophyll and resorption of nutrients, but the proportion of yellow leaves varied greatly across the five sampled plants (from 10 to 97%; Table 1).

Of the five plants that I observed starting in December 2015, all leafed out in late April of 2016. However, by late April of 2017 two of those buckthorns were dead and another was in poor condition, with leaves occurring on just a few branches on the lower half of the plant. The other two plants appeared healthy and had produced flowers.

By leafing out in December, these buckthorns are able to carry out photosynthesis during a time when they are not shaded by the forest canopy. However, day length is relatively short in December, and it appears that any short-term carbon gain is outweighed by the loss of

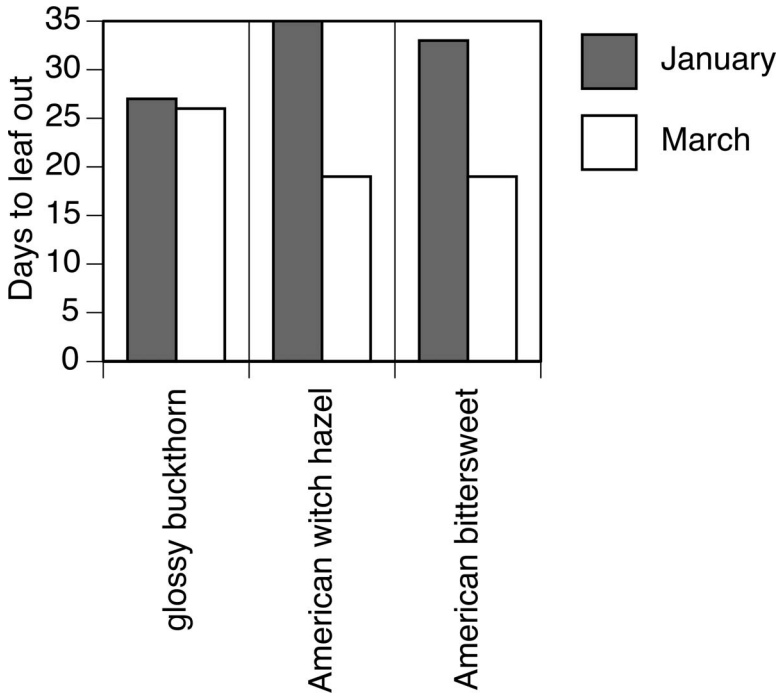

Figure 2. Results of a leaf-out phenology experiment in which dormant twigs of three species (glossy buckthorn, American witch hazel, and American bittersweet; 10 twigs for each species) were collected in the Middlesex Fells Reservation, Winchester, MA at two times (January 7-13 and March 11, 2016) and brought to a laboratory (22°C, 14 hours of light per day) for observation of the number of days to leaf out.

buds to off-season leaf out and resources required to produce a new set of buds and leaves. The two plants that died were relatively small (<2 cm in diameter), and it may be the case that larger buckthorns have larger resource reserves that can be drawn upon in this type of circumstance. On the other hand, both of the buckthorns that were found dead in April 2017 had 2-3 vegetative sprouts growing from their bases, effectively replacing the dead stems.

As a species native to Europe, buckthorn is not adapted to the environmental signals that control the leaf-out phenology of species native to southern New England. Thus, some buckthorn plants in eastern Massachusetts responded to the unusually warm temperatures of December 2015 by leafing out and maintaining those leaves for a period of nearly four weeks. While leafing out during a time of year

when neighboring plants are dormant may afford those buckthorns an opportunity for extra photosynthetic activity, the mortality of a sizable proportion of the observed plants suggests that any benefit is outweighed by the detrimental resource costs of off-season leaf out. However, several factors indicate that buckthorn populations will continue to expand despite any setback due to leafing out in December 2015: (1) not all buckthorns in the vicinity of the study site leafed out during this event; (2) most of the larger buckthorns that did leaf out have not shown any sign of negative consequences; and (3) the plants that died are experiencing vegetative sprouting from their bases. While limited in scope, this study raises new questions about the dynamics of nonnative species and climatic variability, and future research should continue to analyze the triggers and consequences of off-season leaf out for buckthorn and other nonnative species.

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