**From my thesis proposal:**

*From abstract:* Using herbarium records from throughout North America, I will estimate the rate of spatial spread of *F. alnus* and incorporate this estimate into my demographic model as the rate of dispersal. I will also use herbarium records to estimate an observed lag-time for *F. alnus* (*sensu* Catling & Porebski 1994 and Kowarik 1995), and will compare this estimate of lag-time to the ‘inherent’ lag-time described above. Finally, in conjunction with estimates of past land-use and land-disturbance, I will use herbarium records to estimate the effects of disturbance on the spread of *F. alnus.* Coupling the demographic model, informed by the statistical model of spread rate, with an SDM (see below) I will simulate the spatial spread of *F. alnus* from the time of first reported introduction to the present. I will test the accuracy of this simulation by comparing the results to the current spatial distribution of *F. alnus* based on presence records from publicly accessible databases, published literature, and unpublished reports. Preliminary data collection has yielded more than 1000 such presence records throughout northeast North America.

*From Introduction:* Retrospective spatial analyses have been used to help understand ecological processes involved in the spread of invasive non-native species in a novel region. For example, in multiple studies of different invasive plants and in different regions researchers used herbarium records to estimate rates of spread for invasive non-native species (Miller et al. 2009; Aikio et al. 2010). These data have also been used in conjunction with information on land-use to assess the influence of past land-use management on invasion success (McDonald et al. 2008; Mosher et al. 2009). Thus, these data can be used to approximate parameters describing the ecological process of dispersal and success of colonization. Integrating these results with a demographic model and a SDM for a species can result in a better predictive model than any of these models alone.

*Section 2:* The patterns and processes of range expansion are important areas of research for any species invasion (Sakai et al. 2001), and a great deal of research has gone into this (Pyšek & Hulme 2005). Herbarium records can be used to estimate rates of spread through time and space in an introduced region, and methods have been developed that account for imperfect records (e.g., sample bias: Miller et al. 2009; Aikio et al. 2010). Approximating the rate of spread of *F. alnus* through out North America is an important component of my project. I will examine the rate of spread throughout northeast North America by reconstructing the pattern of establishment and range expansion based on herbaria records and early range descriptions found in the literature, *sensu* Catling and Porebski (1994). I have started this process and presented preliminary results at the E&E Retreat 2010. To date I have collected spatial information from 582 herbarium records (Table 2). I continue to collect additional records for *F. alnus*, and will begin to collect records for ecologically similar species to address sampling bias, using the methods outlined below.

Historical presence records can be used to elucidate more than rates of spread rate. Established statistical methods (e.g., SDM, multivariate analysis) can be used to estimate environmental correlates using these records as well. Often a limitation to the usefulness of these methods is the availability of historical environmental conditions. Recently, models of historical land-use have been developed that predict past land-use patterns based on population size trends (Klein Goldewijk et al. 2010a, 2010b). These models reconstruct patterns of land use that encompasses the whole time period of *F. alnus* invasion (i.e., mid 19th century on) and have a spatial resolution of 5 arc-minutes. In addition to these models, in the United States there are some data available through the USGS for land-use since ca. 1970.

I hypothesize that disturbance (land-use change from natural land cover to human-dominated land cover) is an important predictor of the establishment of *F. alnus*. As an initial analysis, I will use logistic regression to test this hypothesis. In addition to land-use change, other predictor variables may be a measure of disturbance intensity, probability of transition between land-use categories, distance to past *F. alnus* infestations, or other measure that arise in the course of my research. Similar analyses have been applied to investigate the effects of land-use change on presence of invasive species in other studies (McDonald et al. 2008; Mosher et al. 2009). Land- use change will be approximated using the two data sets discussed above. With historical herbaria and presence records I will create annual maps depicting invaded and non-invaded areas of *F. alnus*. As a time series, these maps will represent transition from a non-invaded to invaded state. The time of invasion for an area will be determined using the temporal information acquired from herbarium accession records. The earliest reported accession will be considered the time of invasion. I will carryout this analysis at a spatial resolution of 5 arc-minutes (approx. 10km2), as this resolution fits with the accuracy of both predictor and response variables being used, and it is consistent with findings for this species at a local scale in central and western Massachusetts (McDonald et al. 2006; McDonald et al. 2008). For my higher temporal resolution data set (USGS) I can also test for an effect of time since land-use change. The HYDE data set, on the other hand, has a temporal resolution of 10 years, and this may not be fine enough to test for temporal effects. Because many ecological relationships are not linear, I am also considering using non-linear methods. While non-linear methods are well established, I have not reviewed this literature extensively as of yet.

Herbarium records are subject to both temporal and spatial biases in specimen collection, resulting from uneven sampling intensity in time and in space (Delisle et al. 2003). These biases may result in patterns of spatial and temporal correlation among specimens that are not biologically relevant. It is particularly important that I account for these biases, as I expect many of the ecological processes (e.g., dispersal) intrinsic to species invasions yield spatially and/or temporally correlated patterns. One way to test for these biases is to compare specimen observations to a simulated null model (e.g., Aikio et al. 2010). Aikio et al. created a null model by randomizing the species identity and acquisition date information among the spatial data for all herbarium records used. In this study, the authors were working with more than one species. However, in my study I am primarily concerned with records for only one species. I will randomize those acquisition data, and thus test for temporal correlation of specimen collection, but must also apply other methods to address spatial correlation. Miller et al. (2009) developed a method to address this form of bias, which involves comparing herbarium records of the species of interest with common native species with similar habitat requirements. Common native plants should be at equilibrium with their environment (i.e., inhabit all potential habitat), and therefore, any change in the number of acquisitions should represent a change in sampling effort, rather than a change in distribution. I will follow similar methods to test for spatial bias in my collected records. Two candidate species that other researchers have used as native comparisons with *F. alnus* are *Rhamnus alnifolia* (Alder-leaf Buckthorn) (Catling & Porebski 1994) or *Viburnum dentatum* (Arrow-wood) (Sanford et al. 2003). I will collect herbarium records for these native species from the same herbaria that I collected the *F. alnus* data from.

It may be possible to use information indicating transition from invaded to non-invaded to further examine aspects of uneven sampling intensity. Ecologically, it is unlikely that an area, once invaded, will no longer have *F. alnus* in it (for a variety of reasons, that can be further explained). Thus, if an area transitions to un-invaded, then it most likely indicates a lack of collection of *F. alnus* for some reason other than its disappearance.

**From notes on Herbarium Data Collection (originally a google doc I started when doing this project for Northeast Natural History Conference and ESA 2012)**

***Frangula alnus* Initial Introduction**

I have for sometime claimed that southern Ontario is often considered the initial introduction of *Frangula alnus* into northeastern North America.  I made this claim based on what I had read in Frappier et al. 2003 (REF For Ecol Manage) - “Introduced in Canada in the late 1800s, it has spread throughout the northeastern United States and adjacent Canada”.  Frappier et al. cite Converse 1984 and Catling and Porebski 1994 as supporting this statement.  Catling and Porebski (REF 1994) do indeed address the early establishment of *F. alnus*, but there analysis is restricted to its presence in Canada, and to southern Ontario in particular.  They assert that the “earliest collections in Ontario were from the period around the turn of the century”, and particularly from London in 1898 and Ottawa in 1899 and Guelph in 1906.  Converse (REF 1984) does not make any specific mention of location of introduction and claims that introduction likely occurred prior to 1800, which is a claim my findings to-date cannot support.

Howell et al. (REF 1977) reviewed the history of *F. alnus* (referred to as *Rhamnus frangula*) in the Ohio flora.  In their review of the Ohio flora literature they find no reference or mention of the presence of *F. alnus* in descriptions from the 1800’s or the early 1900’s.  The first reference to *F. alnus* is in 1932, from Schaffner’s *Revised Catalog of Ohio Vascular Plants*, which cites collection of this plant from Lake County by Beardlee and Tyler.  The authors of this paper found that the herbarium specimens associated with this claim are in the Oberlin Herbarium and noted as from 1927.  The notes for this specimen include comments suggesting that the species is well established at the collection site - “Becoming well established in Lake County”.

Based on my examination of herbarium records, the initial introduction of *F. alnus* most likely occurred late in the 19th century in the metropolitan New York, NY area.  The earliest record is from 1879, from Hudson County, New Jersey.  All of the records from the 1880’s are from the New York - New Jersey area.  In the late 1890’s and early 1900’s the first records outside of the New York area appear, from southern Ontario and Indiana.  Interestingly, these early records all occur in close proximity to the Great Lakes, suggesting a possible connection between common trade routes (via the Erie Canal).

Based on the ecology of this species, it is highly unlikely that dispersal of *F. alnus* from the New York area to the mid-west occurred without human assisted migration.

**Spread of *Frangula alnus* in time and space - possible lag-phase?**

Catling and Porebski (REF 1994) describe a pattern of spread of *F. alnus* throughout southern Ontario that is dominated by restricted spatial spread for the first 50 to 70 years of the invasion, followed by 40 to 20 years of rapid spatial spread.  This pattern is consistent with a lag-phase of population spread, however it is not clear whether such a pattern is the results of an ‘inherent lag’ expected based on population growth and dispersal, or a ‘prolonged lag’ expected if some environmental change or genetic change must occur prior to the species rapidly expanding.

Frappier et al (REF 2003 For Ecol Manag) investigated invasion patterns and lag-phase behaviour for *F. alnus* in a small forest plot in southern New Hampshire.  This is an interesting study to me, because they observed a lag-phase on a much smaller scale than that reported by Catling and Porebski (REF 1994).  They used a simple reaction-diffusion model to examine rates of spread and carried out an ANOVA to test for lag-phase dynamics, “using the invasion period as the independent variable and the measured spread rate from each invasion period front to the next as the dependent variable.”  The field site for this study was an approximately 2.5 ha forest (College Woods).  Based on their analysis Frappier and colleagues observed significantly slower rates of spatial spread early in the invasion history compared to later in the invasion history.  In the discussion section they posit that this difference may have been related to early local selection and adaptation or to changes in environmental conditions.  They assert that “because we measured the spread rate in linear distance terms, we could rule out population growth as a mechanism of lag-phase”, but this explanation is not clear to me. I will have to look into this further.

The purpose of this study is not necessarily to refute this hypothesis, but rather to begin understanding the invasion history of *F. alnus* at a continental scale, and while doing so, investigate the potential for constructing a general model for lag-phase dynamics of invasive plants.

**Data Collection:**

Key words and terms used: frangula, rhamnus

**Search of On-line Herbarium Databases:**

UCONN Herbarium:

The samples in the UCONN herbarium are listed in the herbarium data extracted from the IPANE database, with the exception of the data outside of New England.  There are five records for data outside of New England, all from northern New Jersey.  To download data from the UCONN herbarium after carrying out a query select ‘map with Berkeley Mapper’.  Once the mapper window is open, select the ‘Options’ tab, and here there is a link to ‘Download records’.

New York Botanical Garden:

A total of seven samples from here – 4 Rhamnus frangula, 3 Frangula alnus

National Museum of Natural History:

There are six records from this database, but I am only including two of them.  The other four are records of cultivated plants on the USDA grounds.  *Frangula alnus* was on the USDA grounds beginning in 1891.  The presence of *F. alnus* on USDA grounds implies that this plant was cultivated during the late 19th century.  Perhaps this is an important addition to add later, or rather just a point to be made.

<http://collections.nmnh.si.edu/emuwebbotweb/pages/nmnh/bot/Query.php>

Wisconsin State Herbarium at Univeristy of Wisconsin:

When accessing the data for the Wisconsin State Herbarium I used the Wisconsing Botanical Information System (<http://botany.wisc.edu/herbarium/>).  From the main page one can navigate to WisFlora or the Wisconsin Herbaria Plant Specimens search tool.  In order to have the option of downloading accession data as a CSV file, I followed the link to WisFlora.  Here, I selected ‘Browse: Common Names’ and selected ‘Glossy Buckthorn’ from the list of species.  This selection directed me to the species name ‘*Rhamnus frangula*’.  Selecting ‘*Rhamnus frangula*’ I was then given the option to ‘View Herbarium Records’, which lead me to 121 accession records (NB: 121 specimens on 3 April 2012, original search yielding 112 specimens was carried out in Spring 2010).

The file that I was able to download in the Spring of 2010 did not appear to have any meta-data.  Thus, for my work, I have created meta-data based on examination of several individual herbaria specimens.

From the Spring of 2010 file, I have 112 specimen accessions, *very few* of which have accurate lat/long information.  I estimated lat/long based on the town and state data given.  This makes the location very inaccurate (by my estimates between 5 and 10 km uncertainty), but since my interest in this data is to examine a general trend in time as to when *Frangula alnus* reached certain locations, I think the estimate will do for now.

Illinois State Herbarium:

Several specimens in this herbaria, none with detailed location data.  The following url brings you to the herbarium database page: <http://www.museum.state.il.us/ismdepts/botany/herbarium/database.html>.  Navigating to both generea *Frangula* and *Rhamnus* results in records of use.  However, location of record was noted by county only.  For the temporal change map I recorded location as being the center of the county.

Virtual Herbarium of the Chicago Region:

This is an online database that includes records from the Field Museum, the Chicago Botanical Garden, the Morton Arboretum, and other partner institutions.  I was able to access the records from the Field Museum alone by carrying out a search for *Rhamnus frangula* at the following site: <http://emuweb.fieldmuseum.org/botany/detailed.php>. I had linked to this site through the NYBG Herbarium names search database.  I found 36 records for the Field, but none with collection dates associated with them.  I linked the data from vPlants with the data downloaded from the Field Museum.

Michigan State University (MSC):

I searched the Michigan State University Herbarium (<http://www.herbarium.msu.edu/>) with the search term ‘frangula’.  This search yielded 28 records, of which I used 25.  Twenty-three of these records required georeferencing.

**Collected via Direct Contact with Currator**

Rutgers Chrysler Herbarium:

I contacted Sean Lynch at the Chrysler Herbarium and he sent me a CD containing photographs of the accessions available.  A total of thirteen accessions were provided to me, of which ten had enough information on them for me to georeference.

Miama University in Ohio:

I contacted Dr. Michael Vincent, the curator of the Willard Sherman Turrell Herbarium and he provided me with an Excel document containing fifty-seven accession records for *F. alnus*, all with lat-long coordinates provided.

Carnegie Mellon Herbarium:

I contacted Ms. Bonnie Isaac, Collection Manager for the Section of Botany at the Carnegie Museum of Natural History, and she provided me with an Excel spreadsheet of data containing sixty-eight accession records for *F. alnus*.  Many of the records were georeferenced following the methods outlined below.  Any use of these data in publication should be cited, acknowledged, and the CM Herbarium should be notified if the manuscript is published.

**No Accessions Found**

Harvard University Herbaria:

No records found that matched *Frangula alnus*.  Of the over 5 million samples held by Harvard and its affiliates, 180,000 records are contained in the online database.  This database includes records from Arnold Arboretum and the New England Botanical Club herbarium.

Consortium of Pacific Northwest Herbaria:

Searched for both rhamnus frangula and frangula alnus.  Specimens were found but there was **no** date or location data associated with specimens.

Royal Ontario Museum:

No specimens found in on-line image search.  It seems likely that there are more samples than are present in the on-line database and further research should be don – contact collections manager.

University of Pennsylvania:

Linking to the UPENN herbarium from the NYBG website, I was sent to the Academy of Natural Sciences of Drexel University.  This online database search tool at this site, sent me to The Academy of Natural Sciences Philadelphia Herbariuam (PH).  This collection has 42,000 of 1.2 million specimens accessible in the online database.  Not entries were found for either *Rhamnus frangula* or *Frangula alnus*.  It is possible that given the size of this collection there are indeed accessions for Glossy Buckthorn, but certainly not online.

Bucknell University:

Searched by browsing by genus for both Rhamnus and Frangula.  There were some entries for *Rhamnus* but none for *Frangula*.  Of the *Rhamnus* entries, none were noted as *Rhamnus frangula*.

**No On-line Database available:**

Bowling Green State University

Kent State University

Ohio University

Ohio State University

Dartmouth University – Jessup Herbarium

West Virginia University: Contact information is at <http://biology.wvu.edu/facilities/herbarium/contact>

**Records Collected via Literature Review:**

Some early records are based on reports in the literature.  In particularly, I extracted early records from Catling and Porebski (REF 1994), Howell et al. (REF 1977), and Taft and Solecki (REF 1990).  These early records have very high spatial uncertainty, as some of them are only county locales.

From Taft and Solecki 1990 *Rhodora* – Glossy buckthorn was first recorded in Illinois in 1912 (Sherff 1912, as cited in Taft and Solecki 1990) in Cook County.  From 1955 it was known from five primary northeastern Ill. Counties.  By 1978 is was established in 18 counties.  In Gavin Bog since at least 1950.  The original Sherff reference the author cites that the invasion into Skokie Bog is likely the result of introduction by birds from nearby Glencoe, where *Rhamnus frangula* is used as an ornamental plant.

**Data Collection: GBIF**

The Global Biodiversity Information Facility (GBIF) provides free and open access to global biodiversity information.  I used the GBIF data portal to search for data accessions for ‘*Frangula alnus*’.  This search also yields results for the synonymn ‘*Rhamnus frangula*’.

**Development of Methods:**

**Geoferencing Specimens:** Many of the records I was able to acquire both via online searches and through direct contact with herbarium staff did not include information regarding latitude and longitude coordinates of collection.  However, most did include information from which I could estimate lat-long values.  I used guidelines for georeferencing presented in GBIF’s *Guide to best practices for georeferencing* (GBIF REF).

**Analysis:** I am examining several studies that incorporate herbarium records in the study of the spread of invasive plant species.  First, (HUEBNER 2003) examined herbarium records for nine different invasive plants in the state of West Virgina, looking at both spatial and temproal patterns on a county level.  She estimated rates of spread (counties/year), number of points of entry, noted data of first records in WV, and associated landscape categories with presence/absence for each invasive.  An analysis such as this is similar to the one I help Abdullah carry out during the summer and fall of 2011.

Miller et al. (REF 2009) present a method for spatio-temporal analysis of invasive plant species using herbarium specimens that incorporate the methods of Delisle et al (REF 2003) and Salo (2005).

**GIS Methods:** I used QGIS to setup spatial analyses for this project.  After compiling all georeferenced herbarium records, I imported them into QGIS using the ‘Add Delimited Text Layer’ Python plug-in.  I overlayed a vector grid on the points, where each grid cell was 11x11km.  I then extracted the grid cell ID for each herbarium point and exported this file as a CSV file.  Because of limitations on char numbers in QGIS, the columns for this new CVS file had to be amended by hand.

Each cell that contained at least one herbarium record observation was marked as having ‘presence’ of *F. alnus*.

**Accounting for sampling effort:**

For the poster presentation, I examined the change in number of occupied cells for herbarium records from UCONN (CONN) for Speckled Alder (*Alnus incanca*, also known as *Alnus rugosa*).  For future corrections I would like to consider all of the following species:

* Speckled Alder - *Alnus incana*
* Smooth Alder - *Alnus serrulata*
* Alderleaf Buckthorn - *Rhamnus alnifolia*
* Meadow Willow - *Salix peiolaris*

These species represent woody plants that are likely to be observed in ecological conditions where Glossy Buckthorn is observed.  Meadow Willow, in particular, was used by Houlahan and Findlay (REF 2004) in a paper comparing invasive and native species.

**Annotated Bibliography**

# (Crawford & Hoagland, 2009)

\* Invasive species and native range expanding species in Oklahoma

\* Applied Delisle et al. 2003 ratio correction method

\* Uses spatial data at resolution of **Township**