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Effects of minimum winter temperatures on southern pine beetle (*Dendroctonus frontalis*) mortality on Long Island, N.Y.

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Master's Project – Research Proposal

**Effects of minimum winter temperatures on southern pine beetle
(*Dendroctonus frontalis*) mortality on Long Island, N.Y.**



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Abstract

Dendroctonus frontalis (the southern pine beetle) was discovered on Long Island, New York in 2014. Additional infestations have since been located in upstate New York, Rhode Island, Connecticut and Massachusetts. Previously found as far north as New Jersey and Pennsylvania, this range expansion now represents the current northern distribution limits of *D. frontalis*. Minimum winter temperatures are a meaningful driver of population dynamics and mortality in *D. frontalis*, and understanding this relationship at the northern range limits can help forest managers better predict and prepare for outbreaks. Studies addressing the relationship between temperature and beetle mortality, and the thermal buffering that host trees provide, have occurred only as far north as New Jersey, and in tree species other than pitch pine (*Pinus rigida*), the primary host of *D. frontalis* in the north. I propose a study that will replicate the work completed in New Jersey and the south. I will examine the relationship between minimum winter temperatures and *D. frontalis* mortality, the thermal buffering potential of pitch pine, and the presence of prepupae (the most cold-tolerant life stage) during the overwintering period. Research will be performed on Long Island, from November 2015 – March 2016, at three mixed species stands of pitch pine infested by *D. frontalis*. Data loggers attached to paired thermocouples will monitor differences between air and phloem temperatures. Bark samples will be extracted monthly from four trees at each site; percent larval mortality will be correlated with the air temperatures, and the presence of different life stages and their position within the tree will be determined. Data will be used to feed models aimed at predicting annual outbreak potential.

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Introduction

***Dendroctonus frontalis* in New York & New England**

Southern pine beetle (*Dendroctonus frontalis*) was first discovered in New York State on Long Island in September, 2014, at Wertheim National Wildlife Refuge. The furthest north it had previously been detected was New Jersey and Pennsylvania (Payne 1908). Initial aerial detection surveys and ground surveys showed widespread and abundant infestations throughout Suffolk County (Fig. 1). The most severe damage was located along the southern shore of Suffolk County, where infestations were advanced and tens of thousands of trees had already died. Middle and northern portions of the county showed scattered, light infestations, with spots averaging in size from about 3 to 20 trees.

Suffolk County is home to the Central Pine Barrens Preserve, a +100,000 acre protected area, dominated by pitch pine (*Pinus rigida*) and oak (*Quercus* sp.). *D. frontalis* is primarily attacking pitch pine on Long Island, and the Pine Barrens Preserve, Long Island's last remaining wilderness that overlies the sole source drinking water aquifer for the island, is severely threatened (Fig. 2).

In addition to the Long Island Pine Barrens, *D. frontalis* poses a threat to the entire Atlantic coastal pine barrens ecosystem, which extends from New Jersey to Maine. Since September 2014, other small infestations have been identified on the coast of Rhode Island and Connecticut. Furthermore, inland forests are being attacked. In June, 2015, pheromone traps caught beetles at Bear Mountain State Park and Minnewaska State Park in the Catskill Mountains of upstate New York, and in north central Massachusetts and western Connecticut (Fig. 3).

Because it grows primarily on poor soils, pitch pine's distribution in the northeastern U.S. is spotty, and is most commonly found on the sandy soils of Cape Cod, Long Island, and southeastern New Jersey (Fig. 4) (Little and Garrett, 1990). However, *D. frontalis* has been found attacking several other species of conifers in the northeast, which greatly increases

the beetles' potential threat to northern forests. On Long Island, it has been found attacking Norway spruce (*Picea abies*) and white pine (*Pinus strobus*). In Connecticut, infestations have been found on red pine (*Pinus resinosa*) and Scots pine (*Pinus sylvestris*). What's more, one of the infestations in Connecticut was found in a stand of 100% red pine. Previously, it had been assumed that *D. frontalis* would only attack other conifer species in the presence of its preferred host, pitch pine (Ayres, personal communication).

Range Expansion of *Dendroctonus frontalis*

In the southern part of its range, which extends from southern Pennsylvania to Florida and west to Texas, eastern Oklahoma and southern Missouri, *D. frontalis* has been the largest single cause of natural disturbance in forests of this region. Their western distribution limits are maintained by a lack of host trees on the edge of the Great Plains, and their northern limits are maintained by mortality from low winter temperatures (Ungerer et al. 1999). Winter mortality has been reported in *D. frontalis* populations that experienced minimum air temperatures of -12° to -18°C. Ungerer et al. (1999) used laboratory measurements and published mortality records of wild populations to indicate that air temperatures of -16°C should result in almost 100% mortality of *D. frontalis*. They showed that the distribution limits for *D. frontalis* were consistent with the isoline corresponding to an annual probability of 0.90 or reaching $\leq -16^{\circ}$ (see Figure 2); therefore, populations had been found as far north as they could possibly occur given average winter temperatures. However, they speculated that actual northern distribution limits likely fluctuate by hundreds of kilometers, depending on the recent winter temperature patterns. And, as there are no other obvious barriers to range expansion, warmer than average winter temperatures associated with climate change will expand the beetles range northward of the isoline corresponding to 0.90 probability of mortality. We are already seeing evidence of this in the northeastern United States.

Statement of Problem and Purpose of Research

Since the first discovery of *D. frontalis* on Long Island, other infestations have been found in the Catskill Mountains of upstate New York, Connecticut, Rhode Island and Massachusetts (see Figure 2). In these states, *D. frontalis* are at their known northern distribution limits. These limits are maintained by the occurrence of lethal winter temperatures, and they reflect extreme, rather than average, occurrences (Ungerer et al. 1999). Cold temperatures are an important cause of beetle mortality, and hence significant controllers of population densities (Bolstad et al. 1997). Land managers in the northeastern states are optimistic that winter mortality will be an important population regulator of *D. frontalis*, and will significantly slow the spread of infestations, allowing us to gain a foothold in the fight against the beetle. However, little is known about the effects of minimum winter temperatures on *D. frontalis* in New England and New York, as all studies regarding this subject have occurred in the southern states and New Jersey. To better understand how temperatures play a role in population regulation, studies that assess the relationship between minimum winter temperatures and percent *D. frontalis* mortality need to be performed within the northern range of the beetle. Data can be used to develop temperature/mortality models that will help land managers assess outbreak potential in a flight season based on temperature patterns from the previous winter.

D. frontalis are protected from extreme winter temperatures by the phloem in which they live and feed. Temperatures within the phloem are consistently warmer than surface bark or air temperatures, but previously published estimates of phloem buffer potential derive from studies that occurred in southern tree species susceptible to *D. frontalis* attack, such as loblolly pine (*Pinus taeda*) and Virginia pine (*Pinus virginiana*). The buffering potential of pitch pine, the preferred host for *D. frontalis* in the northeast, has not been studied. Because phloem-buffering potential varies considerably with tree species (Schmid et al. 1991) collecting phloem temperature data within pitch pine stands throughout New England and New York will contribute important information to the temperature/mortality models that will be developed.

In addition to beetle mortality and phloem-buffering potential, more knowledge must be obtained about which life stages overwintering beetles are occupying in the Northeast. On Long Island, researchers have observed primarily pre-pupae life stages, the most cold-tolerant life stage (Tran et al. 2007), overwintering in pitch pine from December through April (Ayres & Dodds, personal communication). But, these observations arise from only a handful of samples at one or two infested sites. Furthermore, we must determine if beetles are occupying the phloem, the inner bark, or both during their overwintering phase. It has been speculated that phloem may present a more inhospitable environment over the winter than the inner bark, due to its higher moisture content (Dodds, personal communication). If beetles do not make it into the inner bark before winter, we are assuming they will experience higher mortality rates.

Literature Review

Effects of minimum winter temperatures on *D. frontalis*

Historically rare outbreaks of *D. frontalis* at the northern limits of its range are becoming increasingly common in. Ungerer et al. (1999) predicted a northern expansion of outbreaks coinciding with an increase in minimum winter air temperatures. This prediction appears to have been accurate, as outbreaks were been discovered in 2014-2015 throughout New England and New York, further north than researchers had anticipated.

Lethal winter temperatures have been shown to be a meaningful driver of *D. frontalis* population dynamics, especially within the northern distribution limits (Tran et al. 2007). Significant mortality of natural populations has occurred when air temperatures dropped below -12°C (Beal, 1933, McClelland and Hain 1979). Lombardero et al. (2000) determined the supercooling points of *D. frontalis* larvae, pupae, and adults. They found that the lower lethal temperature for adults, which paralleled that supercooling point, averaged $-12.1^{\circ} \pm 4.0^{\circ}\text{C}$ (mean \pm SD). They also showed that brief exposure to

temperatures at or below the supercooling point was lethal to *D. frontalis*, while prolonged exposure to marginally warmer temperatures produced negligible mortality. In addition, Ungerer et al. (1999) showed agreement between the historical northern distribution limits of *D. frontalis* and the annual occurrence of one or more winter nights when air temperature dropped below -16°C. They predicted that the growth rate of the beetle would decrease significantly when air temperatures dropped below -16°C. However, limitations of this work include the fact that studies were restricted to one population from northern Alabama, and climatic models were based on weather stations and ignored variation in micro-climate or elevation. Work by Tran et al. (2007) occurred in New Jersey, much closer in proximity to the current northern distribution limits of *D. frontalis*. They showed that *D. frontalis* cold tolerance varied throughout its range, exhibiting a supercooling point of -9.7 +/- 2.7°C in New Jersey, which was much lower than in adult beetles collected at the same time in Alabama (7.2°C +/- 1.6°C). Figure 5 shows the expected mortality of southern pine beetles from the corresponding air temperatures. These estimates are based on studies by Tran et al. (2007) in New Jersey and Alabama.

Phloem-buffering capacity of host trees

Estimates of phloem-buffering potential vary considerably. Beal (1934) showed that in subzero temperatures, thermal buffering in *Pinus ponderosa* could be as high as 12°C, and fluctuated with bark thickness. But, estimates by Ungerer et al. (1999) show a more reduced potential, using estimates of 1–2°C of buffering in daily temperature minima within the phloem compared to air. Bolstad et al. (1997) also showed high variation between average phloem and air temperatures, from 0.5° to 10.1°C on the south side, to -0.1°–3.8°C on the north side of trees.

Tran et al. (2007) evaluated the relationship between air temperature and phloem temperatures experienced by bark beetles by applying a Newtonian heat transfer model with empirical cooling constants (that also incorporates effects of tree size) to air and phloem temperature measurements. They showed that beetles within host trees are

buffered from the lowest air temperatures by $\sim 1\text{--}4^{\circ}\text{C}$, depending on the tree diameter, bark thickness, and duration of the cold bout.

Discrepancies between these previously published estimates are significant. Beal intentionally measured only larger diameter trees with thick bark (up to 5cm), during a short cold bout with extremely low air temperatures (-6° to -32°C to -12°C within a 35 hour time period). In an analysis of 140 winter temperature series from the southeastern United States, Tran et al. did not find a single occurrence of the high buffering that Beal reported. However, Ungerer et al.'s estimates of $1^{\circ}\text{--}2^{\circ}\text{C}$ were conservative compared with what Tran et al.'s analysis revealed: an average of $1.5^{\circ}\text{--}3.9^{\circ}\text{C}$ (9.2°C max) for trees of 20–50 cm dbh.

Phloem buffering estimates produced from these studies are not wholly applicable to pitch pine forests of the northeastern United States. Previous work done occurred either in other pine tree species, like *P. ponderosa* (Beal 1934) and *P. virginiana* (Tran et al. 2007) or in more southern locations (Ungerer et al. 1999, Tran et al. 2007, Bolstad et al. 1997). Phloem buffering capacity might change depending on the tree species or colder winter temperatures experienced in the northern range of *D. frontalis*.

Overwintering Life Stages of *D. frontalis*

In March 2015, as part of a methods experiment for my proposed research, I collected 24 bark samples from 6 pitch pine trees at 3 sites on Long Island (see Figure 4). Samples were taken from the north and south sides of trees, and from heights of 1 and 2 m. Upon dissection of the samples, I found 100% of *D. frontalis* larvae residing in the phloem, and 100% of the larvae were dead. These findings were consistent with the hypothesis that larvae residing in the phloem are more susceptible to freezing due to the high moisture content (Dodds, personal communication), but incongruent with the findings of Ayres and Dodds, who had observed several pre-pupae larvae in the inner bark at two sites.

In the more northern limits of *D. frontalis* populations, pre-pupae life stages have been found to dominate the overwintering period. Tran et al. (2007) showed that beetle life stages collected from New Jersey infestations in 2005 were dominated by pre-pupae. Of the 1,691 specimens collected, 1,562 were larvae found in the inner bark, the location they move to prior to pupation. Of those, 99.8% were still alive at sampling time. Twenty-six larvae were present in the phloem, and only 7.7% of them were alive at sampling time. The laboratory and field studies performed by Tran et al. showed that prepupae were more cold tolerant (by $>3.5^{\circ}\text{C}$) than other life stages, and that the life stage structure of overwintering beetles were predisposed towards this cold tolerant phase.

Tran et al. (2007) highlighted the value of documenting the distribution of *D. frontalis* life stages, particularly at the farthest northern points of its range. Thatcher (1967) reported the presence of all life stages during December of three winters in east Texas. However, in North Carolina, researchers have reported that *D. frontalis* commonly spends the coldest part of winter in the larval stage (Beal 1933, McClelland and Hain 1979), but they did not quantify what ratio of larvae was feeding in the phloem or preparing to pupate in the outer bark. It is unknown whether northern populations overwintering as prepupae is a phenotypic result of differences among life stages in their developmental responses to temperature (Powell et al. 2000), or could involve genetic differences among populations in different regions (Ayres and Scriber 1994). Tran et al. (2007) suggest that it could be a coincidence instead of an adaptation, hypothesizing that molting to pupae is slowed by low temperatures more than growing through the last larval instar. Prepupae might be more cold tolerant simply because they have no food in their gut. If winter temperatures are responsible for synchronizing the age structure, northern populations would be likely to have one predominating life stage, because there are fewer generations each year to join on a stable age distribution.

Description of Proposed Research

Methods & Analysis

Data will be collected from three sites within mixed species stands of pitch pine (*Pinus rigida*), in Suffolk County, NY, that are experiencing southern pine beetle outbreaks. The study sites include Hubbard County Park, located at the eastern end of the Pine Barrens and bordering Peconic Bay, Rocky Point State Pine Barrens Preserve, at the western end of the Pine Barrens and bordering the north shore of the Island, and Wertheim National Wildlife Refuge, bordering the south shore of the Island (see Figure 5). If, by the start of this project, an established infestation is located in the Catskill Mountains of upstate New York, then additional research sites will be added there. Data will be collected from November 1, 2015-March 30, 2016. Stand characteristics, like basal area, elevation, stand density, and percentage pitch pine will be documented.

*Cold tolerance of *D. frontalis* and dominant overwintering life stages*

Using a 3" hole saw, four 46-cm² circular bark disks will be extracted from 4 infested pitch pine trees at each site on a monthly basis (Nov.-March) (see Figs. 7 and 8). Samples will be taken from Stage 1 and Stage 2 infested trees, at 1 and 2 m heights (from the base of the tree) on the north and south-facing sides of each tree. Samples will be inspected in the lab within 3 days of collection, and percent larval mortality will be assessed by comparing the number of dead and alive larvae. Larvae assumed to be dead will be monitored for several days to check for signs of life. All life stages present in each sample, and their relative location (inner bark vs. phloem) will be recorded.

Side note: In March, 2015, 24 bark samples were taken from 6 pitch pine trees at 3 sites in Suffolk County, NY. Initially, I attempted to use a 6" hole saw (182-cm² circular bark disk) to maximize the surface area of each sample, but a 6" diameter proved to be too wide to effectively remove bark from the narrow, rounded boles. I switched to a 3" hole saw, targeting areas on the bole with obvious pitch tubes, assuming that the presence of a pitch tube would ensure the presence of *D. frontalis* galleries. That assumption was not accurate,

and over 50% of our samples had no galleries at all. Increasing the sample size at each site to 16 (4 from each tree) will compensate for that discrepancy and, hopefully, provide us with more bark samples that contain galleries.

Air and Phloem temperatures

As described in Tran et al. (2007), paired thermocouples (Type T) connected to HOBO data-loggers will be used to monitor air and phloem temperatures at intervals of 1 hour in twelve pine trees (4 per site) at the locations described above. On each tree, at 1.5 m height, one sensor will be placed in the air ≥ 8 cm from the tree, and the other inserted through the outer bark via a small incision into the phloem layer where *D. frontalis* occurs. The incision will be sealed with a spot of silicone (see Fig. 6 for thermocouple setup). Temperature data will be downloaded once a week, using the HOBO shuttle.

The percent mean, standard deviation, range of mortality, and number of hours at various levels of freezing and subfreezing temperatures will be reported, and results will be correlated to the air and phloem temperature data in a table. To summarize thermal buffering in pitch pines, results from temperature measurements (average of $T_{air} - T_{phloem}$) will be fitted to a heat transfer model as described in Tran et al. (2007) and Bolstad et al. (1997).

Anticipated Results

I expect my results to show a strong correlation between the occurrence of minimum winter temperatures in a given period to percent mortality of *D. frontalis*. Months that contain a higher number of extremely cold days (the temperature drops below the supercooling point of *D. frontalis*) should produce a higher percentage of beetle mortality than those months with fewer cold days. Phloem-buffering capacity, I predict, will provide some moderate buffer against cold temperatures, especially when air temperatures are close to their supercooling point, but will not be sufficient in buffering beetles from temperatures that fall significantly below their supercooling point.

I also expect the life stages in the overwintering period to be dominated by prepupae that are present in the outer bark, but in addition to these results, I expect to see numerous samples of beetles that have remained in the phloem as larvae.

The data obtained in this project will be most valuable when compared to data collected from a series of consecutive winters. Otherwise, it will be difficult to make assumptions about mortality, as there are infinite ecological processes and occurrences, capable of influencing beetle mortality, that are not accounted for in the data analysis. Data collected in this project will also be compared with the results from our annual trapping program, in which we estimate the abundance of *D. frontalis* during the spring dispersal phase (Billings 1988).

Figures and Graphs

Fig. 1. Preliminary aerial detection survey results for *D. frontalis*, the proximate extent of pitch pine on Long Island, and the Central Pine Barrens Preserve (Core Preservation Area and Compatible Growth Area).

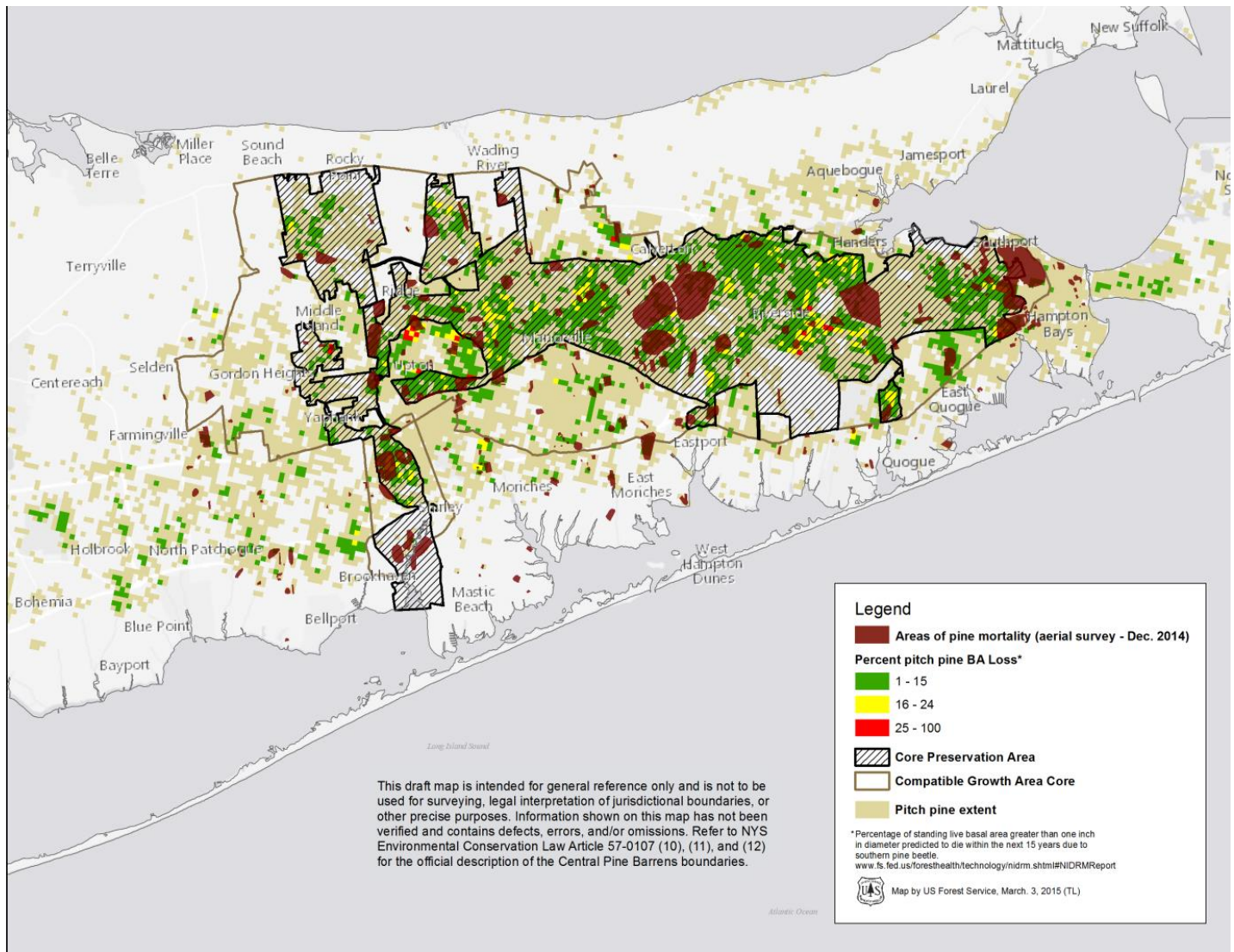


Fig. 2. Southern pine beetle risk/hazard map estimated for Long Island.

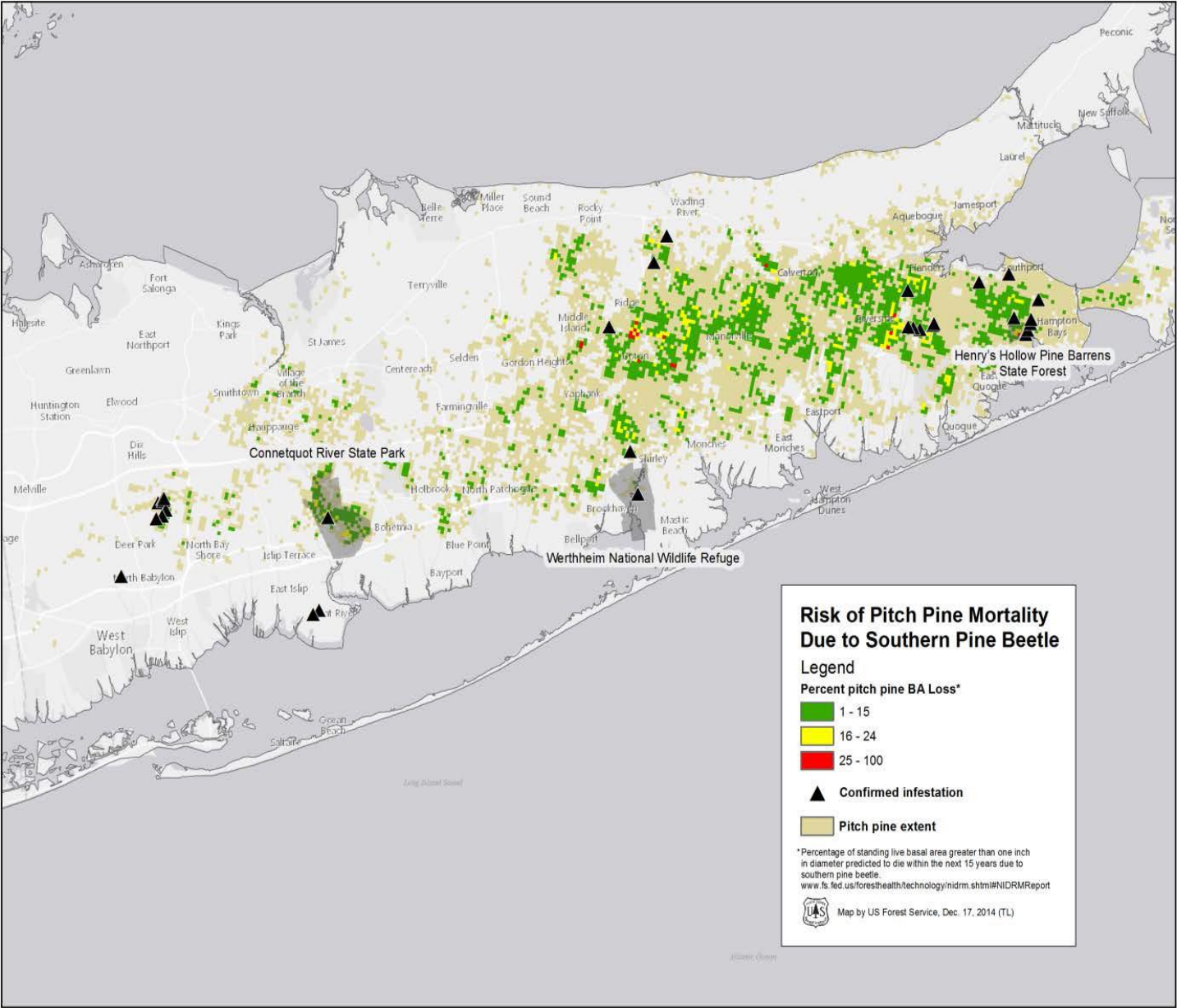


Fig. 3. 2015 northeastern SPB trapping results. Map by Jessica Cancelliere and Kevin Dodds.

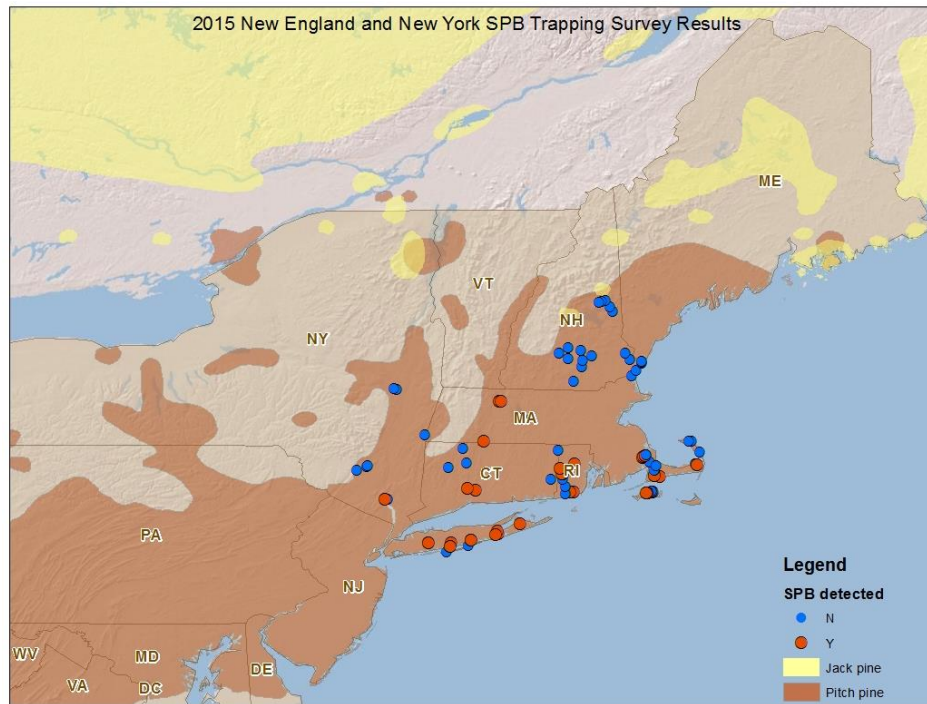


Fig. 4. The native range of pitch pine (from Little, 1971).

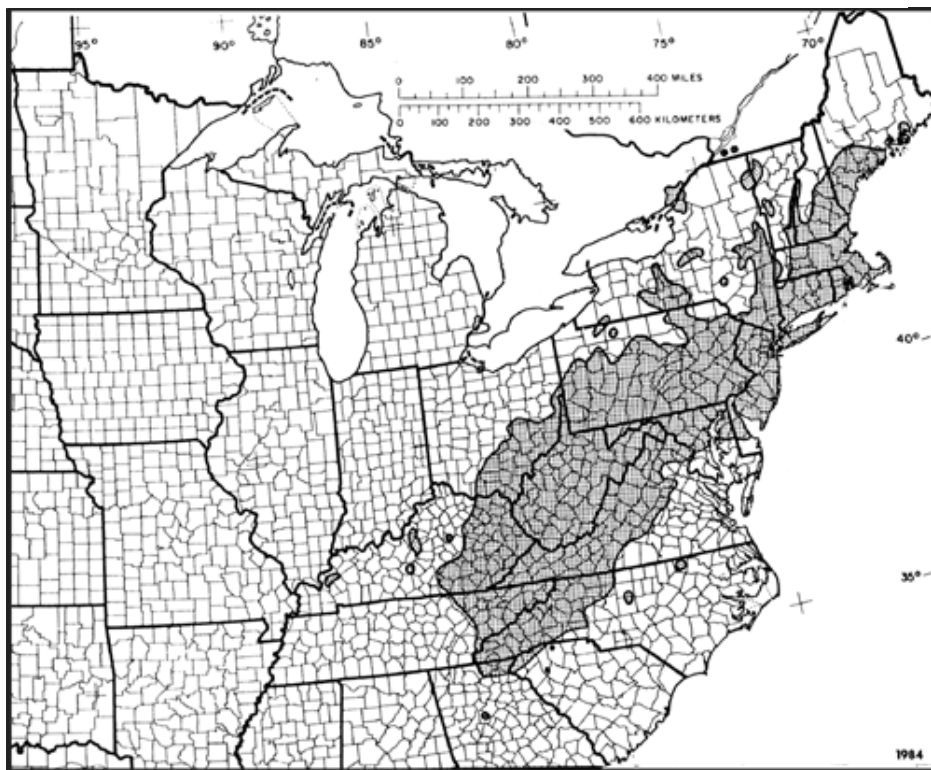
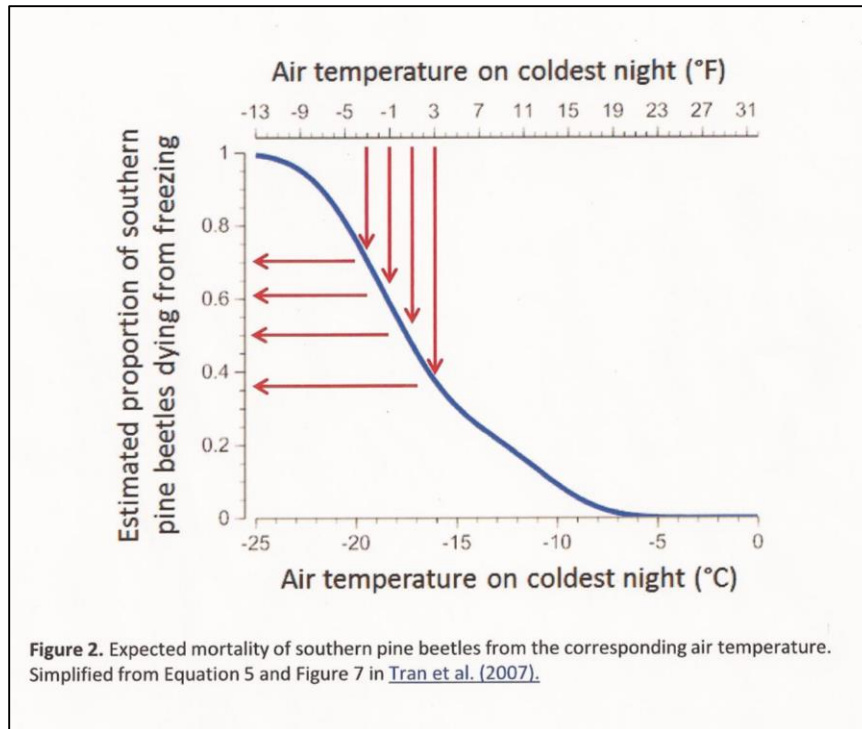


Fig. 5. Expected mortality of *D. frontalis* from corresponding air temperatures (from Tran et al., 2007).



Figs. 7 & 8. Circular disk bark sampling method. Photos taken by Jessica Cancelliere.



Fig. 7.



Fig. 8.

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