

A Cohort Model for Ash Mortality Risk Due to Potential Emerald Ash Borer Infestation

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Abstract

Emerald ash borer (*Agrilus planipennis* Fairmaire) (Coleoptera: Buprestidae) is a phloem-feeding beetle native to Asia that is causing widespread mortality of ash trees in eastern North America. In this study, we quantify ash mortality risk associated with potential anthropogenic-induced introduction of Emerald Ash Borer (EAB) in North Dakota. The cohort model is calibrated with data from Ohio using weighting across factors—proximity to existing ash stands, campgrounds, roads and rails—to get a more accurate assessment of overall ash mortality risk. These factors are known to be associated with introduction of EAB to unaffected areas. Two protocols, a) “detection trees” and b) EAB traps are utilized to investigate EAB presence. Ash mortality risk maps such as the ones produced here may guide the placement of traps. Although North Dakota regions of high density ash tree stands are few, the resulting relative ash mortality risk map displays: a) very high risk areas around the Turtle Mountains and Theodore Roosevelt National Park and b) regions of high relative risk along the main riparian corridors. The applicability of risk maps such as the one developed may aid in assessing areas that may require significant monitoring.

Keywords

Exposure Pathway, Relative Risk, EAB Risk Model

1. Introduction

Given the potential for widespread ash mortality in North America posed by EAB; it is essential that areas cur-

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rently unaffected prepare adequately to monitor their ash resources. This preparation begins with identifying those areas most at risk of EAB introduction. North Dakota has an estimated 78.1 million ash trees [1] and, as EAB was discovered in southern Minnesota in May 2009 [2], it is imperative that a management plan to monitor those resources be put in place. The process outlined in this study describes the development and application of a method of quantifying ash mortality risks in North Dakota. Muirhead *et al.* [3] developed a long distance risk model based upon two scenarios of human-mediated transport of EAB. They used a gravity model to estimate risk. In their approach, they considered spread initiating from campsites as EAB epicenters and proximity to major roads as major conduits for anthropogenically-induced propagation. In the study, population density was used as a proxy for human activities that mediated transportation of EAB beyond the zone of their natural spread. They however did not consider factors that contributed to human-mediated spread of EAB, for example, the likelihood that firewood might be transported to a secluded campground or seasonal home contributing to a long distance induction of EAB. Circular geometric models while computationally simplistic to program usually ignore urban transportation models. These geometric models may also fail to predict alien forest species spread along all transportation corridors.

Various studies have emphasized the importance of transportation corridors especially due to the fact that transported commodities and freight may harbor non-native organisms that end up in locales very far away from their origins [4]-[8]. It has been suggested in previous studies [9] [10] that introduction of EAB to new areas is primarily facilitated by humans. While EAB does spread naturally, its rate of movement has been estimated at less than 20 km per year [9], well below the rates required to account for current distribution patterns. For this reason, foresters and entomologists have identified likely methods of spread associated with human activity [9].

Cohort models have been significantly applied in medical or applied medical sciences. They are amongst the fundamental designs for epidemiological research. Cohort-based studies have helped researchers to better understand disease transmission dynamics and have provided insights into key environmental, lifestyle, clinical, and genetic determinants of disease transmission and associated outcomes [11]-[14]. Cohort-based studies have also been applied in the study of music cognition [15]. At the crux of a cohort model, related to risk factors is a group of normalized associated risk factors that contribute uniquely to each integral risk category before yielding an overall risk. Lantz *et al.* [16] applied a cohort-model to study socioeconomic and behavioral risk factors with respect to mortality in the United States. Schulkind and Davis [15] applied a cohort model of melody identification by investigating two competing hypotheses on melody identification. Black *et al.* [13] developed a way of converting from a relative risk (RR) for people with a fracture risk factor relative to those without, to an RR in the target population compared with the general population.

Minnesota Department of Agriculture [10] developed a risk model for introduction of EAB into Minnesota. The study considered seven factors: proximity to a) campgrounds, b) seasonal homes, c) urban areas, d) sawmills, e) firewood industries, f) nurseries, and g) accessible areas of recreation. Where numerical data was available, an assessment of the relative importance was made on an arbitrary scale of 1 - 1000. Risk values for each factor were classified into 256 equally sized bins and combined according to a regression equation that produced spatial results that matched the expectations of MDA officials.

Ayersman *et al.* [17] presents an EAB risk model for an area encompassing six states based on three risk factors: campgrounds, nurseries and sawmills. Their analysis was based on density calculations of each equal weighted industry based on the assigned echelon. On the other hand, Prasad *et al.* [9] used a more comprehensive model to predict the spread of EAB in Ohio. Their model combines two recognized methods of EAB spread: i) an insect flight model, which models natural spread of the insect, and ii) an insect ride model, which models long distance, human facilitated spread of EAB. The factors considered important in the insect ride model are traffic on roads, wood products industries, population density and campgrounds. Within each factor an increasing, but arbitrary, weight was applied to areas thought to pose more risk, such as roads with increased traffic density, campgrounds with more sites, wood product industries which handled large volumes of ash. Scores for each risk factor were weighted (60% for roads, 20% for campgrounds, 10% for wood products industries and 10% for population density) and the final score used as a multiplier of ash basal area to produce a final risk map. The main aim of this study was to develop a cohort model to identify at-risk areas within North Dakota due to inadvertent introduction of EAB. To our knowledge this study is the first to apply a cohort model in EAB study and our results offers the first baseline study of pre-EAB invasion in North Dakota. The model presented here was developed to serve primarily as a strategic assessment tool for North Dakota Forest Service.

2. Methods

2.1. Cohort Data

The Ohio Department of Agriculture began monitoring EAB in 2005, after early cases were discovered in 2003 and 2004 [9]. In 2005, “detection trees”, 18 from each Ohio Townships, were girdled to make them more attractive to EAB. During the months following the 2005 growing season half of the detection trees were removed and inspected for EAB larvae underneath the bark [9]. The remainder of the “detection trees” were removed and inspected following the 2006 growing season. Data for 10,176 detection trees was obtained from U.S. Forest Service, Northern Research Station (personal communication, Anantha Prasad). The data contained locations of detection trees, set up in 2005 and 2006 and those trees that yielded EAB larvae at the time of removal. Between 2005 and 2007, the Ohio Department of Agriculture set up nearly 20,000 detection trees throughout the state to monitor for EAB [9]. Detection trees were then felled and peeled following adult emergence (after August) and assayed for EAB [9].

2.2. Calibration Data

The data obtained for calibrating the model developed were used as in an epidemiological cohort study, from which risk ratios for various exposure factors can be calculated [11] [13] [18]. In this study, campgrounds, roads, rails and ash tree density were assessed as primary source factors. The Prasad *et al.* [9] model includes wood product industries and nurseries as a risk factor for introduction of EAB. These facilities were not included in this model because there is an increased regulation of such industries after EAB discovery [9]. Campgrounds, while potentially subject to such stricter regulation in the future present more of a challenge due to a) increased numbers of allied businesses statewide and nationwide, and b) relative campground capacities.

2.3. Exposure to Roads

TIGER road centerline files [19] were used as vehicular transportation input. Each road was categorized based on type; according to the Census Feature Class Code (CFCC) descriptions. Increasing CFCC codes denotes decreasing carrying capacity, although no traffic count data was factored in this study. For example, a CFCC code of A1 is a primary highway with limited access, a code of A2 is a primary road without limited access. Proximity to each category except for A4 (local, neighborhood, and rural road) and A6 (road with special characteristics) categories was used as an exposure factor in calculation of risk ratios. The A4 category was excluded because each “detection tree” and confirmed “positive” was within 2 km of a road in this category, implying that a “no exposure” category could not be established. The A6 category was also excluded as it contains roads without clearly definable characteristics.

2.4. Exposure to Rails

TIGER rail centerline files for [19] were used as rail transport input. Each rail is categorized based on type, according to the CFCC description. The main categories used in this study were i) B1—Railroad main track; and ii) B2—Railroad spur track.

2.5. Exposure to Campgrounds

Addresses and numbers of recreational vehicle (RV) sites for each listed campground in were identified from 5 Web sites: i) All campgrounds web portal [20], ii) Go camping web portal [21], iii) Great camping spots web portal [22], iv) Camping USA web portal [23] and v) Ohio Campers web portal [24]. The data was tabulated and geocoded to a street address level. In this way, 229 unique campgrounds were identified. The campgrounds were categorized based on size with breaks based upon five quantiles. Size 1 was designated for up to 64 Recreational Vehicle (RV) sites. Other categories were Size 2 ($65 \leq \text{RV Sites} \leq 120$), Size 3 ($121 \leq \text{RV Sites} \leq 175$), Size 4 ($176 \leq \text{RV Sites} \leq 240$), and Size 5 (>240 RV Sites).

2.6. Exposure to Ash Stands

Since EAB is a specific phloem-feeding beetle specific to *Fraxinus* sp.; it has been hypothesized that large stands are more desirable habitats for EAB and hence, at greater risk of infestation [9]. A raster dataset depicting

ash basal area for Ohio was obtained from the United States Forest Service [25]. The dataset was generated from data gathered during the Forest Inventory and Analysis (FIA) program. Ash basal area was categorized into 5 classes by natural breaks quantile classification with the following output: $0 \text{ m}^2/\text{ha} \leq \text{Class 1} \leq 0.6322 \text{ m}^2/\text{ha}$, $0.6322 \text{ m}^2/\text{ha} \leq \text{Class 2} \leq 2.5288 \text{ m}^2/\text{ha}$, $2.5288 \text{ m}^2/\text{ha} \leq \text{Class 3} \leq 5.9010 \text{ m}^2/\text{ha}$, $5.9010 \text{ m}^2/\text{ha} \leq \text{Class 4} \leq 11.5903 \text{ m}^2/\text{ha}$, $11.5903 \text{ m}^2/\text{ha} \leq \text{Class 5} \leq 53.9477 \text{ m}^2/\text{ha}$. The classified raster data was thereafter converted to shapefile format.

2.7. Generation of Relative Risks

The ArcGIS® Near tool was used to calculate the distance from each “detection tree” and positive tree to the nearest exposure feature, for each dataset analyzed. The near distances were categorized as follows: <1 km, 1 - 2 km, 2 - 5 km, 5 - 10 km, 10 - 20 km and >20 km, based on the density of features throughout the state. Records were summarized by distance category to yield totals for detection trees and confirmed positives in each distance category. Totals were analyzed using contingency tables for each of the exposure feature and distance category. Relative risk (RR) was calculated for each contingency table as shown in Table 1. The standard error (SE) was obtained from running a statistical analysis on distance measurements fitting the near distance categories. A series of buffers corresponding to defined exposure distances (namely <1 km, 1 - 2 km, 2 - 5 km, 5 - 10 km, 10 - 20 km and >20 km) was placed around each exposure feature. Each buffer area was assigned a risk ratio value. The logarithmic format of the relative risk for each exposure was summed to provide a combined relative risk that accounted for each probable exposure source to yield final Ohio and North Dakota risk maps.

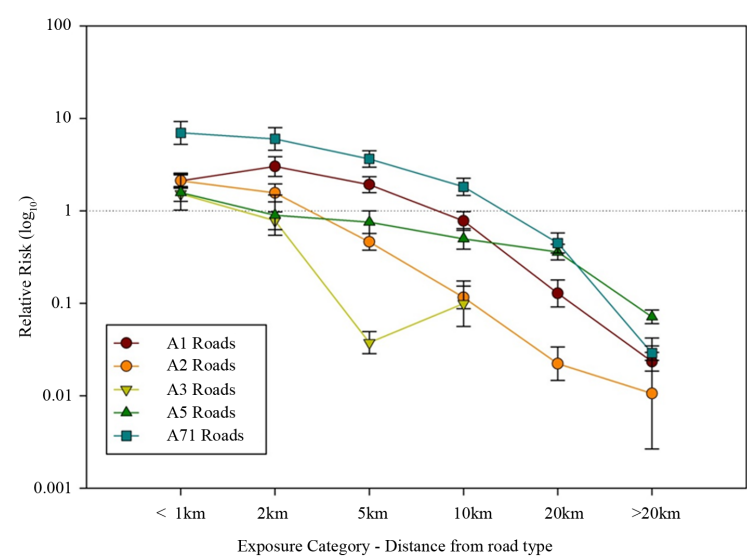
3. Results and Discussion

Figure 1(a) shows that the exposure pathway with the highest relative risk for Ohio was A71 roads (walkways and trails for pedestrians). This result is potentially significant because other risk models discussed [9] [10] do not use proximity to trails as a risk factor for EAB introduction. Unlike most other exposure features and distance categories examined, the relative risk of A71 roads stays above 1 for the 5 - 10 km buffer distance. This suggests that the causal factor associated with this elevated relative risk is not the roads themselves, but something highly correlated yet at a distance. We can speculate that the 10 km radius is consistent with the flight distances of EAB when they are naturally moving to new trees. We suspect that EAB infestation is more likely over that distance because the insects move from their release point before beginning to infest. The causes of this could be movement away from human activity such as hiking, camping (fires, noise?), motor sports. Alternatively there

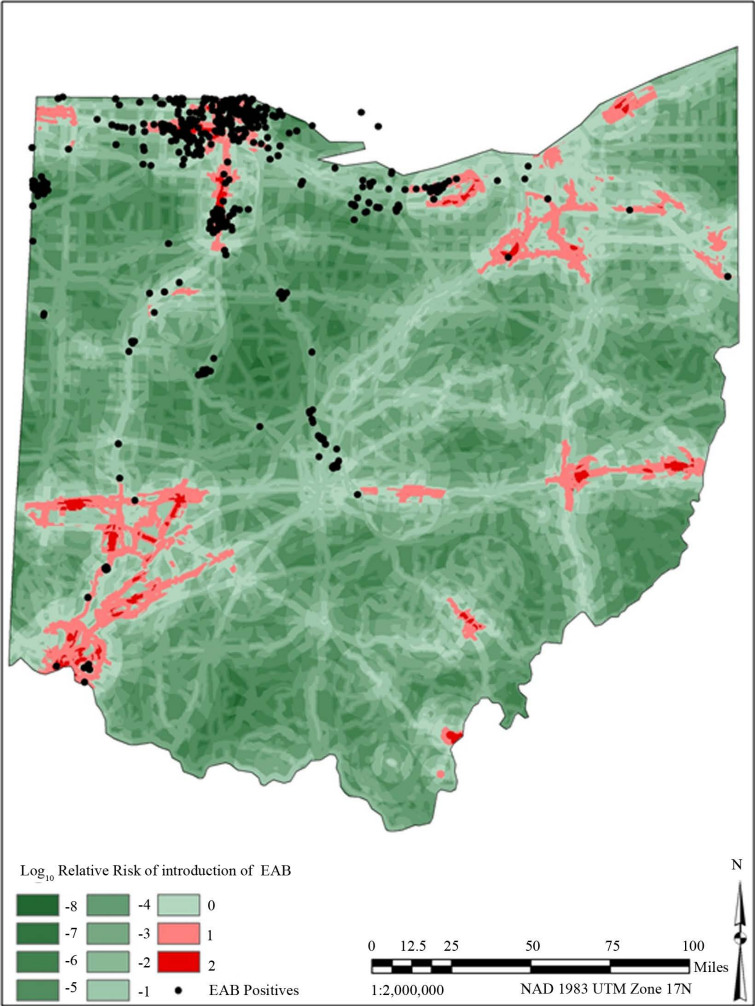
Table 1. Calculation of relative risks.

	Status			Relative Risk (RR)	Confidence Interval Lower 95%	Confidence Interval Upper 95%
	Cases	Controls	Totals			
Exposure Status	<1 km	<i>a</i>	<i>b</i>	<i>c</i>	$RR \cdot e^{-1.96\sqrt{SE}}$	$RR \cdot e^{1.96\sqrt{SE}}$
				$\left[\frac{(a/c)}{(s-a)/(u-c)} \right]$		
	1 - 2 km	<i>d</i>	<i>e</i>	<i>f</i>		
				$\left[\frac{(d/f)}{(s-d)/(u-f)} \right]$		
	2 - 5 km	<i>g</i>	<i>h</i>	<i>i</i>		
				$\left[\frac{(g/i)}{(s-g)/(u-i)} \right]$		
	5 - 10 km	<i>j</i>	<i>k</i>	<i>l</i>		
				$\left[\frac{(j/l)}{(s-j)/(u-l)} \right]$		
	10 - 20 km	<i>m</i>	<i>n</i>	<i>o</i>		
				$\left[\frac{(m/o)}{(s-m)/(u-o)} \right]$		
	>20 km	<i>p</i>	<i>q</i>	<i>r</i>		
				$\left[\frac{(p/r)}{(s-p)/(u-r)} \right]$		
	Totals	<i>s</i>	<i>t</i>	<i>u</i>		

SE is standard error derived from running a statistical analysis on points fitting within each distance category.



(a)



(b)

Figure 1. (a): Risk ratios for exposure to Ohio roads. (b): Ohio EAB risk due to exposure to roads.

could be predation that is drawn to campsites and roads due to the presence of humans. It might be interesting to get Audubon bird count data and see if likely predators of EAB are correlated with campgrounds and roads and not at distances 5 km from those features.

The smaller roads, A3 and A5, secondary and connecting roads, and vehicular trails respectively, show only moderate increase in risk. At the 1 - 2 km exposure distance risk associated with A1, primary roads with limited access, increases from 2 to 3, while the risk associated with all other road types drops considerably. This risk is probably associated with higher populations when vehicles leave the major highways and move to residences or other destinations. This can be evaluated further by comparing population density distribution to the A1 roads. At the 2 - 5 km exposure distance all relative risks, except those for A71 and A1 roads drops below 1, indicating decreased likelihood of EAB introduction. At the 5 - 10 km exposure distance only the A71, pedestrian trails, show an elevated risk. Beyond 10 km the exposure shows lower probability of EAB introduction for all road types.

When the product of the risk ratios for each exposure is plotted on a map of Ohio, areas at highest risk of EAB introduction become apparent and can be identified by patterns similar to major highway corridors (**Figure 1(b)**). The EAB positives largely lie within the areas identified as highest risk by their exposure to roads. The risk map produced by examining the exposure to roads closely resembles that produced by Prasad *et al.* [9]. The predominant observable pattern is exposure to the large highways across the state. The only difference between Prasad *et al.* [9] study and this one is that hereby high risk areas to the southeast of the state are identifiable. This exclusion in Prasad *et al.* [9] study may be due to utilizing an average daily traffic to derive associated weights.

At close distances main tracks and spur tracks in Ohio have similar relative risks (**Figure 2(a)**). However the relative risks associated with main tracks falls below 1 and there is a decreased probability of EAB introduction compared to spur tracks. This finding is consistent with the idea that EAB introduction occurs where trains load and unload cargo. The relative risk associated with main tracks is lowest between 10 km and 20 km and is similar to the relative risk of A2 major roads. When compared to main tracks, increasing the distance from spur tracks is associated with only a decreased relative risk. **Figure 2(b)** depicts the sum of the log of the risk ratios for each exposure due to rail transport.

The relative risk of each campground size in Ohio, with the exception of those with between 176 and 240 RV sites, increases between the first and second distance category (**Figure 3(a)**). As with the relative risks associated with proximity to A71 roads, this suggests that the contributory factor associated with this elevated relative risk is not the campgrounds themselves, for the same reasons as aforementioned. Compared to other exposure scenarios, distance from campgrounds shows little decrease in relative risk. The trend lines stay remarkably flat before dipping between 10 and 20 km from the campgrounds. The largest distances from campgrounds show similar relative risks as the other exposures. Campgrounds with less than 65 RV sites and those with between 176 and 240 RV sites are unique in that they are the only exposures measured that do not show any increased risk EAB introduction. The smallest category possibly has decreased risk of EAB introduction due to the low numbers of campers at each site. It is unclear why the second largest category has a low relative risk. The campgrounds that produce the highest risk are those with between 65 and 120 RV sites. The associated relative risk ($=4.2$) is the second highest seen, is exceeded only by exposure to walking paths and trails. It is unclear what factors associated with these campgrounds could cause the elevated relative risks. The relatively small size of the campgrounds should suggest few campers bringing infested wood. It is possible that campgrounds of this size typically have a management style, clientele or other, non-spatial, factor that increases relative risk. Identification of a category of campsite that produces a high relative risk of EAB introduction could be used to assist in targeted efforts to educate campers about EAB. **Figure 3(b)** shows sum of the log of the risk ratios for each exposure.

The relative risks associated with existing areas of ash stands in Ohio showed decreased likelihood of introduction of EAB (**Figure 4(a)**). The highest basal areas (11.59 - 53.95 m²/ha) had modestly elevated risk of introduction of EAB at small distances, which is surprising because areas dense in ash are predicted to be hotspots in Prasad *et al.*'s [9] gravity model. Further than 2 km from the three densest ash basal areas the relative risk decreases rapidly, showing the lowest relative risks seen in the analysis. This may be attributed to minimal human footprint at areas closest to densest stands. This corollary can be tested by comparing the spatial distribution of dense ash stands to existing land use. If this can be attested, then it lends credence to the idea that human activity is an essential mode of EAB dispersal. **Figure 4(b)** shows sum of the log of the risk ratios for each exposure.

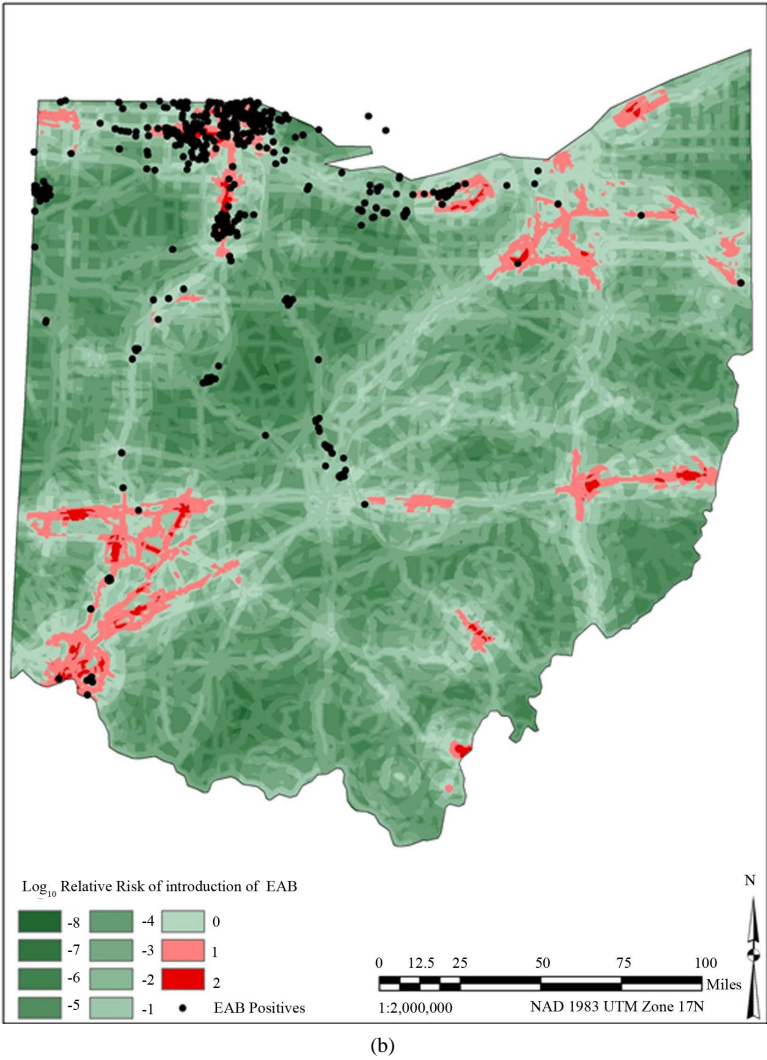
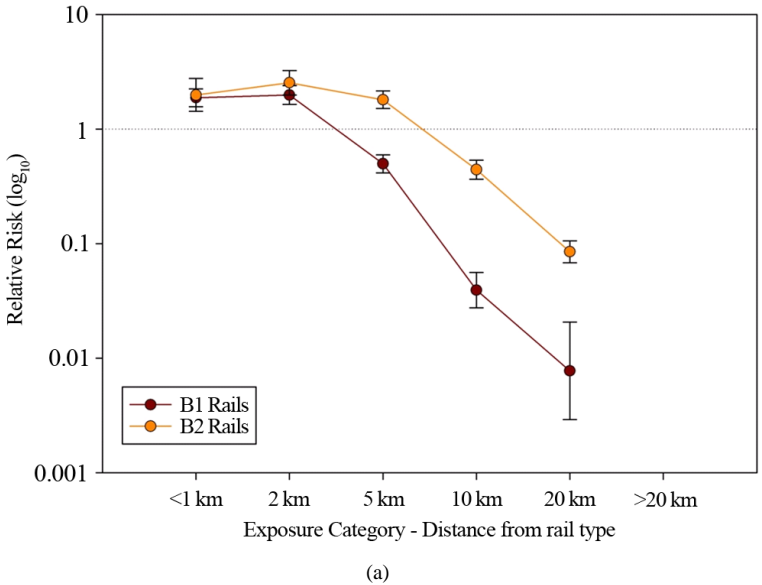
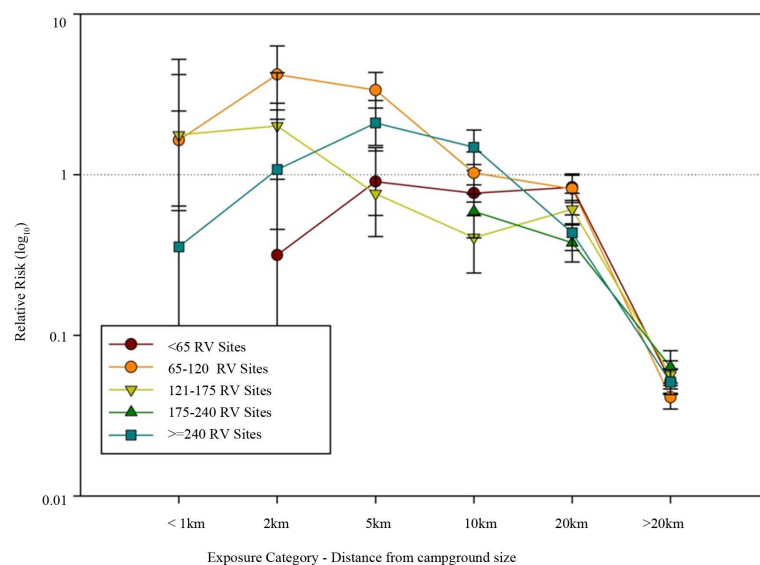
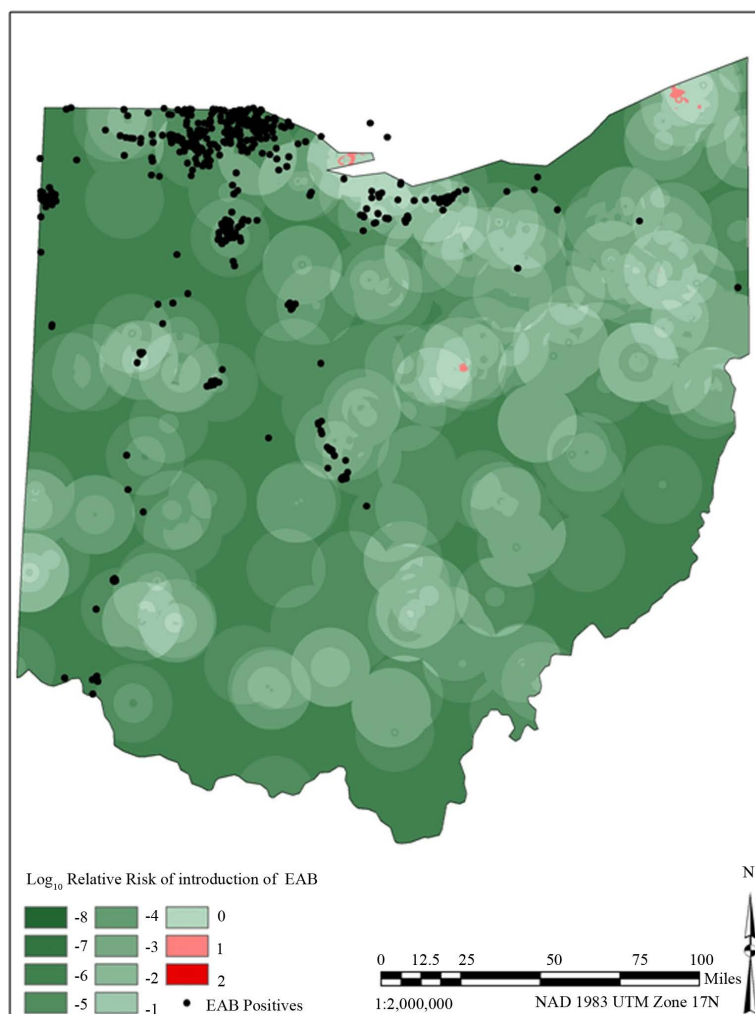


Figure 2. (a): Risk ratios for exposure to Ohio rails. (b): Ohio EAB risk due to exposure to rails.

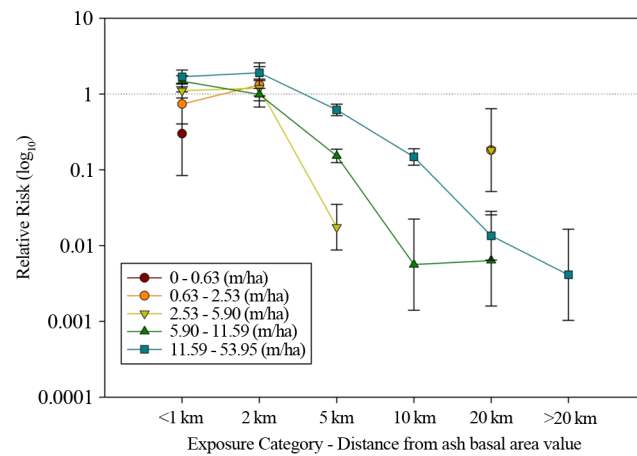


(a)

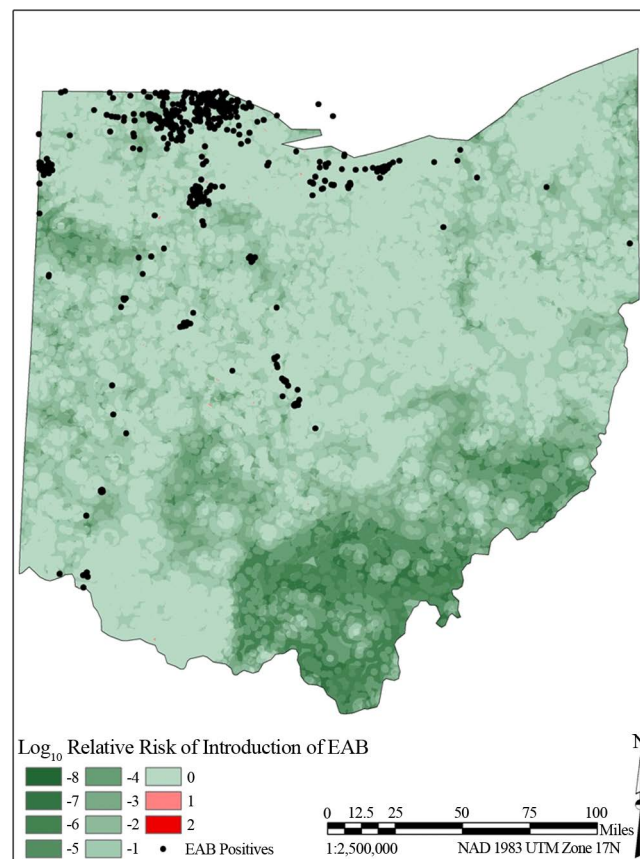


(b)

Figure 3. (a): Risk ratios for exposure to Ohio campgrounds. (b): Ohio EAB risk due to exposure to campgrounds.



(a)



(b)

Figure 4. (a): Risk ratios for exposure to ash trees in Ohio. (b): Ohio EAB risk due to exposure to ash trees.

3.1. Implications

The overall relative risk of introduction of EAB and associated ash mortality can be calculated for an area by summing the logs of the relative risks for each exposure category as in the Ohio example ([Figure 5](#)). The areas with highest combined risk align most prominently with the locations of roads and rails. The risk due to exposure to ash is broadly distributed over the state with the exception of the southeast corner of the state, where relative risks are lower. While there is an increased risk associated with some campgrounds the relatively small numbers have a diminished effect on a statewide scale.

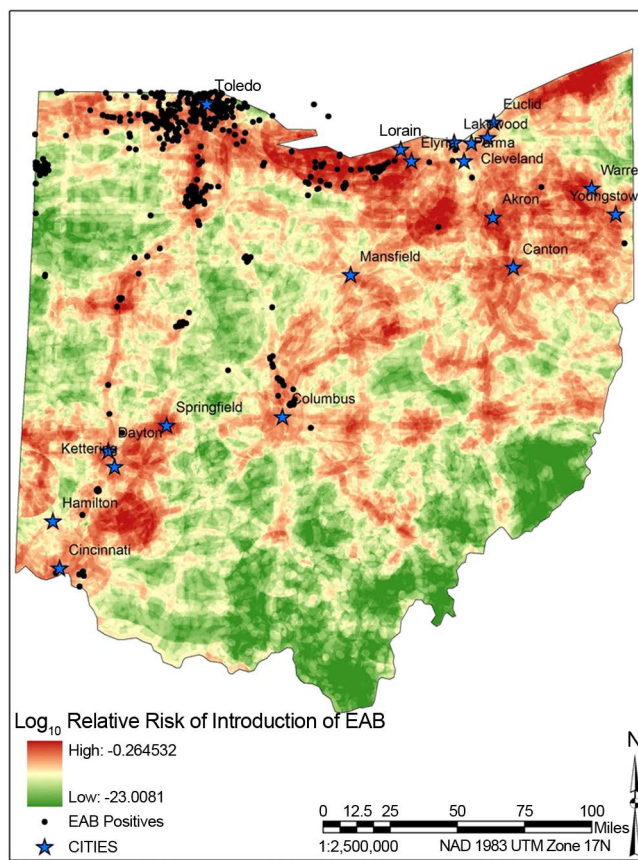
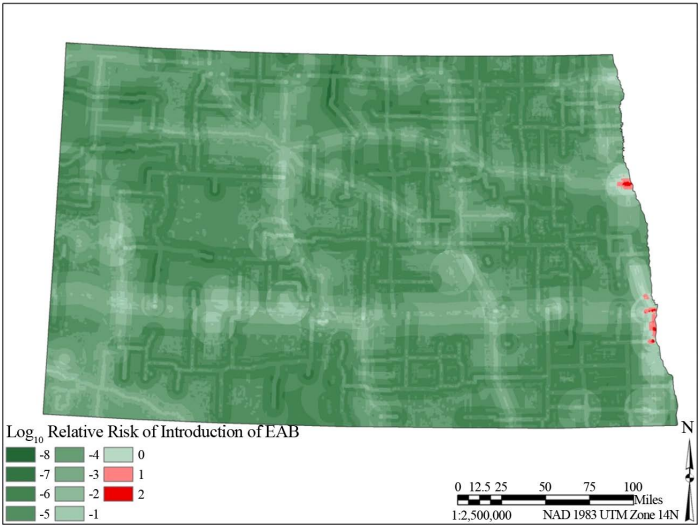


Figure 5. Ohio EAB risk due to combined factors.

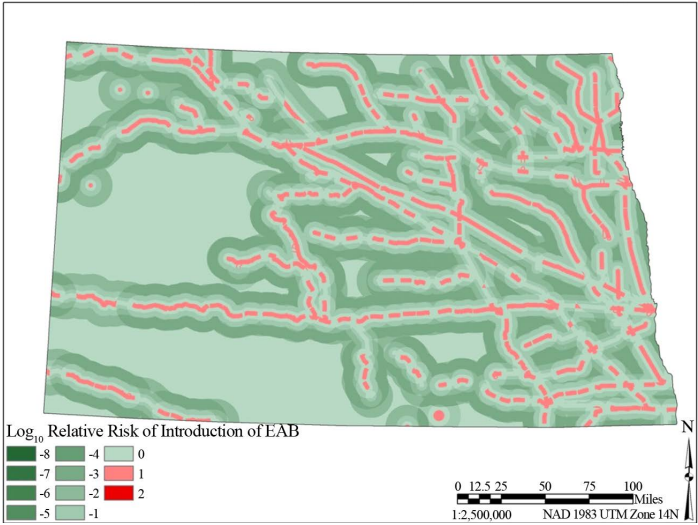
3.2. Model Application

Exposure features corresponding to those defined for Ohio were collected for North Dakota: distance to roads, rails, campgrounds and ash density. The relative risks calculated for each exposure type and distance category as in the Ohio case, were assigned to the corresponding features to generate comparative risk values for North Dakota. The high risk areas for North Dakota are confined to the two major metropolitan areas, Fargo and Grand Forks, where there exists a higher density of roads (**Figure 6(a)**). Exposure to rails is large because of the elevated relative risks across the state. North Dakota is relatively well covered by railway networks, with exceptions on large unconnected areas at Theodore Roosevelt National Park, Little Missouri National Grassland and south of Interstate 94 around the Heart Butte Reservoir Game Management Area (**Figure 6(b)**). The relative paucity of campgrounds in North Dakota implies that the risks due to campground exposure are comparably diminished. However, most of the campgrounds in North Dakota belong to the second size class, which imperatively elevates associated risk (**Figure 6(c)**).

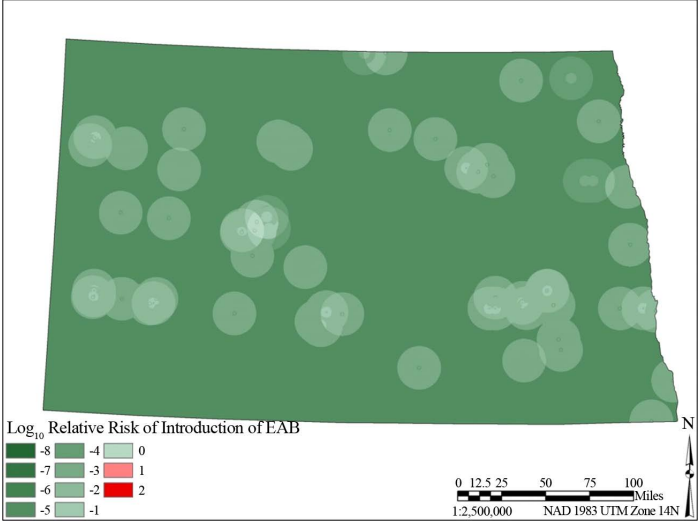
The advantage of using a relative risk model is that you can calculate weights that other models assume. It also allows you to make predictions without knowing causes, if there is a sufficiently strong correlation. This is illustrated in the identification of areas in the southeast of Ohio that were not predicted in Prasad's [9] model. More EAB incidence data will allow more accurate correlation of EAB infestation to geographic features. The disadvantage of using relative risk as a predictive model is that the statistics assume factors are the same in different states. We postulate that this is not the case with ash stands in North Dakota versus Ohio. It is very clear from the basal area maps that ash distribution is different in the two states. In this case we underestimated the importance of ash density when we applied the model to North Dakota scenario which in turn yields a relative risk map displaying high risk areas like Turtle Mountains and Theodore Roosevelt National Park. North Dakota has more isolated regions of high density ash tree stands. In addition there are regions of high relative risk along the main riparian corridors (**Figure 6(d)**). When the log of the relative risks of the four exposure types are



(a)



(b)



(c)

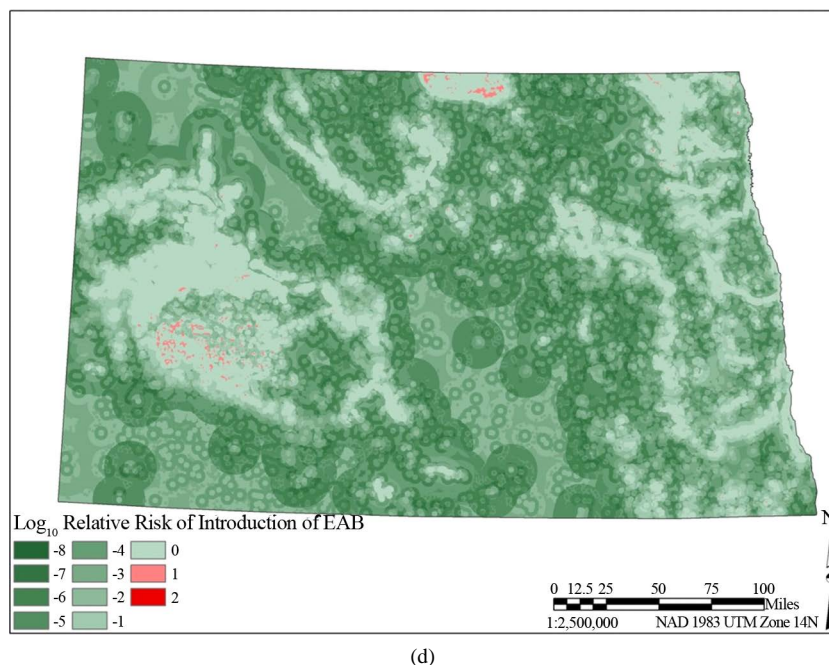


Figure 6. (a): North Dakota EAB risk due to exposure to roads. (b): North Dakota EAB risk due to exposure to rails. (c): North Dakota EAB risk due to exposure to campgrounds. (d): North Dakota EAB risk due to exposure to Ash trees.

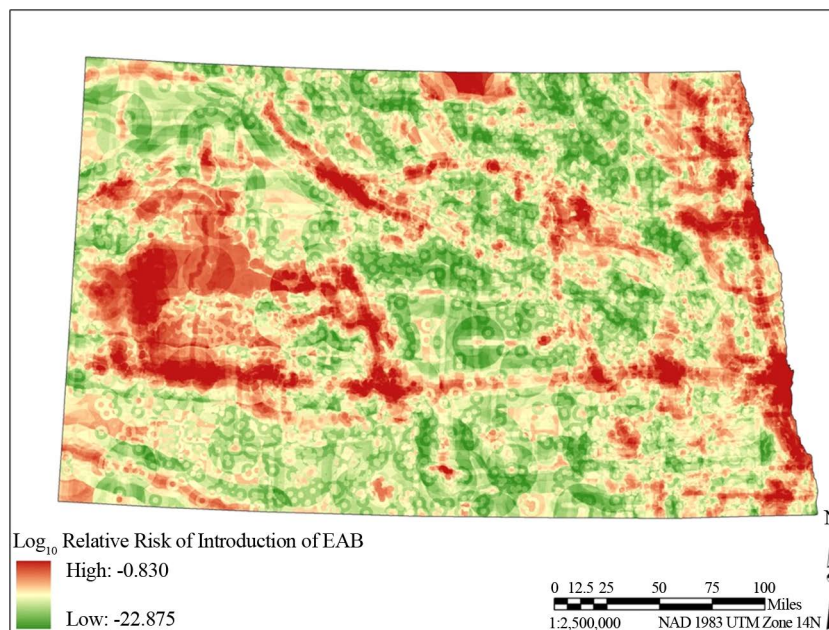


Figure 7. North Dakota EAB risk due to combined factors.

summed the result is a risk map that displays elevated exposure pathways in areas associated with rails and along the major river systems of North Dakota (Figure 7).

4. Conclusion

The model highlighted in this study was developed to serve as a baseline data resource to highlight ash trees at mortality risk due to probable EAB infestation in North Dakota. With EAB already detected in much of the

Midwest, effort is being put into monitoring the outbreak. The question for foresters in states adjacent to confirmed EAB locations is how this information can be used to modify current management practices and aid in quarantine demarcations. The preliminary step usually initiated by most forest health agencies is effective monitoring and tracking EAB. Risk maps as ones produced in this study can be used to help define the area of quarantine as well as determine appropriate regulations to prevent the spread to adjacent areas.

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