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A multi-model approach to predicting emerald ash borer infestations

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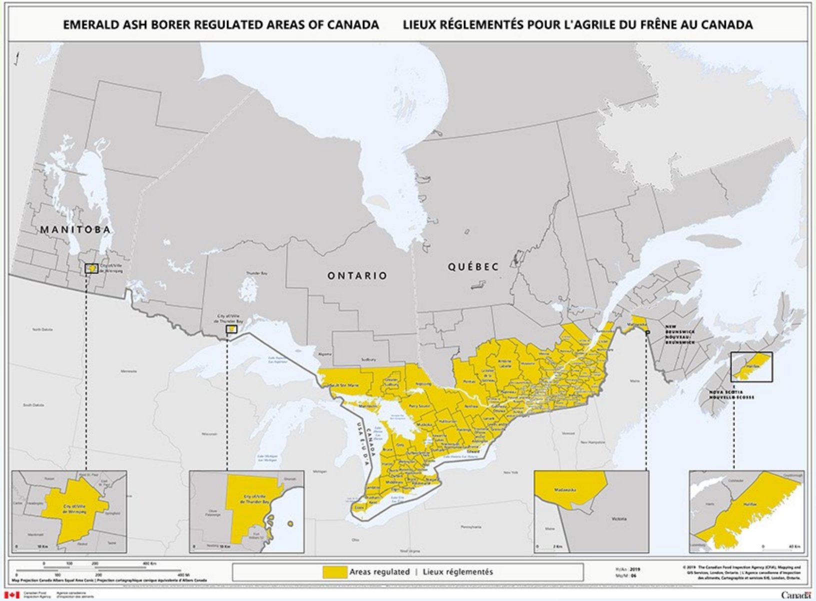
Canada

Emerald ash borer (EAB), *Agrilus planipennis*

- **Buprestid beetle of east Asian origin**
- **Metallic green in colour, rice-grain shaped, ~14 mm long**
- **Detected in North America in 2002**
- **Probably introduced via imported wood packing or crating materials**
- **Attacks and kills all North American ash species (*Fraxinus* spp.)**

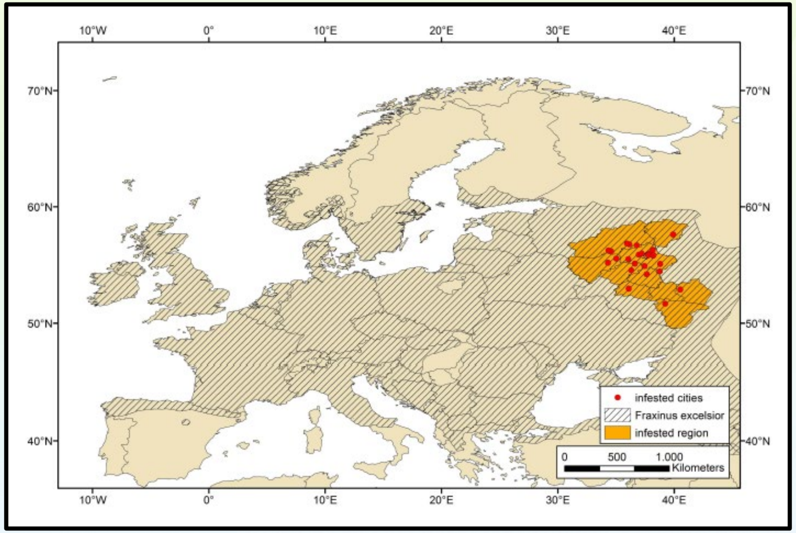
- **EAB is presently found in 5 Canadian provinces and 35 states in the U.S.**

www.emeraldashborer.info

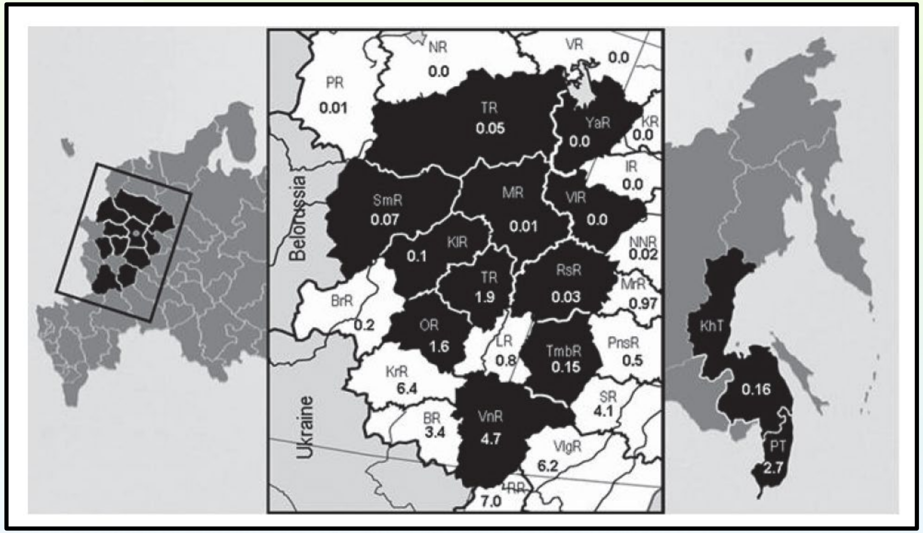


Canadian Food Inspection Agency

- **Found in Moscow, Russia in 2003; potential for spread throughout Europe's ash range**



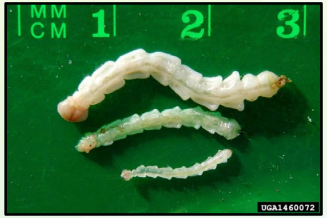
Valenta et al. (2015). A high-resolution map of emerald ash borer invasion risk for southern central Europe. Forests 2015, 6: 3075-3086.



Musolin et al. (2017). Between ash dieback and emerald ash borer: Two Asian invaders in Russia and the future of ash in Europe. Baltic Forestry. 23: 316-333.

EAB life cycle

Egg



Larvae

Pupa

Adult

Egg	Larvae	Pupa	Adult
June – August (t_0)	July (t_0) – May (t_0 + 1 yr)	May (t_0 + 1 yr)	May – Sep (t_0 + 1 yr)
June – August (t_0)	July (t_0) – May (t_0 + 2 yr)	May (t_0 + 2 yr)	May – Sep (t_0 + 2 yr)

Image credit: Egg - Houping Liu, Michigan State University, Bugwood.org; Larvae - David Cappaert, Bugwood.org

Tree damage


Eric R. Day, Virginia Polytechnic Institute and State University, Bugwood.org
5382312

Slowing the spread of EAB

Contributing factors of rapid expansion and survival

- **Human-mediated transport of firewood**
- **Active dispersal of beetles**
  - **Adults mainly colonize trees at distances of <750 m per year from their emergence point**
  - **Most egg depositions and larval galleries are near adult emergence points**
  - **Females can fly 9.8 km/year over their life time (tethered flight experiments)**
- **Lack of effective natural control (native parasitoids)**

- **Not just humans, EAB will appreciate some warm winter weather!!**

EAB modelling literature

Muirhead et al 2006	Local and long-distance dispersal
Bendor et al. 2006; Bendor and Metcalf 2006	Dynamic-spatial modeling of EAB spread
Iverson et al. 2010; Prasad et al. 2010	Various models – active and passive dispersal
Sobek-Swant et al. 2012	Ecological niche modeling (climate-only)
Huset 2013 (unpublished thesis)	Active, passive dispersal , topography + climate factors (western New York)
Vermunt et al. 2012; DeSantis et al. 2013; Cuddington et al. 2018; MacQuarrie et al. 2019	Under-bark temperature and over-wintering mortality
Yemshanov et al. 2012, Yemshanov et al. 2015; Yemshanov et al. 2019	Uncertainty and likelihood of establishment; spread rates; sampling strategies
Zhang et al. 2014	Remote sensing-based analysis
Anderson and Dragicevic 2016	Geospatial modeling taking into account active, passive dispersal + climate factors (Windsor, Ontario, Canada)
Orlova-Bienkowskaja and Bieńkowskii 2018	Kernel-based and pair-wise distance methods

Ensembles vs. Individual models

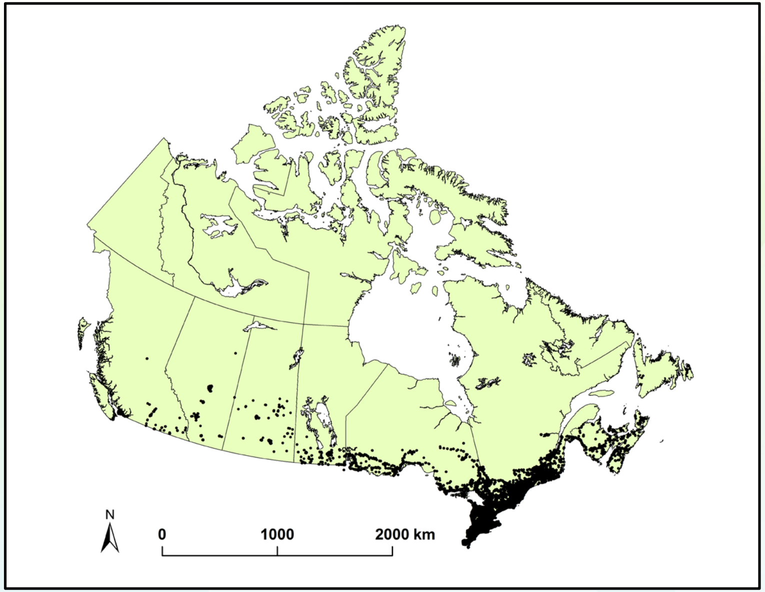
- Multiple modelling algorithms are present. Which one to use?
- Predictive capacity will differ significantly from one model to the other.
- Individual models may not perform well in a new area or in a different time.
- Using an ensemble approach we can:
  - Combine predictions from different model types.
  - Identify variables of highest relative importance.
  - Reduce uncertainty in predictions.

Objectives

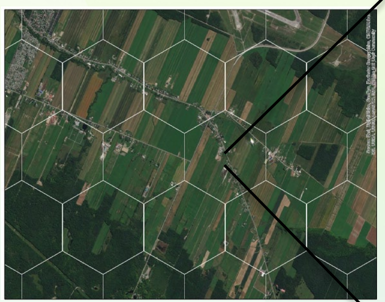
- Study the associations between EAB occurrences and potential drivers of infestations.
- Evaluate multiple modeling algorithms and assess their performances in predicting EAB infestations.

EAB trap collection data

- Trap capture data were collected from many different sources (2002-2018)
    - Canadian Food Inspection Agency (CFIA)
    - Provincial agencies and city managers (e.g., Ottawa, Oakville, Quebec City, Toronto)
    - Pest management companies (GDG, BioForest)
- Branch sampling data, where available



EAB data collection points



n = 19011

Latitude, longitude, topography

Campsites, road length, pop. density, rail, parks

% Treed, % Broad-leaf

Climate-related predictors

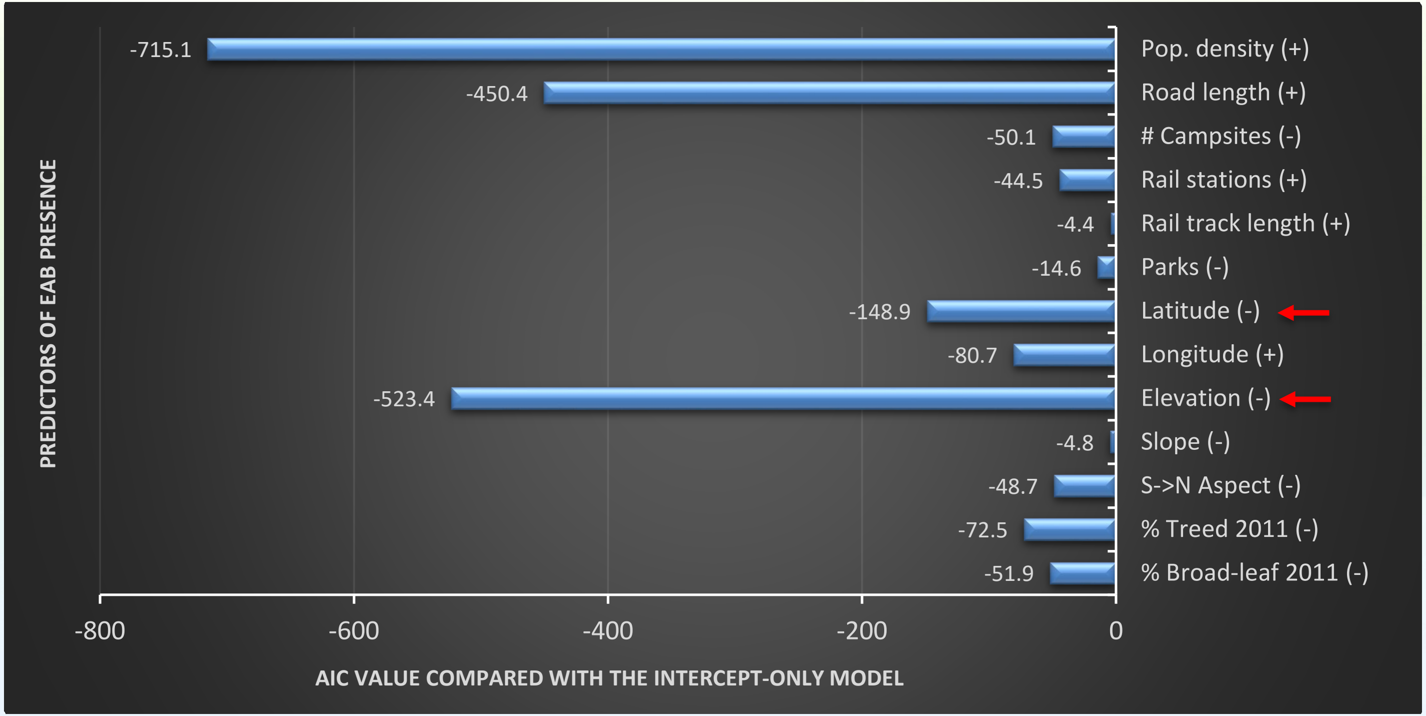
Non-climatic and climate-based predictors

- **Passive dispersal**: Human population density, road length, #campsites, percentage area consisting of parks, # rail stations, rail track length.
- **Positional and topographic**: Latitude, longitude, elevation, slope, aspect.
- **Vegetation-based**: Mean percent treed biomass, mean percent broad-leaf biomass, as proxies for ash tree distribution (Beaudoin et al. 2011).
- **Climate-based**: Degree days ≥ 10°C; coldest quarter mean temperature (°C); warmest quarter water deficit (mm); annual water deficit (mm); coldest quarter total precipitation (mm).

Ensemble models

- R package Biomod2, 10-fold cross-validation
  - Generalized linear model (GLM), Multivariate adaptive regression splines (MARS); Artificial neural networks (ANN), Flexible discriminant analysis (FDA), Classification tree analysis (CTA); Maximum entropy (MAXENT), Generalized boosting models, (GBM), Random forest (RF), and Surface range envelope (SRE).
- Used unweighted and weighted mean probabilities from nine models to derive ensemble predictions.
- Compared performances of individual models with the ensemble model.
  - Area under the curve of the receiver operating characteristic (AUC-ROC)
  - True skill statistic (TSS)

Non-climatic predictors

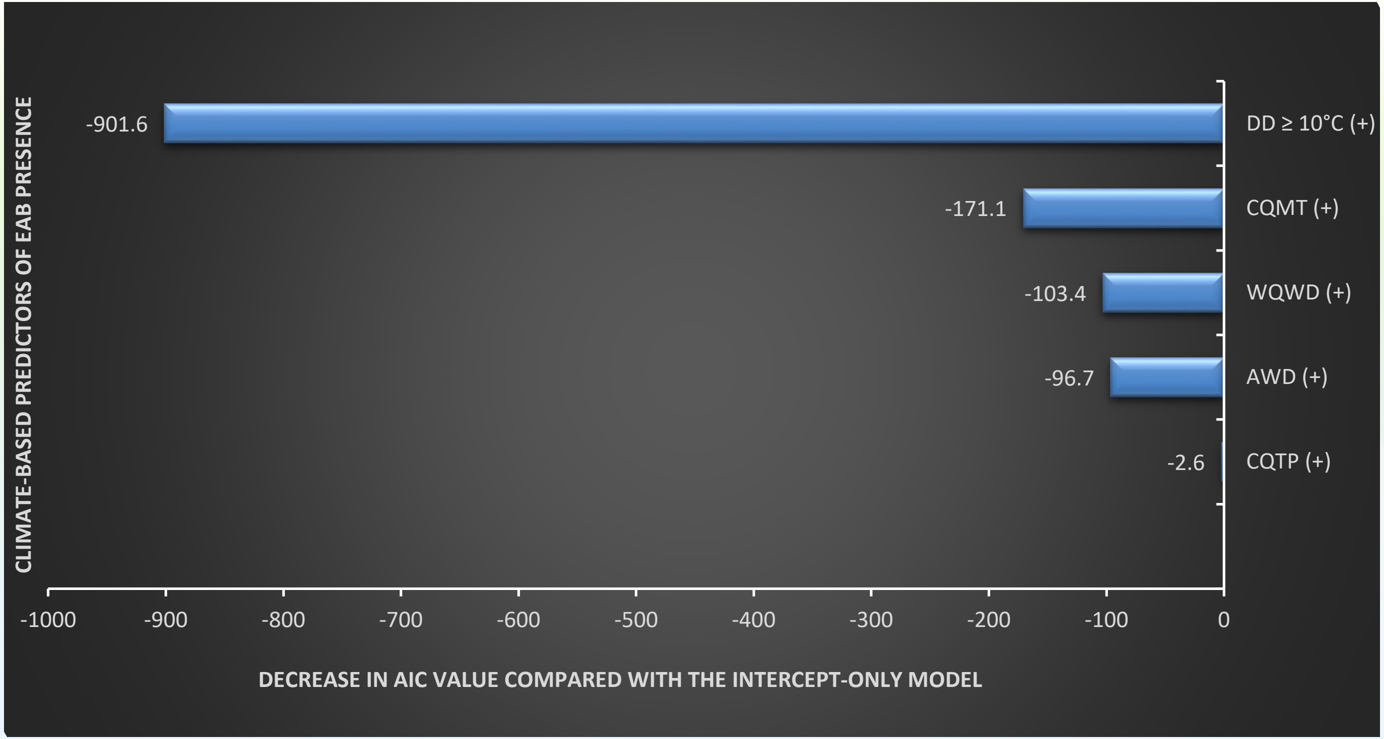


Mean percent treed biomass (Beaudoin et al. 2011)

Mean percent broad-leaf biomass (Beaudoin et al. 2011)

$logit\,[P(EAB = 1)] = \beta_0 + \beta_1 x$; AIC: Akaike Information Criterion

Climate-based predictors



Accumulated degree days ≥ 10°C

Coldest quarter mean temperature (°C)

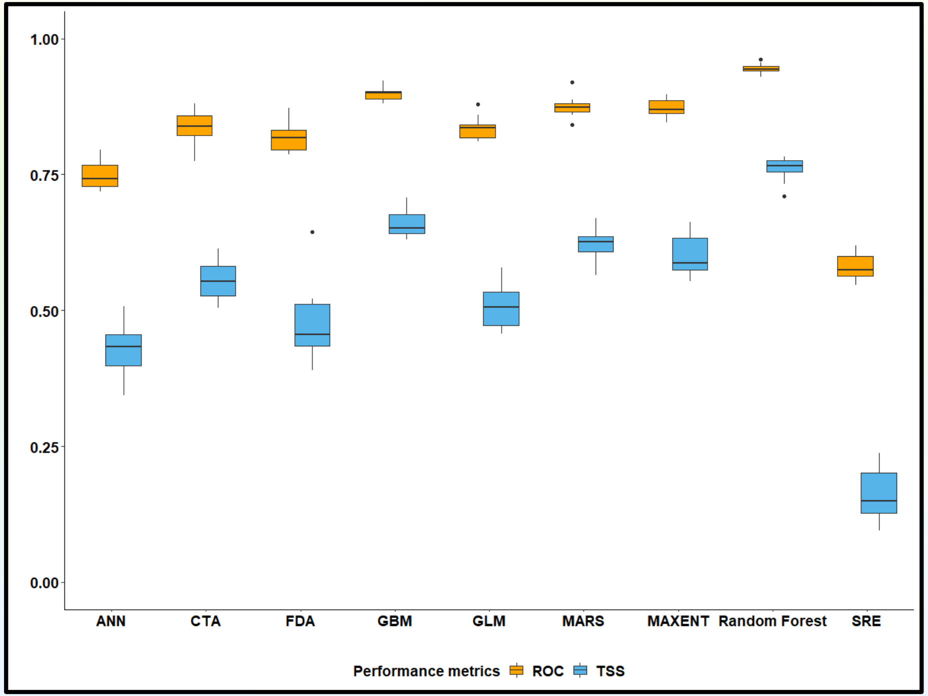
Warmest quarter water deficit (mm)

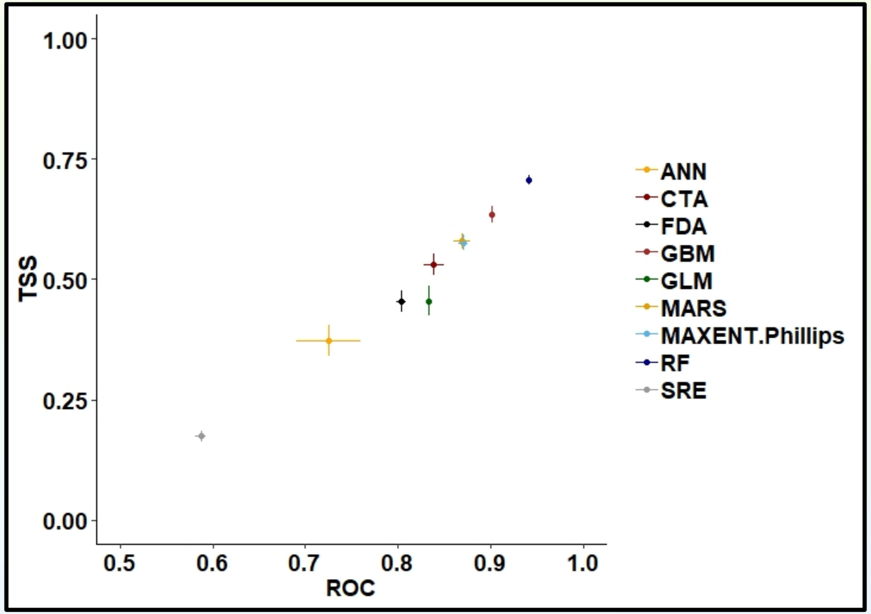
Annual water deficit (mm)

Coldest quarter total precipitation (mm)

$logit\ [P(EAB = 1)] = \beta_0 + \beta_1 x$; AIC: Akaike Information Criterion

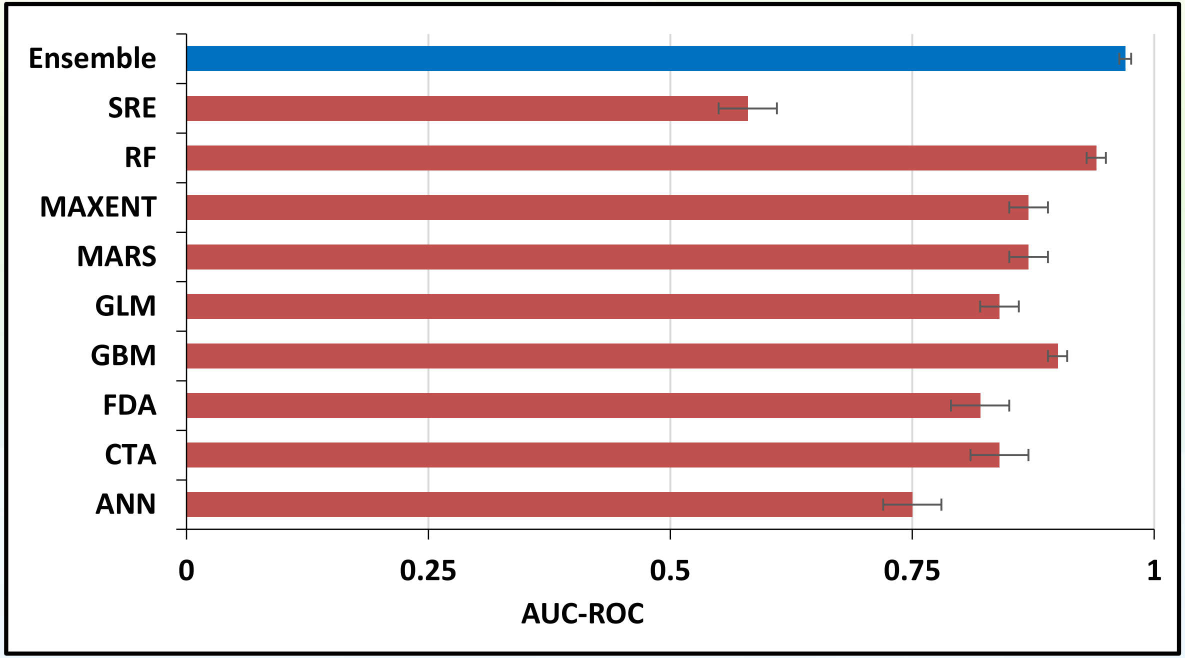
Individual models





Generalized linear model (GLM), Multivariate adaptive regression splines (MARS); Artificial neural networks (ANN), Flexible discriminant analysis (FDA), Classification tree analysis (CTA); Maximum entropy (MAXENT), Generalized boosting models, (GBM), Random forest (RF), and Surface range envelope (SRE).

Ensemble versus individual models



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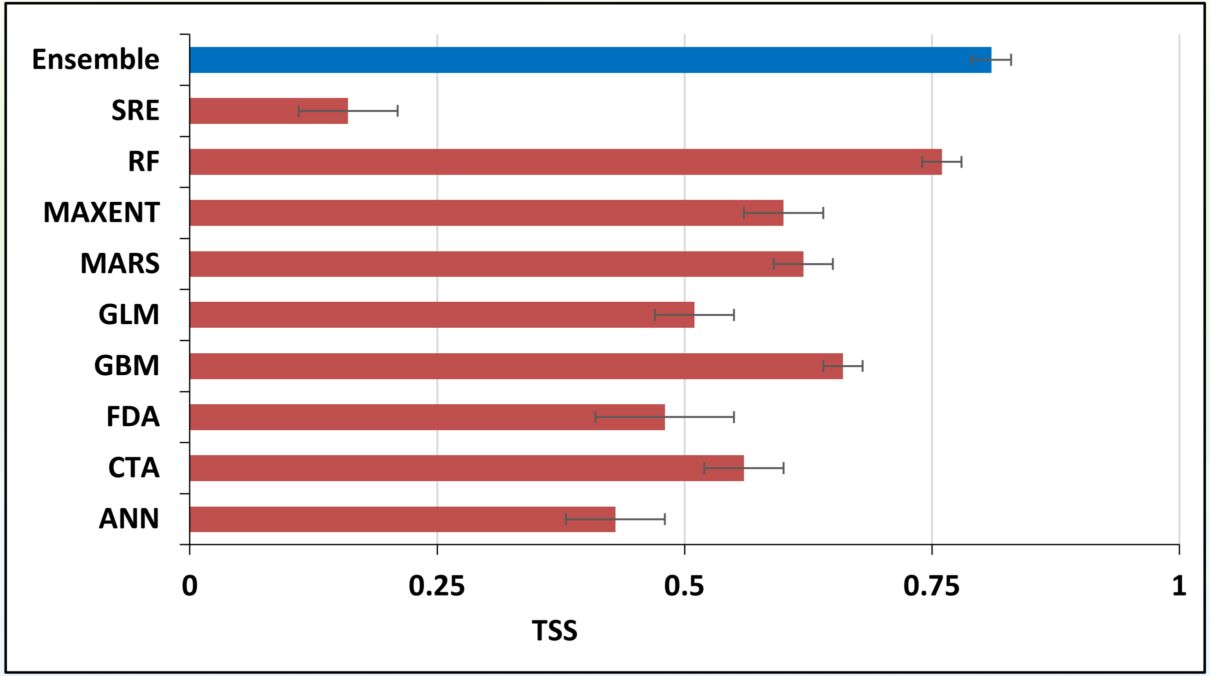

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Summary

- We assessed associations of relevant predictors with EAB distribution in Canada.
- Non-climatic variables included demographic, topographic, and vegetation-based variables.
- Ecologically-relevant weather variables included those that could influence EAB development and survival, and stress trees.
- Predictions varied among individual models.
- Ensemble models performed better than individual models.
- Accumulated degree days (≥ 10°C), elevation, annual water deficit, and human population density were strongly associated with EAB presence.

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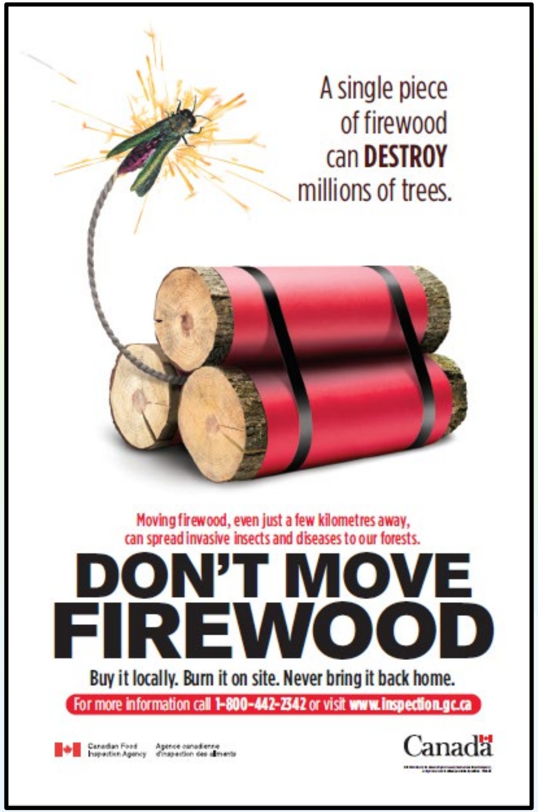

Thank you!

Questions, comments, or suggestions?