Utility of simple mechanistic models of winter mortality for invasive alien species

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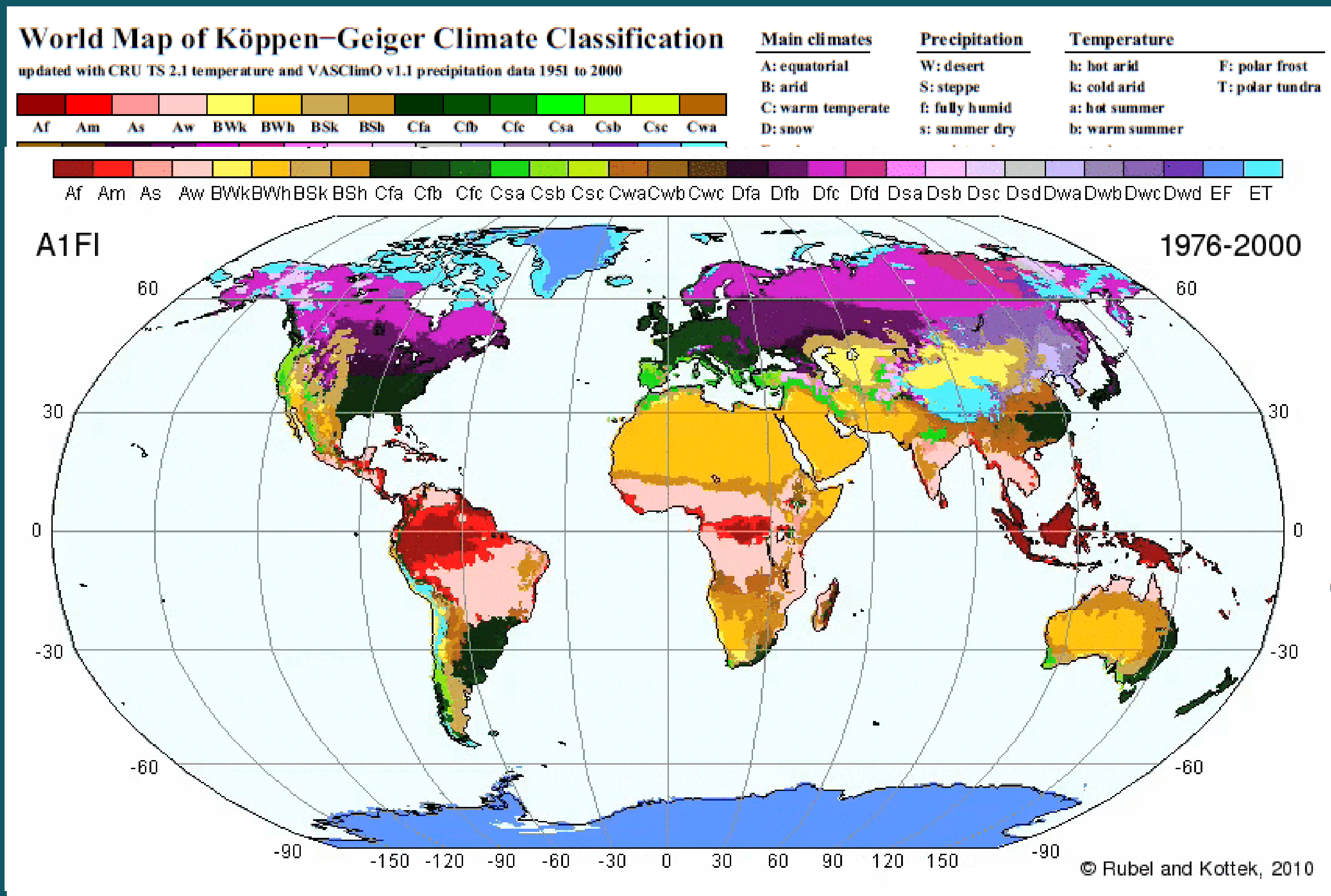
Outline

- Background
- Common procedures to assess insect cold hardiness
- Two examples of cold hardiness assessment and validation
- Concluding thoughts with respect to uncertainty

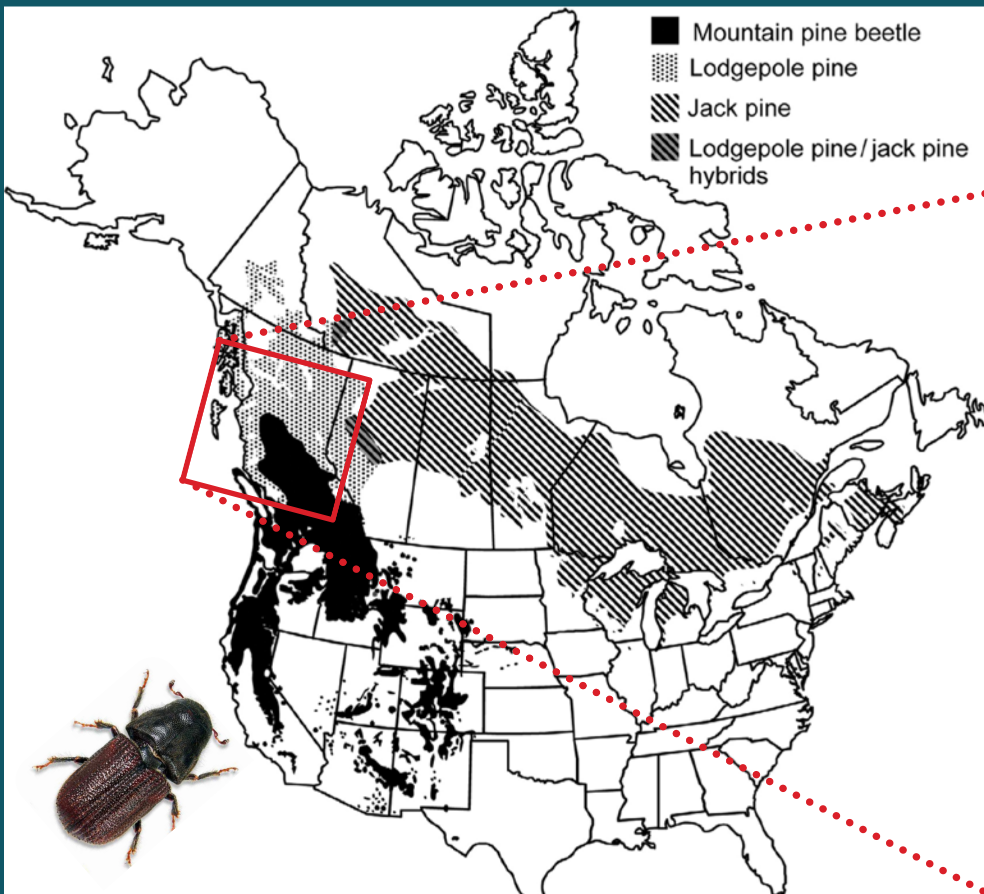
“Winter is coming”

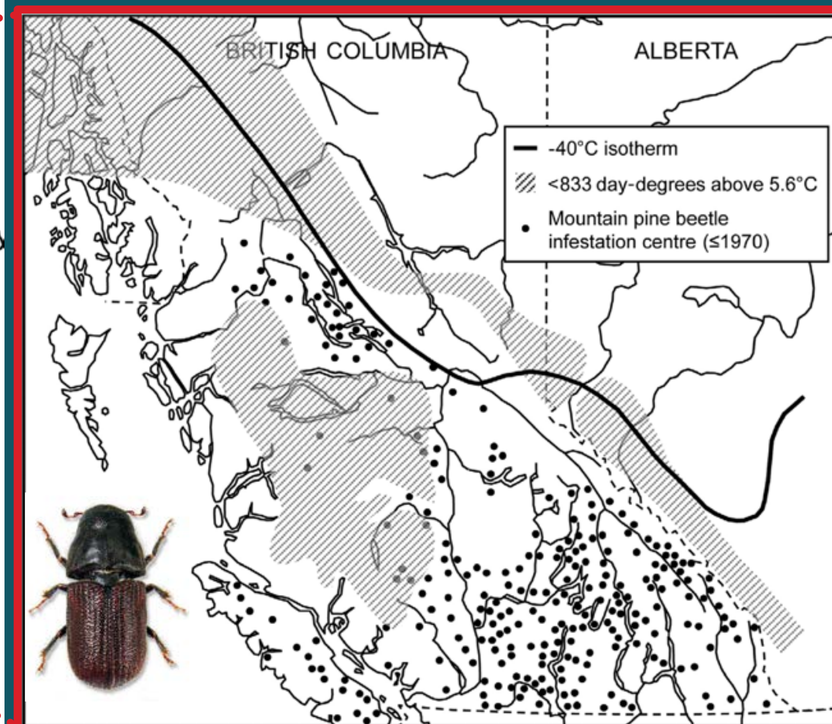


Kottek et al. 2006. Meteorologische Zeitschrift 15(3):259-263

Cold often constrains distribution

Mountain pine beetle
Dedronctonus ponderosae Hopkins





Figures 1 (left) and 4 (right) from Safranyik et al. 2010. Can. Entomol. 142(5):415-442.
Image of MPB adult from nrcan.gc.gov

Many species have (not) evolved means to survive in the cold

"Life in the subnivium"

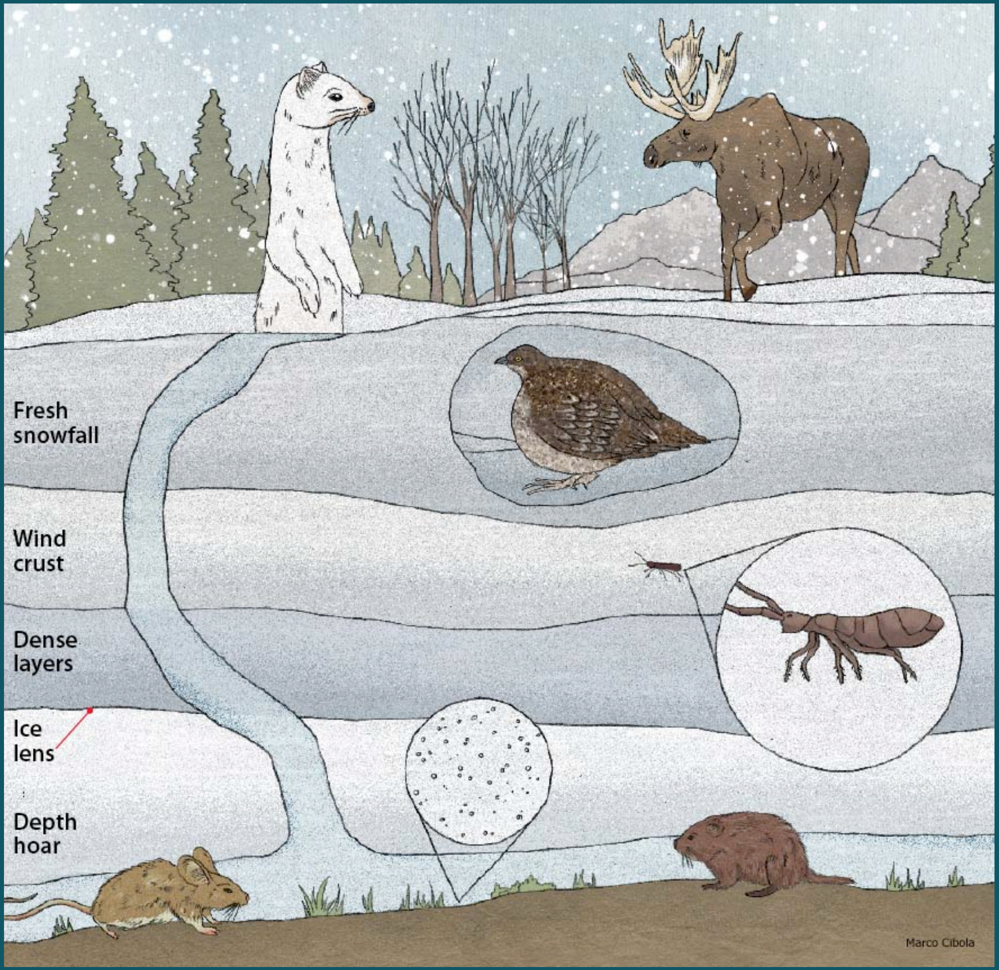


Image: Marco Cibola
http://archive.audubonmagazine.org/truenature/truenature1011.html

Spectrum of strategies

- Freeze avoidant species
- Freeze tolerant species

Physiological processes

- Production of antifreeze/ cryoprotective compounds
- Thermal hysteresis proteins
- Ice nucleating agents

Behavioral processes

- Migration
- Aggregation
- Shelter
- Voiding of the gut

(Reviewed in Baust and Rojas 1985, Leather et al. 1993, Denlinger and Lee 2010)

How to estimate where a species might overwinter?

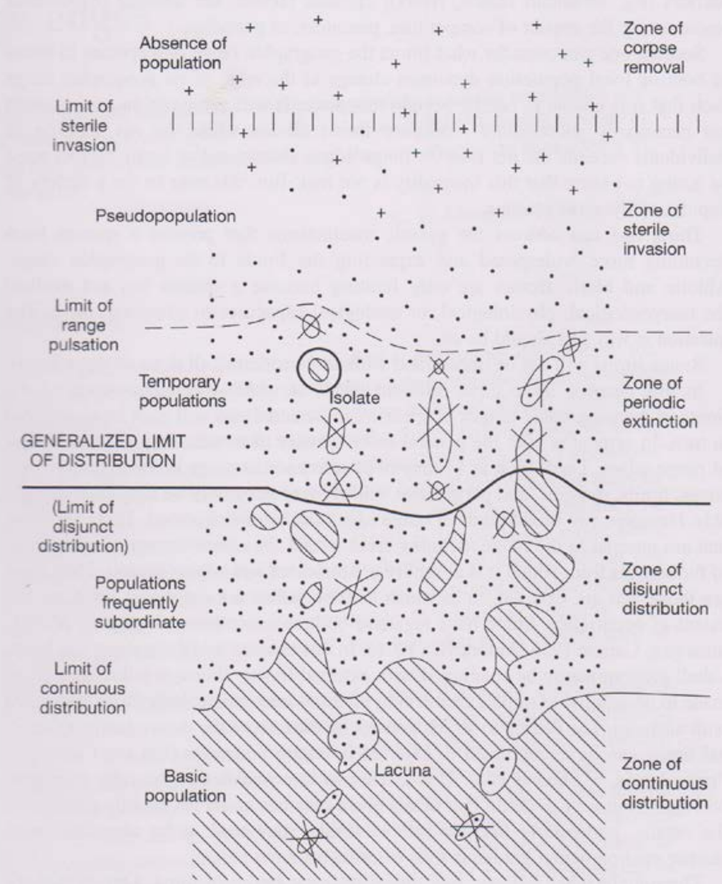
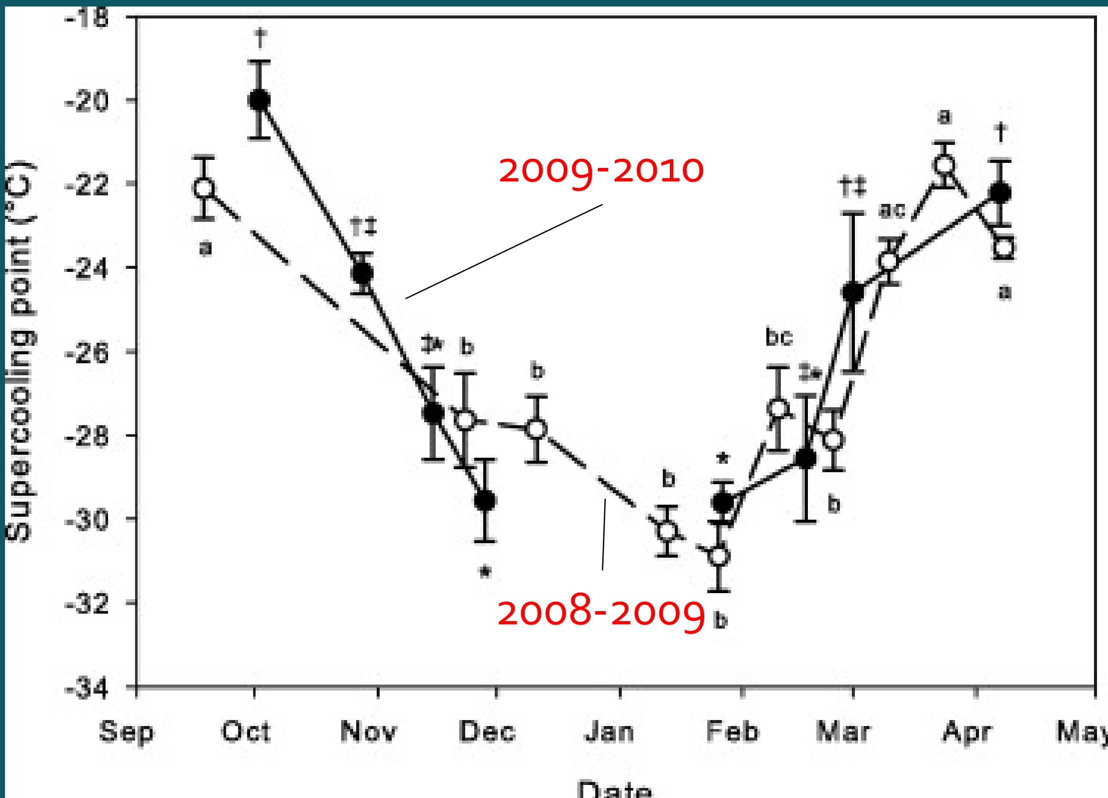


Fig. 2.1 A schematic presentation of the structure of the limits to geographic ranges. Areas with pluses indicate moribund individuals; dots, living individuals; crosses, periodically invading populations; and oblique lining, stable or constant populations. See text for further details. From Gorodkov (1986).

- Infer from geo. distribution
  - Advantages & Disadvantages: as for inductive species distribution models
- Field observation
  - Advantage: ecologically realistic
  - Disadvantages: cannot extrapolate, illegal/immoral for pre-incursion assessments of alien species
- Laboratory observation
  - Advantage: Mechanistic
  - Disadvantages: ecological relevance, physical & logistical constraints

Laboratory assays of cold tolerance



Crosthwaite et al. 2011. Journal of Insect Physiology 57:166-173

Must consider:

- Overwintering habitat
- Overwintering life stage(s)
- Acclimatization (diapause)
- Cold tolerance strategy
- Pre-conditioning
- Assay conditions
- Response: morbidity vs mortality
- Winter duration/severity and variation

Propositions and caveats

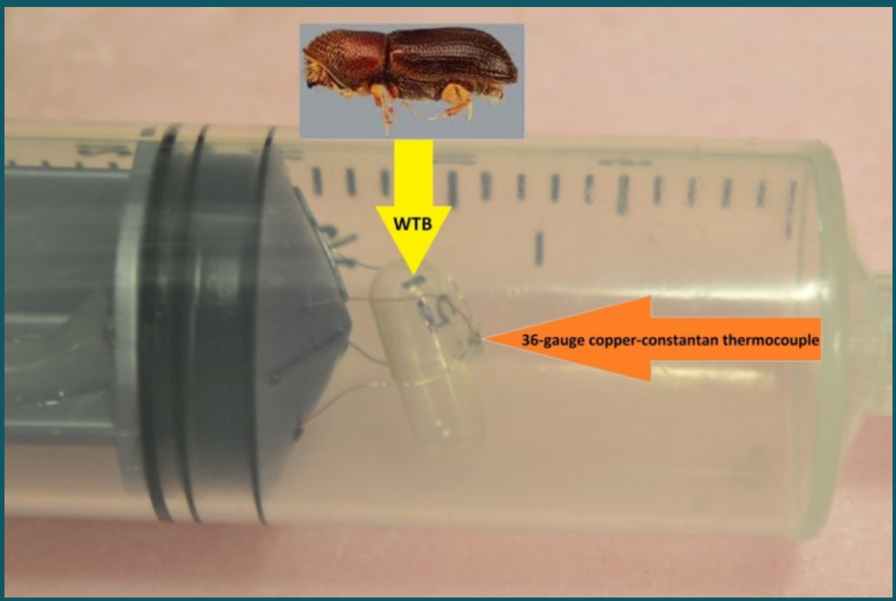
Proposition

- Winter mortality reflects the macro-physiological condition of individuals in the population and the temperatures to which they are exposed.
- For supranivean, freeze-avoidant species, a meaningful approximation of mortality can be forecasted from the temperature-mortality function for the most cold hardy condition and the coldest temperatures to which individuals were (or might be) exposed.
- For subnivean species, mortality may be more related to time spent at ~0°C.

Caveats

- Underestimation of winter mortality is preferable to overestimation.
- Other causes of mortality (e.g., starvation or dehydration) are likely to be under-represented.
- **Any forecast is, at best, a hypothesis to be tested, not a statement of fact!**

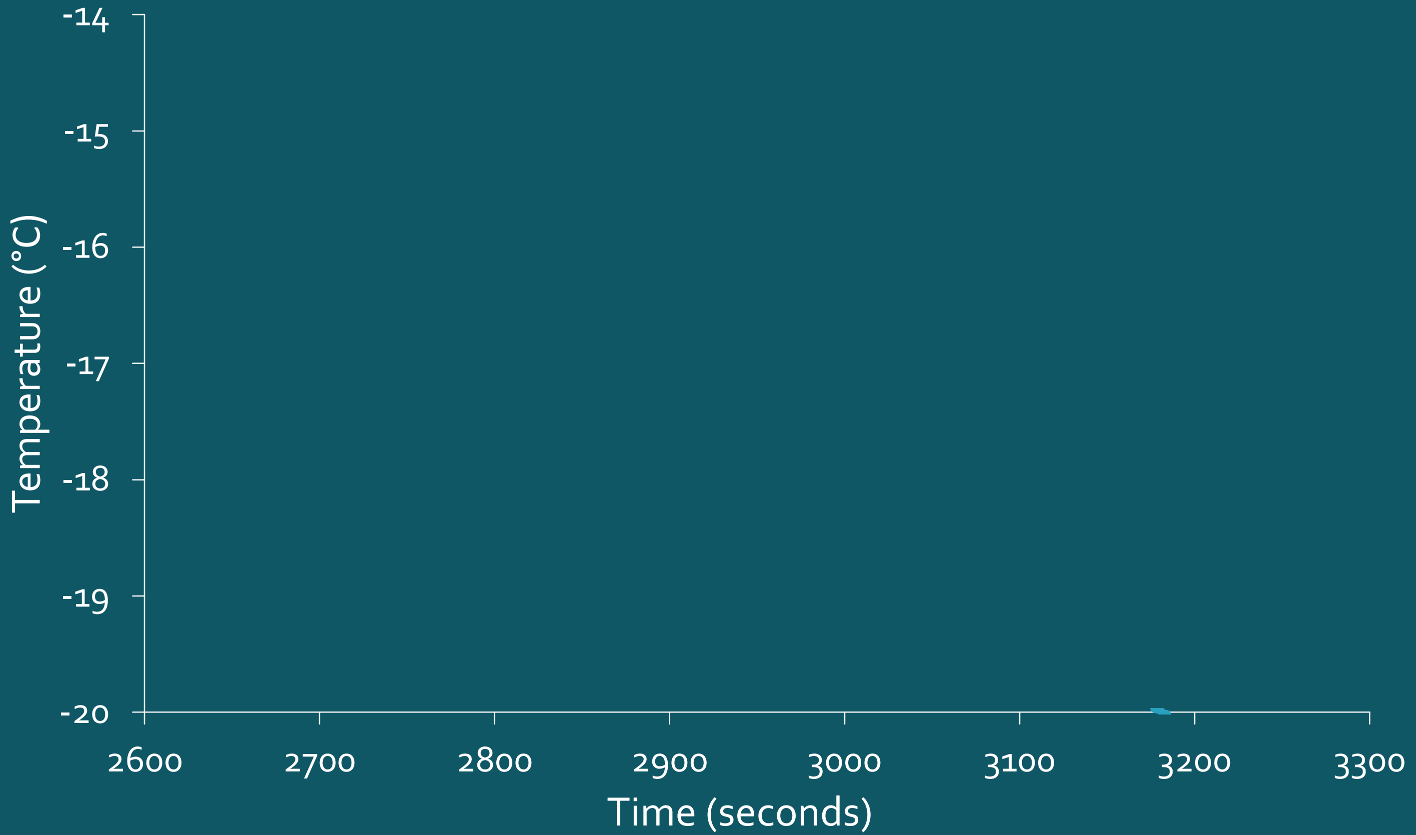
Methods: Measuring insect cold tolerance in the laboratory



Carrillo et al. 2004, Hanson and Venette 2013

Methods: Supercooling point

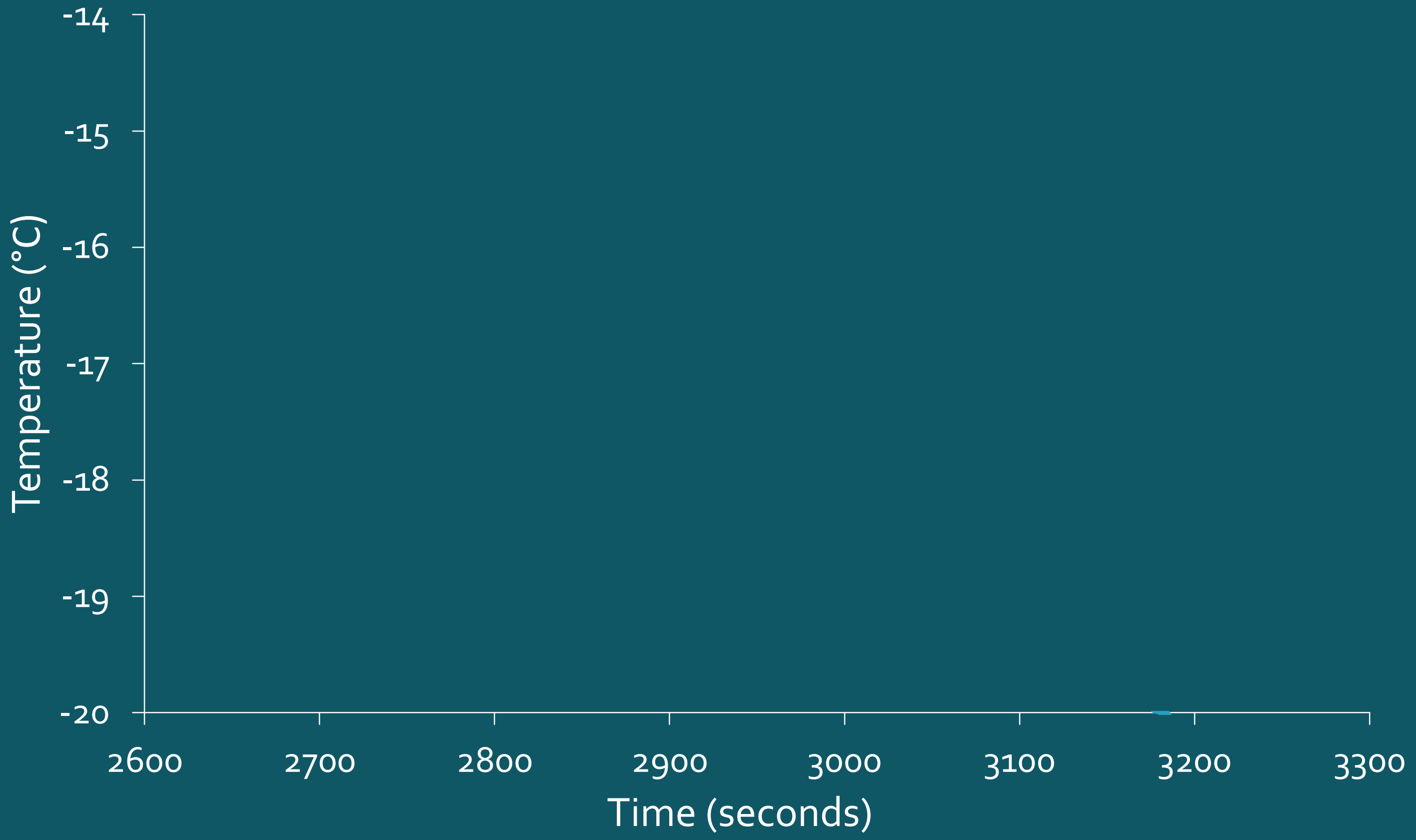
At what temperature does freezing begin?



Carrillo et al. 2004, Lee 2010

Methods: Lower lethal temperature

At what temperature does death begin?



Carrillo et al. 2004, Lee 2010

Methods: Lower lethal temperature

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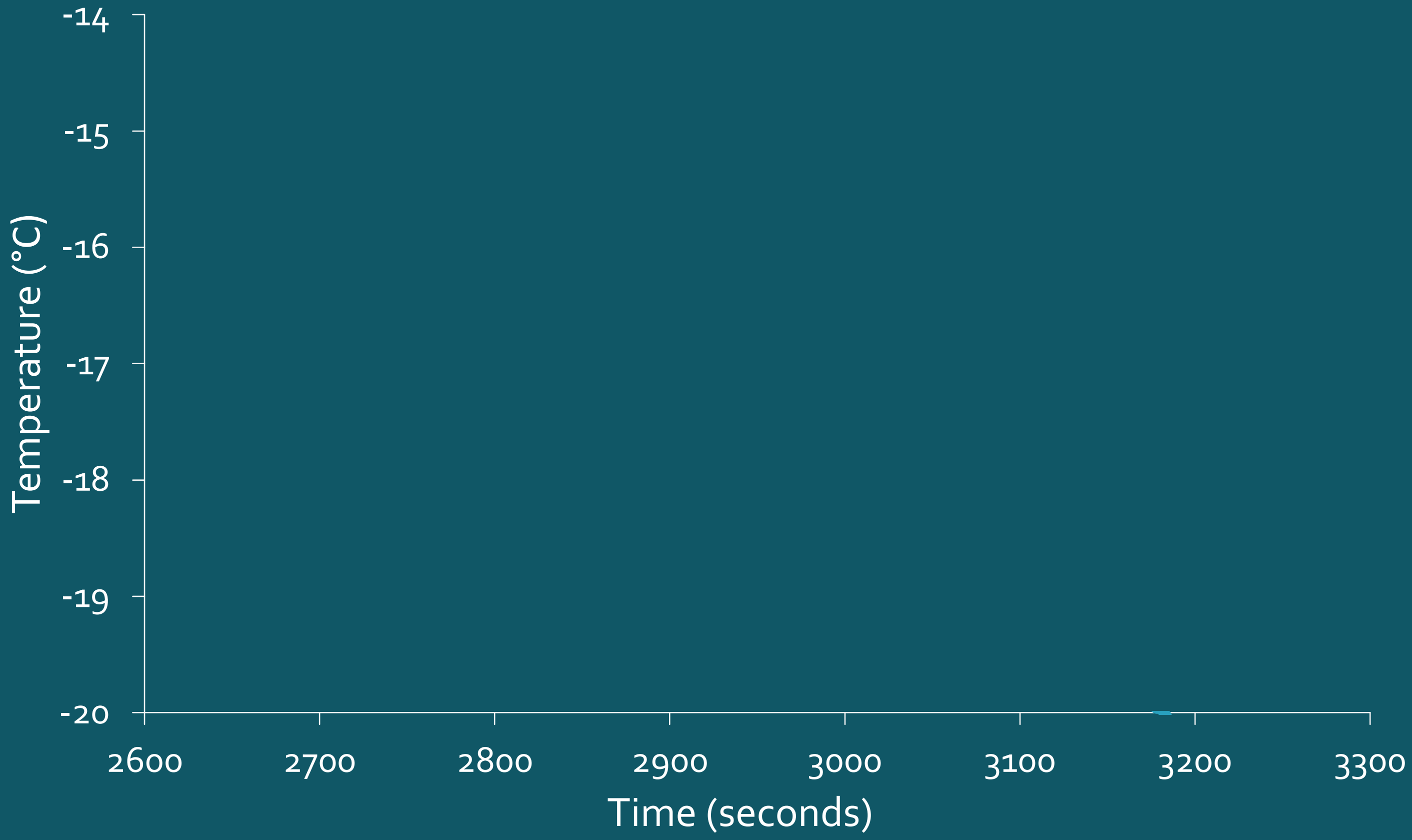
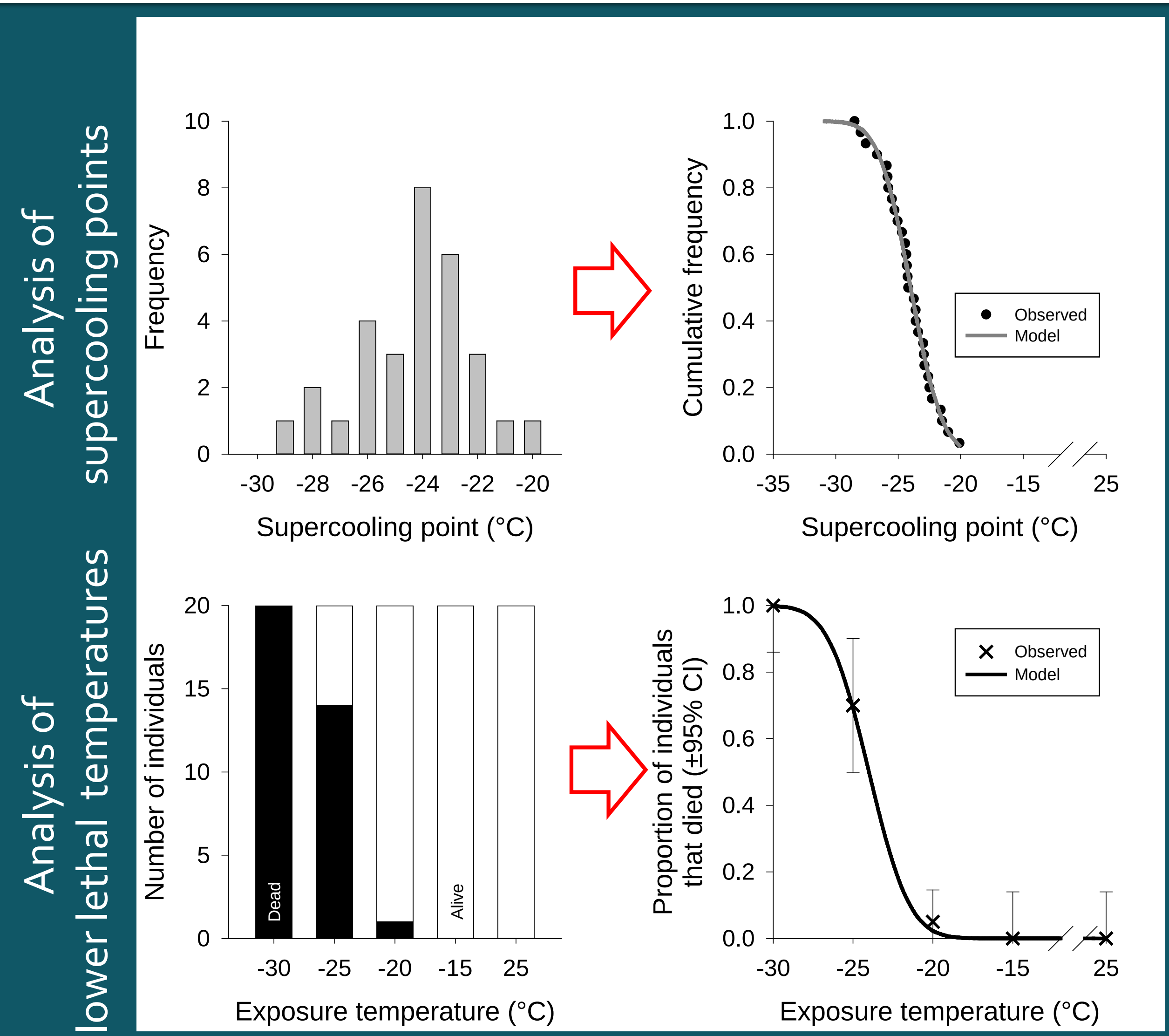
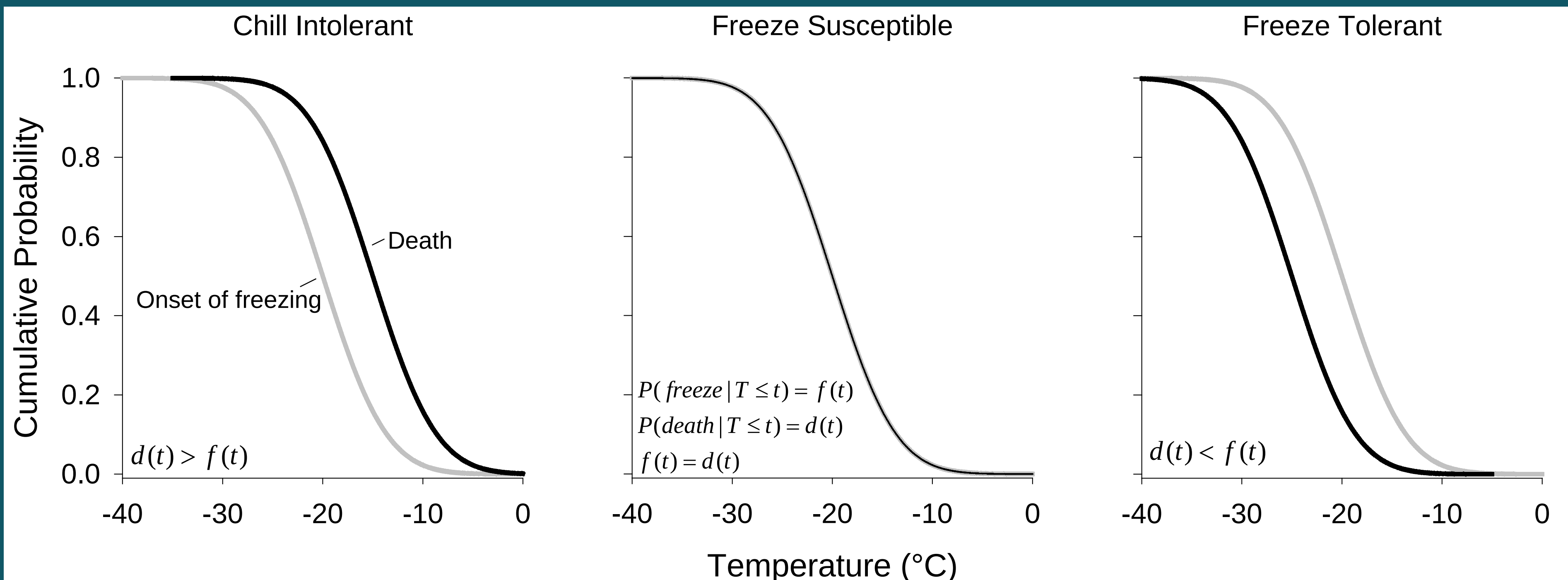


Carrillo et al. 2004, Lee 2010

Resulting data and analysis: illustrative

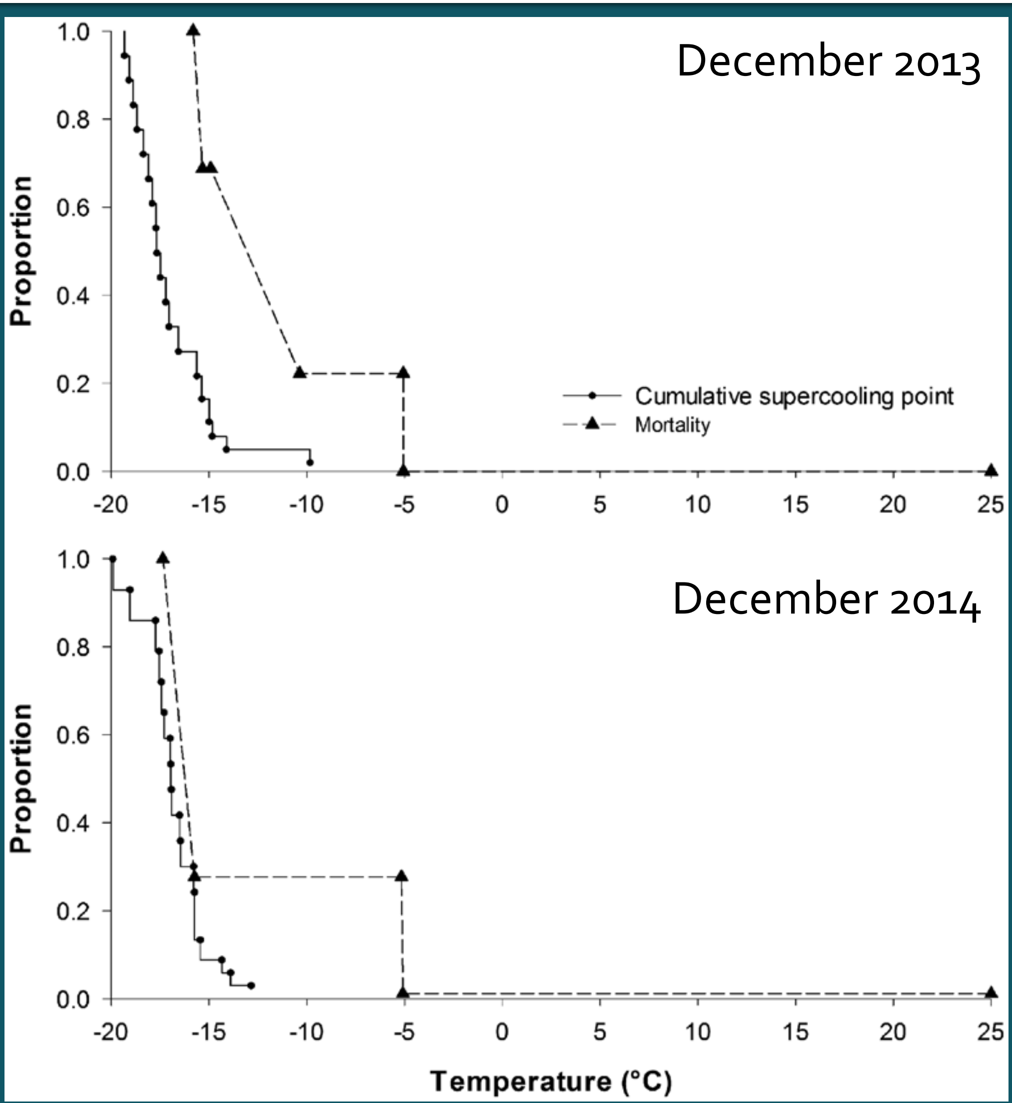


Insect responses to cold



Example 1. Cold tolerance testing and validation (transferability) for invasive alien species: post-incursion

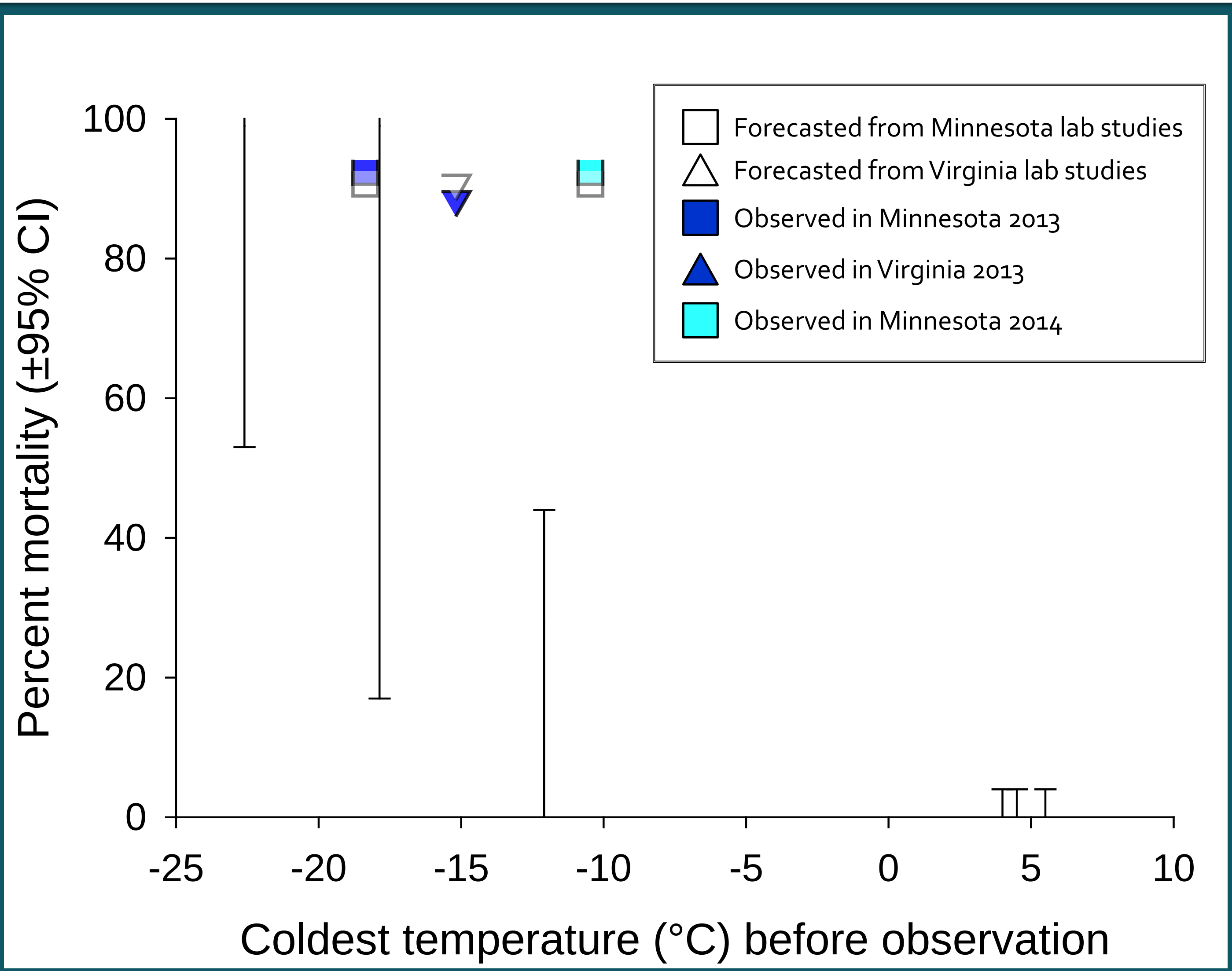
Cold tolerance of *Halyomorpha halys:* field-acclimated in Minnesota



- Brown marmorated stink bug is chill-intolerant.
- Cold tolerance changes seasonally (data not shown here).
- Cold tolerance changes geographically (data not shown here).

Cira et al. 2016. Environ. Entomol. 45: 484-491

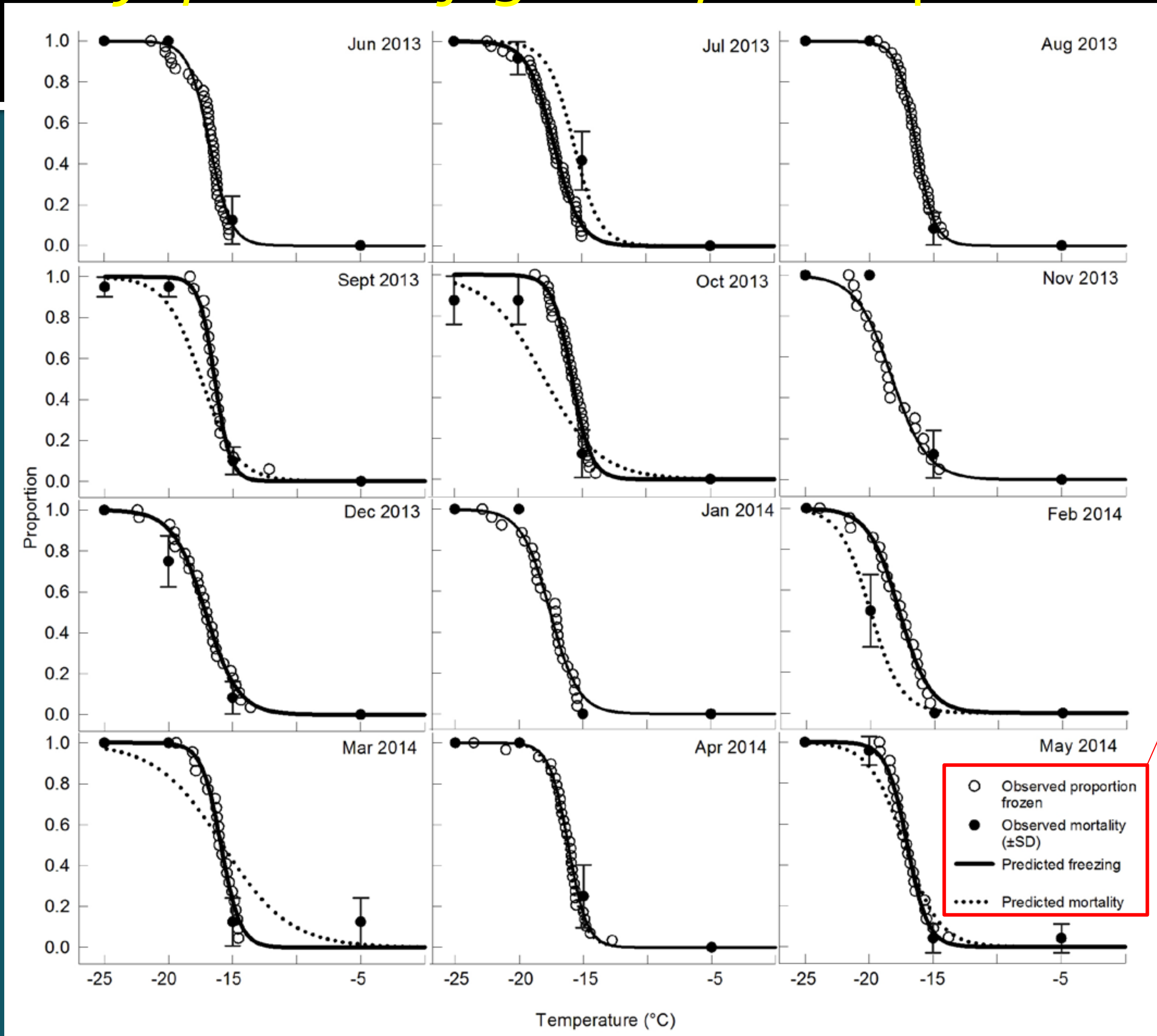
Validation – point observations



Cira et al. 2016. Environmental Entomology 45: 484-491

Example 2. Cold tolerance testing and validation (transferability) for invasive alien species: pre-incursion

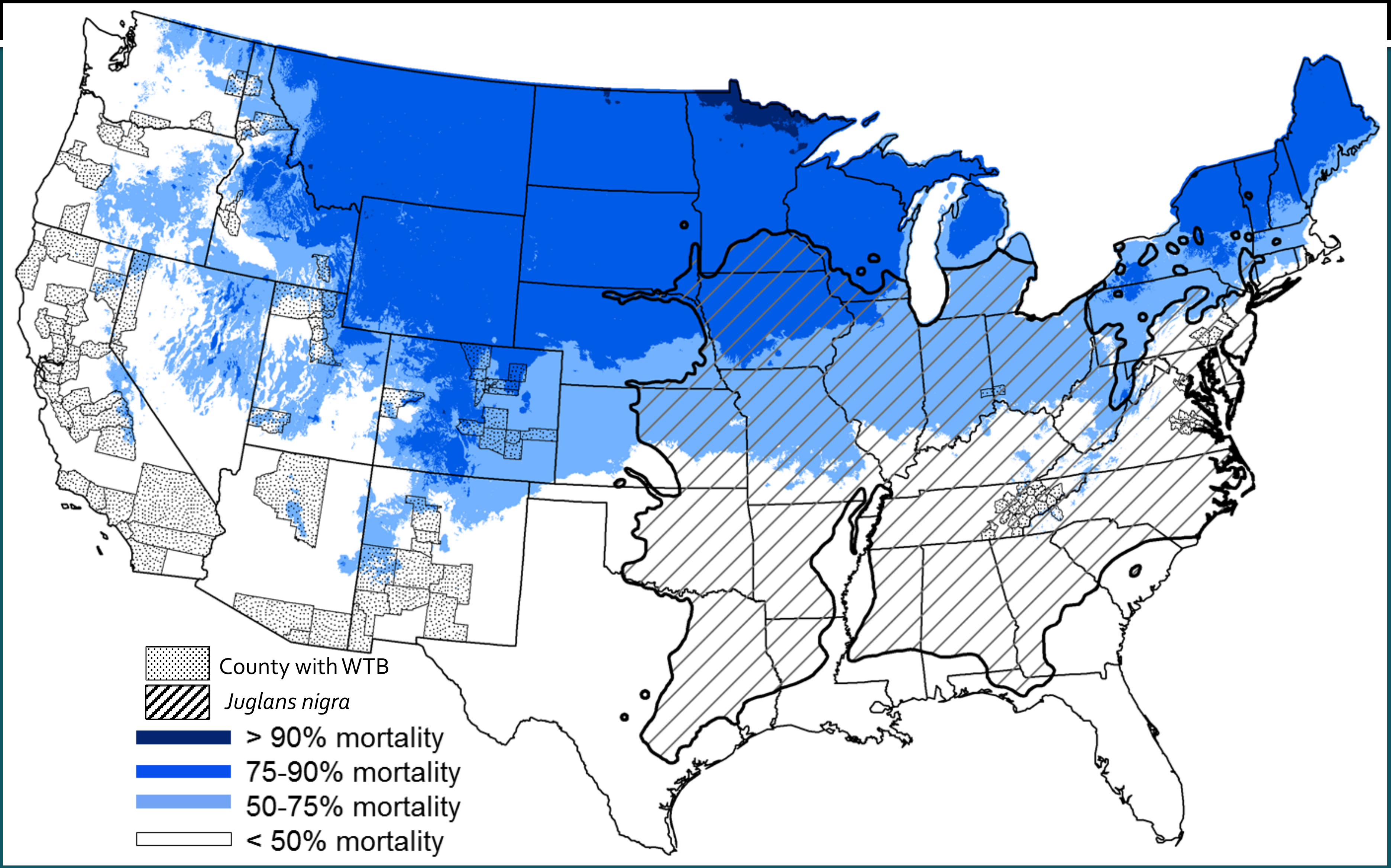
Cold tolerance of walnut twig beetle (WTB), *Pityophthorus juglandis*, a new pest of walnut



○ Observed proportion frozen
● Observed mortality (±SD)
━━ Predicted freezing
······ Predicted mortality

Hefty et al. 2017. Environ. Entomol. 46:967-977

Validation - geographic

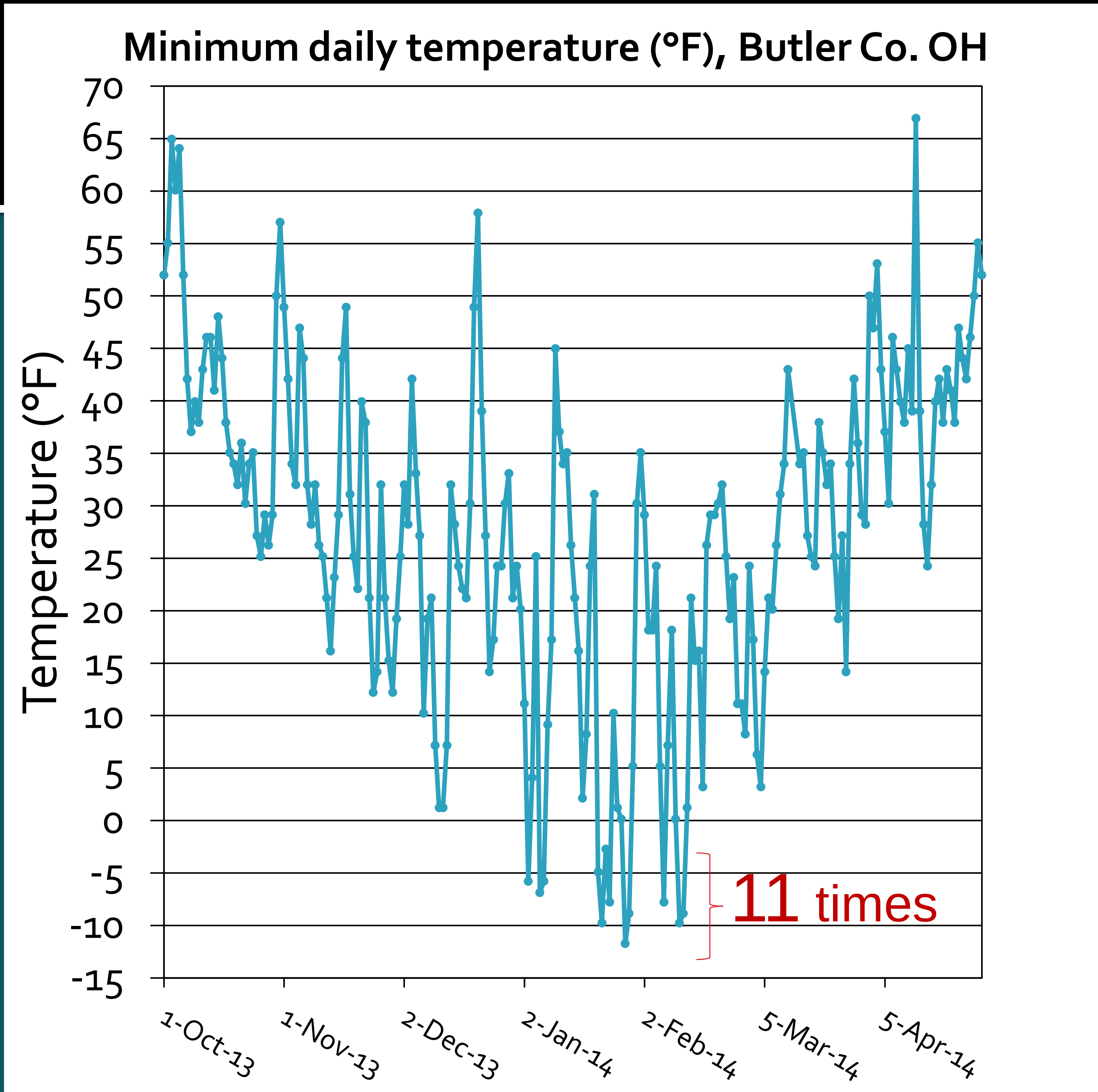


Walnut twig beetle trap catches 2013-2015 (Ohio Dept. of Agriculture)

Year	Time Period	Counties Trapped (#)	Traps Set (#)	Traps with WTB (#)
2013	August – October		106	5 *
2014	June – July	14	109	0
	August – October	14	109	0
2015	June – July 31	19	106	0

* Thousands of WTBs collected from one trap in residential setting in 2013. No beetles collected in 2016.

Data source: Dan Kenney, Ohio Dept. of Agriculture, Reynoldsburg, OH (Annual reports for Farm Bill)



Estimated cold mortality is between 40-60% after brief exposures to -2°F to -12°F.

Data source: NOAA

Other examples from the Venette lab

Species	Common name	Strategy (LT50, °C)	LT50 (°C)	Reference
Helicoverpa zea	Corn earworm	Chill intolerant	-10	Morey et al. 2012
Aphis glycines	Soybean aphid	Freeze intolerant?	-34	McCornack et al. 2005
Drosophila suzukii	Spotted wing drosophila	Chill intolerant	-15.3	Stephens et al. 2015
Spathius agrili	Parasitoid of emerald ash borer	Mixed	-28.9	Hanson et al. 2013
Tetrastichus planipennisi	Parasitoid of emerald ash borer	Chill intolerant	-19.9	Hanson et al. 2013
Oobius agrili	Parasitoid of emerald ash borer	Mixed	-30.5	Hanson et al. 2013
Agrilus planipennis	Emerald ash borer	Mixed	-33.1 to -35.2	Christianson 2014
Dendroctonus ponderosae	Mountain pine beetle	Mixed	-27.5 to -33.3	Rosenberger et al. 2017
Trissolcus japonicus	Parasitoid of BMSB	Chill intolerant	-17.4 to -20.0	Nystrom Santacruz et al. 2017
Trissolus cultratus	Parasitoid of BMSB	Chill intolerant	-19.9	Nystrom Santacruz et al. 2017

Conclusions & future directions

- Laboratory assessments of insect cold tolerance can provide useful, mechanistically-based forecasts of overwintering success.
- "Essentially all models are wrong, but some are useful."- George Box. Utility is demonstrated through independent validation (transferability).
- Need clever approaches to address aleatory and epistemic uncertainties.
  - Use of species distribution models in experimental design
  - Temporal and geographic variation in cold tolerance
  - Potential evolutionary changes in cold tolerance
  - Integration of variable temperatures and time
  - Use of such models in decision-making

Questions?

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Ice Palace
Winter Carnival
St. Paul, MN 1992