

Assessing the global risk of establishment of Codling Moth (*Cydia pomonella*) using CLIMEX and MaxEnt niche models

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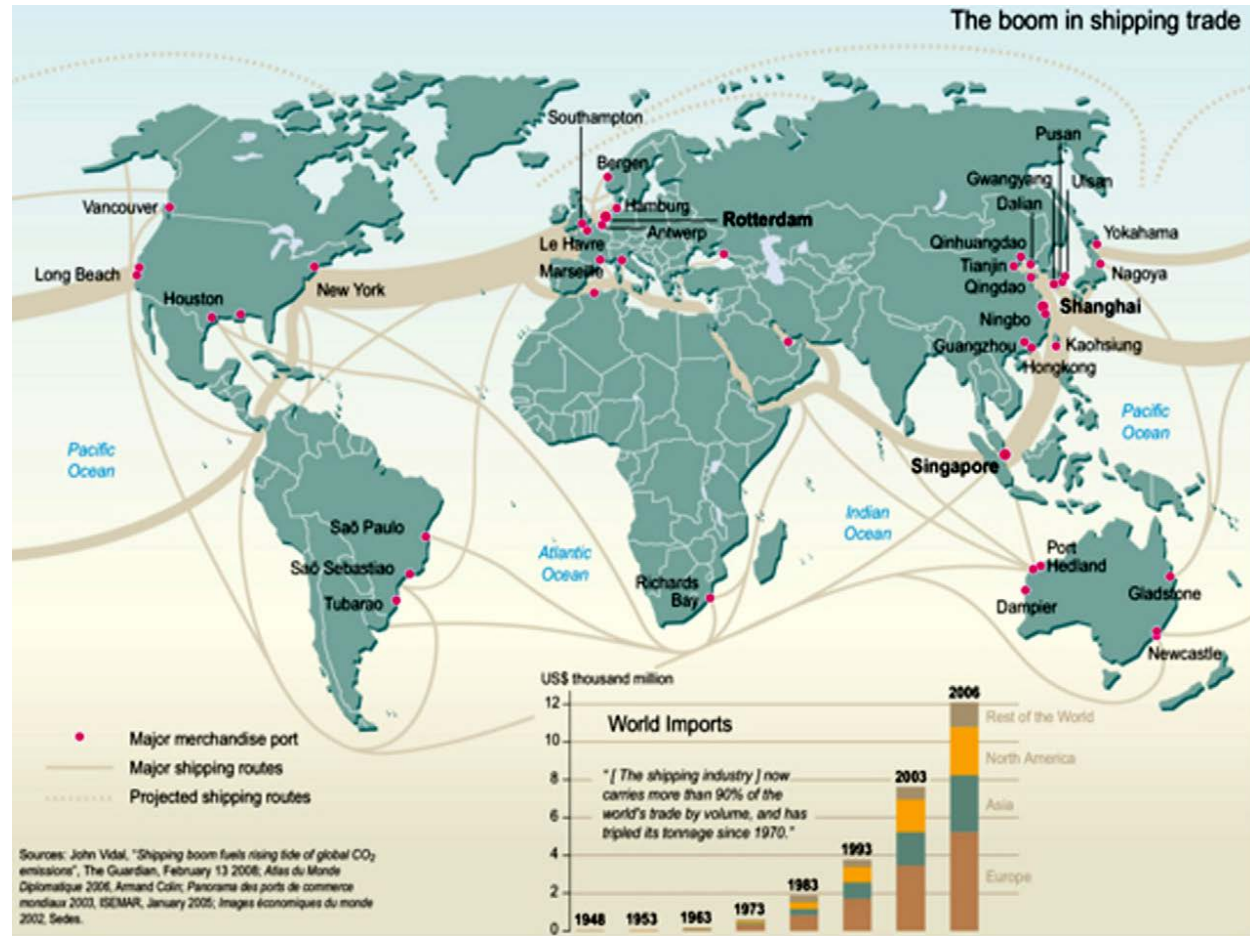
Aug. 26, 2015



Global Trade and Transportation (and Scientists!) are moving species around the world

Stop Trade and Travel?

NO!



Stohlgren TJ, et al. (2013) Globalization Effects on Common Plant Species. In: Levin SA, editor. Encyclopedia of Biodiversity, second edition. Waltham, MA: Academic Press. pp. 700-706.

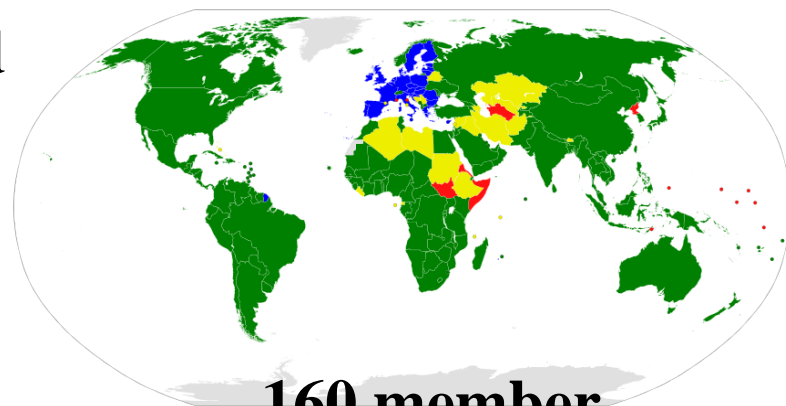
USDA- APHIS Border Inspection



**Fumigation
(Methyl Bromide)**

World Trade Organization (WTO) and PRAs

- The WTO (1995) requires its members to establish national SPS (Sanitary and Phytosanitary Measures) measures consistent with international standards to facilitate trade.
- **Pest Risk Analysis (PRA)** is an essential tool used by countries to proactively protect their resources from potentially invasive species.
- Most often information is insufficient to develop biologically and ecologically accurate PRAs.



**160 member
countries**

USDA-APHIS



**Climate suitability risk maps
& Host Presence**

Trade Negotiations

California Department of Food & Agriculture: South Korea

June 2, 2014

Hi Kumar,

Since the article hasn't actually been published yet, may we have permission from you to provide a copy of the article to **Korea's Quarantine Inspection Agency** as an attachment to the letter we will be sending?

Best regards,

Judy

Judith Macias

Assistant Trade Director

Phytosanitary Issues Management

Plant Protection and Quarantine

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Western Cherry Fruit Fly



Kumar et al. (2014; Ecosphere)



Washington Tree Fruit Research
Commission

Other Countries



Codling Moth

(Cydia pomonella)



**A major pest of Apples,
Walnuts, Pears and Plums**

Codling Moth: Niche Models

A Correlative Niche Model

❖ **MaxEnt**- a Maximum Entropy Model (Phillips et al. 2006)

Phillips, S. J., R. P. Anderson, and R. E. Schapire. 2006. Maximum entropy modeling of species geographic distributions. *Ecological Modelling* 190:231-259.

A Process-based Mechanistic Niche Model

❖ **CLIMEX** is a process-based mechanistic niche model that incorporates a species ecophysiological tolerances (e.g., minimum, max. and optimal temperature) (Sutherst et al. 2007; Kriticos et al. 2015)

Sutherst, R. W., Maywald, G.F., and Kriticos, D.J. 2007. CLIMEX Version 3: User's Guide: Hearne Scientific Software Pty Ltd. Available: <http://www.hearne.com.au/attachments/ClimexUserGuide3.pdf> (Accessed June 27, 2013).

Kriticos, D.J., Maywald, G.F., Yonow, T., Zurcher, E.J., Herrmann, N.I. and Sutherst, R.W. (2015). CLIMEX Version 4: Exploring the effects of climate on plants, animals and diseases. CSIRO, Canberra. 184 pp.

CLIMEX model for Codling Moth (*Cydia pomonella*)

Parameter	Description	Value
Temperature Index (TI)		
DV0	Lower temperature threshold for growth	9°C
DV1	Lower optimum temperature for growth	15°C
DV2	Upper optimum temperature for growth	27°C
DV3	Upper temperature threshold for growth	34.4°C
PDD	Number of degree-days above DV0 needed to complete one generation	580
Moisture Index (MI)		
SM0	Lower soil moisture threshold	0.02 ^a
SM1	Lower optimum soil moisture	0.1 ^a
SM2	Upper optimum soil moisture	1.8 ^a
SM3	Upper soil moisture threshold	2.5 ^a
Light Index (LI)		
LT0	Day length (hours) above which growth is at a maximum	15.5 hours
LT1	Day length (hours) below which growth is zero	13.5 hours
Cold Stress (CS)		
TTCS	Temperature threshold for cold stress	-15°C
THCS	Cold stress accumulation rate	-0.0011 week ⁻¹
Heat Stress (HS)		
TTHS	Temperature threshold for heat stress	35°C
THHS	Heat stress accumulation rate	0.0001 week ⁻¹
Dry Stress (DS)		
SMDS	Soil moisture threshold for dry stress	0.02
HDS	Dry stress accumulation rate	-0.001 week ⁻¹
Wet Stress (WS)		
SMWS	Soil moisture threshold for wet stress	2.5
HWS	Wet stress accumulation rate	0.002 week ⁻¹
Diapause Index (DI)		
DPD0	Diapause induction day length	15
DPT0	Diapause induction temperature	11.0°C
DPT1	Diapause termination temperature	6.0°C
DPD	Diapause development days, defaults to 0, i.e. facultative diapause	90

Initial parameters were obtained from CLIMEX manual (Sutherst et al. 2007) and Rafoss and Saethre (2003) and the values were adjusted



MaxEnt

Global Occurrences of Codling Moth (*Cydia pomonella*)

km

Chinese
Collaborators



**Digitized >1900 apple orchards in the
United States:**

- **National Ag. Pest Infor. System
(NAPIS)**
- **Fruit Growers' privacy issues**




Predicted global potential distribution of Codling Moth (*Cydia pomonella*) using MaxEnt model

20° 0.00'

-20° 0.00'

0 3,000 km



Probability of presence



Strongest predictors (% contribution)

- Mean annual temperature (65%)
- Latitude (26%)
- Precipitation of coldest quarter (6%)

Kumar, S., et al. 2015. Assessing the Global Risk of Establishment of *Cydia pomonella* (Lepidoptera: Tortricidae) using CLIMEX and MaxEnt Niche Models. *J. Economic Entomology* DOI: 10.1093/jee/tov166.





Predicted global potential distribution of Codling Moth (*Cydia pomonella*) using CLIMEX model

20° 0.00'

-20° 0.00'

km

Climatic suitability (Eco-climatic Index; EI)

-  Unsuitable (EI = 0)
-  Marginal (EI = 1 - 3)
-  Moderate (EI = 4 - 10)
-  Highly favorable (EI > 10)

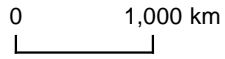


Kumar et al. (2015; JEE)

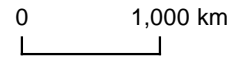
(A) CLIMEX

(B) MaxEnt

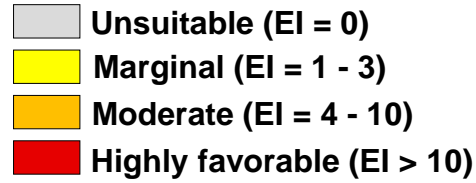
China



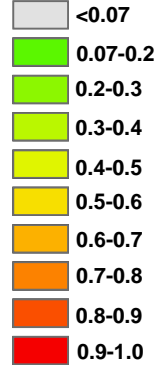
China



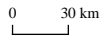
Climatic suitability (Eco-climatic Index; EI)



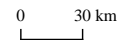
Probability of presence



Taiwan



Taiwan



(A) CLIMEX

(B) MaxEnt





India

India









0 460 km

0 460 km

**Climatic suitability
(Eco-climatic Index; EI)**

-  Unsuitable (EI = 0)
-  Marginal (EI = 1 - 3)
-  Moderate (EI = 4 - 10)
-  Highly favorable (EI > 10)

**Probability of
presence**

-  <0.07
-  0.07-0.2
-  0.2-0.3
-  0.3-0.4
-  0.4-0.5
-  0.5-0.6
-  0.6-0.7
-  0.7-0.8
-  0.8-0.9
-  0.9-1.0

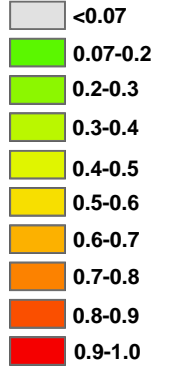
(A) CLIMEX

Vietnam
Laos
Thailand
Cambodia

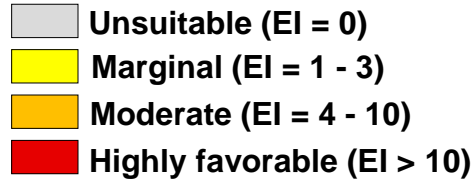
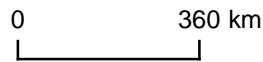
(B) MaxEnt

Vietnam
Laos
Thailand
Cambodia

Probability of presence



**Climatic suitability
(Eco-climatic Index; EI)**



Malaysia

Malaysia

Indonesia

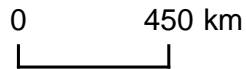


Indonesia



(A) CLIMEX

Colombia
Ecuador
Peru

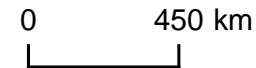


(B) MaxEnt

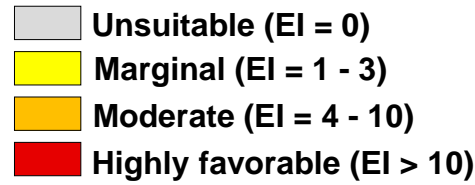
Probability of presence



Colombia
Ecuador
Peru



**Climatic suitability
(Eco-climatic Index; EI)**



Correlative vs. Mechanistic Models

Correlative
Models- less
transferable

Mechanistic
models- to Test
correlative model

More
biology/ecology
of the species:
Species-specific
phenology
variables

0 3,000 km


MaxEnt

km

CLIMEX

Including Species' Physiological Tolerances in MaxEnt model

Used 19 Bioclim Variables: Min., Max., Average, and Extremes

Lower Optimal Threshold:

Degree days at Avg. temperature $>10^{\circ}\text{C}$)

(Shel'deshova 1967)

Diapause- Critical photoperiod (13.5 to 15.5 hrs day length):

Latitude

A 10 degree shift in latitude to the North resulted in

increase of 1.25 hour in day length

(Riedl and Croft 1978)

Kumar, S., et al. 2015. Assessing the Global Risk of Establishment of *Cydia pomonella* (Lepidoptera: Tortricidae) using CLIMEX and MaxEnt Niche Models. *J. Economic Entomology* DOI: 10.1093/jee/tov166.

Effects of Background & Complexity on model projections

Sampling bias corrected

MaxEnt

MaxEnt

India

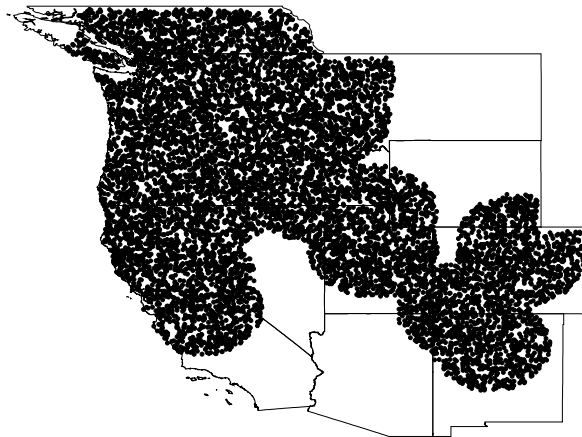
Taiwan

Suitability

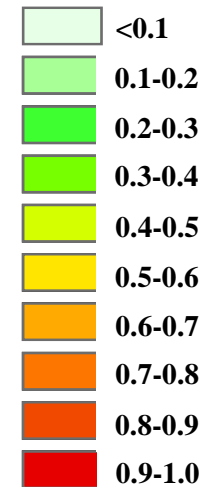


km

Sampling bias NOT corrected

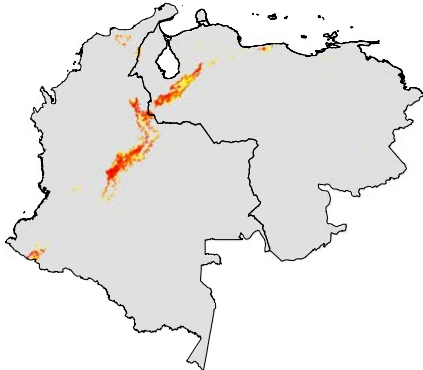


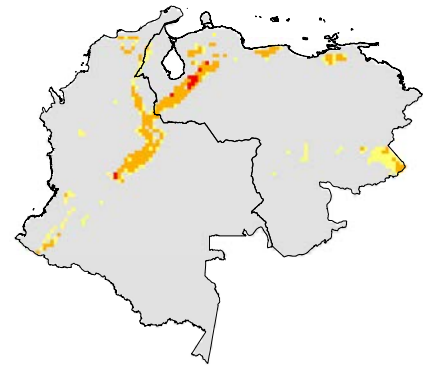











Probability of presence



0 10 20 Miles

Potential for establishment of Western Cherry Fruit Fly (*R. indifferens*)

	Western North America	Colombia & Venezuela	India	Legends
(a)				<p>Suitability</p>  
(b)				<p>Suitability</p> <ul style="list-style-type: none">  Unsuitable (EI = 0)  Marginal (EI = 1 - 5)  Moderate (EI = 6 - 25)  Highly favorable (EI > 25) 
(c)				<p>Minimum temperature $\leq 3^{\circ}\text{C}$ for at least 15 weeks or more</p> <ul style="list-style-type: none">  Yes  No 

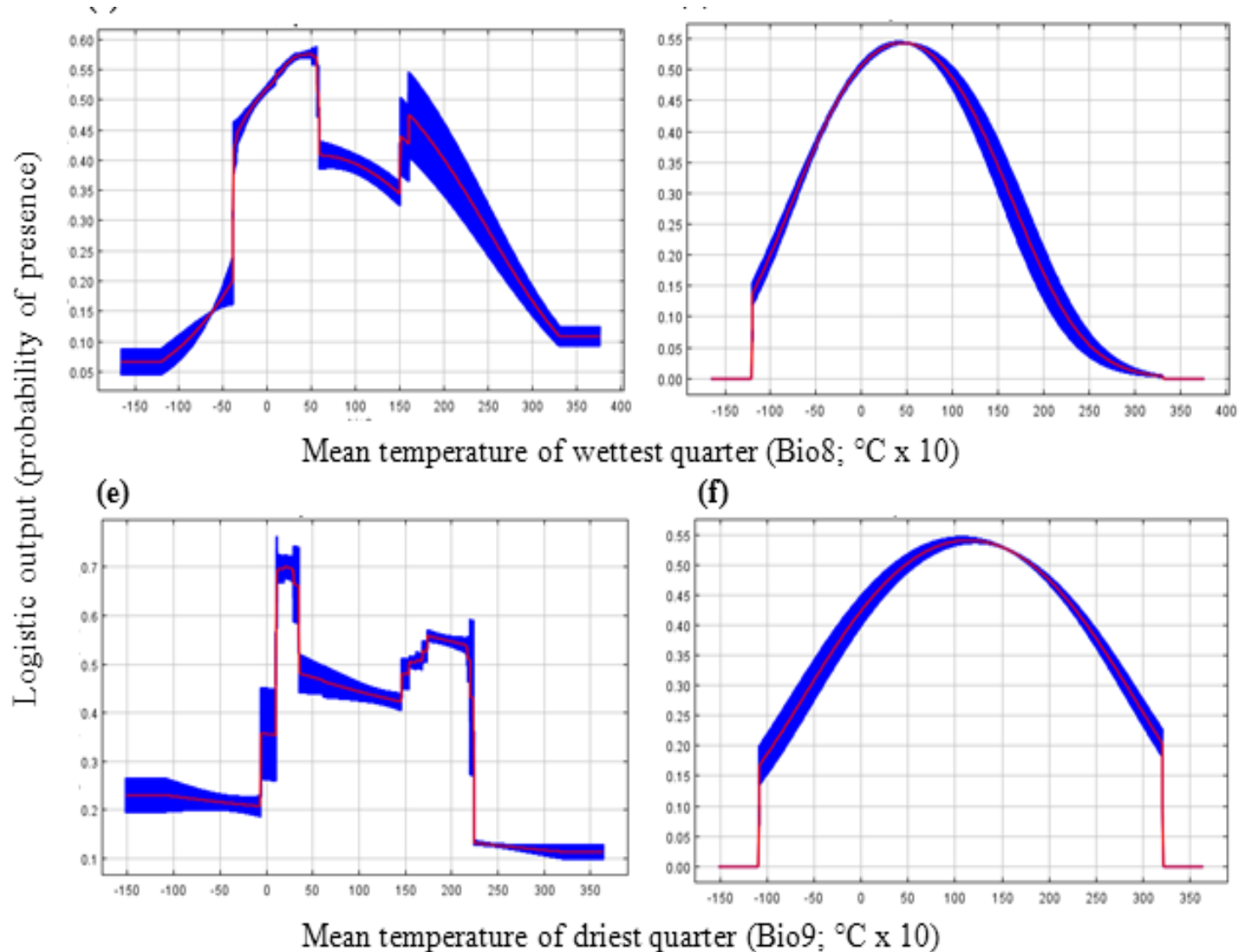
MaxEnt

CLIMEX

NAPPFAST

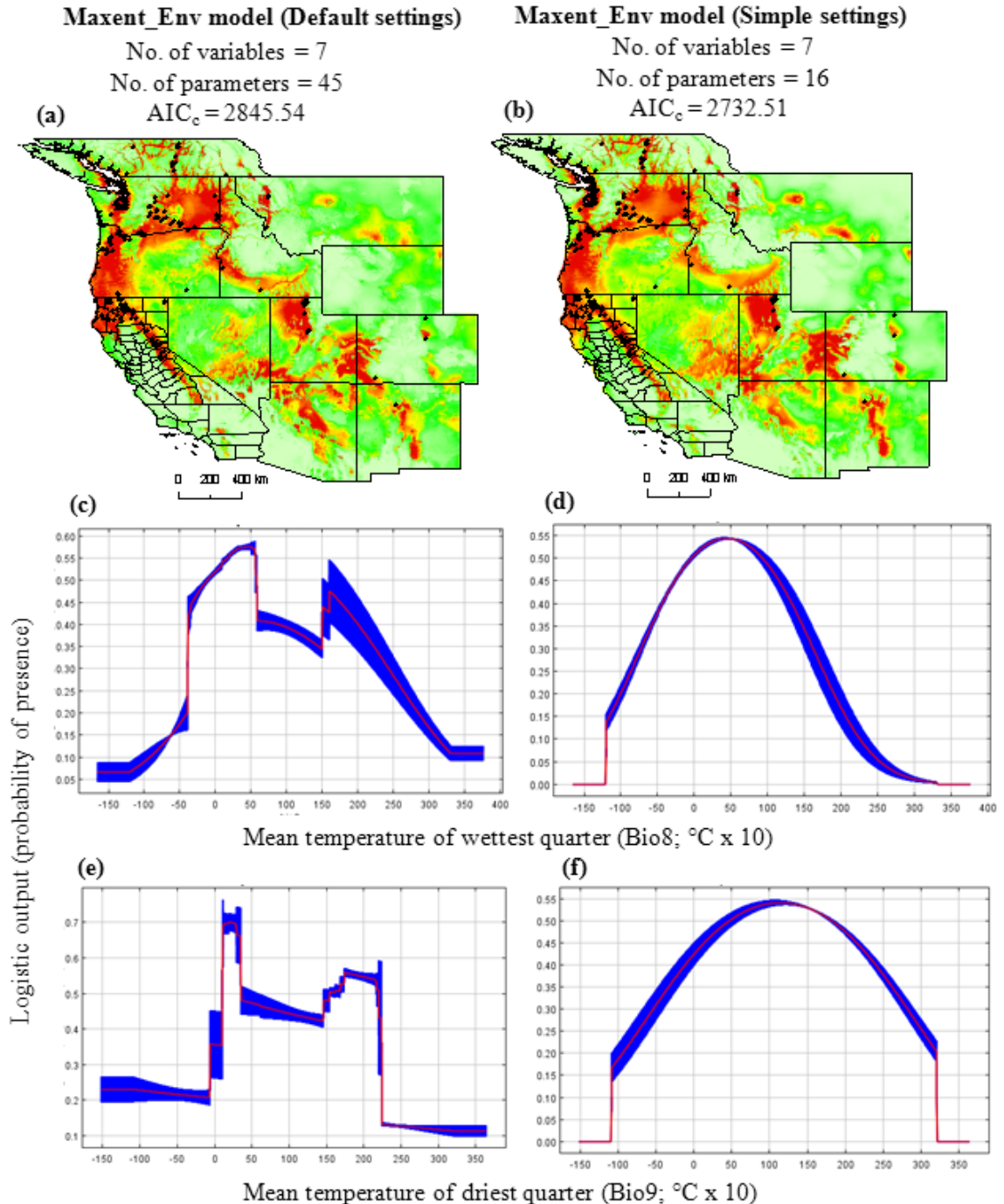
Examine Response Curves!

Do they make Biological Sense for the Species?



Model complexity

- ❖ Model complexity affects the predictions in the novel environments.
- ❖ Complex models are less transferable to new areas.
- ❖ MaxEnt simple settings included only linear, quadratic and product features.



Do Species Care about Multicollinearity?

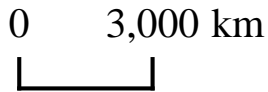
May be NOT!

An Examples from Codling Moth Modeling

Latitude was not dropped even if it had high correlation with **mean annual temperature** (**bio1**; $r = 0.93$) because of its greater indirect influence on codling moth diapause

(A)

Probability of presence



**MaxEnt
(with Latitude)**

**Codling moth
(*Cydia pomonella*)**



20° 0.00'

-20° 0.00'

(B)

Probability of presence



**MaxEnt
(without
Latitude)**

**Codling moth needs a critical photoperiod for
diapause induction and termination**

20° 0.00'

-20° 0.00'

Caveats: Assumptions and Uncertainties

Ecological Informatics 29 (2015) 6–15



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Caveats for correlative species distribution modeling



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- Species in equilibrium with its environment
(correlative models)
- Don't include micro-climates: refugia
- Predictions based mainly on climatic variables
- Natural enemies- predators, parasitoids, competitors
- Model limitations:

Data quality, sampling bias, background selection, model fitting, spatial resolution

Summary

- Correlative niche models' transferability can be improved by including biological/ecological information- work with spp. experts.
- Optimal model complexity & careful calibration
- Niche models can enhance current PRAs.
- Scientifically informed trade decisions.
- Enhanced PRAs- Combine Niche models & probabilistic @Risk model- expert knowledge and propagule pressure

Acknowledgements

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Questions & Comments

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