Quiz

True of False?

1. The fundamental niche is a subset of the realized niche
2. The realized niche is a subset of the fundamental niche
3. The fundamental niche is a subset of the realized environments
4. The realized niche is a subset of the realized environments

Niche Theory

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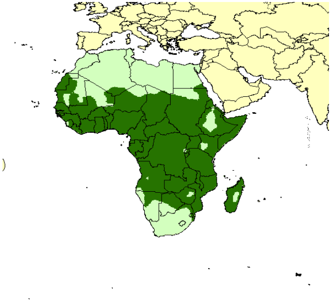
Main question

If species X were to be introduced to place Y, would it persist?

Applications

- Biogeographic consequences of climate change
- Invasive species management and adaptation
- Survey design
- Species translocation for conservation
- Reserve design



Anopheles gambiae distribution in Africa

Related questions

- What is the *potential distribution* of a species?
- What *range of habitats* does a species use?
- Is this species a *specialist* or a *generalist*?
- What other species are *ecologically equivalent*

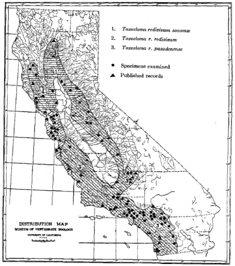
A species persists within its niche

The main question is a *subjunctive conditional*: If species X were to be introduced to place Y, would it persist?

Yes, the species would persist if the environment at Y belonged to the species *niche*, otherwise not.

What is a niche?

The *habitats* in which a species can survive and reproduce



Grinnell, J. (1917). "The niche-relationships of the California Thrasher". Auk 34: 427–433.

What is a niche?

The *set of environments* occupied by a species

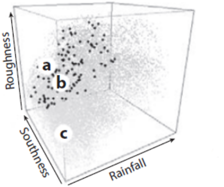


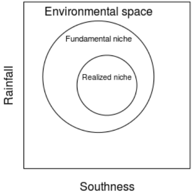
Image: Elith & Leathwick (2009)

- n-dimensional hypervolume

Hutchinson, G.E. (1957). Concluding remarks. Cold Spring Harbor Symposia on Quantitative Biology 22 (2): 415–427.

What is a niche?

The *set of environments* occupied by a species



- Fundamental niche - the *full set of environments* under which a species can persist (Grinnell's concept)
- Realized niche - the *actual set of environments* within which a species is found

Hutchinson, G.E. (1957). Concluding remarks. Cold Spring Harbor Symposia on Quantitative Biology 22 (2): 415–427.

Two kinds of space

Grinnell's concept is a *geographic space*, whereas Hutchinson's concept is an *ecological space*

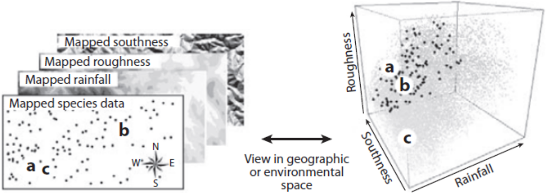


Image: Elith & Leathwick (2009)

Niche: A formal definition

Q. When does a species persist?
A. When growth rate exceeds replacement, i.e., $\lambda > 1$
Q. What does λ depend on?
A. Population size (z) and environment $x = [x_1, x_2, x_3, ...x_n] \in E$
Formal definition $N \in \mathbb{R}^n : x_n \exists z \Leftrightarrow \lambda(x, z) > 1$

What is a niche model?

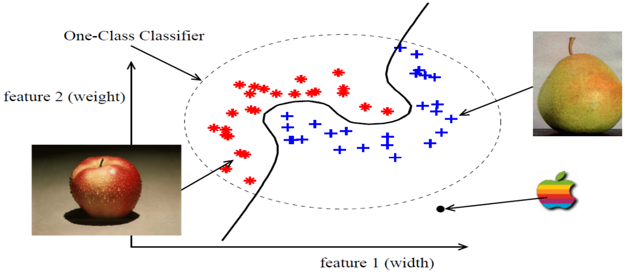
A *niche model* is a representation that takes an environment (a vector of measurements) as input and returns a binary quantityaccording to whether that environment belongs to the niche.
A niche model could be:

- An equation
- A computer program

This suggests that a strategy for modeling ecological niches is to estimate a *decision boundary* between niche and non-niche regions of environmental space.

Two approaches to niche modeling as a decision boundary

- Niche modeling as a *binary classification* problem
- Niche modeling as *support estimation* or *one-class classification*

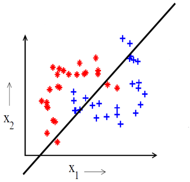


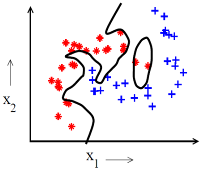
Tax, D.M.J. (2001). One-class classification. PhD thesis.

Niche modeling as binary classification

Benefit: Allows use of classical and modern classification algorithms

- Logistic regression or discriminant analysis
- Neural networks, support vector machines, boosted regression trees





Tax, D.M.J. (2001). One-class classification. PhD thesis.

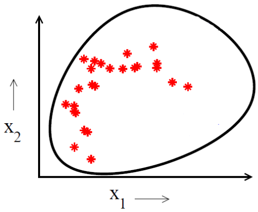
Obstacle: Requires two-class data (ideally in equal proportion)

- Solution 1: "Absence sampling" (but when can one say for certain that a species is not present?)
- Solution 2: "Pseudo-absence sampling" (but this both requires that the translation of geographic-environmental space is fixed and is sensitive to choice of geographic space)
- Solution 3: "Background sampling" (same problems as Solution 2)

Niche modeling as one-class classification

Benefit: Treats the niche problem in the way conceptualized by Hutchinson

- Does not require artificial data
- Infinite number of ways to be "non-niche"



Tax, D.M.J. (2001). One-class classification. PhD thesis.

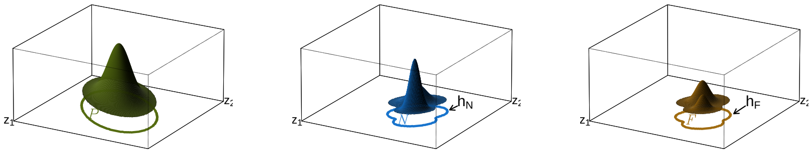
Obstacle: Statistical problem is less familiar and not well defined

- Distribution estimation
- Support vector machines
- Nearest neighbor and other "instance learning" algorithms

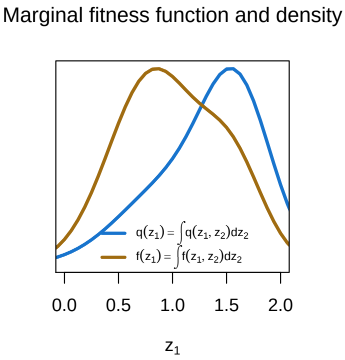
Objective: learning ecological niches from data

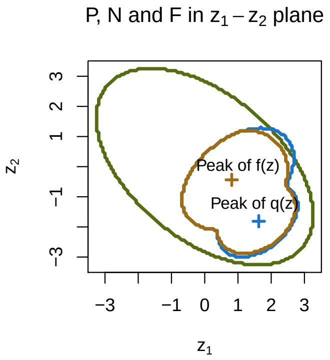
- Modeling from presence-background and presence-only data
- Object of model is ecological niche boundaries (rather than density, mean/variance, etc.)
- Modeling with non-stationary, non-iid data, irrelevant variables, etc...

Probability density of environment p(z) | Habitat selection function q(z)>1 | Density of occupied environments f(z)=p(z)



Modeling niche boundary may be easier than we think



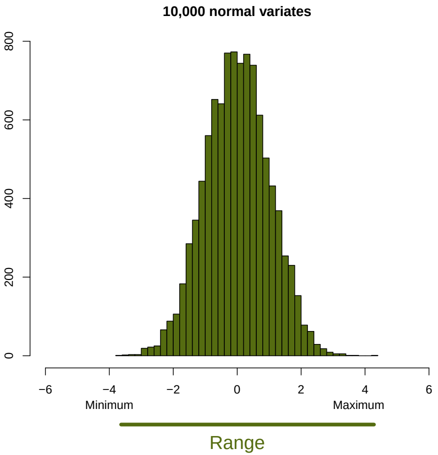


Can we learn the niche boundary from data?

What is a range (one dimension)?

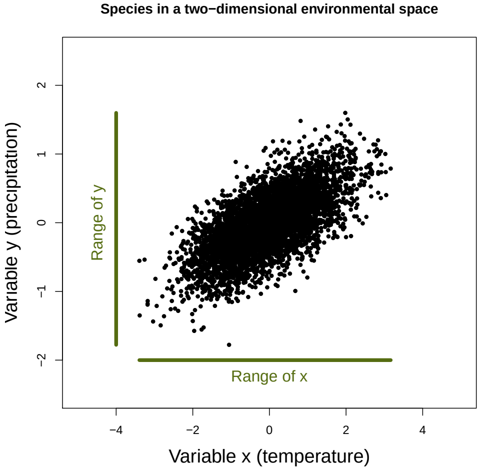
Objectives:

- A presence-only method that is ecologically "interpretable"
- A method that maximally concentrates on estimating species niche boundaries
- A method that is insensitive to contingent species absences
- A method that can be parameterized or partly parameterized with experiments on species tolerances



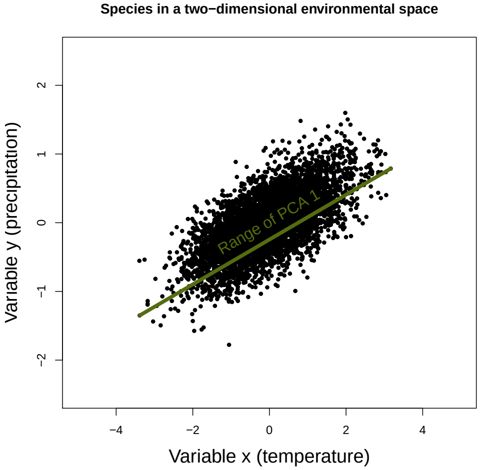
What is a range (two dimensions)?

- In two dimensions there are two ranges...
- In n dimensions there are n ranges



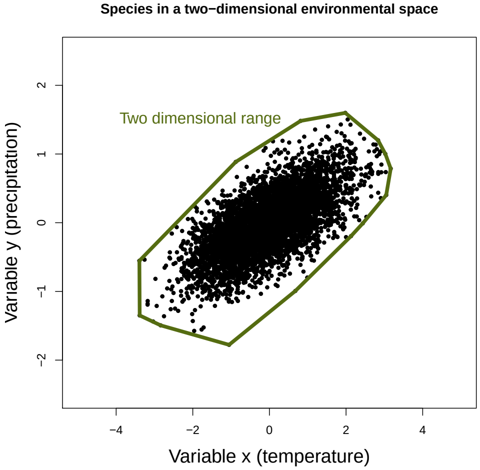
But why this coordinate system?

- The *n* ranges depend on choosing a coordinate system



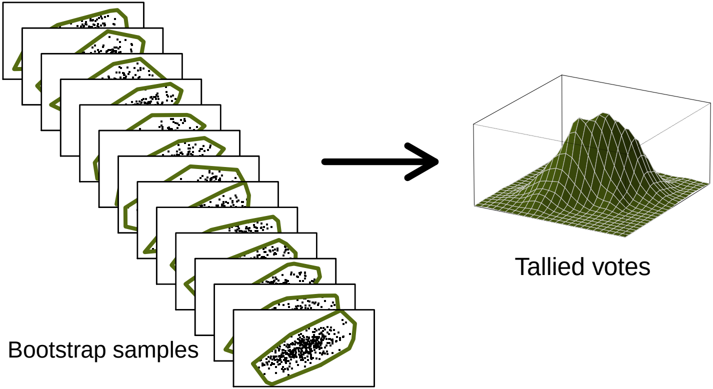
Convex hull

- Convex hull is the boundary of the smallest convex set containing a specified set of points (e.g. environmental conditions at which a species is found)
- Equivalently, the convex hull is the set of endpoints of the ranges in all coordinate systems (rotations)



Range bagging: the proposal

Choose marginal dimension (δ)
Choose boostrap coverage ($w = 1$)
Choose number of bootstrap samples ("votes") (v)



Range bagging: the proposal

Algorithm

Input: $x \times n$ table of environmental records
Tuning variables: δ the dimension of the marginal niche, w boostrap sample size, v iterations (votes)

for $i = 1$ to v, **do**

1. **Sample step.** For a model of order δ, randomly select (without replacement) $\delta < n$ environmental variables. From the resulting $x \times \delta$ table of records, randomly select (without replacement) $w \leq x$ records to be included in the bootstrap sample, X_i.
2. **Marginal niche estimation step.** As a *base learner*, obtain the marginal niche C_i of the points in X_i. If $\delta = 1$, the marginal niche is simply the interval between the minimum and maximum values in the bootstrap sample. For $\delta > 1$, the marginal niche is the convex hull of the bootstrap sample.

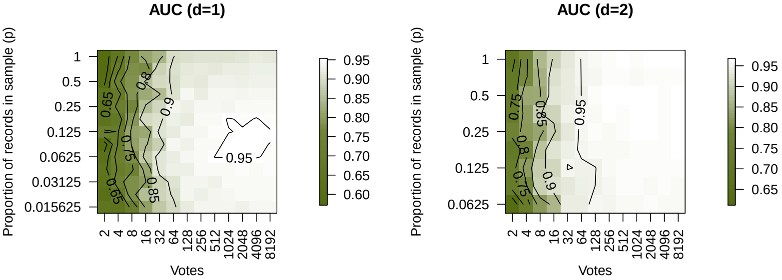
end for

Output: $\mathbb{N} = \{C_1, C_2, C_3, \ldots C_v\}$

To evaluate, calculate the proportion of $\mathbb{N}$ containing a candidate environmental condition.

Range bagging: performance

Performance on two-spined blackfish *Gadopsis bispinosus*



Conclusions:

- Performance comparable to MaxEnt using presence-only data and very little tuning
- Performance does not degrade with the number of votes

Conclusions

- New methods for presence-background and presence-only modeling perform almost as well as existing methods
- Many opportunities for extension to other "data problems" (especially non-stationary data and regional transferability)
- Potential for further use of ensemble methods for variance reduction

References

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Drake, J. M., C. Randin, and A. Guisan. 2006. Modelling ecological niches with support vector machines. Journal of Applied Ecology **43**:424–432.

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