How cryptic is cryptic diversity? Machine learning approaches to fine scale variation in the morphology of *Emys marmorata*.

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Cryptic diversity

Cryptic species are species delimited via molecular means. Taxa were not/cannot be identified via morphology.

How much of cryptic diversity is just a function of sample size and/or method?

Emys marmorata

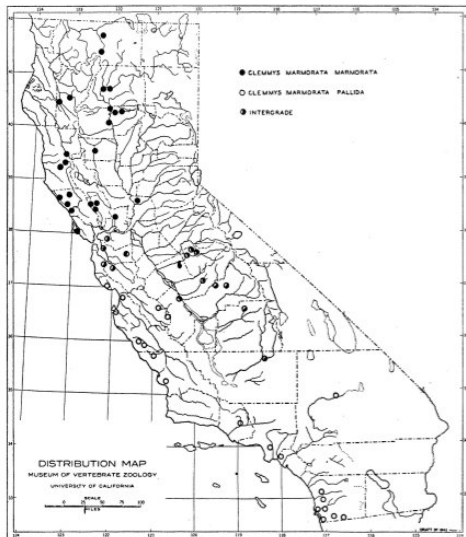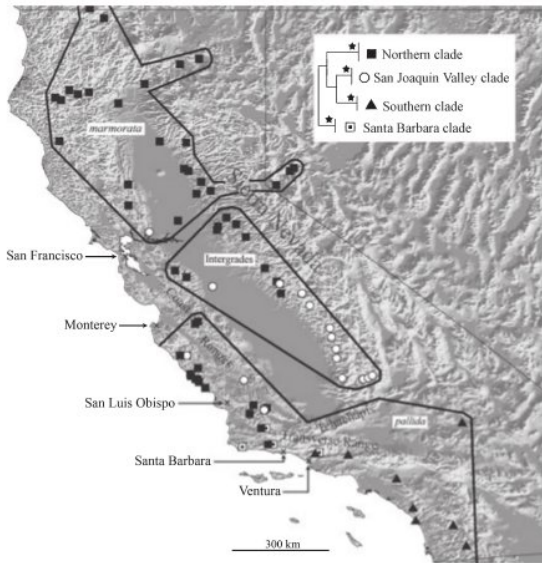

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Morphological hypothesis

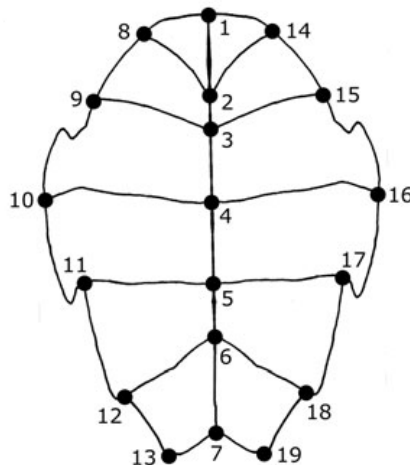Fig. 4. California localities from which specimens have been examined.

Seeliger 1945 *Copeia*

Phylogenetic hypotheses

Spinks *et al.* 2010 *Molec. Ecol*

Methods: morphometrics

- 524 adult individuals
- plastral ("belly") shape
- landmarks averaged across bilat axis
- total 13 landmarks, 7 on bilat axis, 6 off
- geographic information known/inferred

Angielczyk *et al.* 2011 *Evolution*

Unsupervised learning

Fancy way of saying clustering or density estimation.

Partitioning around mediods (PAM) compared with "gap" statistic.

Analogous to k-means clustering, a divisive clustering algorithm.

Minimize sum of dissimilarities between points and medoids.

"Gap" is analogous to goodness-of-clustering.

Supervised learning

Fancy way of saying classification (and regression).

Features (principal components) predict class (subspecific assignment).

Multinomial logistic regression and random forests.

Model training and selection

- split into training and testing sets, 75-25.

- tuning parameters via grid-search

- uncertainty via 10-fold CV

- model selection

    - multinomial logistic regression: min AICc

    - random forest: max ROC

ROC and confusion matrices

		Predicted class	
		1	0
Actual class	1	TRUE POSITIVE	FALSE NEGATIVE
	0	FALSE POSITIVE	TRUE NEGATIVE

ROC

- true positive rate or sensitivity: $\frac{TP}{TP+FN}$
- false positive rate or 1 - specificity: $\frac{FP}{FP+TN}$
- multiclass, all-against one (Hand and Till 2001 *Machine Learning*)
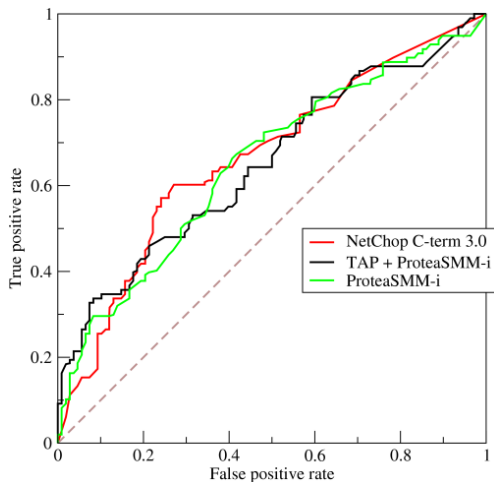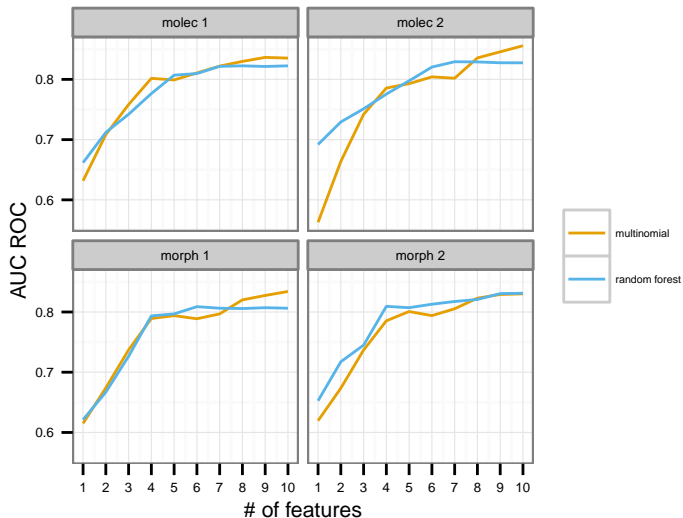

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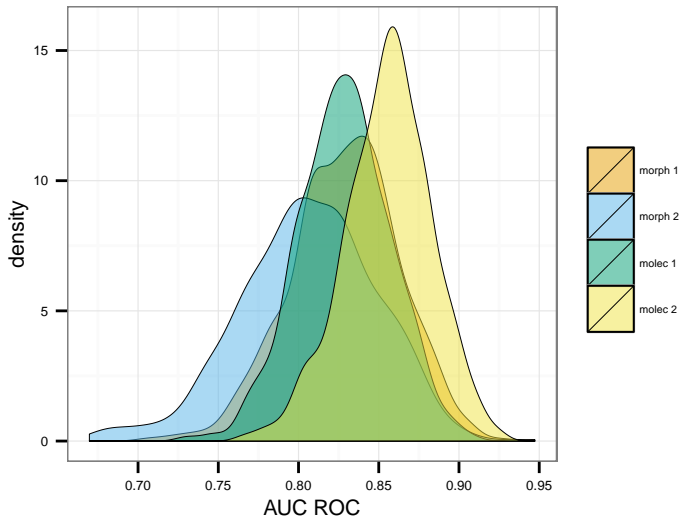
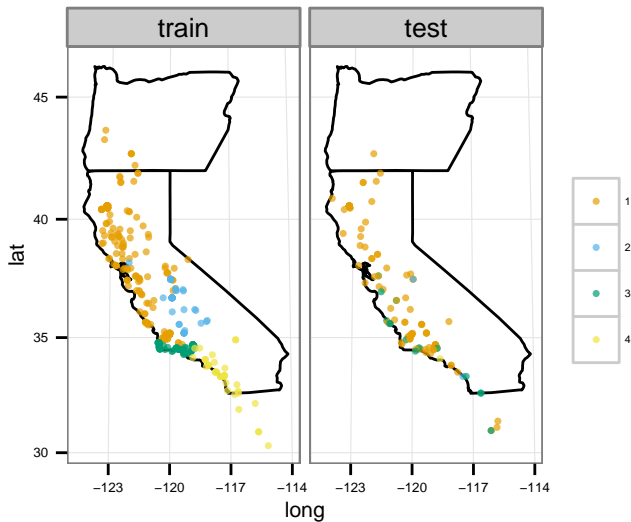# Results: mophometrics
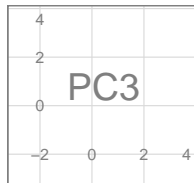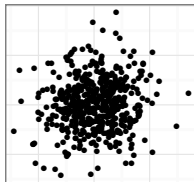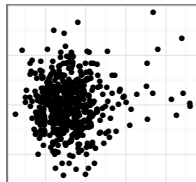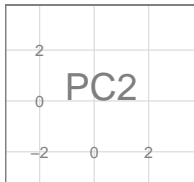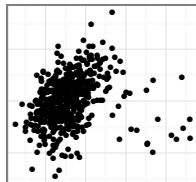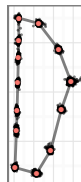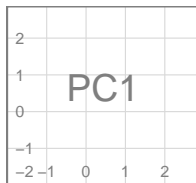
Results: gap clustering
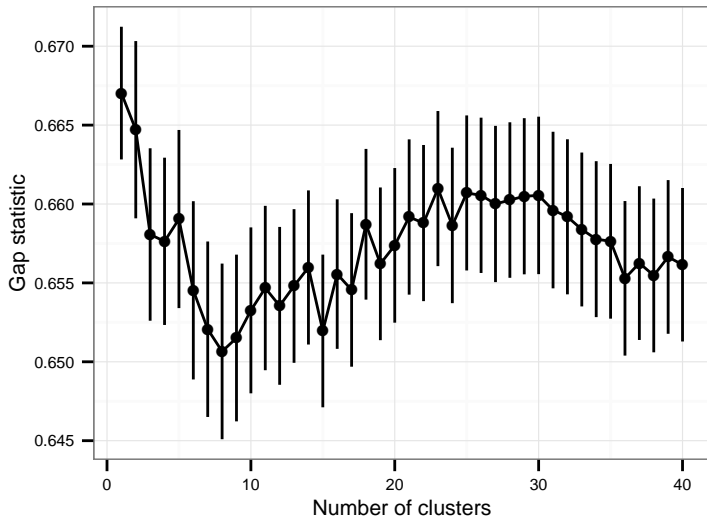
Second best cluster
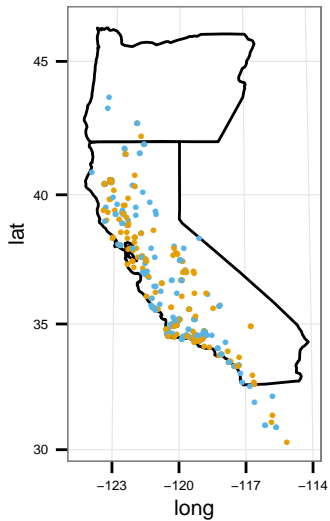
Model selection via ROC

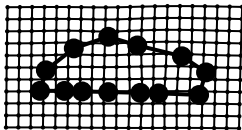# Generalize using best random forest model
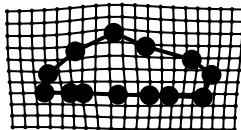
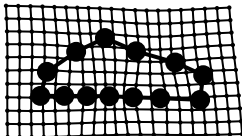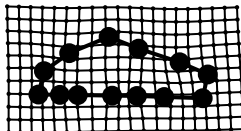# Best classification scheme via RF model results
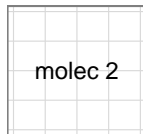
Mean shape of classes

1   **2**

3   **4**

Variable importance of random forest model
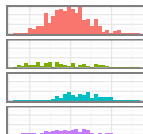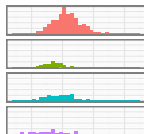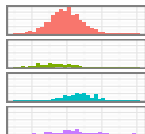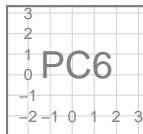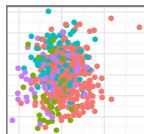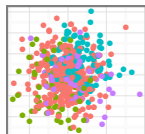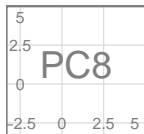
Shape across PC3

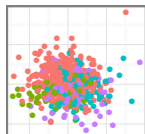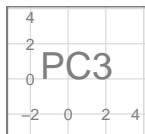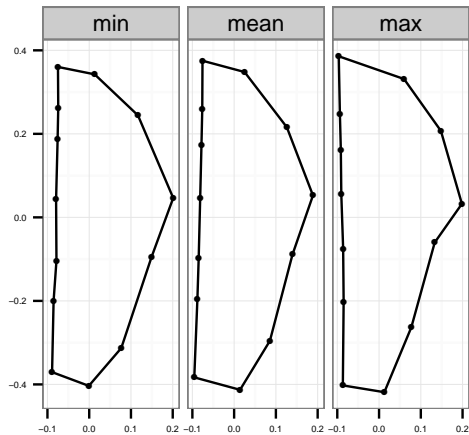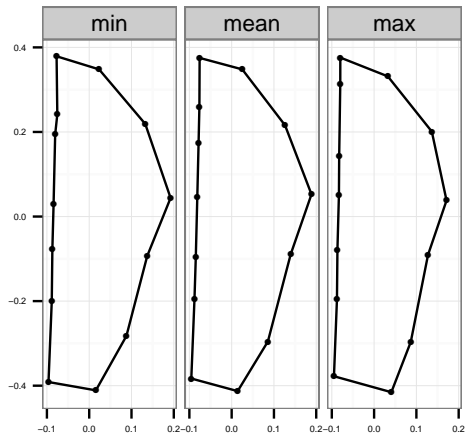# Shape across PC8

Future

- illustration of morphological validation of previously cryptic variation
    - the concordance is remarkable
    - large sample sizes can be difficult
- utility of large data, machine learning methods
- unsupervised methods for when no explicit hypothesis – nonparametric Bayes
- cause of interclass variation – local adaptation? pure isolation?

Acknowledgements

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