Biogeography of Nonindigenous Species: From Description to Prediction

By

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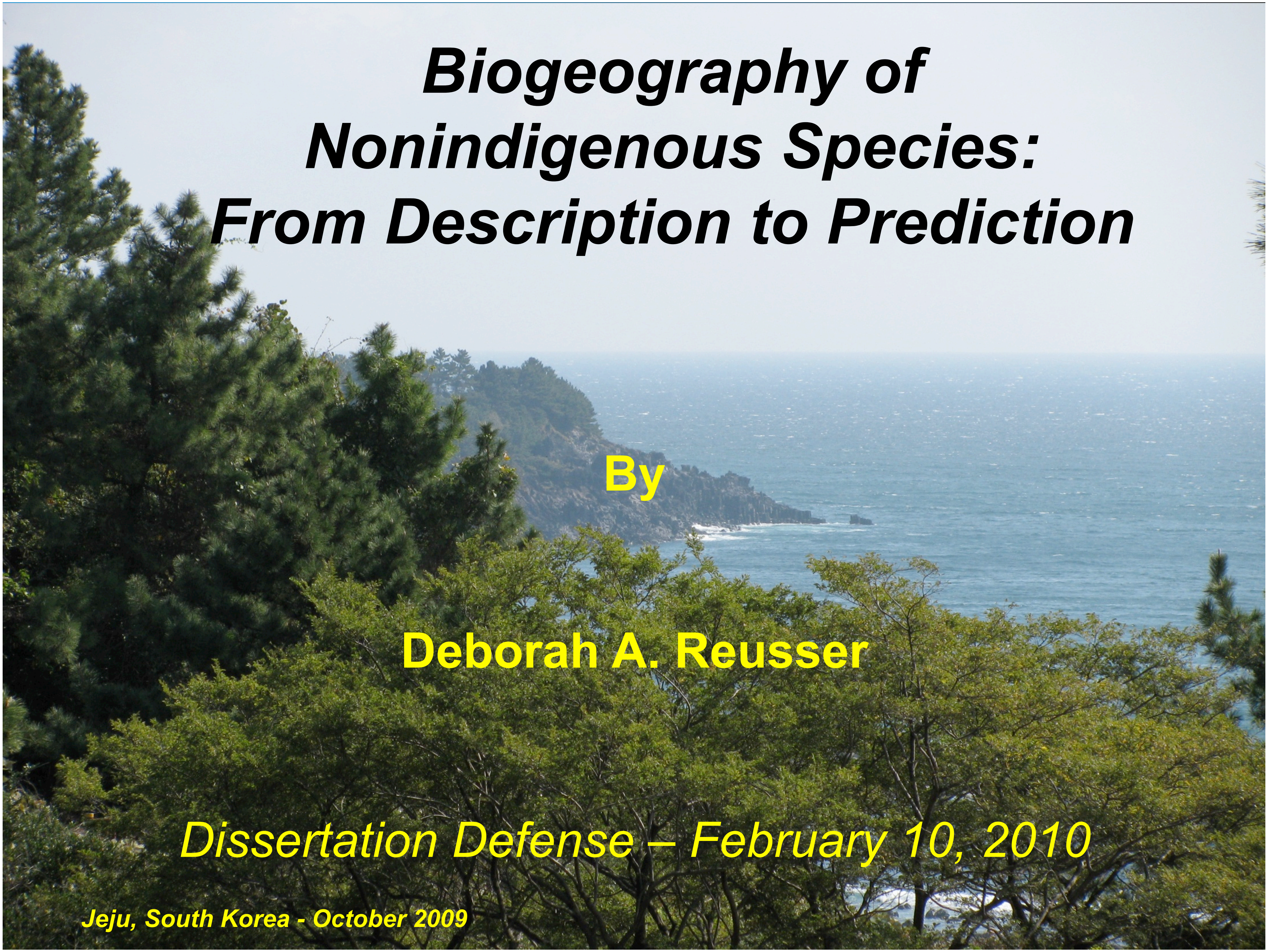
Dissertation Defense – February 10, 2010



Jeju, South Korea - October 2009

Overview

- **Introduction to Nonindigenous Species**
- **Design of an Ecosystem Informatics Framework for Marine Biogeography and Natural History**
- **Developing a Management Strategy for Ballast Water Discharge Standards**
- **Ecological Niche Modeling for Prediction**

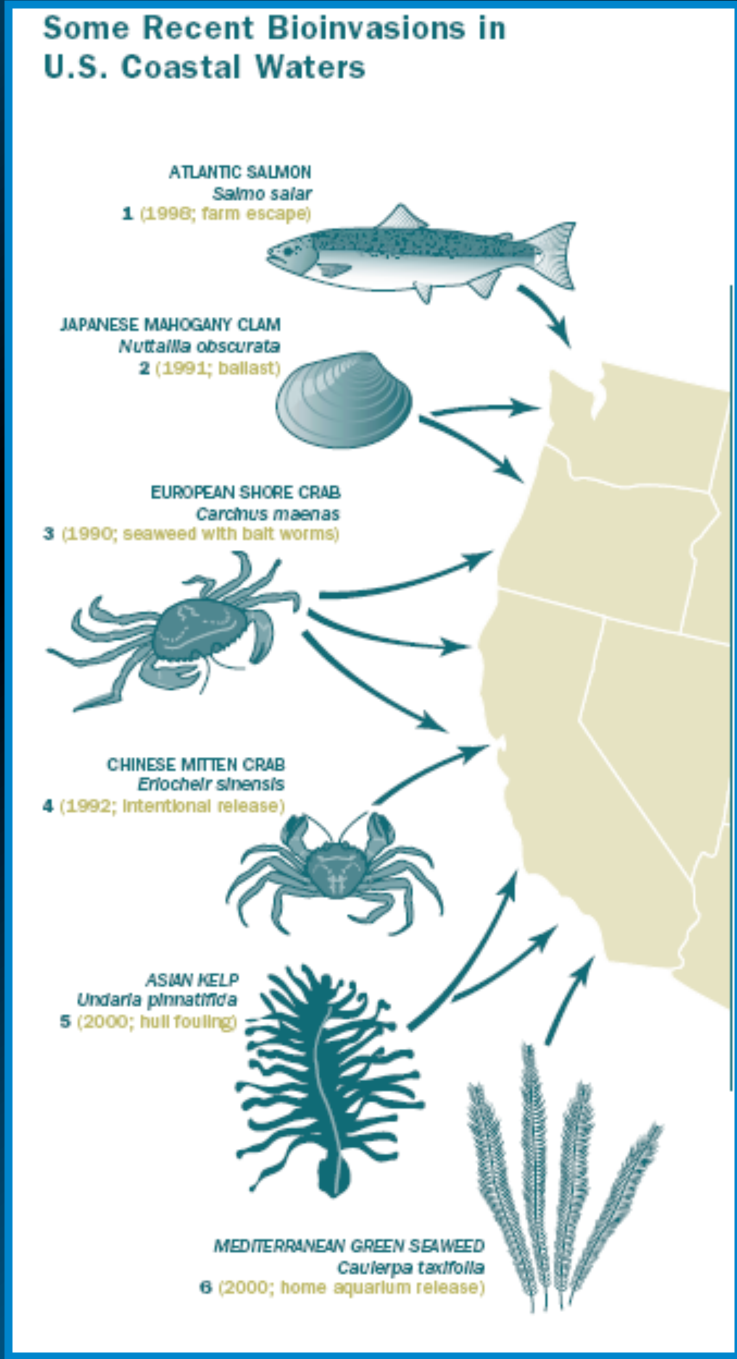
Puget Sound, WA - August 2006

Ecological Problem

Nonindigenous Species (NIS) those species not native to a region - can have serious economic and environmental effects when they establish in new regions.

Eradicating aquatic NIS after establishment is expensive and typically unsuccessful.

Prevention is the best strategy to address NIS in estuarine and coastal environments.

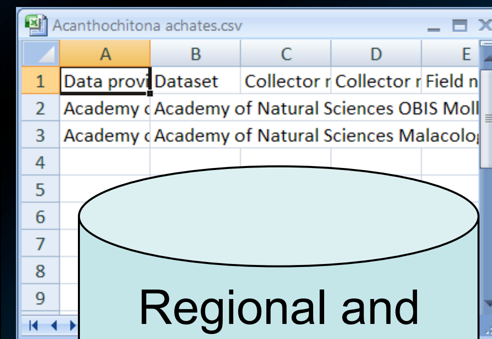


Carlton, J.T. 2001. Introduced Species in U.S. Coastal Waters

Management Strategy for Research Data

First Step

Develop an Informatics solution to collect & store biological data



Regional and Local Databases containing samples and species distributions

Historical Biological Baselines (species lists) for Pacific Coast Estuaries

List of Pacific Coast Estuaries where a species had been found

Evolution of Scale & Scope

Watershed Characteristics for an Estuary

Classification

Invasion vectors

Global distribution

Taxonomy

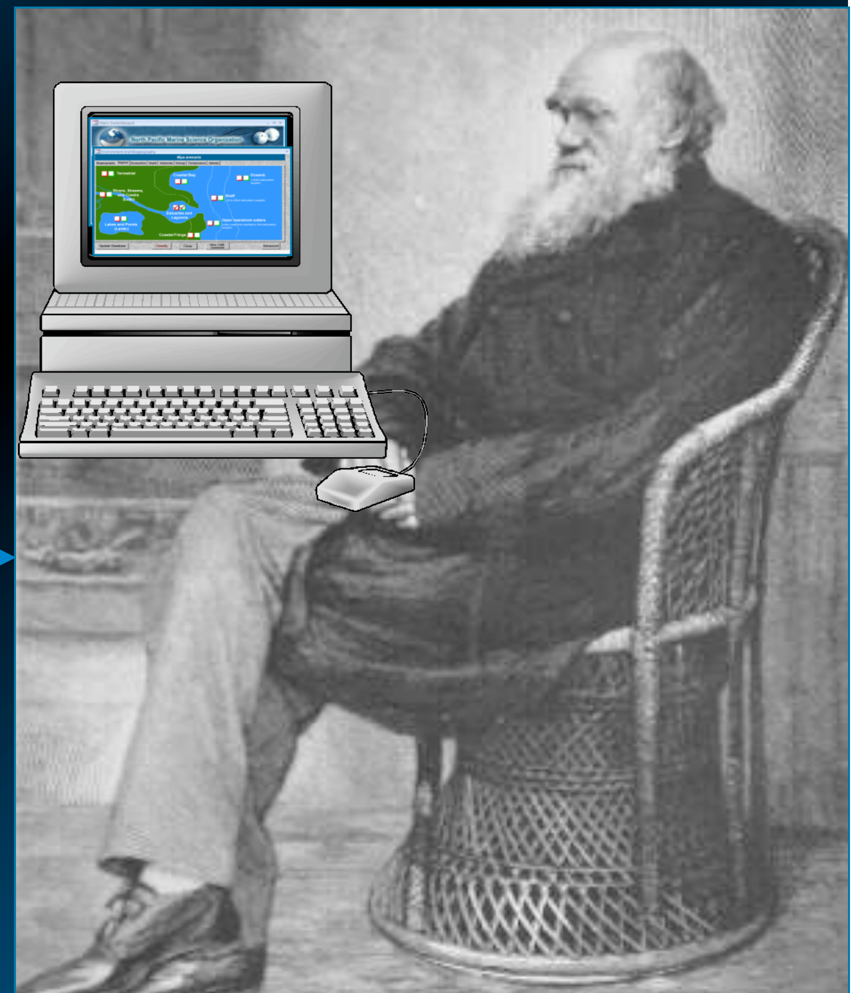
Habitat affinities

Life history characteristics

Integrated Schemas for Capturing Diverse Information

Ecosystem Informatics Framework for Marine Biogeography and Natural History

Text Based



Informatics Based

Basic Principles & Assumptions

For many questions, classes for habitat requirements and/or physiological tolerances will suffice.

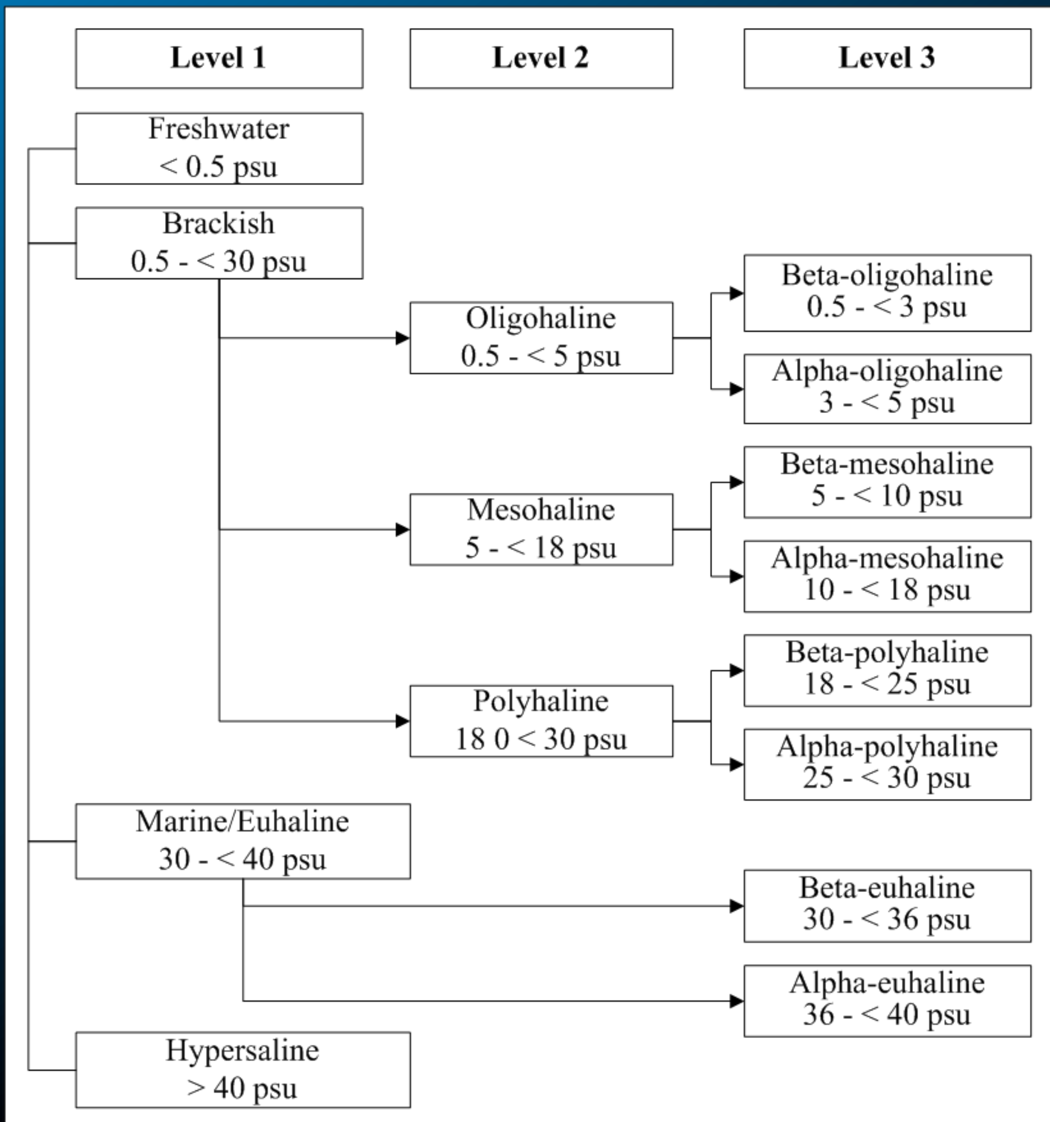
Capture information by hierarchical classes where possible to accommodate different levels of knowledge and needs.

Geography is biology – use distributions to infer habitat specificity.

Queriable natural history requires standardization even at the loss of some ecological nuances.

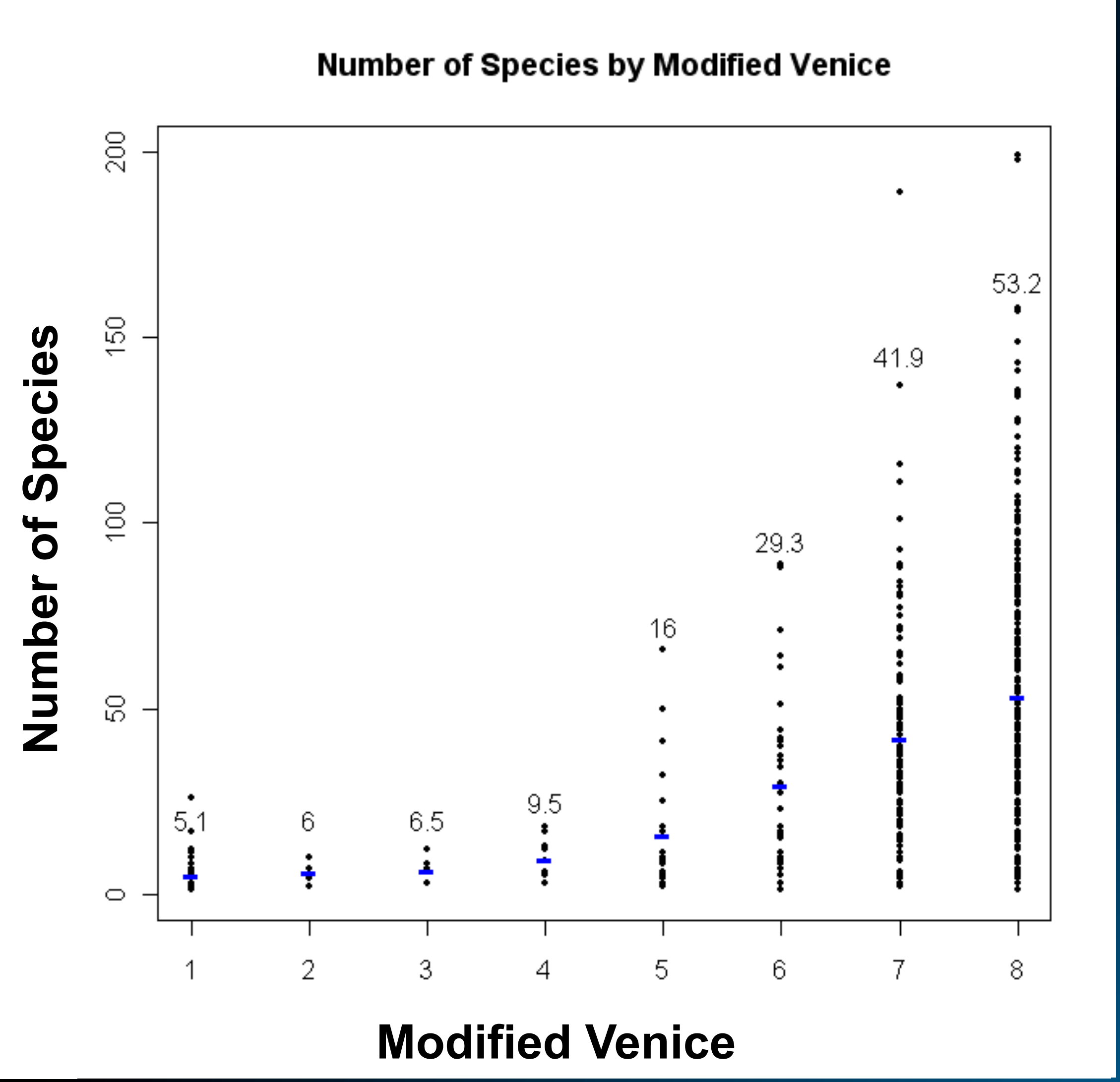
Use established classification schemas if possible.

Hierarchical Schema for Salinity



- Example of a schema for a quantitative attribute hierarchical structure easily imposed
- Level 1 : FishBase
- Level 2 : Venice System developed by the International Union for Biological Sciences (IUBS, 1958).
- Level 3 : Modified Venice System based on the Baltic system (IUBS, 1958)

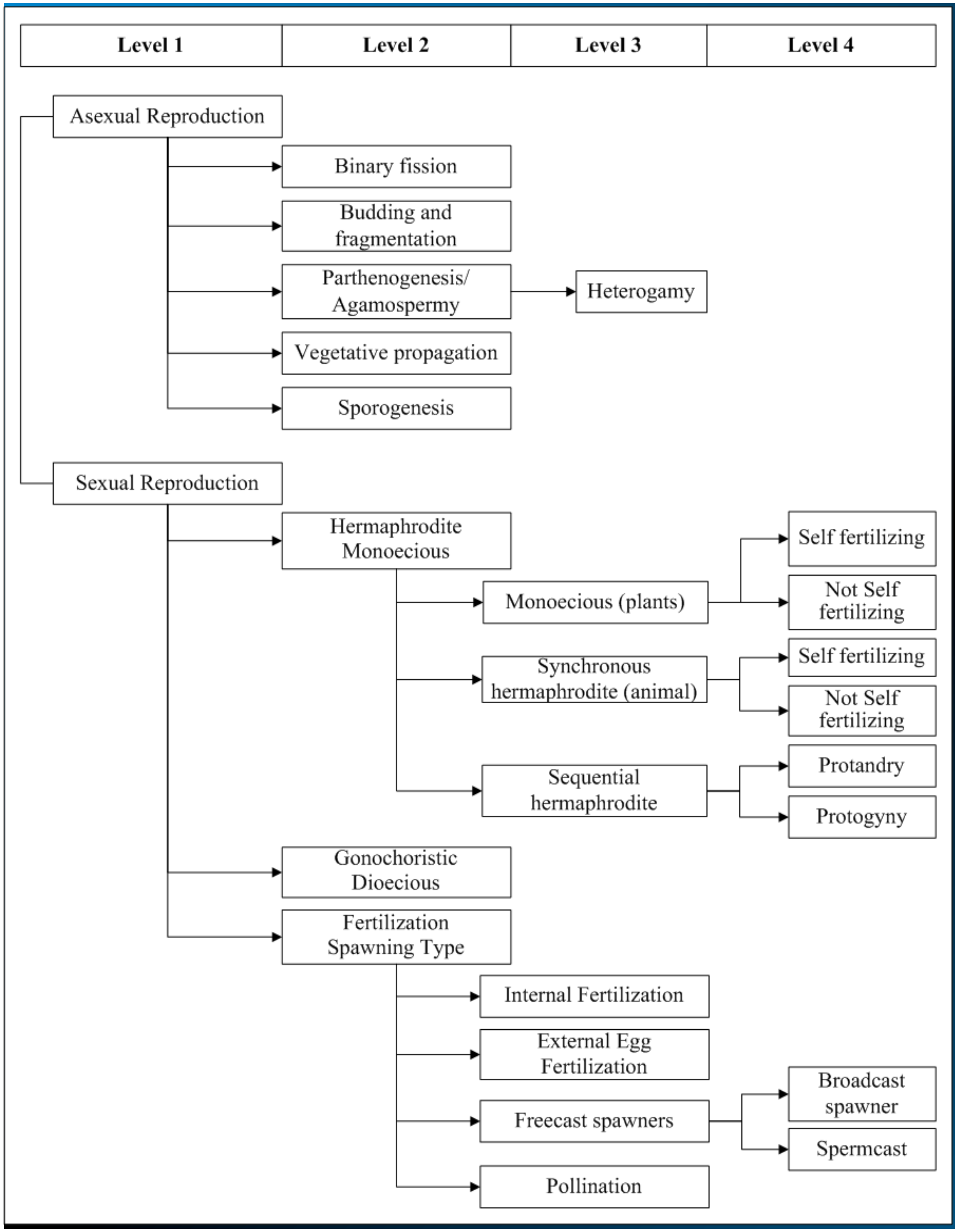
Salinity Values Converted to Modified Venice Classes



- Number of species as a function of salinity class

- As predictive as quantitative values in many cases

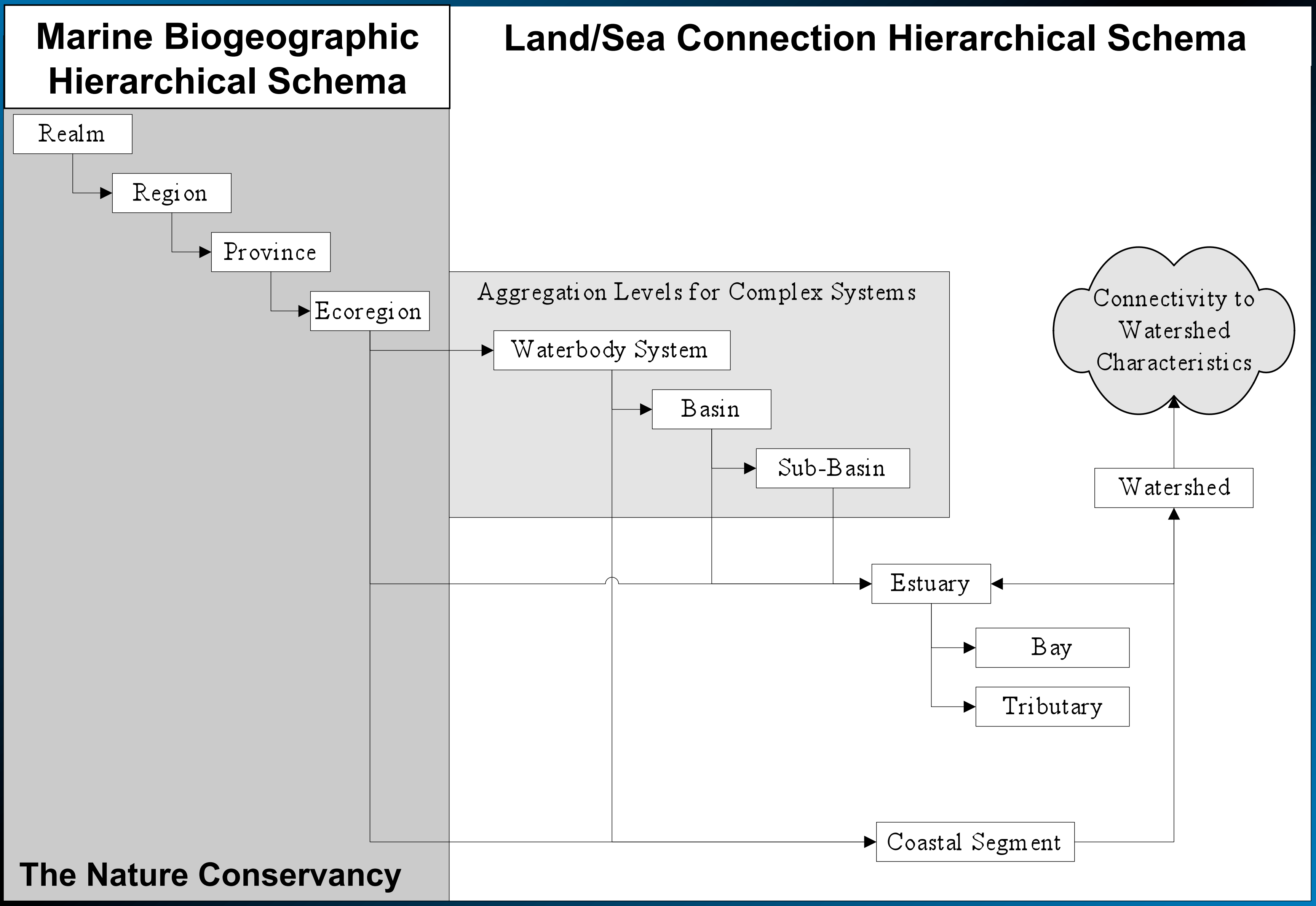
•Quant R^2 = .21
•Class R^2 = .22



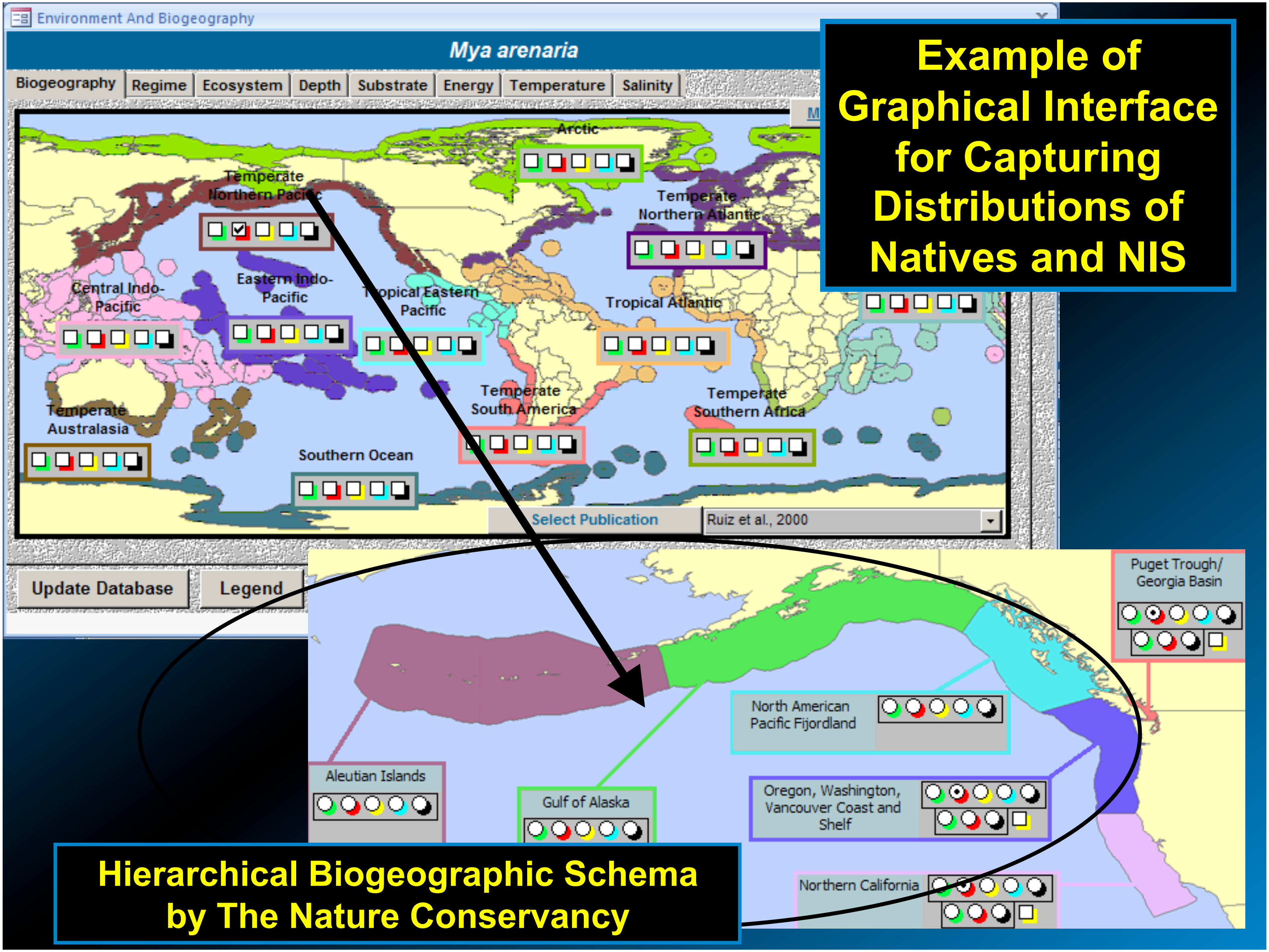
Reproduction Hierarchical Schema

- Example of qualitative Life history characteristic
- Structure can be imposed across all phyla but it is “messy”

Geographic Distribution Schema

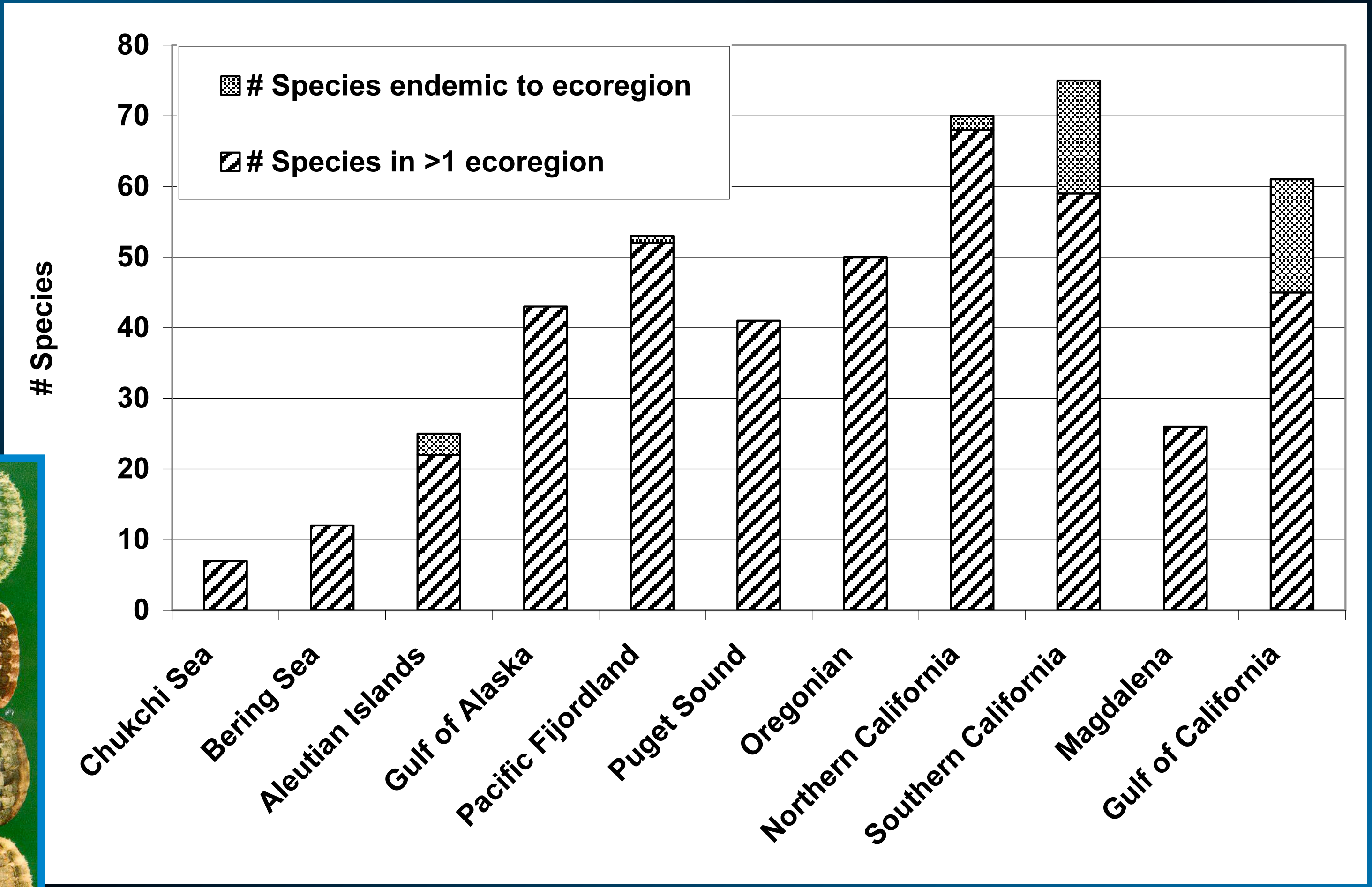


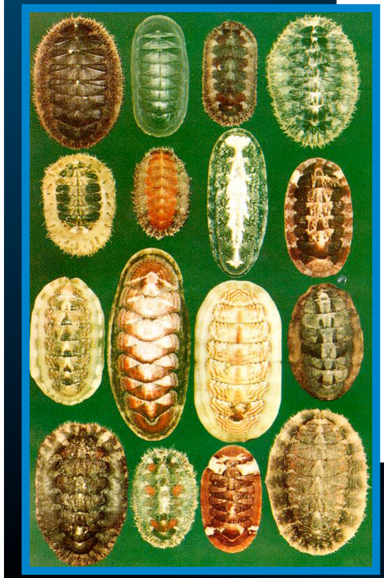
Example of Graphical Interface for Capturing Distributions of Natives and NIS



Hierarchical Biogeographic Schema by The Nature Conservancy

Number of Chitons by Ecoregions in the Northeast Pacific & Arctic

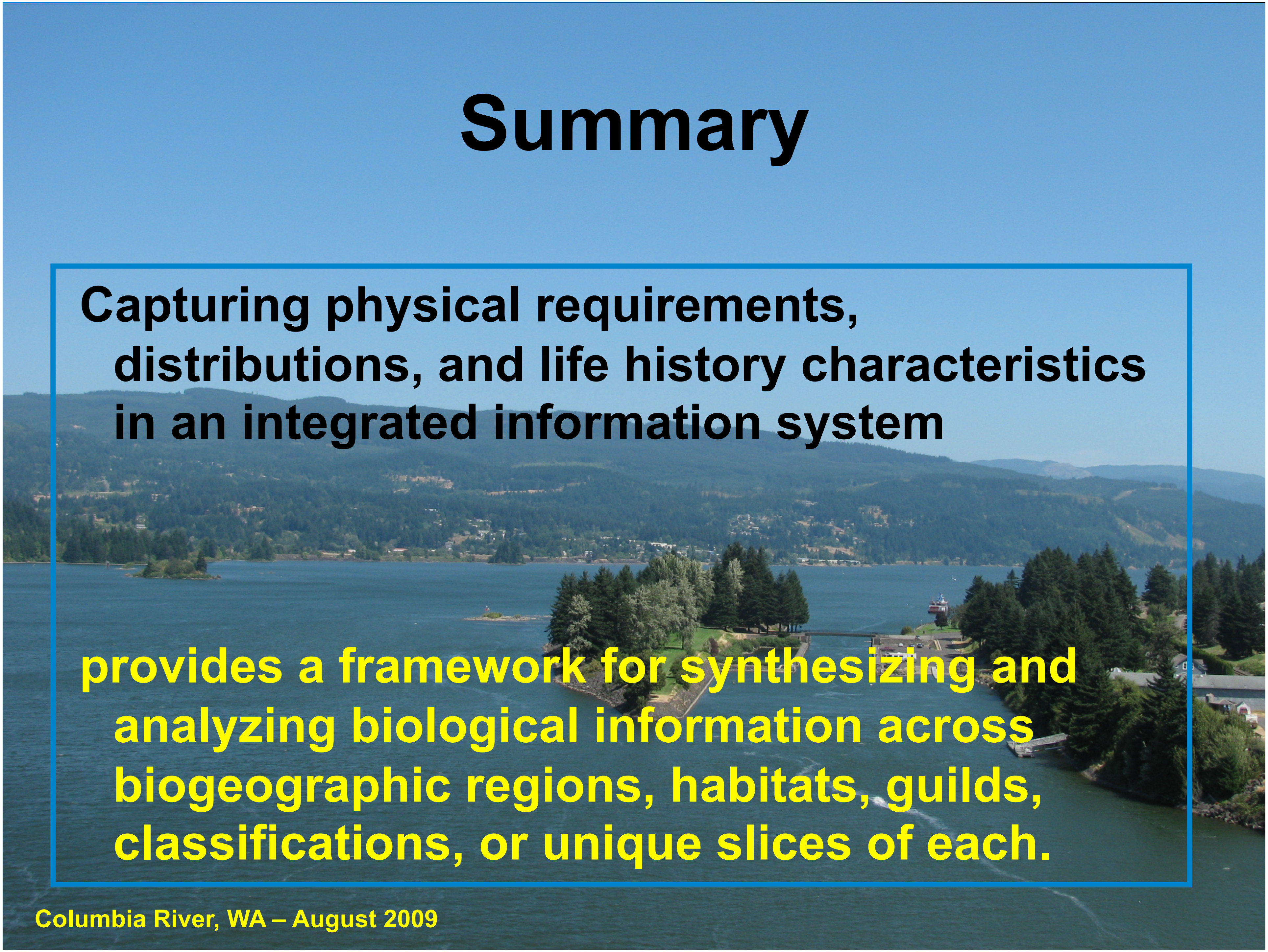




Summary

Capturing physical requirements, distributions, and life history characteristics in an integrated information system

provides a framework for synthesizing and analyzing biological information across biogeographic regions, habitats, guilds, classifications, or unique slices of each.

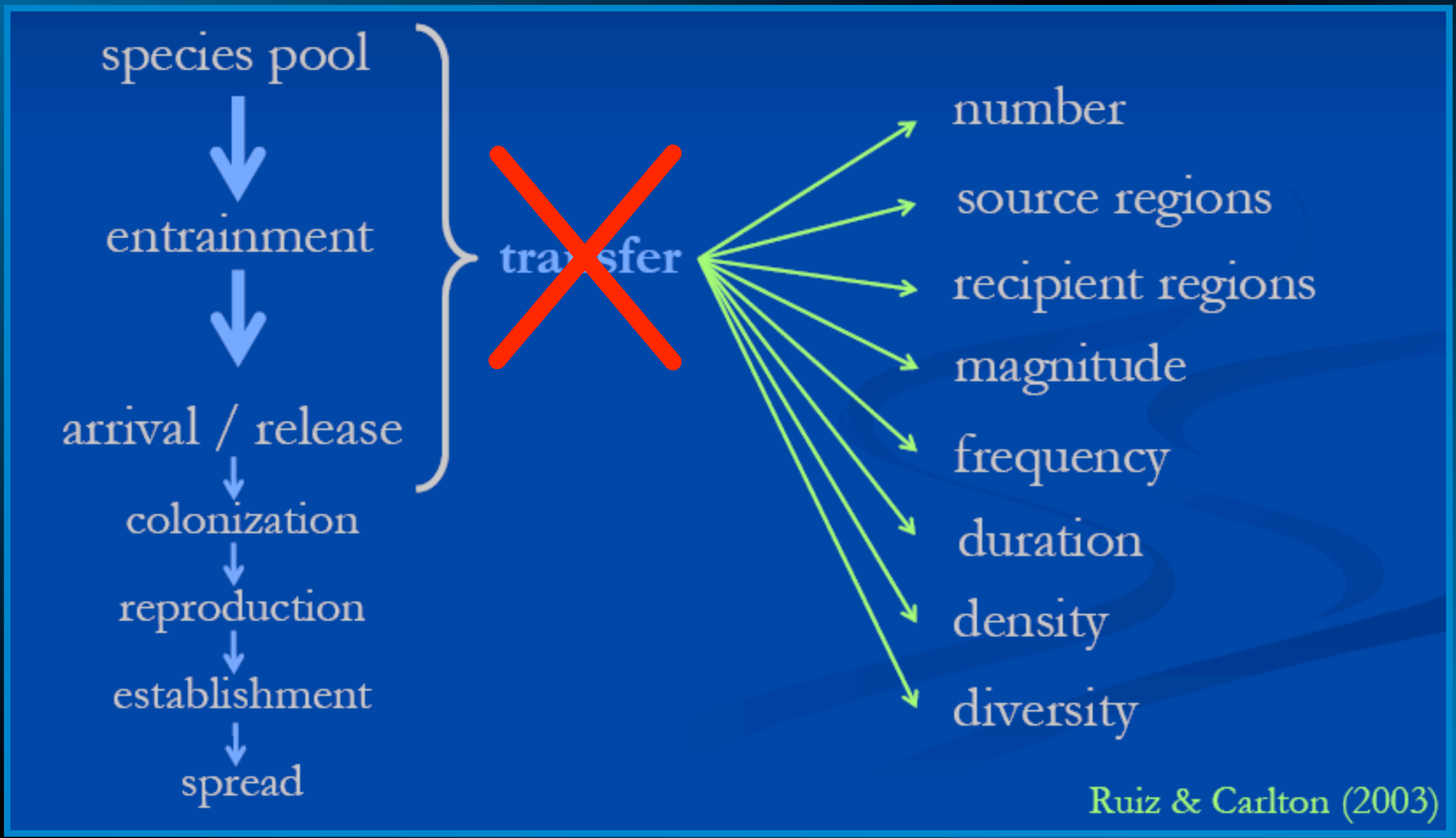


Columbia River, WA – August 2009

Using Information to predict

- Probability of Invasion from Ballast Water Discharges
- Spatial Distributions of Native and Nonindigenous Species (NIS)

Invasion Ecology is Complicated



Vectors For NIS

Primary Vector: Initial process that transports a species from its native region to a recipient region.

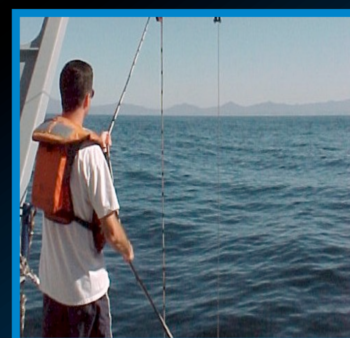
Secondary Vector: Process that redistributes nonindigenous species within the recipient region (along coastline).

Shipping

Ballast, Fouling & Boring

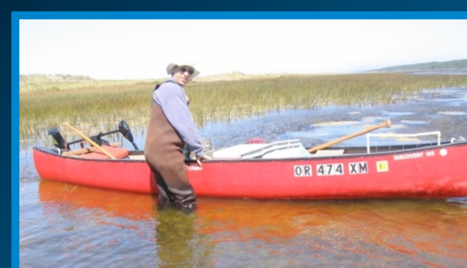
Aquaculture

Along-shore Drift



Migratory Birds & Wildlife

Recreational Boats



Fishing Boats

Pacific Shipping Routes – Primary Vector

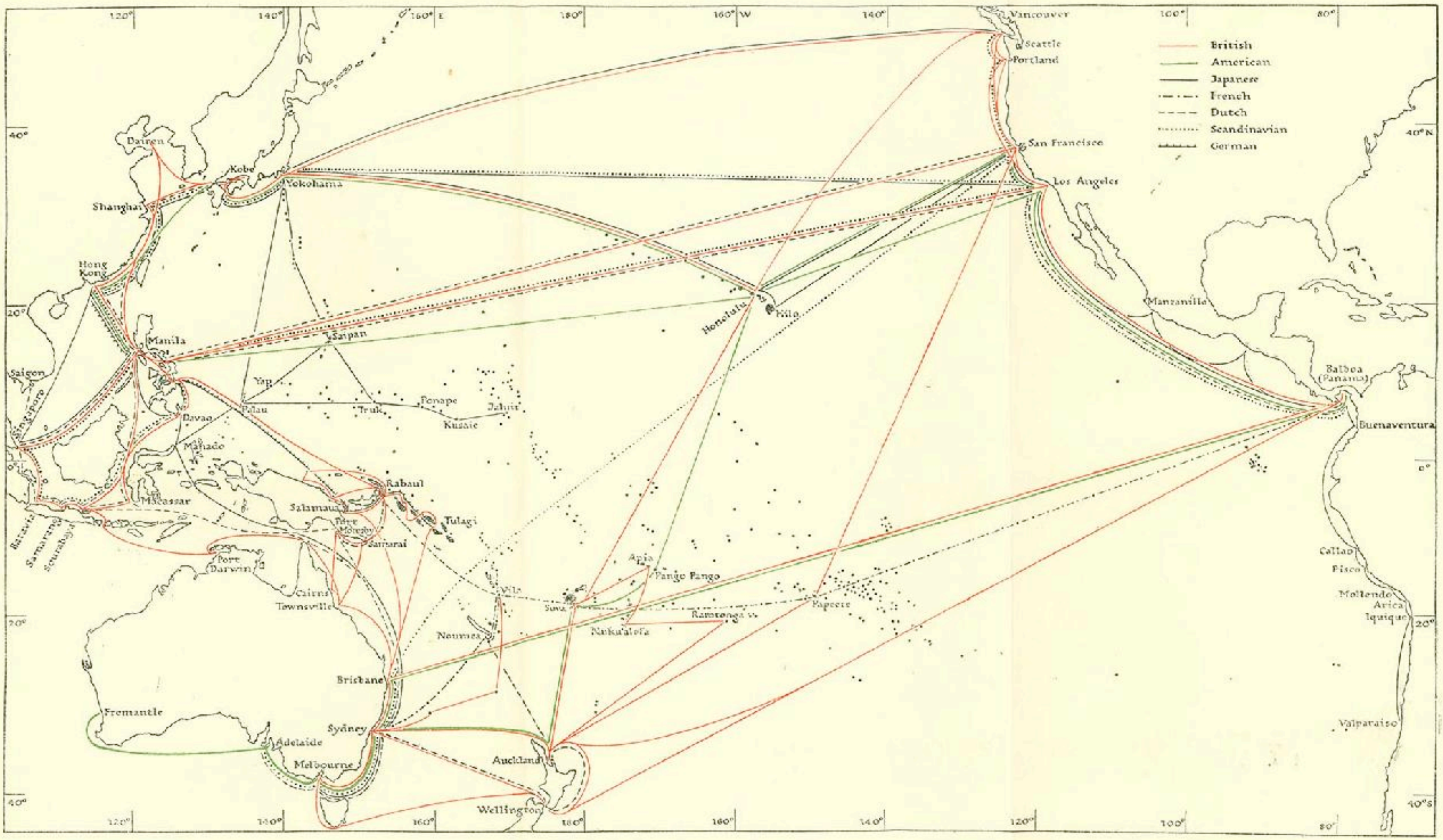


Fig. 117. Shipping routes in the Pacific, showing national interests

This map shows the nationality of vessels operating on the principal routes in 1938–9. Based on various sources.

Management Strategy for Ballast Water

Ballast water was a possible vector in ~70% of shipping-based introductions.

Fofonoff, *et al.*, 2003

Ballast Water Seascape

1000s of species are being transported in ballast water most of which we can not even identify

Dozens to hundreds of International ports in the U.S.

History of ballast water uptake and discharge is convoluted and complex and impossible to predict for any particular ship

Voyage times are getting shorter – better survival

About 110,000 domestic and international ship arrivals to U.S. port annually

International traffic is predicted to increase

Not possible to model all these complexities

IMO Standards
International Ballast Water Treaty

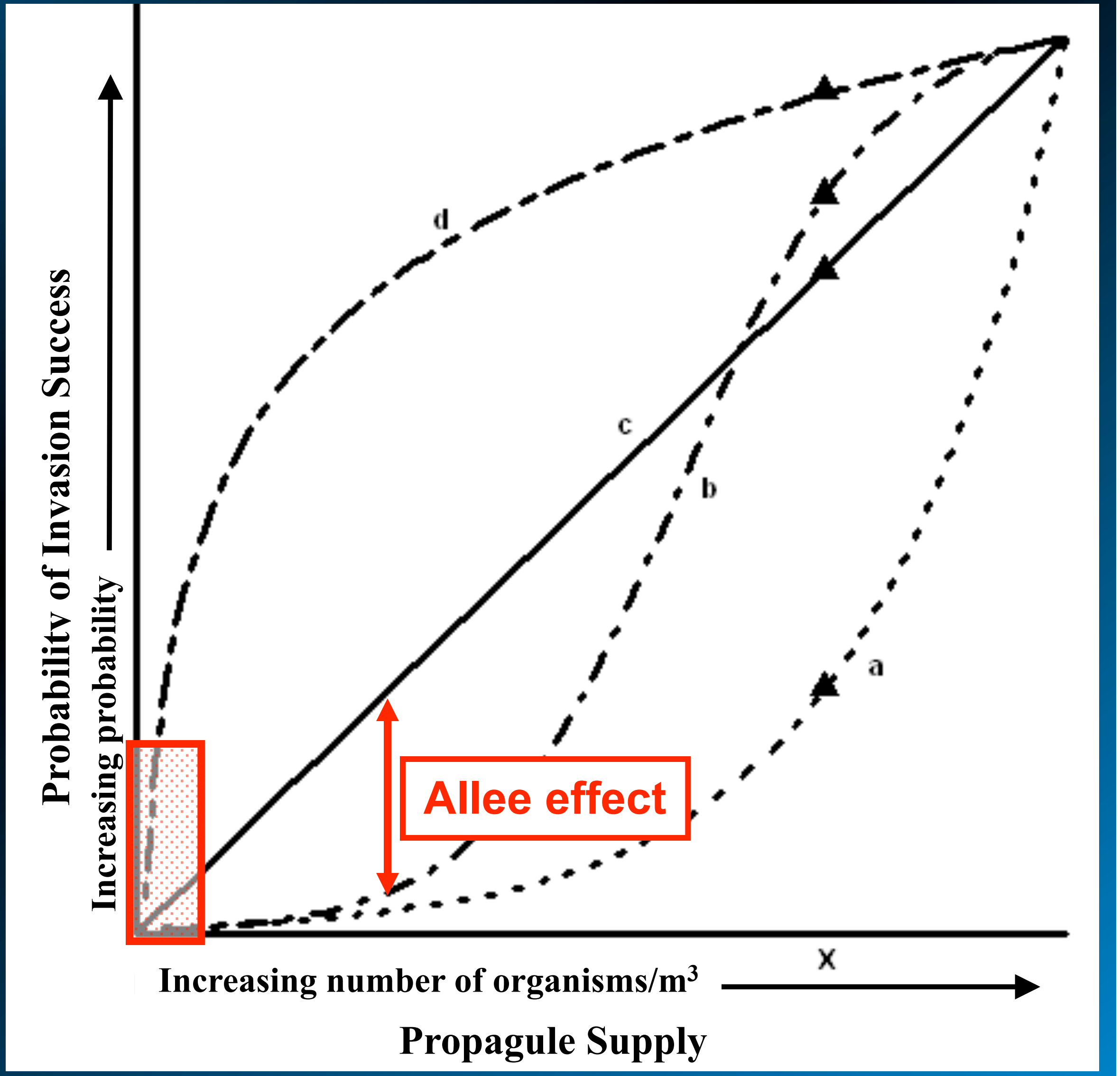
- **International Maritime Organization has established organism concentration limits in ballast water discharge**

Organism Size Class	IMO Regulation D-2[1]
Organisms greater than 50 µm[3] in minimum dimension	< 10 viable organisms per cubic meter
Organisms 10 – 50 µm in minimum dimension	< 10 viable organisms per ml[4]
Living organisms less than 10 µm in minimum dimension	
Escherichia coli	< 250 cfu[5]/100 ml
Intestinal enterococci	< 100 cfu/100 ml
Toxicogenic *Vibrio cholerae* (O1 & O139)	< 1 cfu/100 ml or < 1 cfu/gram wet weight zooplankton samples

Propagule Pressure: Dose-Response Relationship

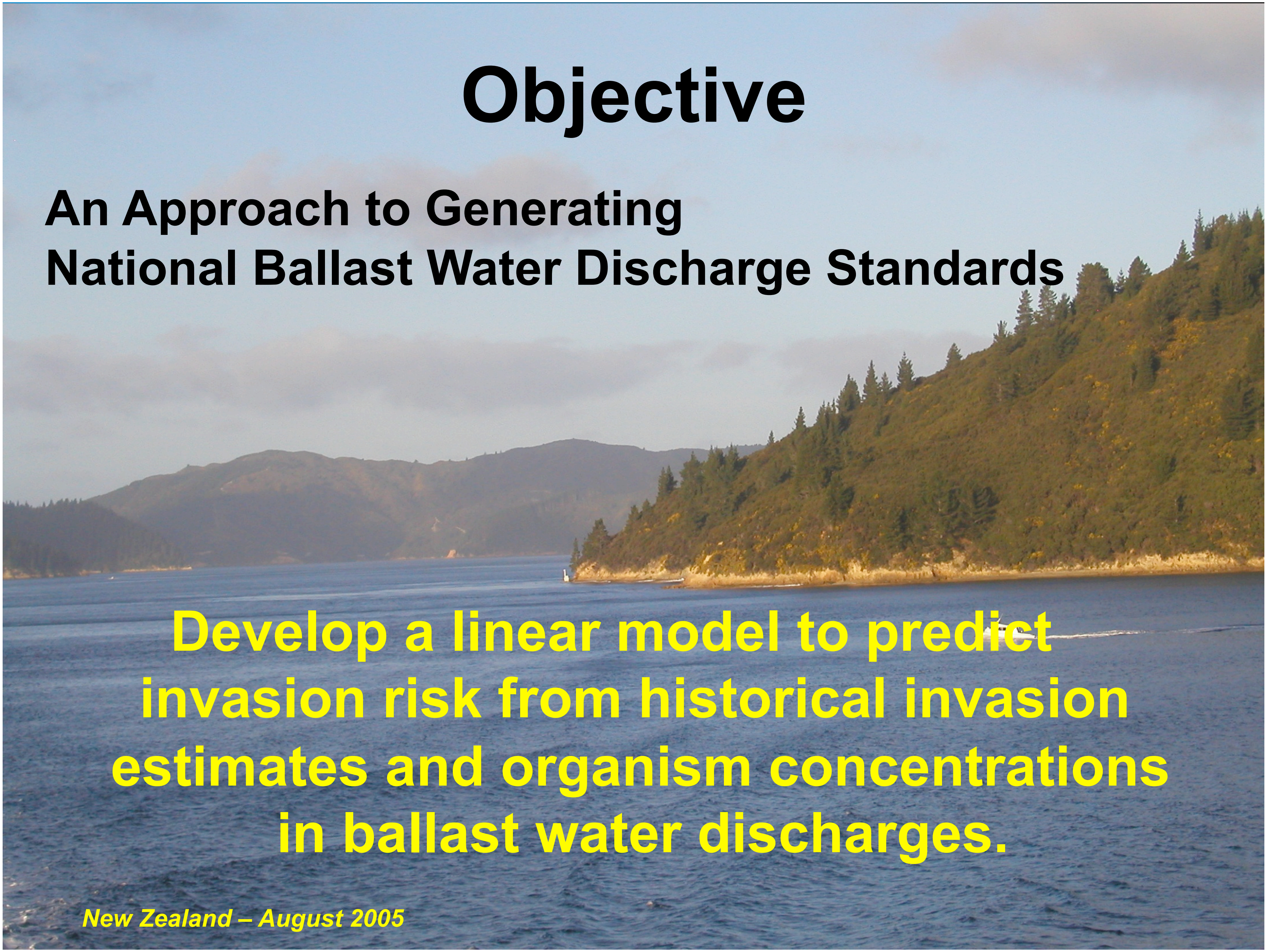
- a & b: Allee effects – the results will be more protective for lower concentrations
- c: Linear response
- d: Unknown response

From Ruiz & Carlton, 2003



Objective

An Approach to Generating National Ballast Water Discharge Standards



Develop a linear model to predict invasion risk from historical invasion estimates and organism concentrations in ballast water discharges.

New Zealand – August 2005

Coastal Invasion Statistics

Coast	Annual Foreign Ballast*	# Invaders 1981-2006	# Ships	High PCIP
East	7,407,832	40	12,860	4.64E-11
Pacific	14,788,369	67	5998	3.83E-11
Gulf	19,605,340	18	11,821	7.67E-12

***Average annual foreign ballast water discharged calculated from records between 2005 – 2007**

PCIP was also calculated for 17 international ports but it created uncertainty in Invasion rate due to secondary dispersal so analysis was redone using coastal data.

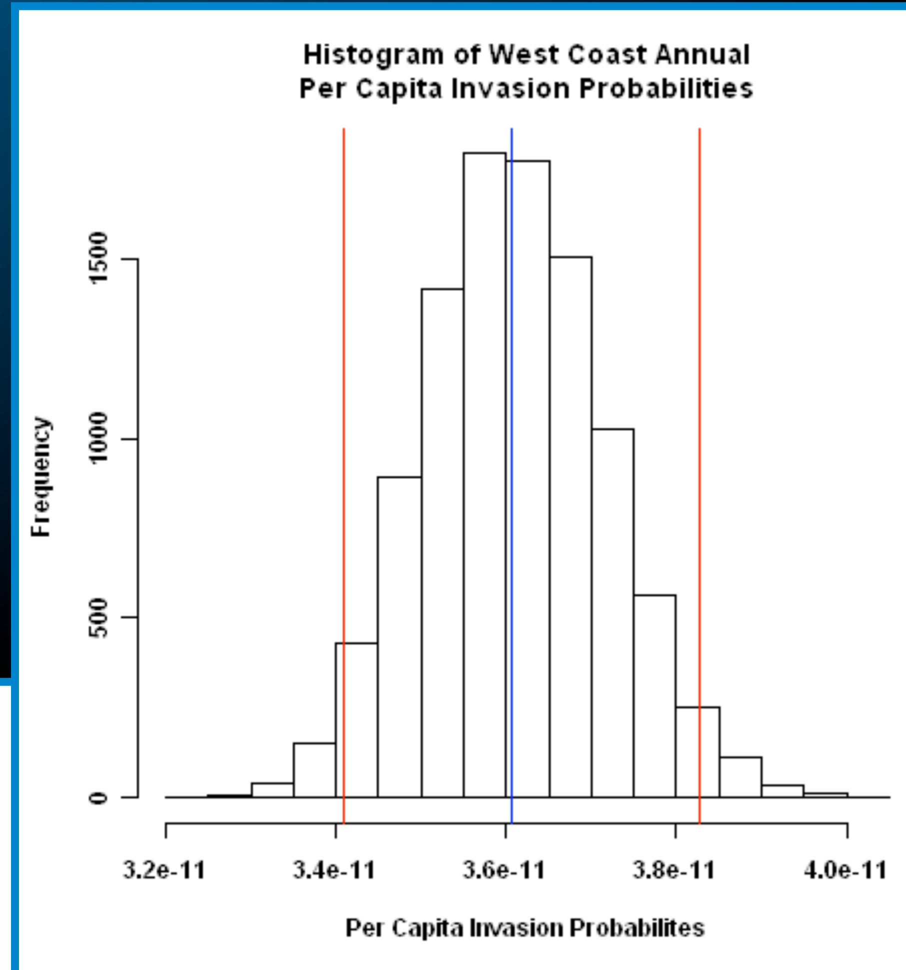
Linear Model

Per Capita Invasion Probability (PCIP) $= \dfrac{\text{Historical Invasions}}{\text{BW Discharge * BW Concentration}}$

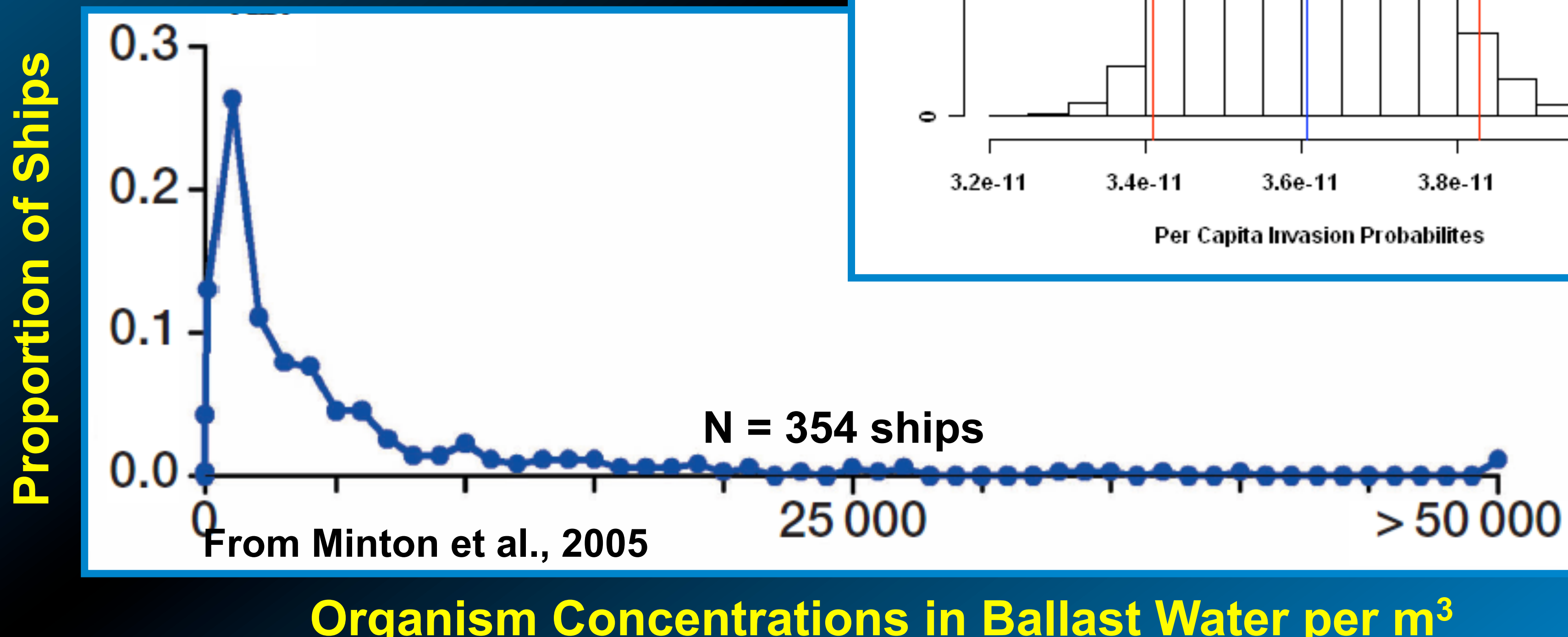
PCIP is the probability that an individual organism will become a new invader in an location

Propagule Supply = BW Discharge * BW Organism Concentration

Simulation to Calculate Range of Invasion Probabilities

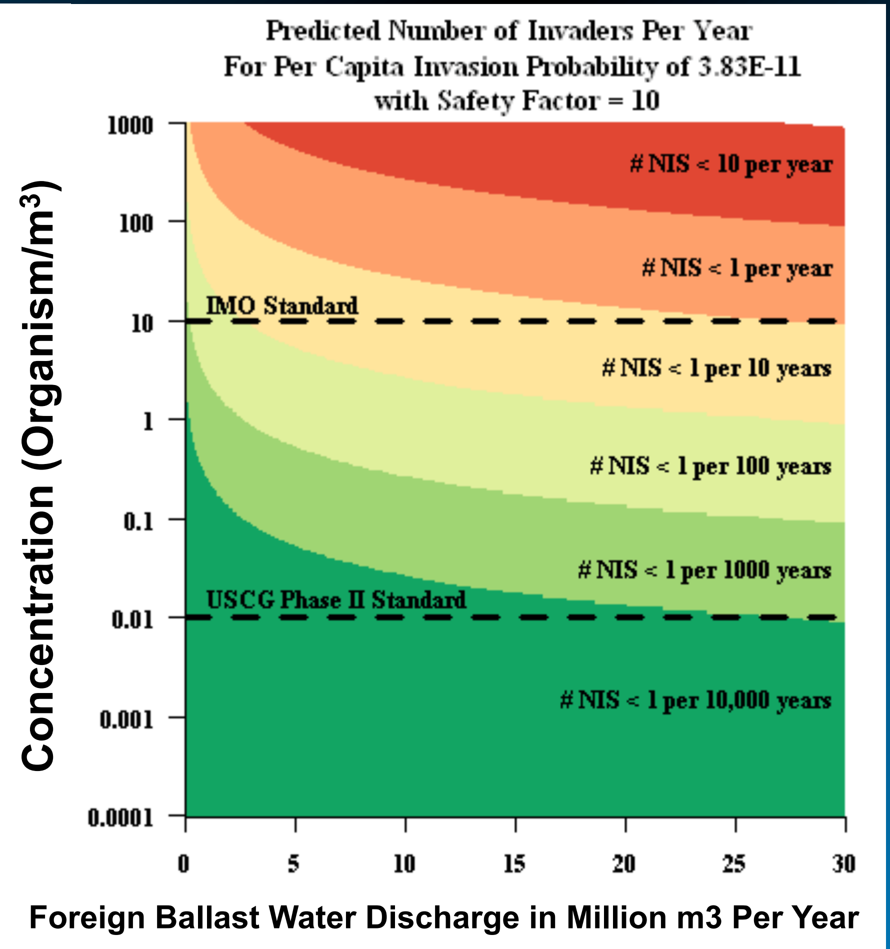


Not all ships' ballast is equal (large variance)



"Regulatory Landscape" of Establishment Probabilities

- Colors indicate number of invaders per year as a function of ballast water discharge and organism concentrations.
- For less than 1 invader per 10,000 years, ballast water and organism concentrations must be in the dark green area.



Invasion rate = PCIP * Concentration * Total Discharge * Safety Factor

Advantages

- The complexities existed historically so have been captured in the historical invasion rate
- It's simple and the assumptions are clear
- Not restricted to a particular guild or taxon
- Level of uncertainty can be assessed with new information
- The level of uncertainty in the coastal models is within an order of magnitude which is better than other approaches

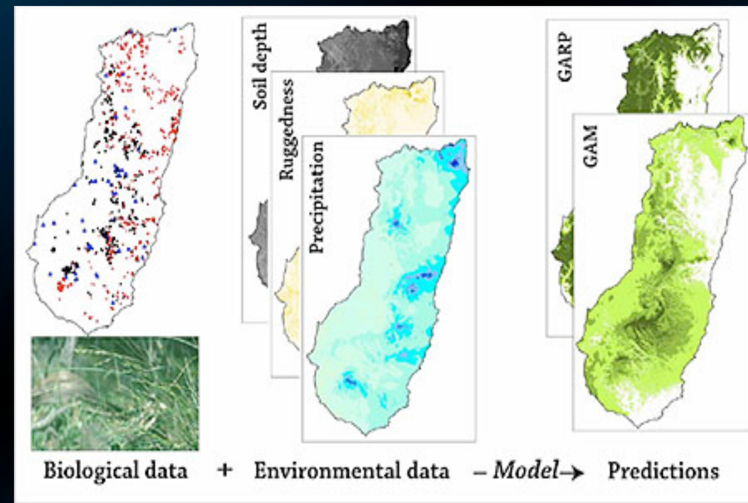
After NIS Arrive
Where Will They Establish?

Ecological Niche Modeling for Prediction

Evaluate a niche modeling approach using species with known distributions.

Evaluate the model at different spatial scales.

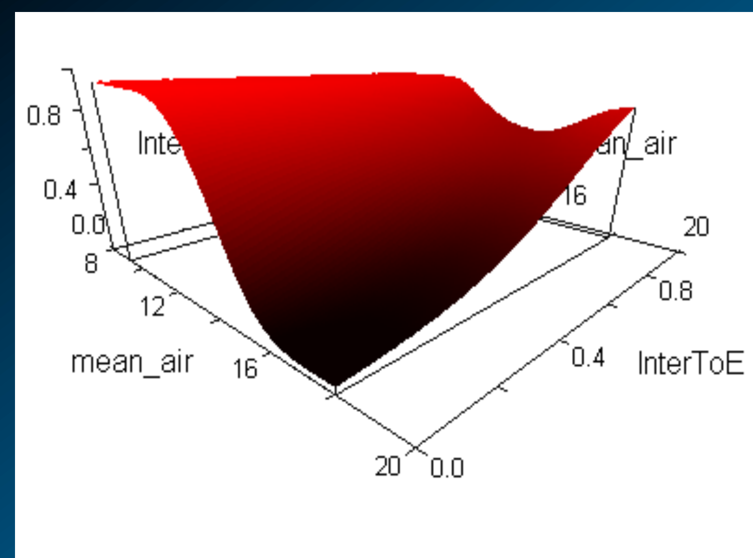
Evaluate different classes of environmental variables.



Niche Model Evaluated

Nonparametric Multiplicative Regression

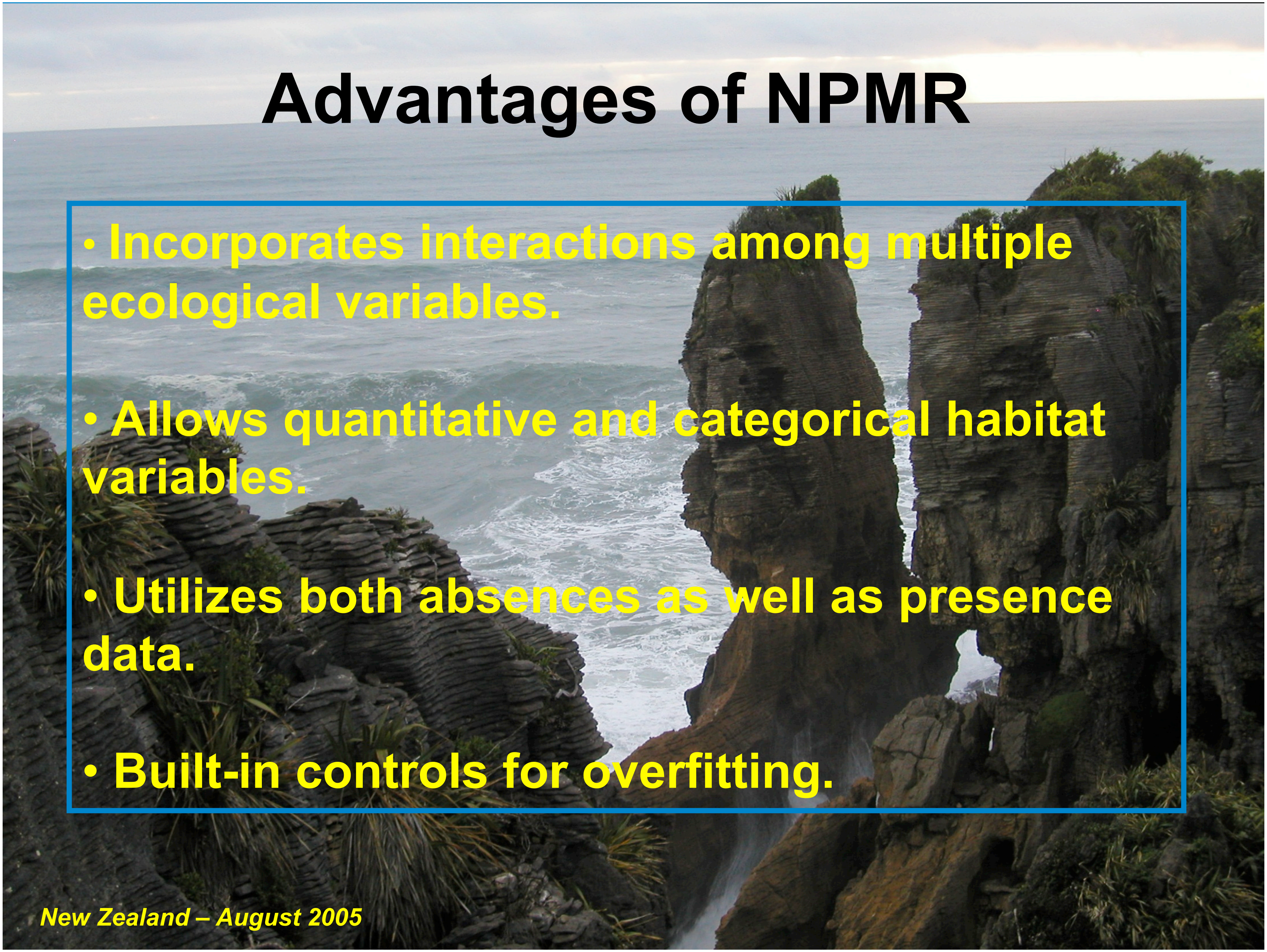
NPMR represents a species' response surface in multidimensional niche space by smoothing the species response in a local area of predictor space by combining information from nearby observations.



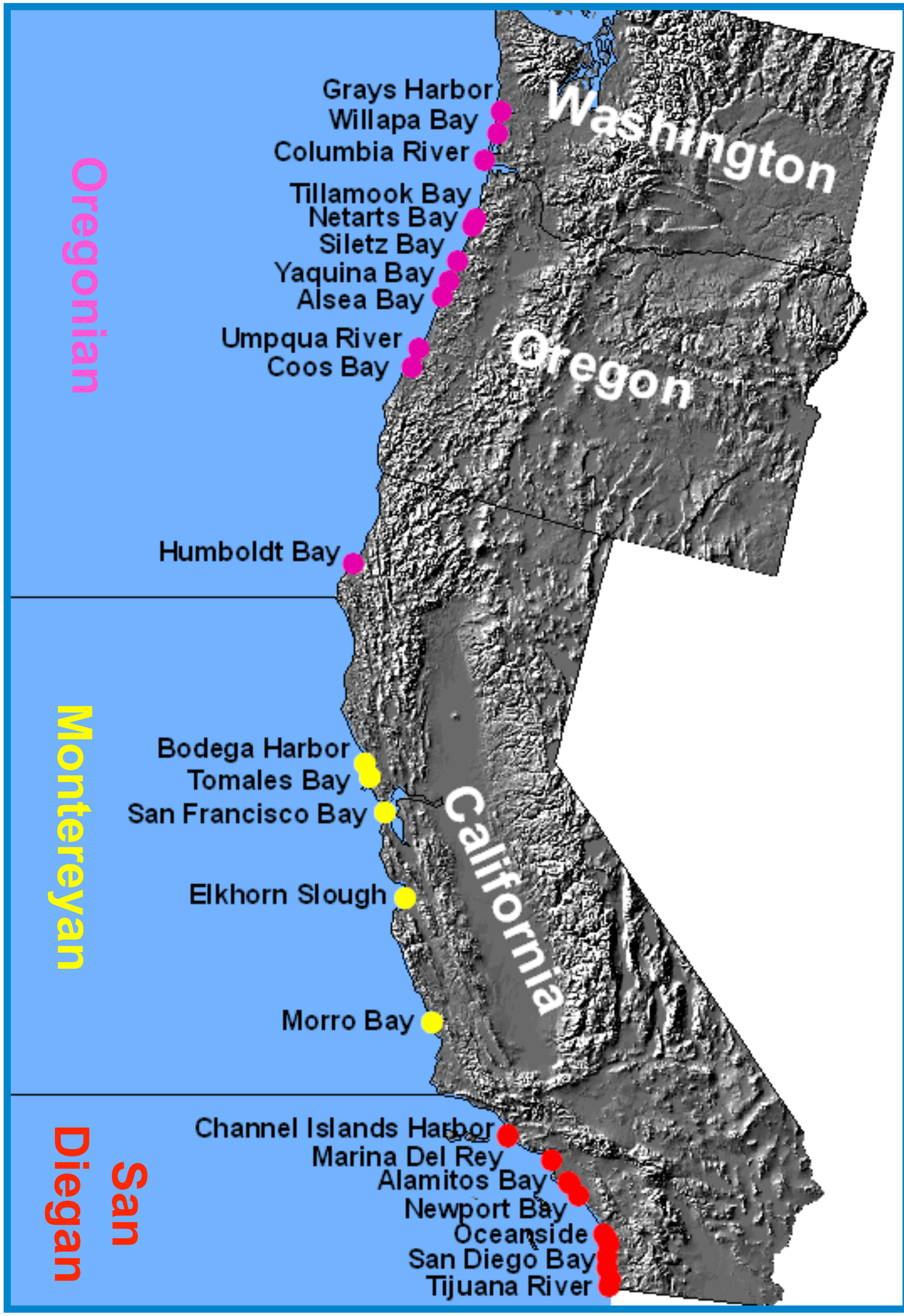
McCune 2006. Non-parametric habitat models with automatic interactions. Journal Vegetation Science 17: 819-830.

Advantages of NPMR

- **Incorporates interactions among multiple ecological variables.**
- **Allows quantitative and categorical habitat variables.**
- **Utilizes both absences as well as presence data.**
- **Built-in controls for overfitting.**



New Zealand – August 2005



Estuary Scale

- Estuaries with at least 100 species (N = 28)
- Distributed across 3 biogeographic ecoregions

Habitat Scale

EMAP
1999 - 2003

AK - CA

Total = 664 benthic samples

Estuary Scale

Variables

Habitat Scale

Watershed

- Land area
- Water area
- Intertidal area
- Subtidal area
- Riverine area

Geographic

- Biogeographic Zone
- Latitude

Habitat

- Sediment
- Depth
- Salinity

Climate

- Temperature
- Precipitation

Ecological Engineering

- P/A Burrowing Shrimp
- P/A Marsh Plants
- P/A Seagrass
- P/A Marcoalgae

Geomorphologic

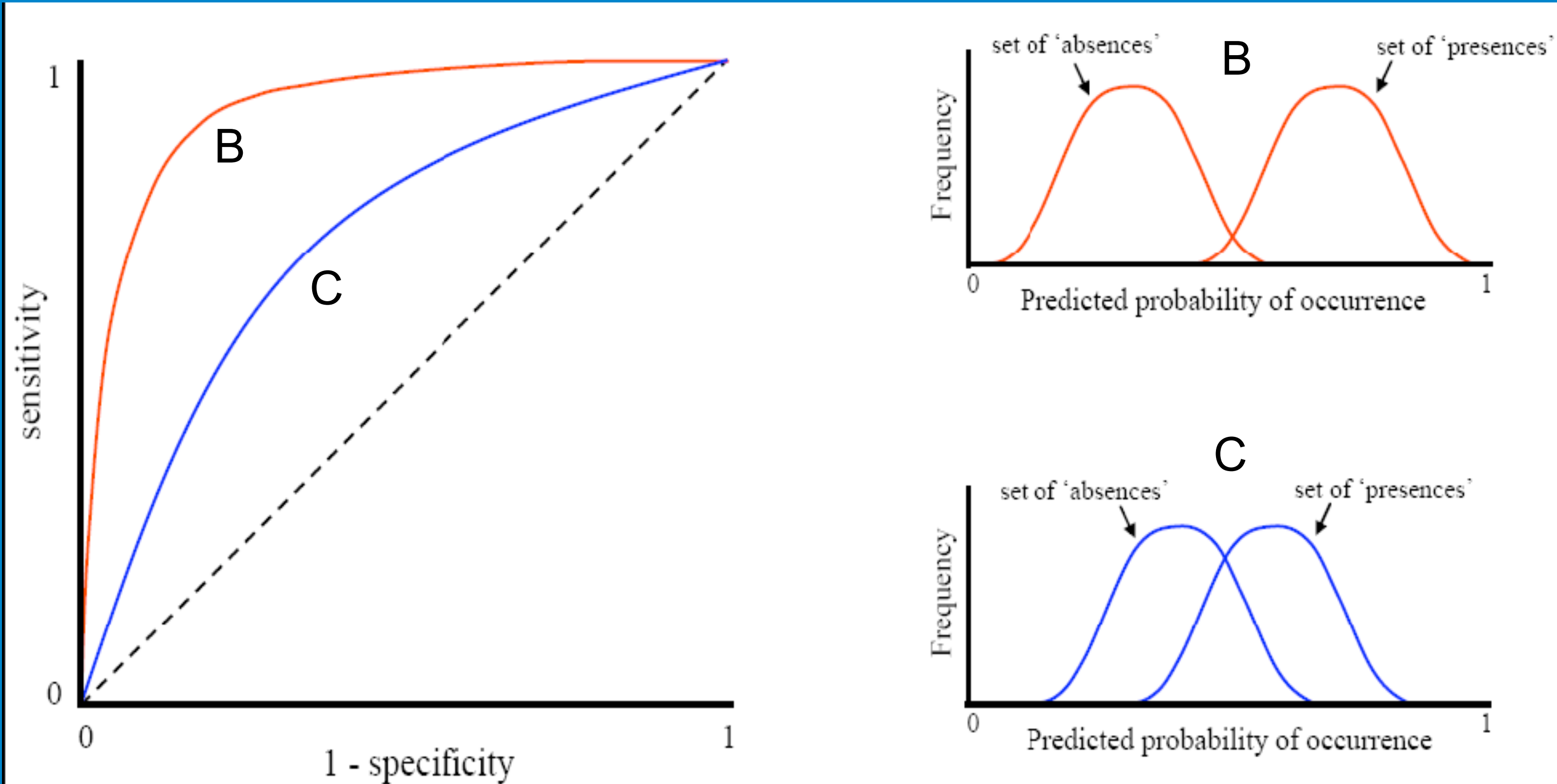
- Water/land
- Subtidal/intertidal
- Riverine/estuarine
- Intertidal/estuarine

Species Selection

- Most frequently occurring species in > 50 habitat samples (N = 28)
- Subset of species occurring in selected estuaries (N=13)

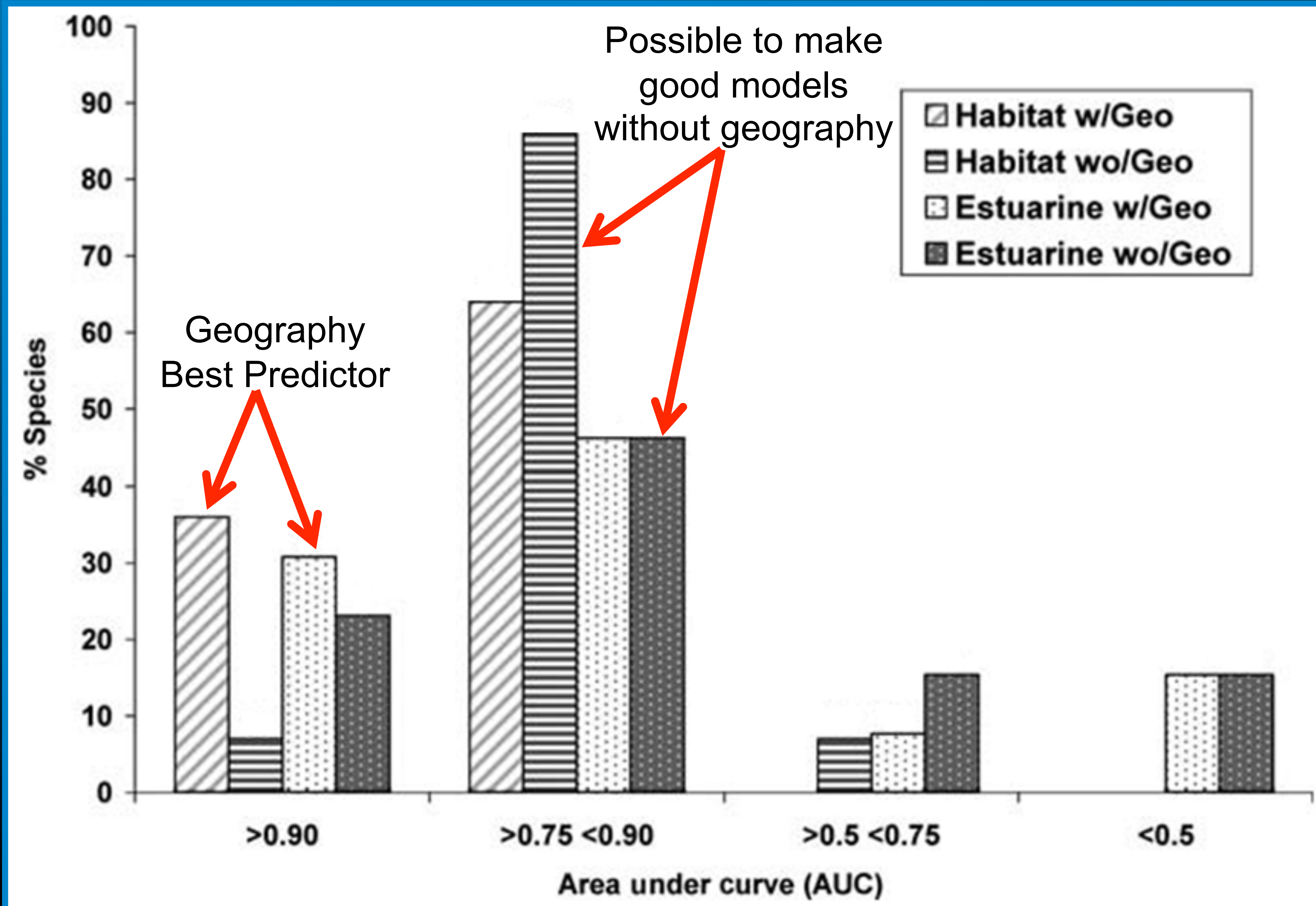
Class	Habitat	Estuary
NIS	11	5
Native	13	7
Cryptogenic	4	1

Measuring Performance of NPMR Models
Area Under the Curve (AUC)

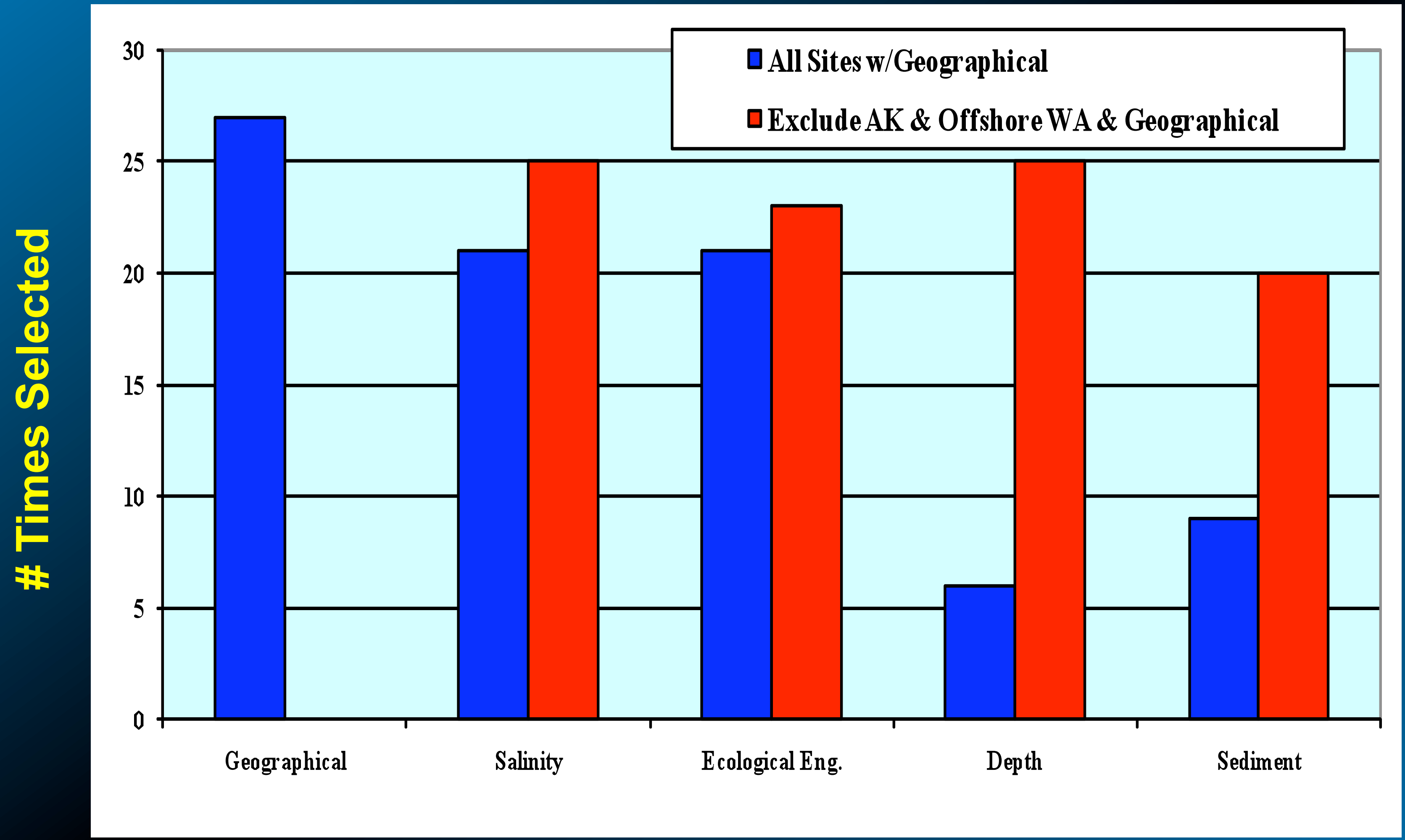


- **AUC > 0.5 model performing better than random**
- **AUC > 0.75 useful amount of discrimination**
- **AUC > 0.90 high discriminatory power**

Variables Effect Model Performance



Times Different Classes of Habitat Variables Were Included in Models



Identify variables independent of scope and scale of samples

Niche Modeling Results

- Geographic variables were the strongest single predictor at both scales.
- Alternative models without geographic variables have similar predictive power at both scales.
- Salinity classes were a viable surrogate to site-specific salinity values.
- NPMR predicts equally well for native and NIS at both scales.

Conclusions

- The integrated hierarchical system is a framework for synthesizing biological information for macro-ecological research questions addressing multiple species across regional to global scales.
- Management of ballast water discharge is critical to reduce the spread of NIS. The per capita invasion model provides a standard based on historical rates that is being reviewed by the National Academy of Sciences.
- Niche models are useful tools to predict where a nonindigenous species has the potential to survive once it has arrived.

Acknowledgements

Yer off the edge of the map, mate

Committee Members: Dr. Dawn Wright; Dr. Sylvia B. Yamada; Dr. Julia Jones; Dr. Michael Bailey; Dr. Dominique Bachelet

Funding: USGS; WRP of ANSTF; EPA AMI-GEOSS; Japanese Government

Assistance with statistics: Dr. Melanie Frazier

ACCESS programming: Rachel Nehmer; Tad Larsen

Ship Data: Smithsonian Institution – Dr. Greg Ruiz

Research assistance and continuous moral support: Dr. Henry Lee II

Moral Support: All Reusser, Boese & Davis Families


Here there be
alien monsters!
Questions
?