MARINE BIODIVERSITY RESEARCH

Prediction and Management of Australia's Marine Biodiversity

RAD Biodiversity: Modelling many species' counts together

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Outline

Voyage of Discovery

The Question

Our Approach
- RAD Description
- Modelling RADs
- Application to WA data
- Current Limitations

Conclusions

Voyage of Discovery

- Aim was to categorise biodiversity on lower shelf and upper slopes
- Study area was south west Australia
- 120 benthic samples taken
- 6 phyla used in this study
- Species counts generated by museum experts

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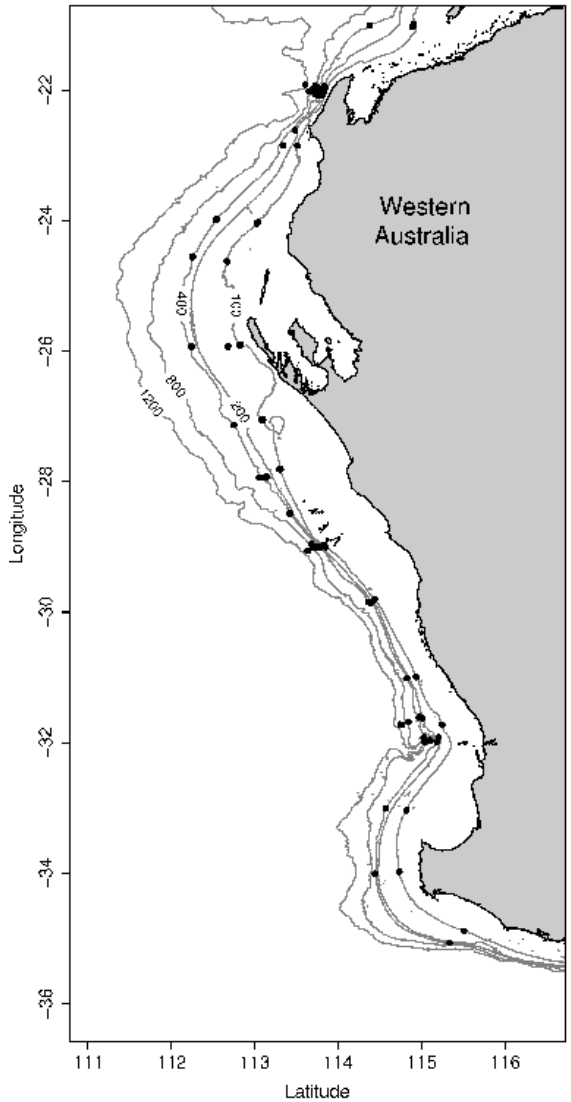
Voyage of Discovery – sample locations



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Voyage of Discovery – biology data

- **1548 species encountered**
  - 55% found at only one site
  - 89.7% found at 5 or less sites
  - Most abundant species found at only 25 sites
- **Very little information on each species!**
  - Almost excludes species based analysis

Why Look at These Data?

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- **To investigate biodiversity – of course!**

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Why look at these data?

- **To investigate biodiversity – of course!**
  - Very vague
  - Many possible definitions of biodiversity
  - Many aspects to biodiversity

Our Question

How does biodiversity change with the environment?

- **Do not want biodiversity based on species**
- **Do want biodiversity based on species observations**
- **Biodiversity indices are an option**
  - Do not seem to vary with covariates appropriately

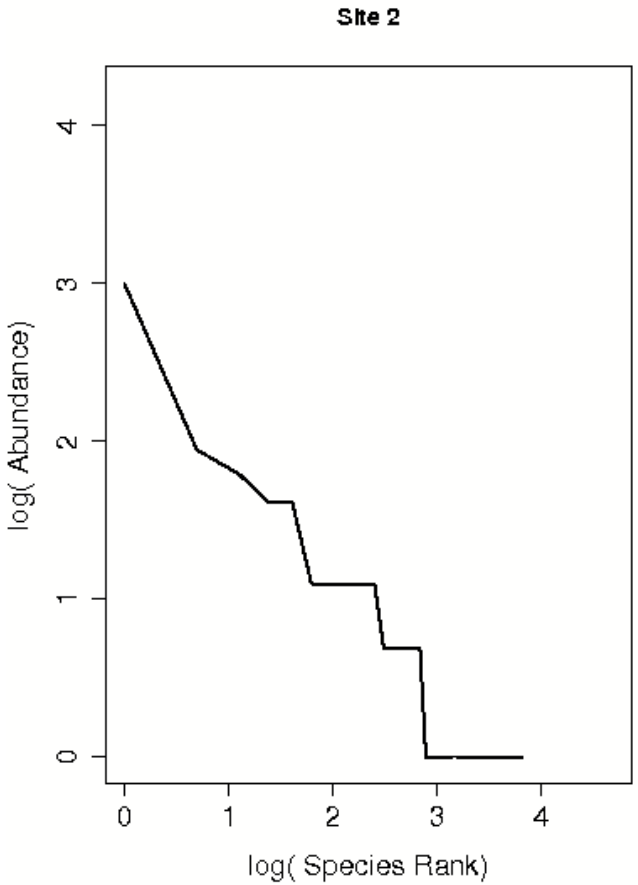
Our Approach

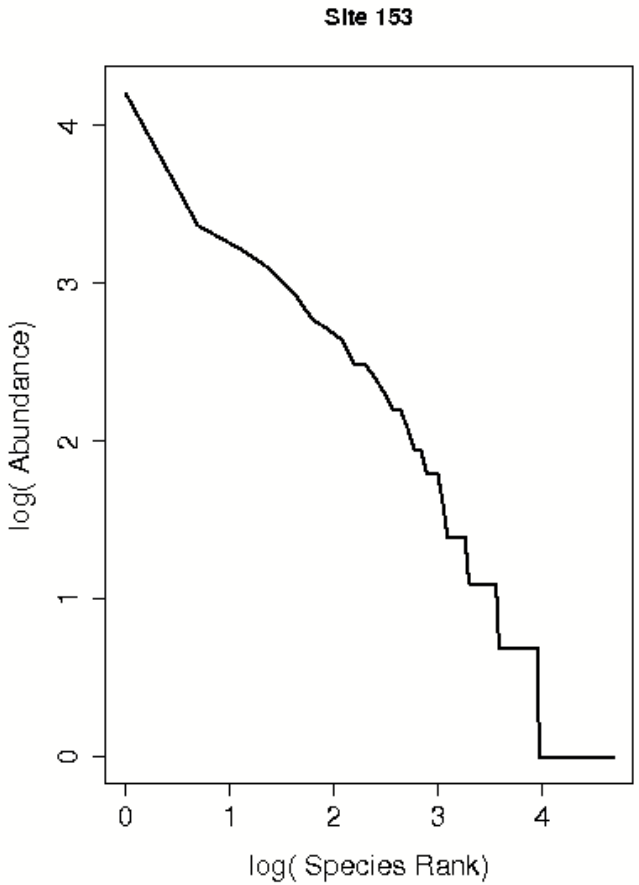
- **Model rank abundance distributions (RADs) of observed species counts**
  - Multivariate outcomes
- **Not species based**
- **Species counts preserved**
- **Allow RADs to change with the environment**

What is a RAD?

- **Rank Abundance Distribution**
- **Listing of the observed species counts from most abundant to least abundant**
- **Species labels are then discarded**
- **Not dependent on species identity – can compare different types of communities**
- **Multivariate observation**

RAD examples





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Information in a RAD

- **RADs capture information on:**
  - The number of individuals (N)
  - The number of species (S), and
  - The relative abundance of those species ($\boldsymbol{n}$)
- **These are three attributes of a community that biodiversity if often defined by.**

Modelling goals

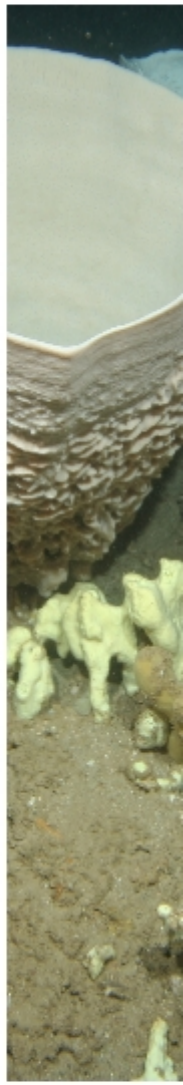
- **Model multivariate RAD observation as a function of environmental gradients**
- **Predict RADs and/or relevant measures of biodiversity with sensible measures of uncertainty**

The modelling approach – Broadly

- **The RAD is completely defined by $(S, \boldsymbol{n})$**
  - Equivalent to $(S, N, \boldsymbol{n})$ with sum constraint
  - Still a multivariate response
- **Model these aspects through**

$$\Pr(S, N, \boldsymbol{n}) = \Pr(N) \Pr(S|N) \Pr(\boldsymbol{n}|N, S)$$

- **Modelling task now decomposed into 3 separate tasks**
  - A model for abundance (univariate)
  - A model for conditional richness (univariate), and
  - A model for relative abundance (multivariate).



A Model for Total Abundance

- **Generalized linear models and similar**
- **Select covariates**
- **Diagnostics using randomised quantile residuals, *sans* randomisation**

A Model for Conditional Species Richness

- **Species richness is commonly analysed *marginally* to abundance via GLM etc**
- ***Conditionally* the statistical model should reflect the identity $S \leq N$**
- **We use a truncated Poisson or Negative Binomial model with log-likelihood**

$$\ell_S\left(\boldsymbol{\tau}_S, \theta_S; \boldsymbol{S} | \boldsymbol{N}\right) = \sum_{i=1}^{T} \left[\log\left\{\Pr\left(Y = S_i\right)\right\} - \log\left\{\Pr\left(Y \leq N_i\right)\right\}\right]$$

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A Model for Conditional Species Richness

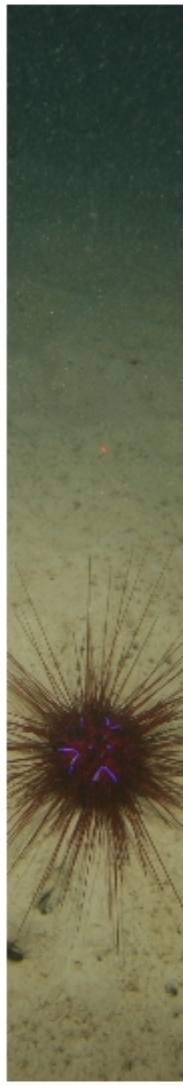
- **Estimation via maximisation of log-likelihood using numerical methods**
- **Model selection**
- **Diagnostics using quantile residuals**
- **Expectations available using brute-force**
- ***Marginal* species richness predictions via parametric bootstrap ('integrating' out total abundance)**

A Model for Conditional Relative Abundance

- **Condition N individuals into S categories (ranks)**
- **Could use multinomial framework but need to specify mean probabilities**
  - Decreasing function (due to ranking)
  - Many (many!) possible from theoretical ecology
  - We use a relation of the broken stick (niche pre-emption) as this empirically agreed with data

$$p_{ij} = \frac{1}{K} \exp\left(-\beta_i \log j\right)$$

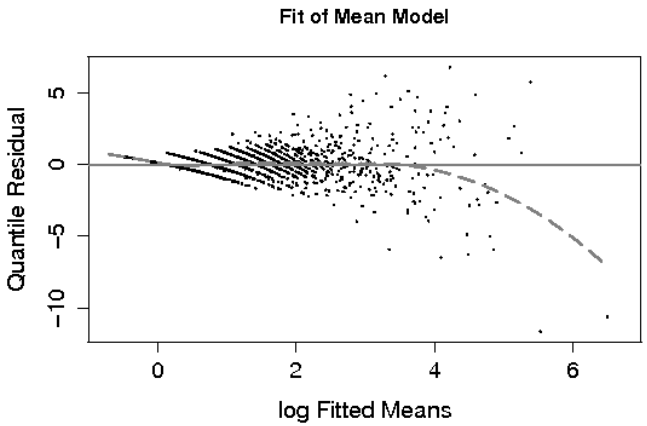
- **Defines all S_i probabilities with single parameter β_i**
- **Model β_i as a linear combination of environmental gradients**

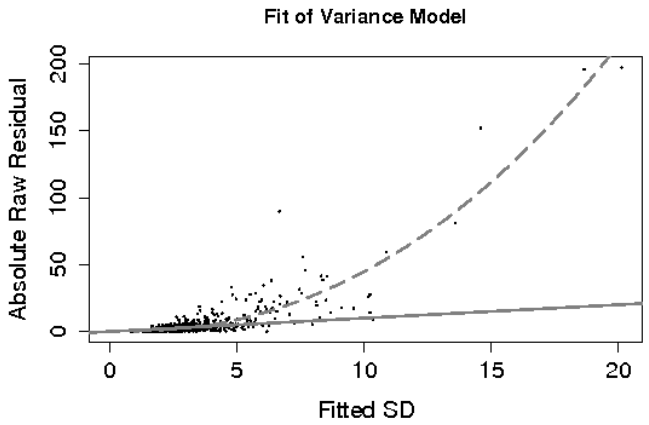


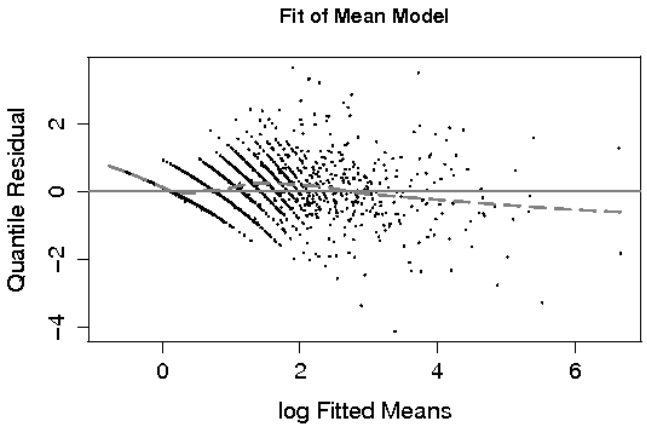
A Model for Conditional Relative Abundance

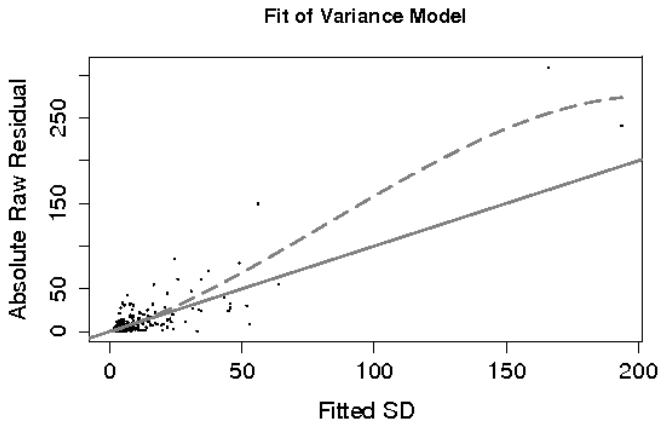
- **Model selection**
- **Quantile residuals used to inspect mean model**
- **Raw residuals used to inspect variance model (not standardised)**
- **Residuals not great for multinomial model (next slide)**
- ***Marginal* predictions available via parametric bootstrap**

Multinomial Model Residuals









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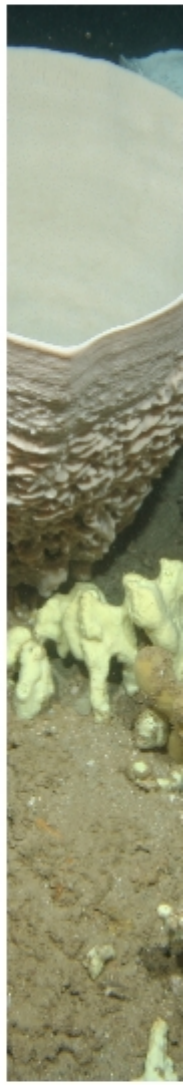
Extensions of Multinomial Model

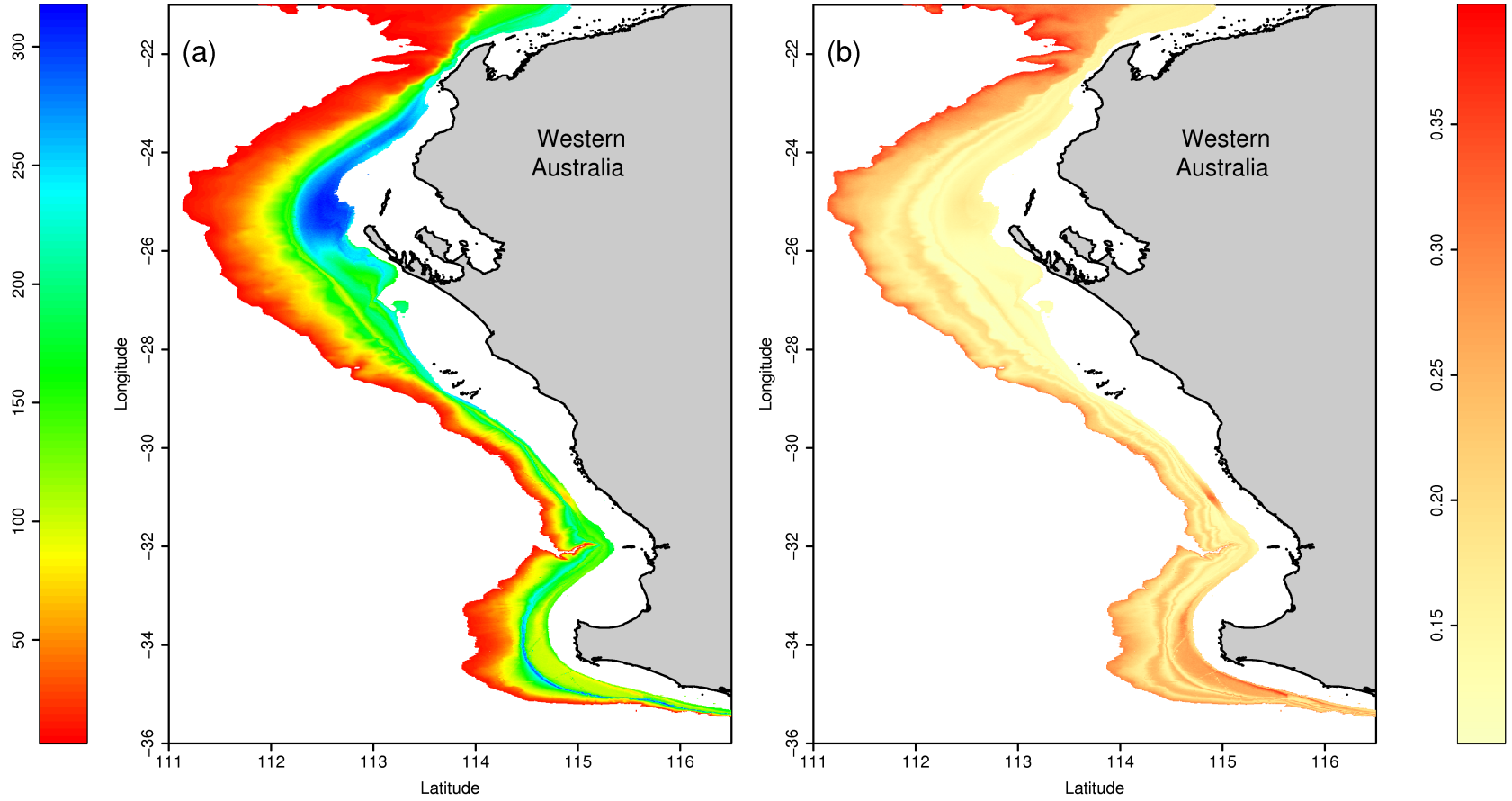
- **Dirichlet-multinomial (DM) provides constant over-dispersion**
  - Provides modest benefit to model fit
  - Not worth the effort
- **Modified DM (M-DM) obtained by modifying DM**
  - Alter the beta-binomial marginals of the DM so that over-dispersion is a decreasing function of rank
  - Some optimisation heart-ache but is now conquered
- **Residuals look much better (see previous slide)**

Biodiversity Measures from RAD Model

- **Many (all?) ecologists would consider the following base information:**
  - the amount of life
  - the variety of life (richness)
  - the manner in which communities are structures (e.g. evenness)
- **These are available through this model as**
  - Total abundance
  - *Marginal* Species richness
  - Derivative of probability function for *marginal* evenness
  - All other indices used can be derived from the information provided from the predicted RAD



Voyage of Discovery Data – abundance



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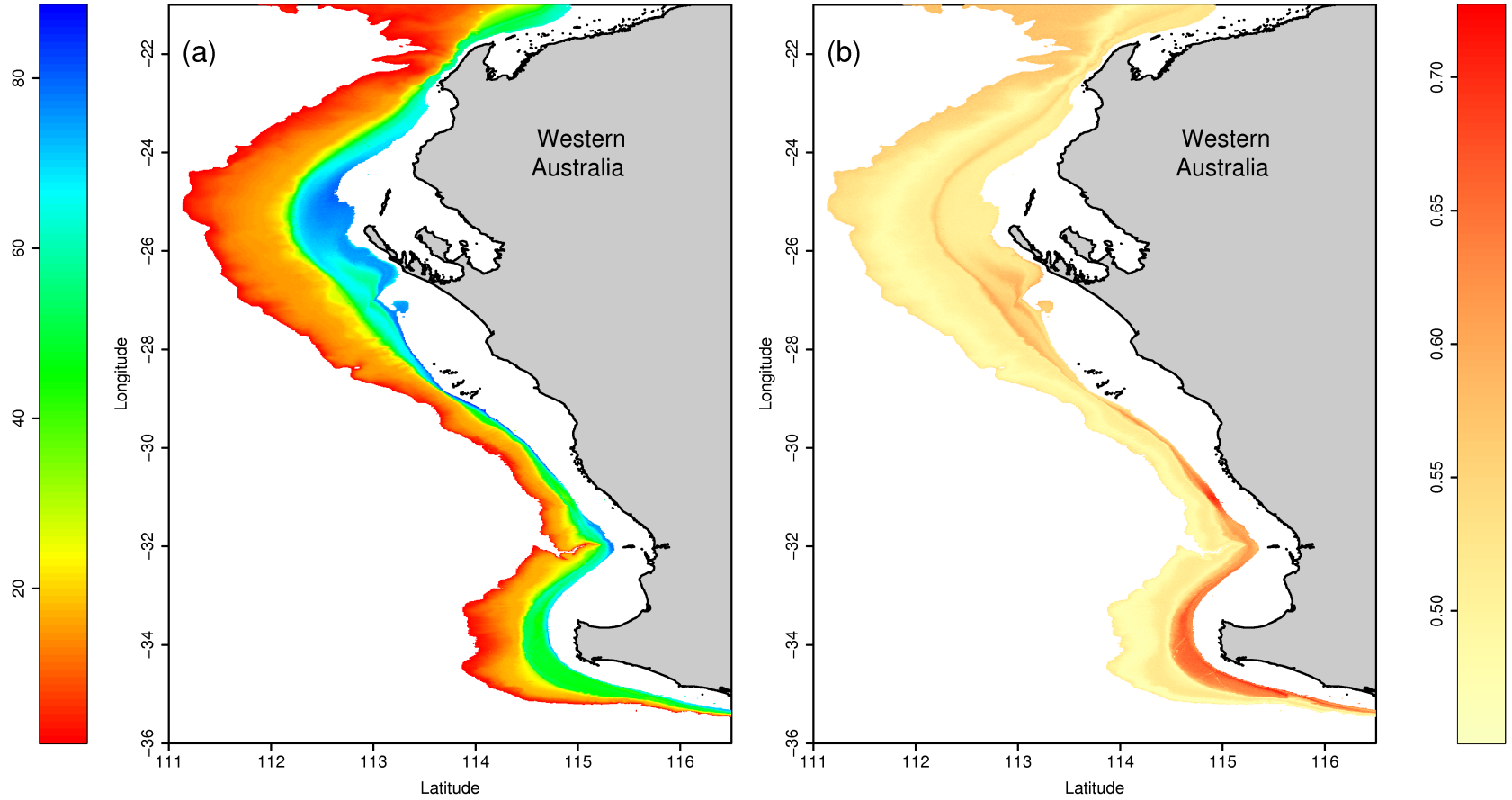
Voyage of Discovery Data – richness



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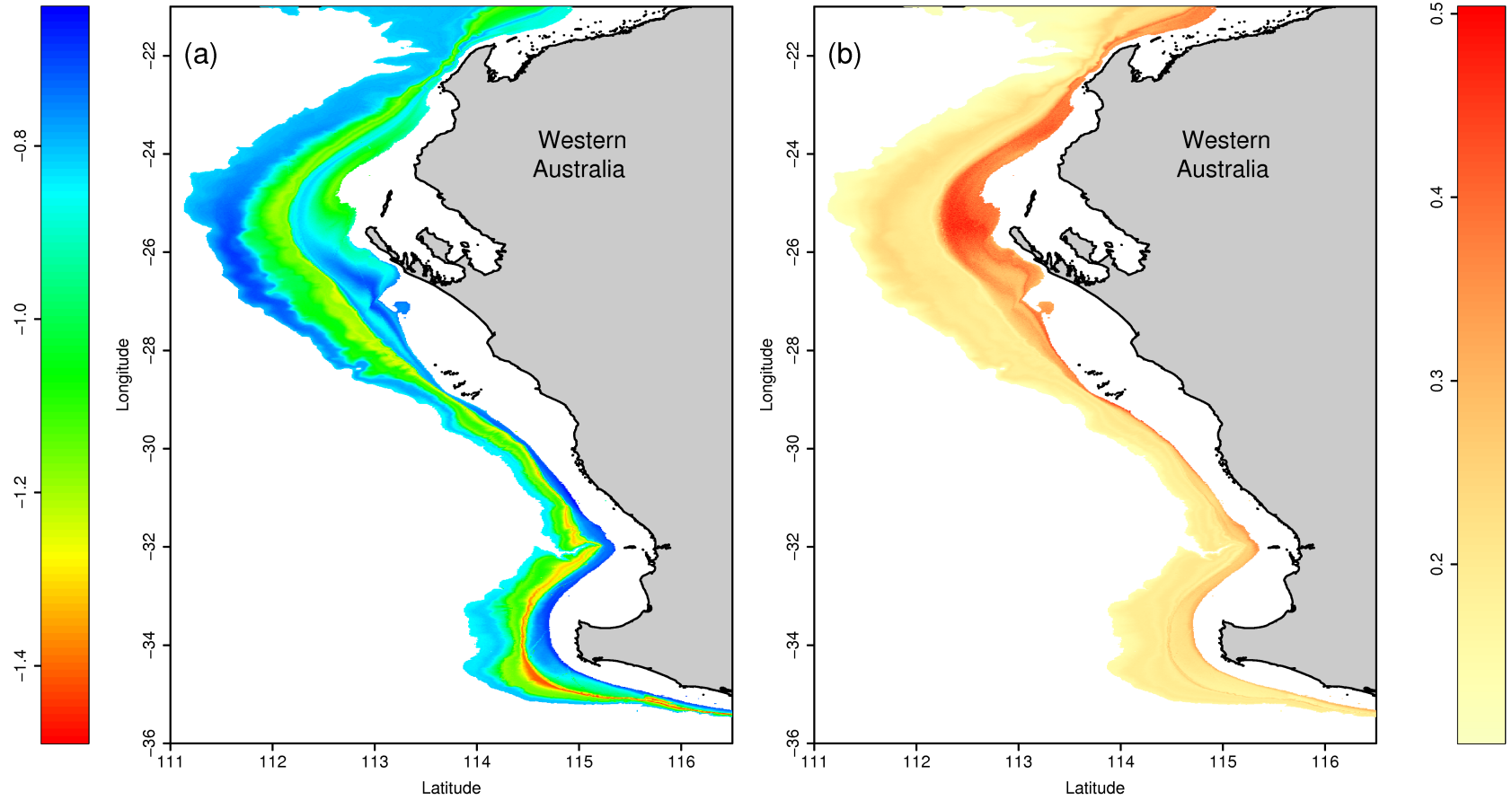
Voyage of Discovery Data – evenness



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Limitations and Future Needs

- **Biomass data**
- **Model for relative abundance is not quite right**
  - Likelihood doesn't guarantee decreasing observations
  - Zeros
  - Still useful
- **More theoretical work on the modified Dirichlet-multinomial**
- **Computing speed**
  - Estimation (automatic differentiation?)
  - Bootstrap predictions

Conclusions

- **We feel the RAD approach is a useful first step**
  - Models ecologically meaningful quantity
  - Indices predicted as simple summaries of models
- **Still require polishing and generalisation**

Conclusions (cont.)

- **Plenty to do**
- **Plenty to consider**
- **A lot of options**
- **But very few simple solutions!**
- **Lots of interesting issues (statistically and ecologically)**

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