Comisión Interamericana del Atún Tropical
Inter-American Tropical Tuna Commission

Introduction to the spatiotemporal model: VAST

Haikun Xu

Workshop on Longline Data, La Jolla, CA, Feb. 11-15, 2019

Background of VAST

- R package developed and maintained by Jim Thorson (AFSC)
- How to install: install_github("james-thorson/VAST")
- Built based upon a previous R package: SpatialDeltaGLMM
- Spatial delta-generalized linear mixed model for multiple categories (species, size, or age classes): separately models encounter probability and positive catch rate
- Well documented with user manual and examples provided (https://github.com/James-Thorson/VAST)
- Very flexible model framework with detailed guidance regarding major decisions provided (https://doi.org/10.1016/j.fishres.2018.10.013)
- Has been used to standardize the catch rate of the dolphin-associated yellowfin fishery in the EPO (https://doi.org/10.1016/j.fishres.2019.01.013)

CIAT IATTC

Model Structure (single species)

VAST separately models encounter probability (p) and positive catch rate (λ) for each catch rate observation i:

$$\text{logit}(p_i) = \beta_1(t_i) + L_{\omega 1}\omega_1(s_i) + L_{\varepsilon 1}\varepsilon_1(s_i, t_i) + L_{\delta 1}\delta_1(v_i) + \sum_{k=1}^{n_k} \lambda_1(k) Q(i,k) + \sum_{p=1}^{n_p} \gamma_1(p) X(s_i, t_i, p)$$

$$\log(\lambda_i) = \beta_2(t_i) + L_{\omega 2}\omega_2(s_i) + L_{\varepsilon 2}\varepsilon_2(s_i, t_i) + L_{\delta 2}\delta_2(v_i) + \sum_{k=1}^{n_k} \lambda_2(k) Q(i,k) + \sum_{p=1}^{n_p} \gamma_2(p) X(s_i, t_i, p)$$

$\beta(t_i)$: intercept in year t_i

$\omega(s_i)$: spatial variation at location s_i; L_ω: scaling factor (sd)

$\varepsilon(s_i, t_i)$: spatiotemporal variation at location s_i in year t_i; L_ε: scaling factor (sd)

$\delta(v_i)$: vessel/targeting effects on catchability; L_δ: scaling factor (sd)

$Q(i,k)$: catchability covariate(s); $\lambda(k)$: associated catchability parameter(s)

$X(s_i, t_i, p)$: habitat covariate(s); $\gamma(p)$: associated habitat parameter(s)

Correlated spatial and spatiotemporal variations

Correlated spatial and spatiotemporal variations:

$\omega_1 \sim \mathrm{MVN}(\mathbf{0}, \mathbf{R}_1)$

$\omega_2 \sim \mathrm{MVN}(\mathbf{0}, \mathbf{R}_2)$

$\varepsilon_1(,t) \sim \mathrm{MVN}(\mathbf{0}, \mathbf{R}_1)$

$\varepsilon_2(,t) \sim \mathrm{MVN}(\mathbf{0}, \mathbf{R}_2)$

where

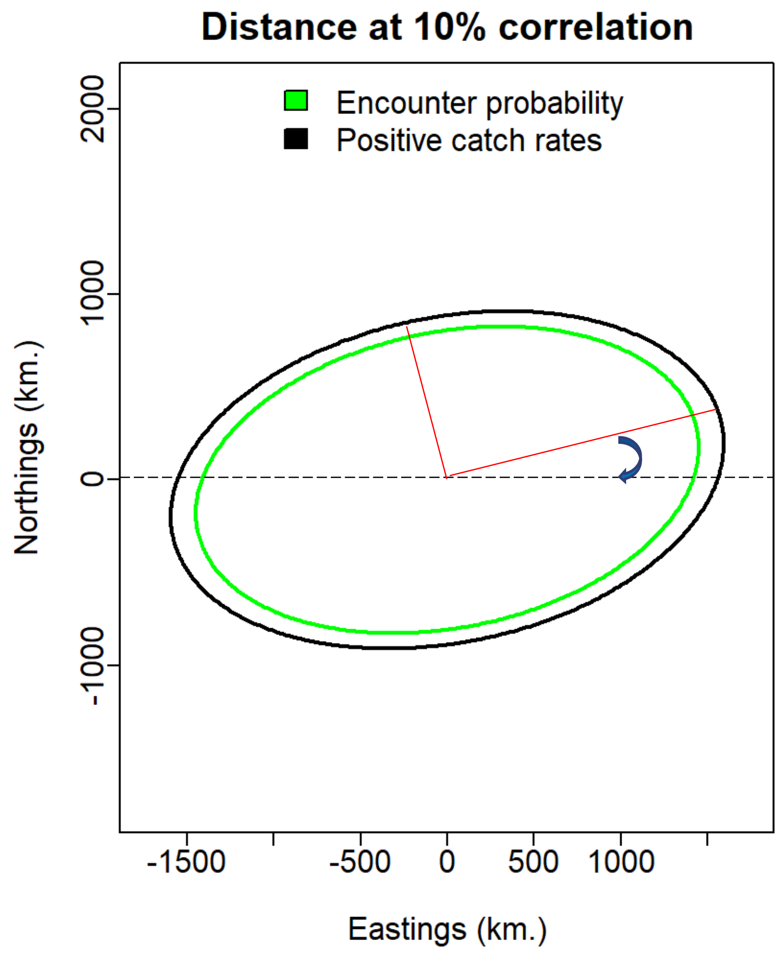
$$\mathrm{R}_1(s,s') = \frac{1}{2^{\nu-1}\Gamma(n)} \times (\kappa_1|\mathbf{H}(s-s')|)^{\nu} \times K_{\nu}(\kappa_1|\mathbf{H}(s-s')|)$$

$$\mathrm{R}_2(s,s') = \frac{1}{2^{\nu-1}\Gamma(n)} \times (\kappa_2|\mathbf{H}(s-s')|)^{\nu} \times K_{\nu}(\kappa_2|\mathbf{H}(s-s')|)$$

decorrelation distance

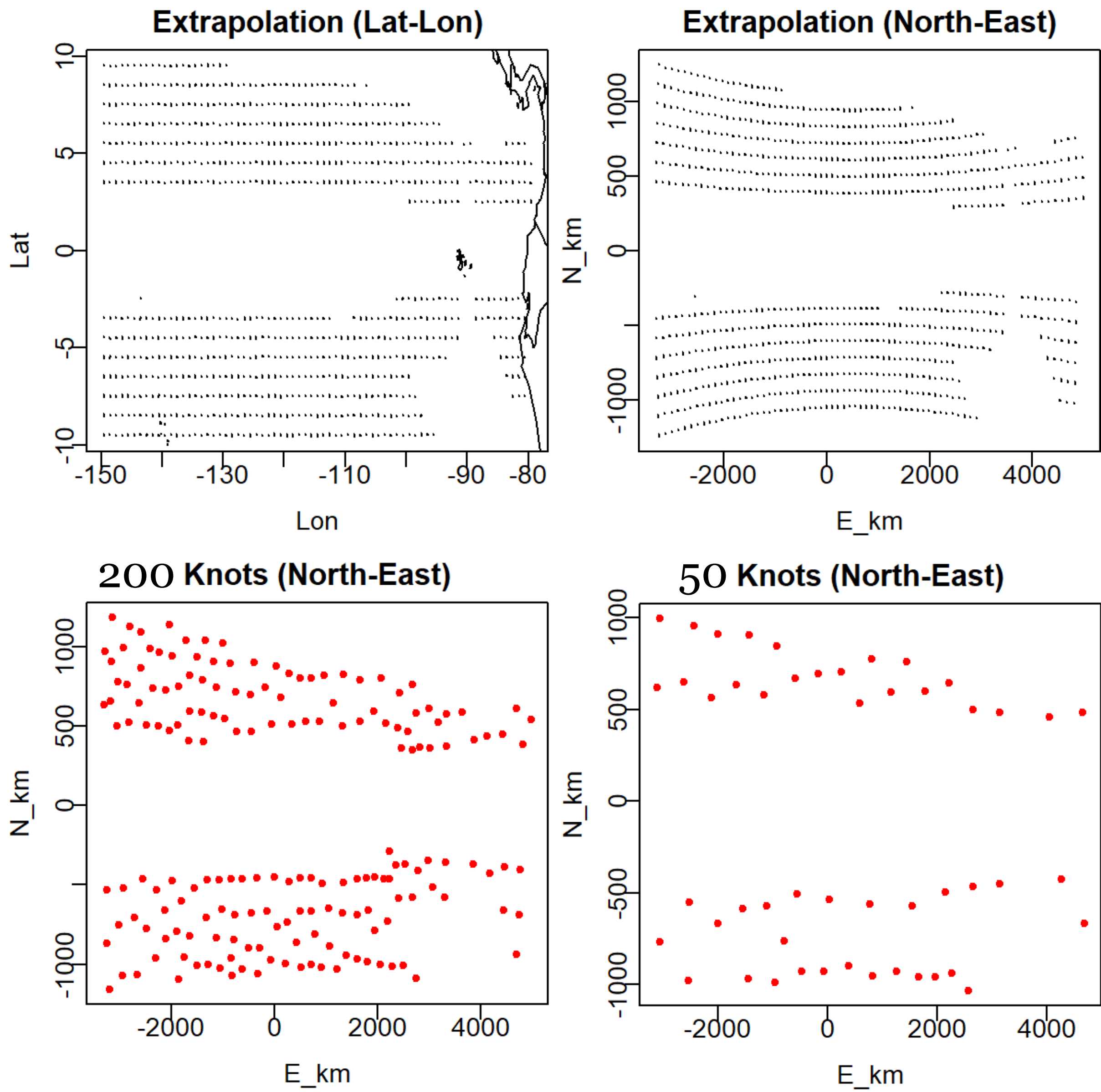
geometric anisotropy

Matérn smoothness



Model assumptions

- To increase computation efficiency, VAST groups all sample locations into a user-specified number of knots
- Assumption: the spatial/spatiotemporal variation associated with a knot is constant within every time step
- Trad-off: high estimation accuracy (a large number of knots) vs. high computation efficiency (a small number of knots)



Model Structure

The probability of catch data c for sample i:

$$\Pr(c_i = c) = \begin{cases} 1 - p_i & \text{if c} = 0 \\ p_i \times \text{Lognormal}(c_i | \log(\lambda_i), \sigma_m^2) & \text{if c} > 0 \end{cases}$$

Standardized index is computed using an area-weighted approach:

$$\boldsymbol{I(t) = \sum_{k=1}^{n_k} (area(k) \times density(k,t))}$$

where $\boldsymbol{density(k,t)} = logit^{-1}\left(\beta_1(t_k) + L_{\omega 1}\omega_1(s_k) + L_{\varepsilon 1}\varepsilon_1(s_k, t_k) + \sum_{p=1}^{n_p} \gamma_1(p) X(s_i, t_i, p)\right) \times \exp\left(\beta_2(t_k) + L_{\omega 2}\omega_2(s_k) + L_{\varepsilon 2}\varepsilon_2(s_k, t_k) + \sum_{p=1}^{n_p} \gamma_2(p) X(s_i, t_i, p)\right)$

*** Vessel/targeting effects (δ) and catchability covariates (Q) are both excluded (set to be 0) in the computation of local density: **index is proportional to abundance**

Flexible model framework

- Turn on (1) or turn off (0) spatial and spatiotemporal components for encounter probability and positive catch rate

  FieldConfig = c("Omega1"=1, "Epsilon1"=1, "Omega2"=1, "Epsilon2"=1)
- Specify the temporal structure for each component (fixed effect, independent, random walk, or autoregressive)

  RhoConfig = c("Beta1"=0, "Beta2"=0, "Epsilon1"=0, "Epsilon2"=0)
- With (1) and without (0) vessel/targeting effects for encounter probability and positive catch rate

  OverdispersionConfig = c(0,0)
- Other link functions for encounter probability and positive catch rate are available

  ObsModel = c(1,1)

Case study: dolphin-associated EPO yellowfin fishery

Fisheries Research 213 (2019) 121–131

Contents lists available at ScienceDirect

Fisheries Research

journal homepage: www.elsevier.com/locate/fishres

Spatiotemporal dynamics of the dolphin-associated purse-seine fishery for yellowfin tuna (*Thunnus albacares*) in the eastern Pacific Ocean

Haikun Xu*, Cleridy E. Lennert-Cody, Mark N. Maunder, Carolina V. Minte-Vera

Inter-American Tropical Tuna Commission, 8901 La Jolla Shores Drive, La Jolla, CA, 92037, USA

A R T I C L E I N F O

Handled by A.E. Punt

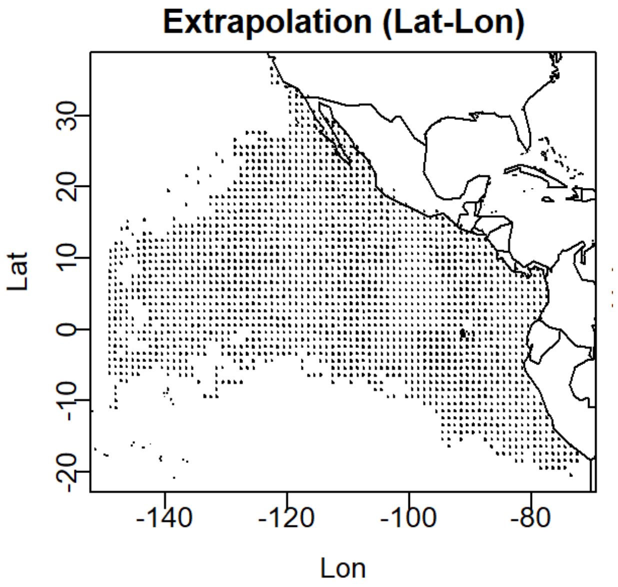
Keywords:

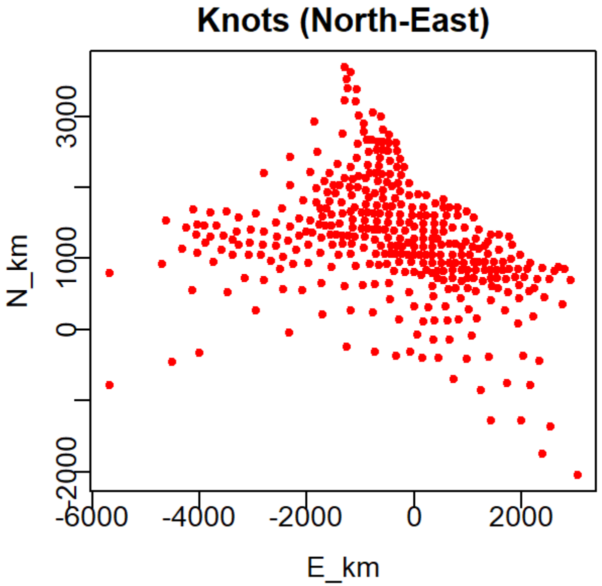
A B S T R A C T

Spatiotemporal models of catch rate data are used in fisheries science to understand the spatiotemporal dynamics of a fishery and, more importantly, to produce a standardized index of relative abundance for stock assessment models. Here, we apply a spatiotemporal delta-generalized linear mixed model to catch rate data

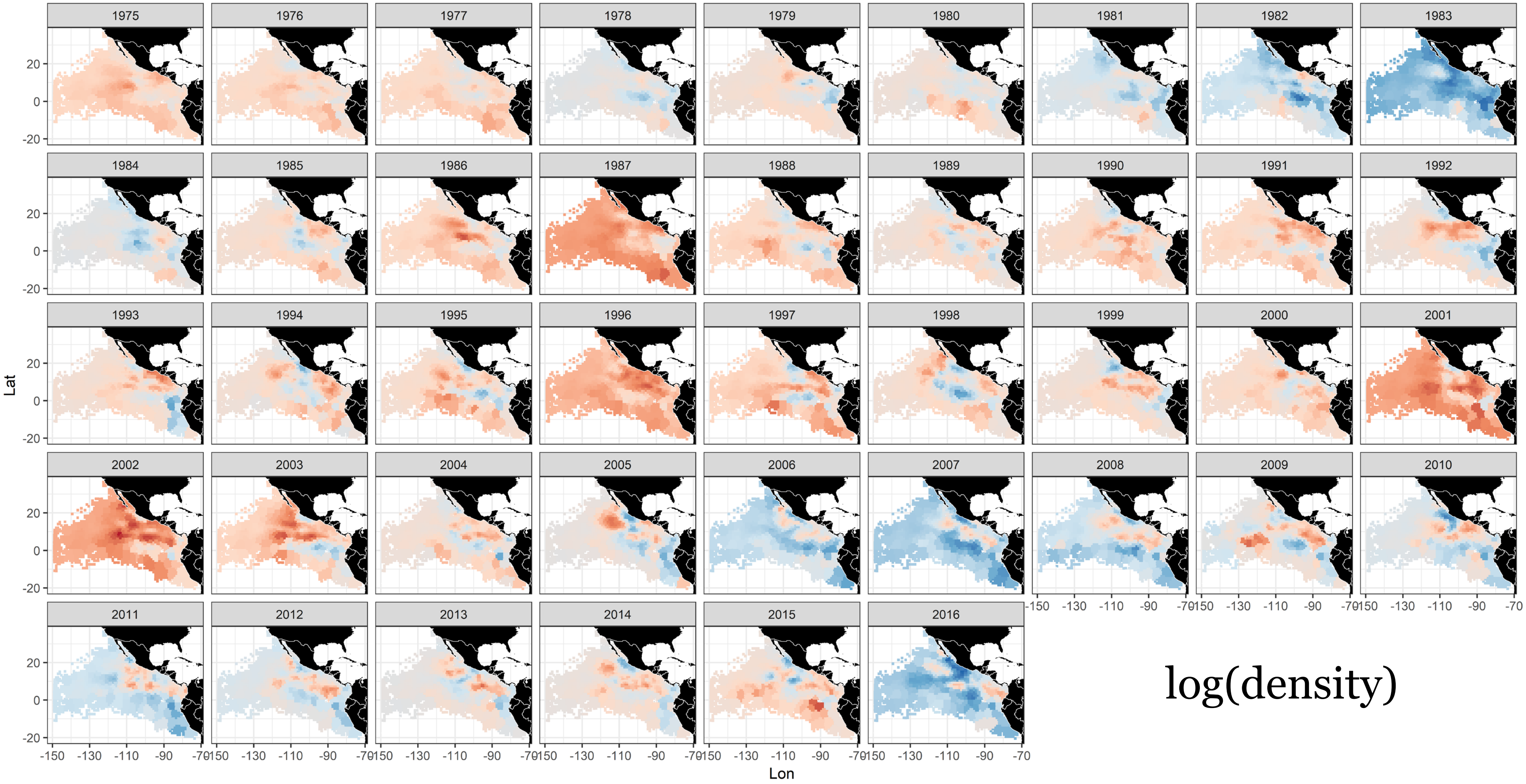
CIAT IATTC

Step 1. Define the spatial domain and “knots”





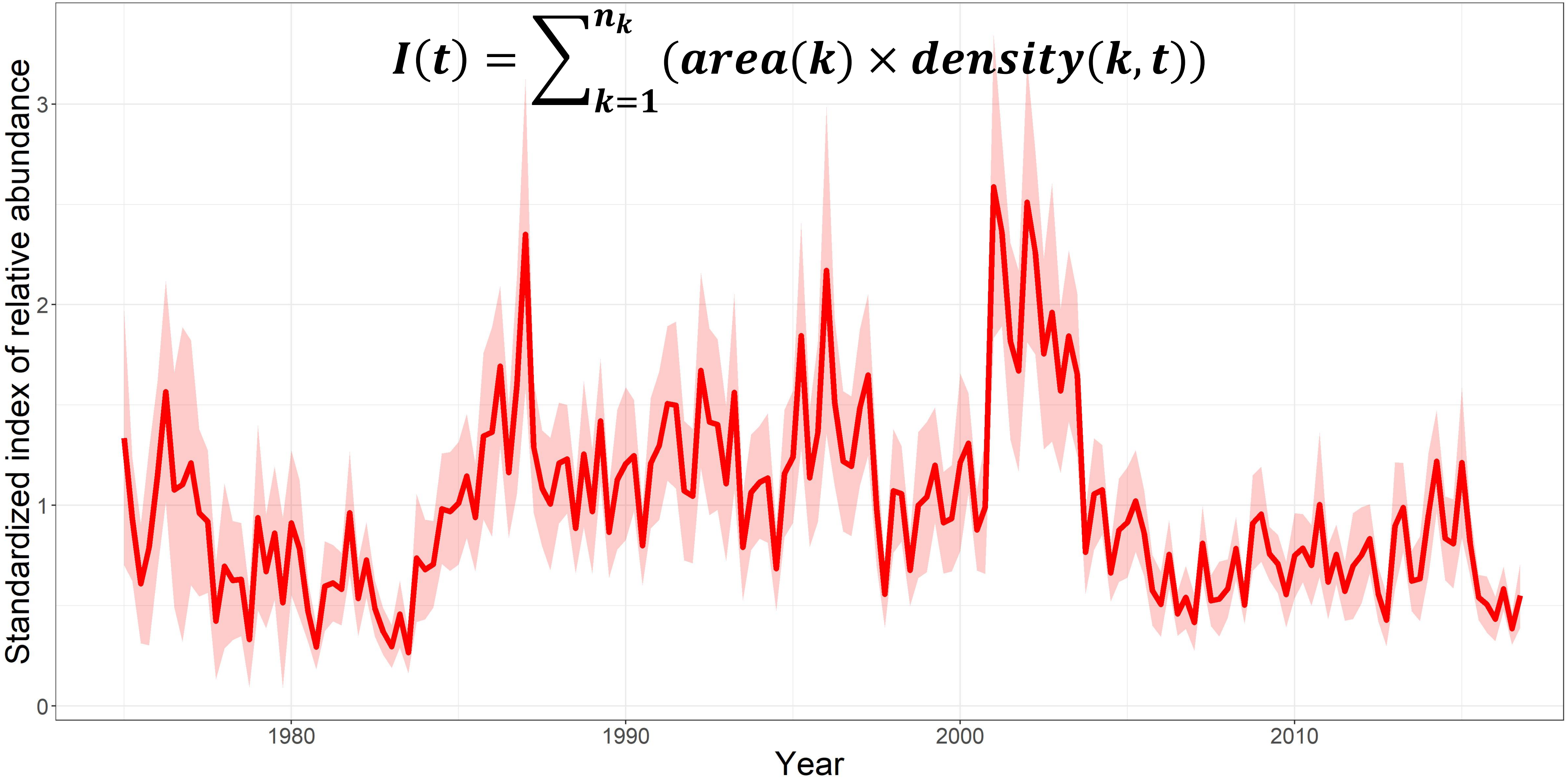
Step 2. Predict density for every year and knot



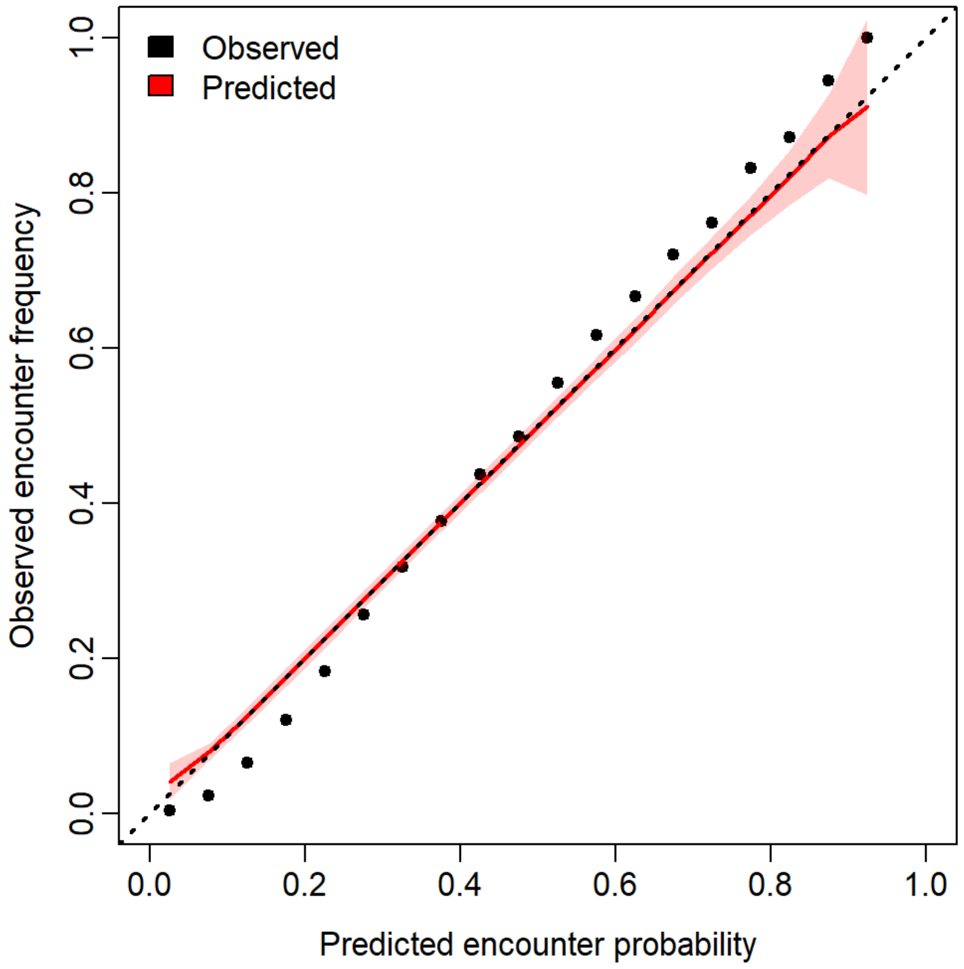
log(density)

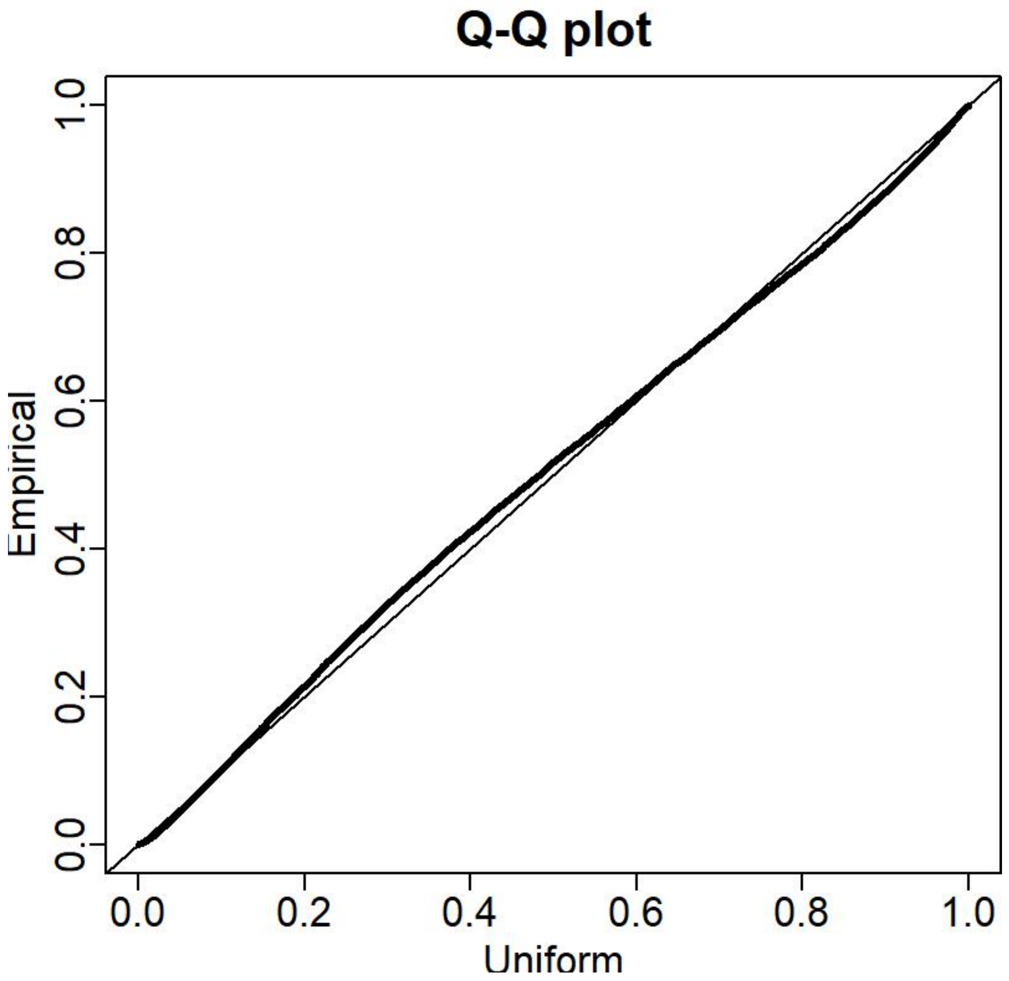
Step 3. Compute index of abundance and CV

$$I(t) = \sum_{k=1}^{n_k} (area(k) \times density(k,t))$$

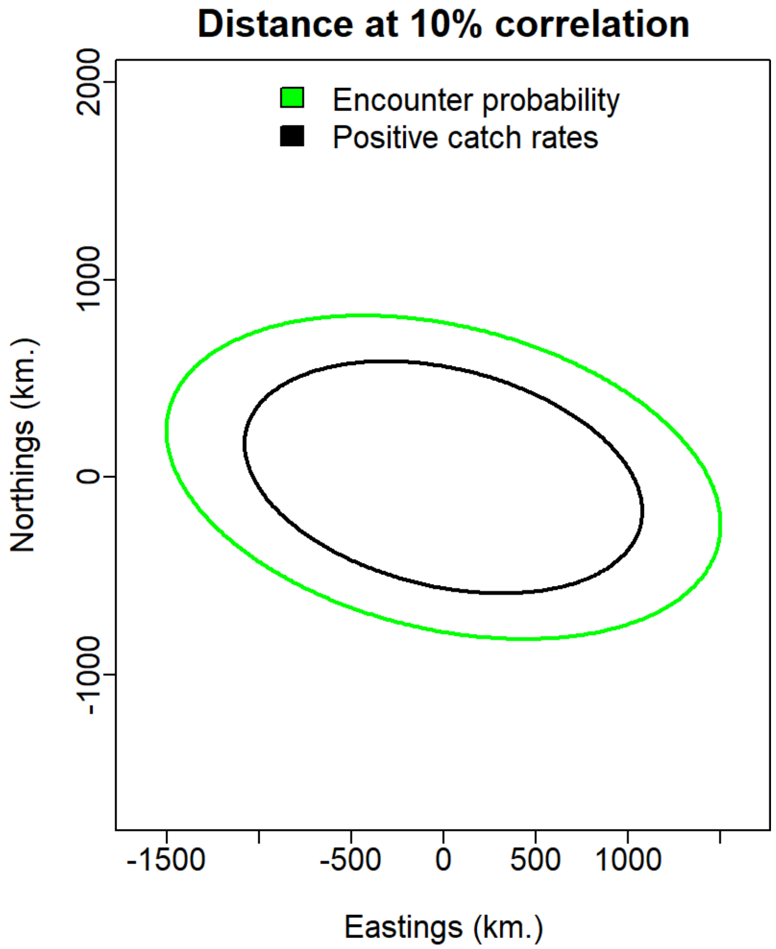


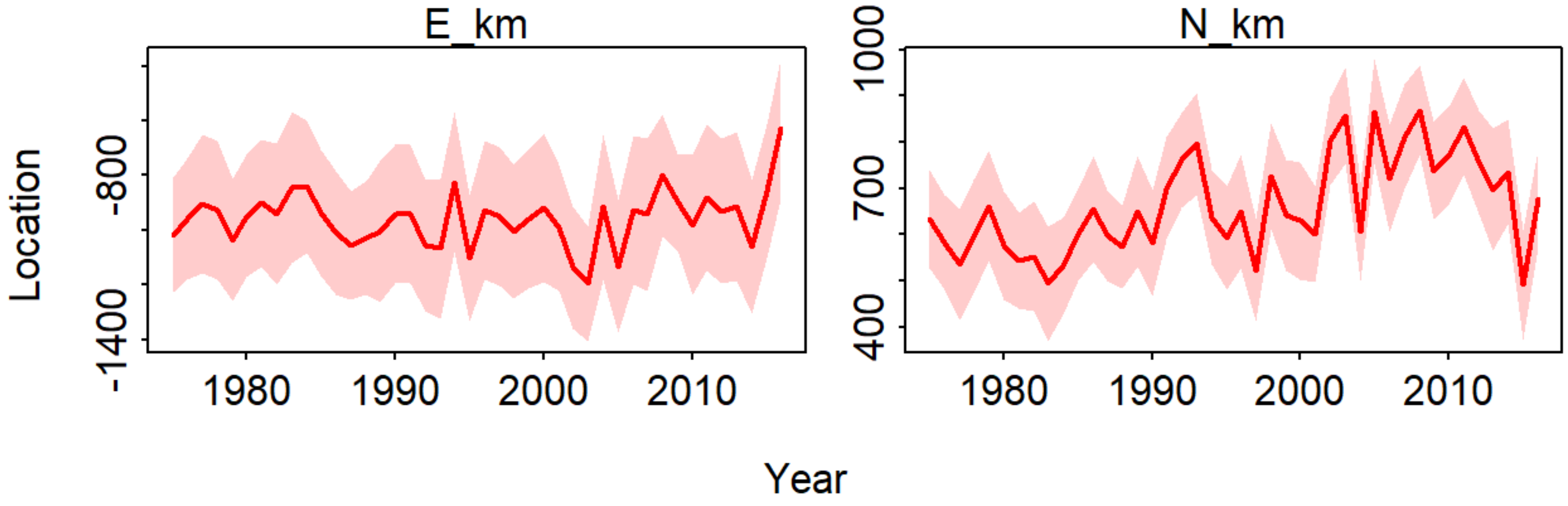
Step 4. Diagnostics

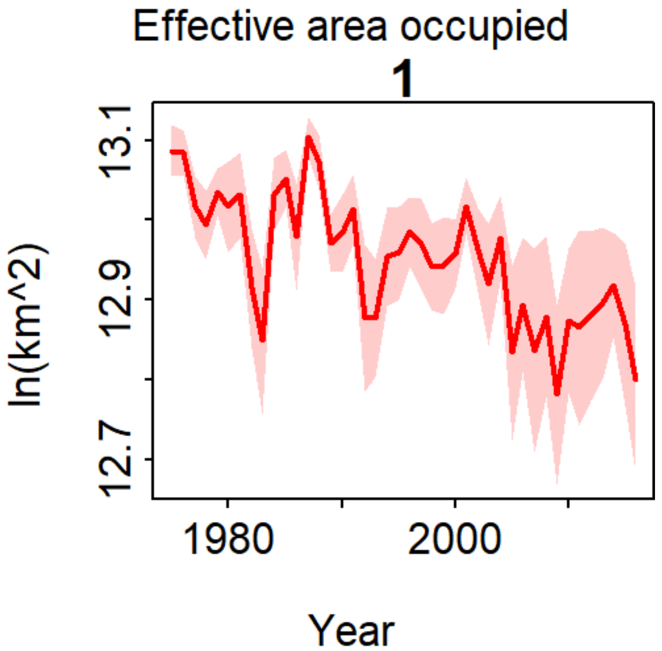




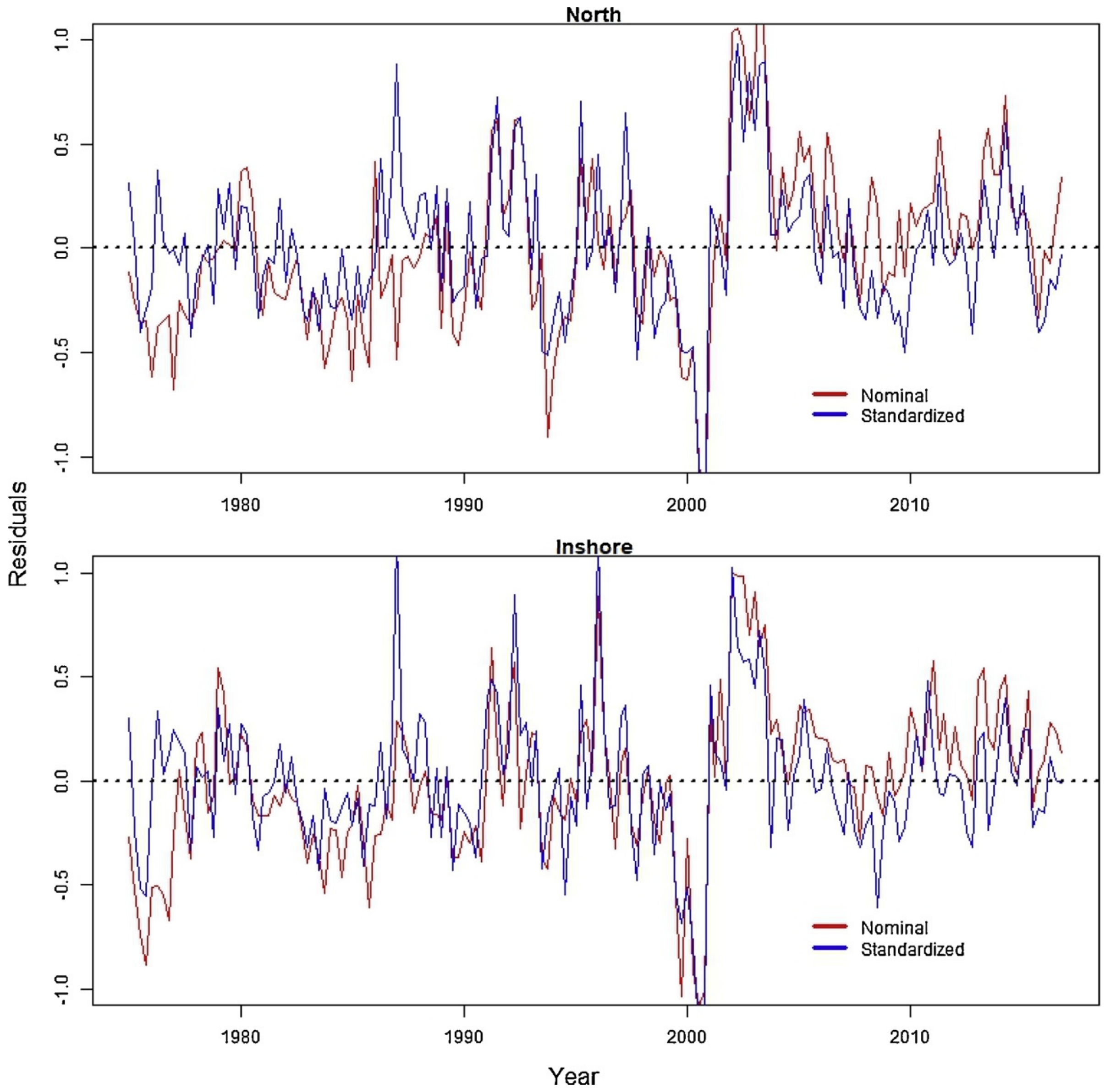
Step 5. Derived Quantities from VAST





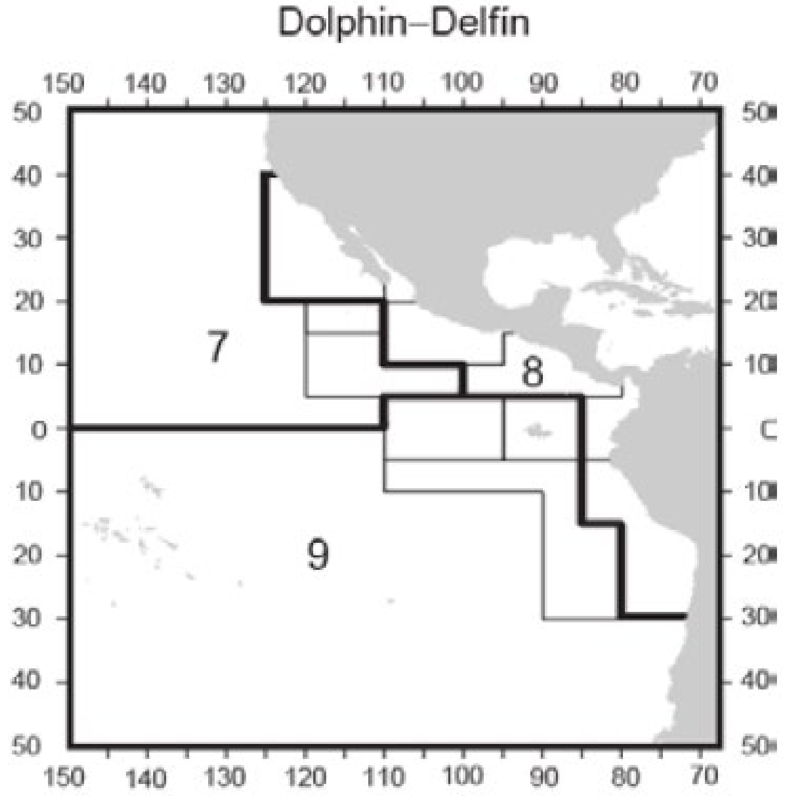


Step 6. Use the standardized index in the assessment



Using the standardized index can improve the stock assessment:

- reduced residual pattern
- 79.27 units increase in log-likelihood



Thank you!