Explicit formulas for non-random sample designs in camera trap density estimation

This document derives multiple camera trap density estimators that allow for non-random sample designs in heterogeneous landscapes. The role of a camera trap density estimator is to estimate the density, λ. Total abundances are then calculated as a function of density, sampling frame (A), camera viewshed area (V), and sampling period (T),

$$N = \frac{\lambda A}{VT}.$$

We estimate densities using the equilibrium solution of the EDE which assumes that animal densities are proportional to animal staying time,

$$\frac{d_q}{\sum d_q} = \frac{\phi_q}{\sum \phi_q},$$

where d_q is a density at location q and ϕ_q is the staying time at location q.

We generalize the EDE by defining densities and staying time by habitat type rather than location, d_h and ϕ_h for habitat type h. Then, we collect habitat-type specific staying times across the landscape with telemetry data. For example, with a GPS data set, we find that animals on average spend 50% of time in forested area, 35% on grassland, and 15% on road. With this information, we now know, for example, that road densities should be about 15% of total densities. We use this to calculate total abundances with camera traps as follows.

TDST Model The TDST model calculates total density by estimating location-specific densities (d_q) and staying time (ϕ_q) with camera trap data,

$$\sum d_q = \frac{\sum \phi_q}{\phi_q} d_q.$$

Total abundances can then calculated with the formula above, $N = \frac{A \sum d_q}{VT}$. Note that the TDST model requires covariate information to inform location-specific staying time and density estimates.

PR model The PR model estimates densities, λ, using only count data. Total abundances are then calculated using the formula above. The PR model may be used with and without covariate information, although random sampled designs are required for non-biased estimates when covariates are not used.

Habitat PR Model We combine the theory behind the TDST model with density estimates obtained with the non-covariate PR model to explicitly calculate habitat-specific abundances using relative staying time estimates obtained from telemetry data. Specifically, in order to calculate habitat-specific abundances, we must first scale the sampling period by the proportion of time that animals spend in the habitat type, $T_h = T\frac{\phi_h}{\sum \phi_h}$, and the proportion of cameras placed in the habitat type, $\frac{C_h}{\sum C_h}$. Then, by using the PR model to estimate densities for each habitat type (λ_h) and restricting the sampling to the area that contains the habitat type, A_h, we calculate habitat-specific abundances using the formula

$$N_h = \frac{\lambda_h A_h}{VT_h} \frac{C_h}{\sum C_h}.$$

The sum over all habitat-specific abundances results in total abundance, $N = \sum N_h$.

The habitat PR model can also be explicitly defined for single-habitat sample designs (i.e., cameras placed exclusively on one habitat type). Specifically, the proportion of cameras placed in the habitat of choice is now 1 while all other habits have 0 cameras, setting all habitat-specific abundances without cameras to zero. Then, total abundance given cameras placed only in habitat h is

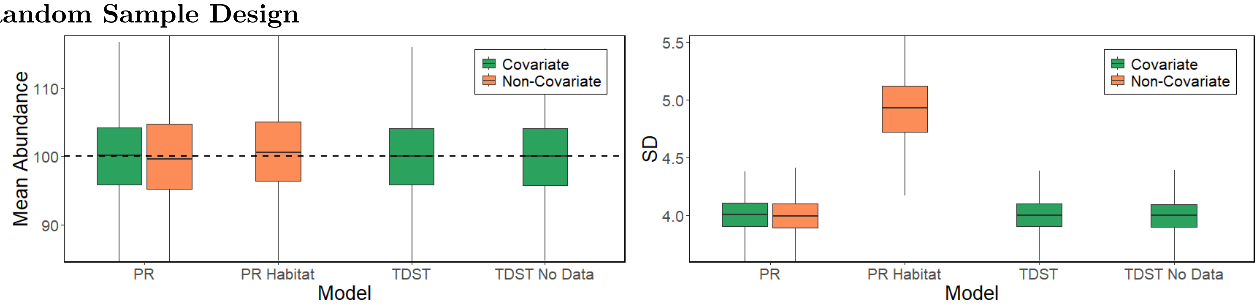
$$N = \frac{\lambda_h A_h}{V T_h},$$

where habitat-specific density, λ_h, is calculated as above.

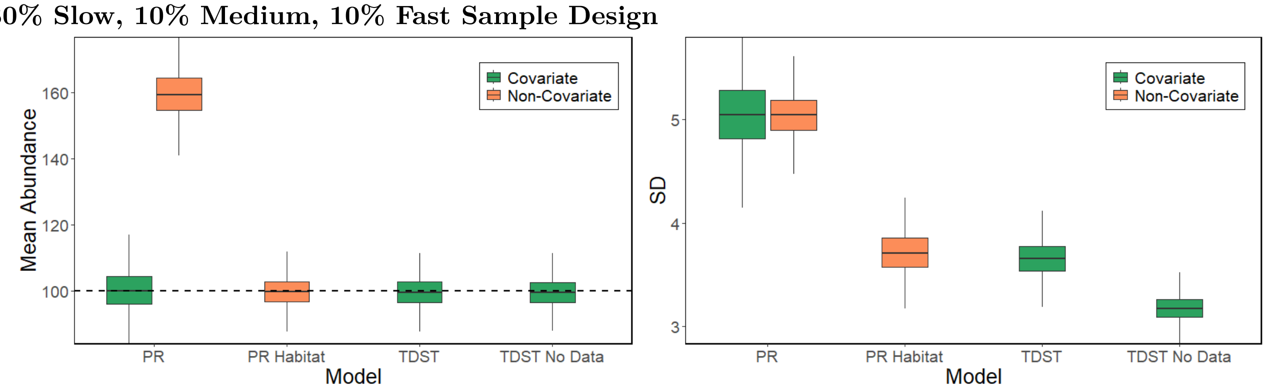
Results To test these models, we ran simulations where animals move with three different speeds depending on habitat type (slow, medium, fast), and place cameras under three sample designs; randomly, non-randomly (80% in slow habitat, 10% each in medium and fast habitats), and single-habitat (cameras placed in only one habitat type). We then estimated total abundances with the TDST model without priors, TDST model with stay-time priors defined by telemetry data but omitting camera stay time data (TDST no-data), PR model with and without covariates, and the habitat PR model.

The following boxplots represent summaries of model runs over 1000 iterations. The random sample design is a good indicator of how well each model is working, and the median results show that all models are within 1% of the true abundance (N = 100). In general, the habitat PR model has slightly higher SD than its counterpart, the TDST No Data model while maintaining accuracy across the different sample designs. Note that accuracy for the TDST No Data model and the PR Habitat model rely on the accuracy of the telemetry data (which is near-perfect for our simulations). In future simulations, we should create a survey design for telemetry data to create variance surrounding the habitat-specific movement speeds.

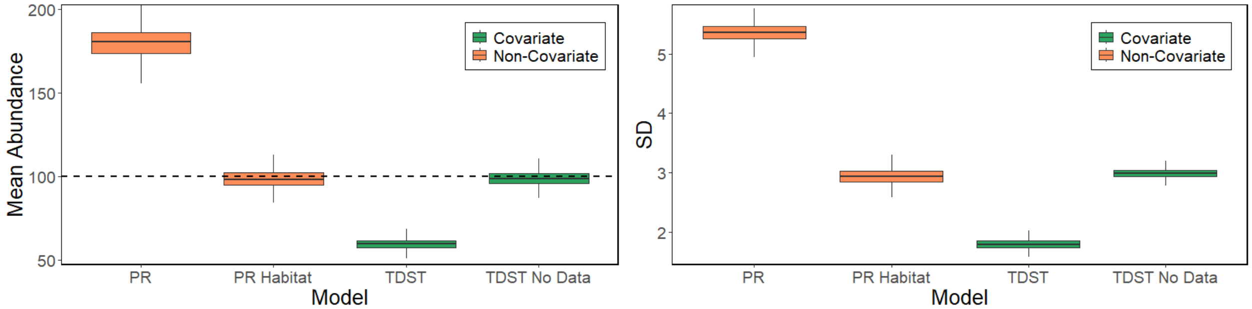
Random Sample Design



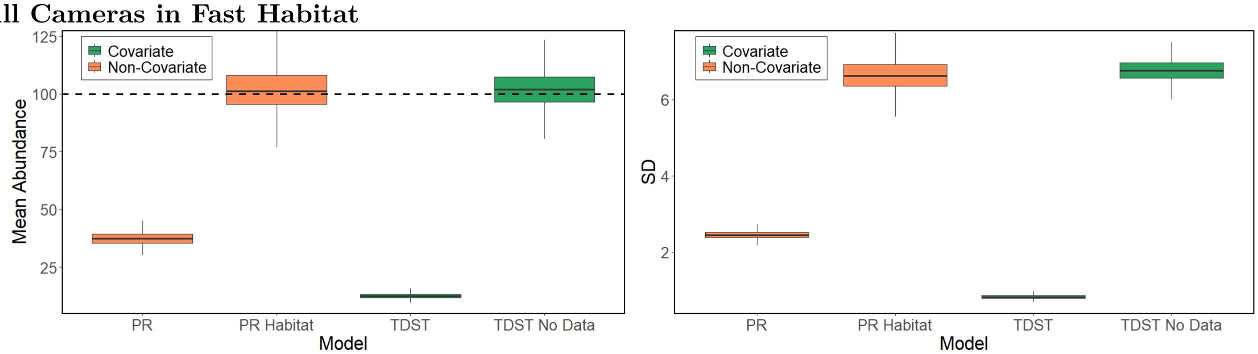
80% Slow, 10% Medium, 10% Fast Sample Design



All Cameras in Slow Habitat



All Cameras in Fast Habitat



Model Summaries

TDST Model

- Uses count and staying time data
- Requires habitat-specific covariate information
- Supports single-habitat camera sample design when auxiliary staying time information is present

PR Model

- Uses count data
- May run with or without covariates
- Requires random sample design when covariates are not used
- Does not support single-habitat camera sample design

Habitat PR Model

- Uses count data and telemetry data
- Supports single-habitat camera sample design

NOTES

- I can't figure out how to translate cell-size staying time to camera viewshed-size staying time. Multiplying by camera area over cell area doesn't seem to work (oddly enough, this scaling works for counts…). Again, this doesn't pose a problem for the TDST when stay time data are omitted, but is useless when staying time data (from cameras) are used.

- We need to think about how to estimate sds from habitat-specific staying time collected from collars. Currently, the habitat PR model does not use any SD and the TDST with priors-no data has a forced small prior variance.