

# Analysis of Stratified Surveys

Section 3.7 of Buckland et al. (2001)

Section 2.3 of Buckland et al. (2015)

# Stratification

- Why stratify?
- Stratification by:
  - Geographic area
  - Survey
  - Species / cluster size
- Limitations of Distance

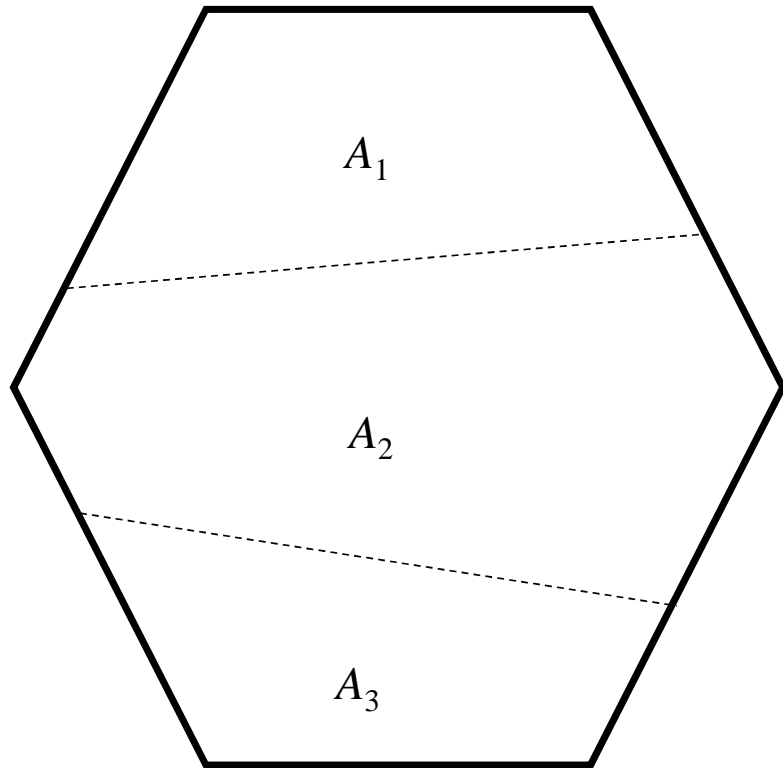
## Stratification is used to:

- reduce variance and improve precision
- and for producing estimates in regions of interest

## Stratify by:

- AREA or GEOGRAPHIC REGION
  - the study region is partitioned into smaller regions
- SURVEY
  - used when different surveys cover the same geographic area
- POPULATION/SPECIES/CLUSTER SIZE
  - same geographic region with different 'sub-stocks' in it

# Area/Geographic stratification



Total size of study region

$$A = A_1 + A_2 + A_3$$

Estimate density in each sub-region

$$\hat{D}_1, \hat{D}_2, \hat{D}_3$$

Abundance in each sub-region is given by

$$\hat{N}_1 = A_1 \hat{D}_1$$

$$\hat{N}_2 = A_2 \hat{D}_2$$

$$\hat{N}_3 = A_3 \hat{D}_3$$

Total abundance is

$$\begin{aligned}\hat{N} &= \hat{N}_1 + \hat{N}_2 + \hat{N}_3 \\ &= A_1 \hat{D}_1 + A_2 \hat{D}_2 + A_3 \hat{D}_3\end{aligned}$$

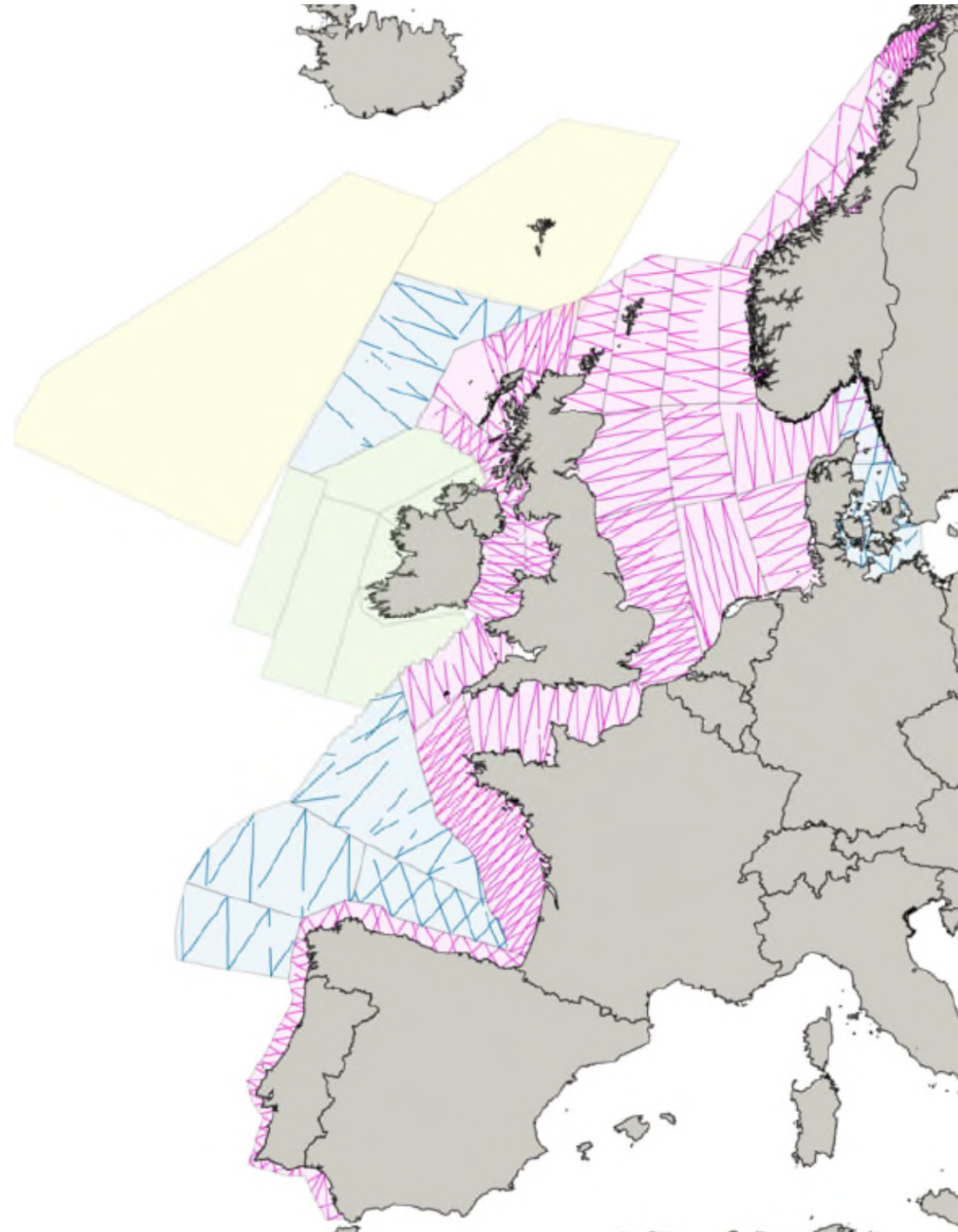
Overall (Global in Distance) density is

$$\begin{aligned}\hat{D} &= \frac{\hat{N}}{A} = \frac{A_1 \hat{D}_1 + A_2 \hat{D}_2 + A_3 \hat{D}_3}{A_1 + A_2 + A_3} \\ &= \left(\frac{A_1}{A}\right) \hat{D}_1 + \left(\frac{A_2}{A}\right) \hat{D}_2 + \left(\frac{A_3}{A}\right) \hat{D}_3 \\ &= \sum_{i=1}^3 \left(\frac{A_i}{A}\right) \hat{D}_i\end{aligned}$$

Note form of equation

# Example: SCANS III (2016)

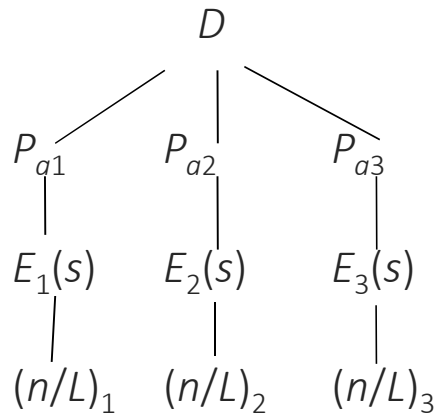
Small Cetaceans in  
European Atlantic waters  
and the North Sea



# Example of stratified data

	Region.Label	Area	Sample.Label	Effort	distance	size
1	Ideal	84734	1	86.75	0.10	1
2	Ideal	84734	1	86.75	0.22	1
3	Ideal	84734	1	86.75	0.16	3
:	:	:	:	:	:	:
45	Ideal	84734	13	75.63	0.03	1
46	Marginal	630582	14	83.33	0.49	1
47	Marginal	630582	14	83.33	1.94	1
48	Marginal	630582	14	83.33	1.10	1
:	:	:	:	:	:	:
99	Marginal	630582	25	107.72	NA	1

# Example: Full geographic stratification

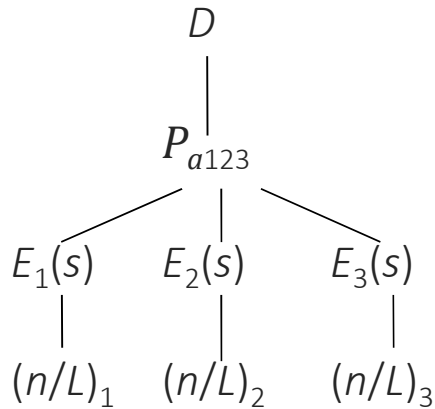


Select strata and fit  $d_s$  to each strata  
E.g. (many ways to perform selection)

```
ideal.dat <- whales[whales$Region.Label=="Ideal", ]  
whales.ideal <- ds(data=ideal.dat, key="hr")
```



## Example: $P_a$ pooled



Data contains different strata in Region.Label  
The ds function performs this stratification by default

```
whale.pool <- ds(whales, key="hr")
```

E.g. Part of output from `summary(whale.pool)`

Summary of clusters ...

Abundance:

	Label	Estimate	se	cv	lcl	ucl	df
1	Marginal	12181.313	4638.5533	0.3807926	5499.920	26979.371	12.96742
2	Ideal	3653.313	910.0737	0.2491091	2181.589	6117.879	17.96142
3	Total	15834.626	4834.1865	0.3052921	8388.389	29890.769	15.25427

## Doing the same thing with `dht2`

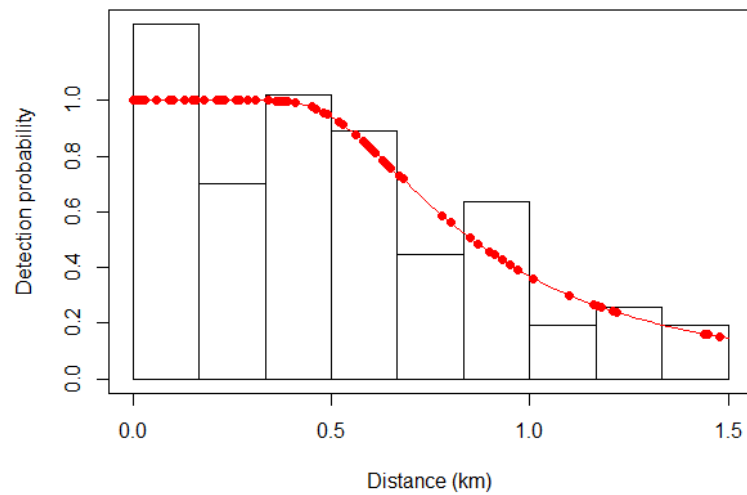
The same stratification (i.e. pooled  $P_a$ ) can be achieved with:

```
dht2(model=whale.pool, flatfile=whales,  
      strat_formula=~Region.Label,  
      stratification="geographical")
```

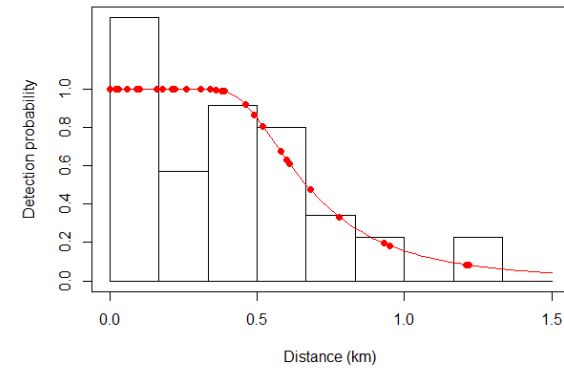
The `dht2` function can be used for more complicated stratification (as we will see later)

# Pooled vs Stratified $P_a$

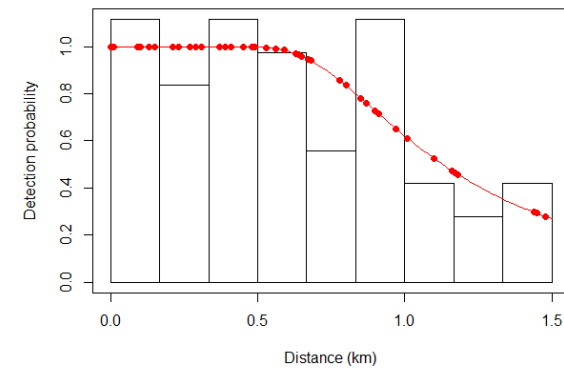
Pooled  $n=88$



Stratified  
Ideal habitat  $n=39$



Marginal habitat  $n=49$



# It is a Model Selection Problem

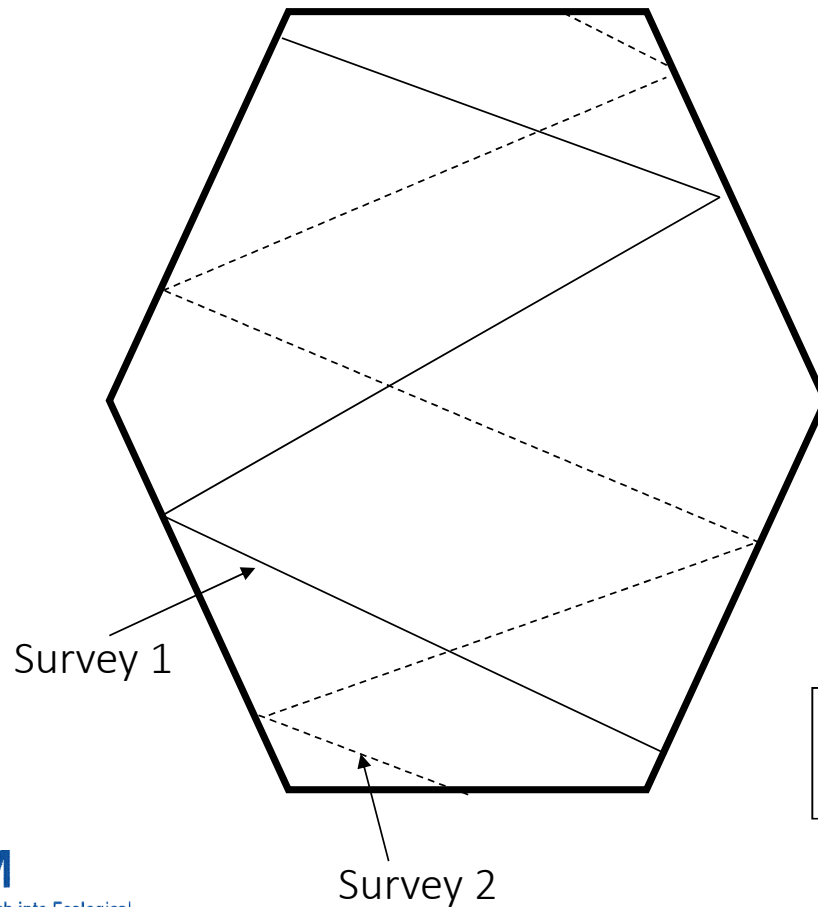
	Pooled	Stratum 1	Stratum 2	Stratum Sum
Log likelihood $\log_e(L)$	-180.490	-72.699	-104.676	-177.375
No. parameters (q)	2	2	2	4
AIC	364.980	149.398	213.352	362.75

Criterion for stratification of  $P_a$ :

Fit separate  $P_a$  for each strata if

$$AIC_{pooled} > \sum_{strata} AIC_{stratum}$$

# Non-geographic stratification -- Stratification by survey



Let  $L_i$  be effort for survey  $i$

Global density is given by

$$\begin{aligned}\hat{D} &= \left( \frac{L_1}{L_1 + L_2} \right) \hat{D}_1 + \left( \frac{L_2}{L_1 + L_2} \right) \hat{D}_2 \\ &= \sum_{i=1}^2 \left( \frac{L_i}{L} \right) \hat{D}_i\end{aligned}$$

This is the same form as before, but weighting factor now depends on effort

# Stratification by survey

Need to use the `dht2` function:

```
dht2(model=whale.pool, flatfile=whales,
```

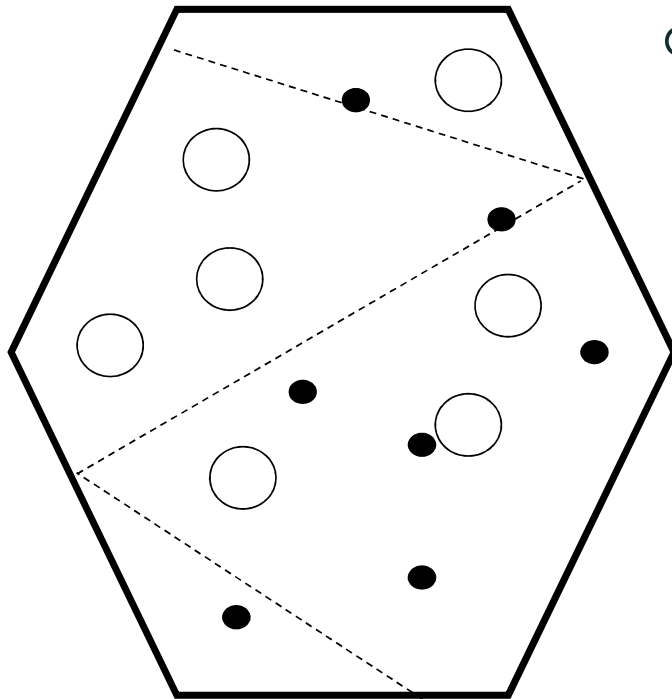
```
  strat_formula=~Region.Label,
```

This represents different surveys

```
  stratification="replicate")
```

# Stratification by species

- *Species 1*
- *Species 2*



$$\hat{D} = \hat{D}_{sp1} + \hat{D}_{sp2}$$

```
dht2(model=whales.pool,  
      flatfile=whales,  
      strat_formula=~species,  
      stratification="object")
```

Need this column  
in data



# When to use `dht2` for density or abundance estimates

- Use density or abundance estimates from **ds** when:
  - no stratification
  - simple geographical stratification (i.e. specified in `Region.Label`)
  - no multipliers/cue counts
  - Typical encounter rate variance estimators  
*Rather than the estimators used to produce better variance estimates under systematic surveys (from precision lecture)*
- Call **dht2** after detection function fitting with **ds** in other situations



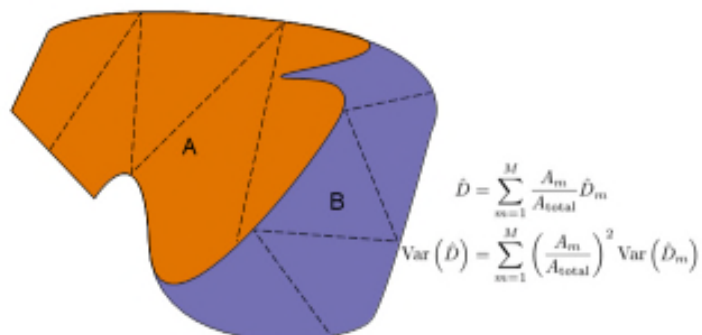
# Stratification in dht2

(Density edition)

There are four stratification options in dht2, this cheatsheet shows how density and its variance are calculated and gives examples of when to use them

## Geographical (stratification="geographical")

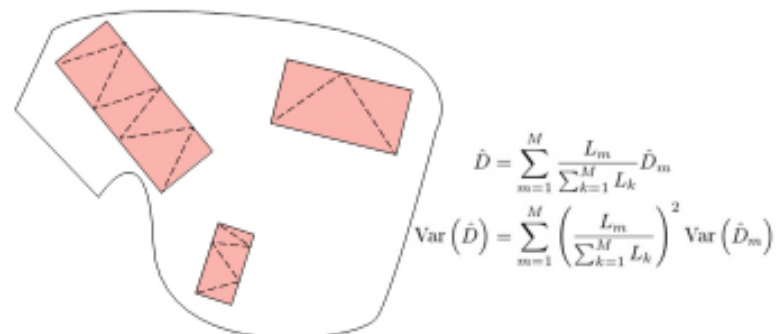
Each stratum represents a different geographical area, we want the total density over all the areas



Example: estimates are required for areas "A" and "B", above as well as an estimate of total density in and its variance.

## Effort-weighted sum (stratification="effort\_sum")

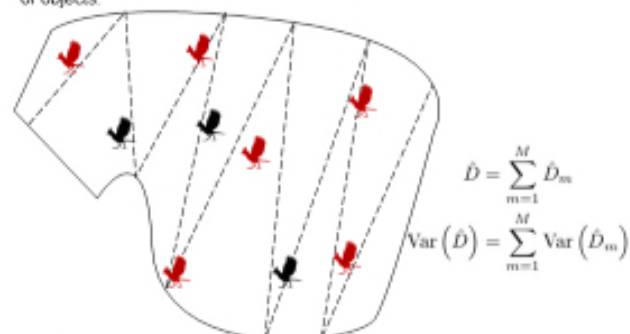
Strata are from surveys (perhaps using different designs) but you don't have many replicates and/or want an estimate of "average variance" and average density



Example: surveys (red) were made and are believed to be representative of the larger study area so they can be summed (weighted by the amount of effort) to obtain an average density.

## Object (stratification="object")

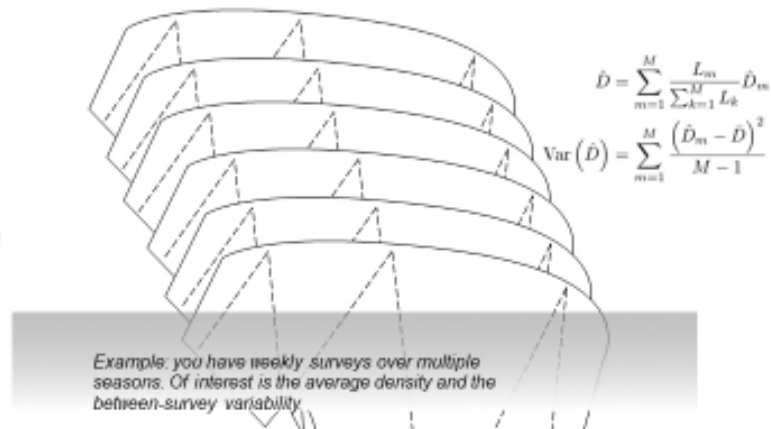
Objects are of different "classes", for example sex, species or life stage. Post-stratification is then required to obtain the density of individuals across all the classes of objects.



Example: if you have stratified by colour (red/black), but also want a total number of animals.

## Replicate (stratification="replicate")

Many replicate surveys have been conducted and the average density weighted by amount of effort is required, along with variance between the surveys

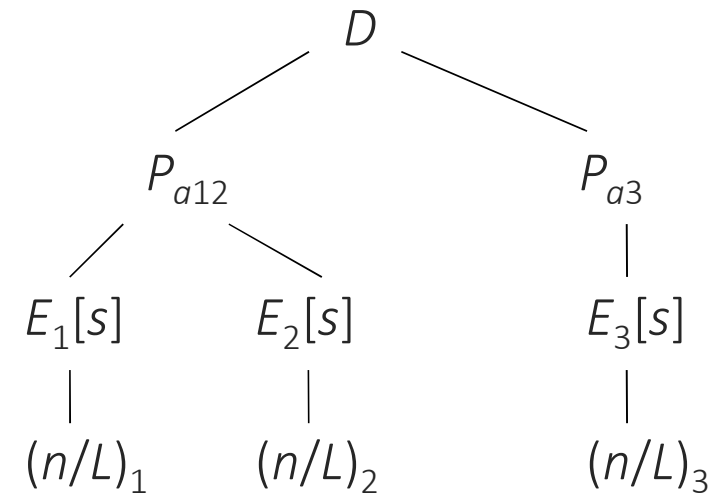


Example: you have weekly surveys over multiple seasons. Of interest is the average density and the between-survey variability.



## Limitations in Distance

- Distance cannot currently do multilevel stratification in one command
- Two runs are necessary
  - Estimate  $P_a$ ,  $E[s]$  and  $n/L$  by stratum
  - Combine strata 1 and 2 to estimate  $P_{a12}$
- Care must be taken when calculating CVs because the density estimates for stratum 1 and 2 have an estimated  $P_a$  in common

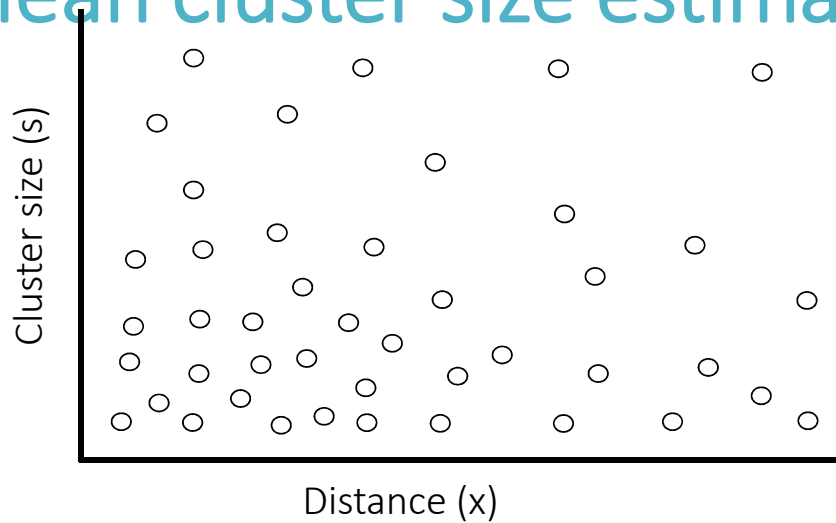


# Alternatives to stratification in Distance

- Small sample sizes can lead to low precision in stratum-specific estimates
- An alternative approach to reducing bias due to heterogeneity is Multiple Covariates Distance Sampling (MCDS)
  - Covariates, other than distance, are incorporated into the scale parameter of the detection function
  - MCDS can be used to fit the detection function at multiple levels e.g. stratum-specific density estimates can be obtained even if you don't have enough data to fit separate detection functions for each stratum
  - MCDS methods are covered in the next lecture.

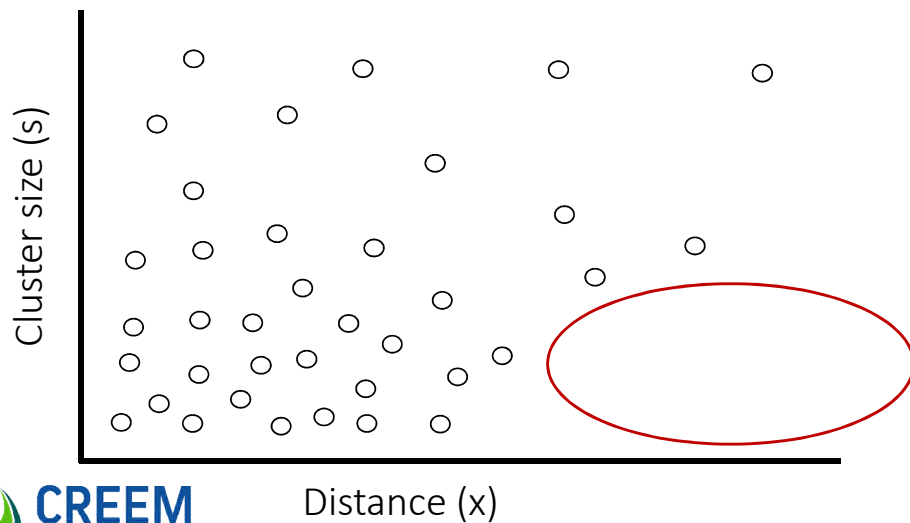
# Analysis of Populations in Clusters

# Mean cluster size estimation



## No Size Bias

- Mean of observed sizes does not change with distance

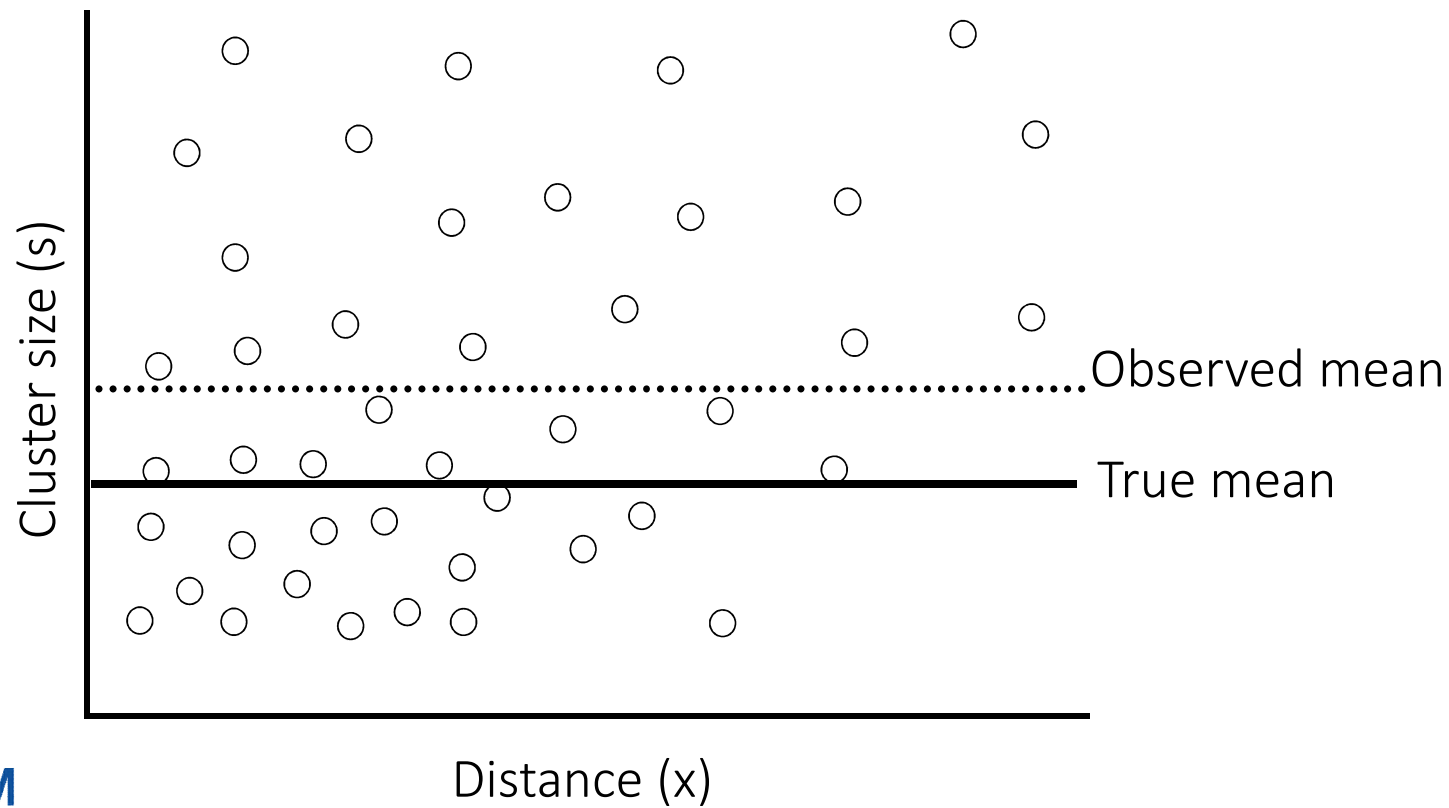


## Size Bias

- Smaller clusters less detectable at larger distances
- Mean observed cluster size **increases** with distance

# Effect of size bias on sample mean

If size bias is present,  $\hat{E}(s) = \bar{s}$  will be positively biased:



# Remedy to size bias

- Recognize that detection of cluster
  - *Depends upon cluster size*
- Model the dependence in the detection function
  - *using **covariates** in the detection function*
- Details in the next lecture