Analyses of telemetry data from migrating fish

Examples from the river Frome, Dorset

Stephen Gregory, Bill Beaumont, Rasmus Lauridsen, Andy Moore, Bill Riley

Cefas

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Outline

- Telemetry data: challenges
- State-Space modelling
- Examples (from the Dorset Frome):
  - Poole harbour sea trout
  - Frome PIT tag movements
- Take away points

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Telemetry data: challenges

- Imperfect detection

$$p < 1 < 0$$

where p = probability of individual detection

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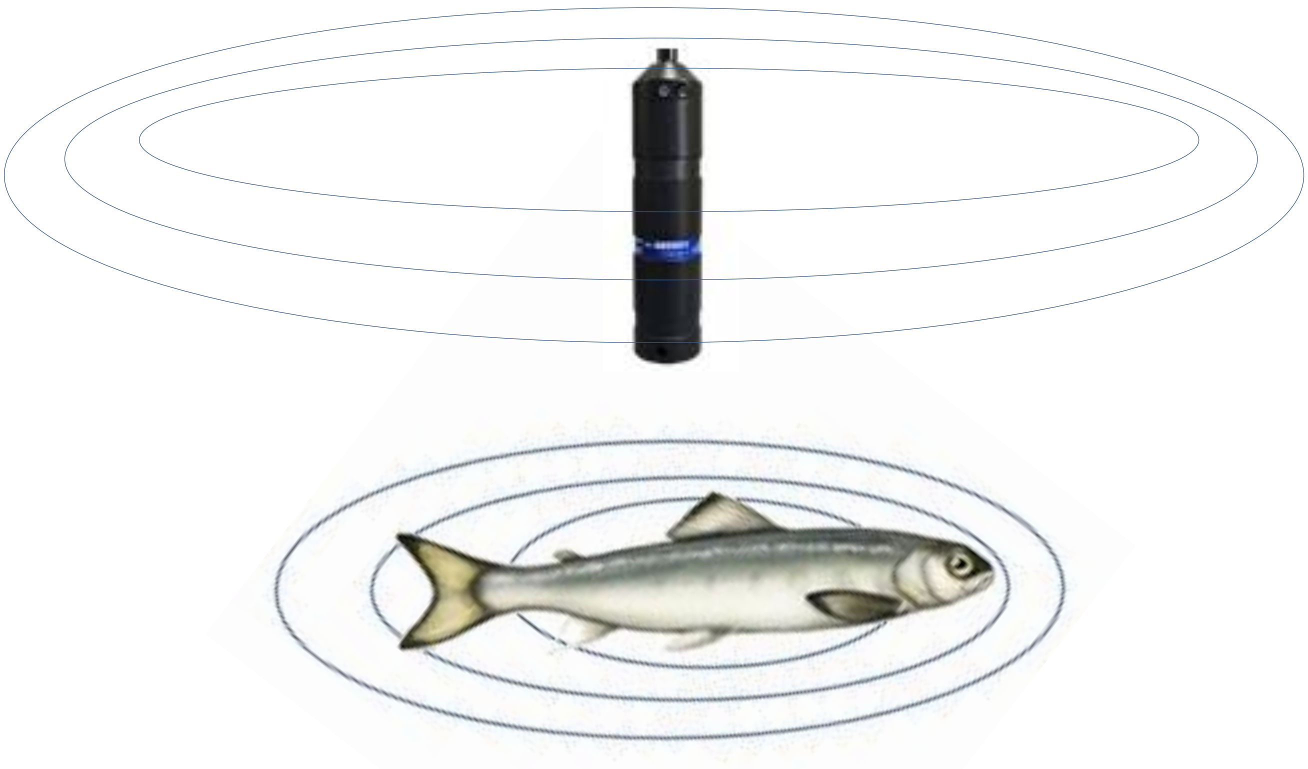

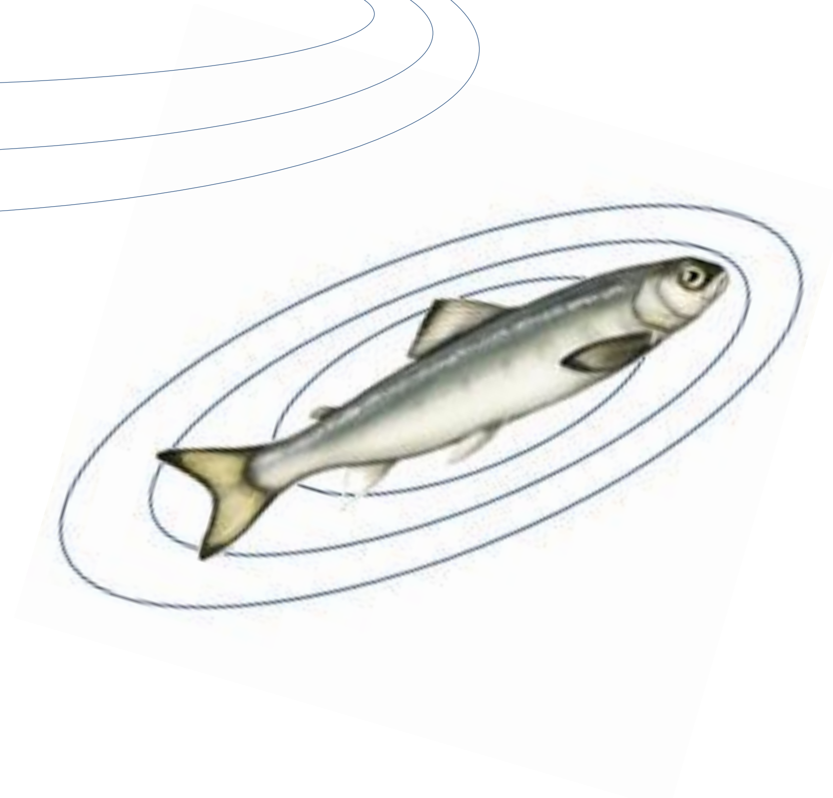

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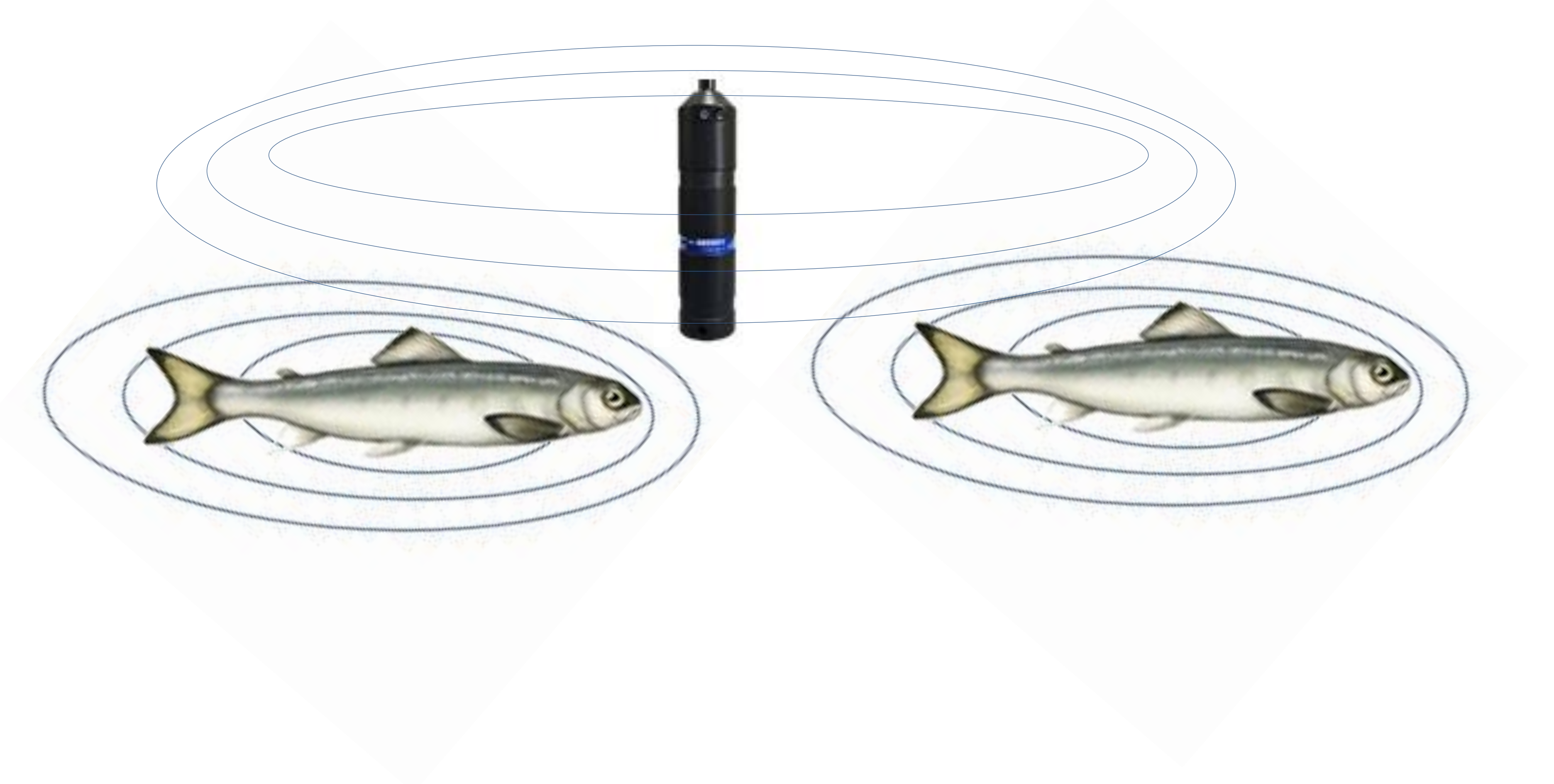
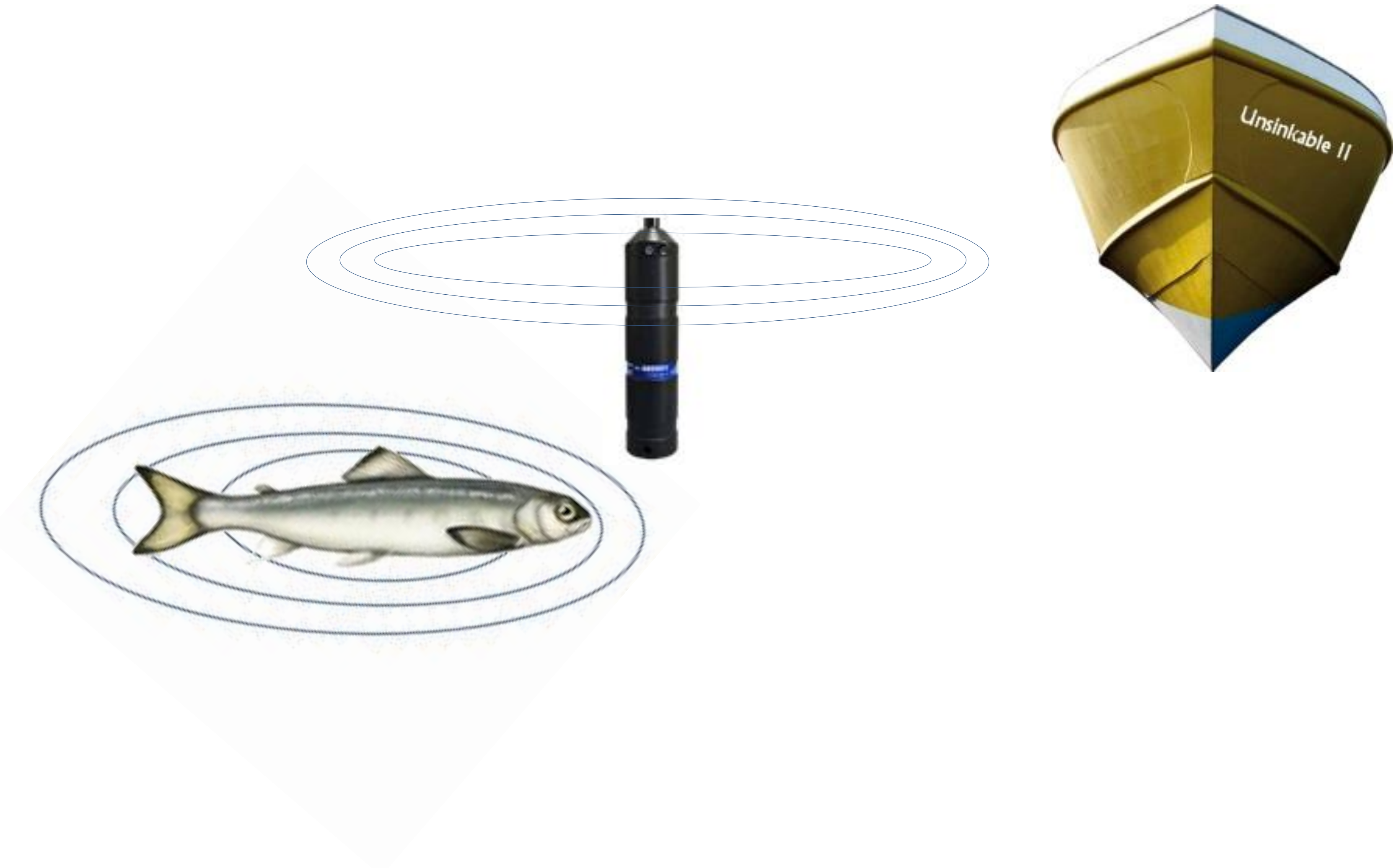
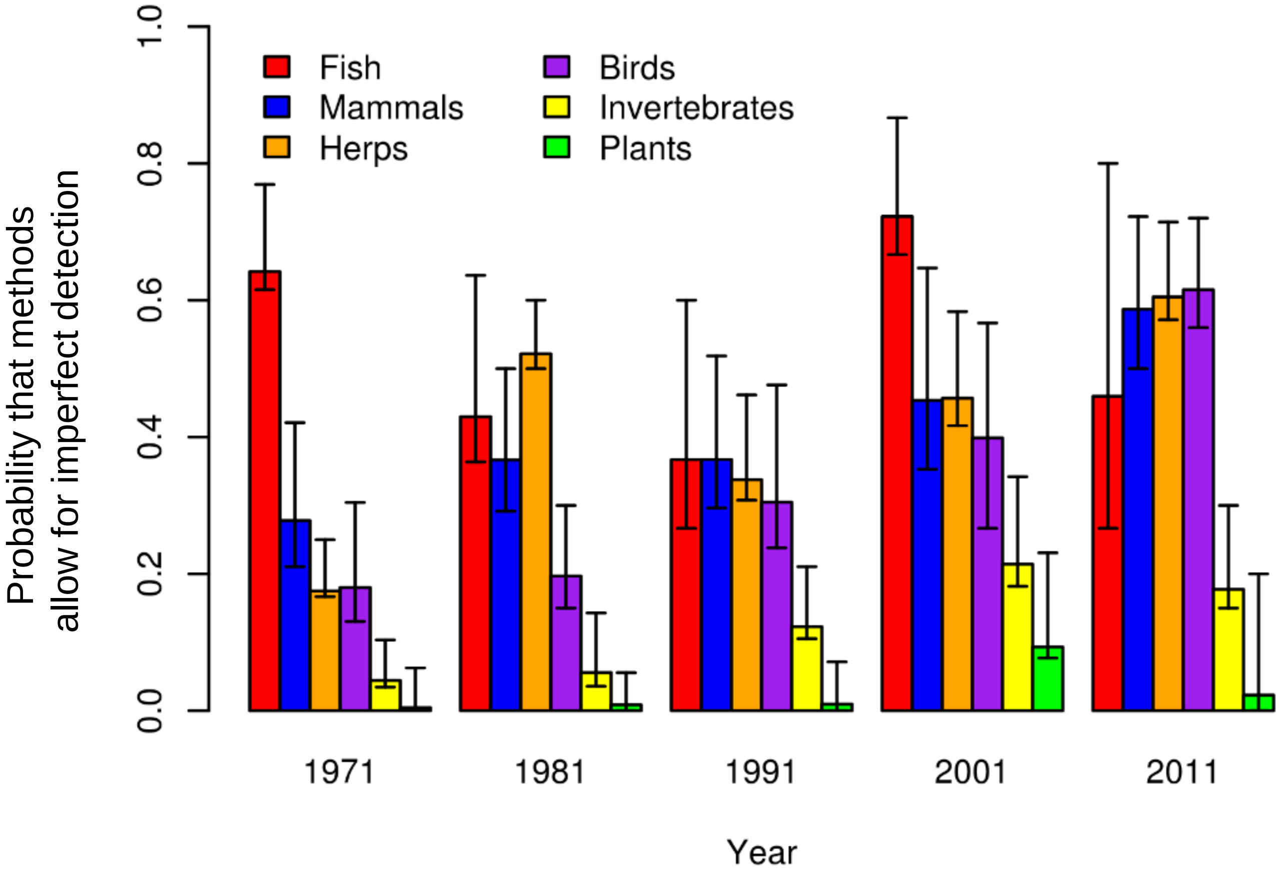



Unsinkable II



Overall: 23%

Kellner KF, Swihart RK (2014) PLoS ONE 9(10): e111436

- Alternatives:

  $p = 1$: under-estimate survival

  $p = x$: over- and under-estimate survival

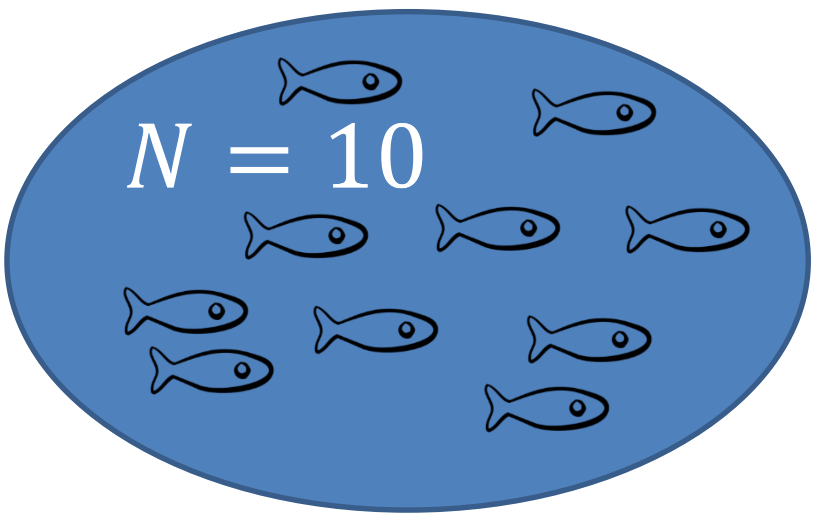
- Usually assumed that p is temporally invariant

Example:

Estimate:

$$p = ?$$

$$n = ?$$



$$N = n \times \frac{1}{p} = ?$$

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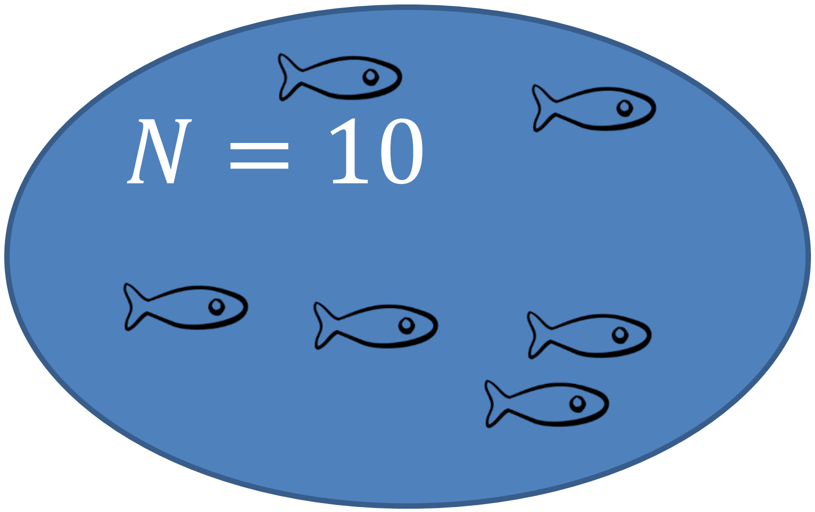
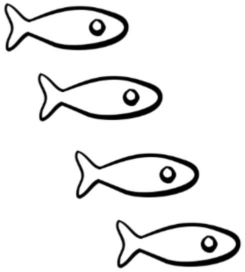
Example:

Estimate:
$p = 0.4$



$n = 4$



$$N = n \times \frac{1}{p} = 10$$

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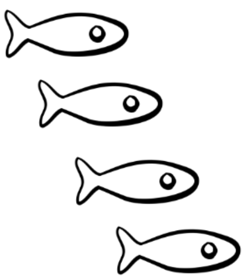
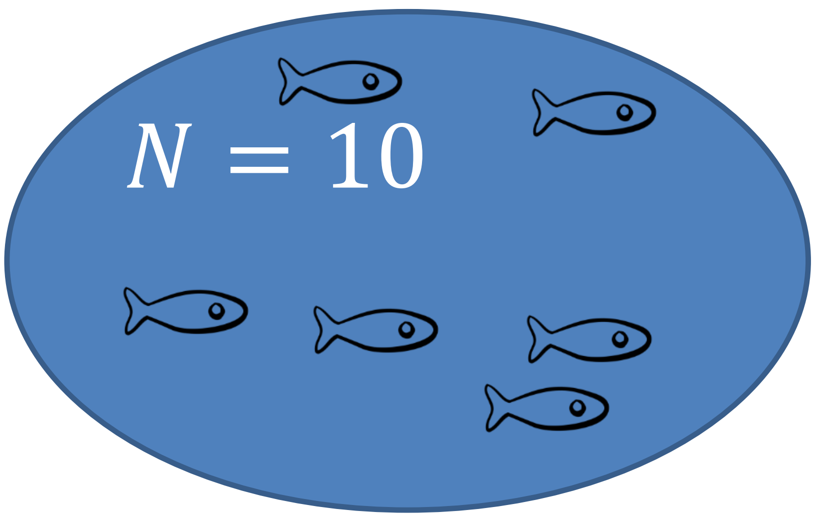
Example:

Assume:
$p = 1$

$n = 4$





$$N = n \times \frac{1}{p} = 4$$

Telemetry data: challenges

- Imperfect detection

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- Small sample sizes

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Telemetry data: challenges

- Imperfect detection
- Small sample sizes

  – Increased probability of inaccurate estimate
  – Increased uncertainty about estimate
  – Usually due to $$$$

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Telemetry data: challenges

- Imperfect detection
- Small sample sizes
- Experimental design

Telemetry data: challenges

- Imperfect detection
- Small sample sizes
- Experimental design

  – Receiver locations

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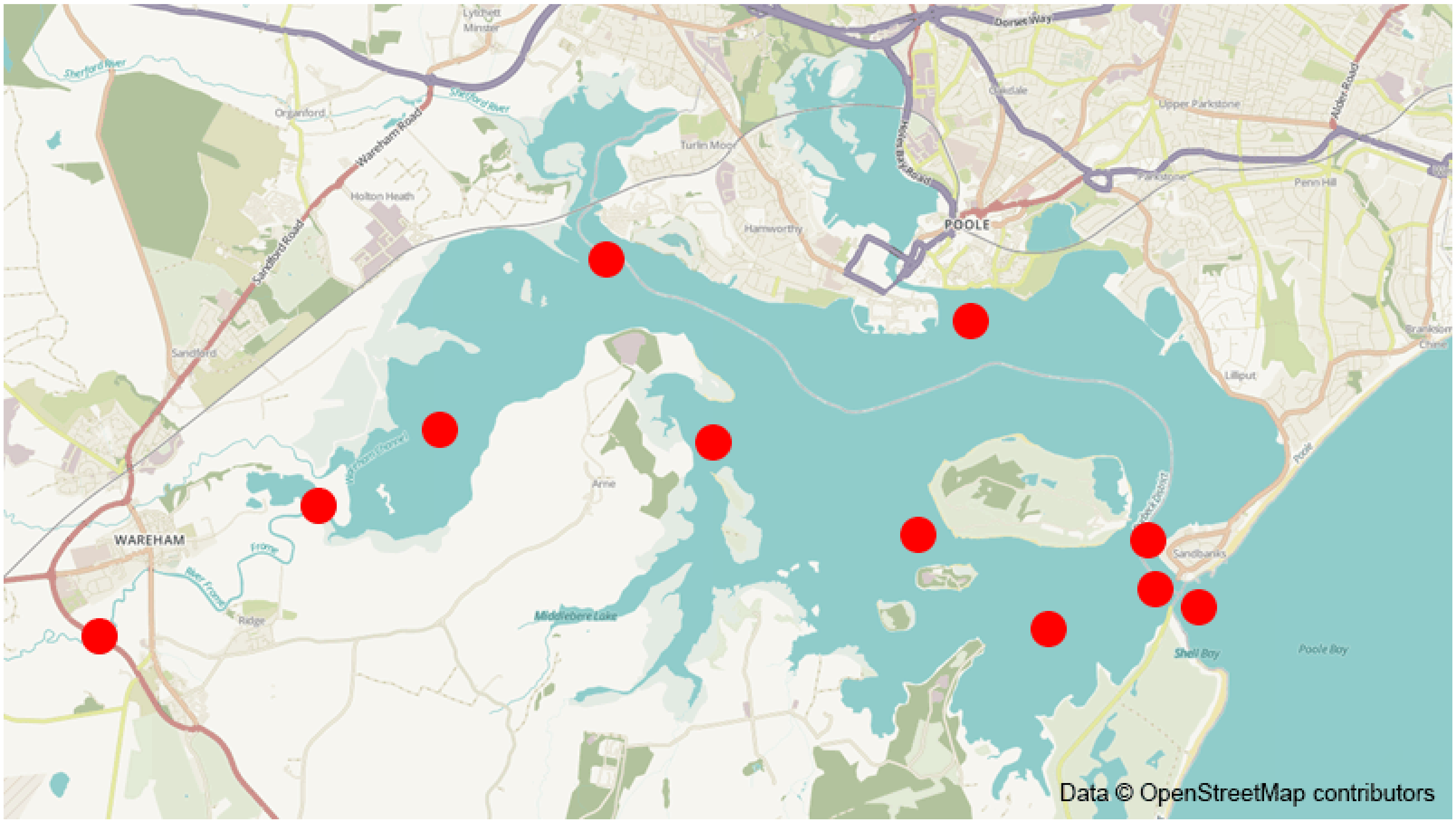

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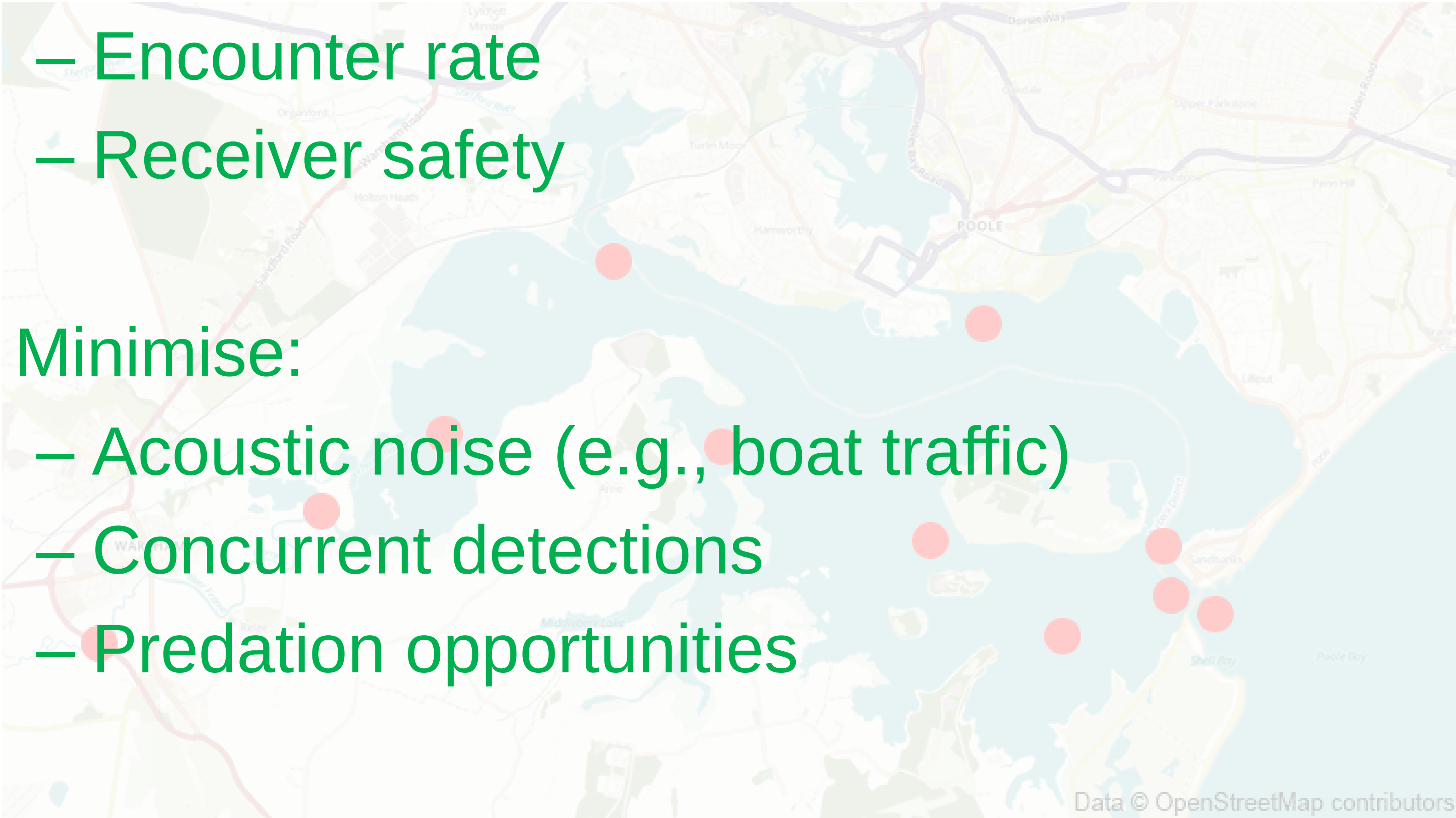
- Maximise:
  - – Encounter rate
  - – Receiver safety
- Minimise:
  - – Acoustic noise (e.g., boat traffic)
  - – Concurrent detections
  - – Predation opportunities



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Telemetry data: challenges

- Imperfect detection
- Small sample sizes
- Experimental design
  - Receiver locations
  - Last receiver

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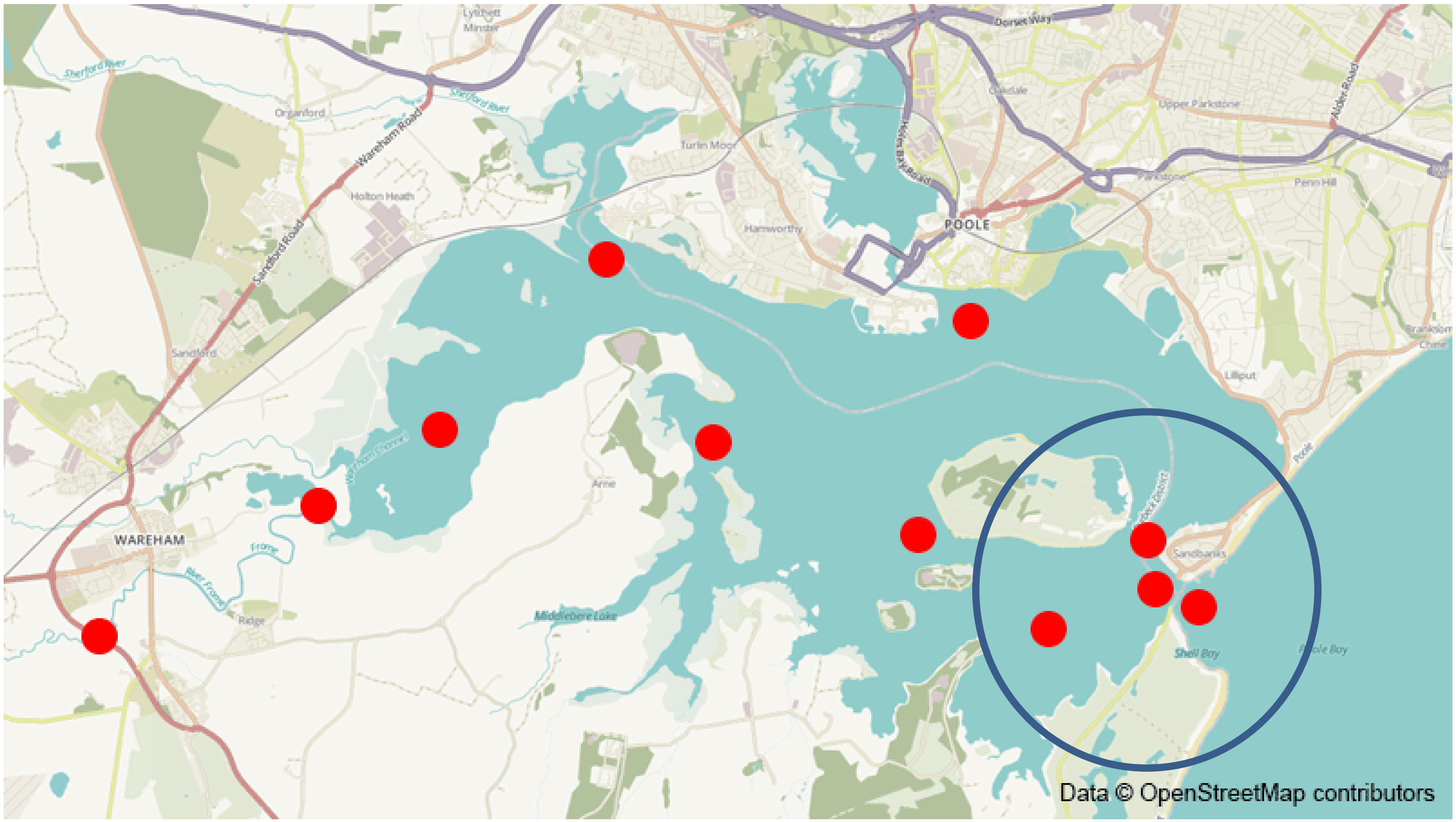

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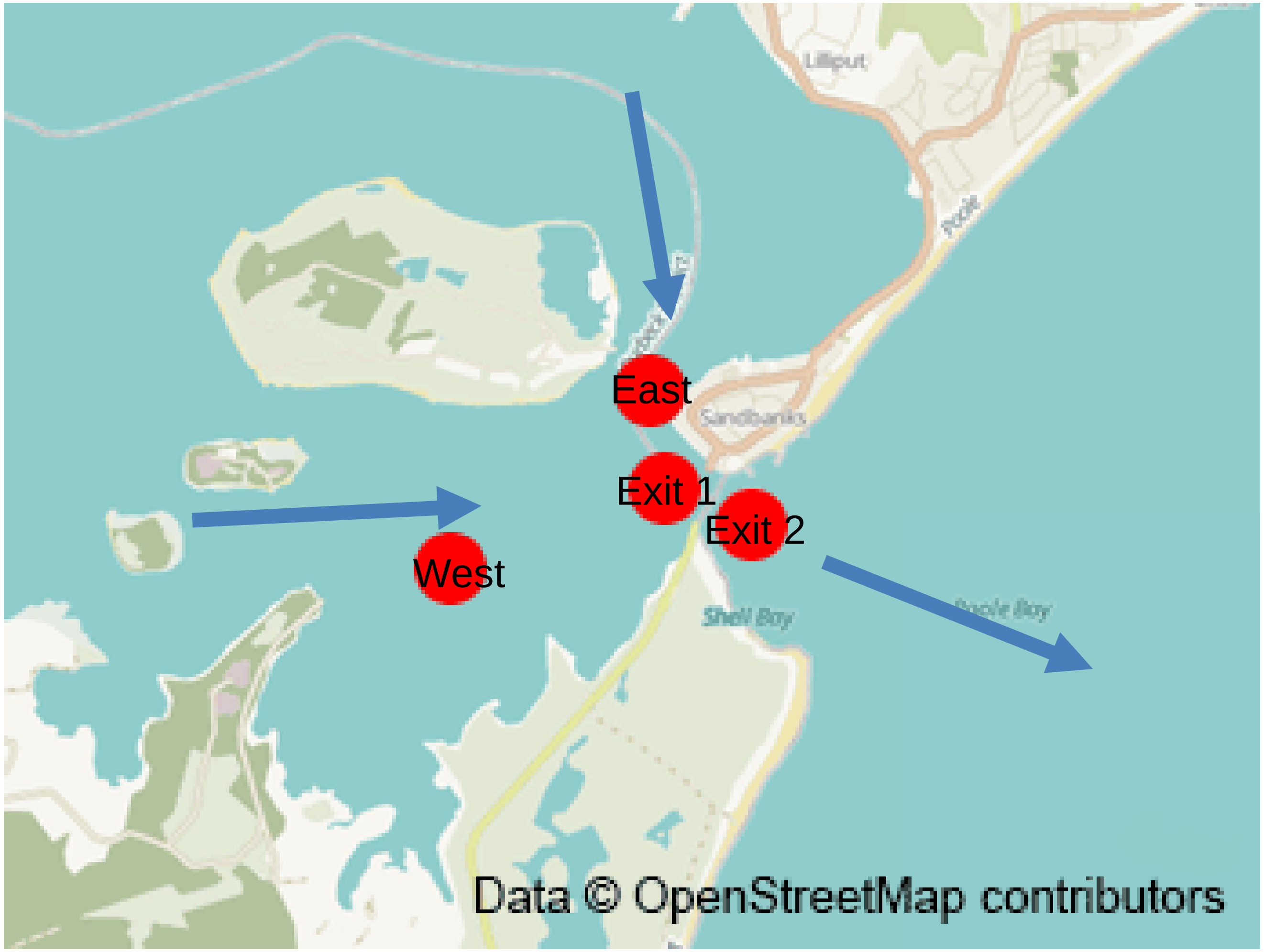

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- Detection probabilities (p) only estimable with detection information farther up- / down- stream!

- % detections at receiver 2 detected at receiver 1

$$n_{r1} \sim Binomial(n_{r2}, p_{r1})$$

East and West receivers efficiencies estimated from Exit 1

Exit 1 receiver efficiency estimated from Exit 2

No efficiency estimate for Exit 2

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State-Space modelling

- Separates nuisance parameter (detection probability p) from parameter of interest (transition probability ϕ)
- Goal: estimate State when not detected and thus detection and transition probabilities
- Explained in Gimenez et al. 2007, *Ecological Modelling, 206*, 431-438

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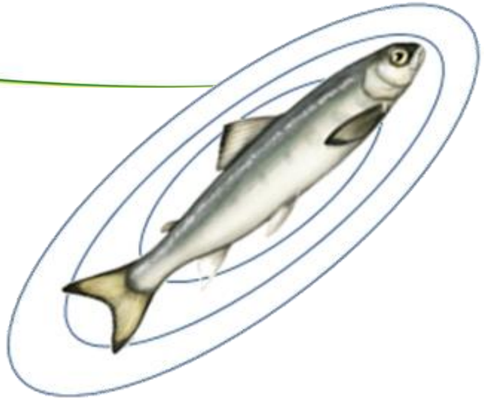
State-Space modelling

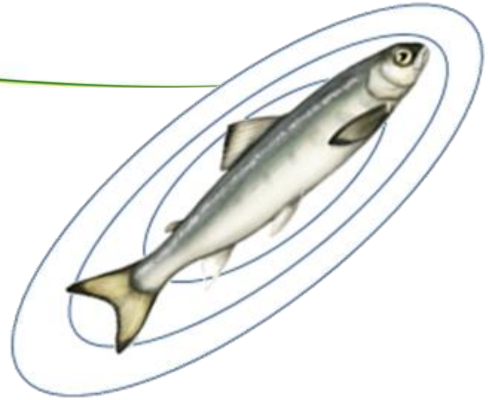


State matrix of individual i $\qquad z_i = [A, ?, B, ?]$

Space matrix of individual i $\qquad w_i = [1, 0, 1, 0]$

Individual i observed in state $k = A$ at time $t = 1$, was unobserved at $t = 2$, was observed in $k = B$ at $t = 3$ and was unobserved at $t = 4$.

State-Space modelling



State

- Survived
- Died
- Stopped migrating
- Etc.

Space

- Time
- Location
- Time & Location
- Etc.

State-Space modelling

JAGS

- Parameter estimates by MCMC (Monte Carlo Markov Chains)
- Estimates joint probability of parameters given the data
- Bayesian inference (but can use frequentist methods)

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Example: Poole harbour sea trout

- Aim: estimate relative risks to sea trout smolts of migration in freshwater and estuarine zones

- Assume:
  - Physical or behavioural differences between individuals were unimportant
  - Individuals travelled independently

- More details: http://stephendavidgregory.github.io/tracking/Holbrook

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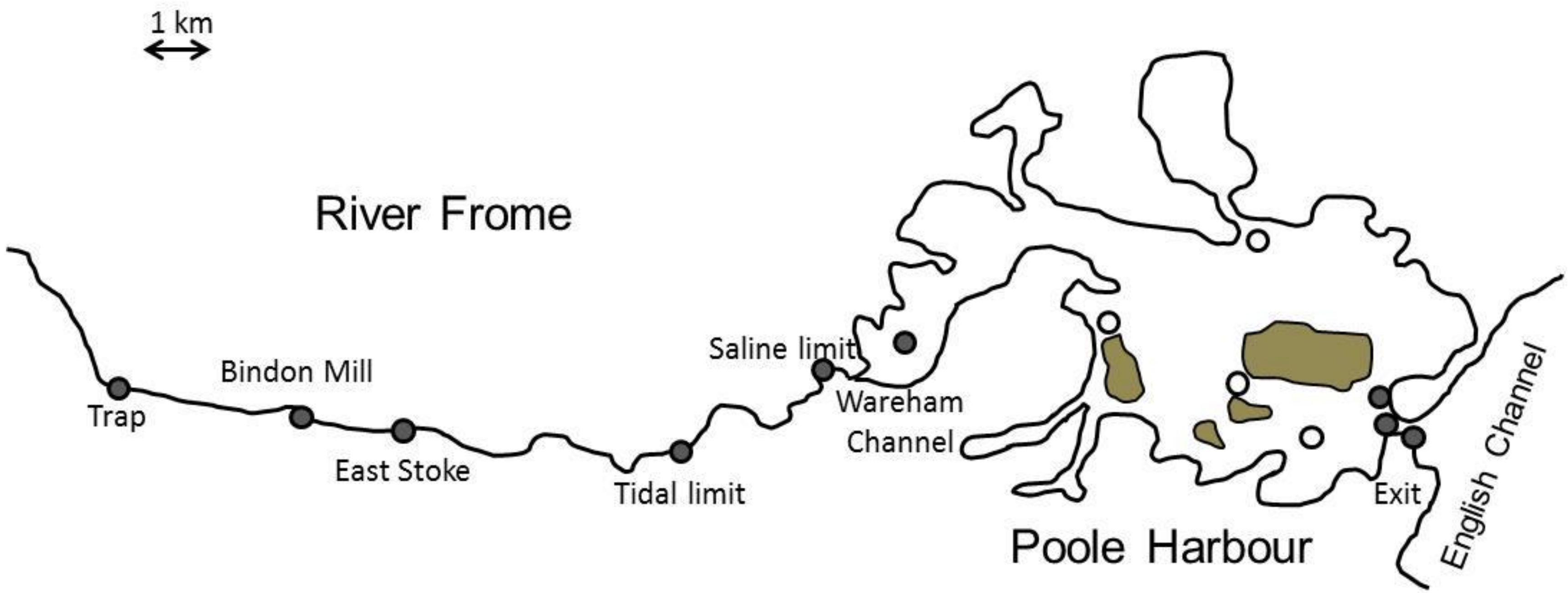
Example: Poole harbour sea trout



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Example: Poole harbour sea trout

2013: 30 smolts ($\bar{x}$ length = 182mm [123-247mm]; $\bar{x}$ weight = 70g [19-177g])

2014: 51 smolts ($\bar{x}$ length = 213mm [163-273mm]; $\bar{x}$ weight = 105g [44-199g])

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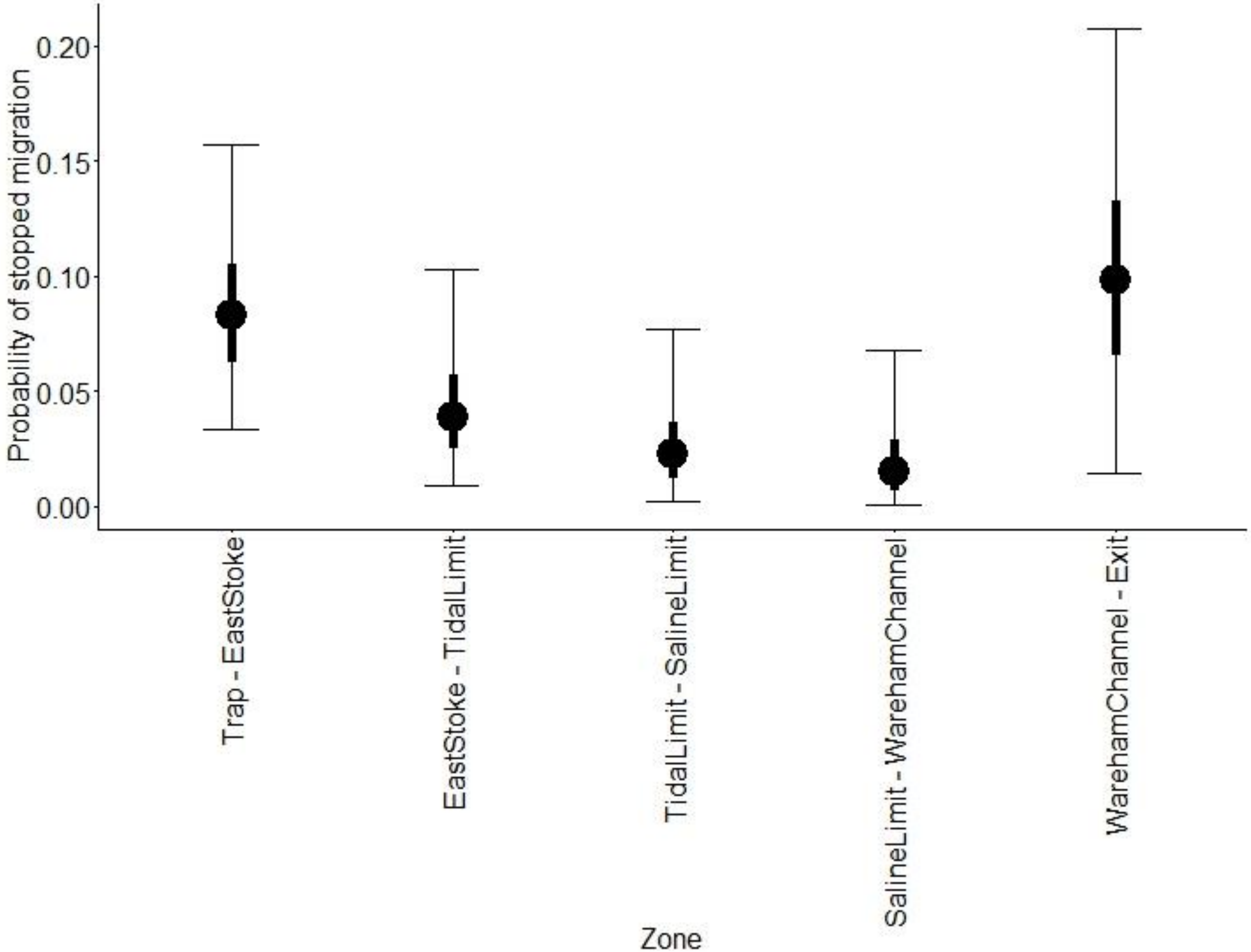
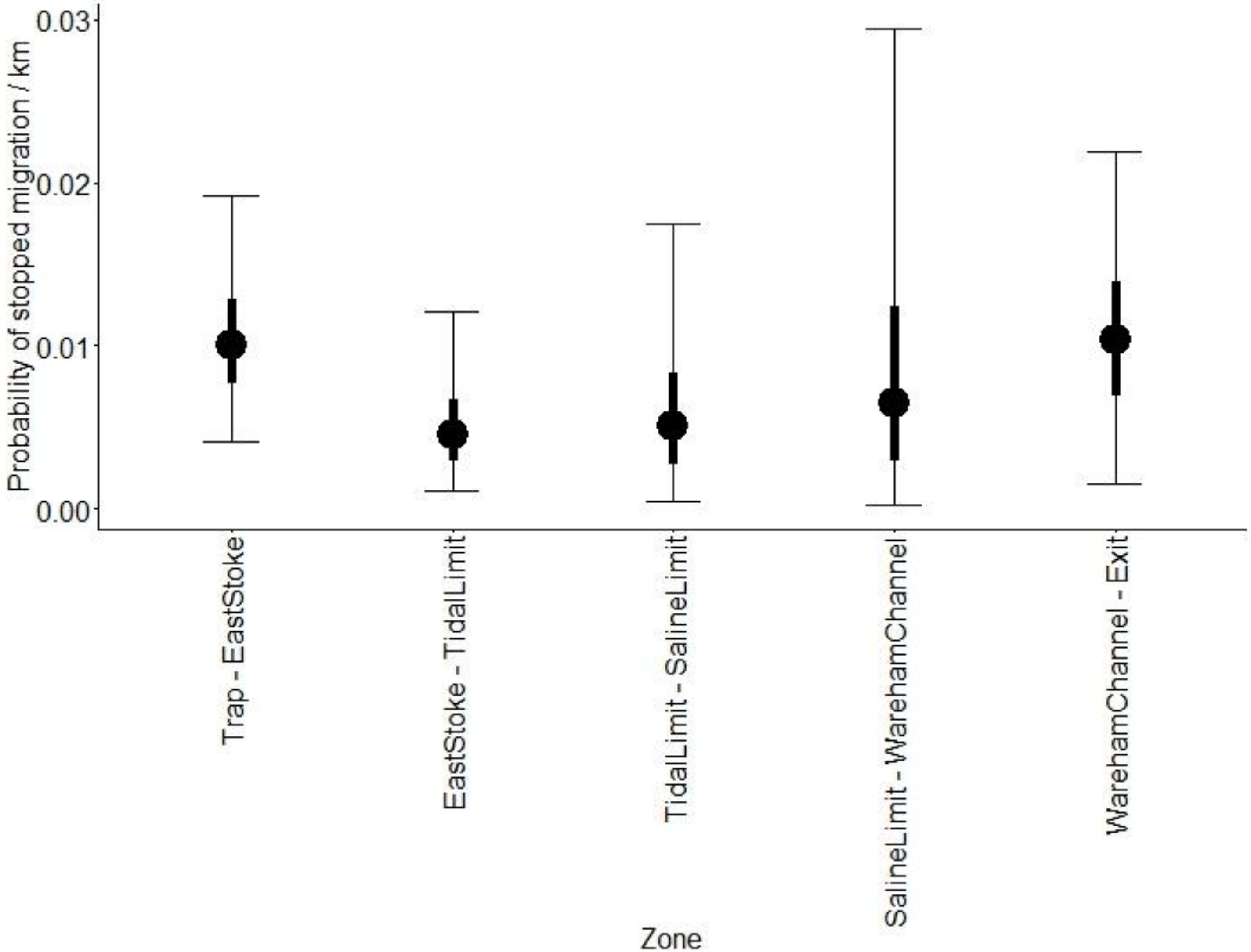
Example: Poole harbour sea trout

Station	*Distance from trap (km)*	*Year*	*No. Tags detected **	*Detection probability (95% CI)*	*Day time obs.*	*Night time obs.*
Bindon Mill	5.4	2013	20	N/A	0%	100%
		2014	36		14%	86%
East Stoke	8.2	2013	25	0.93	0%	100%
		2014	42	(0.86-0.95)	10%	90%
Tidal Limit	16.7	2013	24	0.99	8%	92%
		2014	45	(0.95-1.00)	18%	82%
Saline Limit	21.1	2013	21	0.96	43%	57%
		2014	42	(0.90-0.99)	48%	52%
Wareham Channel	23.4	2013	20	0.81	40%	60%
		2014	37	(0.70-0.84)	62%	38%
Exit	32.9	2013	22	0.84	68%	32%
		2014	36	(0.72-0.87)	56%	44%

Example: Poole harbour sea trout



Example: Poole harbour sea trout



Estimating sea trout smolt migration risks

Estimating transition probabilities with Bayesian State Space models

28 Jan 2016 in Tracking 7 minutes read

http://stephendavidgregory.github.io/

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Example: Frome PIT tag movements

- Aim: describe smolt freshwater migration behaviour in relation to individual characteristics

  – Transition probability ~ River characteristics
  ~ Smolt characteristics
  ~ Temporal variables

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Example: Frome PIT tag movements

- Up to 10,000 salmon parr tagged per year
- Up to 50 locations throughout the catchment

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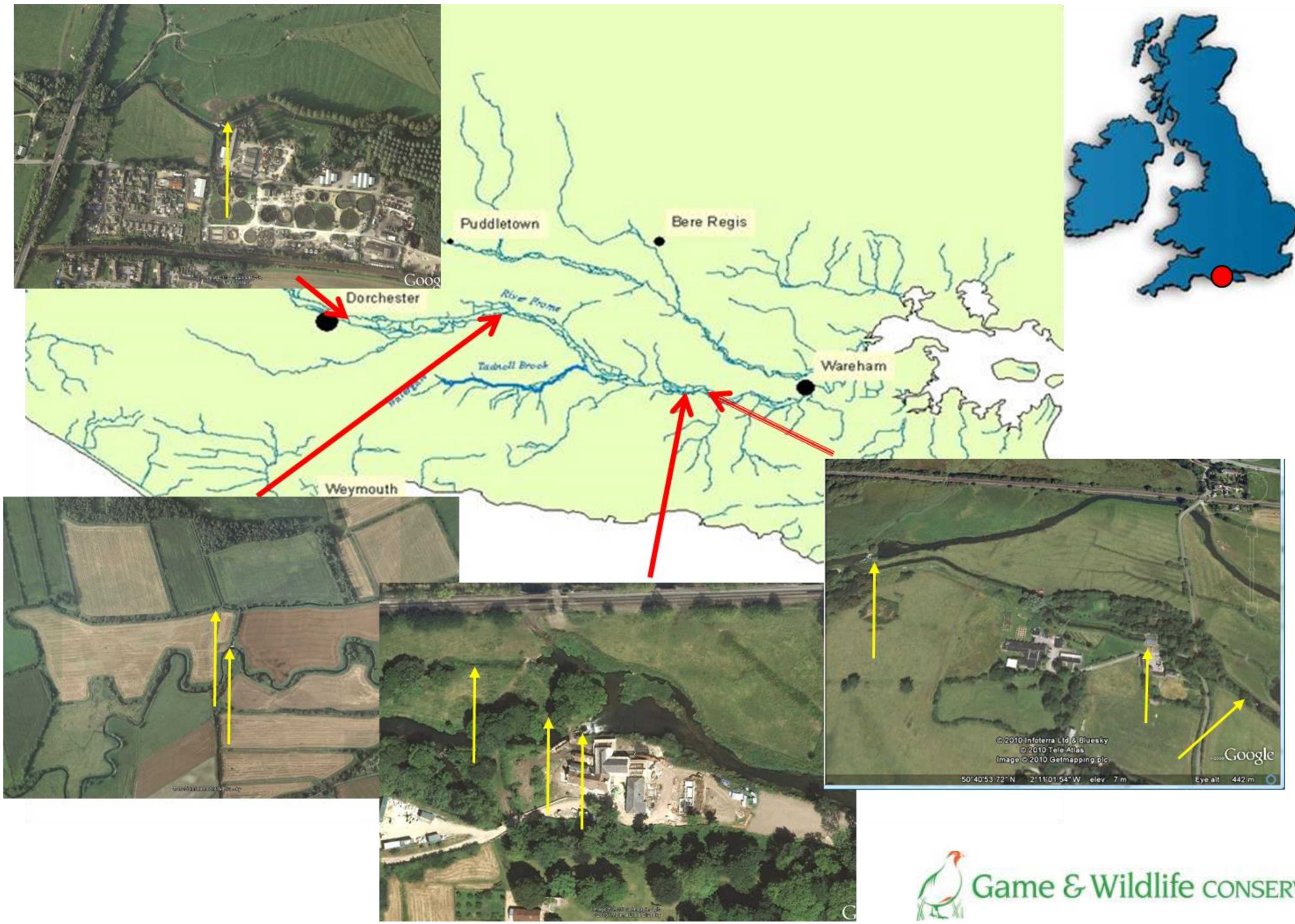
Example: Frome PIT tag movements



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Example: Frome PIT tag movements

- Uninformative prior on transition probability

$$\phi \sim Beta(1,1)$$

- Informative prior, allowing for covariates

$$logit(\phi) \sim \alpha + \beta X$$

Example: Frome PIT tag movements

- Example questions
  - How is the probability and speed of transition related to smolt size?
  - How is the probability and speed of transition related to flow?
  - How is the probability of transition related to shoaling behaviour?
  - …

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Take away points

- Experimental design (last receiver) is important!

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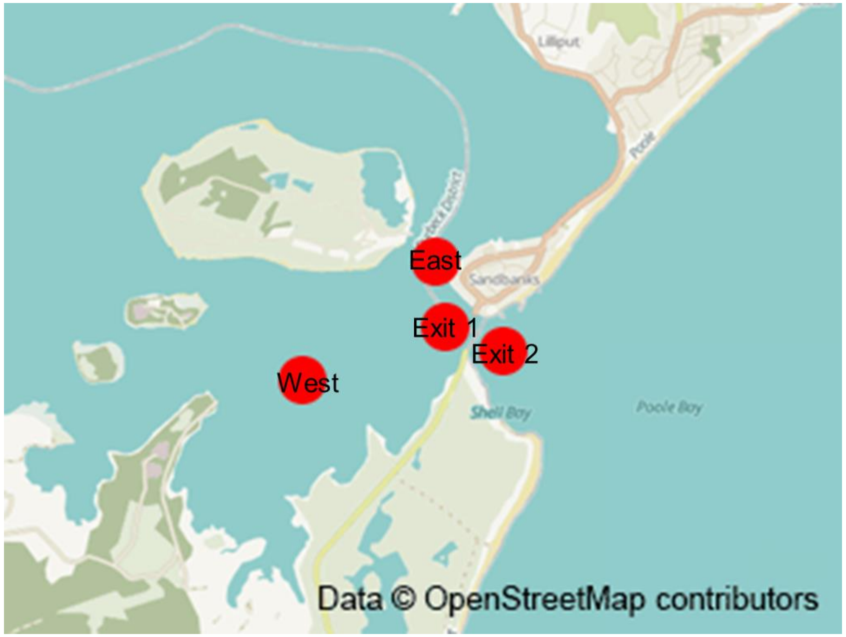

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Take away points

- Experimental design (last receiver) is important!

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Take away points

- Experimental design (last receiver) is important!
- State-Space modelling: efficient use of data
  - Fewer assumptions
  - [Probably] better accuracy
  - Better accounting of uncertainty

Take away points

- Experimental design (last receiver portant!
- State-Space modelling: efficient use of data
- New studies:

$$Tracking\ technology + State{-}Space\ modelling = exciting\ opportunities$$

Thanks

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http://stephendavidgregory.github.io/

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State-Space modelling

JAGS

- Parameter estimates by MCMC (Monte Carlo Markov Chains)
- Estimates joint probability:

$$\pi(\phi, p|z, w) \propto \pi(z, w|\phi, p)\ \pi(\phi)\ \pi(p)$$

where:

$\pi(\phi, p \mid z, w)$ = posterior parameter probabilities

$\pi(z, w \mid \phi, p)$ = product of the likelihood of the data given the parameters

$\pi(\phi)$ = prior probabilities of transition

$\pi(p)$ = prior probabilities of detection

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