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Understanding the causes of population declines in apex marine predators

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Talk objectives

Present two very different approaches to modelling two very similar catastrophic declines in seal populations

Explore the broader methodological implications of modelling ultimate v proximate population drivers

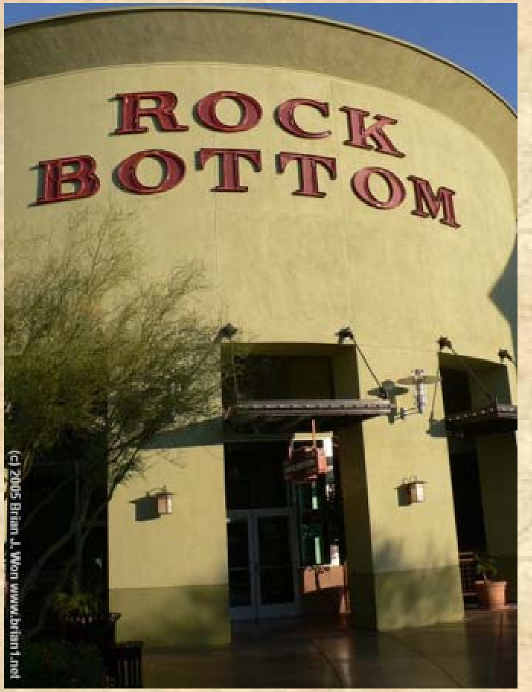
Why do populations decline?

1) Poor quality food
2) Insufficient food
3) Inaccessible food
4) Superabundant predators
5) Disease
6) Hunting
7) Toxic substances
8) By-catch
9) Habitat destruction
10) Competition with other species
11) Competition within population
12) Aggression
13) Indirect ecosystem effects
14) Environmental change

and combinations thereof

1) Too many animals die
2) Not enough animals get born
3) Too many animals move away

and combinations thereof

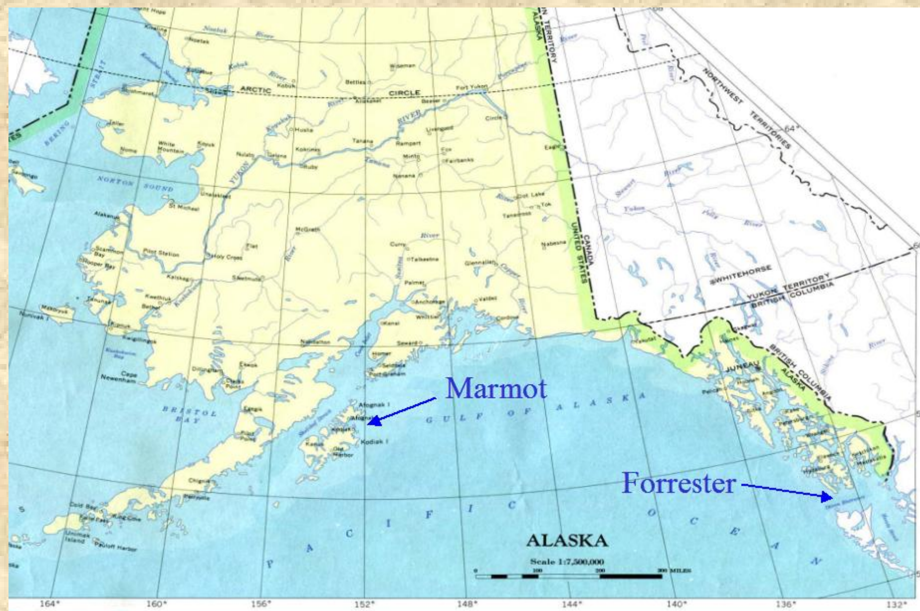


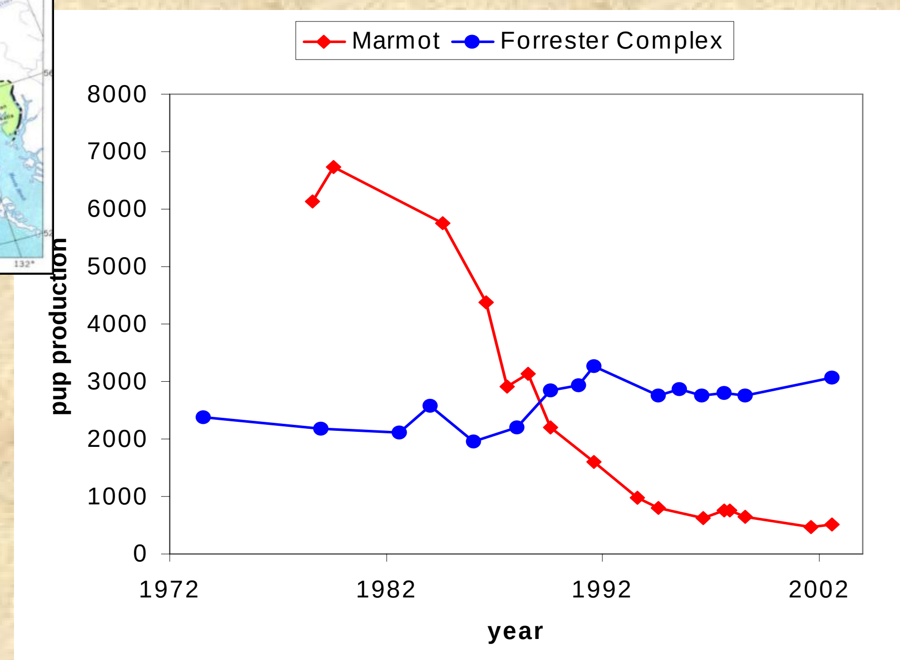
Decline of steller sea lions in Alaska

Population decline

Sea lion population decline at Ugamak Island - Aleutian Islands (NMFS)

Population decline





Dominant hypotheses focus on trophic interactions within the system

Steller sea lions (*Eumetopias jubatus*)

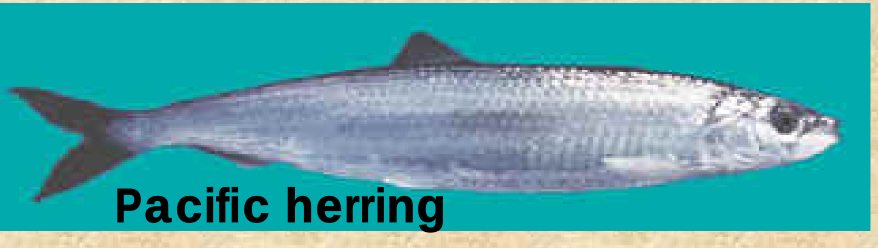
Largest of the otariid pinnipeds

Sexually dimorphic

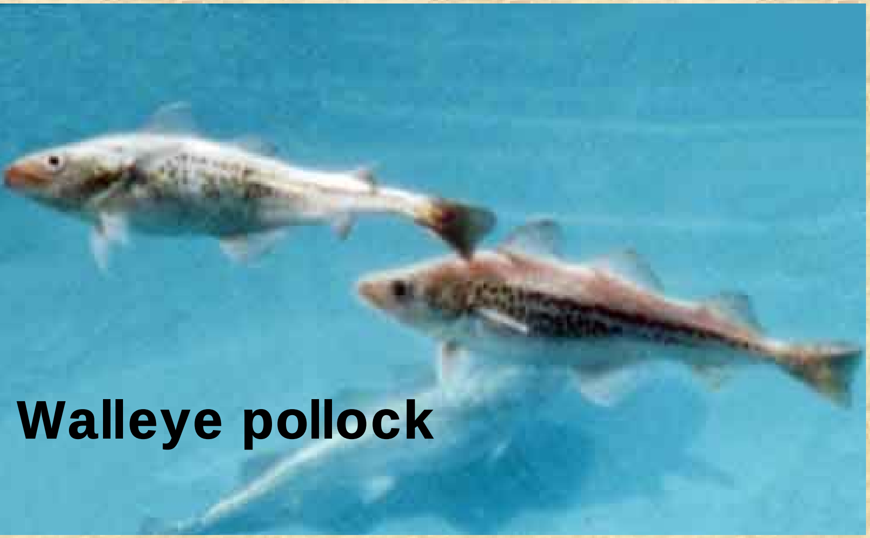
1 pup per year, weaned after 1yr, does not reproduce for 3 yrs or more

Inhabit polar waters but have low levels of thermal insulation. Haul out on shore between foraging trips

The prey


Pacific herring


Pink
salmon


Walleye pollock


Atka mackerel


Eulachon

The predators

Model description

(State variables)

Density states

Prey $P_{\mathbf{x},t}$

Stellers $N_{s,i,\mathbf{x},t}$

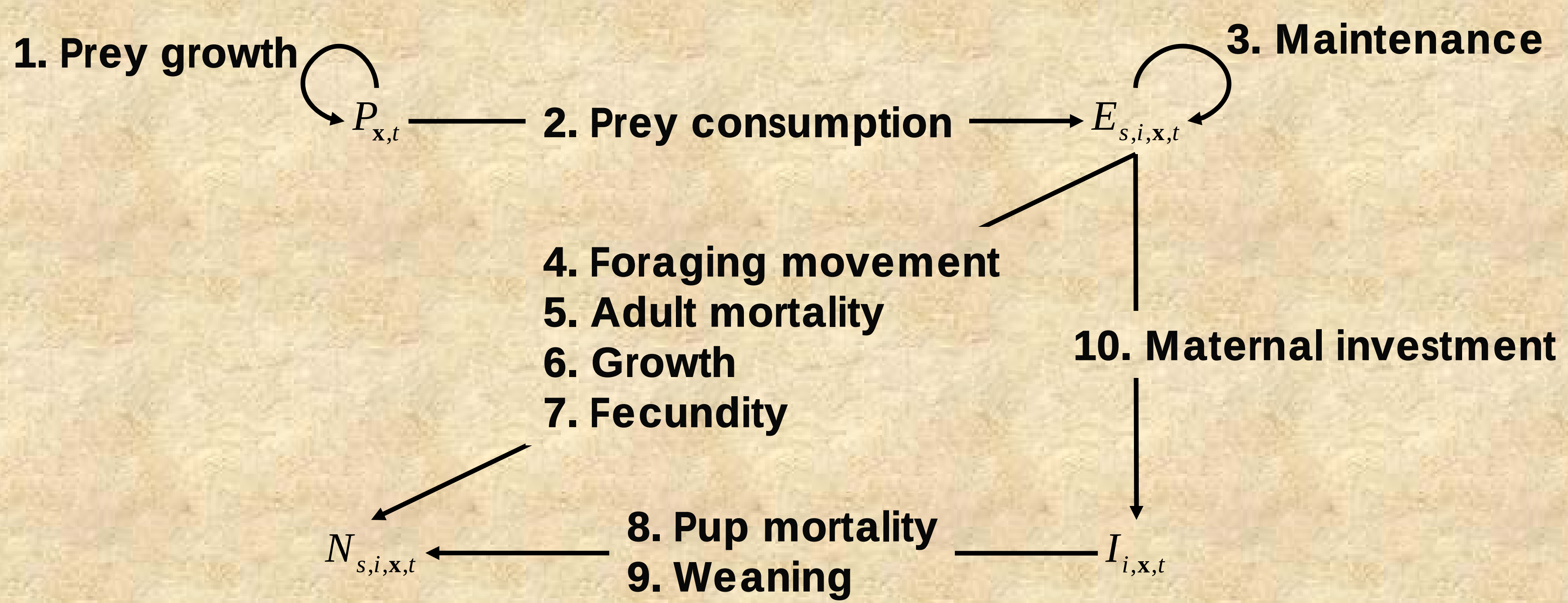
Energy states

Adults $E_{s,i,\mathbf{x},t}$

Pups $I_{i,\mathbf{x},t}$

Model description

(Processes modelled)

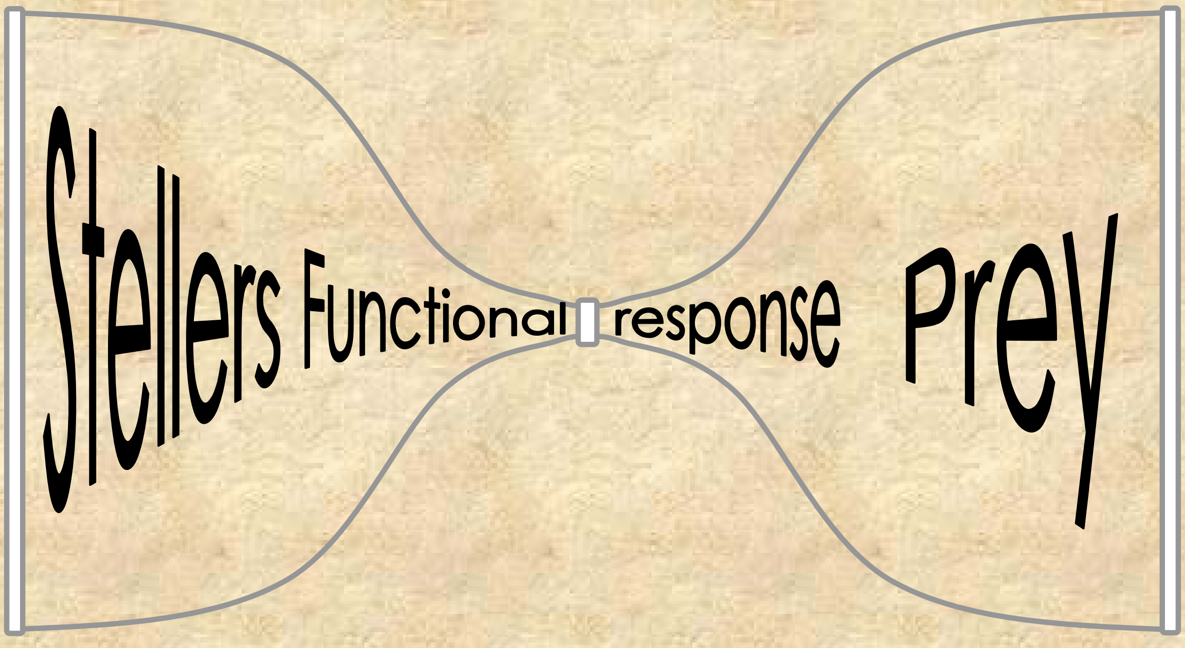


Parameterisation

Data, First Principles & Further modelling:

1) Mass-energy conversions for SSLs
2) Energetic value of prey field
3) Metabolic rates
4) Time travelling to patch
6) Dive speed
7) Initial maternal investment
8) Growth rates
9) Fecundity rates
10) Mass at first breeding
11) Lactation costs
12) Lactation efficiency
13) Maximum dive depth
14) Maximum trip duration
15) Background mortality
16) Starvation mortality
17) Foraging ranges
18) Time offshore
19) Patch switching

Parameterisation
(Bottleneck)

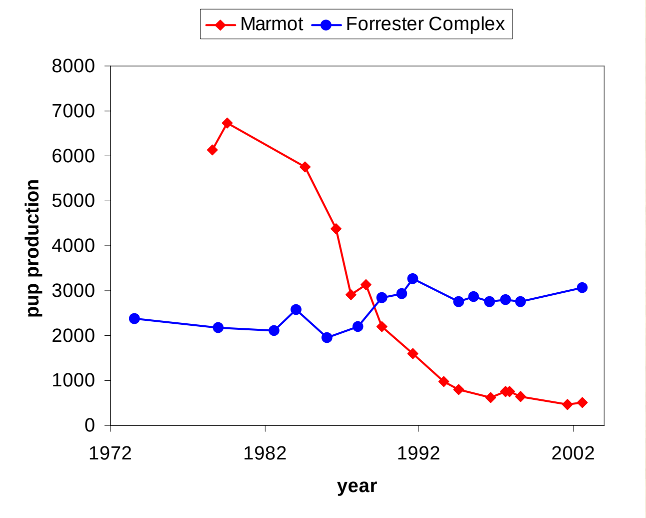


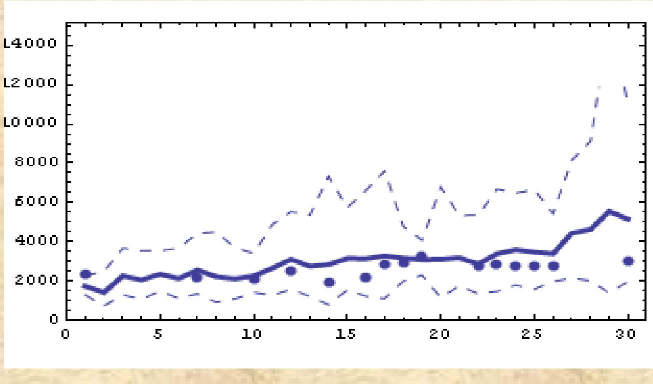
Parameterisation

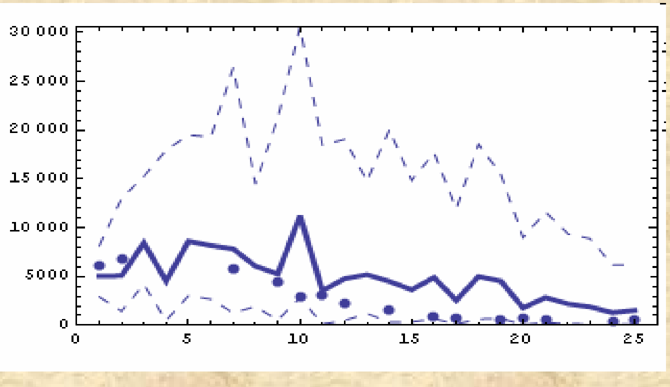
Is there a single set of parameters for the functional response that can emulate qualitatively different population dynamics?

Parameterisation

(Fitting to real data)







Summary of results from historical/forecasting single-factor simulation experiments

1. Predators	✘
2. Accessibility	✘
3. Prey availability	✘
4. Prey quality	✓
5. Prey depth	✓

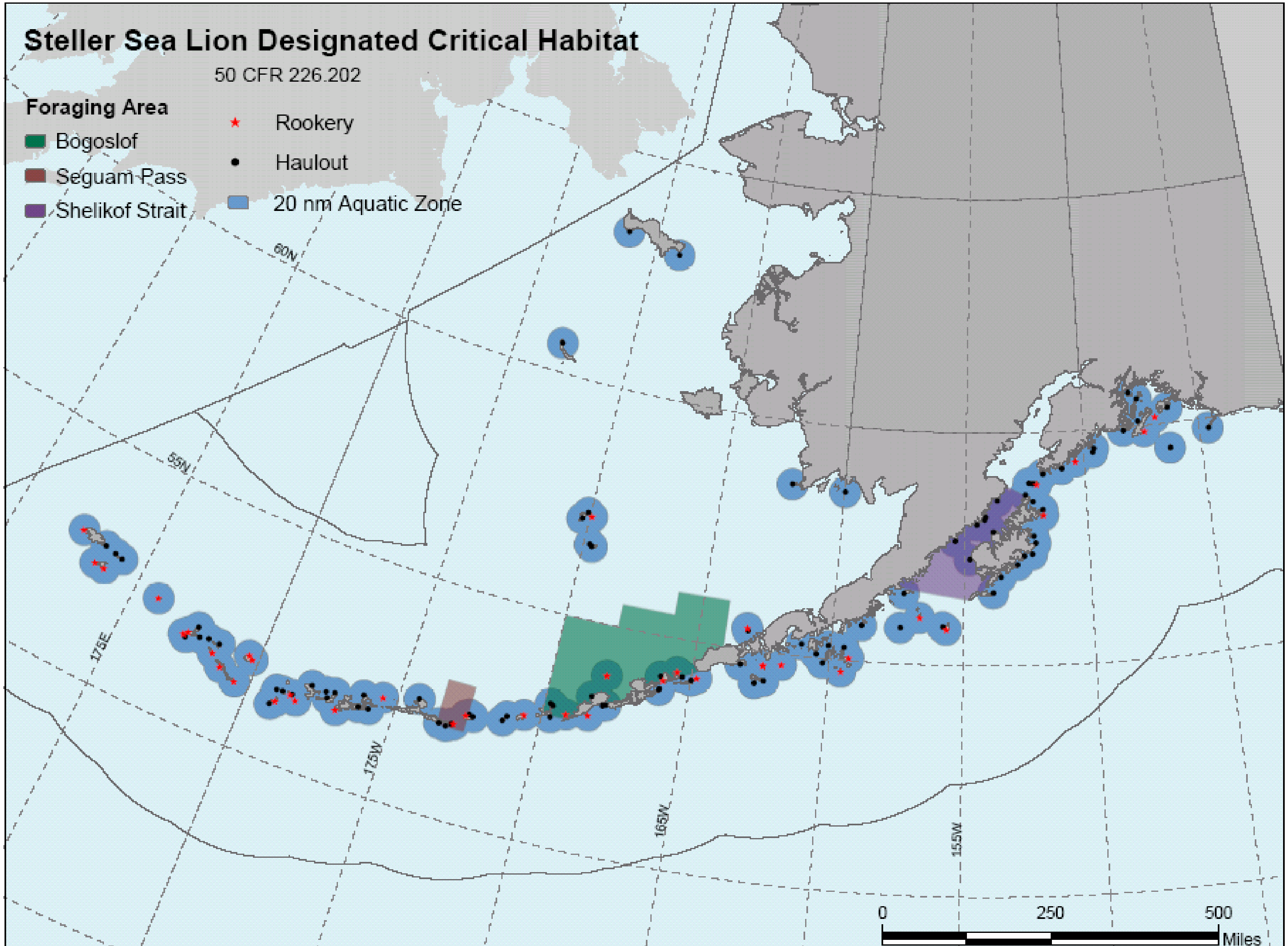
Recommendations from this work

Focus on protection of pelagic, energy-rich prey (Herring, Salmon).

Protection of the biomass of low-energy fish living close to sea bed (Polock, Cod, Mackerel) is not a major concern.

Geographical protection zones are best designed on the basis of the distribution of prey, not the SSLs.

Current protection regime (!)



Decline of common seals in Scotland

Common or Harbour seals (*Phoca vitulina*)

Start to breed at age 4

Up to 1 pup per year

Moulting season in the summer

Motivation

Observed declines in common seal counts could be due to:

1) Reductions in survival

2) Reductions in fecundity

3) Drift in the timing of moult

Demographic model

$$N_{t+1} = R_t N_t \qquad N_t = \begin{pmatrix} m_{1,t} \\ m_{2,t} \\ m_{3,t} \\ m_{4,t} \\ f_{1,t} \\ f_{2,t} \\ f_{3,t} \\ f_{4,t} \end{pmatrix} \qquad R_t = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{2} b_t \\ s_{j,t} & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & s_{j,t} & 0 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & s_{m,t} & s_{m,t} & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{1}{2} b_t \\ 0 & 0 & 0 & 0 & s_{j,t} & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & s_{j,t} & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & s_{f,t} & s_{f,t} \end{pmatrix}$$

Observation model

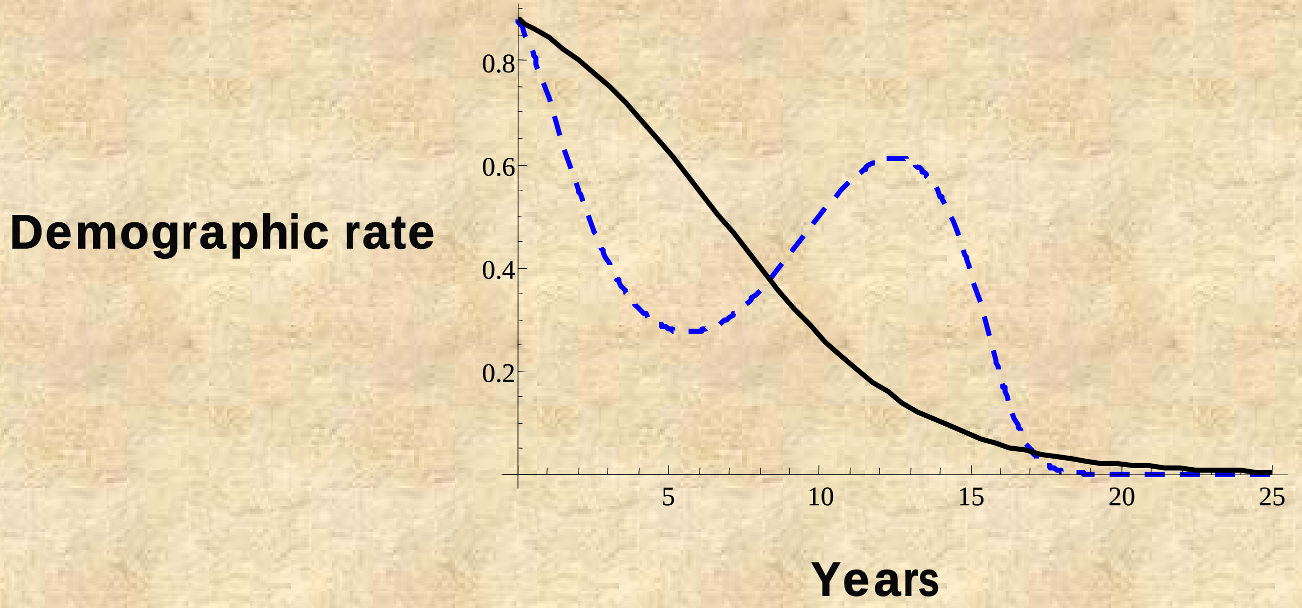
$$P_t = \sum_{i=1}^{4} \left(m_{i,t} \, p_{m,i,t}(d) + f_{i,t} \, p_{f,i,t}(d) \right)$$

Survival

$$s_{*,t} = \frac{\exp(\sigma_{*,0} + \sigma_{*,1}t + \sigma_{*,2}t^2 + \ldots)}{1 + \exp(\sigma_{*,0} + \sigma_{*,1}t + \sigma_{*,2}t^2 + \ldots)}$$

Fecundity

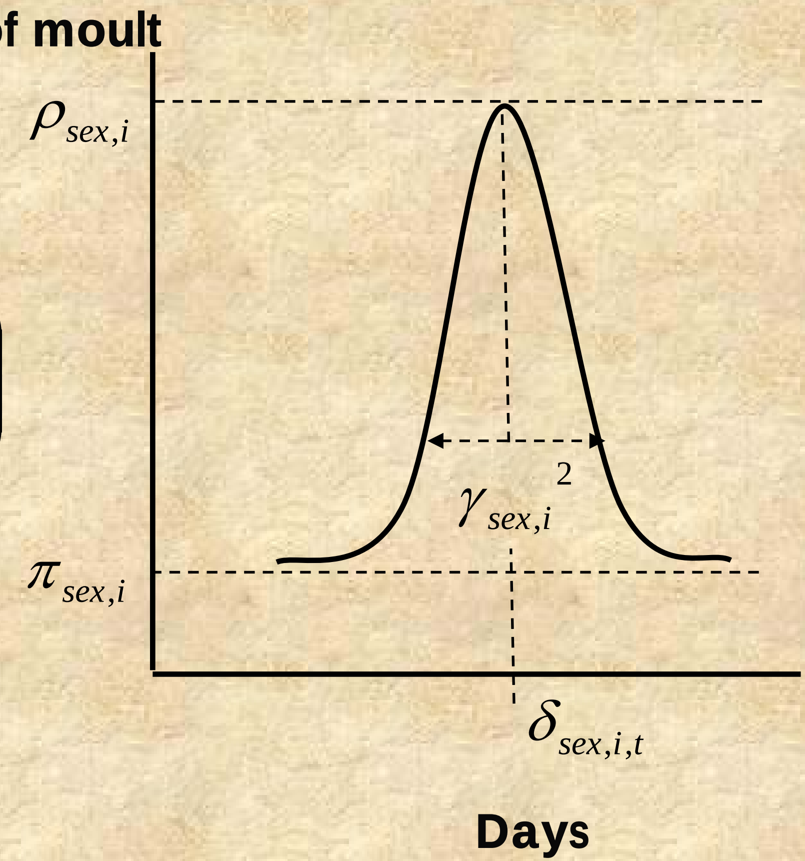
$$b_t = \frac{\exp(\beta_0 + \beta_1 t + \beta_2 t^2 + \ldots)}{1 + \exp(\beta_0 + \beta_1 t + \beta_2 t^2 + \ldots)}$$



Timing of moult

$$p_{sex,i,t}(d) = \pi_{sex,i} + \rho_{sex,i} \exp\left(-\frac{\left(d - \delta_{sex,i,t}\right)^2}{\gamma_{sex,i}{}^2} \right)$$

$$\delta_{sex,i,t} = c_{sex,i} + c_1 t + c_2 t^2 + \ldots$$



Parameterisation

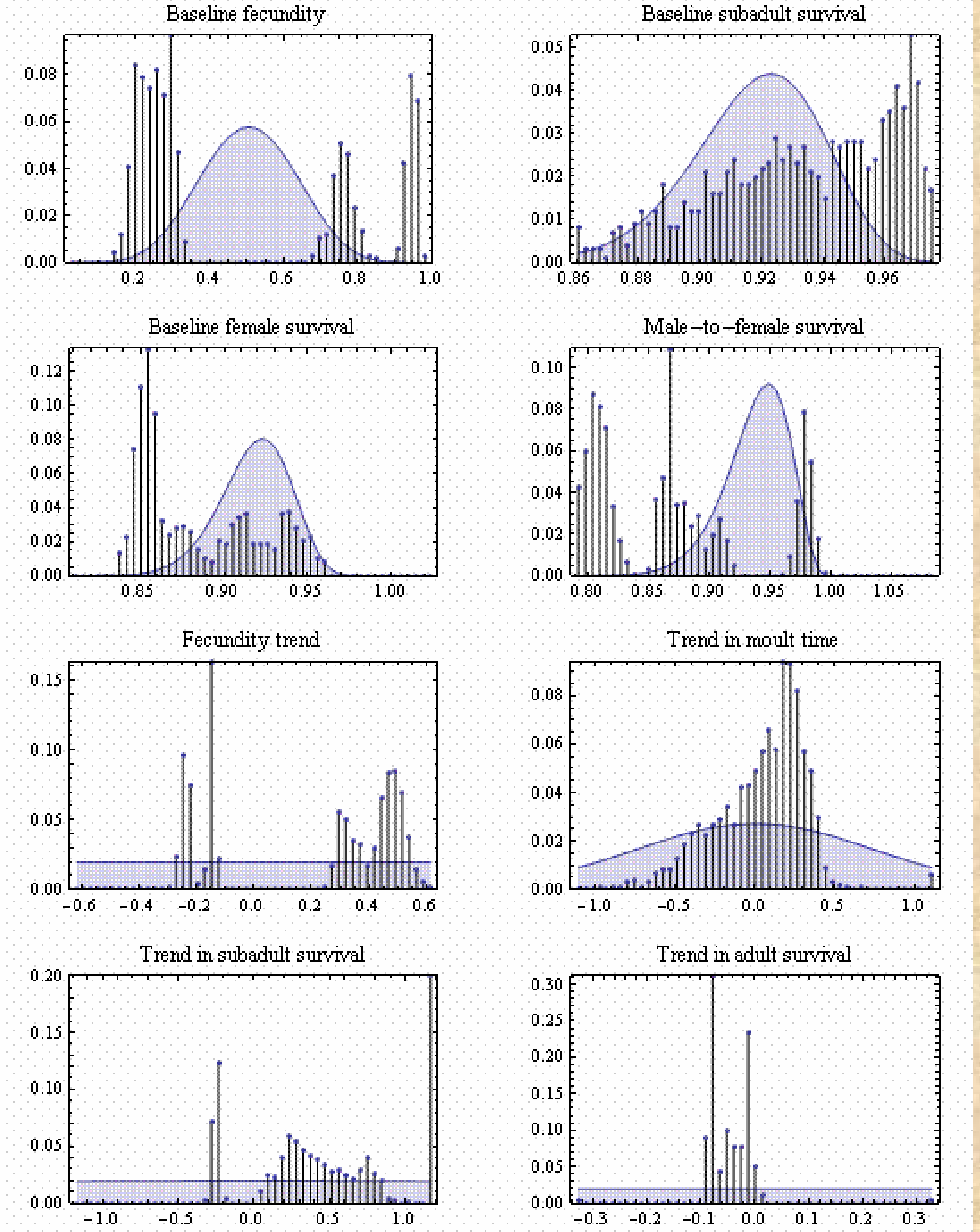
1. Baseline demographic parameters: Informative priors derived from historical mark-recapture studies

2. Trend demographic parameters: Uninformative priors, centred at zero

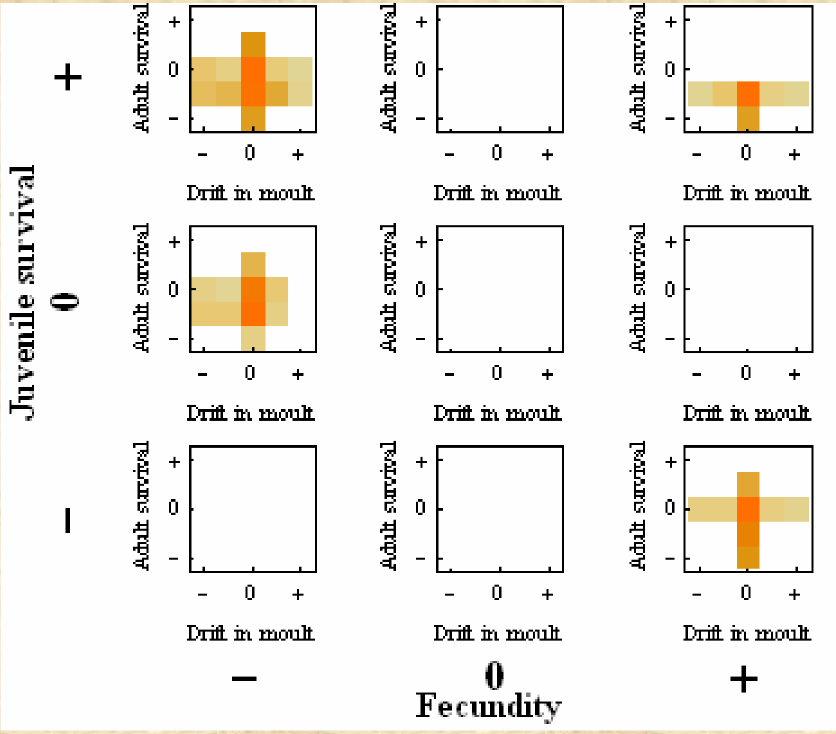
3. Moult haul-out probabilities: Mark-recapture study

4. Initial population structure: Calculated from baseline demographic parameters assuming that trends only became effective after initiation of observation

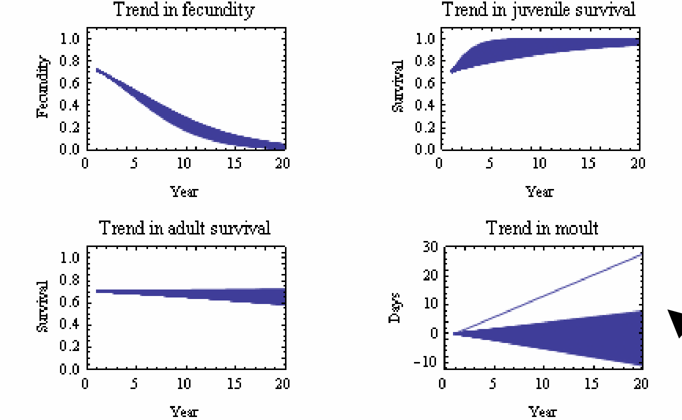
Prior/posterior plots

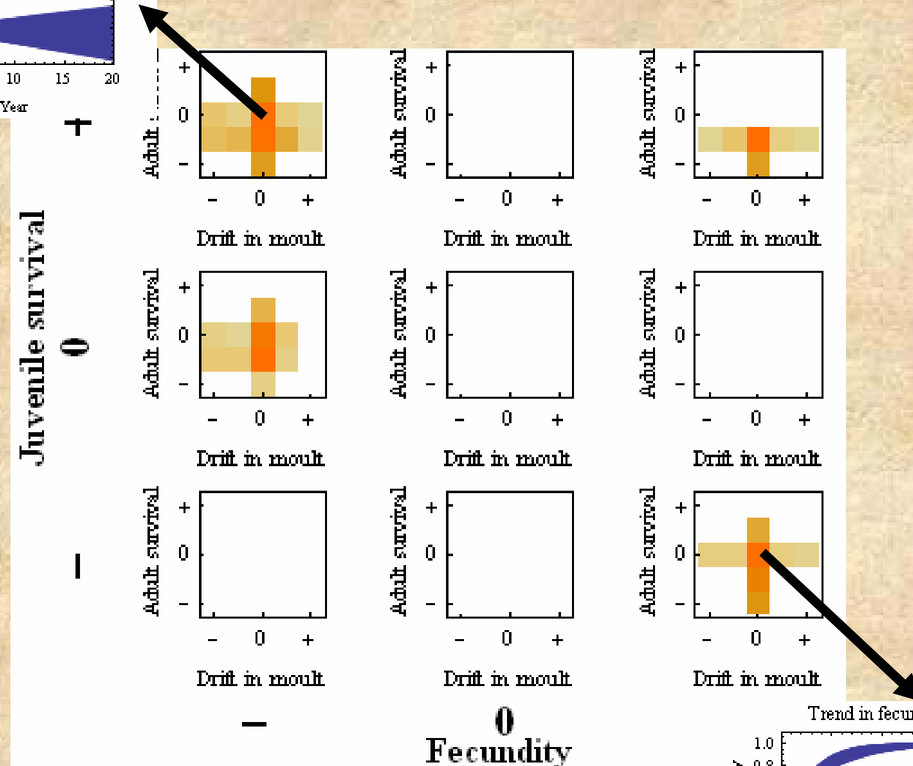


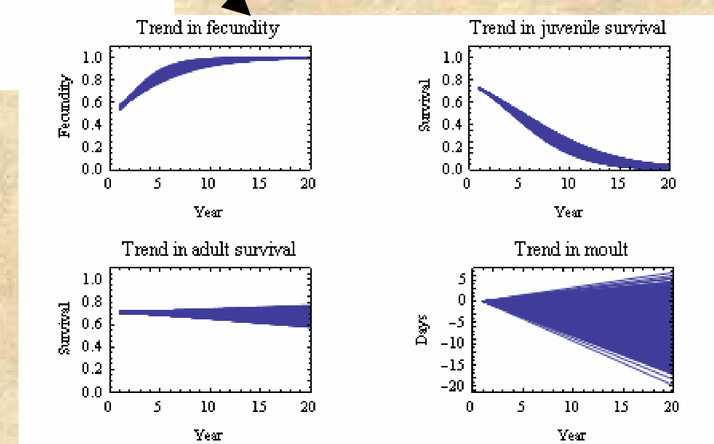
Results overview



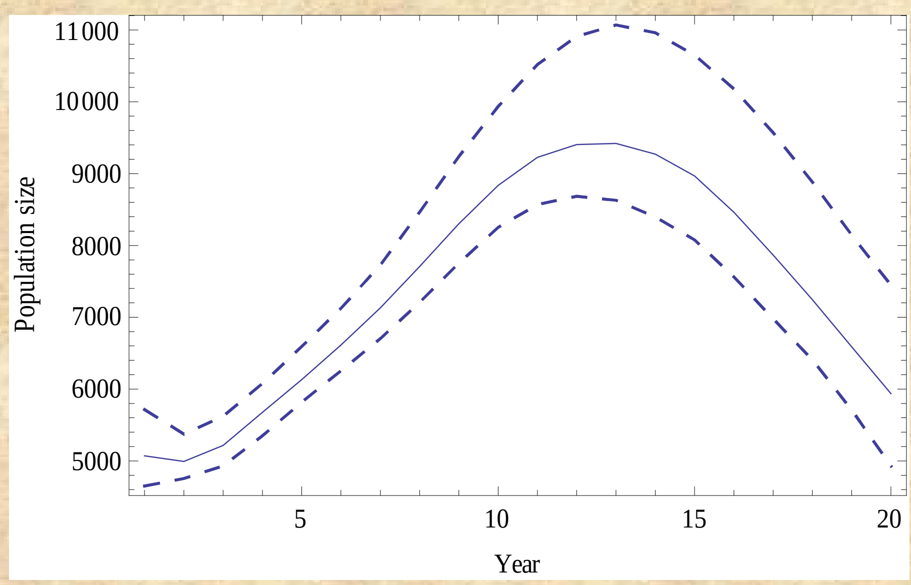
Results overview







Population estimates



Conclusions

1) A finite number of dominant explanations which are, currently, confounded

2) Nevertheless, it seems unlikely that the observations are an artifact of drift in the timing of moult

3) There seems to be some evidence that population is declining

Comparison of approaches to case studies

Steller sea lions

1) Mostly mechanistic
2) Mostly parameterised
3) Slow
4) Highly predictive
5) Certainly mis-specified
6) Deals with ultimate causes
5) Useful for mitigation

Common seals

1) Mostly phenomenological
2) Mostly fitted
3) Fast
4) Mostly descriptive
5) Possibly mis-specified
6) Deals with proximate causes
7) Useful for elimination

20/20 hindsight

Detailed simulations of ultimate causes may seem like the quickest route to informing policy on management and conservation

However, such models are hard to estimate and tend to get lost in the multiplicity of possible mechanisms and end up being more academic than practical

State-space modelling enables estimation of the relative strength of demographic drivers

These can then be fleshed-out incrementally with biological detail, subject to data and computational restrictions

Parameterisation
(Validation with adult counts)