POP2012-02

New Zealand sea lion – demographic assessment of the causes of decline at the Auckland Islands

I — Introduction & Finding Candidate Models

CSP Technical Working Group

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Project objectives & methodology

Project Objectives:

“To identify which demographic parameters are the key drivers of the observed population decline of NZ sea lions at the Auckland Islands.”

“To identify potential demographic mechanisms through which both direct and indirect effects of fishing can impact on sea lion population size at the Auckland Islands, or increase susceptibility of the population to such effects.”

Methodology:

1. Demographic modelling - **proximate** causes of decline
   - Temporal variation in demographic rates: e.g., survival & pupping
   - Fitting to mark-resighting data, age distribution data, and annual pup estimates
2. Correlative analysis - **ultimate** causes of decline
   - Relationships to fishery-related mortalities, pup weights, diet, prey abundance, climate, *etc*.

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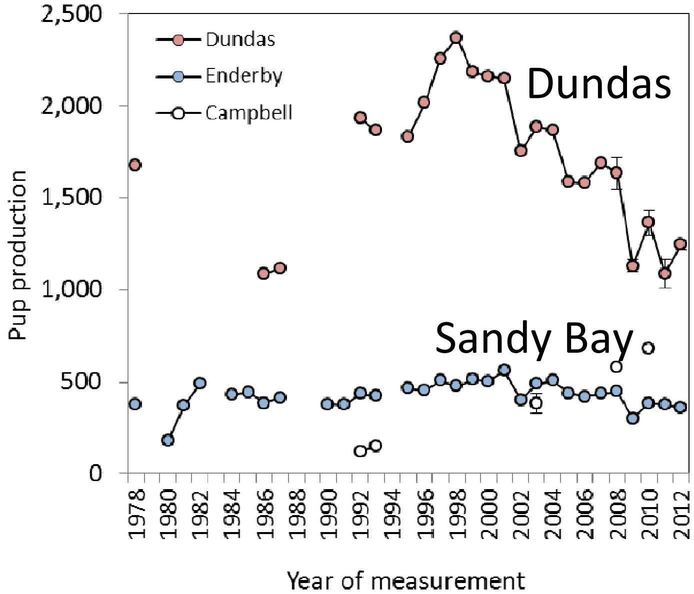
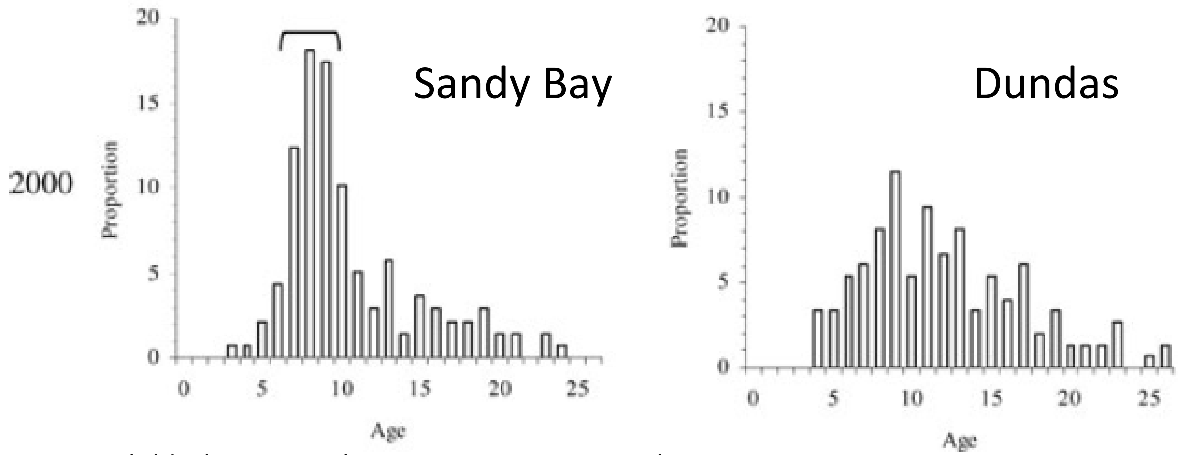
Decline of NZ SLs & area effects



- McKenzie & Chilvers (2012) previously estimated survival and breeding rates at Enderby
- Dundas the largest breeding rookery
- Species assumed to be highly philopatric
- Evidence for rookery effect on population dynamics



Childerhouse *et al.* 2010 *Marine Mammal Science 26:* 123-139.

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Modelling approach

1. **Construct a state-space demographic model using NIWA's SeaBird package -** use mark-recapture observations to estimate survival, pupping probabilities and resighting probabilities.
2. **Develop into a population model** – fit to pup production estimates and age distributions
3. Partition mortality to fishery related mortalities, disease, etc
4. Relate demographic parameter trends to biological and environmental correlates

Reporting results for 1 and 2 only

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SeaBird modelling software

- SeaBird software already used to conduct demographic assessments of 4 NZ seabird species
- SeaBird allows the analysis of individual (*i.e.*, non-aggregated) mark-resighting observations.
    - extension of Cormack-Jolly-Seber model (Cormack 1964; Jolly 1965; Seber 1965)
- Allows integrated analysis, e.g. age distributions, pup production estimates and mark-resighting data.
- User-defined model partitioning (*e.g.* age, area, or breeding status), transitions and equations representing demographic processes.
- Allows Bayesian or likelihood based parameter estimation

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Observations

Sandy Bay (then Dundas)

Female only

<u>Initial demographic model</u>

•**Tagged as pups** from 1990-93 & 1998-2011

•Branded animals omitted (initially we were not dealing with tag shedding)

•Resighting from 1999-2012

<u>Population models</u>

•**Age distribution** lactating females 1998 to 2001 (Childerhouse *et al.* 2010)

•**Pup production** estimates – all with high level of confidence (level 1 or 2, as specified in Breen model report).

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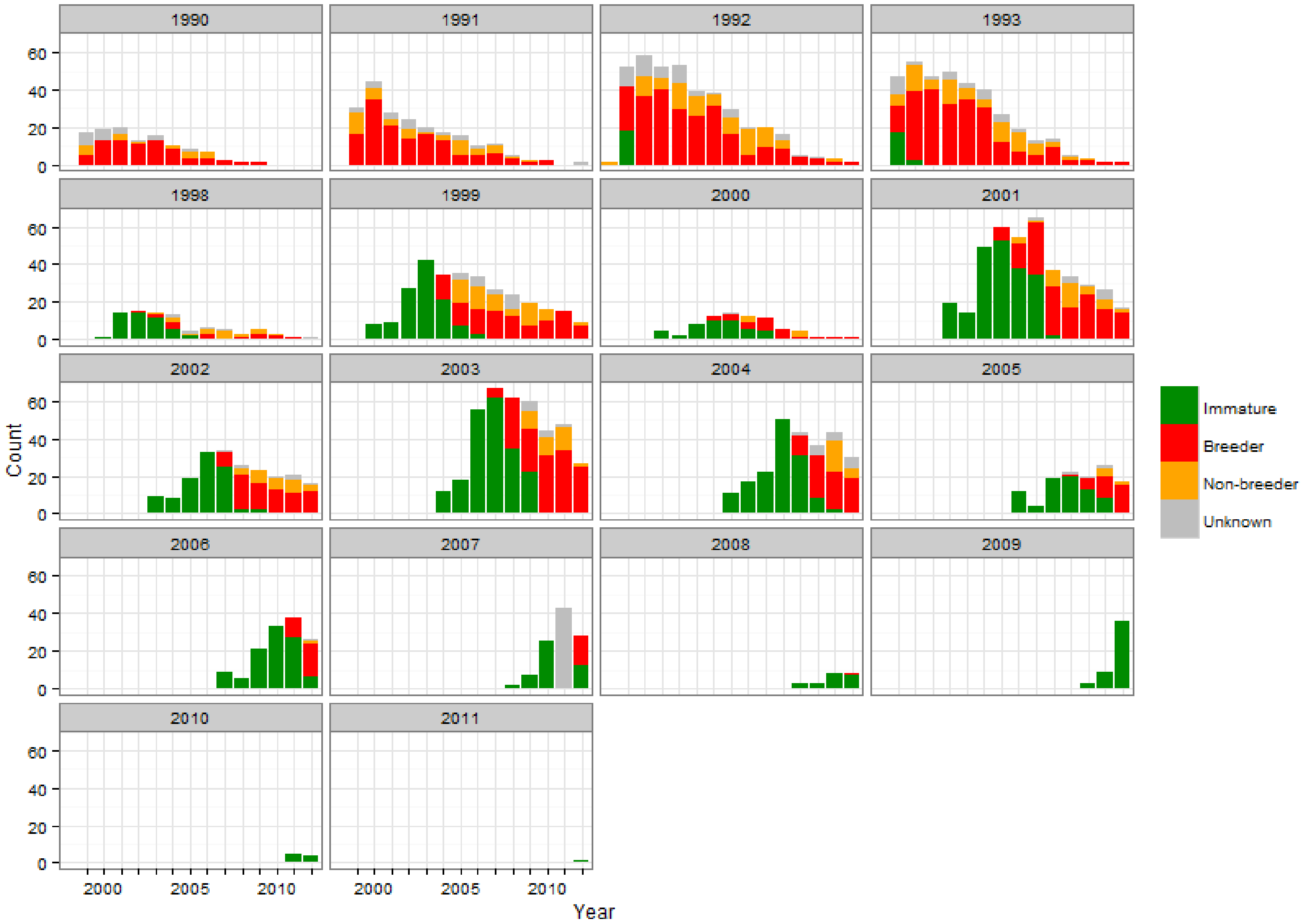
Tag-recapture obs SANDY BAY



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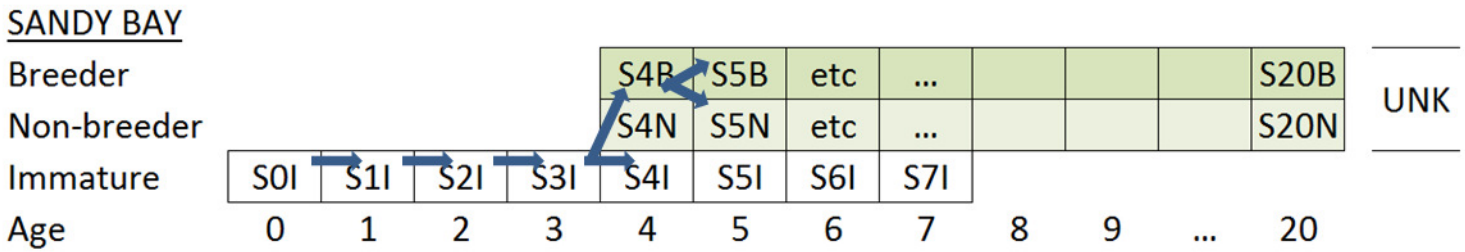
Model partitions & transitions

- Two types of partition:
  1. Age (**0** to **20**)
  2. Breeding status (**I**mmature, **N**on-Breeder, **B**reeder, **U**nknown)
     1. Last three really about pupping at a known rookery
- Rules govern annual transition from one cell to next



- Replicate age & breeding status partitions to allow for 2, 1, or 0 tag to estimate tag shedding
  (work in progress)

MARK model to cross-compare SeaBird

- Analysis by Mark Hindell & Clive McMahon at Univ. Tasmania
- White & Burnham 1999, Cormack–Jolly–Seber (CJS) model
- Fitted to mark-resight data only
- Sandy Bay data, 3602 female pups, 1990-2011
- Corrected for the extra-binomial variation in the data by the variance inflation factor $\hat{c}$ (Lebreton et al. 1992)
- Use QAICc to rank models

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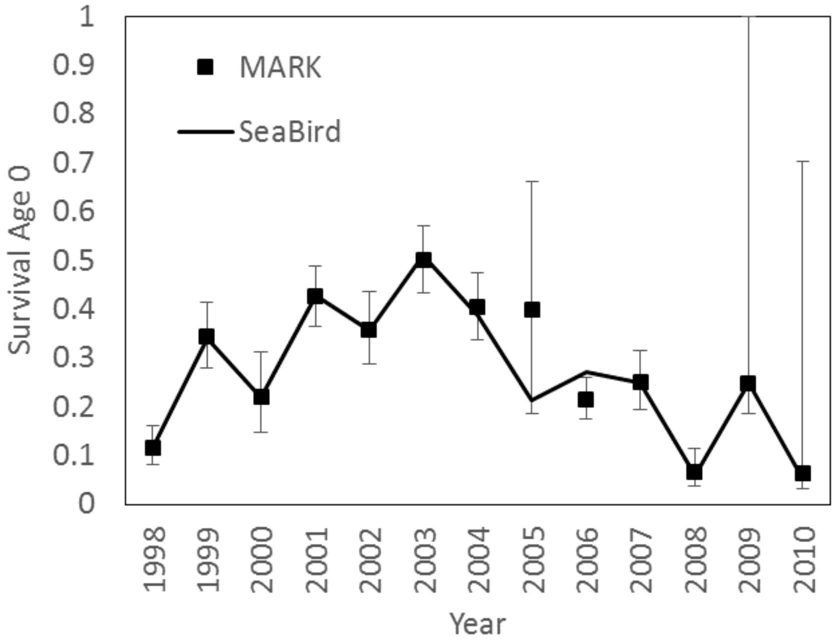
MARK analysis

- Needed over-dispersion factor
- No pupping status used
- Best model used
  - 36 parameters
  - Survival age groups: 0, 1-3, 4-14, 15+
  - Annual resighting probabilities
    - 1990-1998: 0%
    - 1999-2011: 41% to 67%
  - no 0+ survivals for 1991-93 since resight was 0
- Noted that 1-3 year-olds survival estimates are uninformative

MARK v SeaBird estimates



- MARK and SeaBird give near-identical estimates of survival with the similar model configuration
- SeaBird still used pupping status state with resight set to 1 for animals pupping
- Did not investigate differences between SeaBird & Mark for 2005 & 2006

Model development

1. Tag-recapture observations only
   - Investigation of age, cohort & year effects on parameter estimates
   - Tag shedding
   - Model configuration/optimisation
   - MCMC
2. Tag+age observations
   - Strong/weak cohorts in tag and age data?
   - Good fits to both datasets?
3. Tag+pup production
   - Variation in demographic rates explain pup counts?

Model development 1 – tag-resighting obs only

- Age effects
  - blocking of estimates & functional forms
- Cohort effects
- Year effects
  - effects of number of resighting years
- Tag-shedding
- Model optimisation by AIC
- MCMC

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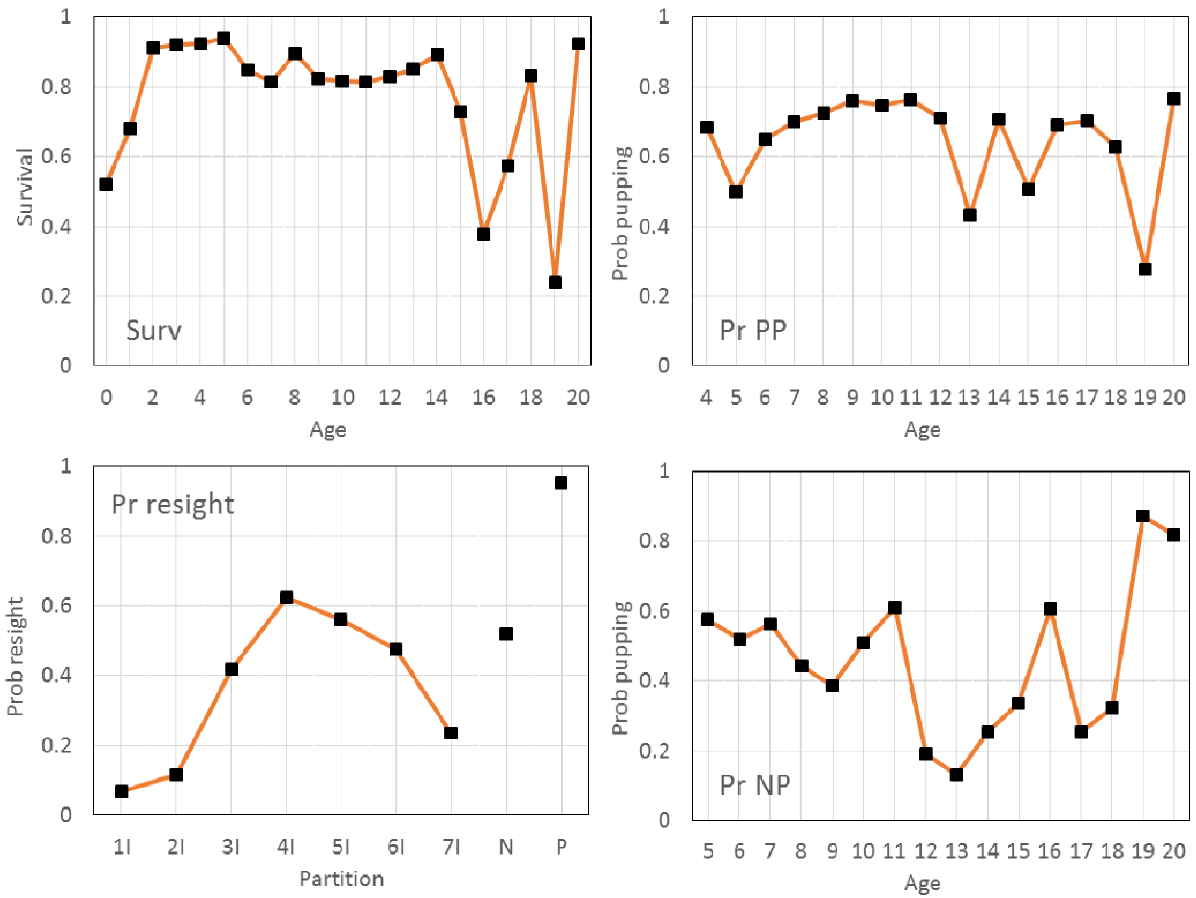
Age effects



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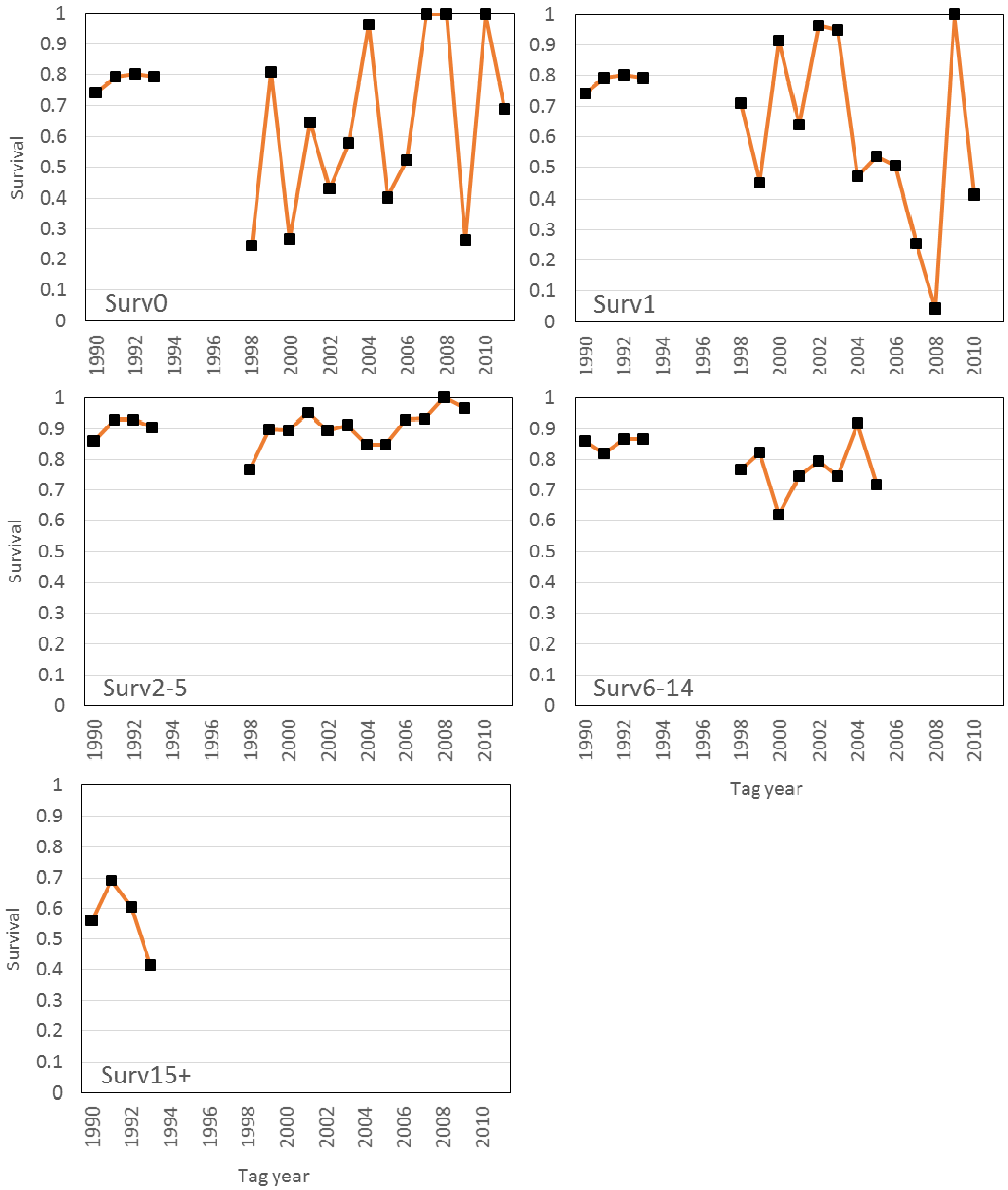
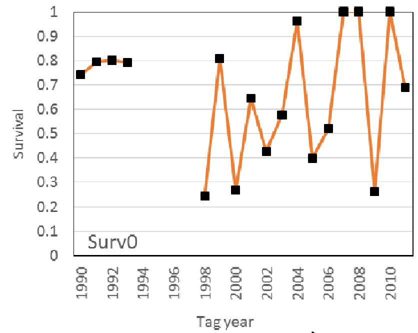
Age effects – summary

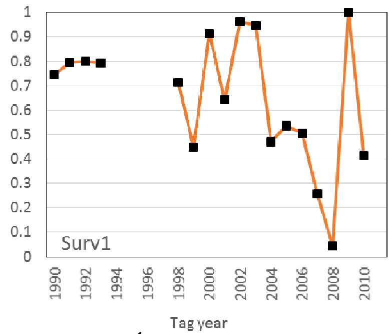
- Peak survival at ages 2-5
- Reduced survival at ages 15+
- For now, used survival age groups: 0, 1, 2-5, 6-14, 15+
- Increase in annual resighting probability up to age 4 (first pupping), then similar to that of non-puppers (~0.5)
- >95% resighting probability of puppers
- Resight groups are: ages juveniles ages 1,2,3, 4, 5, 6, 7; non-puppers, puppers
- Limited evidence for reproductive senescence
- Functional forms to represent changes in survival with age, maturation & reproductive senescence

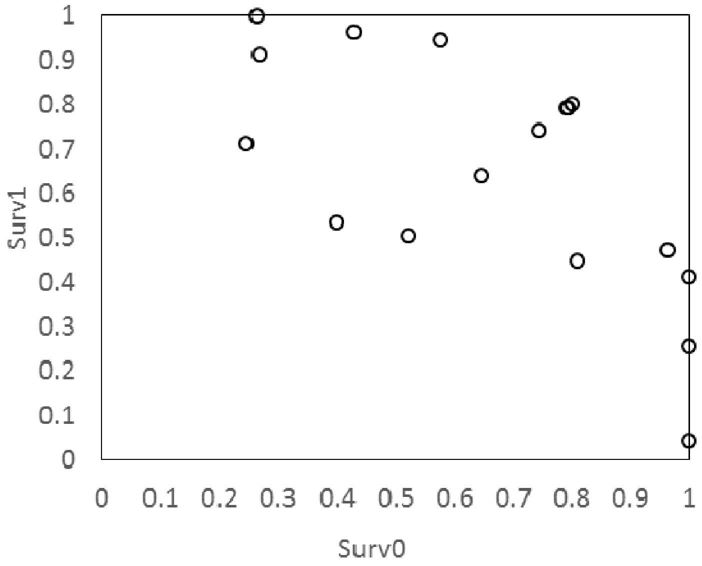
Cohort effects – survival at age

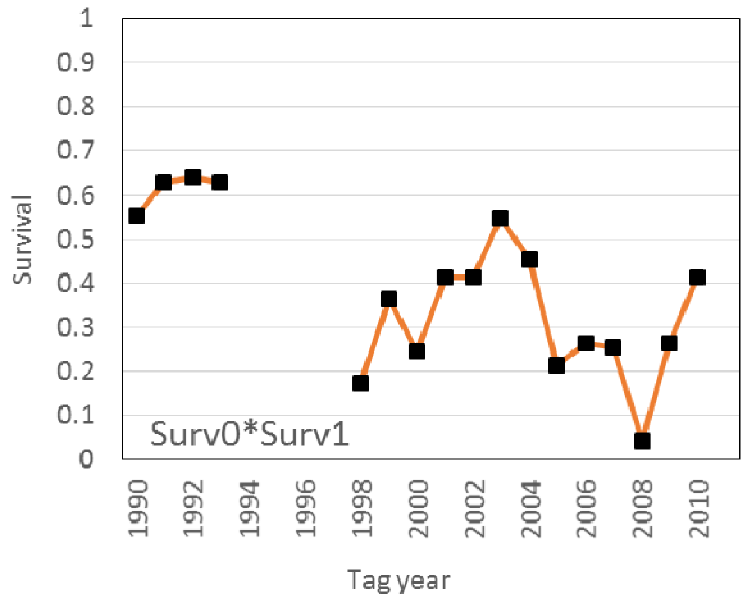


Cohort effects – Survival estimation ages 0 & 1

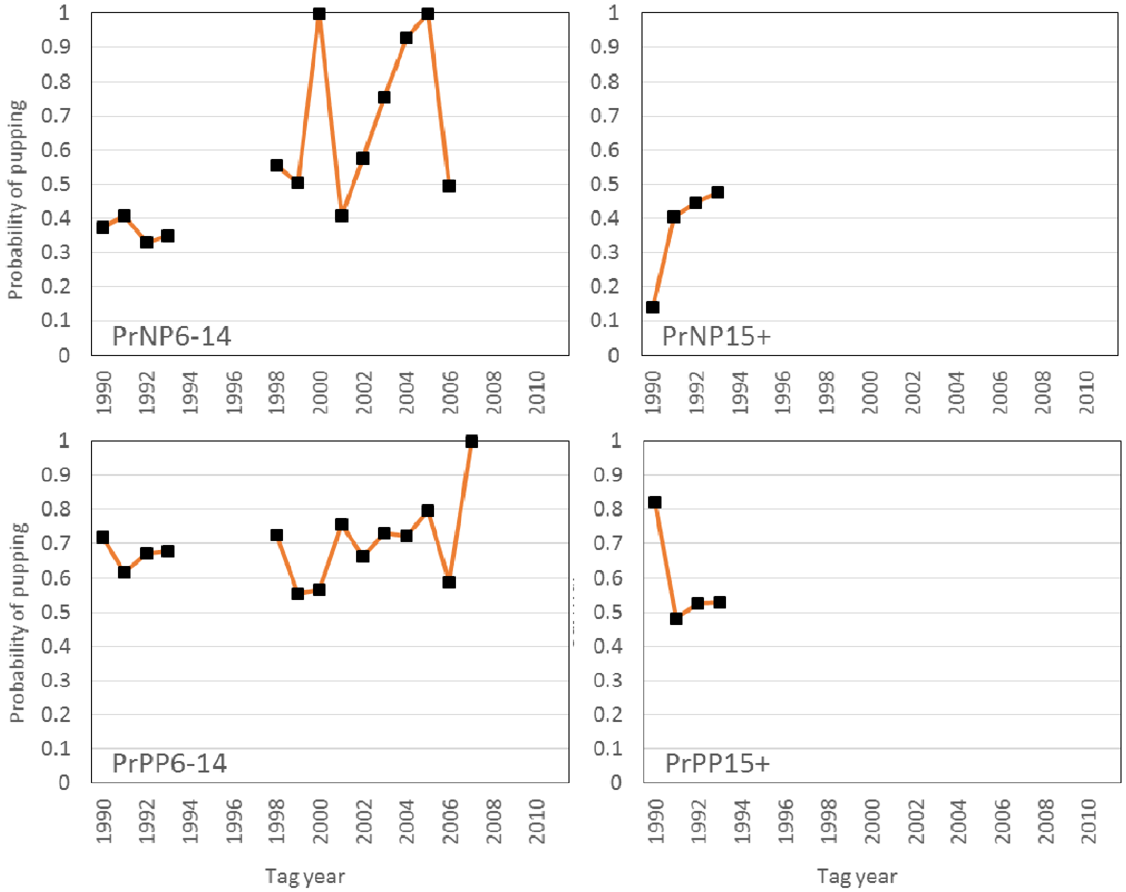








Cohort effects – pupping probability



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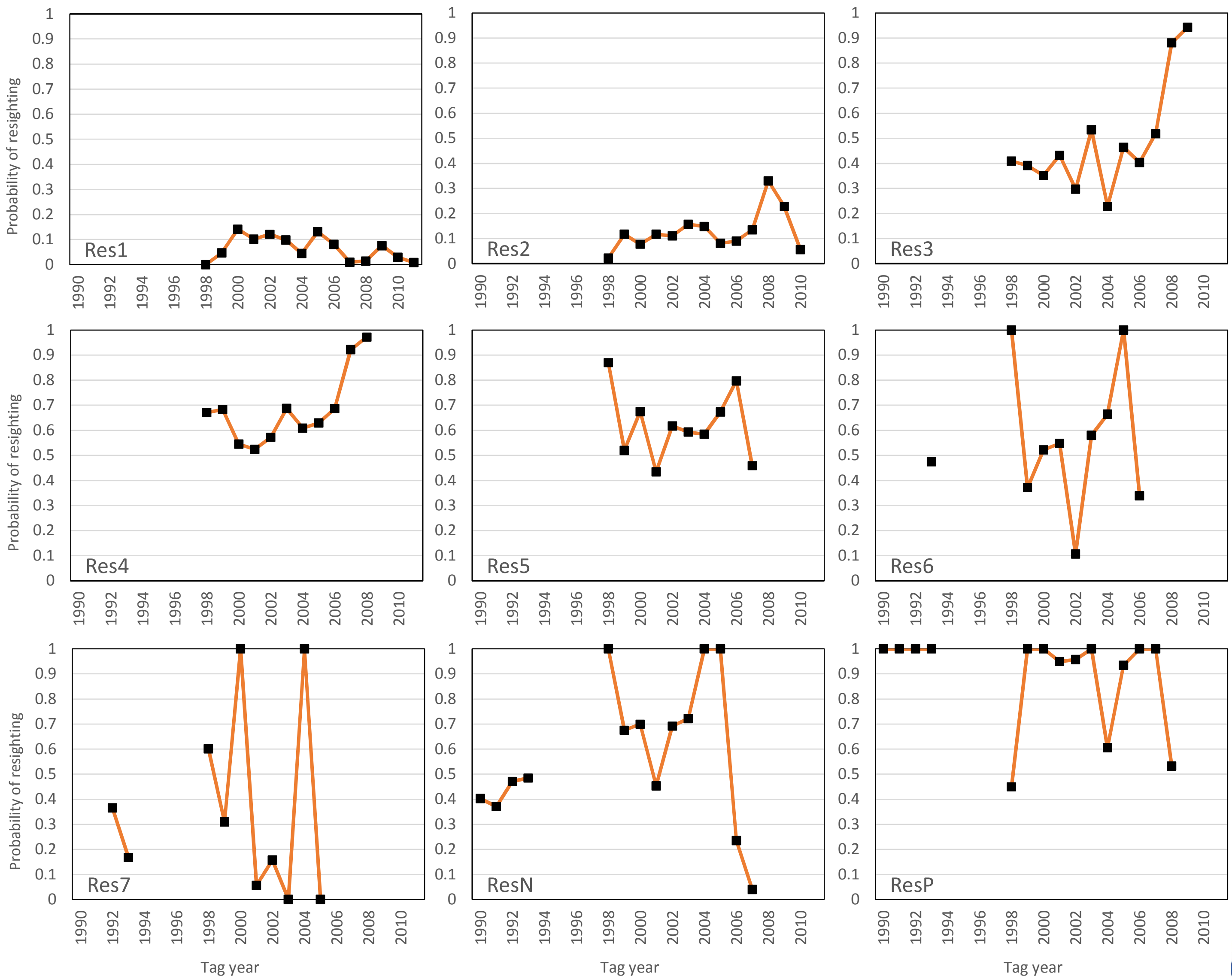
Cohort effects – annual resighting probability



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Cohort effects – summary

- Not all cohorts influence parameter estimation in all years
- Strong cohort effect on survival at ages 0 and 1
- Negative correlation survival ages 0 and 1 – few resightings at these ages, though still long-term trends
- 1990-93 cohorts (single-tagged) have good survival at all ages, though pupping rates not greater than subsequent cohorts
- Evidence for cohort effect on pupping rates

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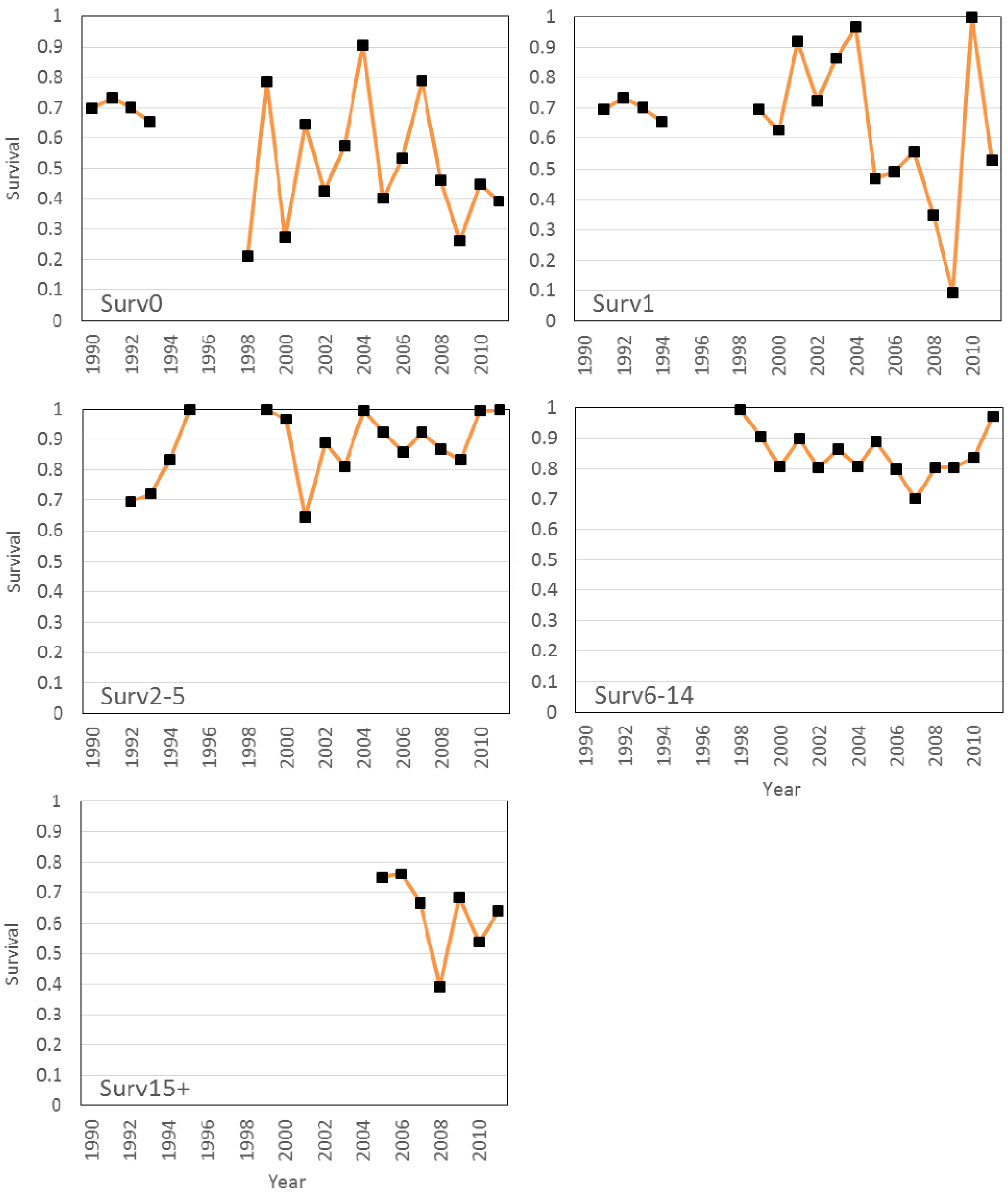
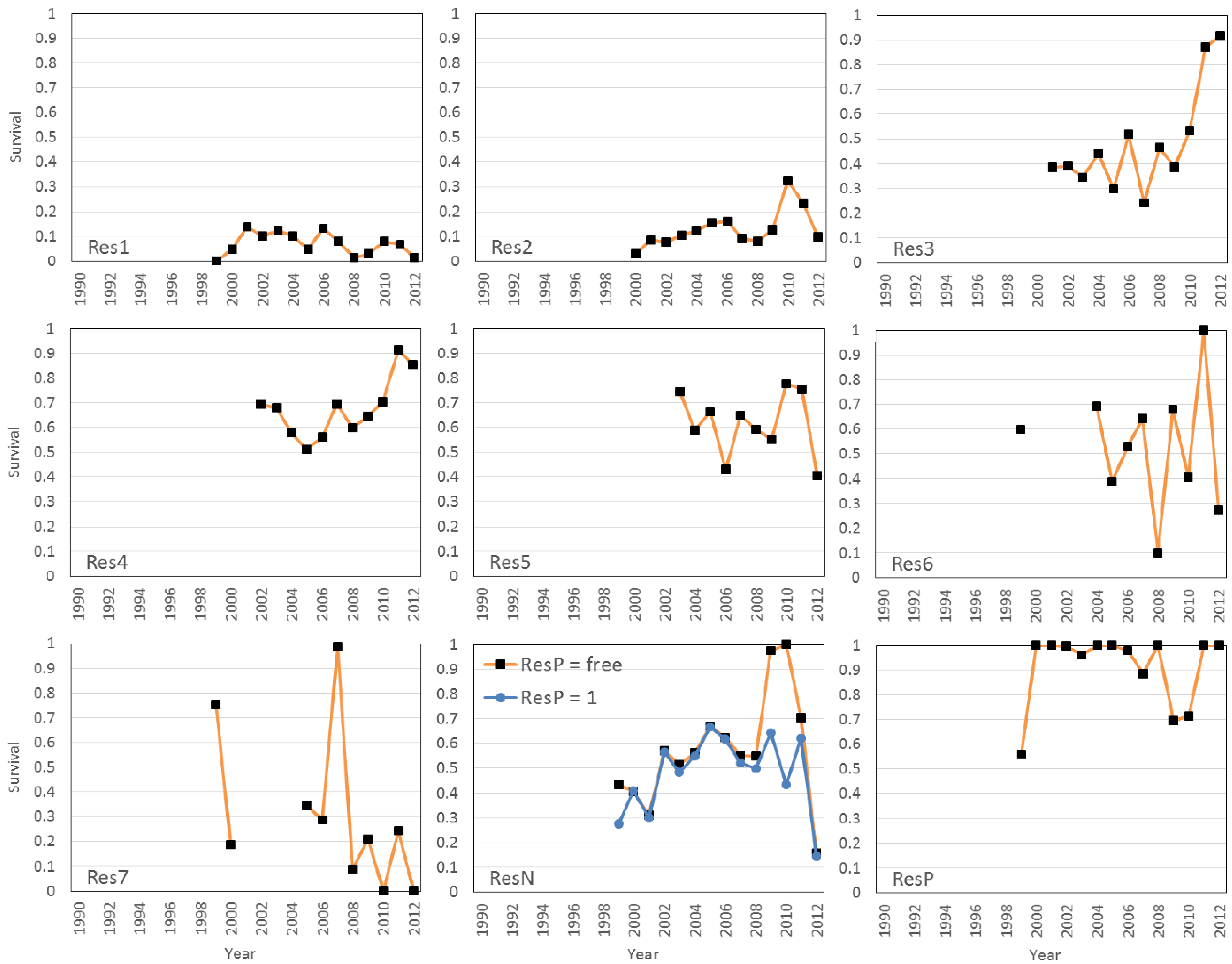
Year effects – survival



Year effects – resighting probability



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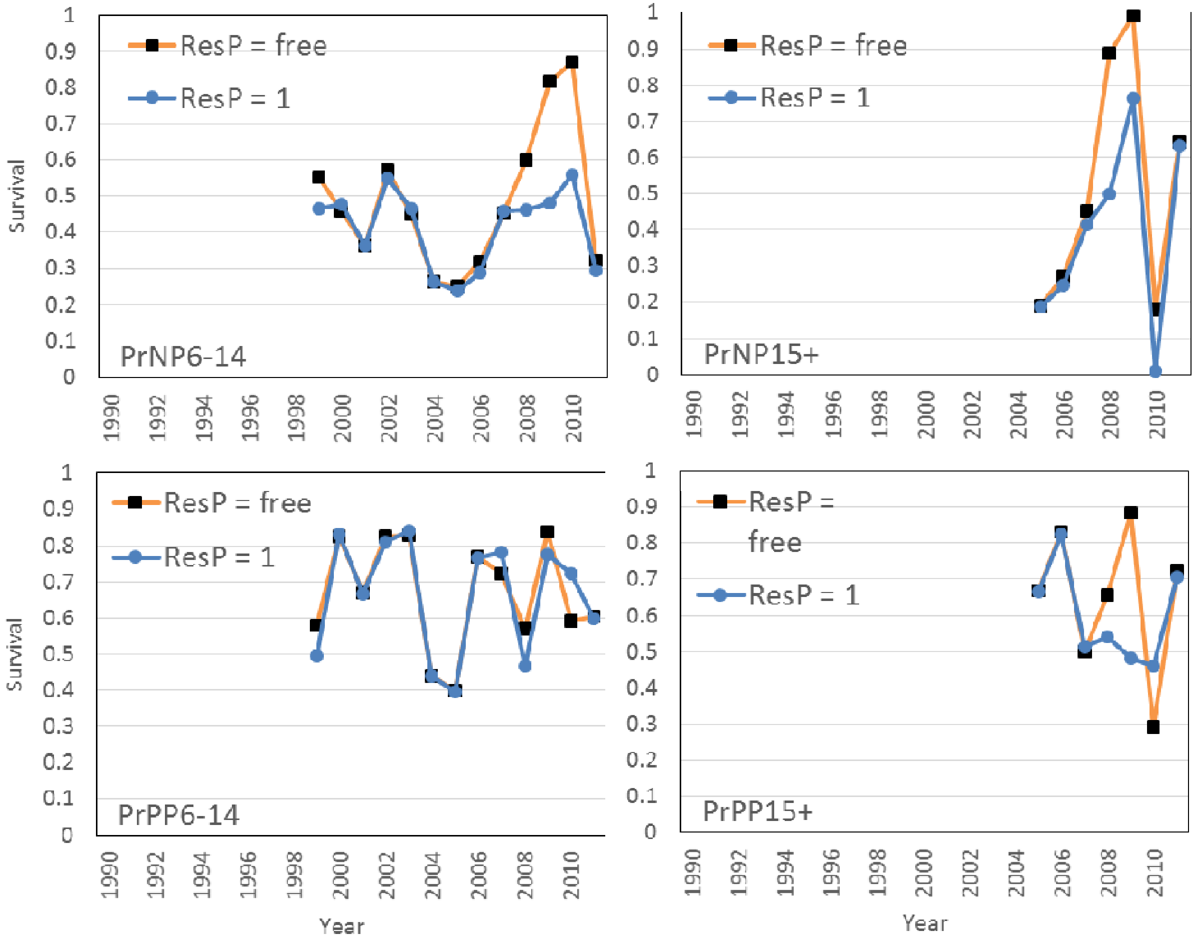
Year effects – pupping rate



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Year effects – summary

- Greatest variation in survival of ages 0 & 1 – consistently high in early 90s; variable since 1998.
- Limited evidence for decline in survival of ages 2-5 & 6-14.
- Prob. of puppers pupping should be fixed (variation through time may indicate skipped pupping).
- Increased resighting probability of ages 3 & 4
- Low probability of puppers & non-puppers pupping in 2002, 2005, 2006 & 2009. No long-term trend.

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Model optimisation

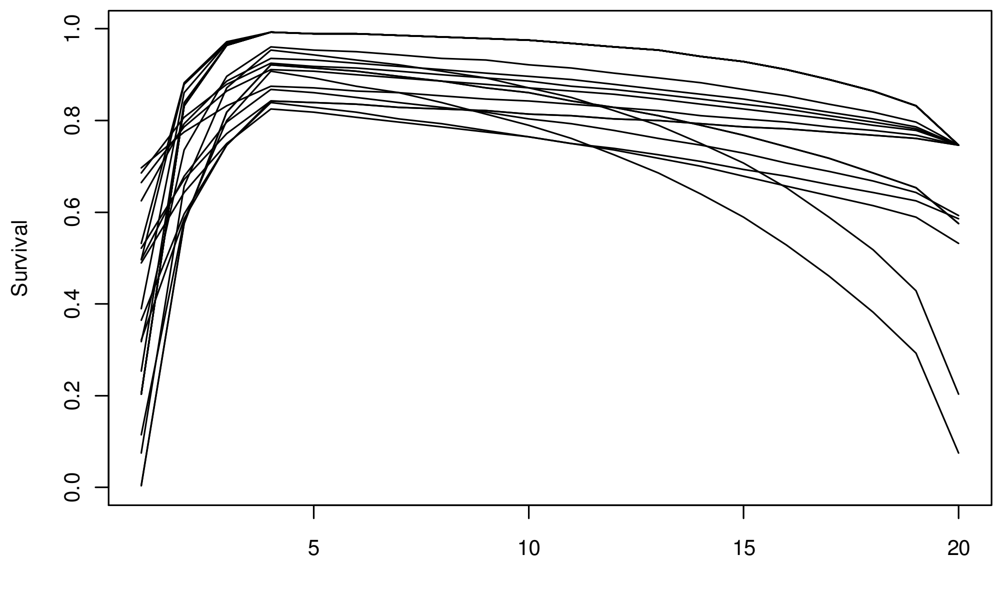
- Explore different parameterisations
- Age effects - functional forms v age blocks
  - Survival
  - Resighting probability
  - Pupping rate
  - Maturation
- Year varying/invariant
- Optimisation
  - Fits to mark-resighting data
  - Model comparison by AIC

Functional forms - survival

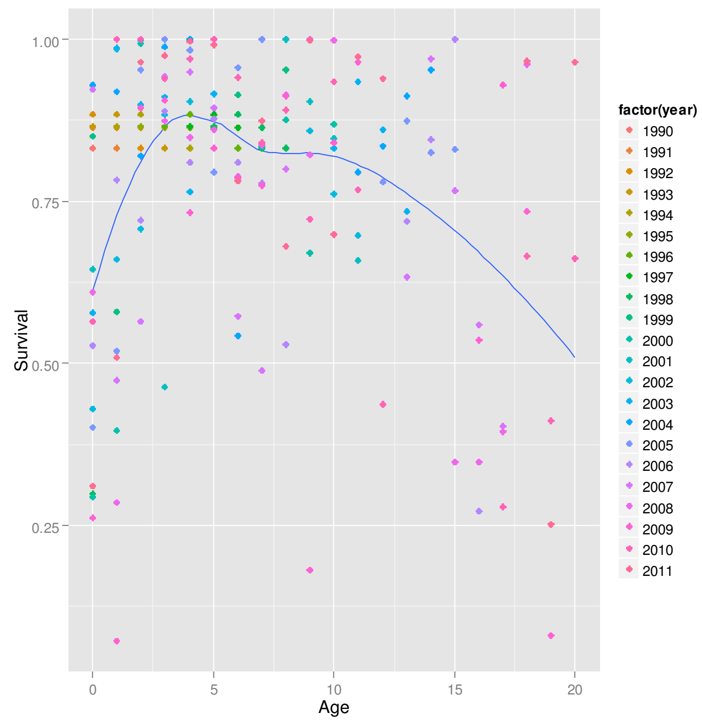
Investigated the parameterisation by Gilbert (2008)

$$
\mathrm{m}(a \mid \underset{\sim}{\mu}) = \begin{cases} \mu_1 \left(\dfrac{\mu_3}{\mu_1} \right)^{\left(\frac{a-\mu_2}{0-\mu_2} \right)} & a \le \mu_2 \\ \mu_1 \left(\dfrac{\mu_4}{\mu_1} \right)^{\left(\frac{a-\mu_2}{20-\mu_2} \right)} & a > \mu_2 \end{cases}
$$

μ_1: the minimum mortality rate
μ_2: the age for the minimum value
μ_3: mortality at age 0,
M_4: mortality at age 20



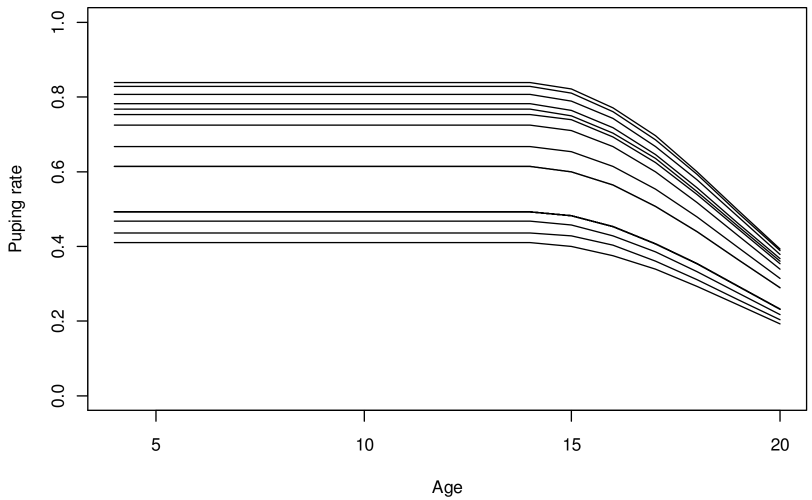
The data suggested maximum survival between age 3 and 5 and then declines with age



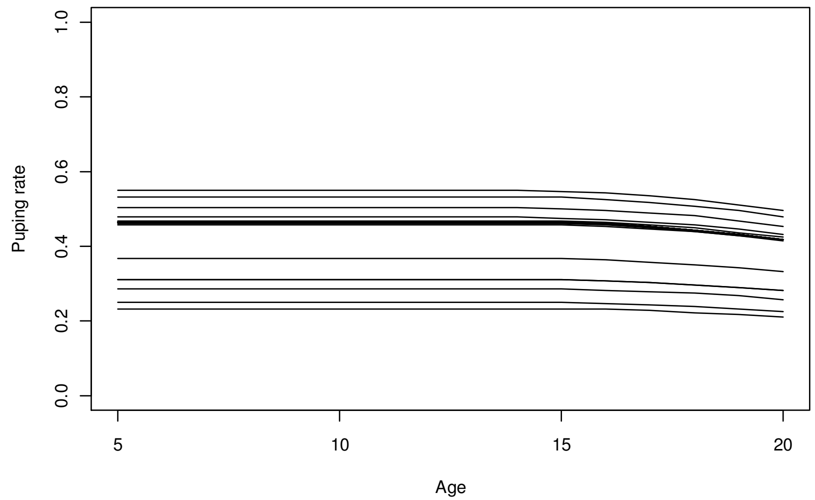
Functional forms - pupping

Investigated a slight variation of the parameterisation by Gilbert (2008), assuming a constant breeding probability up to age 14 then declines To half the value at certain age (estimated)

Puppers pupping



Non-puppers pupping



Models assuming functional forms shows no evidence of improvement in terms of objective function values or fits compared to models with separate parameters by age

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Functional forms – maturation

Probability of first breeding at age (transition from juvenile to breeder)

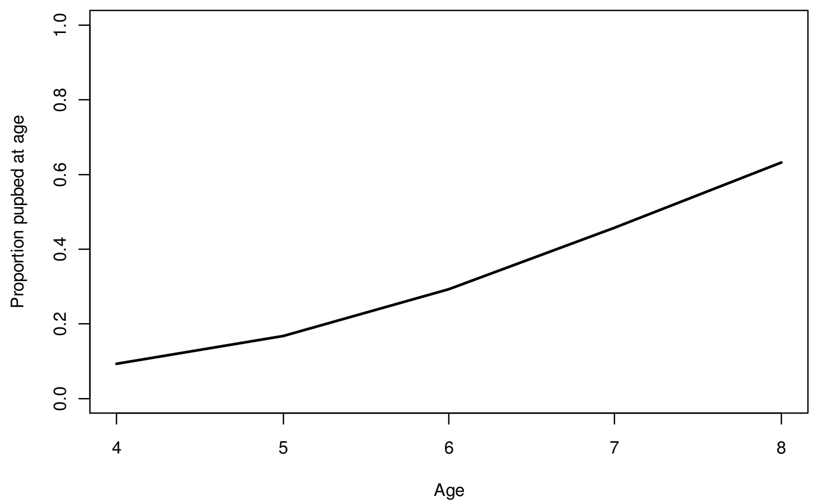
- A juvenile at age a-1, survived to age a, either breeds first time at age a with probability $PrB1st_a$ or remains as a juvenile

$$\log it(\Pr B1st_a) = \log it(\Pr 1st_{a-1}) + (a-4)oddsmult \quad \text{Where} \quad 4 \le a \le 8$$

Estimated two parameters (investigated time-varying)

$PrB1st_4$:Probability of first breeding at age 4

oddsmult: Slope of linear relation between logit(P1stbra) and age a



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Finding candidate models:
Parameters estimated (selection by AIC)

- Annual **survival** estimates for age groupings 0, 1, 2-5, 6-14, 15+
  - Survival at Age 15+ is time-invariant
  - All others have separate estimate for years where data informative

- Annual **breeding probability** for Age 4+ individuals
  - Separate estimates for breeders and non-breeders
  - All time-varying (1998-2011)

- Annual **resighting probability** of age groupings 1-2, 3, 4I-5I, 6I, 7I, B, N
  - Separate estimates for breeders and non-breeders
  - All time varying 1999-2011
  - Decline in resighting probability estimated of breeders after mid-2000s suggests a problem as nearly all breeders should be resighted in every year since 1999. This can be fixed to 1 – all resighted.

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Fits to tagging observations – finding candidate model

Model run	Survival estimates Age	Survival Yr groups	Breeding Prob estimates Age	Breeding Prob Yr groups	Resighting prob estimates Age	Resighting prob Yr groups	Maturation	LL	params	AIC
7a	0, 1, 2-5, 6-14, 15+	15+ time invariant	4+ (P), 4+ (N)	Separate estimates all yrs	1-2,3,4-5,6,7,N	1-2 time invariant	Time varying	-7976.2	178	16,308 ‡
6b	0, 1, 2-5, 6-14, 15+	15+ time invariant	4+ (P), 4+ (N)	Separate estimates all yrs	1-2,3,4-5,6,7,N	1-2 time invariant		-8023.6	152	16,351
6d	0, 1, 2-5, 6-14, 15+	15+ time invariant	functional form	a4 & b4 time invariant	1-2,3,4-5,6,7,N	1-2 time invariant		-8022.8	154	16,354
6a	0, 1, 2-5, 6-14, 15+	15+ time invariant	4+ (P), 4-14 (N), 15+ (N)	Separate estimates all yrs	1-2,3,4-5,6,7,N	1-2 time invariant		-8020.5	159	16,359
5j	0, 1, 2-5, 6-14, 15+	15+ time invariant	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1-2,3,4-5,6,7,N	1-2 time invariant		-8017.1	166	16,366
4m	0, 1, 2-5, 6-14, 15+	0 & 15+ time invariant	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1,2,3,4,5,6,7,N	Separate estimates all yrs		-7999.6	185	16,369
5m	0, 1, 2-5, 6-14, 15+	6+ time invariant	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1-2,3,4-5,6,7,N	1-2 time invariant		-8032.2	153	16,370
6c	0, 1, 2-5, 6-14, 15+	15+ time invariant	functional form	Separate estimates all yrs	1-2,3,4-5,6,7,N	1-2 time invariant		-8019.3	166	16,371
5l	0, 1, 2-5, 6-14, 15+	0 & 15+ time invariant	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1-2,3,4-5,6,7,N	1-2 time invariant		-8036.4	149	16,371
5d	0, 1, 2-5, 6-14, 15+	15+ time invariant	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1-2,3,4-5,6,7,N	Separate estimates all yrs		-8008.5	179	16,375
5b	0, 1, 2-5, 6-14, 15+	15+ time invariant	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1,2,3,4-5,6,7,N	Separate estimates all yrs		-7999.3	192	16,383
5h	0, 1, 2-5, 6-14, 15+	15+ time invariant	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1-2,3,4-5,6,7,N	4-5 time invariant		-8023.8	169	16,386
4i	0, 1, 2-5, 6-14, 15+	15+ time invariant	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1,2,3,4,5,6,7,N	Separate estimates all yrs		-7992.4	202	16,389
4k	0, 1, 2-5, 6-14, 15+	2-5 & 15+ time invariant	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1,2,3,4,5,6,7,N	Separate estimates all yrs		-8008	187	16,390
5f	0, 1, 2-5, 6-14, 15+	15+ time invariant	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1-2,3,4-5,6,7,N	7 time invariant		-8025.2	170	16,390
5i	0, 1, 2-5, 6-14, 15+	15+ time invariant	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1-2,3,4-5,6,7,N	3 time invariant		-8027.5	168	16,391
3	0, 1, 2-5, 6-14, 15+	Separate estimates all yrs	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1,2,3,4,5,6,7,N	Separate estimates all yrs		-7987.6	208	16,391
4j	0, 1, 2-5, 6-14, 15+	6+ time invariant	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1,2,3,4,5,6,7,N	Separate estimates all yrs		-8007.2	189	16,392
5g	0, 1, 2-5, 6-14, 15+	15+ time invariant	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1-2,3,4-5,6,7,N	6 time invariant		-8026.4	170	16,393
4h	0, 1, 2-5, 6+	Separate estimates all yrs	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1,2,3,4,5,6,7,N	Separate estimates all yrs		-8001.7	201	16,405
4e	0, 1, 2-4, 5-14, 15+	Separate estimates all yrs	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1,2,3,4,5,6,7,N	Separate estimates all yrs		-7995.1	208	16,406
4d	0, 1, 2, 3-5, 6-14, 15+	Separate estimates all yrs	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1,2,3,4,5,6,7,N	Separate estimates all yrs		-7981.1	222	16,406
5e	0, 1, 2-5, 6-14, 15+	15+ time invariant	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1-2,3,4-5,6,7,N	N time invariant		-8038.7	166	16,409
4g	0, 1, 2-14, 15+	Separate estimates all yrs	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1,2,3,4,5,6,7,N	Separate estimates all yrs		-8010.7	194	16,409
5k	0, 1, 2-5, 6-14, 15+	15+ time invariant	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1-2,3,4-5,6,7,N	0-7 time invariant		-8087.6	127	16,429
4c	0, 1, 2, 3, 4, 5, 6-14, 15+	Separate estimates all yrs	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1,2,3,4,5,6,7,N	Separate estimates all yrs		-7977	243	16,440
5a	0, 1, 2-5, 6-14, 15+	15+ time invariant	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1,2,3,4-7,N	Separate estimates all yrs		-8053.7	175	16,457
4a	u1, u3, u4, max (u3) at age3	Separate estimates all yrs	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1,2,3,4,5,6,7,N	Separate estimates all yrs		-8140	145	16,570
4b	u1, u3, u4, max (u3) at age2	Separate estimates all yrs	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1,2,3,4,5,6,7,N	Separate estimates all yrs		-8141.1	144	16,570
5c	0, 1, 2-5, 6-14, 15+	15+ time invariant	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1,2,3,4-6,7,N	Separate estimates all yrs		-8411.4	182	17,187
4f	0-1, 2-5, 6-14, 15+	Separate estimates all yrs	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1,2,3,4,5,6,7,N	Separate estimates all yrs		-8476.6	191	17,335
4l	0, 1, 2-5, 6-14, 15+	1 & 15+ time invariant	4-14 (P), 4-14 (N), 15+ (P), 15+ (N)	Separate estimates all yrs	1,2,3,4,5,6,7,N	Separate estimates all yrs		-8483.1	186	17,338

‡ model used to present results

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