Estimation of Demographic Parameters for New Zealand Sea Lions Breeding on the Auckland Islands

POP2007/01 Obj 3

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Survival and Reproduction

- 2 key demographic processes
- Can be estimated from tag-resight data using mark-recapture methods
- Important to account for tag-loss
    - Artificially inflates mortality rates
- Sightability may be different for breeders/non-breeders, branded animals, number of flipper tags

Survival and Reproduction

- 4 components to model tag-resight data
  - Number of flipper tags each year
  - Survival from one year to next
  - Whether female breeds in a year
  - Number of sightings in a year

Survival and Reproduction

- Number of flipper tags in year *t* is multinomial random variable with 1 draw and category probabilities (π's) that depends on number of tags in previous year

Number of tags in year *t*

Number of tags in year *t*-1	0	1	2
0	1	0	0
1	$1-\pi_{1,1}$	$\pi_{1,1}$	0
2	$1-\pi_{1,2}-\pi_{2,2}$	$\pi_{1,2}$	$\pi_{2,2}$

Survival and Reproduction

- Analyses conducted with and without accounting for tag-loss to assess it's effect on estimation of demographic parameters

Survival and Reproduction

- Given female is alive, it's age and breeding status in year *t*-1, whether it is alive in year *t* is a Bernoulli random variable where probability of success (survival) is $S_{age,bred}$

Survival and Reproduction

- Given female is alive in year *t*, it's age and breeding status in year *t*-1, whether it breeds in year *t* is a Bernoulli random variable where probability of success (breeding) is $B_{age,bred}$

Survival and Reproduction

- 3 relationships considered between age and survival/reproduction
  1. Constant
  2. Age groups: 0-3, 4-14, 15+
  3. Logistic-quadratic

Survival and Reproduction

- Given female is alive, it's breeding status, presence of a brand, PIT tag and number of tags in year *t*, the number of times it's sighted during a field season is a binomial random variable with a daily resight probability $p_{t,bred,brand,tags}$

Survival and Reproduction

- Branded animals have the same resight probability regardless of number of flipper tags.
- Animals with no flipper tags can only be resighted if they are chipped or branded.
- PIT tags have no effect on the resight probability if the unbranded animal has 1 or more flipper tags.
- There is a consistent odds ratio (δ) between resighting animals with 1 and 2 flipper tags.
- Resight probabilities are different for breeding and non-breeding animals.
- Resight probabilities vary annually.

Survival and Reproduction

$p_{t,bred,brand}$ - applies to all females with brand

$p_{t,bred,chip}$ - applies to unbranded females with no flipper tags

$p_{t,bred,T1}$ - applies to unbranded females with one flipper tags

$p_{t,bred,T2}$ - applies to unbranded females with two flipper tags

Survival and Reproduction

- Posterior distributions for parameters can be approximated with WinBUGS by defining a model in terms of the 4 random variables
- Some outcomes are actually latent (unknown) random variables, but their ‘true’ value can be imputed by MCMC
- Equivalent to a multi-state mark-recapture model

Survival and Reproduction

- 2 chains of 25,000 iterations
- First 5,000 iterations discarded as burn-in
- Prior distributions:
  - Most probabilities ~ U(0,1)
  - $\pi_{X,2}$ ~ Dirichlet(1,1,1)
  - ln(δ) ~ N(0,10^2)
  - Logistic coefficients ~ N(0,4.47^2)
- Chains demonstrated convergence and good mixing

Survival and Reproduction: Data

- 1990-2003 tagging cohorts
- Resights from 1998-2008 in main field season at Enderby Island
- 2 definitions considered for breeder according to assigned status in database
    - Confirmed breeders (status = 3)
    - Probable breeders (status = 3 or 15)

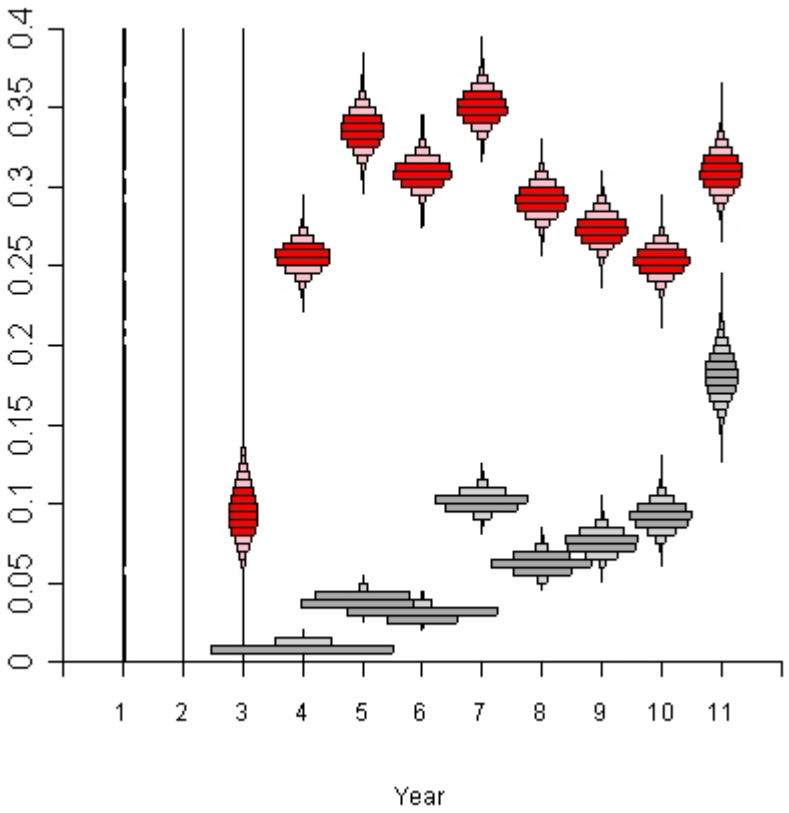
Survival and Reproduction: Data

- Retagged females dealt with using the Lazarus approach

- Almost 1700 tagged females included in analysis

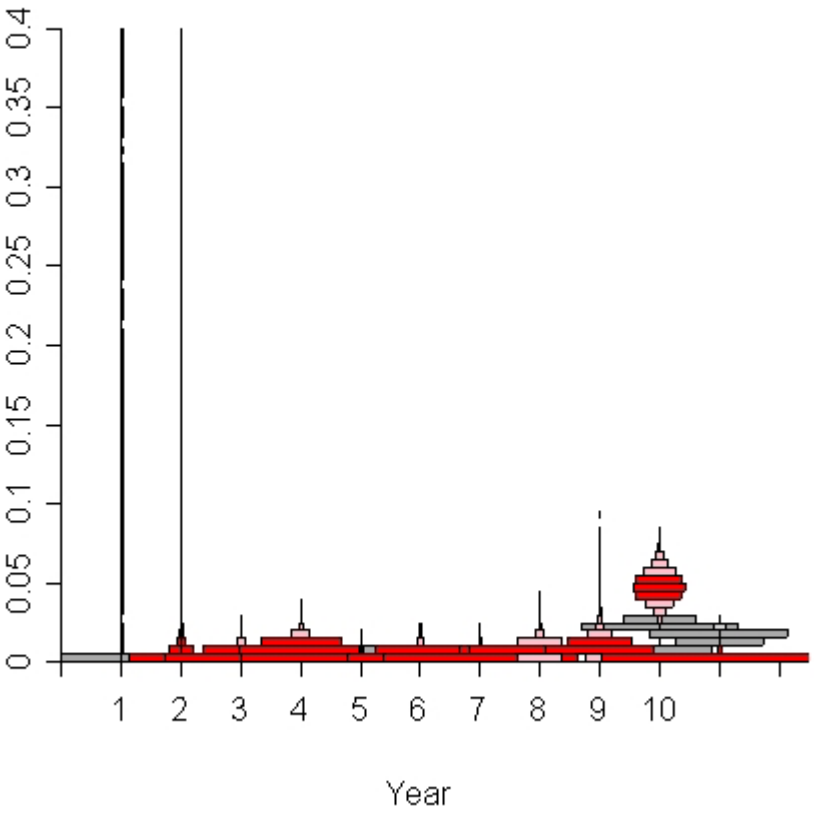
Results

- Daily sighting probabilities - branded



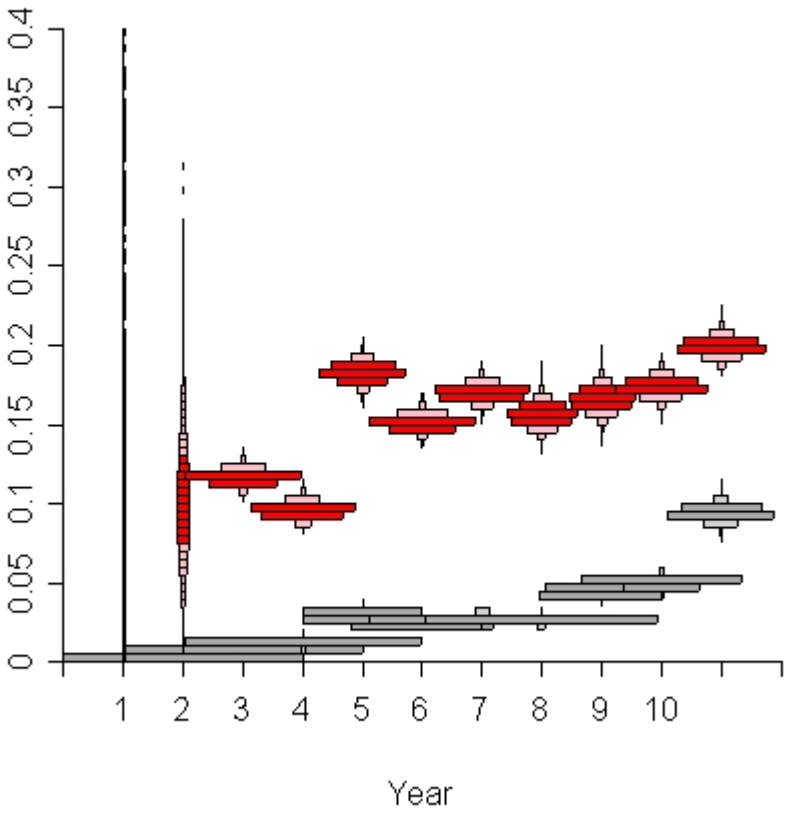
Results

- Daily sighting probabilities – PIT tag, 0 flipper tags



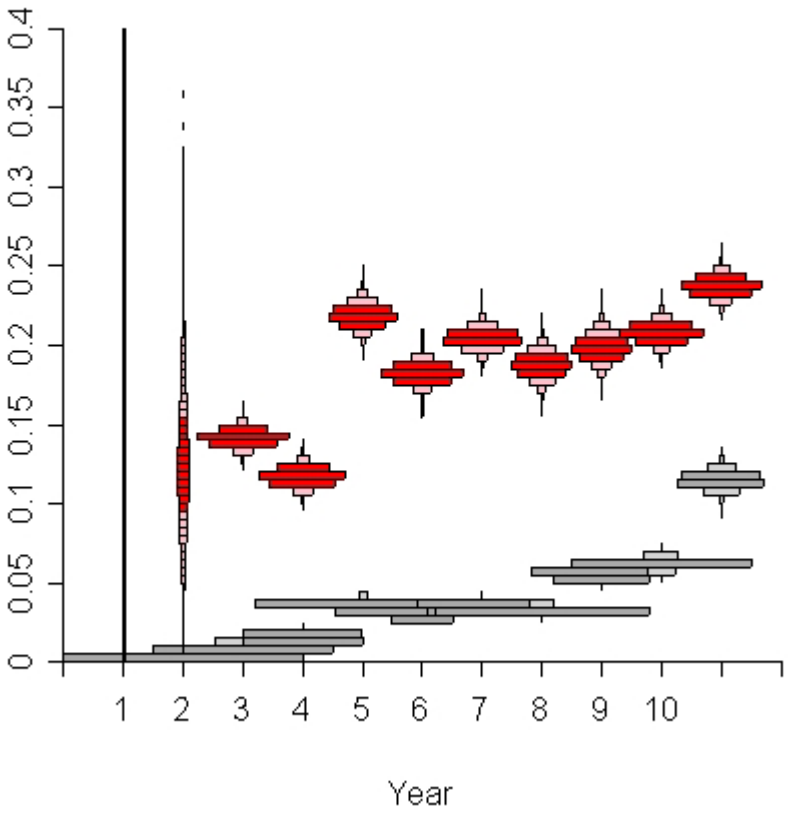
Results

- Daily sighting probabilities – 1 flipper tag



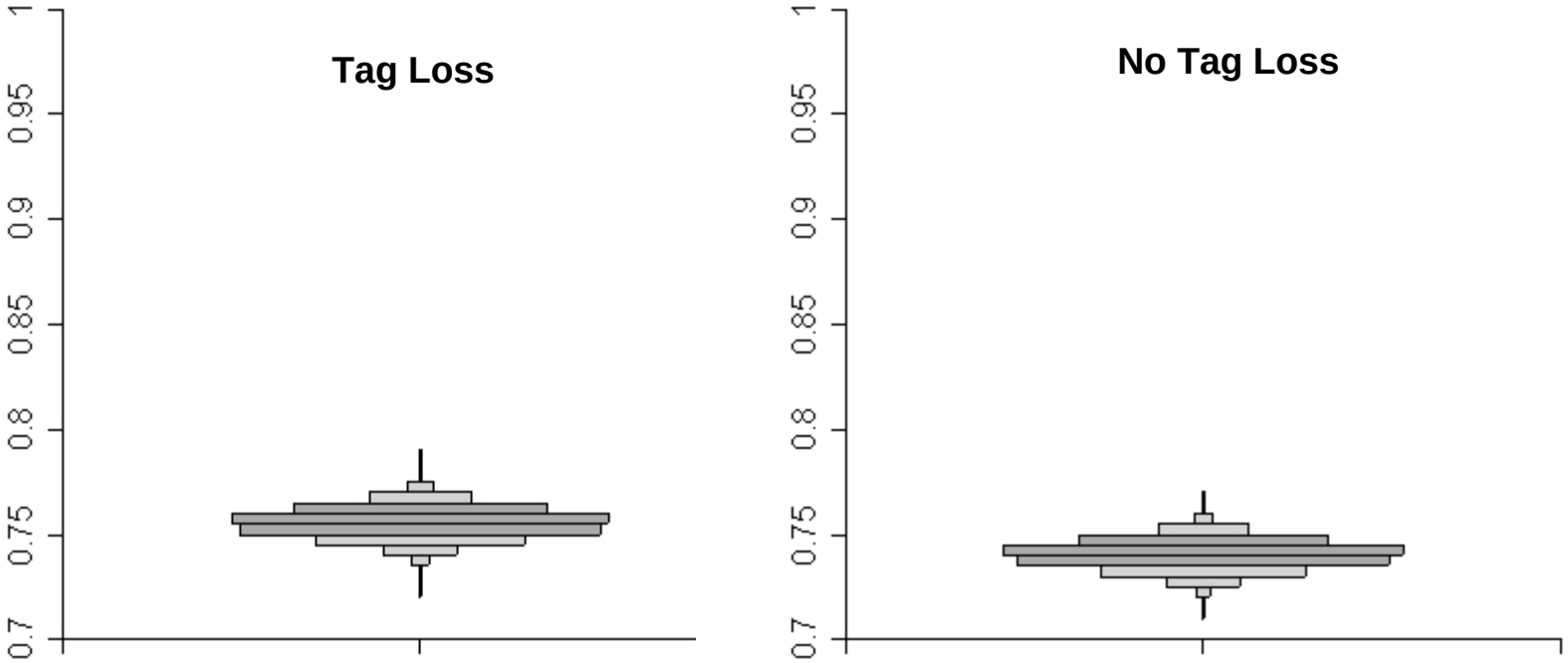
Results

- Daily sighting probabilities – 2 flipper tags



Results

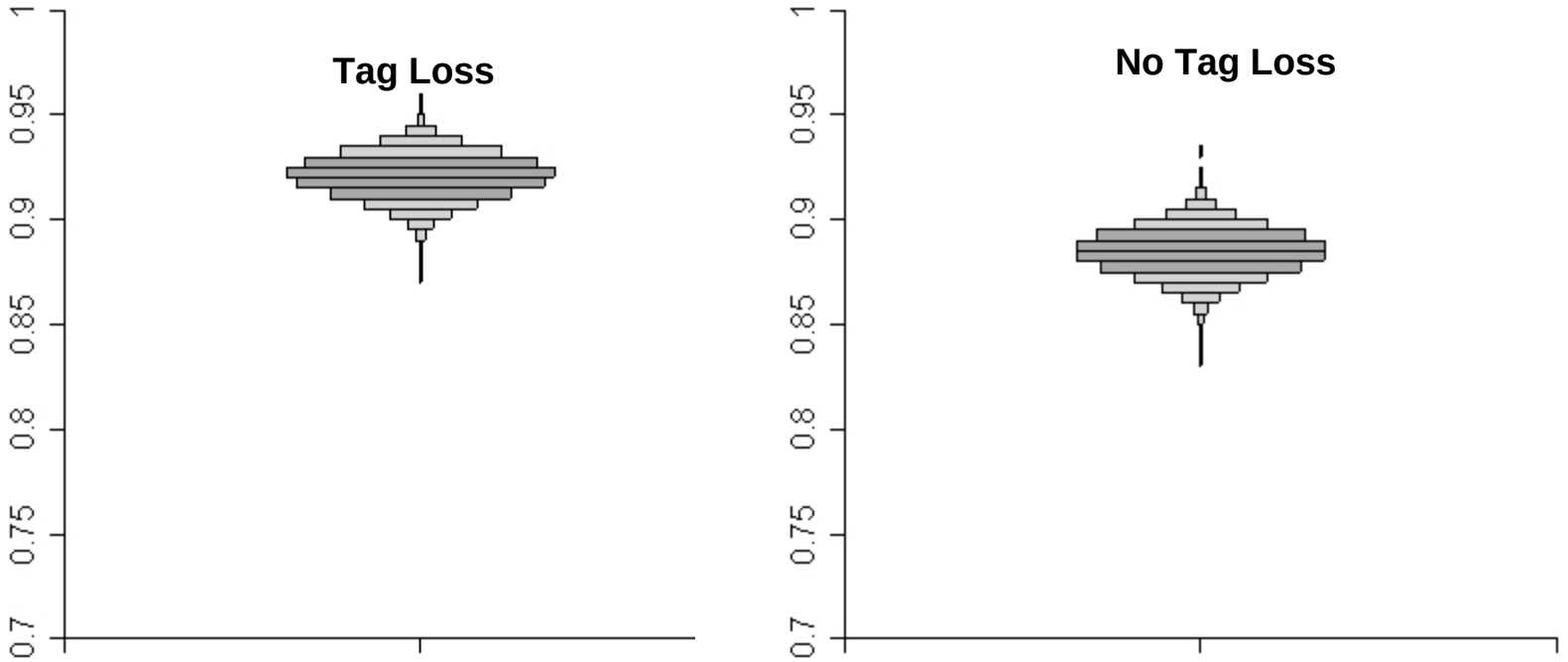
- Constant age effect - survival
  - Non-breeders



	Mean	SD	2.5%ile	Median	97.5%ile
Tag Loss	0.756	0.007	0.742	0.756	0.770
No Tag Loss	0.741	0.007	0.727	0.741	0.754

Results

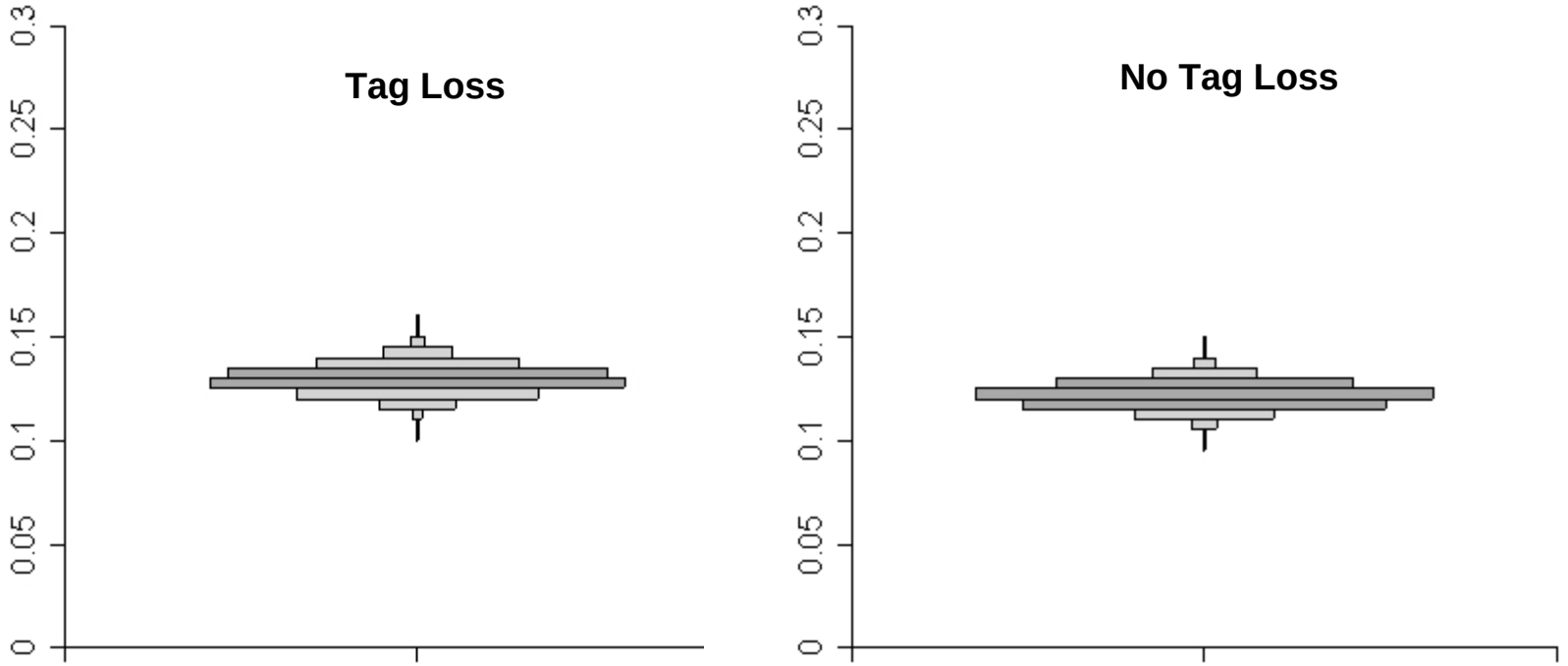
- Constant age effect - survival
  - Breeders



	Mean	SD	2.5%ile	Median	97.5%ile
Tag Loss	0.921	0.010	0.900	0.921	0.941
No Tag Loss	0.885	0.011	0.862	0.885	0.906

Results

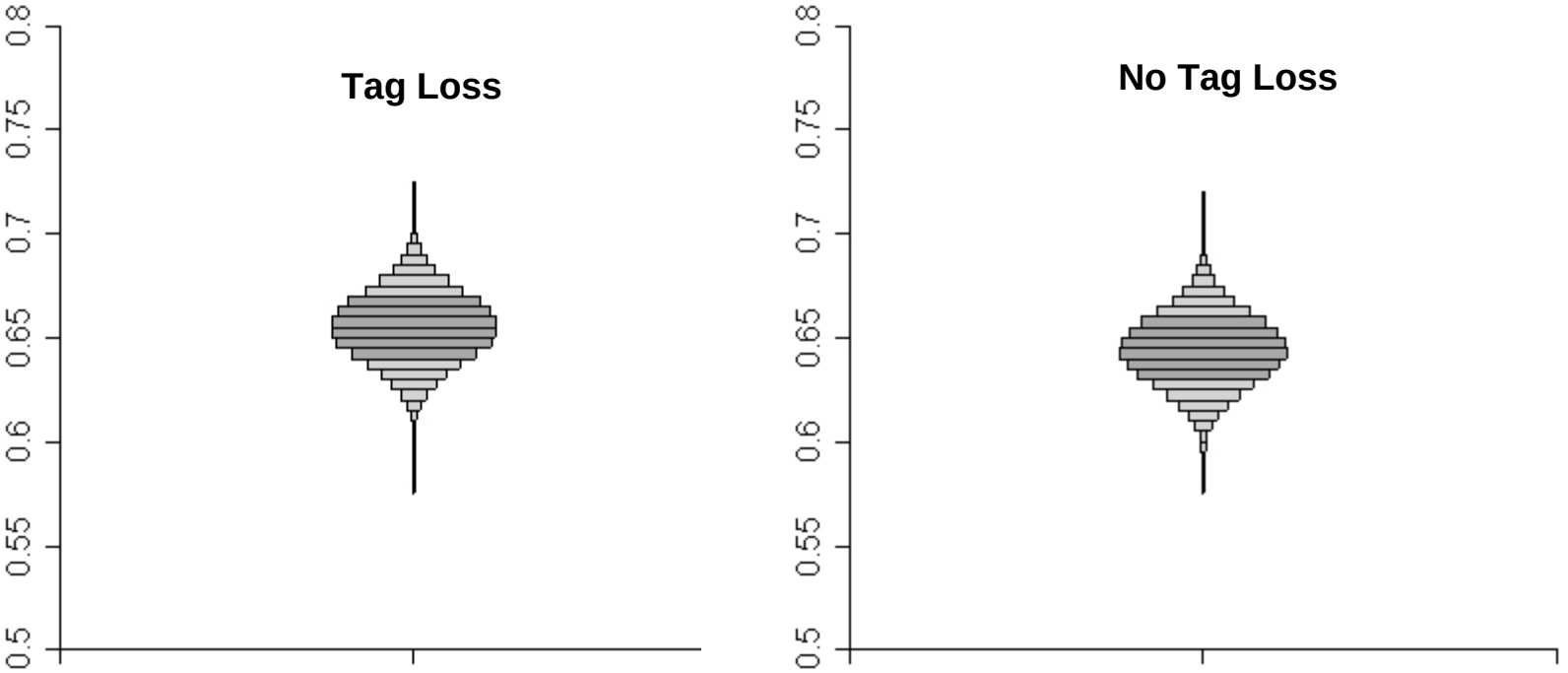
- Constant age effect - reproduction
  - Non-breeders



	Mean	SD	2.5%ile	Median	97.5%ile
Tag Loss	0.130	0.006	0.117	0.130	0.143
No Tag Loss	0.122	0.006	0.111	0.122	0.134

Results

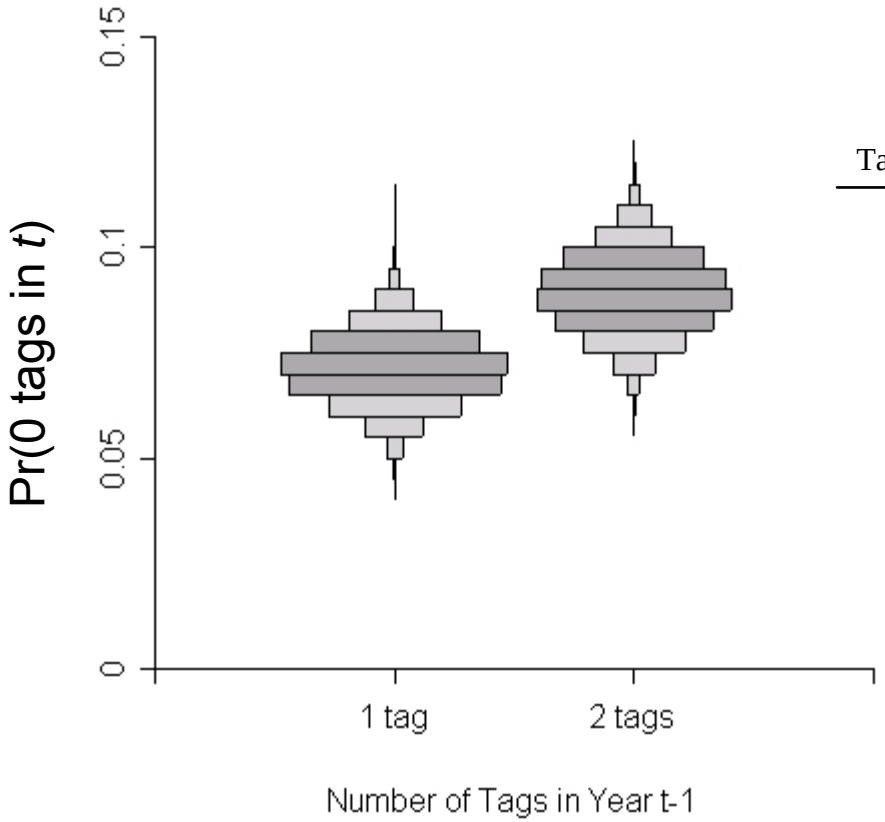
- Constant age effect - reproduction
  - Breeders



	Mean	SD	2.5%ile	Median	97.5%ile
Tag Loss	0.655	0.017	0.622	0.655	0.687
No Tag Loss	0.644	0.017	0.611	0.644	0.677

Results

- Constant age model



Tags in *t*-1	Tags in *t*	Mean	SD	2.5%ile	Median	97.5%ile
1	0	0.071	0.008	0.056	0.071	0.088
1	1	0.929	0.008	0.912	0.929	0.944
2	0	0.089	0.009	0.072	0.089	0.108
2	1	0.161	0.009	0.145	0.161	0.180
2	2	0.749	0.011	0.727	0.749	0.771

Results

Survival

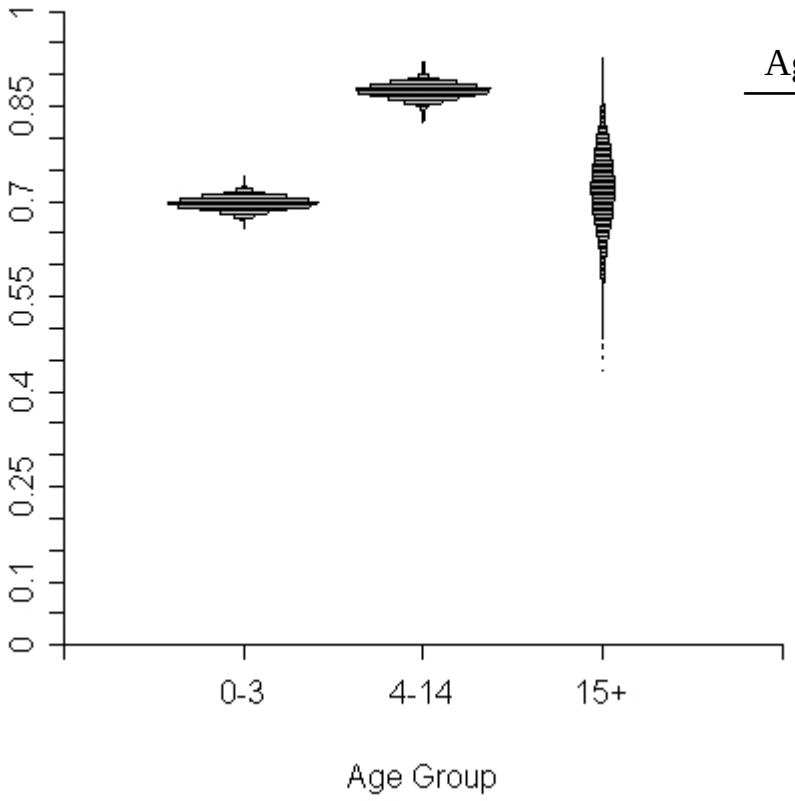
Defn.	Status	Mean	SD	2.5%ile	Median	97.5%ile
Confirmed	Non-breeders	0.756	0.007	0.742	0.756	0.770
	Breeders	0.921	0.010	0.900	0.921	0.941
Probable	Non-breeders	0.755	0.007	0.741	0.755	0.769
	Breeders	0.912	0.010	0.891	0.912	0.932

Reproduction

Defn.	Status	Mean	SD	2.5%ile	Median	97.5%ile
Confirmed	Non-breeders	0.130	0.006	0.117	0.130	0.143
	Breeders	0.655	0.017	0.622	0.655	0.687
Probable	Non-breeders	0.142	0.007	0.129	0.142	0.155
	Breeders	0.682	0.015	0.652	0.682	0.713

Results

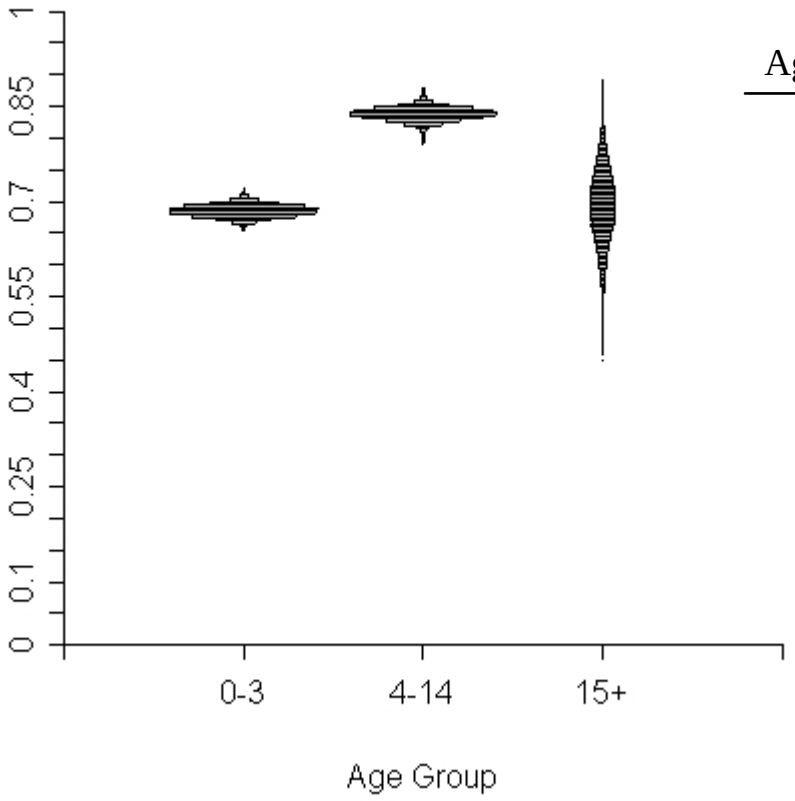
- Age groups - survival
  - Non-breeders, with tag loss



Age Group	Mean	SD	2.5%ile	Median	97.5%ile
0-3	0.697	0.009	0.678	0.697	0.716
4-14	0.874	0.010	0.854	0.875	0.894
15+	0.719	0.062	0.591	0.720	0.835

Results

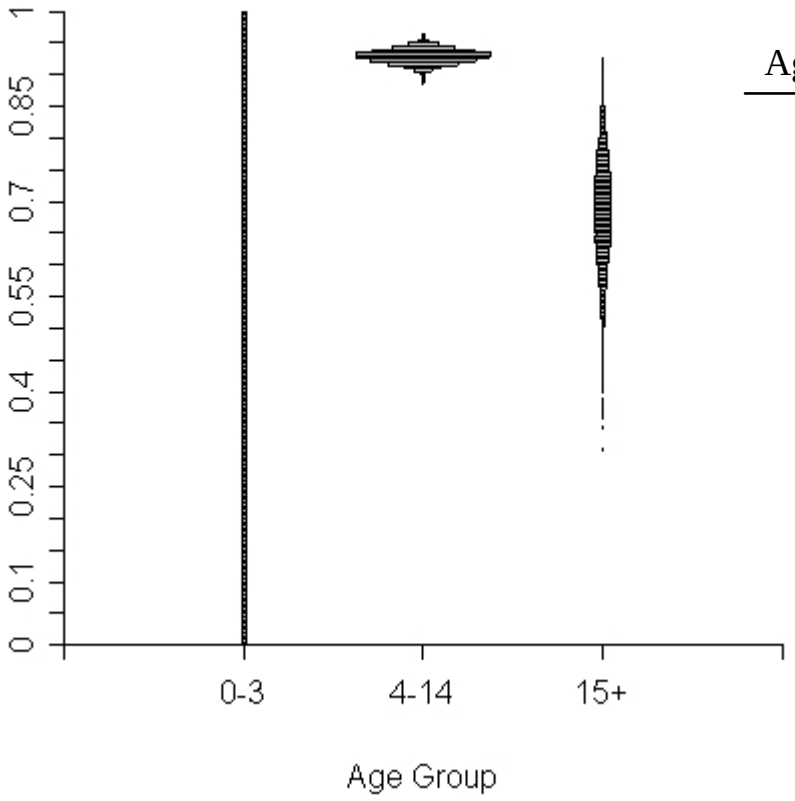
- Age groups - survival
  - Non-breeders, without tag loss



Age Group	Mean	SD	2.5%ile	Median	97.5%ile
0-3	0.686	0.009	0.668	0.686	0.703
4-14	0.839	0.009	0.820	0.839	0.857
15+	0.691	0.057	0.575	0.693	0.797

Results

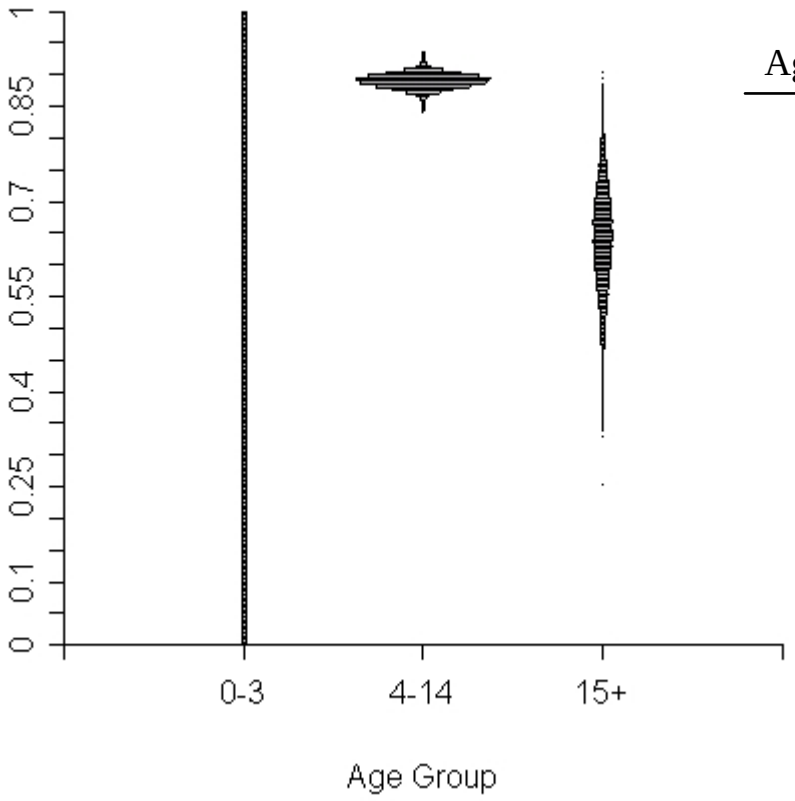
- Age groups - survival
  - Breeders, with tag loss



Age Group	Mean	SD	2.5%ile	Median	97.5%ile
0-3	-	-	-	-	-
4-14	0.929	0.010	0.908	0.929	0.948
15+	0.682	0.081	0.515	0.685	0.832

Results

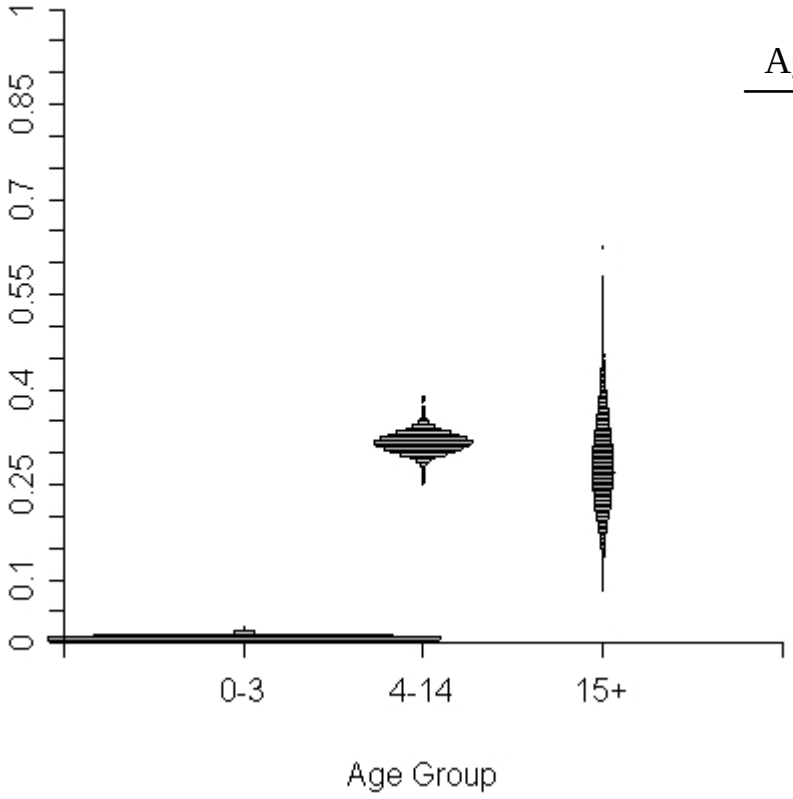
- Age groups - survival
  - Breeders, without tag loss



Age Group	Mean	SD	2.5%ile	Median	97.5%ile
0-3	-	-	-	-	-
4-14	0.890	0.011	0.868	0.891	0.911
15+	0.640	0.079	0.479	0.643	0.787

Results

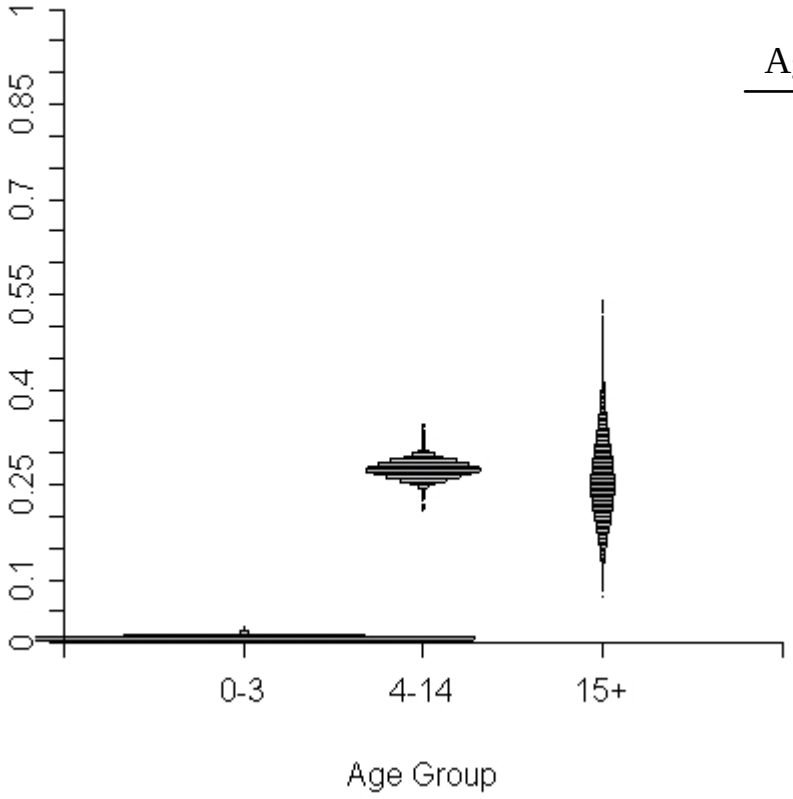
- Age groups - reproduction
  - Non-breeders, with tag loss



Age Group	Mean	SD	2.5%ile	Median	97.5%ile
0-3	0.010	0.002	0.006	0.010	0.015
4-14	0.316	0.015	0.289	0.316	0.346
15+	0.285	0.069	0.162	0.281	0.431

Results

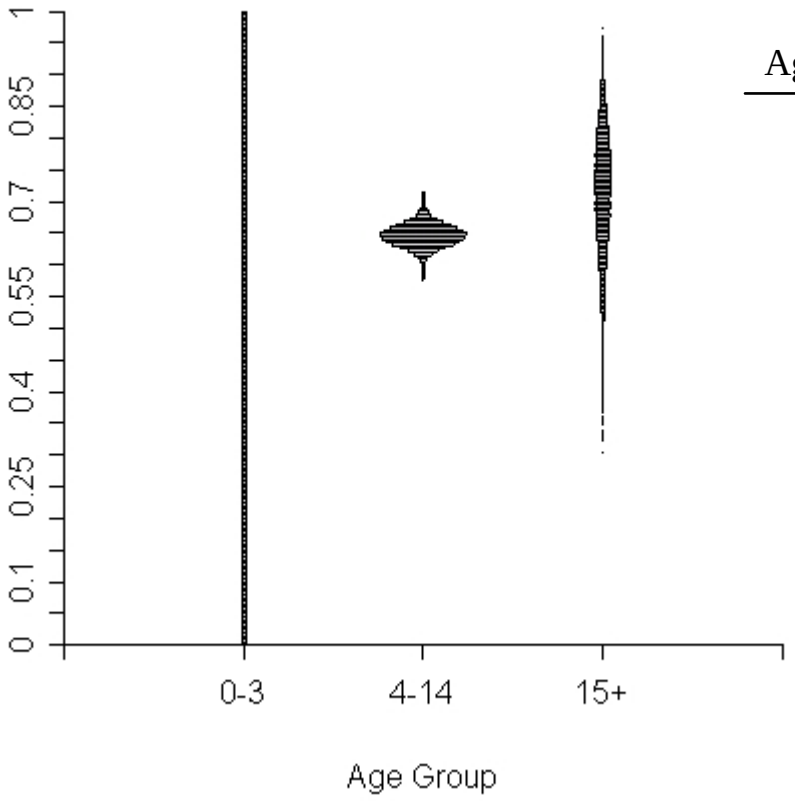
- Age groups - reproduction
  - Non-breeders, without tag loss



Age Group	Mean	SD	2.5%ile	Median	97.5%ile
0-3	0.009	0.002	0.005	0.009	0.014
4-14	0.274	0.012	0.251	0.274	0.300
15+	0.259	0.063	0.146	0.256	0.392

Results

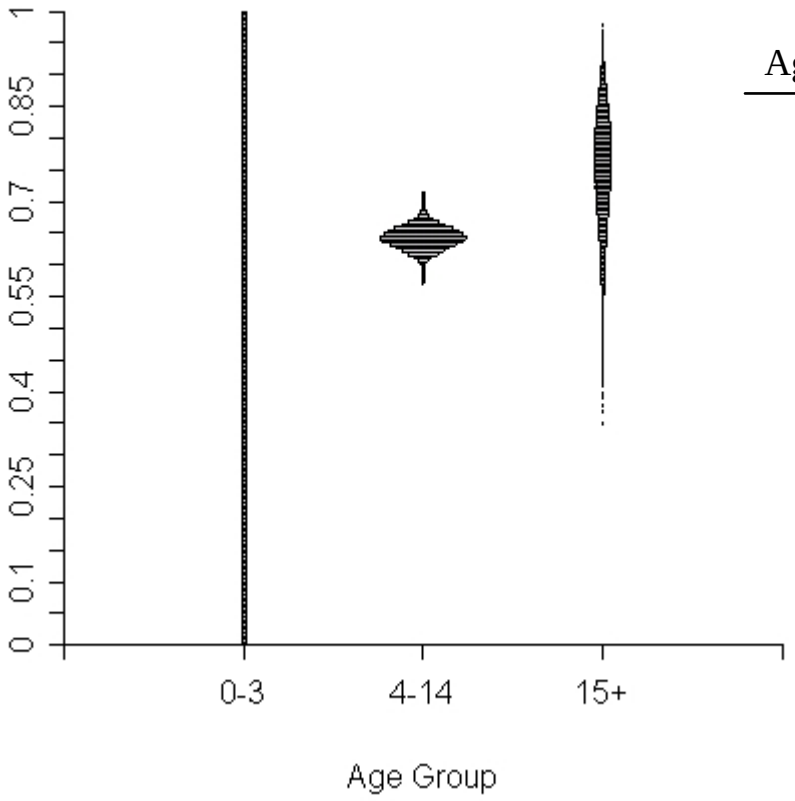
- Age groups - reproduction
  - Breeders, with tag loss



Age Group	Mean	SD	2.5%ile	Median	97.5%ile
0-3	-	-	-	-	-
4-14	0.647	0.017	0.613	0.647	0.679
15+	0.714	0.091	0.521	0.719	0.874

Results

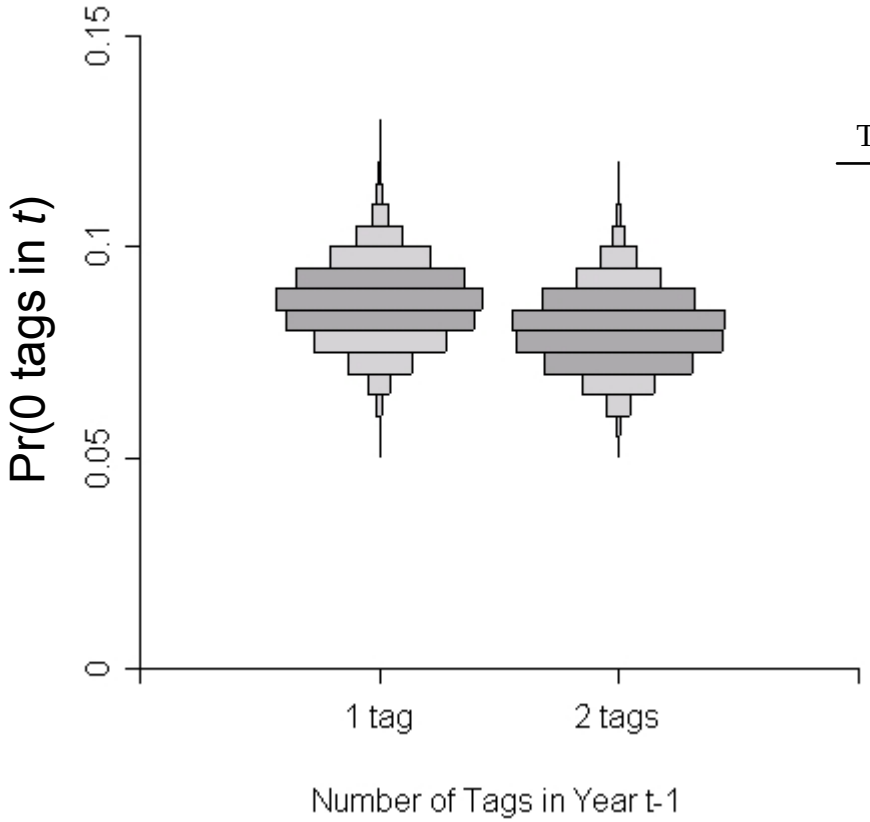
- Age groups - reproduction
  - Breeders, without tag loss



Age Group	Mean	SD	2.5%ile	Median	97.5%ile
0-3	-	-	-	-	-
4-14	0.643	0.017	0.609	0.643	0.676
15+	0.749	0.087	0.562	0.756	0.898

Results

- Age groups



Tags in *t*-1	Tags in *t*	Mean	SD	2.5%ile	Median	97.5%ile
1	0	0.087	0.009	0.069	0.087	0.105
1	1	0.913	0.009	0.895	0.913	0.931
2	0	0.081	0.009	0.064	0.081	0.098
2	1	0.164	0.009	0.147	0.164	0.183
2	2	0.755	0.011	0.733	0.755	0.776

Results

Survival

Defn.	Status	Age Group	Mean	SD	2.5%ile	Median	97.5%ile
Confirmed	Non-breeders	0-3	0.697	0.009	0.678	0.697	0.716
		4-14	0.874	0.010	0.854	0.875	0.894
		15+	0.719	0.062	0.591	0.720	0.835
	Breeders	0-3	-	-	-	-	-
		4-14	0.929	0.010	0.908	0.929	0.948
		15+	0.682	0.081	0.515	0.685	0.832
Probable	Non-breeders	0-3	0.700	0.009	0.682	0.700	0.719
		4-14	0.873	0.010	0.852	0.873	0.893
		15+	0.720	0.066	0.585	0.722	0.842
	Breeders	0-3	-	-	-	-	-
		4-14	0.919	0.011	0.898	0.919	0.939
		15+	0.673	0.077	0.516	0.676	0.817

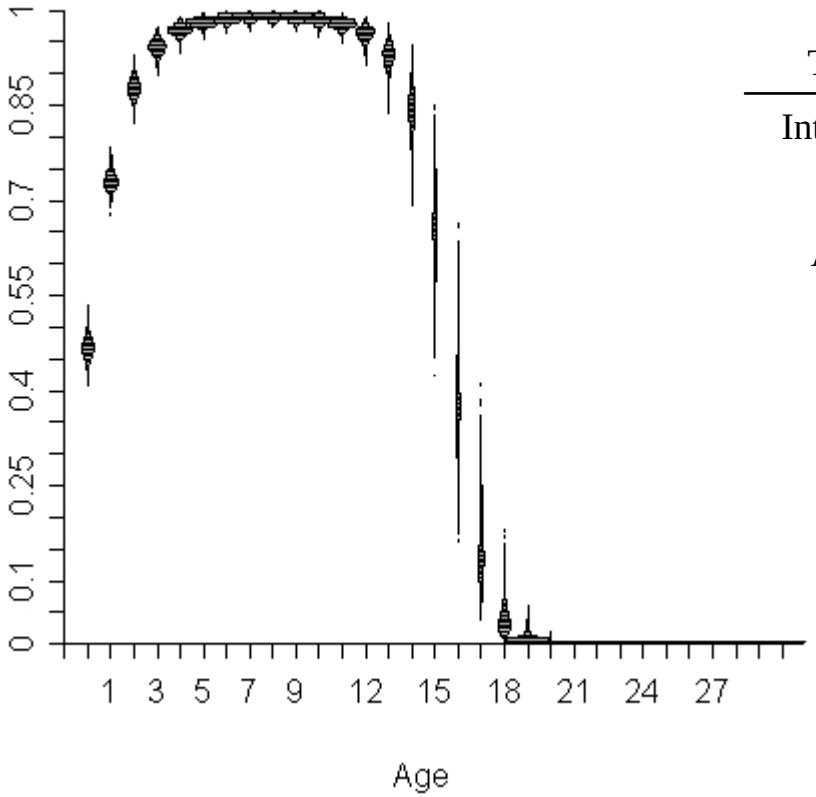
Results

Reproduction

Defn.	Status	Age Group	Mean	SD	2.5%ile	Median	97.5%ile
Confirmed	Non-breeders	0-3	0.010	0.002	0.006	0.010	0.015
		4-14	0.316	0.015	0.289	0.316	0.346
		15+	0.285	0.069	0.162	0.281	0.431
	Breeders	0-3	-	-	-	-	-
		4-14	0.647	0.017	0.613	0.647	0.679
		15+	0.714	0.091	0.521	0.719	0.874
Probable	Non-breeders	0-3	0.010	0.002	0.006	0.009	0.015
		4-14	0.353	0.015	0.323	0.353	0.383
		15+	0.329	0.074	0.193	0.326	0.482
	Breeders	0-3	-	-	-	-	-
		4-14	0.678	0.016	0.646	0.678	0.708
		15+	0.649	0.090	0.465	0.652	0.813

Results

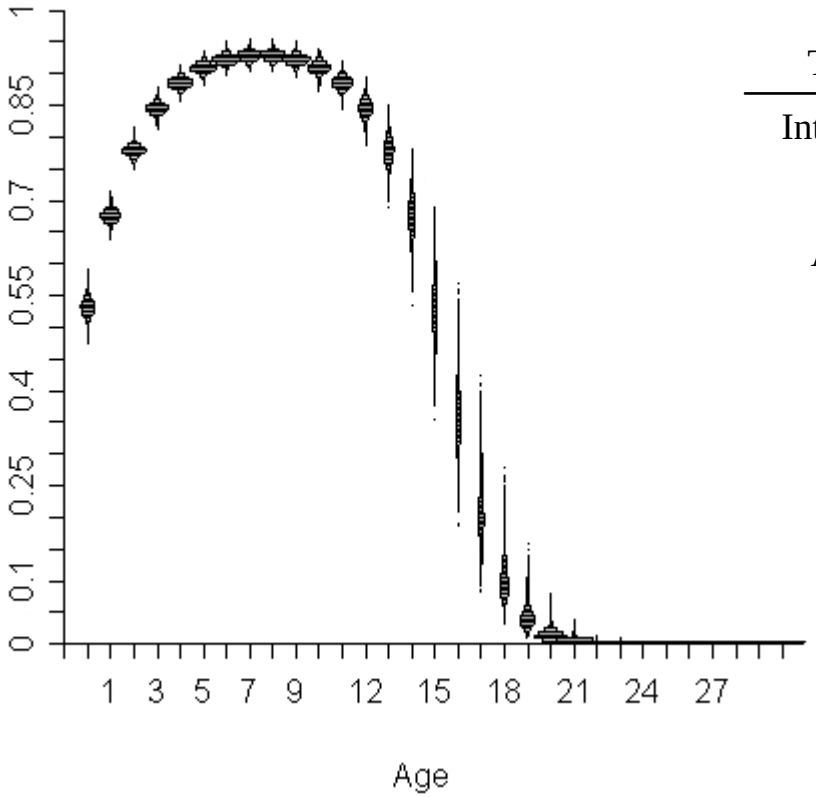
- Logistic-quadratic - survival
  - Non-breeders, with tag loss



Term	Mean	SD	2.5%ile	Median	97.5%ile
Intercept	4.533	0.344	3.920	4.516	5.290
Age	0.130	0.019	0.095	0.130	0.169
Age^2	-0.077	0.006	-0.090	-0.076	-0.065

Results

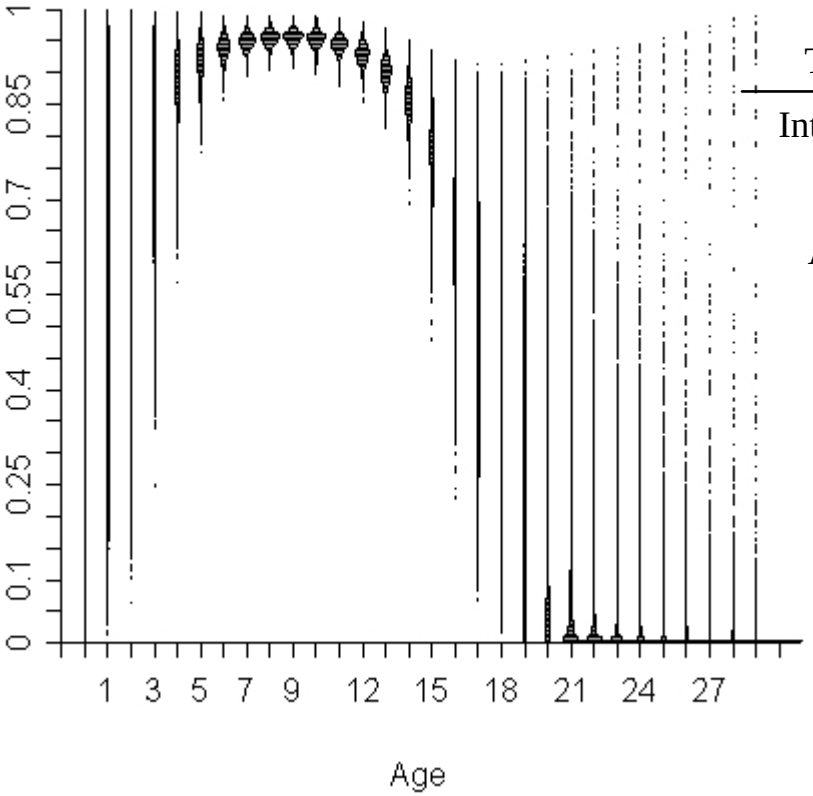
- Logistic-quadratic - survival
  - Non-breeders, without tag loss



Term	Mean	SD	2.5%ile	Median	97.5%ile
Intercept	2.566	0.093	2.387	2.565	2.752
Age	0.044	0.010	0.024	0.044	0.064
Age^2	-0.044	0.002	-0.048	-0.044	-0.039

Results

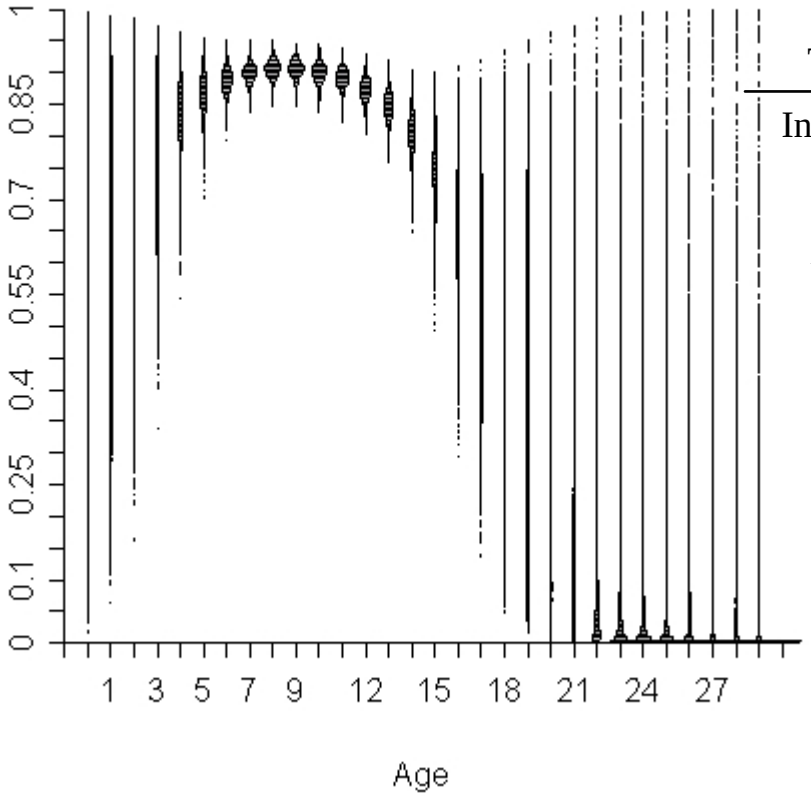
- Logistic-quadratic - survival
  - Breeders, with tag loss



Term	Mean	SD	2.5%ile	Median	97.5%ile
Intercept	2.954	0.248	2.529	2.934	3.503
Age	0.153	0.103	-0.057	0.156	0.347
Age^2	-0.046	0.014	-0.073	-0.046	-0.019

Results

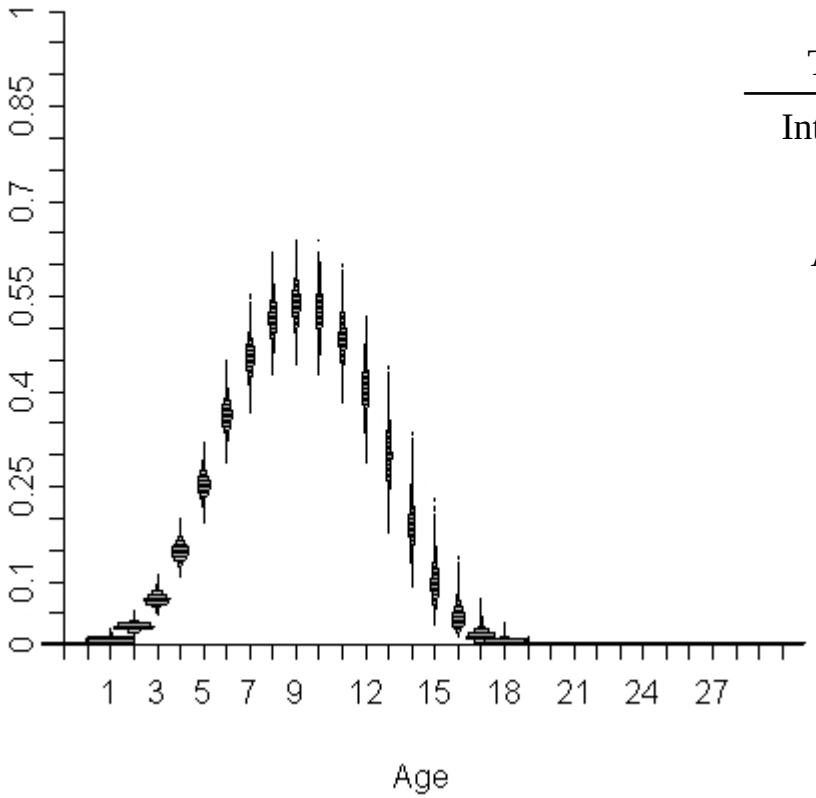
- Logistic-quadratic - survival
  - Breeders, without tag loss



Term	Mean	SD	2.5%ile	Median	97.5%ile
Intercept	2.192	0.140	1.924	2.189	2.474
Age	0.094	0.070	-0.047	0.095	0.229
Age^2	-0.029	0.010	-0.049	-0.029	-0.009

Results

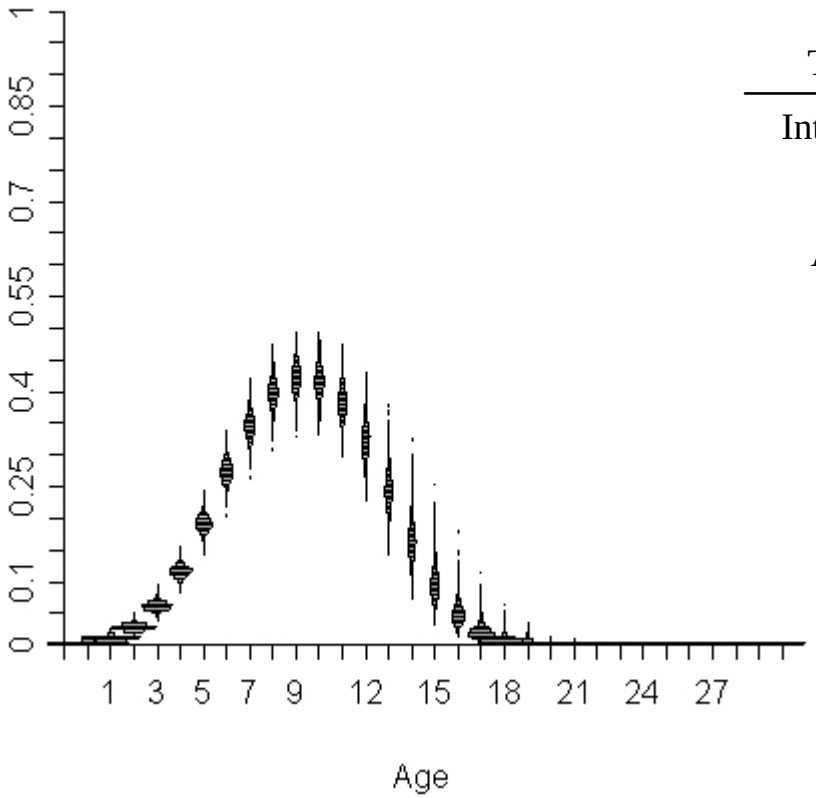
- Logistic-quadratic - reproduction
  - Non-breeders, with tag loss



Term	Mean	SD	2.5%ile	Median	97.5%ile
Intercept	-0.183	0.089	-0.358	-0.183	-0.008
Age	0.311	0.020	0.273	0.311	0.351
Age^2	-0.071	0.005	-0.081	-0.071	-0.061

Results

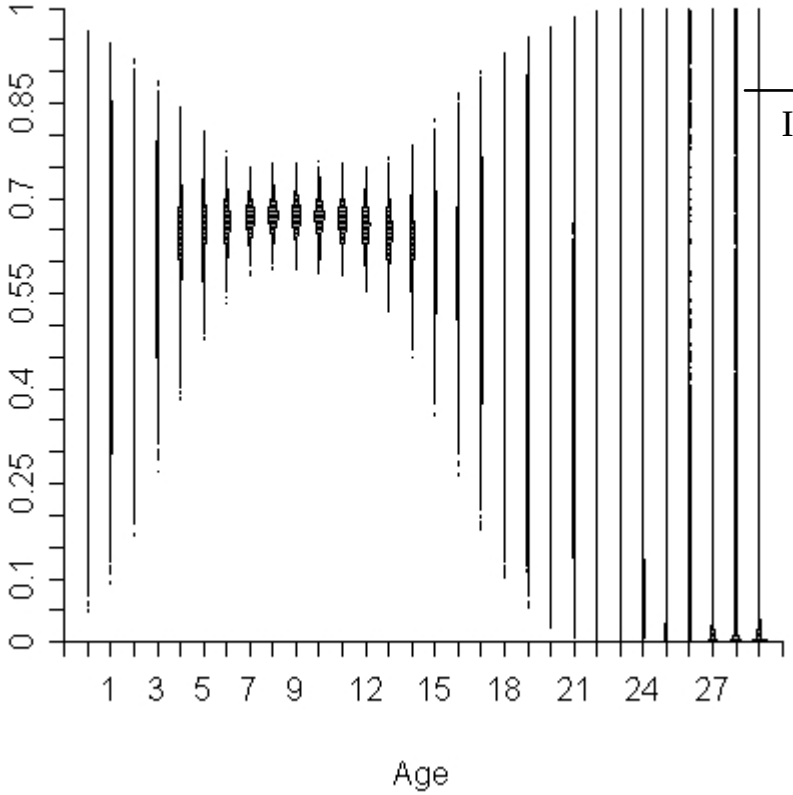
- Logistic-quadratic - reproduction
  - Non-breeders, without tag loss



Term	Mean	SD	2.5%ile	Median	97.5%ile
Intercept	-0.637	0.080	-0.793	-0.637	-0.482
Age	0.281	0.019	0.245	0.281	0.319
Age^2	-0.061	0.005	-0.070	-0.061	-0.052

Results

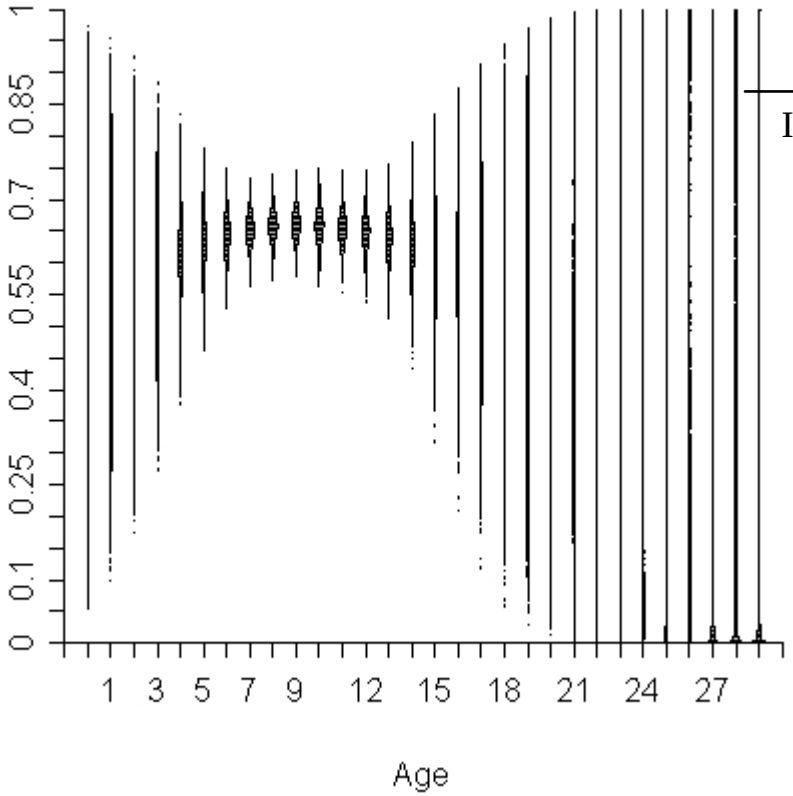
- Logistic-quadratic - reproduction
  - Breeders, with tag loss



Term	Mean	SD	2.5%ile	Median	97.5%ile
Intercept	0.705	0.097	0.516	0.704	0.899
Age	0.020	0.053	-0.083	0.020	0.125
Age^2	-0.006	0.009	-0.024	-0.006	0.011

Results

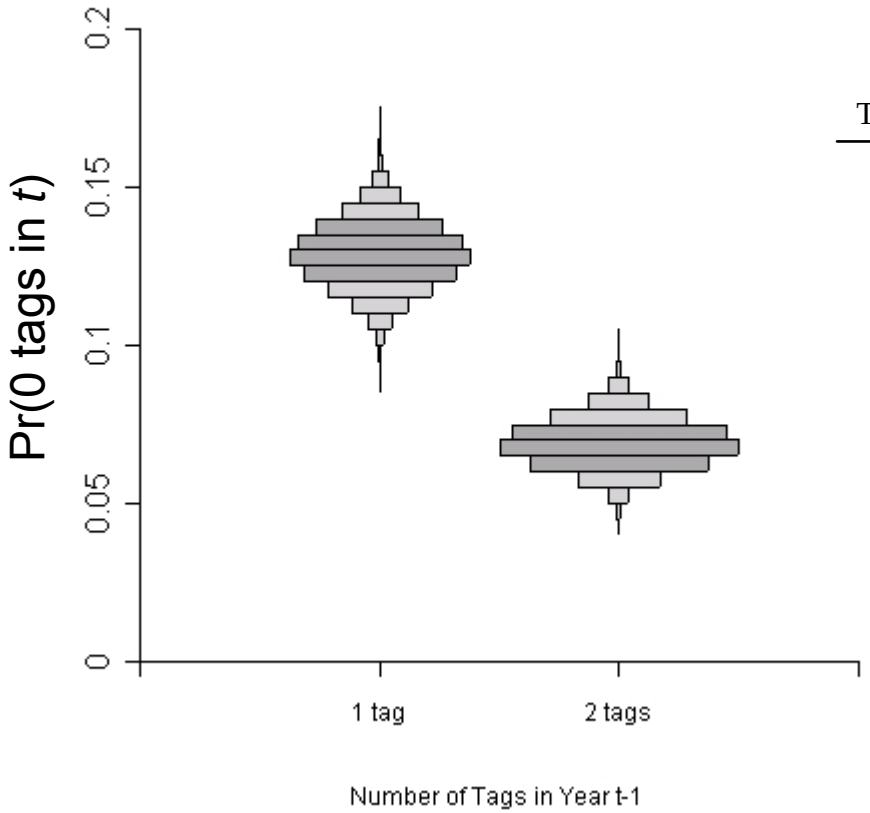
- Logistic-quadratic - reproduction
  - Breeders, without tag loss



Term	Mean	SD	2.5%ile	Median	97.5%ile
Intercept	0.627	0.096	0.439	0.626	0.817
Age	0.028	0.053	-0.078	0.028	0.133
Age^2	-0.006	0.009	-0.024	-0.006	0.011

Results

- Logistic-quadratic



Tags in *t*-1	Tags in *t*	Mean	SD	2.5%ile	Median	97.5%ile
1	0	0.129	0.011	0.109	0.129	0.150
1	1	0.871	0.011	0.850	0.871	0.891
2	0	0.069	0.008	0.055	0.069	0.085
2	1	0.166	0.009	0.148	0.166	0.185
2	2	0.764	0.011	0.743	0.765	0.785

Results

Survival

Defn.	Status	Term	Mean	SD	2.5%ile	Median	97.5%ile
Confirmed	Non-breeders	Intercept	4.533	0.344	3.920	4.516	5.290
		Age	0.130	0.019	0.095	0.130	0.169
		Age^2	-0.077	0.006	-0.090	-0.076	-0.065
	Breeders	Intercept	2.954	0.248	2.529	2.934	3.503
		Age	0.153	0.103	-0.057	0.156	0.347
		Age^2	-0.046	0.014	-0.073	-0.046	-0.019
Probable	Non-breeders	Intercept	3.825	0.229	3.406	3.814	4.305
		Age	0.105	0.016	0.075	0.105	0.136
		Age^2	-0.064	0.005	-0.073	-0.064	-0.055
	Breeders	Intercept	2.658	0.189	2.306	2.651	3.049
		Age	0.133	0.088	-0.044	0.135	0.300
		Age^2	-0.040	0.012	-0.063	-0.040	-0.016

Results

Reproduction

Defn.	Status	Term	Mean	SD	2.5%ile	Median	97.5%ile
Confirmed	Non-breeders	Intercept	-0.183	0.089	-0.358	-0.183	-0.008
		Age	0.311	0.020	0.273	0.311	0.351
		Age^2	-0.071	0.005	-0.081	-0.071	-0.061
	Breeders	Intercept	0.705	0.097	0.516	0.704	0.899
		Age	0.020	0.053	-0.083	0.020	0.125
		Age^2	-0.006	0.009	-0.024	-0.006	0.011
Probable	Non-breeders	Intercept	-0.055	0.100	-0.249	-0.057	0.144
		Age	0.340	0.021	0.299	0.339	0.381
		Age^2	-0.072	0.005	-0.082	-0.072	-0.062
	Breeders	Intercept	0.767	0.094	0.582	0.767	0.956
		Age	0.066	0.052	-0.036	0.066	0.168
		Age^2	-0.014	0.008	-0.030	-0.014	0.003

Population Size

- Gales-Fletcher approach
  - OK to give ball-park estimates of total population
  - Unlikely to give reliable annual estimates
  - Decided to not proceed with reassessment of method

- Traditional mark-recapture methods cannot be applied to tag-resight data

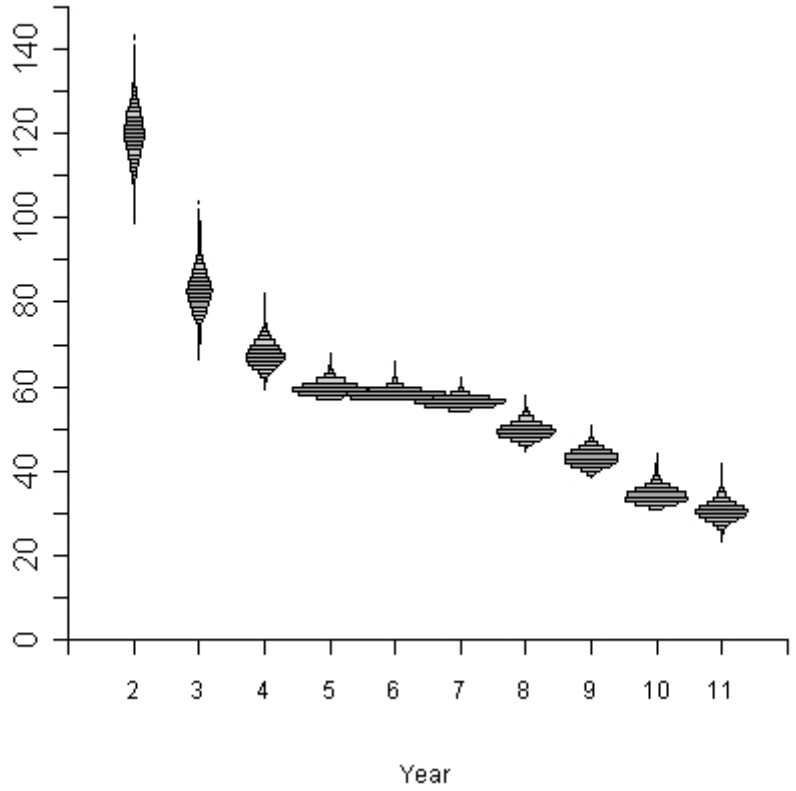
Population Size

- As part of previous analysis, whether an animal is alive each year is predicted as part of the estimation

- Number of females still alive each year from specific cohorts can be readily obtained: $\hat{n}_{cohort,t}$

Population Size

Number of female sea lions estimated to be alive that were first released in year 1 (1998) on Enderby Island



Population Size

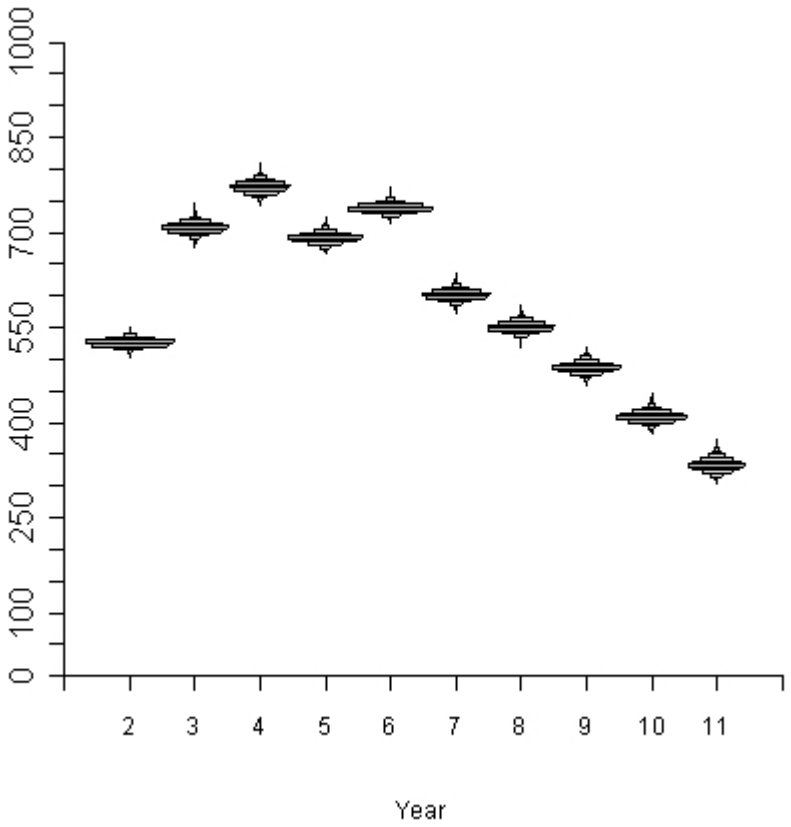
- Given the fraction of pups produced in a cohort year that were tagged (r_{cohort}), then:

$$\hat{N}_{cohort,t} = \frac{\hat{n}_{cohort,t}}{r_{cohort}}$$

$$\hat{N}_t = \sum_{cohort} \hat{N}_{cohort,t}$$

Population Size

Number of female sea lions estimated to be alive that where first released between years 1 and 6 (1998-2003) from Enderby Island



Discussion Points

- Tag loss has minimal effect on reproduction estimates, but significant effect on survival
- Using biased estimates of demographic parameters in population models will underestimate population growth rate
- Tag loss should be accounted for in all subsequent analyses

Discussion Points

- Flipper tags are not lost independently. Only possible to identify this through branded/chipped animals

- Assumed no PIT tag loss
  - Unlikely in practice
  - Current estimates may still be biased low

Discussion Points

- More liberal definition of ‘breeders’ has little effect on survival estimate, but increases reproduction significantly
  - Debatable which definition might be more accurate
- Still plan to assess alternative approach based upon the chance of seeing the required evidence of reproduction with each resighting

Discussion Points

- Difficult to formally compare models using Bayesian inference
  - Suggest the age groups model as comprise between realism and simplicity

Discussion Points

- Population size estimates should be a key demographic parameter to fisheries/sea lion management
- Suggested approach makes use of current data, not ideal in some respects
- Additional data would need to be collected for alternative approaches