Demographic rates of northern royal albatross at Taiaroa Head

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Goals

Estimation of:

- Annual survival rate of different age classes of northern royal albatross
- Age at first return to the colony
- Age at first reproduction
- Population size
- Ratio of the total population to the number of annual breeding pairs

How?

- Bayesian multi-state capture-recapture model
- 22 years of data on presence/absence and breeding at Taiaroa Head colony

Update of the Potential Biological Removal (PBR)

Rationale

At risk from commercial fisheries in NZ (Richard et al. 2013)

- Potential annual fatalities: 108 (95% c.i.: 72–160)
- Potential Biological Removal (PBR): 396 (95% c.i.: 164–782)
- Large uncertainty in PBR driven by uncertainty in adult survival rate

Existing adult survival rates from 20 years ago (Robertson 1993)

Taiaroa Head: great quality data; potential extrapolation to the whole species.

Northern royal albatross

- Endemic to New Zealand
- Conservation status: “Endangered” (IUCN) / “Naturally Uncommon” (DOC)
- Breeds predominantly in the Chatham Islands. 5 200–5 800 annual breeding pairs
- Biennial breeder; breeding season October–November
- Single egg laying: October–December
- Hatching: late January / early February
- Fledging: August–October
- Age at first return: minimum 3 year-old
- Age at first reproduction: 8 year-old

Taiaroa Head colony

A small colony self-established on the New Zealand mainland at Taiaroa Head, at the tip of the Otago peninsula.

- First fledgling in 1938
- Administered as a Nature Reserve in 1964
- Now a major tourist attraction
- 130 000 visitors/year

Taiaroa Head

Taiaroa Head

- Banding of individuals since 1938
- Colony intensively monitored since 1968
- Predator control
- Fostering of eggs and chicks

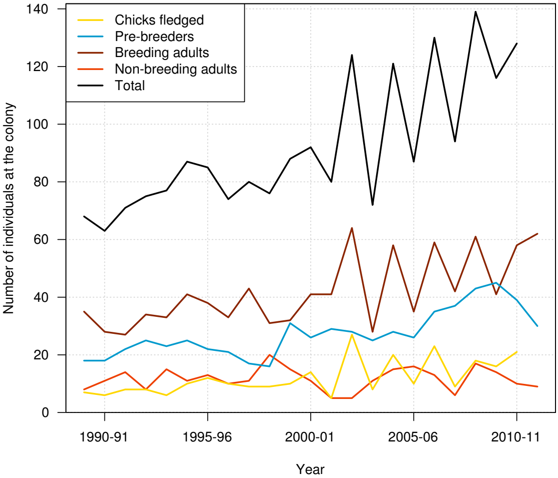
Data

Records:

- Presence at the colony (present or not)
- Status
    - Juvenile (from fledging to 1^{st} return)
    - Pre-breeder (from 1^{st} return to 1^{st} breeding)
    - Breeding adult
    - Non-breeding adult
- Outcome of breeding attempt (successful or not)
- Age
- Sex

Daily visits summarised at year level.
Data available from 1989–90 to 2011–12.
2128 annual resightings of 355 banded individuals of known-age.
27 immigrants from the Chathams not included.

At a glance


Chicks fledged
Pre-breeders
Breeding adults
Non-breeding adults
Total
Number of individuals at the colony
0
20
40
60
80
100
120
140
1990-91
1995-96
2000-01
2005-06
2010-11
Year

Survival analysis

Year:	1	2	3	4	5	6	7	8	9
Data:	1 →	0 →	0 →	1 →	0 →	1 →	0 →	0 →	0
Status:	Alive						Dead?		

Survival analysis

Survival rate needs to be jointly estimated with detection probability. Here,

- Detection probability $= 1$
- When not recorded at colony, individual either at sea or dead.

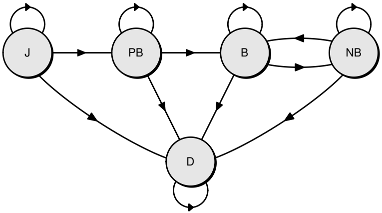
Survival and detection probability depend on the state of the individual.

- Juveniles have lower survival
- Pre-breeders have higher colony attendance
- Adult breeding successfully are generally not seen at the colony the following year.

Modelling

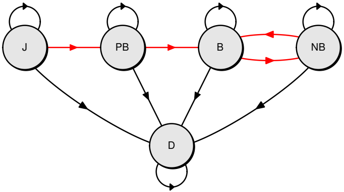
Bayesian multi-state capture-recapture model

- Integrated model, adapted from Dillingham *et al.* (2011)
- Estimation of the transitions between states
- States are observed or not



J: Juvenile
PB: Pre-breeder
B: Breeding adult
NB: Non-breeding adult
D: Dead

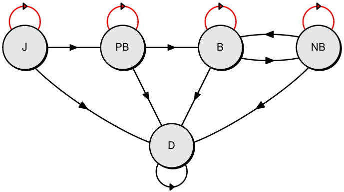
Base model



Transitions between classes

$$P(\mathrm{PB}_t|\mathrm{J}_{t-1}) = R_a\phi_\mathrm{J}$$
$$P(\mathrm{B}_t|\mathrm{PB}_{t-1}) = B_a\phi_\mathrm{PB}$$
$$P(\mathrm{B}_t|\mathrm{NB}_{t-1}) = P(\text{breed}|\text{non-breeder})\phi_\mathrm{A}$$
$$P(\mathrm{NB}_t|\mathrm{B}_{t-1}) = \begin{cases} \big(1 - P(\text{breed again}|\text{success})\big)\phi_\mathrm{A} & \text{after successful breeding attempt} \\ \big(1 - P(\text{breed again}|\text{fail})\big)\phi_\mathrm{A} & \text{after failed breeding attempt} \end{cases}$$

Base model



Probabilities of remaining in the same live state:

$$P(\mathrm{J}_t|\mathrm{J}_{t-1}) = (1-R_a)\phi_{\mathrm{J}}$$

$$P(\mathrm{PB}_t|\mathrm{PB}_{t-1}) = (1-B_a)\phi_{\mathrm{PB}}$$

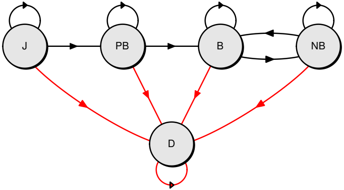
$$P(\mathrm{NB}_t|\mathrm{NB}_{t-1}) = \big(1-P\left(\text{breed}|\text{non-breeder}\right)\big)\phi_{\mathrm{A}}$$

$$P(\mathrm{B}_t|\mathrm{B}_{t-1}) = \begin{cases} P(\text{breed again}|\text{success})\phi_{\mathrm{A}} & \text{after successful breeding attempt} \\ P(\text{breed again}|\text{fail})\phi_{\mathrm{A}} & \text{after failed breeding attempt} \end{cases}$$

Base model

Probabilities of being dead (D):

$$P(\mathrm{D}_t|\mathrm{J}_{t-1}) = 1 - \phi_{\mathrm{J}}$$
$$P(\mathrm{D}_t|\mathrm{PB}_{t-1}) = 1 - \phi_{\mathrm{PB}}$$
$$P(\mathrm{D}_t|\mathrm{B}_{t-1}) = 1 - \phi_{\mathrm{A}}$$
$$P(\mathrm{D}_t|\mathrm{NB}_{t-1}) = 1 - \phi_{\mathrm{A}}$$
$$P(\mathrm{D}_t|\mathrm{D}_{t-1}) = 1$$

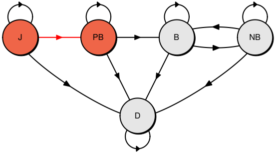


Death is a state typically unobservable.
10 birds reported dead at or near the colony + 2 deaths reported from pelagic longline fisheries off Uruguay.

Base model

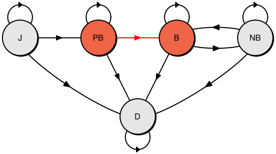
Probability R_a of a juvenile of age a returning to the colony:

$$\begin{cases} R_a = 0 & \text{for } 1 \leq a < 3 \\ R_a = P(\text{first return}|\text{age} = a) & \text{for } 3 \leq a < 8 \\ R_a = P(\text{first return}|\text{age} \geq 8) & \text{for } a \geq 8 \end{cases}$$



Probability B_a of breeding for the first time at age a:

$$\begin{cases} B_a = 0 & \text{for } 1 \leq a < 6 \\ B_a = P(\text{first breeding}|\text{age} = a) & \text{for } 6 \leq a < 11 \\ B_a = P(\text{first breeding}|\text{age} \geq 11) & \text{for } a \geq 11 \end{cases}$$



Base model

Probability of being at the colony:

$$
\begin{aligned}
P(\mathrm{C}_t|\mathrm{J}_t) &= 0 \\
P(\mathrm{C}_t|\mathrm{PB}_t) &= \gamma_{\mathrm{PB}} \\
P(\mathrm{C}_t|\mathrm{NB}_t) &= \gamma_{\mathrm{NB|S}}, \text{for adults who bred successfully the previous year} \\
P(\mathrm{C}_t|\mathrm{NB}_t) &= \gamma_{\mathrm{NB|F}}, \text{for adults who did not breed successfully the previous year} \\
P(\mathrm{C}_t|\mathrm{B}_t) &= 1 \\
P(\mathrm{C}_t|\mathrm{D}_t) &= 0.
\end{aligned}
$$

Increasing model complexity

- Adult survival may vary between males and females

$$\text{logit}(\phi_M) = \text{logit}(\phi_F) + \beta_M.$$

- Senescence – Survival declines with age

$$\text{logit}(\phi_a) = \begin{cases} \text{logit}(\phi_6) & \text{for } 1 \leq a < 6, \\ \text{logit}(\phi_6) + \alpha_\text{A}(a-6) + \beta_\text{A}(a-6)^2 & \text{for } a \geq 6. \end{cases}$$

- Inter-annual variation in survival
    - Year as fixed effect
    - Year as random effect

Results

Model selection

	Deviance		
Model	Mean	Variance	ΔDIC
S_J(year_re), S_{PB}(year_re), S_A(age+year_re)	3079.10	548.40	0.00
S_J(.), S_{PB}(.), S_A(age+year_re)	3078.90	566.81	9.01
S_J(.), S_{PB}(.), S_A(age)	3082.64	559.60	9.14
S_J(.), S_{PB}(.), S_A(.)	3087.27	555.73	11.83
S_J(.), S_{PB}(.), S_A(sex+age)	3082.64	566.48	12.58
S_J(year_re), S_{PB}(year_re), S_A(year_re)	3083.95	565.01	13.16
S_J(year_re), S_{PB}(year_re), S_A(sex+age+year_re)	3078.91	577.59	14.41
S_J(.), S_{PB}(.), S_A(year_re)	3083.24	569.45	14.66
S_J(.), S_{PB}(.), S_A(sex+age+year_re)	3078.59	582.92	16.74
S_J(year), S_{PB}(year), S_A(age+year)	3172.26	747.69	192.81

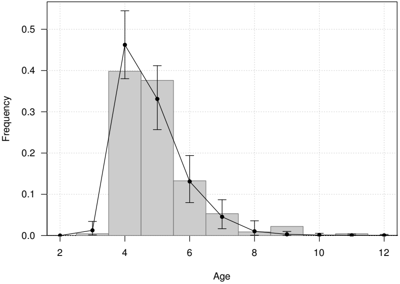
Best model: senescence, random annual variations, no gender difference

Estimates

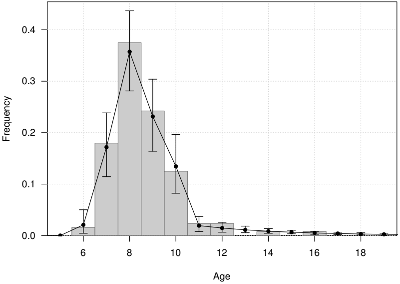
Parameter	Mean	95% c.i. Lower limit	95% c.i. Upper limit
Juvenile survival	0.933	0.908	0.966
Pre-breeder survival	0.966	0.950	0.980
Adult survival - overall	0.950	0.941	0.959
6 year-old	0.976	0.963	0.988
20 year-old	0.968	0.957	0.979
40 year-old	0.915	0.879	0.946
Mean age at first return	4.813	4.631	5.058
Mean age at first breeding	8.851	8.532	9.291
γ_{NB}|fail	0.954	0.917	0.979
γ_{NB}|success	0.162	0.129	0.195
γ_{PB}	0.991	0.982	0.997
P(breed again|fail)	0.828	0.789	0.864
P(breed again|success)	0.006	0.001	0.015
P(breed|non-breeder)	0.791	0.757	0.823
Proportion of adults breeding	0.567	0.565	0.569

Model fit

Age at first return

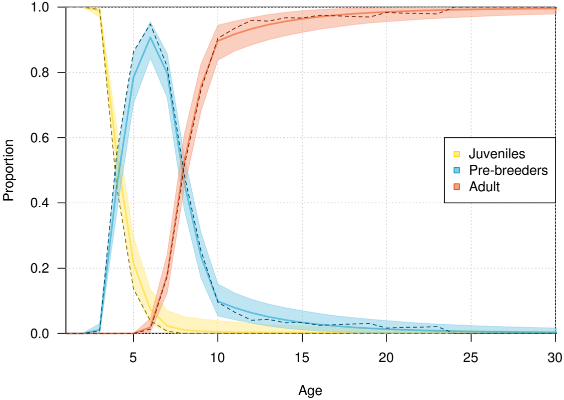


Age at first breeding



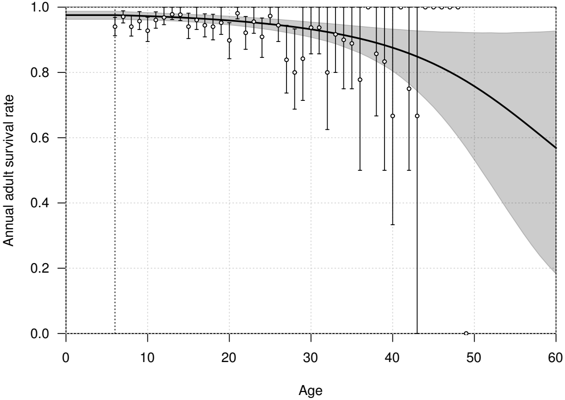
Model fit

Distribution of age classes with age



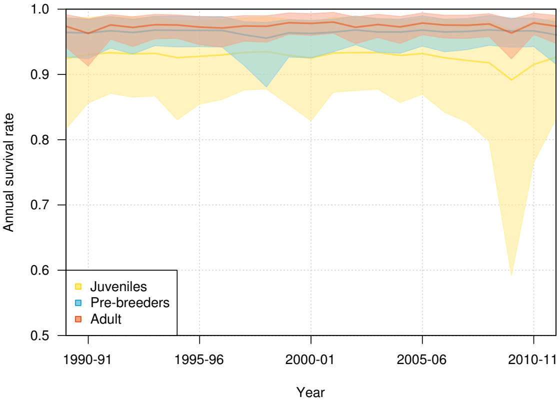
Senescence

Adult survival declines with age after 20 years.



Inter-annual variability

No trend over time ⇒ No fundamental change in conditions.



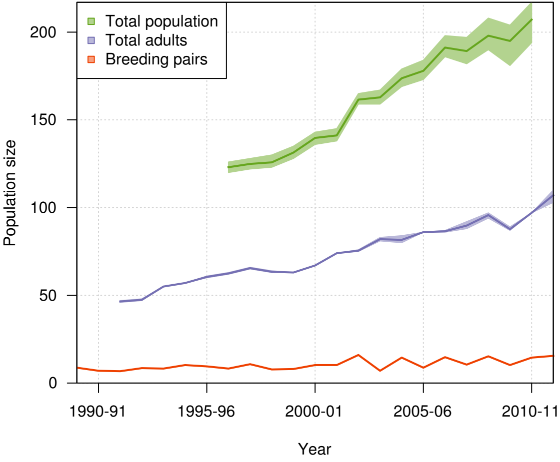
Limitations

- Extrapolation of survival rate to the whole species unclear
  - Management of the colony
  - Potentially different foraging area
  - But existing estimate from the Chathams is similar (0.952)

- Local survival rate
  - Emigration to Chatham Islands not included in model
  - One case of a bird from Taiaroa Head found breeding in the Chathams
  - 27 visitors or immigrants from the Chathams to Taiaroa

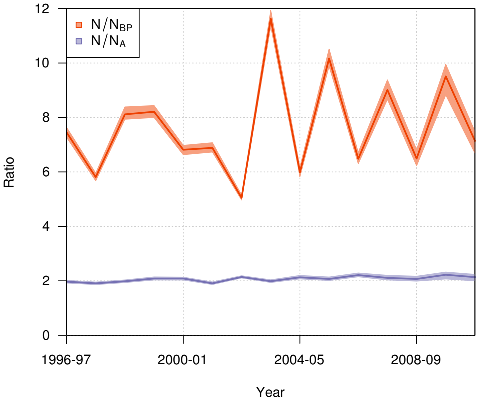
Population size and growth

Current total population size at Taiaroa Head exceeds 200 individuals.



Total population vs. annual breeding pairs

$N/N_{BP} = 7.65$ (95% c.i.: 5.03–11.64)
Highly variable between years.



Risk assessment update

Slight decrease in the PBR_1 with the updated estimates of adult survival and age at first reproduction, From 396 (95% c.i.: 164–782) to 316 (95% c.i.: 161–550)

Slight increase in the risk ratio (fatalities / PBR_1), from 0.29 (95% c.i.: 0.12–0.7) to 0.35 (95% c.i.: 0.17–0.74).

However, same probability of fatalities exceeding PBR_1 (0.3%).

Conclusions

- Updated estimates in concordance with previous estimates.
- No detection of a trend over time in survival.
- The Taiaroa Head population doubled in the last 20 years.
- Long-term monitoring is essential, and Taiaroa Head provides a unique opportunity for research (e.g. density-dependence).

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