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Review of mark-recapture studies on UK seabirds that are run through the BTO's Retrapping Adults for Survival (RAS) network

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Please note that this report was prepared from research conducted in 2015.

Summary

In the UK, the abundance and breeding success of seabirds are monitored through several coordinated programs that span a large number of colonies. The estimation of survival rates requires individual-based mark-recapture (MR) data that entail significantly more staff time and costs. Consequently, the survival rates of seabird are monitored at considerably fewer sites.

Citizen science projects run through the BTO's Retrapping Adults for Survival (RAS) network have increased the number of MR studies conducted on seabirds in the UK. This model of citizen science projects, supported by a central co-ordinator, offers the potential to increase the geographic range of survival estimates for seabirds. The studies registered in the network achieve different levels of field effort, and therefore an evaluation of field protocols is necessary in order to minimise the risk that studies fail to achieve targets, such as reliably estimating survival rates.

This report evaluates the performance of active and non-active seabird projects registered in the BTO's RAS network. We compared the estimates of adult survival rates from RAS with those generated from more intensively monitored colonies. We also conducted a power analysis to evaluate how different levels of field effort (marking and recapture) may impact the ability to estimate a constant adult survival rate, as well as detecting annual and individual-level variation (e.g. due to age). Finally, to examine the motivations and challenges associated with RAS participation, we interviewed a selection of active and non-active RAS seabird ringers, as well as regular seabird ringers not registered in the network.

To accurately estimate survival with a time series of ten years, the minimum marking effort was 200 individuals per year, and the minimum recapture rate was 0.4. Longer-term studies (>20 years) were more able to accurately estimate survival with lower levels of marking and recapture effort. In total, 35% of the 33 RAS studies with over four years of data, achieved levels of field effort that should result in a reliable estimation of a constant adult survival rate.

In order to detect temporal or individual-level variation in survival rates, levels of marking and recapture effort needed to be greater than were required to estimate a constant survival rate. Fewer than 25% of the 33 RAS studies with over four years of data achieved the levels of field effort that should permit these processes to be reliably detected.

The ability to maintain a consistent level of survey effort over time was highlighted by the RAS volunteers as a principal challenge facing continuity. The volunteers highlighted three areas for further assistance: logistical support (e.g. developing field protocols and arranging access to sites); specific feedback; and financial assistance (e.g. with equipment and transport costs).

In this study, we demonstrated that the amount of effort applied to marking will determine the ideal rate of recapture. Furthermore, the levels of field effort required to accurately estimate survival changed with the duration of the time series. This result highlights the importance of having consistent programs for monitoring the survival rates of seabirds, as well as considering the longevity of programs when designing or adjusting field protocols.

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1. Introduction

Seabirds are exposed to a range of anthropogenic pressures, such as climate change, renewable developments, pollution events and competition with fisheries (Burthe *et al* 2014). In order to adequately focus conservation efforts, it is essential to understand how these pressures influence demographic parameters (e.g. breeding success and survival). The ability to examine these relationships largely depends on the quantity and precision of the demographic data.

For seabirds, it is possible to estimate the size of a breeding population and the annual rate of breeding success using data collected within a single breeding season. In the UK, these demographic parameters are monitored through several coordinated programs that span a large number of colonies. To estimate survival rates typically requires individual-based mark-recapture (MR) data collected over several years. Here, longer time series are needed to overcome any biases associated with incomplete recapture rates. These approaches often entail significant staff time and costs, and therefore studies are usually limited to a small number of sites (e.g. the Seabird Monitoring Programme key sites). Data from these intensively monitored key sites have provided much of our understanding on local seabird demography (e.g. Frederiksen *et al* 2008). However, the limited geographic scope associated with these sites risks missing spatial variations that may be important both ecologically, and for assessing anthropogenic pressures in regions without long-term data (Frederiksen *et al* 2005).

A recent study by Lahoz-Monfort *et al* (2014) indicated that it is possible to maintain the capacity for estimating seabird survival rates under reduced scenarios of marking and recapture effort. Consequently, one solution for overcoming the logistical and financial barriers that restrict the spatial representivity of intensive MR programs is to utilise the skills of volunteers, or citizen scientists, to carry out studies with lower levels of field effort. In the last two decades, citizen science projects run through the BTO's Retrapping Adults for Survival (RAS) network have increased the number of MR studies conducted on seabirds in the UK. RAS studies are flexible in terms of ring-type and catching methods, and participants aim to recapture at least 30 individuals that were ringed as adults in a previous season (see http://www.bto.org/volunteer-surveys/ringing/surveys/ras/taking-part/scheme-downloads for more detailed methods).

This report builds on previous work that reviewed the spatial range of MR based monitoring of seabirds in the UK, and examined the suitability of this approach for monitoring the different species (Robinson & Ratcliffe 2010; Robinson & Baillie 2012). Here, we evaluate the performance of the BTO's RAS network in order to minimise the risk that studies fail to achieve targets, such as reliably estimating survival rates. The report contains six main sections that cover the following objectives:

- In Section 2, we detail the spatial range and average survey effort of the active and non-active studies registered in the BTO's RAS network.
- Section 3 examines how varying levels of field effort may influence the ability to estimate a constant adult survival rate.
- Sections 4 and 5 examine how varying levels of field effort may influence the ability to detect annual variation in survival rates, and differences within the population (e.g. due to age or transience).
- In Section 6, we investigate the motivations and challenges associated with RAS participation by citizen scientists.
- Finally, in Section 7 we discuss briefly the priorities for developing RAS for future research and conservation.

2. Review of the BTO's Retrapping Adults for Survival (RAS) network

This section details the spatial range and average survey effort of active and non-active studies registered in the BTO's Retrapping Adults for Survival (RAS) network. The RAS network was initiated in 1998, but many of the registered studies also operated prior to that date. The RAS network has supported the collection of mark-recapture (MR) data from 40 seabird and sea duck colonies (Figure 1), and in 2014, there were 15 active and 18 non-active projects with over four years of data (Table 1). Of these, nine were based on resighting colour rings (Table 1). In addition, the distribution of active studies was concentrated in western Scotland (Figure 1), reflecting the greater number of seabird colonies in that region. Considerably fewer studies were present in Wales and England, and all of the studies in northern and eastern Scotland were non-active (Figure 1). In 2014, the species monitored by the RAS network included (in taxonomic order): common eider (*Somateria mollissima*), storm petrel (*Hydrobates pelagicus*), Manx shearwater (*Puffinus puffinus*), European shag (*Phalacrocorax aristotelis*), black-legged kittiwake (*Rissa tridactyla*), black-headed gull (*Chroicocephalus ridibundus*), lesser black-backed gull (*Larus fuscus*), Arctic tern (*Sterna paradisaea*), common guillemot (*Uria aalge*), razorbill (*Alca torda*) and Atlantic puffin (*Fratercula arctica*). Coverage of sea ducks was limited to common eider, therefore for the purpose of this report this species has been grouped with the true seabirds.

2.1. Methods

Annual adult survival rates were estimated for each species using data from active and non-active RAS studies. Studies with less than four years of data were removed from the analysis (Table 1). RAS studies conducted on auks that were predominantly conducted before the introduction of hard rings in 1983 were also removed (RAS 19, Table 1). Survival rates were estimated using program MARK (White & Burnham 1999), accessed through RMark (Laake 2013; R Core Team 2014). To control for colony- and annual-variation associated with local environmental conditions and variable levels of field effort, species-specific survival was modelled as year-dependent and recapture rates were modelled as site- and year-dependent. In addition, survival rates were modelled with an age-structure that permitted age-specific survival rates during the fledging year and controlled for transience (see Section 5). The mean survival rates are presented for birds older than one year and the standard deviation reflects the year-to-year variation (Table 2).

The species-specific estimates of survival rates from RAS data were compared with published values from more intensively monitored colonies (Table 2). When published estimates were available for more than one colony, the presented value reflects the mean weighted by the duration of each study. This provides an estimate across a broader geographic area. The comparison was focused on studies from the UK, but when local information was lacking the geographic scope was widened (Table 2).

2.2. Results and Discussion

The mean estimates of adult survival are detailed in Table 2 (annual estimates of adult survival are detailed in Appendix 1). The survival rates of black-legged kittiwake, European shag, common guillemot, razorbill and Atlantic puffin are thought to be relatively consistent across different UK colonies (Harris *et al* 2005; Cook & Robinson 2010). In agreement with this, the mean survival rates estimated from RAS data were comparable to those from the published literature for black-legged kittiwake, razorbill and Atlantic puffin (Table 2). The RAS estimates of survival for eider, European shag and common guillemot were also similar to published estimates, albeit with considerably larger variation between years (Table 2). The level of field effort currently achieved by many RAS studies may prevent reliable estimation of annual variation (see Section 4). Consequently, we infer that the larger variation observed in these species may reflect study-specific levels of field effort, as opposed to actual biological variability between colonies. For example, the confidence interval for European shag significantly increased post 2006 when two of the three RAS studies on this species stopped collecting data (Table 1; Appendix 1).

Studies that examine regional variation in survival rates are lacking for eider, black-headed gull, lesser black-backed gull, storm petrel and Manx shearwater. For black-headed gull, lesser black-backed gull, and to a lesser extent storm petrel, the estimates of survival from the RAS data were lower than those published for more intensively monitored colonies (Table 2). The published estimates of survival on lesser black-backed gull indicated that regional variation may exist for this species (Wanless *et al* 1996; Taylor *et al* 2010). Consequently, the RAS estimate may reflect colony-specific survival rates, possibly associated with local differences in breeding dispersal (reviewed in Horswill & Robinson 2015).

It has been previously suggested that seabird ringing projects in the UK require a sample of approximately 150 newly marked individuals per year in order to reliably estimate adult survival rates (Harris 1989). Ringing (or marking) effort in the RAS network was highly variable (range: 10-1061 per year). The mean ringing effort was above 150 individuals per year (mean=176; SD=265), however under half (40%) of the RAS studies achieved this level of effort (Table 1). The recapture rates currently achieved in the RAS network were also highly variable (range: 0.05-0.66; mean=0.29; SD=0.17; Table 1). RAS participants currently aim to recapture at least 30 individuals ringed as adults in a previous season. An annual recapture effort of 30 individuals equates to a recapture rate of 0.05 for a population that includes 600 marked individuals, or a recapture rate of 0.66 for a population that includes 45 marked individuals; i.e. the ideal level of recapture effort largely depends on the existing marking effort.

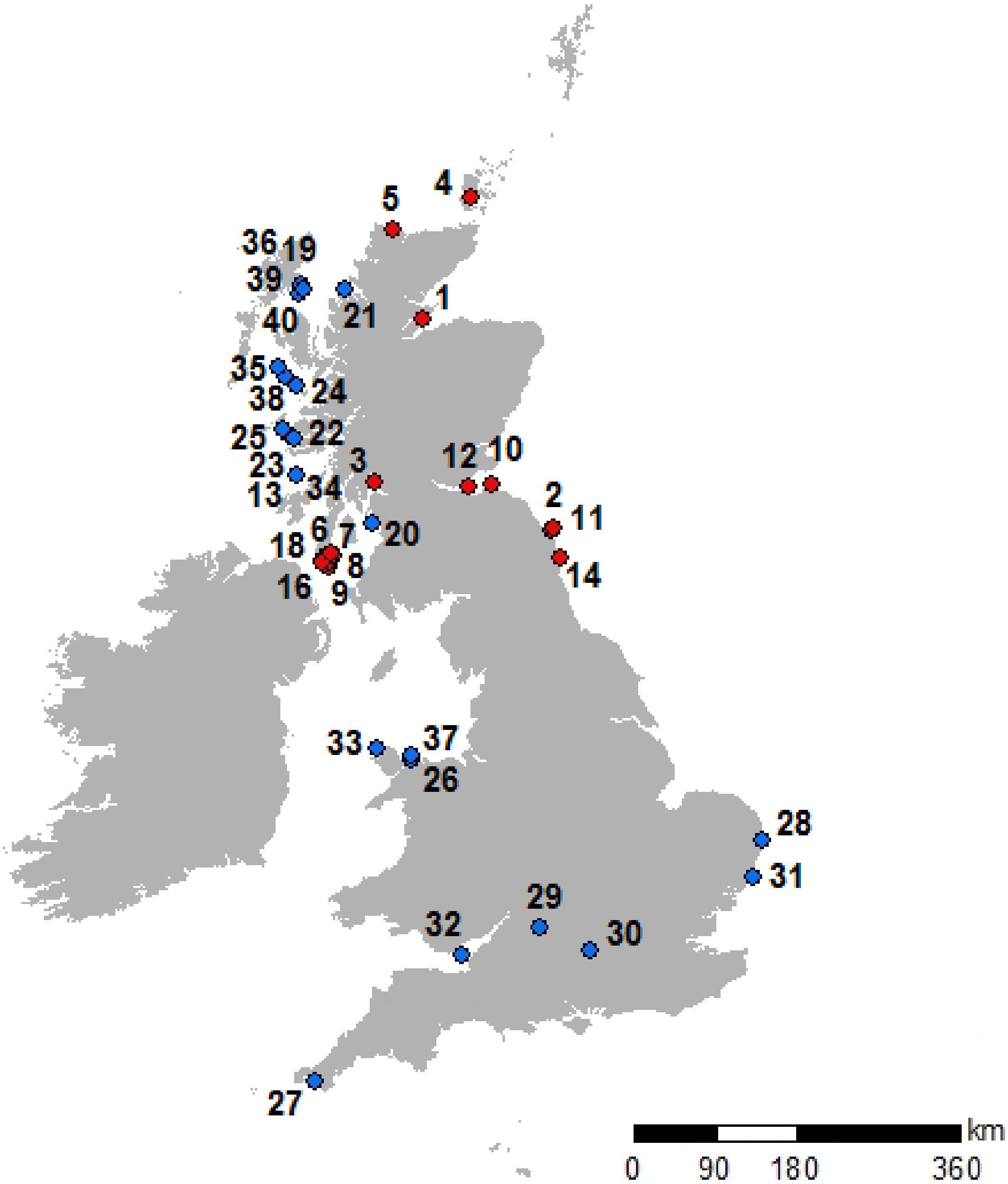

Figure 1. A map of active (blue) and non-active (red) studies registered in the BTO's Retrapping Adults for Survival (RAS) network. Numbers match with the RAS studies listed in Tables 1 and 2.

Table 1. Active and non-active studies registered in the BTO's RAS network and mean ringing and recapture efforts per year. Studies are ordered by current activity and taxonomy. Red shading reflects studies not included in the estimation of survival rates in Table 2 and Appendix S1 because of duration; grey shading reflects studies not included because of ring-type; ** studies were included but had very low levels of ringing and recapture effort. End year is not listed for studies that are currently active (RAS no. 20-40).

RAS no.	Species	Location	Start year	End year	Duration (years)	Colour rings	Mean ind. marked (year^{-1}) ± SD	Mean recapture (year^{-1})
1	Eider	Nigg	1998	2005	7	N	56 ±22	0.56
2	Eider	Inner Farne	1998	2009	11	N	112 ±48	0.37
3	Eider	Faslane	2001	2007	5	Y	69 ±21	0.26
4	Eider	Orkney	2002	2004	2		21 ±15	
5	Storm petrel	Eilean Hoan	1996	2012	16	N	110 ±76	0.30
6	Storm petrel	Sanda Island	2000	2006	6	N	109 ±69	0.32
7	Storm petrel	Sanda Island	2010	2014	4	N	59 ±77	
8	Manx shearwater	Sanda Island	2000	2005	5	N	48 ±27	0.22
9	Manx shearwater	Sanda Island	2010	2013	3	N	10 ±16	
10	European shag	Craigleith	1992	2006	14	N	32 ±16	0.15
11	European shag	Staple Island	2000	2006	6	N	69 ±43	0.25
12	Black-legged kittiwake	Inchkeith	1992	2007	15	N	19 ±18	0.05
13	Black-legged kittiwake	Port Ban, Isle of Colonsay	1988	2006	18	Y	34 ±18	0.47
14	Arctic tern	Coquet Island	2000	2003	3	N	131 ±67	
15	Common guillemot	Sanda Island	2000	2006	6	N	121 ±76	**
16	Common guillemot	Sanda Island	2010	2013	3	N	41 ±55	**
17	Razorbill	Sanda Island	1998	2006	8	N	116 ±46	**
18	Razorbill	Sanda Island	2010	2013	3	N	22 ±33	
19	Atlantic puffin	Garbh Eilean, Shiant Islands	1970	1985	15	N	512 ±441	
20	Eider	Horse Isle, Ardrossan	2001	-	13	Y	78 ±54	0.32
21	Storm petrel	Priest Island	2001	-	13	N	851 ±291	0.19
22	Storm petrel	Lunga (1)	2003	-	11	N	227 ±162	0.09
23	Storm petrel	Lunga (2)	2001	-	13	N	87 ± 42	0.19
24	Manx shearwater	Hallival, Askival & Trollaval, Isle of Rum	1994	-	20	N	743 ± 352	0.16

RAS no.	Species	Location	Start year	End year	Duration (years)	Colour rings	Mean ind. marked ($year^{-1}$) ± SD	Mean recapture ($year^{-1}$)
25	European shag	Lunga, Treshnish Isles	2007	-	8	Y	70 ± 15	0.61
26	Black-legged kittiwake	Puffin Island	2002	-	12	Y	119 ± 46	0.34
27	Black-legged kittiwake	Rinsey Cliffs	2012	-	2	Y	22 ± 12	
28	Black-legged kittiwake	Claremont Pier, Lowestoft	2012	-	2	Y	84 ± 23	
29	Black-headed gull	Cotswold Water Park	2009	-	5	Y	37 ± 27	0.32
30	Black-headed gull	Hosehill Lake LNR	2010	-	4	Y	55 ± 12	0.66
31	Lesser black-backed gull	Orfordness	2003	-	11	Y	97 ± 31	0.57
32	Lesser black-backed gull	Flat Holm	2003	-	11	Y	29 ± 14	0.42
33	Arctic tern	Skerries, Anglesey	2013	-	1	Y	69 ± 27	
34	Common guillemot	Port Ban, Colonsay	1989	-	25	N	118 ± 68	0.32
35	Common guillemot	Geugasgor Cliffs, Canna	1981	-	33	N	1061 ± 447	0.20
36	Razorbill	North Beach, Carnach Mhor, Shiant Isles	2009	-	5	N	371 ± 126	0.21
37	Razorbill	Puffin Island	2004	-	10	N	90 ± 34	0.18
38	Razorbill	Geugasgor Cliffs, Canna	1981	-	33	N	91 ± 46	0.11
39	Atlantic puffin	Garbh Eilean, Shiant Islands	2008	-	6	N	963 ± 254	0.15
40	Atlantic puffin	North Beach, Garbh Eilean	2008	-	6	N	101 ± 55	0.06

Table 2. Mean apparent adult survival rates estimated from studies registered in the BTO's RAS network, and to estimates of mean survival rate for the same species based on intensively monitored colonies. The standard deviation is a measure of the year-to-year variation in survival. The published estimates were focused on studies from the UK, but when UK information was lacking, the geographic scope was widened; the location of study colonies and the data collection method are listed in the footnotes, see Table 1 for RAS studies. The RAS estimates of annual survival rates are shown by species in Appendix 1.

RAS No.	Species	Max. length of RAS time series (years)	RAS survival estimate (mean ± SD)	Published survival estimate (mean ± SD)	Reference for the published estimate
1 / 2 / 3 / 20	Eider	15	0.84 ± 0.21	0.87 ± 0.02	[1]Coulson 1984†; [2]Hario *et al* 2009†
5 / 6 / 21 / 22 / 23	Storm petrel	15	0.79 ± 0.04	0.83	[3]Oro *et al* 2005†
8 / 24	Manx shearwater	19	0.93 ± 0.03	0.87 ± 0.08	[4]Büche *et al* 2013†
10 / 11 / 25	European shag	15	0.83 ± 0.15	0.86 ± 0.01	[5]Coulson & White 1957†‡; [6]Frederiksen *et al* 2008†‡
12 / 13 / 26	Black-legged kittiwake	13	0.82 ± 0.09	0.85 ± 0.06	[7]Oro & Furness 2002†; [6]Frederiksen *et al* 2004†; [8]Coulson & Strowger 1999†; [4]Taylor *et al* 2010†
29 / 20	Black-headed gull	4	0.65 ± 0.13	0.83 ± 0.03	[9]Majoor *et al* 2005†; [10]Péron *et al* 2010†
31 / 32	Lesser black-backed gull	10	0.75 ± 0.09	0.89 ± 0.02	[6]Wanless *et al* 1996†; [4]Taylor *et al* 2010†;
15 / 16 / 34 / 35	Common guillemot	32	0.87 ± 0.12	0.94 ± 0.02	[6]Lahoz-Monfort *et al* 2011†; [4,6,11,12]Reynolds *et al* 2011†; [4]Meade *et al* 2013†
17 / 36 / 37 / 38	Razorbill	32	0.91 ± 0.06	0.89 ± 0.07	[4]Taylor *et al* 2010†; [6]Lahoz-Monfort *et al* 2011†
19 / 39	Atlantic puffin	5	0.93 ± 0.05	0.92 ± 0.01	[4,6,13,14]Harris *et al* 2005†; [6]Lahoz-Monfort *et al* 2011†; [4]Taylor *et al* 2010†

Study site: [1]Coquet Island, NE England; [2]Soderskar Game Research Station, Finland; [3]Benidorm Island, Spain; [4]Skomer, Wales; [5]UK; [6]Isle of May, SE Scotland; [7]Foula, Shetland; [8]Tyne and Wear region, NE England; [9]Netherlands; [10]La Ronze, France; [11]Canna, W Scotland; [12]Colonsay, W Scotland; [13]Fair Isle, N Scotland; [14]Norway. *Study method:* † Mark-recapture study; †‡ Joint mark-recapture and ring-recovery study.

3. How does field effort affect the ability to estimate adult survival rates?

This section explores how differing levels of field investment may influence the ability to accurately estimate a constant survival rate.

3.1. Methods

3.1.1. Suitability to estimate a constant survival rate

The influence of field effort on the accuracy of survival estimation was examined by simulating a constant value (φ=0.83) under 75 scenarios of marking and recapture effort. The selected value of survival was the mean of the RAS estimates. Field effort was progressively increased in a three-stage nested design (see Appendix 2). Here, four different scenarios of marking effort were selected to represent the BTO's Retrapping Adults for Survival (RAS) network (50, 100, 200, 500 and 1000 newly marked individuals released per sampling interval). For ease of interpretation, a sampling interval is here on referred to as a year. Each marking condition was tested at five different levels of recapture effort (0.05, 0.1, 0.2, 0.4 and 0.6), and three durations of time series (5 years, 10 years and 20 years). Models were constructed in Program MARK using the 'live recaptures (CJS)' framework (White & Burnham 1999). This approach permits the estimation of survival and recapture rates in a restricted framework that allows for year- and group-specific effects. Each model was run for 100 simulations to provide a distribution of survival estimates.

The precision of the estimated values of survival was assessed by standardising to $\bar{x} = 0$ and examining the ability to estimate survival (φ=0.83) within 1% (0.01) or 2% (0.02) of the true mean with 95% confidence.

3.1.2. Performance of RAS studies

The suitability of the RAS studies (Table 2) to estimate a constant survival rate was graded based on the marking and recapture conditions required to estimate the true mean within the 95% confidence limit. Here, marking effort, recapture effort and the length of the time series for each RAS study were rounded to the nearest set of scenario conditions. Each RAS study was graded as meeting the conditions to estimate survival within 1% of the true mean ("good"), within 2% of the true mean ("intermediate"), or not achieving these conditions ("poor")

3.2. Results and Discussion

3.2.1. Suitability to estimate a constant survival

For a five year dataset, high levels of marking and recapture effort were required to estimate survival within 1% or 2% of the true mean with 95% confidence. It was not possible to accurately estimate survival within 1% or 2% of the true mean when 200 or fewer individuals were marked per year (Figure 2A, D & G). When marking effort was increased to 500 new individuals per year, recapture rate needed to be at least 0.4 to achieve the 95% confidence limit within 2% of the true mean, and it was not possible to resolve survival within 1% (Figure 2J). When 1000 new individuals were marked per year, the recapture rate needed to be 0.4 or 0.6 to resolve survival within 2% or 1%, respectively (Figure 2M).

For the 10 year dataset, high levels of marking or recapture effort were required to estimate survival within 1% or 2% of the true mean with 95% confidence. It was not possible to accurately estimate survival within 1% or 2% when 50 individuals were marked per year (Figure 2B). When 100 new individuals were marked per year, the recapture rate needed to be at least 0.4 to accurately estimate survival within 2% of the true mean, and it was not possible to resolve survival within 1% (Figure 2E). When 200 or 500 new individuals were marked per year, recapture rate needed to be at least 0.2 to achieve the 95% confidence limit within 2% of the true mean, and 0.4 to accurately estimate within 1% (Figure 2H&K). Finally, when 1000 new individuals were marked it was possible to resolve survival within 1% of the true mean even at very low recapture probabilities (Figure 2N).

For a 20 year dataset, lower levels of marking and recapture effort were required to estimate survival within 1% or 2% of the true mean with 95% confidence. Recapture probabilities needed to be at least 0.2 to accurately estimate survival within 1% of the true mean when 50 or 100 new individuals were marked per year (Figure 2C & F). When 100 new individuals were marked it was also possible to resolve survival at the lower recapture rates within 2% of the true mean (Figure 2F). When 200 individuals were marked per year, the required recapture rate decreased to 0.1 in order to resolve survival within 1%, and 0.05 to resolve survival within 2% (Figure 2I). Finally, it was possible to resolve survival within 1% of the true mean with 95% confidence at all levels of recapture rate when the marking effort was 500 or more individuals per year (Figure 2L & O).

3.2.2. Performance of RAS studies

Less than half of the RAS studies with over 4 years of data in 2014 (35%) were graded as being able to estimate survival within 2% of the true mean with 95% confidence (Table 3). Furthermore, 6% were able to estimate survival within 1% of the true mean with 95% confidence. Species that had two or more 'good' studies were, in most cases, in different parts of the breeding range indicating that the RAS network can improve the regional understanding of survival monitoring in the UK. Furthermore, if the currently active projects that scored "intermediate" or "poor" are sustained at their current levels of field investment, these may become "good" with time (Table 3). This process could be accelerated for a number of studies by increasing the marking or recapture effort.

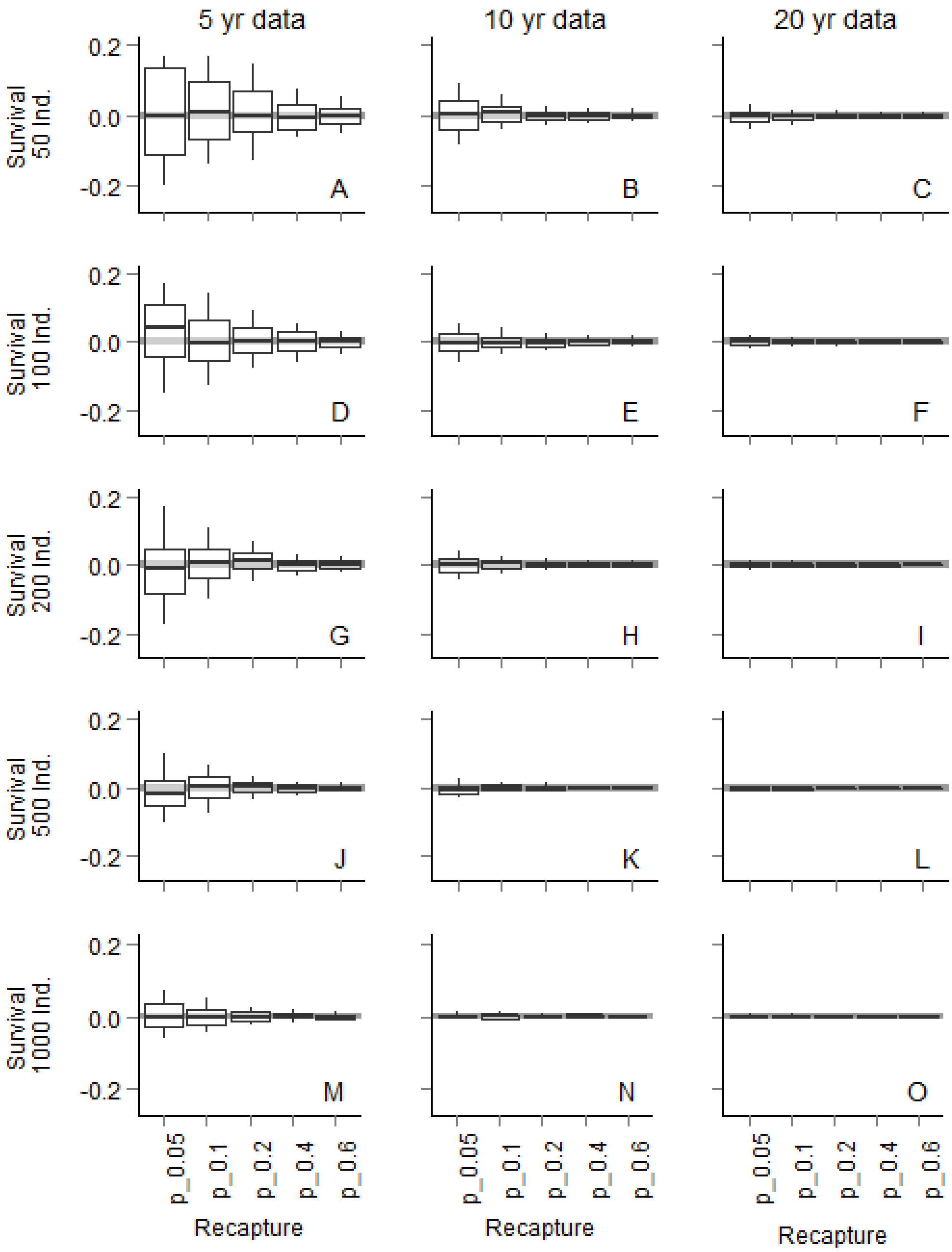

Figure 2. The accuracy (deviation from true survival) of a constant survival rate estimated under different scenarios of field effort; marking effort was examined at 50 (A-C), 100 (D-F), 200 (G-I), 500 (J-L) and 1000 (M-O) newly marked individuals released into the population per year. Each marking effort was examined at five levels of recapture effort (p); 0.05, 0.1, 0.2, 0.4, and 0.6. Left-hand column presents data simulated with a five year time series, middle column presents data simulated with a 10 year time series, and the right-hand column presents data simulated with a 20 year time series. Each box shows the inter-quartile range, the thick bar represents the median and the whiskers show the 95% interval of 100 simulations. Survival estimates within 1% of the true mean fall within the central grey band. To highlight variance the survival rates were standardised by subtracting the mean.

Table 3. The suitability of RAS studies with over four years of data to estimate a constant adult survival rate. The study on Atlantic puffin that was predominantly based on hard rings was also excluded. Studies are colour coded: green – "good" should estimate survival within 1% of the true mean with 95% confidence; orange – "intermediate" should estimate survival within 2% of the true mean with 95% confidence; red – "poor" cannot estimate survival within 2% of the true mean with 95% confidence. ** Studies with very low recapture effort.

RAS No.	Species	Location	Duration (year)	Mean ind. marked (year^{-1})	Mean recapture rate
1	Eider	Nigg	7	56	0.56
2	Eider	Inner Farne	11	112	0.37
3	Eider	Faslane	6	69	0.26
20	Eider	Horse Isle, Ardrossan	13	78	0.32
5	Storm petrel	Eilean Hoan	16	110	0.3
6	Storm petrel	Sanda Island	6	109	0.32
21	Storm petrel	Priest Island	13	851	0.19
22	Storm petrel	Lunga (1)	11	227	0.09
23	Storm petrel	Lunga (2)	13	87	0.19
8	Manx shearwater	Sanda Island	5	48	0.22
24	Manx shearwater	Hallival, Askival & Trollaval, Isle of Rum	20	743	0.16
10	European shag	Craigleith	14	32	0.15
11	European shag	Staple Island	6	69	0.25
25	European shag	Lunga, Treshnish Isles	8	70	0.61
12	Black-legged kittiwake	Inchkeith	15	19	0.05
13	Black-legged kittiwake	Port Ban, Isle of Colonsay	18	34	0.47
26	Black-legged kittiwake	Puffin Island	12	119	0.34
29	Black-headed gull	Cotswold Water Park	5	37	0.32
30	Black-headed gull	Hosehill Lake LNR	4	55	0.66
31	Lesser black-backed gull	Orfordness	11	97	0.57
32	Lesser black-backed gull	Flat Holm	11	31	0.42
15	Common guillemot	Sanda Island	6	121	**
16	Common guillemot	Sanda Island	3	41	**
34	Common guillemot	Port Ban, Colonsay	25	118	0.32
35	Common guillemot	Geugasgor Cliffs, Canna	33	1061	0.2
17	Razorbill	Sanda Island	8	116	**
36	Razorbill	North Beach, Carnach Mhor, Shiant Isles	5	371	0.21
37	Razorbill	Puffin Island	10	90	0.18
38	Razorbill	Geugasgor Cliffs, Canna	33	91	0.11
39	Atlantic puffin	Garbh Eilean, Shiant Islands	6	963	0.15
40	Atlantic puffin	North Beach, Garbh Eilean	6	101	0.06

4. How does field effort affect the ability to detect variation in survival between years?

This section explores how differing levels of field effort may influence the ability to detect changes in survival between years. The reliable estimation of annual variation in survival rates enables the detection of changes that may generate population-level impacts.

4.1. Methods

4.1.1. Suitability to estimate annual changes in survival

The influence of field effort on the detection of annual differences in survival was examined by simulating a 5% step change in survival (i.e. survival dropped from 0.83 to 0.78), under the 75 scenarios of marking and recapture effort described in Section B. The change occurred half way through the time series to provide an equal amount of data for each value for all of the time series. The variability in survival was based on published estimates (Table 2). Within each scenario, two models were constructed and fitted to the simulated time series. The starting model (here on referred to as the 'reference model') was constructed to have the largest number of parameters; i.e. it included an extra parameter to account for the 5% step change in survival. The second model assumed that survival rates were constant through time. The simulated estimates of survival from the reference model and the constant survival model were compared using a likelihood ratio test (LRT). The LRT assessed whether the difference in model deviances (between the reference model and the constant survival model) was significant against a χ^2 distribution at the α=0.05 level with degrees of freedom equal to the difference in the number of parameters between the two models (n=1; Burnham & Anderson 2002). We present the percent of the simulations that achieved this condition. Here, larger percentages indicate a better ability to detect the change in survival. For comparison, the mean difference in Akaike Information Criterion (ΔAIC), evidence ratio and model likelihood for the reference model relative to the constant model are also presented in the supplementary material. For AIC, a difference of less than two AIC units was taken to suggest that the constant model received a similar amount of support from the data; i.e. the difference in survival could not be detected (Burnham & Anderson 2002). The evidence ratio and model likelihood quantified the weight of evidence for the reference model relative to the constant model; i.e. small model likelihood indicates that all likelihood was assigned to the reference model and a difference was detected.

4.1.2. Performance of RAS studies

The suitability of studies registered in the BTO's Retrapping Adults for Survival (RAS) network to detect variation in survival between years was graded based on the marking and recapture conditions required to detect a 5% change in survival over time. Here, marking effort, recapture effort and the duration of the time series for each RAS study were rounded to the nearest set of scenario conditions. Each RAS study was graded as meeting the field effort conditions to detect variation with a probability greater than 90% based on the LRT results: yes = "good", no ="poor".

4.2. Results and Discussion

4.2.1. Suitability to estimate annual changes in survival

For a five year dataset, it was not possible to detect a 5% true difference in survival between years under the marking and recapture scenarios examined (
Figure **3**A; Appendix 3). When 500 and 1000 newly marked individuals were marked, it was possible to detect the difference based on ΔAIC when recapture probabilities were at least

0.6 (Appendix 3), however, based on the LRT, the probability of detecting the difference was less than 90% (
Figure **3**A; Appendix 3).

For a 10 year dataset, high levels of marking and recapture effort were required to be able to detect a 5% true difference in survival between years. It was not possible to detect the change when only 50 or 100 individuals were marked each year (
Figure **3**B; Appendix 3). When 200 individuals were marked, the recapture rate needed to be at least 0.6 for the probability of detecting a difference to be greater than 90% (
Figure **3**B). Finally, when 500 or 1000 new individuals were marked each year, the recapture rate needed to be above 0.4 and 0.2, respectively, to achieve a probability of detection above 90% (
Figure **3**B; Appendix 3).

For a 20 year dataset, lower levels of marking and recapture effort were required to detect a 5% difference in survival between years. It was not possible to detect the difference when 50 new individuals were marked per year, however with 100 new marked individuals per year, recapture probabilities needed to be greater than 0.2 for the probability of detecting a 5% difference in survival with close to, or more than, 90% probability (
Figure **3**C; Appendix 3). The difference could be reliably detected when 200 or more individuals were marked with recapture probabilities greater than 0.05 (
Figure **3**C; Appendix 3).

4.2.2. Performance of RAS studies

There were five RAS studies (16%) that achieved the marking and recapture conditions that should enable annual differences in survival rate to be detected with a probability close to or above 90% (Table 4). This proportion will improve if ongoing RAS projects are maintained, especially because several studies were established relatively recently (running for 5-7 years). However, studies with very low marking effort may not achieve this level of precision without adapting their field protocols, i.e. by increasing their recapture rates. This study evaluated a step-change in survival half-way through the time series, the ability to detect this difference may vary if the step-change occurs earlier or later in the time series, or if survival rates change in a linear function.

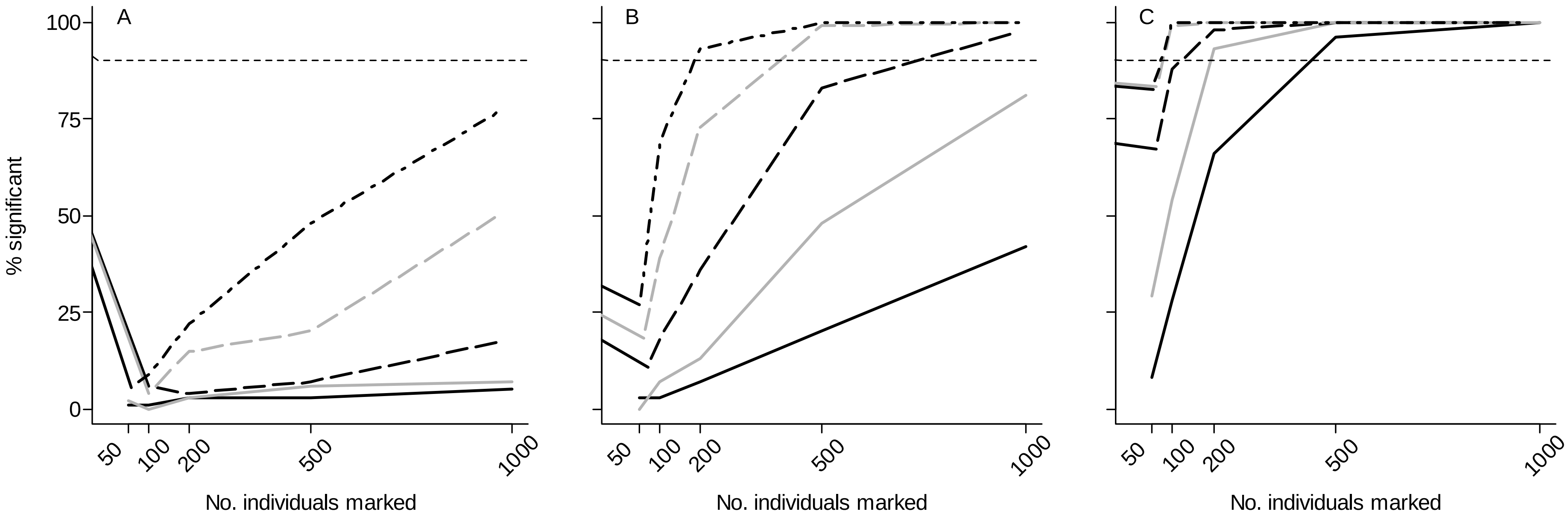

Figure 3. The percentage of simulations able to detect a 5% difference in survival rates between years under 75 different marking and recapture scenarios; A) 5 year time series; B) 10 year time series; and C) 20 year time series. Recapture scenarios as follows: black solid line=0.05, grey solid line=0.1, black dashed line=0.2, grey dashed line=0.4, black dot-dash line=0.6. Figure shows results from the likelihood ratio test and the horizontal dotted line indicates the 90% threshold for reliably identifying the difference.

Table 4. The suitability of RAS studies with over 4 years of data to estimate a 5% change in survival rates between years. The study on Atlantic puffin that was predominantly based on hard rings was also excluded. Each study is colour coded to indicate whether the difference can be detected with greater than 90% probability: green – "yes=good"; red – "no=poor".

RAS No.	Species	Location	Duration (year)	Mean ind. marked ($year^{-1}$)	Mean recapture rate
1	Eider	Nigg	7	56	0.56
2	Eider	Inner Farne	11	112	0.37
3	Eider	Faslane	6	69	0.26
20	Eider	Horse Isle, Ardrossan	13	78	0.32
5	Storm petrel	Eilean Hoan	16	110	0.3
6	Storm petrel	Sanda Island	6	109	0.32
21	Storm petrel	Priest Island	13	851	0.19
22	Storm petrel	Lunga (1)	11	227	0.09
23	Storm petrel	Lunga (2)	13	87	0.19
8	Manx shearwater	Sanda Island	5	48	0.22
24	Manx shearwater	Hallival, Askival & Trollaval, Isle of Rum	20	743	0.16
10	European shag	Craigleith	14	32	0.15
11	European shag	Staple Island	6	69	0.25
25	European shag	Lunga, Treshnish Isles	8	70	0.61
12	Black-legged kittiwake	Inchkeith	15	19	0.05
13	Black-legged kittiwake	Port Ban, Isle of Colonsay	18	34	0.47
26	Black-legged kittiwake	Puffin Island	12	119	0.34
29	Black-headed gull	Cotswold Water Park	5	37	0.32
30	Black-headed gull	Hosehill Lake LNR	4	55	0.66
31	Lesser black-backed gull	Orfordness	11	97	0.57
32	Lesser black-backed gull	Flat Holm	11	31	0.42
15	Common guillemot	Sanda Island	6	121	**
16	Common guillemot	Sanda Island	3	41	**
34	Common guillemot	Port Ban, Colonsay	25	118	0.32
35	Common guillemot	Geugasgor Cliffs, Canna	33	1061	0.2
17	Razorbill	Sanda Island	8	116	**
36	Razorbill	North Beach, Carnach Mhor, Shiant Isles	5	371	0.21
37	Razorbill	Puffin Island	10	90	0.18
38	Razorbill	Geugasgor Cliffs, Canna	33	91	0.11
39	Atlantic puffin	Garbh Eilean, Shiant Islands	6	963	0.15
40	Atlantic puffin	North Beach, Garbh Eilean	6	101	0.06

5. How does field effort affect the ability to detect differences in survival within the population?

This section explores how differing levels of field effort may influence the ability to detect differences in survival rate between individuals from the same population. Conventional mark-recapture (MR) models assume that recapture probabilities do not vary within a population. Testing for heterogeneity is an essential process in all MR analyses in order to construct an appropriate starting model; inappropriate starting models may result in unsuitable model selection and biased model estimates (Pradel *et al* 2005). Heterogeneous demographic rates are typically generated by age-effects and processes such as trap-dependence and transience (Pradel *et al* 1997).

5.1. Trap-dependence

Trap-dependence can occur as "trap-shyness" or "trap-happiness". Trap-shyness is characterised by animals that were just encountered being recaptured at the next occasion with a lower probability than animals that were not sighted. This result may indicate that individuals were harder to recapture following disturbance. In contrast, trap-happiness is a tendency for animals just sighted to be recaptured at the next occasion with a higher probability than animals that were not sighted. This result may indicate that particular nesting sites, or individuals, are consistently easier to trap or observe. All of the identified seabird-demographic studies reporting trap-dependence found it operating as trap-happiness (Table 5). The majority reported immediate trap-happiness, i.e. recapture rates were higher at the sampling interval following tagging, however longer term trap-happiness was also reported (Table 5). To account for this heterogeneity, models typically include a factor such as 'years since last resighting' on the estimation of the recapture rate (Pradel 1993).

Table 5. A selection of studies that report trap-dependence effects in MR analysis of seabirds.

Species	Shyness or Happiness	Duration	Reference
Cormorant	Happiness	Immediate	Frederiksen & Bregnballe 2000
Blue petrel	Happiness	Immediate	Barbraud & Weimerskirch 2003
Northern fulmar	Happiness	Immediate	Grosbois & Thompson 2005
Southern fulmar	Happiness	Immediate	Jenouvrier *et al* 2003
Black-legged kittiwake	Happiness	Immediate Long term (>1yr.)	Frederiksen *et al* 2004; Sandvik *et al* 2005
Black-headed gull	Happiness	Immediate	Péron *et al* 2010
Audouin's gull	Happiness	Immediate	Cam *et al* 2004
Common guillemot	Happiness	Immediate	Crespin *et al* 2006; Votier *et al* 2008; Lahoz-Monfort *et al* 2011
		Long term (>1yr.)	Sandvik *et al* 2005
Razorbill	Happiness	Immediate	Lahoz-Monfort *et al* 2011
Atlantic puffin	Happiness	Immediate	Harris *et al* 2005; Lahoz-Monfort *et al* 2011
		Long term (>1yr.)	Sandvik *et al* 2005

5.1.1. Transience

A transient individual permanently emigrates from the study population following its first release (Pradel *et al* 1997). This may occur if marked juveniles recruit into a different colony from their natal one, or if adults were marked during a transitory visit. This group of individuals will have lower observed survival rates during the year following marking, compared to the resident individuals marked in earlier years. Accounting for this heterogeneity in MR models typically involves introducing a single-year effect on the estimation of survival rate (Pradel 1993).

Table 6. A selection of studies that report transience effects in MR analysis of seabirds.

Species	Reference
Great cormorant	Hénaux *et al* 2007
Black-headed gull	Prévot-Julliard *et al* 1998; Péron *et al* 2010
Audouin's gulls	Oro *et al* 1999; Tavecchia *et al* 2007
Common tern	Szostek & Becker 2012
Common guillemot	Votier *et al* 2008

5.2. Methods

5.2.1. Suitability to estimate differences in survival within the population

This section explores how different levels of marking and recapture effort may impact the ability to detect transience, i.e. different observed survival rates among individuals from the same colony during the year of first release. In agreement with the level of transience reported by Tavecchia *et al* (2007), a 10% step change in survival was simulated to occur following the year of first release; i.e. survival rates were restricted to be 0.73 during the year following first release, and 0.83 from the second year onwards. The ability to detect this change in survival was tested under 75 different scenarios of marking and recapture effort, as described in Section 3. Two models were constructed within each scenario and fitted to the simulated time series. The first framework was a "reference model" that included an extra parameter to account for the step change in survival associated with transience. The second model assumed that survival rates were constant through time. Within each scenario, each set of models was run for 100 simulations. The ability to detect individual variation was examined using the same model comparison techniques employed in Section 4.

5.2.2. Performance of RAS studies

The suitability of the BTO's Retrapping Adults for Survival (RAS) studies (Table 2) to detect variation in survival within the population was graded based on the marking and recapture conditions required to detect a 10% change associated with transience. Here, the duration of the total study period, the marking effort and the recapture effort for each RAS study were rounded to the nearest set of scenario conditions. Each RAS study was graded as meeting the conditions to detect variation with a probability greater than 90%: yes = "good", no ="poor".

5.3. Results and Discussion

5.3.1. Suitability to estimate differences in survival within the population

For a five year data set, high levels of marking and recapture effort were required to detect a 10% difference in survival associated with transience. It was not possible to detect this variation when 200 or fewer individuals were marked per year (Figure 4A; Appendix 4). When marking effort was increased to 500 or 1000 individuals per year, it was possible to detect the difference when recapture probabilities were above 0.6 and 0.4, respectively (Figure 4A; Appendix 4).

For a 10 year data set, high levels of marking and recapture effort were also required. It was not possible to detect the 10% difference associated with transience when 50 newly marked individuals were marked per year (Figure 4B; Appendix 4). When 100 or 200 individuals were marked, recapture probabilities needed to be at least 0.6 and 0.4, respectively. When

500 or 1000 individuals were marked, the recapture rate needed to be above 0.2 in order to achieve a probability of detection close to, or above 90% (Figure 4B; Appendix 4).

For a 20 year data set, lower levels of marking or recapture effort were required to detect a 10% difference associated with transience; and these rates could be offset against each other. It was not possible to detect the difference with a recapture rate of 0.05 (Figure 4C; Appendix 4). However, when the marking effort was 100 individuals per year, the recapture rate needed to be greater than 0.4 to achieve a probability of detection above 90%. The recapture rate required for detection decreased to 0.2 when 200 individuals were marked per year and 0.1 when at least 500 new individuals were marked per year (Figure 4C; Appendix 4).

5.3.2. Performance of RAS studies

There were seven RAS studies (23%) that achieved the field effort conditions that should enable a 10% difference in survival rate between individuals from the same colony to be detected with a probability close to or above 90% (Table 7).

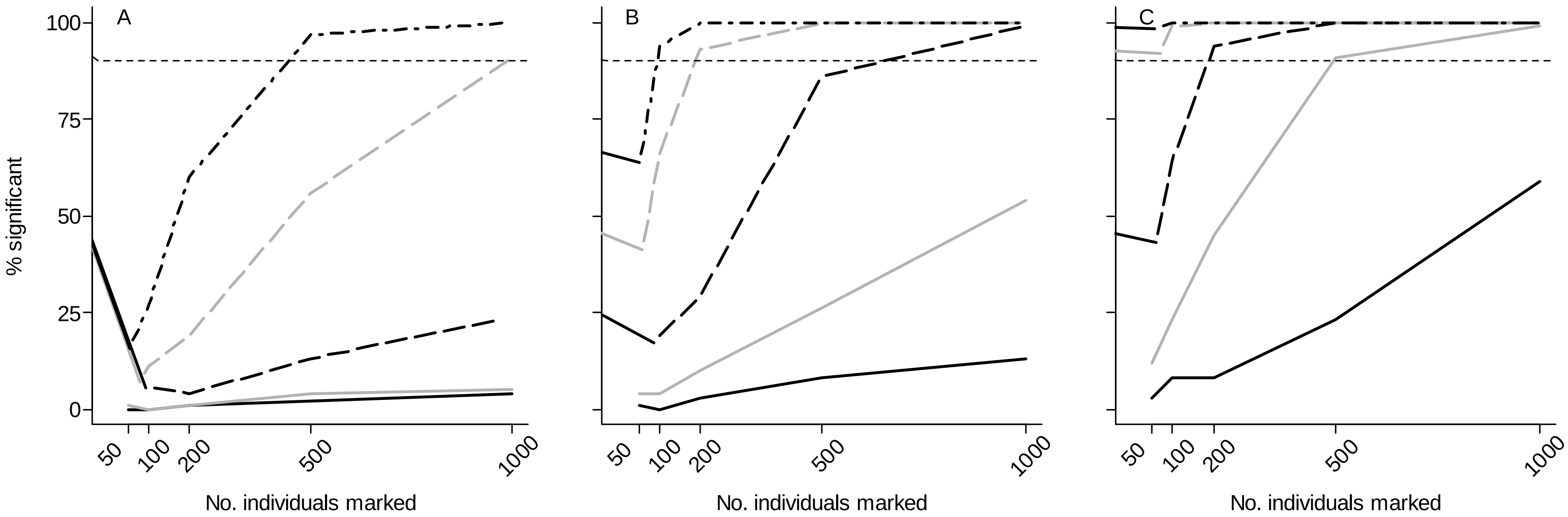

Figure 4. The percentage of simulations able to detect a 10% difference in survival rates associated with transience under 75 different marking and recapture scenarios; A) 5 year data set; B) 10 year dataset; and C) 20 year dataset. Recapture scenarios as follows: black solid line=0.05, grey solid line=0.1, black dashed line=0.2, grey dashed line=0.4, black dot-dash line=0.6. Figure shows results from the likelihood ratio test and the horizontal dotted line indicates the 90% threshold for reliably identifying the difference.

Table 7. The suitability of RAS studies with over four years of data to estimate a 10% difference in survival rate associated with transience. The study on Atlantic puffin that was predominantly based on hard rings was also excluded. Each study is colour coded to indicate whether the difference can be detected with greater than 90% probability: green – "yes=good"; red – "no=poor".

RAS No.	Species	Location	Duration (year)	Mean ind. marked ($year^{-1}$)	Mean recapture rate
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21	Storm petrel	Priest Island	13	851	0.19
22	Storm petrel	Lunga (1)	11	227	0.09
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8	Manx shearwater	Sanda Island	5	48	0.22
24	Manx shearwater	Hallival, Askival & Trollaval, Isle of Rum	20	743	0.16
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11	European shag	Staple Island	6	69	0.25
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26	Black-legged kittiwake	Puffin Island	12	119	0.34
29	Black-headed gull	Cotswold Water Park	5	37	0.32
30	Black-headed gull	Hosehill Lake LNR	4	55	0.66
31	Lesser black-backed gull	Orfordness	11	97	0.57
32	Lesser black-backed gull	Flat Holm	11	31	0.42
15	Common guillemot	Sanda Island	6	121	**
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6. The motivations and challenges associated with RAS participation

In this section we investigate the motivations and challenges associated with volunteer participation in the BTO's Retrapping Adults for Survival (RAS) network. Studies in the network are operated predominantly by volunteer ringers, therefore to maintain and develop membership it is essential to understand the motivations and challenges of the volunteers involved. A questionnaire (Appendix 5) that requested information relating to seabird ringing experiences was sent to 15 active RAS ringers that covered 21 active and five non-active RAS studies. The questionnaire was also sent to five non-active RAS ringers that covered ten non-active RAS studies. Finally, ten seabird ringers that have not registered in the RAS network were also interviewed. The questionnaires were largely descriptive and were assessed qualitatively.

6.1. Existing RAS projects

Responses were received from ten RAS ringers; a 67% return of the questionnaires sent to active RAS ringers. The respective studies encompassed almost all of the RAS focal species: eider, storm petrel, Manx shearwater, black-legged kittiwake, black-headed gulls, Arctic tern, common guillemot, razorbill and puffin. Site visits were usually undertaken between May and July, although one project covered April to August. Visit dates tended to be fixed and consistent between years; however the frequency of visits depended on the accessibility of the colony. Some groups conducted expeditions of fixed lengths, others visited sites weekly, fortnightly or on set dates throughout the breeding season. In total, eight of the ringers undertook RAS projects on islands that included two or more species. Those undertaking 'expedition' ringing typically needed to charter a boat.

Most ringing visits were undertaken by teams that were limited in size by the capacity of the boat (range 2-12 people). In contrast, colour ring re-sighting was more likely to be carried out in projects operated by a single individual. Annual costs of undertaking projects ranged from under £100 for projects that did not require boat travel, to £6,000 when access required greater logistical support. For more expensive projects, the bulk of the money was spent on chartering a boat. The total direct costs incurred by these projects averaged in excess of £16,000 per year. Although some projects received grants from JNCC, Seabird Group, RSPB and local societies, the majority of the costs were covered by the participating ringers. Most respondents thought the projects were sustainable for as long as the ringers were prepared to contribute towards the trips, however these costs were considered to be a barrier towards others starting a study.

Current ringing methodologies included catching by hand, noose poles or hooks, as well as using nest traps, mist nets and landing nets (to catch eider). Although consistency in the catching method was intended, the employed technique generally depended on the weather, tide state, timing of breeding, local breeding success, movement of colonies, predation and restrictions enforced by wardens.

Although some (13%) of the 21 active projects run by the interviewees were initiated as RAS studies, the majority (87%) were also in operation before being registered in the network (range 1-44 years). The reasons for registering existing studies included financial incentives (two ringers). Several ringers were also incentivised by the scientific and conservation benefits of contributing to a national monitoring scheme; we received comments such as 'seemed the most useful way to get results', 'realisation I could resight so many ringed adults, and understanding this is a direction that BTO wishes to go', and 'I always like to maximise the conservation value of all ringing that I do, as long as it does not compromise bird welfare or the breeding success'.

Suggestions of the incentives that would encourage ringers to continue running RAS projects included logistical support, such as assistance arranging access to sites, guidance analysing data, easier paperwork at the BTO, and support identifying ringers to help with projects, regular feedback, and financial support, such as free rings and help with transport costs. One ringer commented that they would continue regardless of additional support.

6.2. Former RAS projects

Two responses were received in relation to four non-active RAS studies; a 40% return of the questionnaires sent to former RAS ringers. These projects were on eider (9 years), shag (7 years), kittiwake (19 years) and Arctic tern (Table 1). Site visits were mostly carried out between mid-May and mid-June, although dates were flexible depending on the progression of the season. The costs of running these studies were covered by organisations, and were not a particular concern to the individual ringers. Adult shags and eider were caught by hand, and Arctic terns were either caught by hand, small walk-in traps or small pull-nets set over nests. All studies were based on metal rings, and were registered in the RAS network within a couple of years of starting.

For eider, the projects ended due to concern about nest desertion (1-3 nests per 50-100 targeted). For Arctic tern, the projects were terminated following concerns about the study design, and increased management limitations. For shag, the projects ended following a decline in colony size and an interruption by other research activities. This finding indicates the general importance of co-ordination of activities in colonies across organisations and projects. Greater assistance with study design would have encouraged one ringer to continue, highlighting the need for active scheme co-ordination. Ringing of Arctic tern and shag continued at specific sites, but the numbers are too low to be used in the estimation of survival rates for RAS. Eider ringing is also still carried out sporadically.

6.3. Non-RAS seabird ringing

Responses were received from four seabird ringers; a 40% return of the questionnaires sent to ringers not registered in the RAS network. These individuals target a range of species including: red-throated divers, storm petrels, Manx shearwater, northern fulmar, gannets, cormorants, shags, skuas, kittiwakes, herring gulls, great black-backed gulls, Arctic terns, guillemot, razorbill, and puffin. Focal species changed annually, depending on local breeding success and accessibility to colonies that provided reasonable ringing opportunity. All ringing was conducted on island sites, and some studies have been running for 50 years.

The visiting frequency for non-RAS ringing ranged from annual to 3-5 year intervals. Site visits were typically carried out in June and July, with some projects carried out from March, and some continuing until November. Visits were generally timed around the breeding season. Some studies could be flexible to the weather conditions, but expeditions planned several years in advance were less flexible. The number of ringers involved in an expedition project varied from one individual to 12 people per week (30 in total for the largest expedition). For non-expedition ringing, the number of ringers ranged between one and six, depending on the project or species.

The majority of projects received no external financial support, but some projects benefitted from grants or sponsorship from organisations such as bird observatories and Wildlife Trusts. The cost of the largest expedition was ~£27,000 per trip (every 3-5 years), of this £19,000 was spent on boat hire.

Ringing methodology differed between the sites. Some studies only ringed chicks, some mist-netted (storm petrels and puffins), and some ringed adults and pulli at burrows (Manx shearwater). Colour ringing projects were undertaken on cormorants, great black-backed gulls and puffins with large amounts of effort being put into re-sighting. Where possible, studies attempted to be consistent in their recapture effort between site visits, and inconsistency in the reported numbers was generally related to the number of birds present, rather than a lack of standardised methodology.

The reasons given by the interviewed ringers for not registering their work under RAS included that they were mostly ringing chicks, or that they had concerns about being able to maintain annual effort on hard to reach islands. One ringer did not consider free rings to be a sufficient incentive to register a RAS project; another ringer commented that they would like to register in the network but could not unless RAS was altered to cope with projects that do not collect annual data. Undertaking expeditions every year was not possible for one group due to the amount of organisation required. One proposed solution to enable annual data collection required was more people to organise and run the trips, so that each 'leader' could participate every three years.

6.4. General remarks

The introduction of the permit rebate (£25) encouraged a number of ringers to register their active MR projects in the RAS network. A small number of studies received additional financial assistance; however the majority of RAS ringing on seabirds was carried out at the expense of the participants. The bulk of the costs were spent on transport, particularly boat charter for those visiting islands. Most existing RAS ringers indicated that they were likely to continue projects at their own expense; however additional financial support, particularly towards transport expenses and the cost of rings, would be valued.

It appears that the majority of the seabird ringing projects that are not registered with RAS would not be eligible under the current guidelines. In the majority of cases the main limitation was the ability to maintain an annual recapture effort. The majority of non-active RAS projects were terminated following anecdotal evidence of population decline, or because the project no longer operated within the RAS guidelines.

7. Priorities for developing RAS for future research and conservation

Citizen science projects run through the BTO's Retrapping Adults for Survival (RAS) network have increased the number of mark-recapture (MR) studies conducted on seabirds in the UK. This model of citizen science projects, supported by a central co-ordinator, offers the potential to increase the geographic range of survival estimates. In 2014, the distribution of RAS sites was concentrated in western Scotland, with considerably fewer studies in Wales and England (Figure 1). Although this largely reflects the distribution of seabird colonies in the UK, new RAS studies should aim to expand the existing geographic range. Species-specific recommendations for colour-ringing programmes are detailed by Robinson and Baillie (2012). In order to improve species coverage, future studies should also consider great black-backed gull (*Larus marinus*), herring gull (*Larus argentatus*), and species of skua and tern. More studies on sea ducks and divers would also improve the species coverage.

For species where the mean rates of survival are thought to be relatively constant across different colonies, the estimates of survival from RAS were very similar to those in the published literature. For species where regional variation in survival rates has not been published, the estimates of survival from RAS differed slightly from those in the published literature. In these latter cases, RAS data may provide a valuable complement to the more intensively monitored colonies (e.g. the Seabird Monitoring Program Key Sites). By combining RAS datasets with those from the Seabird Monitoring Program it may be possible to examine regional trends in survival rates within the context of population trends.

It has been previously suggested that seabird ringing projects require a sample of around 150 newly marked individuals per year (Harris 1989). In this report, we demonstrated that the amount of effort applied to marking will determine the ideal rate of recapture. Furthermore, the level of field effort required to accurately estimate survival changed with the duration of the time series. This result highlights the importance of having consistent programs to monitor the survival rates of seabirds, as well as considering the longevity of programs when designing or adjusting field protocols. When the time series was very short (five years), the ability to estimate a constant survival rate was highly dependent on marking and recapture effort. By increasing the time series to ten years, the minimum marking effort needed to be 200 individuals per year and the recapture rate needed to be 0.4. For this time series, it may also be possible to accurately estimate survival rates with a lower marking effort (i.e. 100 individuals per year) and recapture rates greater than considered in this study (i.e. >0.6). Longer-term studies (>20 years) were more able to estimate survival with lower levels of marking and recapture effort. Although the mean overall marking effort for the RAS network was above 150 individuals per year (Table 1), the mean overall recapture rate was less than 0.3.

To detect temporal or individual variation in survival rates (i.e. between years, individuals or age classes), levels of marking and recapture effort needed to be greater than were required to estimate a constant survival rate. Considerably fewer RAS studies achieved the field effort conditions that should permit this variation to be reliably detected (Section 4 and 5). Consequently, the current ability of RAS data to estimate levels of transience, age-specific variation in survival, and annual differences between colonies is limited. The ability of each RAS study to increase their recapture rate will largely depend on the accessibility of the colony, the number of volunteers, the time dedicated to recapturing individuals, and finally, whether the study is based on colour-rings. Currently, the recommended minimum recapture effort for adults ringed in a previous season does not reflect the overall ringing effort at the site. Consultations between the BTO and different RAS groups are recommended in order to offer advice on field protocols. This may, at the very least, permit the detection of years when there is a (reasonably large) colony-specific deviation from the mean.

The questionnaire indicated that most ringers are committed to the RAS program and understand its goals. Three areas for further assistance were highlighted (Section 6): 1. logistical support with site access and study design; 2. specific feedback; and 3. financial assistance. The first two of these topics highlight the need for a central co-ordinator that has sufficient expertise and available time to provide the necessary level of support to participants. Maintaining the enthusiasm and motivation of volunteers is central to sustaining effort at existing sites, as well as supporting new developments. The BTO aims to provide each RAS study with an analysis of their data, and advice on how to improve their field protocols. Through the BTO/JNCC Partnership, the BTO provides free permits to individuals that run RAS projects, and offers subsidised rings on some species. We also run a small grants scheme to support purchasing of equipment, such as nets and rings. These contributions are often relatively small compared to the overall costs of undertaking a RAS project on seabirds. Consequently, many ringers secure additional financial support and accessibility to these schemes should be promoted.

7.1. Key Recommendations

- RAS studies that are not meeting the current levels of field effort necessary to reliably estimate a constant adult survival rate should be provided with advice and if possible, financial support, to improve their field protocol.

- Additional resources should be put into identifying and capacity-building non-RAS ringing groups that are annually or biannually targeting specific species of seabirds at a regular site.

- RAS studies which include colour-ringing programs should be encouraged whenever possible because resighting individuals can be achieved by a single person without the need to repeatedly capture the bird.

- RAS projects that are no longer active should be evaluated for potential continuation.

- A number of new RAS studies should be implemented in order to increase the existing geographic scope. Target species include great black-backed gull, herring gull, and species of diver, skua and tern.

8. Acknowledgments

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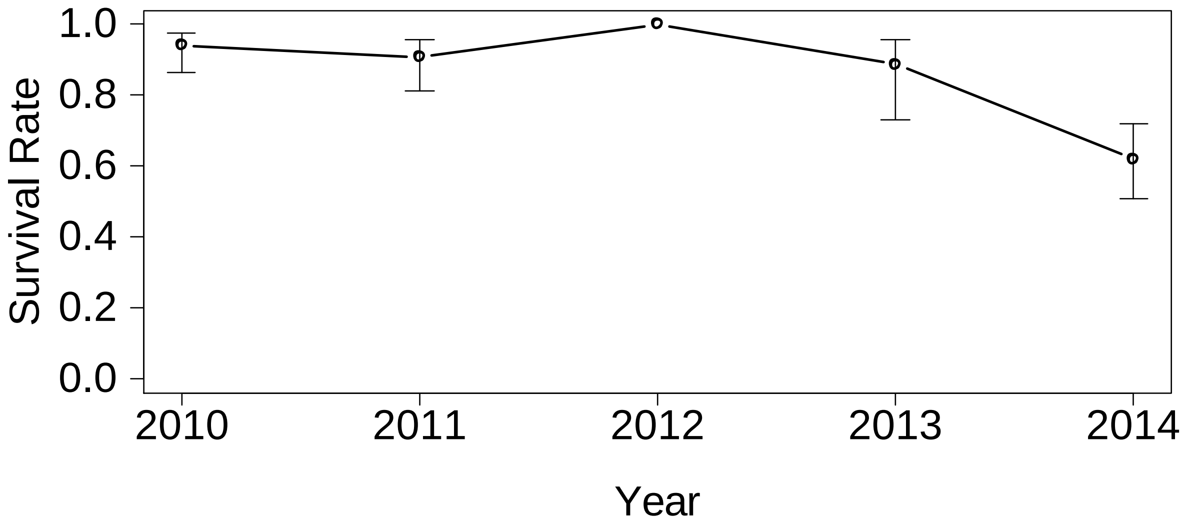
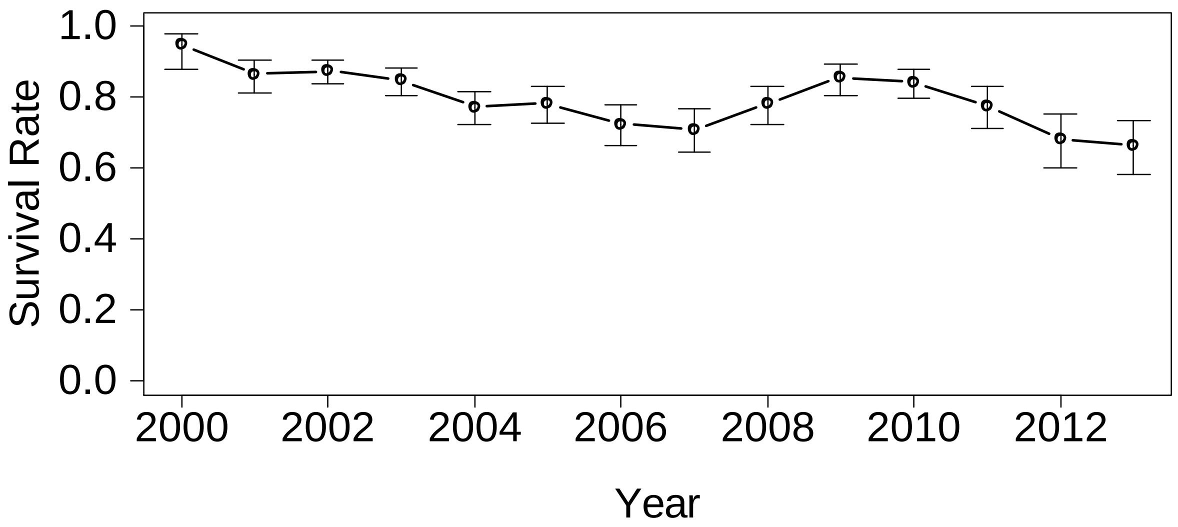
Appendix 1: Estimates of survival rate based on the BTO's RAS scheme

The year indicated the year in which the survival interval ended (i.e. survival between 2000 and 2001 is referred to as 2001). Bars indicate the 95% confidence interval.

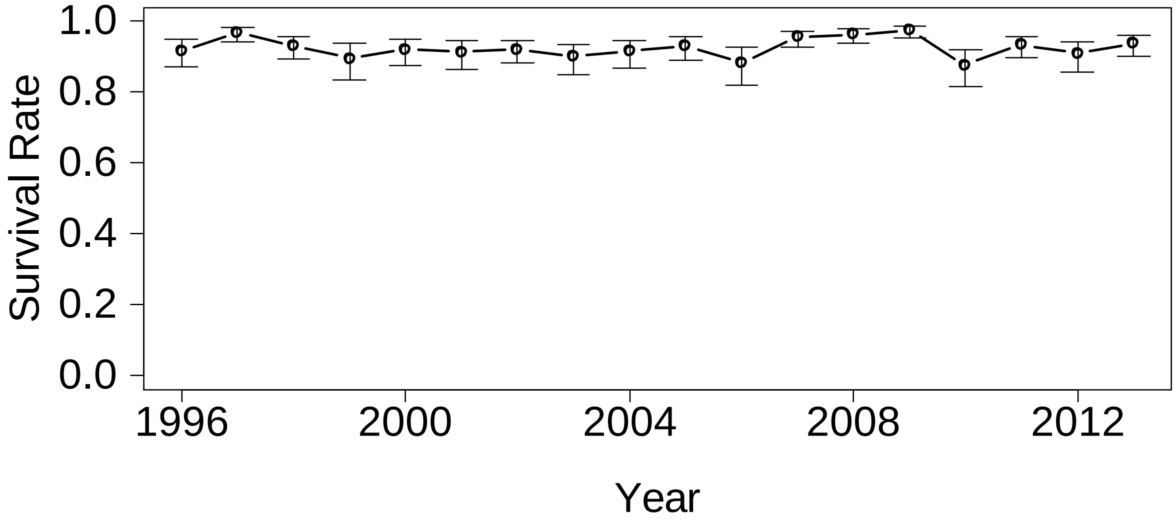
Eider



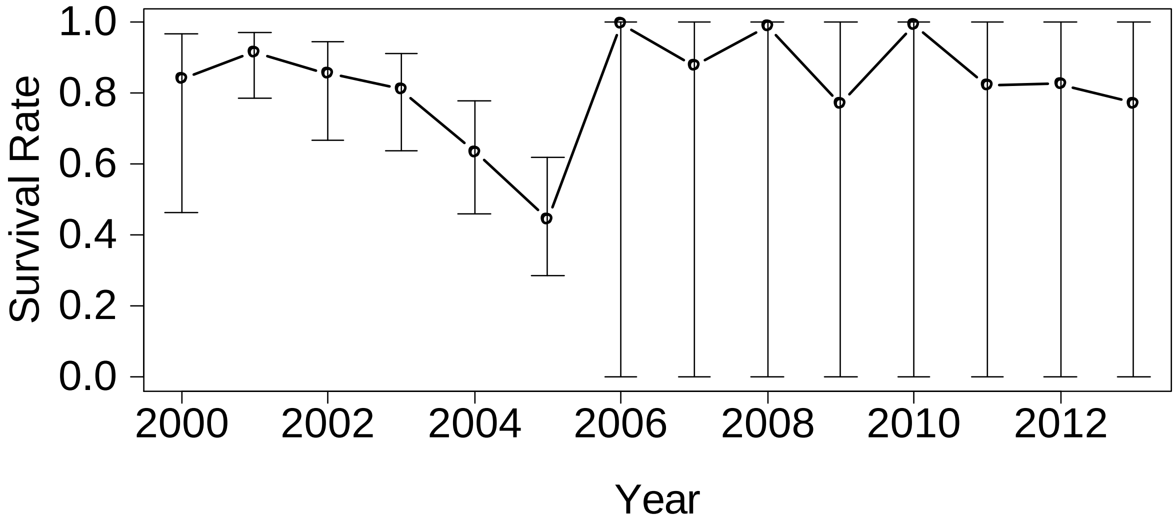
Storm petrel



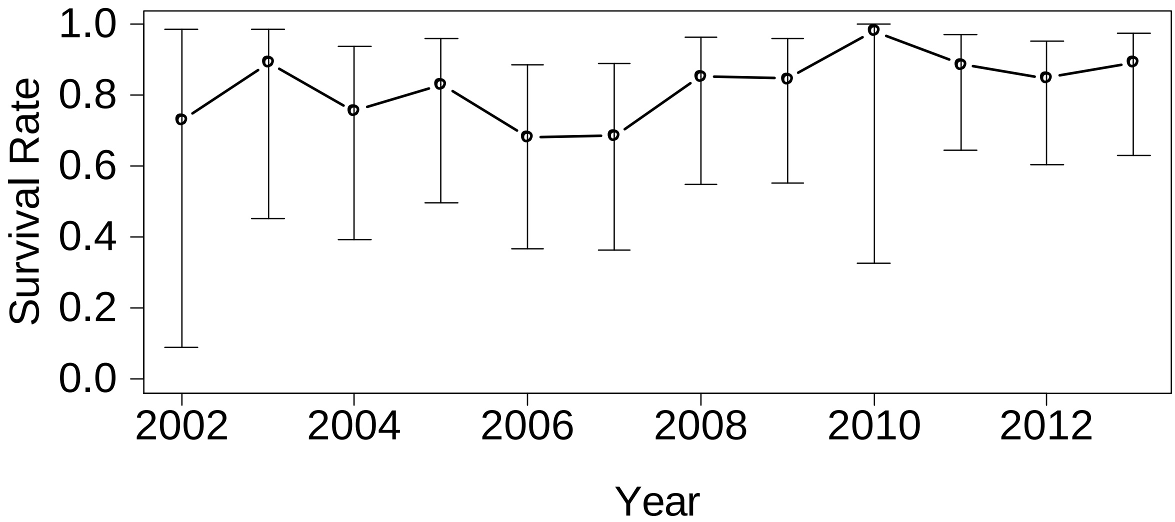
Manx shearwater



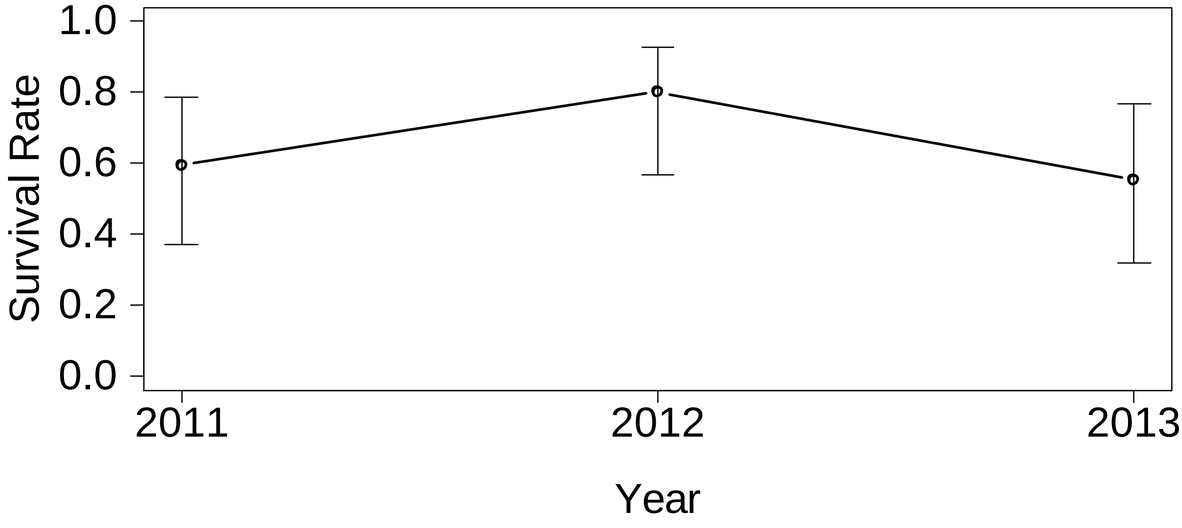
European shag



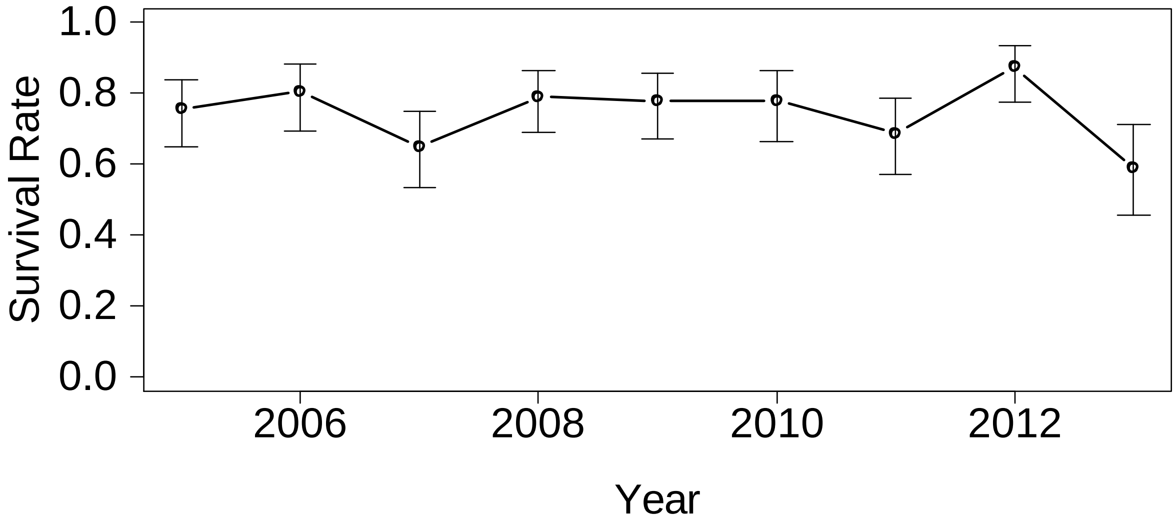
Black-legged kittiwake



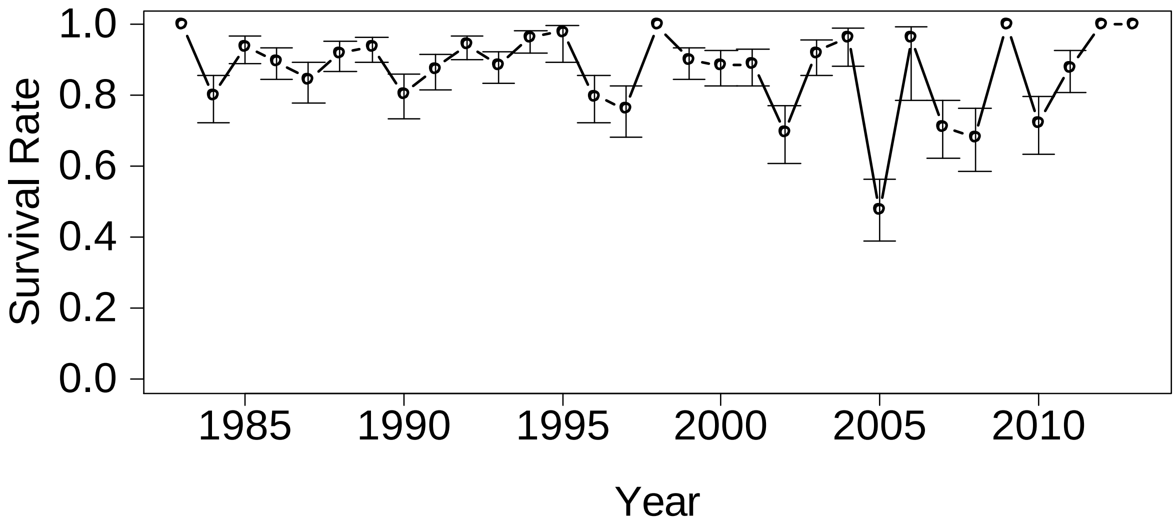
Black-headed gull



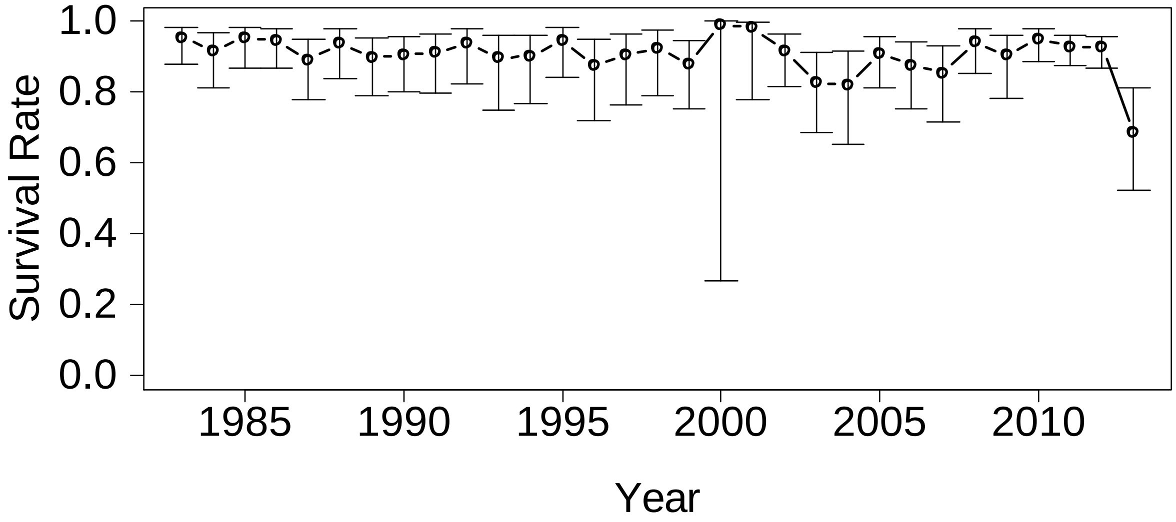
Lesser black-backed gull



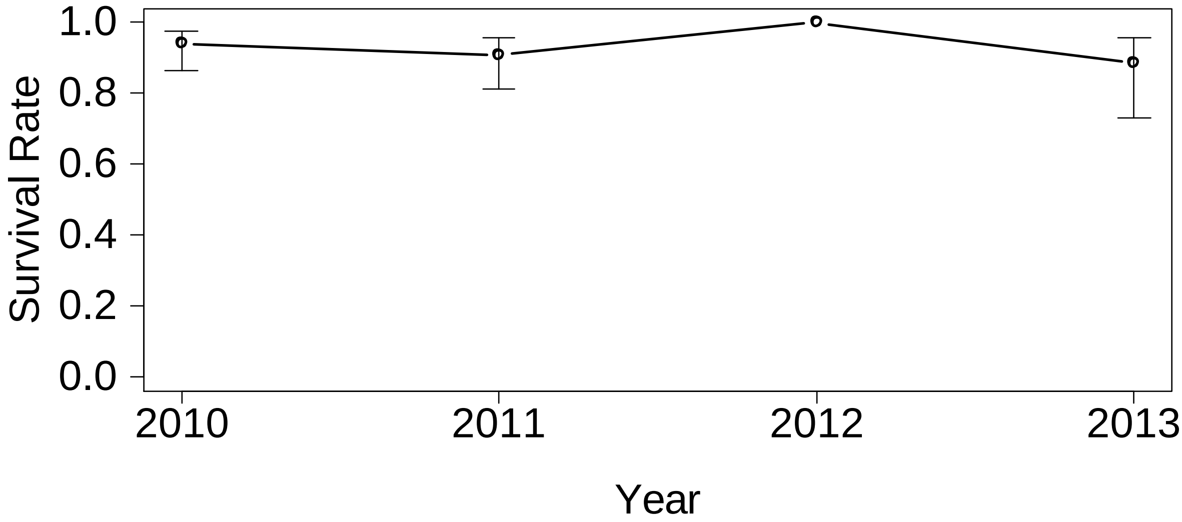
Common guillemot



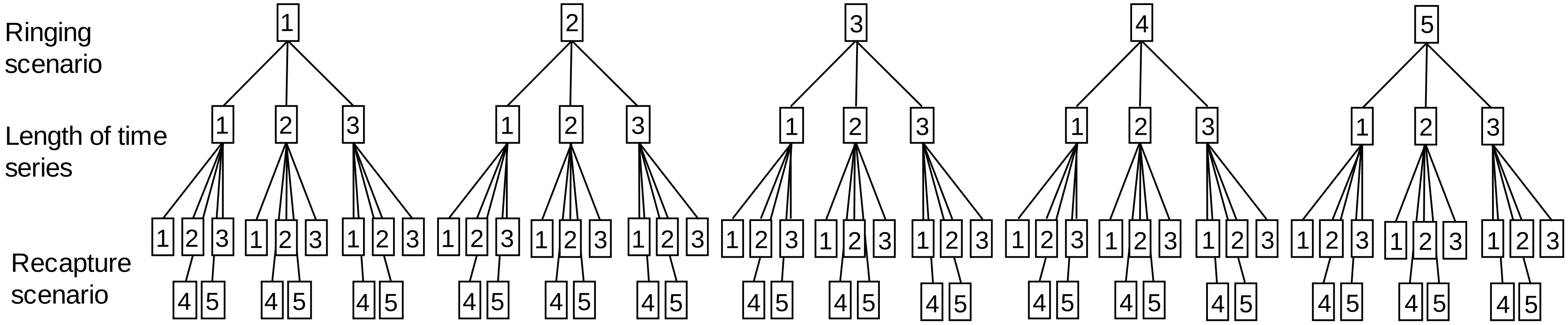
Razorbill



Atlantic puffin



Appendix 2: The three-stage nested design used to examine different marking and recapture scenarios



Marking scenarios: 1) 50 new individuals year^{-1}, 2) 100 new individuals year^{-1}, 3) 200 new individuals year^{-1}, 4) 500 new individuals year^{-1}, 5) 1,000 new individuals year^{-1}. Length of time series: 1) 5 years, 2) 10 years, 3) 20 years. Recapture probabilities: 1) 0.05; 2) 0.1, 3) 0.2, 4) 0.4, 5) 0.6.

Appendix 3: Model selection for the ability to detect a 5% difference in survival between years under 75 scenarios of marking and recapture effort

The percent of simulations that could detect the difference in model deviances between the reference model and the constant survival model with 90% confidence (models achieving precision are shown in bold). The mean ΔAIC, evidence ratio and model likelihood are shown for the reference (time-dependent) model relative to the constant model.

No. of individuals marked	Study period	Recapture rate	% significant	Mean *ΔAIC*	Evidence ratio	Model likelihood
50	5	0.05	1	-1.19	2.05	0.79
50	5	0.1	2	-1.05	1.95	1.07
50	5	0.2	4	-0.70	1.84	4.42
50	5	0.4	2	-0.83	1.81	1.06
50	5	0.6	5	-0.33	1.59	1.87
100	5	0.05	1	-1.07	1.95	0.86
100	5	0.1	0	-0.95	1.84	0.81
100	5	0.2	6	-0.74	1.80	1.27
100	5	0.4	4	-0.29	1.54	1.54
100	5	0.6	9	0.29	1.36	8.60
200	5	0.05	3	-0.92	1.84	0.98
200	5	0.1	3	-0.88	1.86	1.15
200	5	0.2	4	-0.62	1.74	1.83
200	5	0.4	15	0.58	1.41	17.69
200	5	0.6	22	1.59	1.00	15.11
500	5	0.05	3	-0.76	1.81	1.20
500	5	0.1	6	-0.36	1.64	2.19
500	5	0.2	7	-0.09	1.60	48.37
500	5	0.4	20	1.59	0.96	22.88
500	5	0.6	48	4.58	0.42	2.45E+04
1000	5	0.05	5	-0.39	1.60	1.74
1000	5	0.1	7	-0.11	1.57	14.52
1000	5	0.2	18	1.09	1.16	10.70
1000	5	0.4	52	5.41	0.42	2.48E+05
1000	5	0.6	79	9.43	0.15	3.09E+04
50	10	0.05	3	-0.62	1.79	2.90
50	10	0.1	0	-0.68	1.69	0.97
50	10	0.2	6	-0.06	1.50	8.07
50	10	0.4	13	0.94	1.11	42.96
50	10	0.6	26	2.58	0.76	48.14
100	10	0.05	3	-0.85	1.86	1.26
100	10	0.1	7	-0.11	1.62	11.72
100	10	0.2	18	0.99	1.17	21.26
100	10	0.4	39	3.82	0.50	217.72

100	10	0.6	69	7.15	0.22	3257.44

No. of individuals marked	Study period	Recapture rate	% significant	Mean *ΔAIC*	Evidence ratio	Model likelihood
200	10	0.05	7	0.00	1.46	2.10
200	10	0.1	13	0.81	1.26	21.12
200	10	0.2	36	3.61	0.64	1111.83
200	10	0.4	73	8.74	0.17	7101.69
200	**10**	**0.6**	**93**	**13.32**	**0.06**	**3.12E+06**
500	10	0.05	20	1.29	1.11	22.77
500	10	0.1	48	4.65	0.47	9074.97
500	10	0.2	83	9.69	0.13	4.71E+04
500	**10**	**0.4**	**99**	**23.03**	**0.00**	**1.66E+10**
500	**10**	**0.6**	**100**	**34.47**	**0.00**	**2.28E+13**
1000	10	0.05	42	3.97	0.58	322.16
1000	10	0.1	81	9.06	0.14	4.48E+05
1000	**10**	**0.2**	**98**	**19.95**	**0.01**	**5.10E+08**
1000	**10**	**0.4**	**100**	**44.12**	**0.00**	**3.69E+16**
1000	**10**	**0.6**	**100**	**68.58**	**0.00**	**1.05E+23**
50	20	0.05	08	0.41	1.26	3.97
50	20	0.1	29	2.52	0.75	54.93
50	20	0.2	62	5.97	0.30	506.59
50	20	0.4	78	9.10	0.11	9035.76
50	20	0.6	82	11.43	0.11	4.97E+06
100	20	0.05	28	2.31	0.83	1447.53
100	20	0.1	54	5.22	0.39	673.88
100	20	0.2	88	11.37	0.07	7.05E+05
100	**20**	**0.4**	**99**	**18.97**	**0.01**	**8.97E+07**
100	**20**	**0.6**	**100**	**25.14**	**0.00**	**3.40E+11**
200	20	0.05	66	6.33	0.34	1.16E+04
200	**20**	**0.1**	**93**	**12.01**	**0.06**	**4.02E+04**
200	**20**	**0.2**	**98**	**22.12**	**0.01**	**1.30E+09**
200	**20**	**0.4**	**100**	**40.00**	**0.00**	**6.61E+12**
200	**20**	**0.6**	**100**	**53.06**	**0.00**	**3.54E+17**
500	**20**	**0.05**	**96**	**16.85**	**0.02**	**2.27E+08**
500	**20**	**0.1**	**100**	**31.71**	**0.00**	**3.54E+13**
500	**20**	**0.2**	**100**	**59.61**	**0.00**	**9.77E+21**
500	**20**	**0.4**	**100**	**100.01**	**0.00**	**1.62E+31**
500	**20**	**0.6**	**100**	**122.40**	**0.00**	**1.14E+36**
1000	**20**	**0.05**	**100**	**33.40**	**0.00**	**2.50E+12**
1000	**20**	**0.1**	**100**	**64.34**	**0.00**	**1.23E+19**
1000	**20**	**0.2**	**100**	**121.30**	**0.00**	**6.33E+36**
1000	**20**	**0.4**	**100**	**205.04**	**0.00**	**8.47E+55**
1000	**20**	**0.6**	**100**	**241.42**	**0.00**	**2.07E+65**

Appendix 4: Model selection for the ability to detect a 10% difference in survival associated with transience under 75 scenarios of marking and recapture effort

The percent of simulations that could detect the difference in model deviances between the reference model and the constant survival model with 90% confidence (models achieving the level of precision are shown in bold). The mean ΔAIC, evidence ratio and model likelihood are shown for the reference (time-dependent) model relative to the constant model.

No. of individuals ringed	Study period	Recapture rate	% significant	Mean *ΔAIC*	Evidence ratio	Model likelihood
50	5	0.05	0	-1.52	2.27	0.55
50	5	0.1	1	-1.39	2.17	0.67
50	5	0.2	2	-0.95	1.87	0.97
50	5	0.4	2	-0.64	1.72	1.11
50	5	0.6	15	0.67	1.27	6.13
100	5	0.05	0	-1.38	2.14	0.57
100	5	0.1	0	-1.29	2.07	0.64
100	5	0.2	6	-0.57	1.78	3.85
100	5	0.4	11	0.41	1.32	3.77
100	5	0.6	27	2.27	0.73	58.15
200	5	0.05	1	-1.16	2.01	0.77
200	5	0.1	1	-1.12	2.01	0.81
200	5	0.2	4	-0.19	1.45	2.03
200	5	0.4	19	1.49	1.05	16.74
200	5	0.6	60	6.05	0.34	3.22E+04
500	5	0.05	2	-0.91	1.86	0.98
500	5	0.1	4	-0.65	1.79	2.64
500	5	0.2	13	0.28	1.43	6.49
500	5	0.4	56	5.96	0.34	5963.08
500	**5**	**0.6**	**97**	**15.24**	**0.01**	**2.04E+06**
1000	5	0.05	4	-1.01	1.96	1.02
1000	5	0.1	5	-0.12	1.55	2.83
1000	5	0.2	24	1.77	1.00	150.41
1000	**5**	**0.4**	**91**	**13.99**	**0.05**	**5.63E+08**
1000	**5**	**0.6**	**100**	**34.01**	**0.00**	**8.05E+11**
50	10	0.05	1	-1.16	1.98	0.76
50	10	0.1	4	-0.63	1.79	3.24
50	10	0.2	13	0.41	1.37	4.79
50	10	0.4	36	3.05	0.69	52.40
50	10	0.6	63	5.99	0.29	335.61
100	10	0.05	0	-1.10	1.92	0.70
100	10	0.1	4	-0.61	1.71	1.25
100	10	0.2	19	1.04	1.15	20.57
100	10	0.4	66	6.53	0.30	3.08E+04

100	**10**	**0.6**	**94**	**15.96**	**0.05**	**3.20E+06**
No. of individuals ringed	Study period	Recapture rate	% significant	Mean *ΔAIC*	Evidence ratio	Model likelihood
200	10	0.05	3	-0.72	1.83	5.48
200	10	0.1	10	0.09	1.51	4.74
200	10	0.2	29	3.03	0.69	137.65
200	**10**	**0.4**	**93**	**13.95**	**0.06**	**4.19E+07**
200	**10**	**0.6**	**100**	**30.24**	**0.00**	**4.07E+12**
500	10	0.05	8	-0.46	1.71	1.97
500	10	0.1	26	2.03	0.97	309.04
500	10	0.2	86	9.99	0.07	2.76E+04
500	**10**	**0.4**	**100**	**40.45**	**0.00**	**1.39E+14**
500	**10**	**0.6**	**100**	**79.29**	**0.00**	**1.55E+28**
1000	10	0.05	13	0.58	1.34	40.26
1000	10	0.1	54	5.46	0.44	1584.79
1000	**10**	**0.2**	**99**	**21.90**	**0.00**	**2.36E+10**
1000	**10**	**0.4**	**100**	**81.18**	**0.00**	**7.59E+23**
1000	**10**	**0.6**	**100**	**162.38**	**0.00**	**1.26E+45**
50	20	0.05	3	-0.72	1.80	2.57
50	20	0.1	12	0.27	1.37	3.53
50	20	0.2	38	3.46	0.64	172.23
50	20	0.4	87	12.01	0.09	2.14E+06
50	**20**	**0.6**	**98**	**20.35**	**0.01**	**3.37E+06**
100	20	0.05	08	-0.34	1.69	4.12
100	20	0.1	23	1.80	1.01	25.93
100	20	0.2	64	6.50	0.25	572.49
100	**20**	**0.4**	**99**	**23.96**	**0.00**	**2.77E+10**
100	**20**	**0.6**	**100**	**43.40**	**0.00**	**5.47E+19**
200	20	0.05	8	0.16	1.33	2.35
200	20	0.1	45	4.18	0.61	268.78
200	**20**	**0.2**	**94**	**15.60**	**0.04**	**1.91E+07**
200	**20**	**0.4**	**100**	**50.46**	**0.00**	**1.09E+17**
200	**20**	**0.6**	**100**	**86.24**	**0.00**	**7.16E+28**
500	20	0.05	23	2.28	0.83	68.04
500	**20**	**0.1**	**91**	**11.68**	**0.07**	**1.29E+07**
500	**20**	**0.2**	**100**	**42.64**	**0.00**	**8.82E+18**
500	**20**	**0.4**	**100**	**127.24**	**0.00**	**3.14E+37**
500	**20**	**0.6**	**100**	**219.27**	**0.00**	**2.77E+67**
1000	20	0.05	59	5.97	0.34	956.77
1000	**20**	**0.1**	**99**	**24.34**	**0.01**	**2.89E+08**
1000	**20**	**0.2**	**100**	**83.86**	**0.00**	**3.27E+27**
1000	**20**	**0.4**	**100**	**250.81**	**0.00**	**2.81E+74**
1000	**20**	**0.6**	**100**	**446.49**	**0.00**	**6.41E+120**

Appendix 5: RAS questionnaire

1. Group or individual ringer's name:
2. RAS species and project location:
3. When do you go to site (rough dates) and is the date fixed each year or flexible depending on local breeding season conditions?
4. Do you work individually or as part of a team / group? If the latter, how many are in the team?
5. Roughly how much does it cost to undertake the RAS? (If your RAS is undertaken as part of an expedition, please give estimated costs for the whole trip)?
   Rings:
   Subsistence:
   Travel:
   Other:
6. Do you get any financial assistance or are the costs covered entirely by the ringers? If the latter, is this sustainable?
7. Please describe the methodology you use for your RAS e.g. do you ring for a fixed length of time each year, do you use colour rings and dedicate time to resightings, do you mist net, catch by hand or mostly ring pulli in a colony etc.?
8. How easy it is it to maintain a consistent approach (e.g. in terms of timing, birds sampled) each year.
9. How do you define your visit and hours figure on your RAS return? Do you include catching time or resighting time or both? How easy is it to come up with these figures? Do you think they are representative of the effort or a guesstimate?
10. How long had you been ringing on site before you registered the project as a RAS and what encouraged you to register it?
11. What additional help could we give you to encourage you to keep doing the study?

Additional questions to former or non-RAS ringers:

12. Why did you stop your RAS project? / Why don't you carry out a RAS project?
13. Is there anything we could do to encourage you to (re)start a seabird RAS?