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Australian Sea Lion Monitoring Framework: statistical model

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Introduction

The Australian sea lion (ASL - Neophoca cinerea) is endemic to Australia with a breeding range from Houtman Abrohlos (Western Australia (WA)) to The Pages Island (South Australia (SA)). Breeding occurs on islands or sections of remote coastline that are often difficult to access. The breeding season is difficult to track due to the unusual asynchronous nature (approx. 17-18 month breeding cycle), which differs by colony/location. Females exhibit a high amount of site fidelity; to the point of the colonies effectively representing closed populations. These factors combined with the estimated small population size resulted in ASL being listed as Vulnerable under the threatened species category of the Commonwealth Environment Protection and Biodiversity Act 1999 (EPBC Act), Vulnerable under the South Australian National Parks and Wildlife Act (1972) and Endangered under the International Union for the Conservation of Nature (IUCN) Redlist (Goldsworthy et al. 2015).

In managing the recovery of a species like ASL, it is critical to be able to track changes in the size of the population through time. The expense and difficulty in obtaining accurate estimates of abundance mean that in the past, except for a small number of colonies, data has been sparse and collected using varying methodologies (even at a given site). However, recently Goldsworthy et al. 2015 published the results of a comprehensive survey of the SA ASL population, including pup estimates for most colonies within an 18 month period (one breeding cycle). The most accurate way to track the status of ASL through time would be to survey each colony every breeding season, however this is impossible from both a monetary and logistical perspective. This level of accuracy would also not be warranted given the rate of the estimated decline of the overall population (~2.9% per year or 4.4% per breeding cycle Goldsworthy et al. 2015). An alternative is to develop a monitoring regime with sufficient precision to estimate substantial (specified) changes in abundance over a prescribed time period.

A draft statistical monitoring framework for ASL was discussed at a workshop of key stakeholders in April 2014. The goal of the statistical framework is to develop a means of testing different monitoring designs and assess whether, if there is a substantial change in abundance, the designs will be able to detect it. The benefit of using a tool such as this is that most of the available data can be examined, despite the different estimation methods and sparcity at some sites, and a range of designs assessed. The remainder of this report details a statistical model that may form the basis of a statistical monitoring framework for ASL, the estimation process and the results of using the model to test the degree to whether several hypothetical future sampling schedules are able to detect changes in ASL abundance. This is a small study and as such we have not attempted to explore many design options or to second-guess the monitoring objectives. Instead we have focused on setting up an appropriate monitoring framework, including R scripts, and populate it with data. We hope that these tools will make exploring different sampling schedules, monitoring objectives and statistics to report on, relatively straightforward for others to undertake in the future.

Methodology

Data

The available ASL monitoring data was compiled and provided separately by SA and WA.

SA Data

The SA monitoring dataset contains surveys dating back to as early as 1965. However, in the early years the surveys are sparse in space and time. In consultation with SARDI, we compiled a subset of the dataset that was considered accurate (in terms of survey timing) and consistent (in terms of methodology). The dataset is similar to that used by SARDI in the analysis described in Goldsworthy 2015 et al., but it includes multiple measures of abundance (rather than selecting the most accurate) where multiple methods were used at a site in a given season. These multiple measures are important as this data allows us to estimate the bias factors described in the model below. A copy of the data is provided in Appendix 1.

The counts in the SA monitoring dataset are collected using three methods (further details described in Goldsworthy et al. 2015):

> Direct count (Count) – direct counts of live and dead pups. This method underestimates total pup production, as pups that are hidden from view or absent from the colony are not counted. This method is considered to be more accurate for small colonies (most sites) than large ones. As the colony gets larger the breeding season gets longer and the estimates of this method compared to the others diverge.
>
> Mark-recapture (MR) – individual pups are tagged using numbered plastic tags and individual re-sights are recorded for each field trip. The number of pups tagged, untagged and recorded dead are noted on each survey and then a variation of the Peterson method (formula) is used to arrive at an estimate of abundance. The dataset contains estimates of this method for Dangerous Reef, Olive, Lilliput and Blefuscu Islands.
>
> Cumulative pup production (CPP) – this method builds on the MR by estimating the number of pup births that occur between consecutive mark-recapture surveys through the use of multiple Peterson estimates. Total cumulative pup production is then the sum of the Peterson estimate for the first survey, the cumulative number of dead pups recorded up to the end of the first survey and the estimates of pup births between each subsequent

survey. The dataset contains estimates of this method for Dangerous Reef, Seal Bay, Olive, Lilliput and Blefuscu Islands.

WA Data

The WA monitoring dataset is very sparse (1998-2015). Beagle and Nth fish are the only two colonies (out of 23) with more than a couple of data points. Many of the recorded counts may not be accurate due to missing season timing. Due to the level of sparcity and the small proportion of the population that the WA data represents (~15%) we have not incorporated the WA monitoring data into the statistical model. If a baseline survey of ASL in WA were completed it would be relatively simple to then incorporate the WA data into the model that follows.

Statistical Model

The monitoring framework is centered on a statistical model. The model is described here in generic terms as the proposed model is very flexible meaning that different factors thought to be related to ASL abundance or recovery could be incorporated into the model as further data is collected. The model is also very flexible in that it does not require a rigid monitoring protocol eg. Equally spaced sampling. The point of this model is to let observations “borrow strength” from each other. If most colonies have been trending in some direction, then it may be a reasonable assumption that an unmonitored but “similar” colony has been going the same way. Of course, the only way to be absolutely sure is to sample that colony. However, it is not feasible to sample every colony, every season, and nor is it necessary if the objective is to be able to estimate total or regional level ASL numbers within tolerable precision levels. The statistical model encapsulates these ideas.

The model is a special case of a Generalized Linear Mixed Model (GLMM);

$$Y_{it} = q_{it} N_{i0} e^{r_i t + \varepsilon_{it}}$$

Where:

i is the site label

t is the sampling date (with 0 standing for an arbitrary "reference date" for the monitoring program);

Y_{it} is an abundance estimate obtained for that site in that year

q_{it} is a "bias" factor that depends on the method of survey

N_{i0} is the abundance of colony i at the reference date.

r_i is the rate-of-Change for colony i that can be allowed to depend on various factors

ε_{it} is the noise/error associated with that particular measurement, which includes measurement error, natural variability in abundance (e.g. proportion of females actually breeding that season). The likely magnitude of ε_{it} will depend on the colony and the survey method used.

Statistically, the *Y* 's are the observations, the ε 's are the errors, and the linear predictor is given by $\log\mathrm{E}[Y_{it}] = \ log q_{it} + log N_{i0} + t r_i$

$r_i = X_i \beta + \zeta_i$

r_i is a mixed effect that (i) allows for various factors such as colony size or exposure to gillnetting, as specified through a design matrix *X* and captured through appropriate components of the estimable parameters β, and (ii) allows each colony to have its own additional trend ζ_i.

We implemented the statistical model using the R v3.2.3 (R Core Team 2015) statistical software (available online at http://www.r-project.org/) and a pre-release version (provided by the author) of the mgcv package (v1.8_13 Wood 2016, Wood 2011).

We modeled the estimated number of pups 'Estimate' as:

Estimate = Site + count_bias + extra_seal_bay_bias + MR_bias + s(ID_im, by=RE_im, bs='re')

+ s(ID_noim, by=RE_noim, bs='re')+ y2000 %in% Region +ypost_mgmt

In this model Site is the name of the individual site, count_bias is a bias factor applied to 'big' sites when the 'Count' method is used, extra_sealbay_count_bias is a bias factor applied to Seal Bay only, MR_bias is a bias factor only when the 'MR' method is used, ID_im and ID_ noim indicate separate random effects for sites that do/don't experience immigration/emigration, y2000 %in% Region is the long term trend at the Region level and ypost_mgmt is the trend to indicate when changes in abundance may be expected due to management actions (currently post 2016).

More details on how these variables were constructed are described below.

- *count_bias* : If the MR or CPP method have ever been used at a site, the site is classified as 'big'. This factor was introduced as the bigger sites have longer breeding seasons and so the direct count method is more likely to result in an underestimate (the extent of which is estimated via this effect).
- *extra_sealbay_count_bias:* A preliminary analysis involving a calibration of Count vs CPP, at sites where data were available for both methods in a given season, revealed that the method bias is similar for Lilliput, Olive and Dangerous reef but Seal Bay was significantly different. We introduced this factor just for Seal Bay to account for this difference.
- *MR_bias:* A bias factor to account for the use of this method
- *s(ID_noim, by=RE_im, bs='re'):* Gaussian random effects for sites that do not experience immigration/emigration. We used these random effects as a means of allowing the immigration/no immigration sites to have different (unknown) variances. The sites were Seal Bay, Dangerous Reef, Liguanea, Cap, Rocky South, West Waldegrave, Pearson, Nicolas Baudin, Olive, Breakwater/Gliddon and Nuyts Reef. Note: the ability to incorporate random effects in this manner is new to mgcv and so this term will only work for mgcv 1.8 – 13 or later.
- *s(ID_im, by=RE_im, bs='re'):* Gaussian random effects for sites that experience immigration/emigration. Colonies subject to immigration from nearby earlier-breeders, should have higher variance in count data. The sites were all those not listed in *ID_count_noim* and were estimated separately to allow for movement between sites.
- *y2000 %in% Region:* the trend estimated at the Region level using the year 2000 as the baseline.
- *ypost_mgmt:* A trend, post the year 2016, designed to detect a change in trend due to management action. The year can be changed depending when you could expect changes in abundance due to management actions likely to take effect.

The model was fitted using the 'REML' method with a Tweedie distribution (p=1.2, link='log') to account for overdispersion. The Tweedie is an exponential family distribution for which the variance of the response is given by the mean response to the power p where p is between 1 and 2.

Monitoring framework

The above statistical model can be fitted to the existing monitoring data. To move beyond estimating a statistical model, into creating a monitoring framework, we created an R function that allowed us to combine the existing data with hypothetical future sample schedules to allow us to test the impact of differing sampling schedules (Scenarios outlined below) on various estimates of precision (such as the coefficient of variation of the estimate of ASL for a given Region in a given year).

The R function goes through the following sequence of steps:

(1) Form a dataset of past surveys including estimates based on different methods for the same site and season

(2) Fit the statistical model, estimating all variances and all coefficients

(3) Form a design data frame containing both the past data and a sampling schedule relating to the scenario being tested (with missing data for the estimates)

(4) Get the predictions for the model fitted above for all observations in the design data frame

(5) Refit the model to estimate coefficients, but with all the variances fixes at their original estimated values from step (2)

(6) Compute the precision on quantities of interest. For example, Coefficient of Variation (CV) of abundance or standard error of log-trend

The results should then mimic the information content (and thus the precision of any inferences) that will be possible once the extra data (future samples) are collected.

Scenarios

The following sampling schedules were considered. These test scenarios are intended to show how our software could be used to decide on monitoring. We are not trying to evaluate every possible option, nor to second-guess what questions are most important nor how much the answers are "worth", but rather to show how this can be done fairly systematically and easily, and to provide a software framework for doing so.

1. Main colony in each region every 3 years

Bunda Cliffs – Bunda09 in 2017, 2020, 2023, ….,2044

Chain of Bays – Olive in 2017, 2020, 2023, ….,2044

Kangaroo Island – Seal Bay in 2017, 2020, 2023, ….,2044

Nuyts-Archipelago – Lilliput in 2017, 2020, 2023, ….,2044

Spencer gulf – Dangerous Reef in 2017, 2020, 2023, ….,2044

SW Eyre – Rocky North in 2017, 2020, 2023, ….,2044

2. Main colony in each region every 6 years

Bunda Cliffs – Bunda09 in 2017, 2023, ….,2041

Chain of Bays – Olive in 2017, 2023, ….,2041

Kangaroo Island – Seal Bay in 2017, 2023, ….,2041

Nuyts-Archipelago – Lilliput in 2017, 2023, ….,2041

Spencer gulf – Dangerous Reef in 2017, 2023, ….,2041

SW Eyre – Rocky North in 2017, 2023, ….,2041

3. Four key colonies every 3 years

* These are the four colonies identified in Goldsworthy et al. 2015

Chain of Bays – Jones and Olive in 2017, 2020, 2023, ….,2044

Kangaroo Island - Seal Bay and Seal Slide in 2017, 2020, 2023, ….,2044

4. Rotating Regions

Bunda Cliffs in years 2017, 2023, 2029, 2035 and 2041

Bunda 00, Bunda02, Bunda04, Bunda06, Bunda08, Bunda09, Bunda12, Bunda18, Bunda 19, Bunda22

Chain of Bays in years 2018, 2024, 2030, 2036 and 2042

Jones, Nicolas Baudin, Olive, Pearson, Pt Labatt, Ward, West Waldegrave

Kangaroo Island in years 2021, 2027, 2033 and 2039

Cape Bouger, North Casuarina, Seal Bay, Seal Slide, The Pages

Nuyts – Archipelago in years 2017, 20232029, 2035 and 2041

Blefescu, Breakwater/Giddon, Fenelon, Lilliput, Lounds, Nuyts Reef, Purdie, West

Spencer Gulf in years 2020, 2026, 2032, 2038 and 2044

Albatross, Curta, Dangerous Reef, East, English, Lewis, Liguanea, North, Peaked Rocks, South Neptune, Williams

SW Eyre in 2020 and 20262020, 2026, 2032, 2038 and 2044

Cap, Four Hummocks, Little Hummock, Price, Rocky North, Rocky South

5. All colonies every 3 years

Bunda Cliffs – All colonies in years 2017, 2020, 2023, ….,2044

Chain of Bays – All colonies in years 2017, 2020, 2023, ….,2044

Kangaroo Island – All colonies in years 2017, 2020, 2023, ….,2044

Nuyts – Archipelago – All colonies in years 2017, 2020, 2023, ….,2044

Spencer Gulf – All colonies in years 2017, 2020, 2023, ….,2044

SW Eyre – All colonies in years 2017, 2020, 2023, ….,2044

Estimates of Interest

We looked at several estimates of interest to compare across the sampling scenarios, these are by no means exhaustive and have just been chosen as examples of metrics that one may wish to focus on when designing a sampling strategy. If an accurate estimate of the total number of ASL pups is of primary interest then you would look to minimise the coefficient of variation (CV) of the predicted total (after considering budget constraints). We used the delta-method (Oehlert 1992) to calculate the CV of the predicted total (as this is not calculated by the *mgcv* package in R).

Estimating the number of pups at the region level may also be important for some or all regions, particularly those with quickly declining or growing populations. We calculated the CV of the predicted number of pups by region and year, for each of the scenarios, also using the delta method. Finally, it may be of primary interest to obtain an accurate estimate of the trend so we have also estimated the standard error (SE) of the trend by region and across all regions.

Results

Below is a summary of the model fitted to the existing data. The regional trend terms (y2000:Region) show that the trend is downward in all regions with the slowest decrease in Kangaroo Island (~0.5% per year) and the greatest in SW Eyre (~5.4% per year). The standard GLM diagnostics did not show a lack of fit and that the Tweedie parameter fixed at 1.2 was adequate.

Family: Tweedie (1.2)
Link function: log
Formula:
Estimate ~ Site + count_bias + extra_sealbay_count_bias + MR_bias + s(ID_im, by = RE_im, bs = "re") + s(ID_noim, by = RE_noim, bs = "re") + y2000 %in% Region + ypost_mgmt

Parametric coefficients:

	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	4.458879	0.176055	25.327	< 2e-16 ***
SiteBlefuscu	0.800824	0.238054	3.364	0.000975 ***
SiteBreakwater/Gliddon	-0.845634	0.294429	-2.872	0.004667 **
SiteBunda 00 (B1)	-2.156451	0.480982	-4.483	1.45e-05 ***
SiteBunda 02 (B1.1)	-2.966043	0.640617	-4.630	7.85e-06 ***
SiteBunda 04 (B2)	-3.525644	0.530112	-6.651	5.07e-10 ***
SiteBunda 06 (B3)	-1.992279	0.264725	-7.526	4.45e-12 ***
SiteBunda 08 (B4)	-3.919597	0.741001	-5.290	4.25e-07 ***
SiteBunda 09 (B5)	-1.775726	0.270944	-6.554	8.42e-10 ***
SiteBunda 12 (B6)	-3.359948	0.383727	-8.756	3.88e-15 ***
SiteBunda 18 (B7)	-2.714364	0.433434	-6.262	3.77e-09 ***
SiteBunda 19 (B8)	-2.218308	0.319332	-6.947	1.05e-10 ***
SiteBunda 22 (B9)	-2.577418	0.413999	-6.226	4.55e-09 ***
SiteCap	-0.192292	0.887094	-0.217	0.828684
SiteCape Bouguer	-2.198406	0.541356	-4.061	7.84e-05 ***
SiteCurta	-2.183936	0.587230	-3.719	0.000282 ***
SiteDangerous Reef	2.087028	0.170294	12.255	< 2e-16 ***
SiteEast	-1.815666	0.367633	-4.939	2.07e-06 ***
SiteEnglish	-0.870035	0.218836	-3.976	0.000109 ***
SiteFenelon	-0.568912	0.321519	-1.769	0.078846 .
SiteFour Hummocks	-1.525025	0.843245	-1.809	0.072523 .
SiteJones	-1.392942	0.251772	-5.533	1.37e-07 ***
SiteLewis	0.411114	0.203515	2.020	0.045152 *
SiteLiguanea	-0.884212	0.257662	-3.432	0.000775 ***
SiteLilliput	0.457526	0.242133	1.890	0.060740 .
SiteLittle Hummock	-1.793253	0.945475	-1.897	0.059789 .
SiteLounds	-0.653341	0.326978	-1.998	0.047506 *
SiteNicolas Baudin	0.281520	0.255175	1.103	0.271682
SiteNorth	-1.088135	0.295933	-3.677	0.000328 ***
SiteNorth Casuarina	-1.997735	0.505275	-3.954	0.000118 ***
SiteNuyts Reef	0.881730	0.343463	2.567	0.011229 *
SiteOlive	1.147976	0.210838	5.445	2.07e-07 ***
SitePeaked Rocks	-0.157145	0.300257	-0.523	0.601487
SitePearson	-0.687730	0.257834	-2.667	0.008483 **

SitePrice	-0.182652	1.005349	-0.182	0.856078
SitePt Labatt	-3.079051	0.492406	-6.253	3.96e-09 ***
SitePurdie	0.530815	0.240706	2.205	0.028955 *
SiteRocky North	-0.083190	0.823745	-0.101	0.919693
SiteRocky South	-1.289632	0.920819	-1.401	0.163415
SiteSeal Bay	1.142620	0.186364	6.131	7.33e-09 ***
SiteSeal Slide	-2.030144	0.238357	-8.517	1.57e-14 ***
SiteSouth Neptune	-2.378924	0.441803	-5.385	2.74e-07 ***
SiteThe Pages	1.690406	0.179272	9.429	< 2e-16 ***
SiteWard	-0.186877	0.263642	-0.709	0.479527
SiteWest	-0.413082	0.268432	-1.539	0.125937
SiteWest Waldegrave	0.595476	0.226057	2.634	0.009316 **
SiteWilliams	-2.520409	0.664079	-3.795	0.000213 ***
count_biasTRUE	-0.371025	0.056916	-6.519	1.01e-09 ***
extra_sealbay_count_biasTRUE	-0.328846	0.096011	-3.425	0.000792 ***
MR_biasTRUE	-0.155511	0.044578	-3.489	0.000637 ***
ypost_mgmt	0.000000	0.000000	NA	NA
y2000:RegionBunda Cliffs	-0.052504	0.014703	-3.571	0.000478 ***
y2000:RegionChain of Bays	-0.040404	0.010170	-3.973	0.000110 ***
y2000:RegionKangaroo Island	-0.004865	0.003638	-1.337	0.183079
y2000:RegionNuyts-Archipelago	-0.045777	0.013021	-3.516	0.000580 ***
y2000:RegionSpencer Gulf	-0.021935	0.005718	-3.836	0.000184 ***
y2000:RegionSW Eyre	-0.054033	0.062618	-0.863	0.389567

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Approximate significance of smooth terms:

	edf	Ref.df	F	p-value
s(ID_im):RE_im	6.757	90	0.101	0.11144
s(ID_noim):RE_noim	13.828	46	0.594	0.00216 **

Rank: 699/700

R-sq.(adj) = 0.951 Deviance explained = 98.6%

fREML = 400.68 Scale est. = 1.4766 n = 227

Figure 1 (and Table 1) show how the CV of the predicted total ASL pup count varies by year under each of the scenarios. Scenario 5, which involves sampling every site every 3 years, is the best scenario for obvious reasons. Scenario 4 which involves sampling the sites on a 6-year rotations is the next best and outperforms sampling the key colonies every 3 years. Note that regardless of the chosen scenario, the predicted value is the same (it is jut the CV that varies; Table 1).

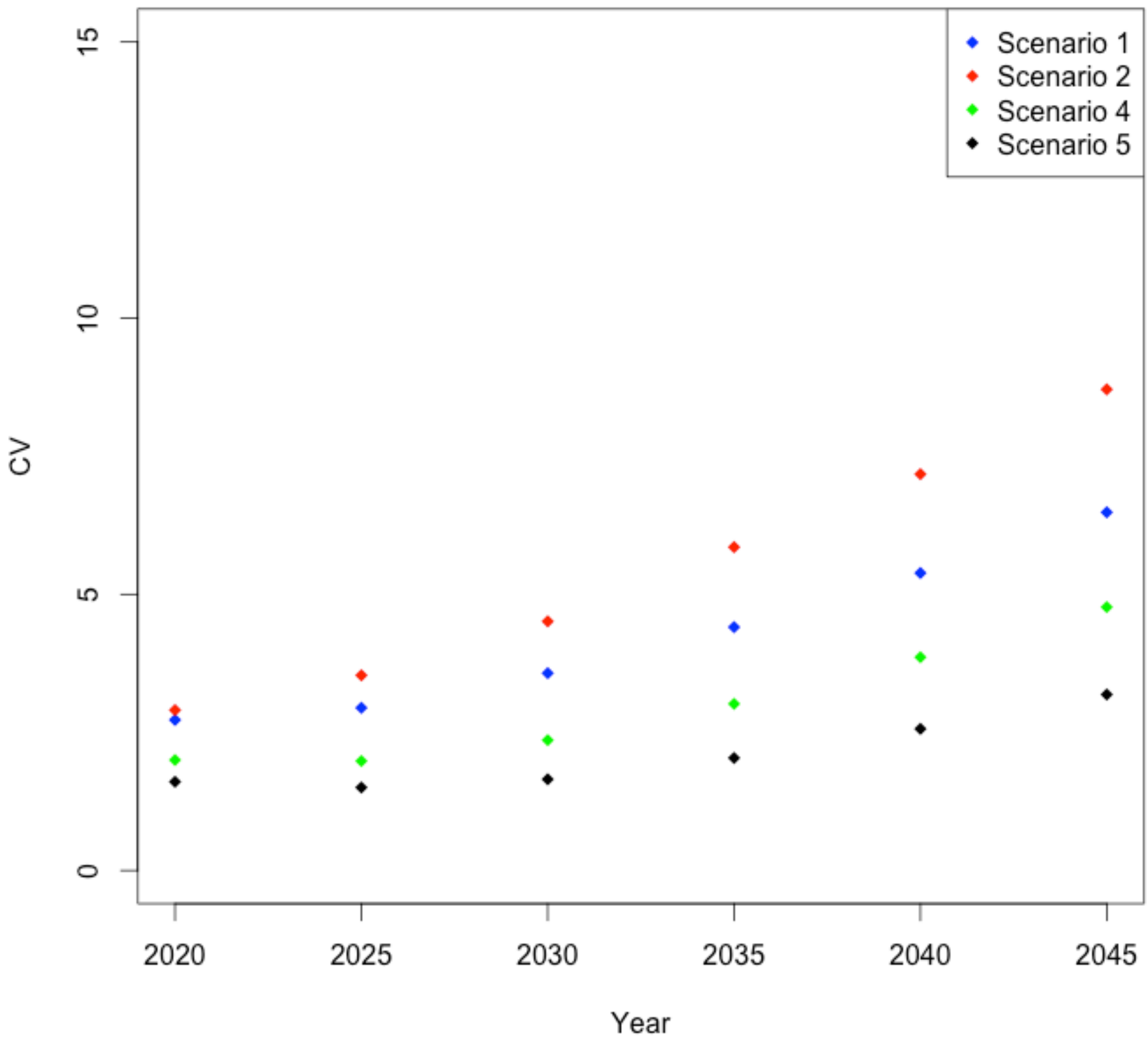

Figure 1 CV of predicted total ASL pup count for each of the sampling scenarios

Table 1 Predicted total and CV (%) by scenario

	2015	2020	2025	2030	2035	2040	2045
Prediction	2244.00	1983.00	1765.00	1582.00	1428.00	1297.00	1186.00
Scenario 1 CV	2.67	2.73	2.95	3.57	4.41	5.39	6.48
Scenario 2 CV	2.75	2.90	3.53	4.51	5.85	7.17	8.71
Scenario 4 CV	2.15	2.00	1.98	2.36	3.02	3.86	4.77
Scenario 5 CV	1.80	1.61	1.50	1.65	2.04	2.56	3.19

Table 2 to Table 6 summarise the predicted number of pups at the region level, and CVs under each of the scenarios. While Bunda Cliffs and SW Eyre have the smallest estimates, they have the largest CV's. If, for example, a minimum CV was required for each region then more sampling effort may need to be directed to these two areas. There are no results reported for Scenario 3 as the model did not fit, due to a lack of information about four of the six regions.

Table 2 Predicted number of pups at the region level

	2015	2020	2025	2030	2035	2040	2045
Bunda Cliffs	31.76	24.43	18.79	14.45	11.11	8.55	6.57
Chain of Bays	327.07	267.24	218.36	178.42	145.78	119.11	97.32
Spencer Gulf	655.41	587.33	526.32	471.65	422.66	378.75	339.41
SW Eyre	124.37	94.93	72.45	55.30	42.21	32.22	24.59
Kangaroo Island	717.54	700.30	683.47	667.04	651.01	635.37	620.10
Nuyts-Archipelago	387.82	308.48	245.37	195.17	155.24	123.48	98.22

Table 3 CV (%) for regional level predictions for Scenario 1

	2015	2020	2025	2030	2035	2040	2045
Bunda Cliffs	13.89	17.28	21.18	25.37	29.73	34.18	38.70
Chain of Bays	5.28	6.23	7.65	9.50	11.54	13.69	15.90
Spencer Gulf	3.94	4.30	5.00	5.90	6.94	8.05	9.22
SW Eyre	11.03	11.72	14.13	17.62	21.65	25.99	30.49
Kangaroo Island	4.32	4.45	4.62	5.43	6.55	7.85	9.25
Nuyts-Archipelago	7.45	8.61	10.52	12.92	15.59	18.40	21.29

Table 4 CV (%) for regional level predictions for Scenario 2

	2015	2020	2025	2030	2035	2040	2045
Bunda Cliffs	15.45	19.73	24.50	29.52	34.68	39.93	45.24
Chain of Bays	5.58	7.10	9.38	11.99	14.92	17.79	20.73
Spencer Gulf	4.21	4.95	6.01	7.35	8.78	10.26	11.80
SW Eyre	11.12	12.81	16.98	22.27	28.08	34.13	40.29
Kangaroo Island	4.47	4.60	5.42	6.66	8.66	10.40	12.12
Nuyts-Archipelago	7.66	9.53	12.40	15.77	19.52	23.31	27.06

Table 5 CV (%) for regional level predictions for Scenario 4

	2015	2020	2025	2030	2035	2040	2045
Bunda Cliffs	8.67	9.98	12.07	14.59	17.37	20.30	23.31
Chain of Bays	4.00	4.03	4.69	5.89	7.37	9.01	10.69
Spencer Gulf	2.92	2.95	3.37	4.07	4.92	5.87	6.87
SW Eyre	8.57	7.23	7.44	9.14	11.68	14.64	17.81
Kangaroo Island	3.48	3.37	3.47	4.13	5.12	6.33	7.56
Nuyts-Archipelago	4.43	4.19	4.65	5.78	7.26	8.93	10.68

Table 6 CV (%) for regional level predictions for Scenario 5

	2015	2020	2025	2030	2035	2040	2045
Bunda Cliffs	7.29	7.64	8.80	10.49	12.51	14.73	17.05
Chain of Bays	3.52	3.24	3.50	4.27	5.33	6.55	7.84
Spencer Gulf	2.52	2.38	2.60	3.10	3.78	4.55	5.38
SW Eyre	7.30	5.86	5.63	6.75	8.71	11.08	13.64
Kangaroo Island	2.88	2.62	2.49	2.71	3.26	3.99	4.82
Nuyts-Archipelago	3.88	3.39	3.41	4.00	4.98	6.15	7.43

The predicted numbers of ASL at each site, in each year under each scenario are provided in Appendix 3.

The estimated trend between 2045 and 2015 is a decline of 2.12% per year. The associated standard errors by scenario are Scenario 1: 0.23%, Scenario 2: 0.30%, Scenario 4: 0.18% and Scenario 5: 0.13%. The SE of the trend is clearly the lowest for Scenario 5, however Scenario 4 only involves half the sampling for a relatively minor increase in SE.

The regional level trends and SE's are summarized in Table 7. Increasing sampling effort obviously reduces the SE on the trend in all regions (Scenario 2 least effort, Scenario 5 most). The SE for the trend for Kangaroo Island is obviously the smallest for all scenarios. However, the trend is also the smallest by at least a factor of 4. In Scenario 1 only Seal Bay is sampled every 3 years while in Scenario 5 all of the sites are sampled every 3 years, which reduces the SE for the trend by 0.13% for the Kangaroo Island region. Whether or not the extra sampling warrants this size decrease depends entirely on the monitoring goals.

Table 7 Trend (2045 compared to 2015) and associated SE's under each of the scenarios

	Trend	SE 1	SE 2	SE 4	SE 5
Bunda Cliffs	-5.25%	0.95%	1.10%	0.65%	0.52%
Chain of Bays	-4.04%	0.47%	0.62%	0.37%	0.29%
Spencer Gulf	-2.19%	0.26%	0.33%	0.22%	0.19%
SW Eyre	-5.40%	0.98%	1.30%	0.70%	0.57%
Kangaroo Island	-0.49%	0.32%	0.40%	0.28%	0.19%
Nuyts-Archipelago	-4.58%	0.62%	0.80%	0.38%	0.29%

Discussion

The model proposed is very flexible, in that it does not require any particular rigid design, no need for equally spaced sampling, etc. Also, if circumstances change and the monitoring design needs to be changed, there is no problem in accommodating the new data nor in re-planning future data collection. This flexibility does not, of course, mean that common-sense principles of good design can be discarded; "bad" designs (unbalanced and/or too sparse) will still unavoidably give imprecise estimates. However, the use of a model should make a bad design fairly obvious from the numerical results.

Clearly, there is a huge range of possible designs that could be explored using this framework. Although there is in principle a suite of techniques for "optimal design" which aim to choose *automatically* the best amongst possible designs, in practice these techniques are unlikely to be much use for ASLs. First, there will be a number of "givens" in the design process (e.g. desire to sample some colonies regularly for other reasons) that may be hard to incorporate into an optimal design algorithm, but that are easy to just impose manually. Second, optimality has to be aimed at one specific criterion, e.g. change in overall abundance of ASLs, or detecting the effects of some management action; it is unlikely that there will be consensus in advance about what "the" goal should be, and it is more important to be able to explore interactively the extent of trade-offs between different criteria. Third, optimality algorithms require either a predefined cost-benefit trade-off or an explicit budget; for ASL monitoring, though, there is currently no clear notion of how much money is "available" and how it might be broken down.

The process of exploration of future monitoring regimes for ASL will be best handled interactively, so that scientists and managers can develop some feel for what precision about various quantities-of-interest is, and is not, actually achievable over various timescales, and at what financial cost. We hope that this project will help narrow down the candidate designs and provide a means for testing further designs to find a sampling regime that adequately meets the chosen monitoring objectives and logistical constraints for ASL.

While we tried to incorporate the most critical terms into the model, the small scale of this project prevented us from incorporating all terms that might be worth exploring. In particular it would be useful to investigate incorporating the regional level trends as a random-effect ie. turning y2000 %in% region into a random effect. Including the trends in such a manner would make more use of the notion of 'borrowing strength' across regions and time. Once future data is collected, and the model updated, changes in trend should be reported and in particular the post management trend will become relevant (currently incorporated but has a value of 0 as no data post 2015).

There was insufficient WA data to incorporate in the statistical model but should a baseline study be conducted in WA it would be relatively straightforward to update the R code and model to reflect the new data.

We have downloaded the version of R and associated packages and will archive these alongside the project code to ensure that the R code remains useable in the future and is robust to future package changes.

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Appendix 1 – Data

Site	Region	Year	Estimate	Method	Gillnet_exposure
Seal Bay	Kangaroo Island	1985.5	154	Count	High
Seal Bay	Kangaroo Island	1987	166	Count	High
Seal Bay	Kangaroo Island	1988.5	136	Count	High
Seal Bay	Kangaroo Island	1990	162	Count	High
The Pages	Kangaroo Island	1990	522	Count	High
Seal Bay	Kangaroo Island	1991.5	128	Count	High
The Pages	Kangaroo Island	1991.5	431	Count	High
Seal Bay	Kangaroo Island	1993	153	Count	High
The Pages	Kangaroo Island	1993	448	Count	High
Seal Bay	Kangaroo Island	1994.5	124	Count	High
The Pages	Kangaroo Island	1994.5	439	Count	High
Bunda 08 (B4)	Bunda Cliffs	1995	1	Count	Low
Bunda 04 (B2)	Bunda Cliffs	1995	2	Count	Low
Bunda 12 (B6)	Bunda Cliffs	1995	5	Count	Low
Bunda 22 (B9)	Bunda Cliffs	1995	7	Count	Low
Bunda 00 (B1)	Bunda Cliffs	1995	13	Count	Low
Bunda 06 (B3)	Bunda Cliffs	1995	13	Count	Low
Bunda 19 (B8)	Bunda Cliffs	1995	16	Count	Low
Bunda 09 (B5)	Bunda Cliffs	1995	18	Count	Low
Seal Bay	Kangaroo Island	1996	145	Count	High
The Pages	Kangaroo Island	1996	381	Count	High
Seal Bay	Kangaroo Island	1997.5	149	Count	High
The Pages	Kangaroo Island	1997.5	445	Count	High
Seal Bay	Kangaroo Island	1999	148	Count	High
Dangerous Reef	Spencer Gulf	1999	383	Count	Low
Dangerous Reef	Spencer Gulf	1999	425	MR	Low
The Pages	Kangaroo Island	1999	438	Count	High
Dangerous Reef	Spencer Gulf	2000.5	393	Count	Low
Bunda 04 (B2)	Bunda Cliffs	2001	3	Count	Low
Bunda 12 (B6)	Bunda Cliffs	2001	3	Count	Low
Bunda 06 (B3)	Bunda Cliffs	2001	16	Count	Low
Bunda 09 (B5)	Bunda Cliffs	2001	16	Count	Low
Seal Bay	Kangaroo Island	2001	135	Count	High
The Pages	Kangaroo Island	2001	461	Count	High
English	Spencer Gulf	2002	32	Count	Low
Dangerous Reef	Spencer Gulf	2002	426	Count	Low
Seal Slide	Kangaroo Island	2002.5	9	Count	High
Seal Bay	Kangaroo Island	2002.5	147	Count	High
The Pages	Kangaroo Island	2002.5	609	Count	High
Pt Labatt	Chain of Bays	2003.5	1	Count	High
Pearson	Chain of Bays	2003.5	29	Count	High
West Waldegrave	Chain of Bays	2003.5	157	Count	High
Dangerous Reef	Spencer Gulf	2003.5	499	Count	Low
Dangerous Reef	Spencer Gulf	2003.5	507	MR	Low
Seal Slide	Kangaroo Island	2004	11	Count	High
Seal Bay	Kangaroo Island	2004	148	Count	High
Seal Bay	Kangaroo Island	2004	272	CPP	High
The Pages	Kangaroo Island	2004	490	Count	High
Bunda 06 (B3)	Bunda Cliffs	2004.5	10	Count	Low
Pt Labatt	Chain of Bays	2005	6	Count	High
East	Spencer Gulf	2005	14	Count	High
Jones	Chain of Bays	2005	15	Count	High
Breakwater/Gliddon	Nuyts-Archipelago	2005	24	Count	High
English	Spencer Gulf	2005	27	Count	Low
North	Spencer Gulf	2005	28	Count	Low
Pearson	Chain of Bays	2005	35	Count	High
Liguanea	Spencer Gulf	2005	43	Count	High
West	Nuyts-Archipelago	2005	56	Count	High
West Waldegrave	Chain of Bays	2005	104	Count	High
Blefuscu	Nuyts-Archipelago	2005	124	Count	High
Purdie	Nuyts-Archipelago	2005	132	Count	High
Dangerous Reef	Spencer Gulf	2005	574	MR	Low
Dangerous Reef	Spencer Gulf	2005	585	Count	Low
Seal Slide	Kangaroo Island	2005.5	10	Count	High
Seal Bay	Kangaroo Island	2005.5	125	Count	High

The Pages	Kangaroo Island	2005.5	543	Count	High
South Neptune	Spencer Gulf	2006.5	6	Count	High
Jones	Chain of Bays	2006.5	15	Count	High
Ward	Chain of Bays	2006.5	45	Count	High
Nicolas Baudin	Chain of Bays	2006.5	98	Count	High
Lewis	Spencer Gulf	2006.5	149	Count	Low
Olive	Chain of Bays	2006.5	197	MR	High
Olive	Chain of Bays	2006.5	200	CPP	High
Dangerous Reef	Spencer Gulf	2006.5	575	Count	Low
Dangerous Reef	Spencer Gulf	2006.5	709	MR	Low
Dangerous Reef	Spencer Gulf	2006.5	831	CPP	Low
Bunda 18 (B7)	Bunda Cliffs	2007	1	Count	Low
Bunda 12 (B6)	Bunda Cliffs	2007	2	Count	Low
Bunda 19 (B8)	Bunda Cliffs	2007	4	Count	Low
Bunda 06 (B3)	Bunda Cliffs	2007	7	Count	Low
Bunda 09 (B5)	Bunda Cliffs	2007	11	Count	Low
Seal Slide	Kangaroo Island	2007	15	Count	High
Seal Bay	Kangaroo Island	2007	154	Count	High
Seal Bay	Kangaroo Island	2007	254	CPP	High
The Pages	Kangaroo Island	2007	403	Count	High
Bunda 12 (B6)	Bunda Cliffs	2008	1	Count	Low
Bunda 02 (B1.1)	Bunda Cliffs	2008	2	Count	Low
Bunda 06 (B3)	Bunda Cliffs	2008	5	Count	Low
Bunda 19 (B8)	Bunda Cliffs	2008	8	Count	Low
Bunda 18 (B7)	Bunda Cliffs	2008	9	Count	Low
Jones	Chain of Bays	2008	15	Count	High
Breakwater/Gliddon	Nuyts-Archipelago	2008	22	Count	High
English	Spencer Gulf	2008	23	Count	Low
Lounds	Nuyts-Archipelago	2008	34	Count	High
West	Nuyts-Archipelago	2008	39	Count	High
Fenelon	Nuyts-Archipelago	2008	40	Count	High
Lilliput	Nuyts-Archipelago	2008	55	Count	High
Lilliput	Nuyts-Archipelago	2008	66	MR	High
Lilliput	Nuyts-Archipelago	2008	70	CPP	High
Purdie	Nuyts-Archipelago	2008	95	Count	High
Blefuscu	Nuyts-Archipelago	2008	113	MR	High
Olive	Chain of Bays	2008	162	MR	High
Olive	Chain of Bays	2008	169	CPP	High
Dangerous Reef	Spencer Gulf	2008	335	Count	Low
Dangerous Reef	Spencer Gulf	2008	520	MR	Low
Dangerous Reef	Spencer Gulf	2008	543	CPP	Low
Seal Slide	Kangaroo Island	2008.5	12	Count	High
Seal Bay	Kangaroo Island	2008.5	122	Count	High
Seal Bay	Kangaroo Island	2008.5	268	CPP	High
The Pages	Kangaroo Island	2008.5	478	Count	High
Bunda 12 (B6)	Bunda Cliffs	2009.5	1	Count	Low
Jones	Chain of Bays	2009.5	11	Count	High
English	Spencer Gulf	2009.5	39	Count	Low
Albatross	Spencer Gulf	2009.5	69	Count	Low
Olive	Chain of Bays	2009.5	221	CPP	High
Olive	Chain of Bays	2009.5	221	MR	High
Dangerous Reef	Spencer Gulf	2009.5	435	Count	Low
Dangerous Reef	Spencer Gulf	2009.5	488	MR	Low
Dangerous Reef	Spencer Gulf	2009.5	629	CPP	Low
Seal Slide	Kangaroo Island	2010	10	Count	High
Seal Bay	Kangaroo Island	2010	119	Count	High
Seal Bay	Kangaroo Island	2010	267	CPP	High
The Pages	Kangaroo Island	2010	478	Count	High
Jones	Chain of Bays	2010.5	12	Count	High
Four Hummocks	SW Eyre	2010.5	14	Count	High
Rocky North	SW Eyre	2010.5	34	Count	High
Lilliput	Nuyts-Archipelago	2010.5	47	Count	High
Lilliput	Nuyts-Archipelago	2010.5	66	MR	High
Blefuscu	Nuyts-Archipelago	2010.5	120	MR	High
Olive	Chain of Bays	2010.5	173	MR	High
Olive	Chain of Bays	2010.5	199	CPP	High
Bunda 22 (B9)	Bunda Cliffs	2011	1	Count	Low
Bunda 04 (B2)	Bunda Cliffs	2011	2	Count	Low
Bunda 06 (B3)	Bunda Cliffs	2011	2	Count	Low
Bunda 08 (B4)	Bunda Cliffs	2011	2	Count	Low

Bunda 12 (B6)	Bunda Cliffs	2011	2	Count	Low
Bunda 18 (B7)	Bunda Cliffs	2011	3	Count	Low
Bunda 09 (B5)	Bunda Cliffs	2011	9	Count	Low
North	Spencer Gulf	2011	21	Count	Low
English	Spencer Gulf	2011	34	Count	Low
Peaked Rocks	Spencer Gulf	2011	58	Count	Low
Albatross	Spencer Gulf	2011	69	Count	Low
Dangerous Reef	Spencer Gulf	2011	329	Count	Low
Dangerous Reef	Spencer Gulf	2011	399	MR	Low
Dangerous Reef	Spencer Gulf	2011	413	CPP	Low
Seal Slide	Kangaroo Island	2011.5	13	Count	High
Seal Bay	Kangaroo Island	2011.5	84	Count	High
Seal Bay	Kangaroo Island	2011.5	249	CPP	High
Four Hummocks	SW Eyre	2012	9	Count	High
Little Hummock	SW Eyre	2012	10	Count	High
Jones	Chain of Bays	2012	12	Count	High
Rocky South	SW Eyre	2012	12	Count	High
Cap	SW Eyre	2012	38	Count	High
Rocky North	SW Eyre	2012	44	Count	High
Lilliput	Nuyts-Archipelago	2012	69	Count	High
Lilliput	Nuyts-Archipelago	2012	70	MR	High
Blefuscu	Nuyts-Archipelago	2012	80	MR	High
Olive	Chain of Bays	2012	101	MR	High
Olive	Chain of Bays	2012	109	Count	High
Olive	Chain of Bays	2012	135	CPP	High
Bunda 18 (B7)	Bunda Cliffs	2012.5	1	Count	Low
Bunda 12 (B6)	Bunda Cliffs	2012.5	2	Count	Low
Bunda 09 (B5)	Bunda Cliffs	2012.5	5	Count	Low
Bunda 19 (B8)	Bunda Cliffs	2012.5	7	Count	Low
South Neptune	Spencer Gulf	2012.5	7	Count	High
Bunda 06 (B3)	Bunda Cliffs	2012.5	8	Count	Low
Lewis	Spencer Gulf	2012.5	79	Count	Low
Cape Bouguer	Kangaroo Island	2013	9	Count	High
Seal Slide	Kangaroo Island	2013	10	Count	High
North Casuarina	Kangaroo Island	2013	11	Count	High
Seal Bay	Kangaroo Island	2013	99	Count	High
Seal Bay	Kangaroo Island	2013	259	CPP	High
Pt Labatt	Chain of Bays	2013.5	2	Count	High
Jones	Chain of Bays	2013.5	16	Count	High
Liguanea	Spencer Gulf	2013.5	17	Count	High
Pearson	Chain of Bays	2013.5	27	Count	High
Ward	Chain of Bays	2013.5	46	Count	High
Rocky North	SW Eyre	2013.5	47	Count	High
Nicolas Baudin	Chain of Bays	2013.5	57	Count	High
Lilliput	Nuyts-Archipelago	2013.5	68	MR	High
Lilliput	Nuyts-Archipelago	2013.5	73	Count	High
Olive	Chain of Bays	2013.5	76	Count	High
Lilliput	Nuyts-Archipelago	2013.5	78	CPP	High
Blefuscu	Nuyts-Archipelago	2013.5	86	CPP	High
West Waldegrave	Chain of Bays	2013.5	91	Count	High
Olive	Chain of Bays	2013.5	139	MR	High
Olive	Chain of Bays	2013.5	150	CPP	High
Bunda 19 (B8)	Bunda Cliffs	2014	0	Count	Low
Bunda 02 (B1.1)	Bunda Cliffs	2014	3	Count	Low
Bunda 09 (B5)	Bunda Cliffs	2014	7	Count	Low
Bunda 22 (B9)	Bunda Cliffs	2014	7	Count	Low
Bunda 06 (B3)	Bunda Cliffs	2014	9	Count	Low
East	Spencer Gulf	2014	9	Count	High
Lewis	Spencer Gulf	2014	82	Count	Low
Dangerous Reef	Spencer Gulf	2014	288	Count	Low
Dangerous Reef	Spencer Gulf	2014	408	MR	Low
Dangerous Reef	Spencer Gulf	2014	485	CPP	Low
Seal Slide	Kangaroo Island	2014.5	8	Count	High
Seal Bay	Kangaroo Island	2014.5	103	Count	High
Seal Bay	Kangaroo Island	2014.5	239	CPP	High
Little Hummock	SW Eyre	2015	4	Count	High
Williams	Spencer Gulf	2015	5	Count	High
Four Hummocks	SW Eyre	2015	6	Count	High
Curta	Spencer Gulf	2015	7	Count	High
Rocky South	SW Eyre	2015	11	Count	High

Jones	Chain of Bays	2015	19	Count	High
Fenelon	Nuyts-Archipelago	2015	19	Count	High
Lounds	Nuyts-Archipelago	2015	20	Count	High
West	Nuyts-Archipelago	2015	20	Count	High
Liguanea	Spencer Gulf	2015	25	Count	High
Breakwater/Gliddon	Nuyts-Archipelago	2015	27	Count	High
Pearson	Chain of Bays	2015	30	Count	High
Cap	SW Eyre	2015	31	Count	High
Price	SW Eyre	2015	32	Count	High
Rocky North	SW Eyre	2015	35	Count	High
Ward	Chain of Bays	2015	44	Count	High
Lilliput	Nuyts-Archipelago	2015	52	Count	High
Nicolas Baudin	Chain of Bays	2015	63	Count	High
Lilliput	Nuyts-Archipelago	2015	67	MR	High
Purdie	Nuyts-Archipelago	2015	67	Count	High
Lilliput	Nuyts-Archipelago	2015	72	CPP	High
West Waldegrave	Chain of Bays	2015	89	Count	High
Blefuscu	Nuyts-Archipelago	2015	97	CPP	High
Olive	Chain of Bays	2015	103	Count	High
Nuyts Reef	Nuyts-Archipelago	2015	105	Count	High
Olive	Chain of Bays	2015	131	MR	High
Olive	Chain of Bays	2015	142	CPP	High

Appendix 2 – R Code

‘ASL Main Script.R’

```
###THIS IS THE MAIN SCRIPT

#Set working directory to an appropriate location and make sure all of your scripts and Excel files are in that directory
setwd("~//Documents/Data/ASL/Mark")

#If you have not installed the mgcv and mvbutils packages previously you will need to do so by saving the packages to a directory and then choosing the 'browse' option for installing a package.
#install.packages("mgcv")
#install.packages("mvbutils")
require( mgcv, quietly=TRUE)
require(mvbutils, quietly=TRUE)

#Source R scripts
source("prepare_fn3.R")
source("prepare_frame2.R")
source("Other_functions.R")

# List sites with no immigration (this is here so it can be used across all scripts)
  nonimsus <- c(
    "Seal Bay", "Dangerous Reef", "Liguanea", "Cap", "Rocky South", "West Waldegrave",
    "Pearson", "Nicolas Baudin", "Olive", "Breakwater/Gliddon", "Nuyts Reef")

# Prepare the prediction frame first
  ## Just need to change filename here. This should contain all sites for each year a prediction value may be required
  # (Variables: Site, Region, Year (eg. 2020, 2025), Method, Gillnet_exposure)
  Frame <- prepare_frame2( filename='Pred_frame_AllSites.csv',
                      nonimsus=nonimsus)

# Fit Model to data. To change the scenario you just need to change the filename where the file has the future sampling schedule
  Model<- prepare_fn3(filename='Scenario_all_every3.csv',
                 nonimsus=nonimsus,
                 predlevs_im=levels( Frame$ID_im),
                 predlevs_noim=levels( Frame$ID_noim))

#Predictions at the colony/site by year level
  Pred_yearcol <- predict(Model$refit, newdata=Frame, type="response", se=TRUE)
  Pred_yearcol <- cbind(Frame[,1:6],Pred_yearcol)
  Pred_yearcol

#CV of Total (or regional level total) for a particular year using the delta method. region="NA" if you want the Total across all regions otherwise enter region name in ""
# The chosen year must be in the prediction frame (Frame)
  delta_method(year="2020",region="Kangaroo Island")
```

```
#CV of Trend from "yearNow" to "yearFuture". region="NA" if you want the Total across all regions
otherwise enter region name in ""
# The chosen years must be in the prediction frame
delta_method_trend(data=Frame,yearFuture="2045",yearNow="2000",region="NA")

################################################################################
```

'prepare_3.R'

```
prepare_fn3 <- function ( filename= 'Scenario_keycol.csv', nonimsus, predlevs_im, predlevs_noim) {
  # the main function that prepares the data and fits the model
  asl.data <- read.table( filename, sep=',', header=TRUE, row=NULL, stringsAsFactors=FALSE)
  asl.data$Site<-as.factor(asl.data$Site)

  # Big sites assumed to have count bias due to long season--- based on a "big-site" method having ever
been used there
  asl.data$sites_mrcpp <- with(asl.data, ifelse (Method %in% c('MR','CPP'),1,0))
  test <- with(asl.data, tapply(sites_mrcpp,Site,sum))
  big_sites <- names(test[test>0])

  # only use sites with at least one obs
  usable <- with(asl.data %where% (Year<2016 & Estimate>0),tapply(Estimate,Site,length))
  usable.sites <- names(usable[usable>0])
  data.usable <- asl.data %where% (Site %in% usable.sites)

  # Now add columns for fitting
  data.usable <- within(data.usable, {
    count_bias <- (Site %in% big_sites) & (Method=='Count') # small sites (short season): count OK if timed
right
    extra_sealbay_count_bias <- count_bias & (Site=='Seal Bay') # Seal Bay clearly has a different amount of
bias associated with it
    MR_bias <- Method=='MR'
    count_noise <- Method=='Count' # regardless of site type

    ID <- seq_along( Site) # 1:"n"; MVB taking advantage of new mgcv
    ID[ !count_noise] <- 1L # reduce unused factor levels

    RE_im <- (count_noise & (Site %not.in% nonimsus)) * 1
    RE_noim <- (count_noise * (Site %in% nonimsus)) * 1

    # Seems to run into trouble if same ID is used for im and noim smooths
    ID_im <- ifelse( RE_im, ID, 1L)
    ID_noim <- ifelse( RE_noim, ID, 1L)

#Set up two basline year variables - Year 2000 and Year 2016 (post-management action)
    y2000 <- Year-2000
    ypost_mgmt <- (Year>2015) * (Year-2016) * (Gillnet_exposure=='High') # should quantify old per cap
exposure; 2016 is arguably first year that effects might be seen
    FUTURE <- Year > 2015

  })

  factorify <- function( vals, prefix, extralevs) {
    vals <- prefix %&% vals
    vals <- factor( vals, levels=c( unique( vals), extralevs))
```

```
  return( vals)
 }

 data.usable$ID_im <- factorify( data.usable$ID_im, 'IX', predlevs_im)
 data.usable$ID_noim <- factorify( data.usable$ID_noim, 'NX', predlevs_noim)

 # Real stuff (plus fake rows...)
 data.real <- data.usable %where% !FUTURE
 data.future <- data.usable %where% FUTURE # for making up data later
 data.future$count_noise <- FALSE # turn off for predicting mean


 # We are using bam from mgcv 1.8.13 not gam, with new miracle feature to allow "more coefficients than
data"
 fit <-    bam( Estimate ~
             Site
            + count_bias
            + extra_sealbay_count_bias
            + MR_bias
            + s( ID_im, by=RE_im, bs='re')
            + s( ID_noim, by=RE_noim, bs='re')
            +  y2000 %in% Region
            + ypost_mgmt,
            family=Tweedie( p=1.2, link='log'),
            discrete=TRUE,
            drop.unused.levels=FALSE,
            data=data.real)


data.future$Estimate <- 1 # for 'predict', this has to be there (Any non-NA value is ok)
#data.future$RE_noim<-0  # For no random effect remove comment
#data.future$RE_im<-0    # For no random effect remove comment

preddo <- predict( fit, newdata=data.future, type='response')
data.future$Estimate <- preddo
data.both <- rbind( data.real, data.future)

refit <- update( fit, sp=fit$sp, scale=fit$sig2,data=data.real) # just a check; should be the same as fit;
refit <- update( fit, sp=fit$sp, scale=fit$sig2, data=data.both) # past & future together
Vfuture <- vcov( refit)
Vnow <- vcov( fit)


returnList( data.usable, Vfuture, Vnow, fit, refit)
}
```

##

'prepare_frame2.R'

```
prepare_frame2 <- function(filename='Pred_frame_Allsites.csv', nonimsus){
 ### Function to prepare the prediction frame
 Pred_frame_AllSites <- read.csv(filename)
```

```
  big_sites <- c("Blefuscu","Dangerous Reef","Lilliput","Olive","Seal Bay" )

  Pred_frame_AllSites <- within(Pred_frame_AllSites, {
    count_bias <- (Site %in% big_sites) & (Method=='Count') # small sites (short season): count OK if timed
right
    extra_sealbay_count_bias <- count_bias & (Site=='Seal Bay') # SB has clearly...
    # ... different q cf

    MR_bias <- Method=='MR'
    count_noise <- Method=='Count' # regardless of site type

    #Change the *0 to *1 to put the REs back into the prediction
    RE_im <- (count_noise & (Site %not.in% nonimsus)) * 0
    RE_noim <- (count_noise * (Site %in% nonimsus)) * 0

    y2000 <- Year-2000
    ypost_mgmt <- (Year>2015) * (Year-2016) * (Gillnet_exposure=='High') # should quantify old per cap
exposure; 2016 is arguably first year that effects might be seen
    FUTURE <- Year > 2015

    ID <- seq_along( Site) # 1:"n"; MVB taking advantage of new mgcv
    ID[ !count_noise] <- 1L # reduce unused factor levels. This line is otiose
    ID_im <- ifelse( RE_im, ID, 1L)
    ID_noim <- ifelse( RE_noim, ID, 1L)

    ID_im <- factor( 'IY' %&% ID_im) # called 'X' in fit-frame
    ID_noim <- factor( 'NY' %&% ID_noim)
  })
  return(Pred_frame_AllSites)
}

##################################################################################
```

'Other_functions.R'

```
# Function to sum the predictions on the response scale
TotalPredict<-function (coefs,lpmatrix)
{
  # This gives the sum of predictions (which are medians)
  temp <- lpmatrix %*% coefs # on the predictor scale
  temp<- exp(temp) # inverse log to get to the response scale
  temp<- sum(temp)
  return(temp)
}

# Mark's function to calculate the numerical derivative
Numderiv<-function(f,x0,eps=0.0001,...) {
  #Mark's function
  f0 <- f(x0,...)
  n <- length( x0)
  m <- matrix( 0, length(f0), n)
  for( i in 1:n) {
    this.eps <- eps * if( x0[ i]==0) 1 else x0[ i]
    m[,i] <- ( f( x0+this.eps * (1:n==i), ...) - f0) / this.eps }
```

```
  if( !is.null( dim( f0)))
    dim( m) <- c( dim( f0), n)
  return(m)
}

#Now need a function to use delta-method to calculate Total or Regional estimates by year. For total by
year then region="NA"

delta_method <- function(data=Frame,year="2025",region="Kangaroo Island"){
  temp <- if(region=="NA") subset(Frame, Year==year) else subset (Frame, Year==year & Region==region)
  Vfuture <- vcov(Model$refit) # This give the variance-covariance matrix
  coefs <- Model$refit$coefficients  # GAM coefficients
  lpmatrix <- predict(Model$refit, newdata=temp, type='lpmatrix')  #Prediction  matrix
  deriv <- Numderiv( TotalPredict, coefs, lpmatrix=lpmatrix)# Calculate the derivative
  Variance <- deriv%*%Vfuture%*%t(deriv) # Calculate the variance
  pred <- TotalPredict( coefs, lpmatrix=lpmatrix)
  CV <- (sqrt(Variance)/TotalPredict( coefs, lpmatrix=lpmatrix))*100  # Calculate the CV (sd/mean)
  returnList (CV, pred, Variance)
  #want to calculate total and variance by year
}

#Function to calculate the trend (Number of seals)

delta_method_trend <- function(data=Frame,yearFuture="2025",yearNow="2015",region="Kangaroo
Island"){
  temp <- if(region=="NA") subset(Frame, Year %in% c(yearNow,yearFuture)) else subset (Frame, Year %in%
c(yearFuture,yearNow) & Region==region)
  n_sites <- nrow(temp)/2

  Trend<-function (coefs,lpmatrix,yearNow,yearFuture)
  {
    ans<- (log(sum(exp(lpmatrix[1:n_sites,] %*% coefs)))-log(sum(exp(lpmatrix[(n_sites+1):(n_sites*2),] %*%
coefs))))/(as.numeric(yearFuture)-as.numeric(yearNow))
    return(ans)
  }

  Vfuture <- vcov(Model$refit) # This give the variance-covariance matrix
  coefs <- Model$refit$coefficients  # GAM coefficients
  lpmatrix <- predict(Model$refit, newdata=temp, type='lpmatrix')  #Prediction  matrix
  deriv <- Numderiv( Trend, coefs, lpmatrix=lpmatrix,  yearFuture=yearFuture,yearNow=yearNow)#
Calculate the derivative
  Variance <- deriv%*%Vfuture%*%t(deriv) # Calculate the variance
  log_trend <- Trend( coefs, lpmatrix=lpmatrix, yearFuture=yearFuture,yearNow=yearNow)
  SE<- sqrt(Variance)
  trend <- (sum(exp(lpmatrix[1:n_sites,] %*% coefs))-sum(exp(lpmatrix[(n_sites+1):(n_sites*2),] %*%
coefs)))/(as.numeric(yearFuture)-as.numeric(yearNow))
  returnList (SE, trend, log_trend)
  #want to calculate total and variance by year
```

Appendix 3 – Model predictions

Table 8 Predictions by site for each year for each scenario. Estimate is the estimated pup count in that year for that site, and the SE variables correspond to the standard error of the prediction under each of the sampling scenarios.

Site	Region	Year	Method	Estimate	SE1	SE2	SE4	SE5
Bunda 00 (B1)	Bunda Cliffs	2015	Count	4.55	2.19	2.24	1.33	1.08
Bunda 02 (B1.1)	Bunda Cliffs	2015	Count	2.02	1.21	1.21	0.81	0.66
Bunda 04 (B2)	Bunda Cliffs	2015	Count	1.16	0.60	0.61	0.46	0.40
Bunda 06 (B3)	Bunda Cliffs	2015	Count	5.36	1.10	1.14	0.90	0.81
Bunda 08 (B4)	Bunda Cliffs	2015	Count	0.78	0.57	0.58	0.41	0.35
Bunda 09 (B5)	Bunda Cliffs	2015	Count	6.66	1.01	1.17	1.13	1.01
Bunda 12 (B6)	Bunda Cliffs	2015	Count	1.37	0.47	0.48	0.40	0.37
Bunda 18 (B7)	Bunda Cliffs	2015	Count	2.60	0.98	0.98	0.77	0.67
Bunda 19 (B8)	Bunda Cliffs	2015	Count	4.28	1.16	1.18	0.92	0.82
Bunda 22 (B9)	Bunda Cliffs	2015	Count	2.99	1.15	1.17	0.86	0.74
Jones	Chain of Bays	2015	Count	11.70	1.79	1.80	1.53	1.36
Nicolas Baudin	Chain of Bays	2015	Count	62.45	9.08	9.12	6.47	5.36
Olive	Chain of Bays	2015	Count	102.49	5.11	5.53	5.34	4.80
Pearson	Chain of Bays	2015	Count	23.69	4.03	4.06	3.04	2.59
Pt Labatt	Chain of Bays	2015	Count	2.17	0.99	0.99	0.73	0.61
Ward	Chain of Bays	2015	Count	39.09	6.25	6.27	4.50	3.73
West Waldegrave	Chain of Bays	2015	Count	85.48	9.88	10.06	7.31	6.21
Cape Bouguer	Kangaroo Island	2015	Count	8.91	4.54	4.54	2.11	1.43
North Casuarina	Kangaroo Island	2015	Count	10.89	5.13	5.13	2.38	1.62
Seal Bay	Kangaroo Island	2015	CPP	251.77	10.79	11.56	11.06	9.35
Seal Slide	Kangaroo Island	2015	Count	10.55	1.68	1.68	1.41	1.18
The Pages	Kangaroo Island	2015	Count	435.42	26.11	26.51	19.26	15.60
Blefuscu	Nuyts-Archipelago	2015	Count	66.82	6.02	6.22	4.90	4.35
Breakwater/Gliddon	Nuyts-Archipelago	2015	Count	18.66	3.94	3.98	2.83	2.38
Fenelon	Nuyts-Archipelago	2015	Count	24.61	5.67	5.68	3.67	3.01
Lilliput	Nuyts-Archipelago	2015	Count	47.41	2.91	3.12	3.05	2.81
Lounds	Nuyts-Archipelago	2015	Count	22.62	5.38	5.39	3.48	2.85
Nuyts Reef	Nuyts-Archipelago	2015	Count	105.00	23.39	23.39	11.68	9.17
Purdie	Nuyts-Archipelago	2015	Count	73.92	9.40	9.64	6.57	5.59
West	Nuyts-Archipelago	2015	Count	28.76	5.02	5.09	3.60	3.04
Albatross	Spencer Gulf	2015	Count	62.17	10.35	10.36	6.31	4.94
Curta	Spencer Gulf	2015	Count	7.00	3.94	3.94	1.84	1.36
Dangerous Reef	Spencer Gulf	2015	Count	345.80	11.86	13.76	13.16	11.46
East	Spencer Gulf	2015	Count	10.12	3.32	3.32	2.05	1.60
English	Spencer Gulf	2015	Count	26.04	3.72	3.74	2.85	2.41
Lewis	Spencer Gulf	2015	Count	93.78	11.08	11.10	7.57	6.14
Liguanea	Spencer Gulf	2015	Count	25.68	5.07	5.07	3.52	2.84
North	Spencer Gulf	2015	Count	20.94	5.14	5.14	3.15	2.46
Peaked Rocks	Spencer Gulf	2015	Count	53.13	13.30	13.31	6.76	5.09
South Neptune	Spencer Gulf	2015	Count	5.76	2.36	2.36	1.45	1.13
Williams	Spencer Gulf	2015	Count	5.00	3.21	3.21	1.49	1.11
Cap	SW Eyre	2015	Count	31.69	7.14	7.15	4.99	4.02
Four Hummocks	SW Eyre	2015	Count	8.36	2.41	2.42	1.82	1.51
Little Hummock	SW Eyre	2015	Count	6.39	2.55	2.55	1.74	1.38
Price	SW Eyre	2015	Count	32.00	9.99	9.99	5.73	4.35
Rocky North	SW Eyre	2015	Count	35.35	3.95	4.17	4.13	3.58
Rocky South	SW Eyre	2015	Count	10.58	3.54	3.54	2.42	1.93
Bunda 00 (B1)	Bunda Cliffs	2020	Count	3.50	1.75	1.82	1.03	0.83
Bunda 02 (B1.1)	Bunda Cliffs	2020	Count	1.56	0.94	0.94	0.62	0.51
Bunda 04 (B2)	Bunda Cliffs	2020	Count	0.89	0.47	0.48	0.36	0.31

Bunda 06 (B3)	Bunda Cliffs	2020	Count	4.12	0.95	1.01	0.73	0.64
Bunda 08 (B4)	Bunda Cliffs	2020	Count	0.60	0.45	0.45	0.32	0.27
Bunda 09 (B5)	Bunda Cliffs	2020	Count	5.12	0.83	1.02	0.92	0.79
Bunda 12 (B6)	Bunda Cliffs	2020	Count	1.05	0.38	0.39	0.32	0.29
Bunda 18 (B7)	Bunda Cliffs	2020	Count	2.00	0.77	0.78	0.59	0.51
Bunda 19 (B8)	Bunda Cliffs	2020	Count	3.29	0.96	0.99	0.73	0.64
Bunda 22 (B9)	Bunda Cliffs	2020	Count	2.30	0.92	0.95	0.67	0.57
Jones	Chain of Bays	2020	Count	9.56	1.51	1.55	1.26	1.11
Nicolas Baudin	Chain of Bays	2020	Count	51.02	7.63	7.79	5.18	4.24
Olive	Chain of Bays	2020	Count	83.74	4.27	5.20	4.62	3.99
Pearson	Chain of Bays	2020	Count	19.36	3.44	3.52	2.49	2.09
Pt Labatt	Chain of Bays	2020	Count	1.77	0.81	0.82	0.60	0.50
Ward	Chain of Bays	2020	Count	31.94	5.22	5.32	3.63	2.98
West Waldegrave	Chain of Bays	2020	Count	69.84	8.56	9.00	5.94	4.94
Cape Bouguer	Kangaroo Island	2020	Count	8.70	4.44	4.44	2.04	1.39
North Casuarina	Kangaroo Island	2020	Count	10.63	5.01	5.01	2.31	1.57
Seal Bay	Kangaroo Island	2020	CPP	245.72	9.05	10.08	10.28	8.50
Seal Slide	Kangaroo Island	2020	Count	10.29	1.65	1.65	1.37	1.15
The Pages	Kangaroo Island	2020	Count	424.95	26.67	27.56	18.63	14.61
Blefuscu	Nuyts-Archipelago	2020	Count	53.15	5.35	5.88	3.97	3.42
Breakwater/Gliddon	Nuyts-Archipelago	2020	Count	14.85	3.24	3.33	2.25	1.88
Fenelon	Nuyts-Archipelago	2020	Count	19.58	4.60	4.67	2.90	2.35
Lilliput	Nuyts-Archipelago	2020	Count	37.71	2.41	2.94	2.53	2.25
Lounds	Nuyts-Archipelago	2020	Count	17.99	4.36	4.42	2.75	2.23
Nuyts Reef	Nuyts-Archipelago	2020	Count	83.52	18.78	18.89	8.92	6.93
Purdie	Nuyts-Archipelago	2020	Count	58.80	8.14	8.70	5.22	4.34
West	Nuyts-Archipelago	2020	Count	22.88	4.18	4.35	2.86	2.39
Albatross	Spencer Gulf	2020	Count	55.71	9.35	9.41	5.57	4.33
Curta	Spencer Gulf	2020	Count	6.27	3.53	3.53	1.63	1.21
Dangerous Reef	Spencer Gulf	2020	Count	309.88	11.31	14.49	12.95	10.77
East	Spencer Gulf	2020	Count	9.07	2.99	3.00	1.82	1.41
English	Spencer Gulf	2020	Count	23.34	3.38	3.43	2.56	2.15
Lewis	Spencer Gulf	2020	Count	84.04	10.07	10.19	6.66	5.35
Liguanea	Spencer Gulf	2020	Count	23.01	4.59	4.61	3.08	2.47
North	Spencer Gulf	2020	Count	18.77	4.62	4.65	2.81	2.18
Peaked Rocks	Spencer Gulf	2020	Count	47.61	11.99	12.04	5.77	4.31
South Neptune	Spencer Gulf	2020	Count	5.16	2.12	2.12	1.29	1.00
Williams	Spencer Gulf	2020	Count	4.48	2.88	2.88	1.33	0.98
Cap	SW Eyre	2020	Count	24.19	5.66	5.82	3.62	2.87
Four Hummocks	SW Eyre	2020	Count	6.38	1.89	1.94	1.38	1.13
Little Hummock	SW Eyre	2020	Count	4.88	1.97	1.99	1.31	1.03
Price	SW Eyre	2020	Count	24.42	7.72	7.79	4.11	3.07
Rocky North	SW Eyre	2020	Count	26.98	2.59	3.07	3.08	2.57
Rocky South	SW Eyre	2020	Count	8.07	2.75	2.78	1.81	1.43
Bunda 00 (B1)	Bunda Cliffs	2025	Count	2.69	1.41	1.48	0.81	0.65
Bunda 02 (B1.1)	Bunda Cliffs	2025	Count	1.20	0.73	0.74	0.48	0.39
Bunda 04 (B2)	Bunda Cliffs	2025	Count	0.68	0.38	0.39	0.28	0.24
Bunda 06 (B3)	Bunda Cliffs	2025	Count	3.17	0.83	0.90	0.61	0.52
Bunda 08 (B4)	Bunda Cliffs	2025	Count	0.46	0.35	0.35	0.25	0.21
Bunda 09 (B5)	Bunda Cliffs	2025	Count	3.94	0.73	0.92	0.76	0.64
Bunda 12 (B6)	Bunda Cliffs	2025	Count	0.81	0.31	0.32	0.25	0.22
Bunda 18 (B7)	Bunda Cliffs	2025	Count	1.54	0.62	0.63	0.46	0.40
Bunda 19 (B8)	Bunda Cliffs	2025	Count	2.53	0.80	0.85	0.59	0.50
Bunda 22 (B9)	Bunda Cliffs	2025	Count	1.77	0.75	0.78	0.53	0.44
Jones	Chain of Bays	2025	Count	7.81	1.29	1.36	1.05	0.92
Nicolas Baudin	Chain of Bays	2025	Count	41.69	6.54	6.88	4.28	3.44
Olive	Chain of Bays	2025	Count	68.42	4.18	5.59	4.33	3.57
Pearson	Chain of Bays	2025	Count	15.82	2.99	3.12	2.10	1.73

Pt Labatt	Chain of Bays	2025	Count	1.45	0.67	0.68	0.49	0.41
Ward	Chain of Bays	2025	Count	26.10	4.44	4.64	2.99	2.43
West Waldegrave	Chain of Bays	2025	Count	57.07	7.58	8.30	5.02	4.06
Cape Bouguer	Kangaroo Island	2025	Count	8.49	4.33	4.34	1.99	1.35
North Casuarina	Kangaroo Island	2025	Count	10.38	4.90	4.91	2.25	1.52
Seal Bay	Kangaroo Island	2025	CPP	239.81	8.14	10.49	10.25	7.96
Seal Slide	Kangaroo Island	2025	Count	10.05	1.63	1.65	1.35	1.12
The Pages	Kangaroo Island	2025	Count	414.74	27.59	30.07	18.77	13.85
Blefuscu	Nuyts-Archipelago	2025	Count	42.28	5.00	5.82	3.39	2.80
Breakwater/Gliddon	Nuyts-Archipelago	2025	Count	11.81	2.70	2.85	1.81	1.50
Fenelon	Nuyts-Archipelago	2025	Count	15.57	3.79	3.93	2.32	1.86
Lilliput	Nuyts-Archipelago	2025	Count	29.99	2.36	3.14	2.22	1.89
Lounds	Nuyts-Archipelago	2025	Count	14.31	3.58	3.71	2.20	1.77
Nuyts Reef	Nuyts-Archipelago	2025	Count	66.43	15.35	15.72	7.01	5.37
Purdie	Nuyts-Archipelago	2025	Count	46.77	7.23	8.08	4.31	3.47
West	Nuyts-Archipelago	2025	Count	18.20	3.56	3.82	2.32	1.91
Albatross	Spencer Gulf	2025	Count	49.92	8.49	8.61	4.98	3.85
Curta	Spencer Gulf	2025	Count	5.62	3.18	3.18	1.45	1.07
Dangerous Reef	Spencer Gulf	2025	Count	277.69	11.77	15.92	13.34	10.76
East	Spencer Gulf	2025	Count	8.12	2.71	2.73	1.62	1.25
English	Spencer Gulf	2025	Count	20.91	3.10	3.19	2.33	1.93
Lewis	Spencer Gulf	2025	Count	75.31	9.25	9.48	5.99	4.76
Liguanea	Spencer Gulf	2025	Count	20.62	4.23	4.30	2.74	2.18
North	Spencer Gulf	2025	Count	16.82	4.18	4.21	2.51	1.95
Peaked Rocks	Spencer Gulf	2025	Count	42.66	10.94	11.06	5.01	3.71
South Neptune	Spencer Gulf	2025	Count	4.63	1.91	1.92	1.15	0.89
Williams	Spencer Gulf	2025	Count	4.02	2.59	2.59	1.18	0.87
Cap	SW Eyre	2025	Count	18.46	4.65	4.99	2.77	2.15
Four Hummocks	SW Eyre	2025	Count	4.87	1.52	1.61	1.07	0.86
Little Hummock	SW Eyre	2025	Count	3.72	1.54	1.59	1.00	0.79
Price	SW Eyre	2025	Count	18.64	6.10	6.30	3.06	2.27
Rocky North	SW Eyre	2025	Count	20.59	2.12	2.94	2.51	2.02
Rocky South	SW Eyre	2025	Count	6.16	2.17	2.26	1.38	1.08
Bunda 00 (B1)	Bunda Cliffs	2030	Count	2.07	1.14	1.21	0.65	0.51
Bunda 02 (B1.1)	Bunda Cliffs	2030	Count	0.92	0.57	0.58	0.37	0.30
Bunda 04 (B2)	Bunda Cliffs	2030	Count	0.53	0.30	0.31	0.22	0.19
Bunda 06 (B3)	Bunda Cliffs	2030	Count	2.44	0.73	0.80	0.52	0.43
Bunda 08 (B4)	Bunda Cliffs	2030	Count	0.35	0.27	0.28	0.19	0.16
Bunda 09 (B5)	Bunda Cliffs	2030	Count	3.03	0.66	0.83	0.64	0.53
Bunda 12 (B6)	Bunda Cliffs	2030	Count	0.62	0.25	0.27	0.20	0.18
Bunda 18 (B7)	Bunda Cliffs	2030	Count	1.18	0.50	0.51	0.37	0.31
Bunda 19 (B8)	Bunda Cliffs	2030	Count	1.95	0.67	0.73	0.48	0.40
Bunda 22 (B9)	Bunda Cliffs	2030	Count	1.36	0.61	0.64	0.42	0.35
Jones	Chain of Bays	2030	Count	6.38	1.12	1.22	0.90	0.77
Nicolas Baudin	Chain of Bays	2030	Count	34.06	5.70	6.21	3.65	2.89
Olive	Chain of Bays	2030	Count	55.91	4.35	6.02	4.22	3.37
Pearson	Chain of Bays	2030	Count	12.92	2.63	2.80	1.81	1.47
Pt Labatt	Chain of Bays	2030	Count	1.18	0.55	0.56	0.40	0.33
Ward	Chain of Bays	2030	Count	21.32	3.84	4.14	2.54	2.03
West Waldegrave	Chain of Bays	2030	Count	46.63	6.83	7.78	4.42	3.48
Cape Bouguer	Kangaroo Island	2030	Count	8.29	4.24	4.25	1.94	1.31
North Casuarina	Kangaroo Island	2030	Count	10.13	4.79	4.81	2.19	1.48
Seal Bay	Kangaroo Island	2030	CPP	234.05	9.01	13.04	11.28	8.16
Seal Slide	Kangaroo Island	2030	Count	9.80	1.62	1.67	1.33	1.10
The Pages	Kangaroo Island	2030	Count	404.77	29.88	34.52	20.62	14.32
Blefuscu	Nuyts-Archipelago	2030	Count	33.63	4.73	5.72	3.01	2.40
Breakwater/Gliddon	Nuyts-Archipelago	2030	Count	9.39	2.28	2.47	1.48	1.21
Fenelon	Nuyts-Archipelago	2030	Count	12.39	3.16	3.37	1.89	1.50

Lilliput	Nuyts-Archipelago	2030	Count	23.86	2.42	3.30	2.03	1.65
Lounds	Nuyts-Archipelago	2030	Count	11.38	2.98	3.17	1.79	1.42
Nuyts Reef	Nuyts-Archipelago	2030	Count	52.84	12.75	13.38	5.70	4.30
Purdie	Nuyts-Archipelago	2030	Count	37.20	6.51	7.54	3.70	2.89
West	Nuyts-Archipelago	2030	Count	14.48	3.07	3.41	1.93	1.56
Albatross	Spencer Gulf	2030	Count	44.74	7.75	7.93	4.51	3.47
Curta	Spencer Gulf	2030	Count	5.04	2.86	2.87	1.30	0.96
Dangerous Reef	Spencer Gulf	2030	Count	248.84	12.61	17.38	13.91	11.08
East	Spencer Gulf	2030	Count	7.28	2.47	2.51	1.46	1.13
English	Spencer Gulf	2030	Count	18.74	2.86	2.98	2.13	1.76
Lewis	Spencer Gulf	2030	Count	67.49	8.57	8.93	5.49	4.33
Liguanea	Spencer Gulf	2030	Count	18.48	3.96	4.09	2.50	1.98
North	Spencer Gulf	2030	Count	15.07	3.78	3.83	2.27	1.75
Peaked Rocks	Spencer Gulf	2030	Count	38.23	10.09	10.31	4.49	3.33
South Neptune	Spencer Gulf	2030	Count	4.14	1.73	1.75	1.04	0.80
Williams	Spencer Gulf	2030	Count	3.60	2.33	2.34	1.06	0.78
Cap	SW Eyre	2030	Count	14.09	3.90	4.38	2.23	1.72
Four Hummocks	SW Eyre	2030	Count	3.72	1.24	1.36	0.85	0.68
Little Hummock	SW Eyre	2030	Count	2.84	1.22	1.29	0.78	0.61
Price	SW Eyre	2030	Count	14.23	4.91	5.23	2.38	1.77
Rocky North	SW Eyre	2030	Count	15.72	2.04	2.99	2.17	1.70
Rocky South	SW Eyre	2030	Count	4.70	1.75	1.87	1.08	0.84
Bunda 00 (B1)	Bunda Cliffs	2035	Count	1.59	0.93	0.99	0.52	0.40
Bunda 02 (B1.1)	Bunda Cliffs	2035	Count	0.71	0.45	0.46	0.29	0.24
Bunda 04 (B2)	Bunda Cliffs	2035	Count	0.40	0.24	0.25	0.18	0.15
Bunda 06 (B3)	Bunda Cliffs	2035	Count	1.88	0.63	0.71	0.44	0.36
Bunda 08 (B4)	Bunda Cliffs	2035	Count	0.27	0.22	0.22	0.15	0.12
Bunda 09 (B5)	Bunda Cliffs	2035	Count	2.33	0.59	0.75	0.54	0.44
Bunda 12 (B6)	Bunda Cliffs	2035	Count	0.48	0.21	0.22	0.16	0.14
Bunda 18 (B7)	Bunda Cliffs	2035	Count	0.91	0.40	0.42	0.29	0.25
Bunda 19 (B8)	Bunda Cliffs	2035	Count	1.50	0.57	0.62	0.40	0.33
Bunda 22 (B9)	Bunda Cliffs	2035	Count	1.04	0.50	0.53	0.34	0.28
Jones	Chain of Bays	2035	Count	5.22	0.99	1.11	0.78	0.66
Nicolas Baudin	Chain of Bays	2035	Count	27.83	5.03	5.65	3.19	2.49
Olive	Chain of Bays	2035	Count	45.68	4.46	6.22	4.12	3.22
Pearson	Chain of Bays	2035	Count	10.56	2.32	2.52	1.59	1.27
Pt Labatt	Chain of Bays	2035	Count	0.97	0.46	0.47	0.33	0.27
Ward	Chain of Bays	2035	Count	17.42	3.35	3.72	2.20	1.73
West Waldegrave	Chain of Bays	2035	Count	38.10	6.20	7.28	3.99	3.08
Cape Bouguer	Kangaroo Island	2035	Count	8.09	4.15	4.18	1.90	1.28
North Casuarina	Kangaroo Island	2035	Count	9.88	4.70	4.73	2.15	1.45
Seal Bay	Kangaroo Island	2035	CPP	228.43	11.07	16.57	13.00	8.93
Seal Slide	Kangaroo Island	2035	Count	9.57	1.63	1.71	1.34	1.08
The Pages	Kangaroo Island	2035	Count	395.05	33.07	40.00	23.57	15.76
Blefuscu	Nuyts-Archipelago	2035	Count	26.75	4.44	5.50	2.73	2.11
Breakwater/Gliddon	Nuyts-Archipelago	2035	Count	7.47	1.94	2.16	1.23	0.99
Fenelon	Nuyts-Archipelago	2035	Count	9.85	2.67	2.91	1.56	1.22
Lilliput	Nuyts-Archipelago	2035	Count	18.98	2.42	3.32	1.88	1.48
Lounds	Nuyts-Archipelago	2035	Count	9.06	2.51	2.73	1.47	1.16
Nuyts Reef	Nuyts-Archipelago	2035	Count	42.03	10.71	11.55	4.77	3.55
Purdie	Nuyts-Archipelago	2035	Count	29.59	5.86	6.98	3.24	2.47
West	Nuyts-Archipelago	2035	Count	11.51	2.67	3.05	1.62	1.29
Albatross	Spencer Gulf	2035	Count	40.09	7.10	7.35	4.13	3.18
Curta	Spencer Gulf	2035	Count	4.51	2.58	2.60	1.17	0.87
Dangerous Reef	Spencer Gulf	2035	Count	222.99	13.47	18.62	14.46	11.47
East	Spencer Gulf	2035	Count	6.52	2.27	2.32	1.33	1.03
English	Spencer Gulf	2035	Count	16.80	2.65	2.80	1.97	1.62
Lewis	Spencer Gulf	2035	Count	60.48	7.99	8.48	5.13	4.03

Liguanea	Spencer Gulf	2035	Count	16.56	3.75	3.94	2.34	1.84
North	Spencer Gulf	2035	Count	13.50	3.43	3.50	2.06	1.59
Peaked Rocks	Spencer Gulf	2035	Count	34.26	9.38	9.71	4.16	3.10
South Neptune	Spencer Gulf	2035	Count	3.71	1.58	1.60	0.94	0.73
Williams	Spencer Gulf	2035	Count	3.22	2.10	2.11	0.95	0.71
Cap	SW Eyre	2035	Count	10.76	3.31	3.86	1.87	1.43
Four Hummocks	SW Eyre	2035	Count	2.84	1.03	1.16	0.68	0.54
Little Hummock	SW Eyre	2035	Count	2.17	0.98	1.06	0.62	0.48
Price	SW Eyre	2035	Count	10.86	4.00	4.41	1.93	1.45
Rocky North	SW Eyre	2035	Count	12.00	2.00	2.95	1.93	1.50
Rocky South	SW Eyre	2035	Count	3.59	1.42	1.56	0.87	0.67
Bunda 00 (B1)	Bunda Cliffs	2040	Count	1.22	0.75	0.81	0.42	0.32
Bunda 02 (B1.1)	Bunda Cliffs	2040	Count	0.54	0.36	0.37	0.23	0.18
Bunda 04 (B2)	Bunda Cliffs	2040	Count	0.31	0.19	0.21	0.14	0.12
Bunda 06 (B3)	Bunda Cliffs	2040	Count	1.44	0.55	0.61	0.37	0.30
Bunda 08 (B4)	Bunda Cliffs	2040	Count	0.21	0.17	0.18	0.12	0.10
Bunda 09 (B5)	Bunda Cliffs	2040	Count	1.79	0.52	0.66	0.46	0.37
Bunda 12 (B6)	Bunda Cliffs	2040	Count	0.37	0.17	0.19	0.13	0.11
Bunda 18 (B7)	Bunda Cliffs	2040	Count	0.70	0.33	0.35	0.23	0.20
Bunda 19 (B8)	Bunda Cliffs	2040	Count	1.15	0.48	0.53	0.33	0.27
Bunda 22 (B9)	Bunda Cliffs	2040	Count	0.80	0.41	0.44	0.27	0.22
Jones	Chain of Bays	2040	Count	4.26	0.87	1.01	0.68	0.57
Nicolas Baudin	Chain of Bays	2040	Count	22.74	4.46	5.16	2.84	2.19
Olive	Chain of Bays	2040	Count	37.32	4.46	6.20	3.97	3.07
Pearson	Chain of Bays	2040	Count	8.63	2.06	2.27	1.41	1.11
Pt Labatt	Chain of Bays	2040	Count	0.79	0.38	0.39	0.27	0.23
Ward	Chain of Bays	2040	Count	14.24	2.95	3.36	1.93	1.50
West Waldegrave	Chain of Bays	2040	Count	31.13	5.63	6.77	3.64	2.77
Cape Bouguer	Kangaroo Island	2040	Count	7.89	4.07	4.11	1.87	1.26
North Casuarina	Kangaroo Island	2040	Count	9.65	4.61	4.66	2.12	1.43
Seal Bay	Kangaroo Island	2040	CPP	222.94	13.65	20.41	15.07	10.09
Seal Slide	Kangaroo Island	2040	Count	9.34	1.65	1.78	1.35	1.08
The Pages	Kangaroo Island	2040	Count	385.55	36.78	45.94	27.11	17.82
Blefuscu	Nuyts-Archipelago	2040	Count	21.28	4.10	5.16	2.47	1.87
Breakwater/Gliddon	Nuyts-Archipelago	2040	Count	5.94	1.66	1.90	1.03	0.82
Fenelon	Nuyts-Archipelago	2040	Count	7.84	2.26	2.53	1.30	1.01
Lilliput	Nuyts-Archipelago	2040	Count	15.09	2.35	3.22	1.72	1.33
Lounds	Nuyts-Archipelago	2040	Count	7.20	2.12	2.36	1.23	0.96
Nuyts Reef	Nuyts-Archipelago	2040	Count	33.43	9.08	10.05	4.08	3.00
Purdie	Nuyts-Archipelago	2040	Count	23.54	5.26	6.38	2.87	2.15
West	Nuyts-Archipelago	2040	Count	9.16	2.32	2.72	1.38	1.08
Albatross	Spencer Gulf	2040	Count	35.93	6.53	6.85	3.83	2.95
Curta	Spencer Gulf	2040	Count	4.05	2.34	2.37	1.06	0.79
Dangerous Reef	Spencer Gulf	2040	Count	199.83	14.19	19.53	14.88	11.81
East	Spencer Gulf	2040	Count	5.85	2.09	2.16	1.23	0.95
English	Spencer Gulf	2040	Count	15.05	2.46	2.64	1.84	1.50
Lewis	Spencer Gulf	2040	Count	54.19	7.49	8.10	4.85	3.81
Liguanea	Spencer Gulf	2040	Count	14.84	3.58	3.83	2.23	1.75
North	Spencer Gulf	2040	Count	12.10	3.11	3.20	1.87	1.45
Peaked Rocks	Spencer Gulf	2040	Count	30.70	8.79	9.22	3.96	2.97
South Neptune	Spencer Gulf	2040	Count	3.33	1.44	1.47	0.86	0.66
Williams	Spencer Gulf	2040	Count	2.89	1.90	1.91	0.86	0.64
Cap	SW Eyre	2040	Count	8.21	2.82	3.37	1.60	1.22
Four Hummocks	SW Eyre	2040	Count	2.17	0.85	0.99	0.56	0.44
Little Hummock	SW Eyre	2040	Count	1.66	0.79	0.87	0.49	0.38
Price	SW Eyre	2040	Count	8.29	3.29	3.73	1.61	1.22
Rocky North	SW Eyre	2040	Count	9.16	1.91	2.79	1.72	1.33
Rocky South	SW Eyre	2040	Count	2.74	1.16	1.31	0.70	0.55

Bunda 00 (B1)	Bunda Cliffs	2045	Count	0.94	0.61	0.66	0.34	0.26
Bunda 02 (B1.1)	Bunda Cliffs	2045	Count	0.42	0.28	0.30	0.18	0.15
Bunda 04 (B2)	Bunda Cliffs	2045	Count	0.24	0.16	0.17	0.11	0.09
Bunda 06 (B3)	Bunda Cliffs	2045	Count	1.11	0.47	0.53	0.32	0.25
Bunda 08 (B4)	Bunda Cliffs	2045	Count	0.16	0.13	0.14	0.09	0.08
Bunda 09 (B5)	Bunda Cliffs	2045	Count	1.38	0.46	0.58	0.39	0.31
Bunda 12 (B6)	Bunda Cliffs	2045	Count	0.28	0.14	0.16	0.11	0.09
Bunda 18 (B7)	Bunda Cliffs	2045	Count	0.54	0.27	0.29	0.19	0.16
Bunda 19 (B8)	Bunda Cliffs	2045	Count	0.89	0.40	0.45	0.27	0.22
Bunda 22 (B9)	Bunda Cliffs	2045	Count	0.62	0.33	0.36	0.22	0.18
Jones	Chain of Bays	2045	Count	3.48	0.77	0.91	0.59	0.49
Nicolas Baudin	Chain of Bays	2045	Count	18.58	3.96	4.69	2.54	1.94
Olive	Chain of Bays	2045	Count	30.50	4.33	6.00	3.76	2.90
Pearson	Chain of Bays	2045	Count	7.05	1.82	2.04	1.25	0.98
Pt Labatt	Chain of Bays	2045	Count	0.65	0.31	0.33	0.23	0.19
Ward	Chain of Bays	2045	Count	11.63	2.60	3.03	1.71	1.32
West Waldegrave	Chain of Bays	2045	Count	25.44	5.09	6.24	3.33	2.52
Cape Bouguer	Kangaroo Island	2045	Count	7.70	3.99	4.05	1.85	1.25
North Casuarina	Kangaroo Island	2045	Count	9.41	4.52	4.59	2.09	1.41
Seal Bay	Kangaroo Island	2045	CPP	217.58	16.41	24.29	17.30	11.45
Seal Slide	Kangaroo Island	2045	Count	9.11	1.68	1.85	1.37	1.08
The Pages	Kangaroo Island	2045	Count	376.29	40.75	52.01	30.91	20.20
Blefuscu	Nuyts-Archipelago	2045	Count	16.92	3.74	4.75	2.23	1.67
Breakwater/Gliddon	Nuyts-Archipelago	2045	Count	4.73	1.42	1.66	0.87	0.68
Fenelon	Nuyts-Archipelago	2045	Count	6.23	1.92	2.20	1.09	0.84
Lilliput	Nuyts-Archipelago	2045	Count	12.01	2.22	3.03	1.57	1.20
Lounds	Nuyts-Archipelago	2045	Count	5.73	1.80	2.05	1.03	0.79
Nuyts Reef	Nuyts-Archipelago	2045	Count	26.59	7.73	8.76	3.53	2.58
Purdie	Nuyts-Archipelago	2045	Count	18.72	4.68	5.76	2.55	1.89
West	Nuyts-Archipelago	2045	Count	7.29	2.02	2.41	1.18	0.91
Albatross	Spencer Gulf	2045	Count	32.19	6.03	6.40	3.58	2.77
Curta	Spencer Gulf	2045	Count	3.62	2.12	2.16	0.97	0.72
Dangerous Reef	Spencer Gulf	2045	Count	179.07	14.70	20.13	15.14	12.05
East	Spencer Gulf	2045	Count	5.24	1.93	2.02	1.14	0.88
English	Spencer Gulf	2045	Count	13.49	2.29	2.50	1.72	1.40
Lewis	Spencer Gulf	2045	Count	48.56	7.05	7.75	4.63	3.64
Liguanea	Spencer Gulf	2045	Count	13.30	3.43	3.73	2.15	1.68
North	Spencer Gulf	2045	Count	10.84	2.84	2.94	1.72	1.33
Peaked Rocks	Spencer Gulf	2045	Count	27.51	8.27	8.80	3.84	2.91
South Neptune	Spencer Gulf	2045	Count	2.98	1.32	1.36	0.79	0.61
Williams	Spencer Gulf	2045	Count	2.59	1.72	1.74	0.79	0.58
Cap	SW Eyre	2045	Count	6.27	2.39	2.92	1.37	1.06
Four Hummocks	SW Eyre	2045	Count	1.65	0.71	0.84	0.46	0.37
Little Hummock	SW Eyre	2045	Count	1.26	0.64	0.72	0.40	0.31
Price	SW Eyre	2045	Count	6.33	2.71	3.16	1.36	1.04
Rocky North	SW Eyre	2045	Count	6.99	1.77	2.56	1.51	1.17

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