Updated Analyses of the Results from the Island Closure Feasibility Study for the Dassen/Robben and St Croix/Bird Island Pairs given Revised Data and Responses to Matters Raised in Documents MARAM/IWS/DEC14/Peng/A3

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Summary

Repetition of earlier analyses of the data from the island closure feasibility study, given some corrected and extended data series, makes little change to results for Robben and Dassen Islands, except that the estimated power of foraging–related response variables to achieve statistically significant results decreases appreciably. However for St Croix Island, the inference of a negative impact of fishing is strengthened. The rationales offered in MARAM/IWS/DEC14/Peng/A3 for using closure instead of catch as a covariate in the analysis, and for restricting data to the years from 2008 onwards, are questioned. Comparisons conducted by applying the MARAM/IWS/DEC14/Peng/B4 approach, which uses annual means of response variables, indicate that the use of closure rather than catch as the covariate generally results in poorer precision and fewer statistically significant estimates of the fishing effect parameter λ. Furthermore when catch is used as the covariate, appreciably better precision for estimates of λ is generally achieved by including all years in the analyses, rather than by restricting them to the period from 2008 onwards. Importantly comparative estimates of λ from the Peng/B4 approach are shown to achieve better precision generally than those from the more complex and data-intensive Peng/A3 approach, thus negating the assertions in Peng/A1 and Peng/A2 that estimates from the former are compromised by their dependence on response variable means alone. The failure of Peng/A3 to report the variance estimates needed for input to the power analysis required for the feasibility study is noted. Furthermore Peng/A3 offers no specification of the simulation studies necessary to carry out a power analysis for the estimators which it proposes, so that it has failed to address this key first step in this overall closure study process. Peng/A3 has prodived some strongish evidence that closures may benefit penguins, but for the Eastern Cape colonies only. However it has failed to address the primary aim of the feasibility study itself to ascertain for how long an experimental closures programme would need to continue for reliable determination of the impact of fishing in the near vicinity of island colonies on penguin reproductive success. Use of the Peng/B4 approach indicates that this period is appreciably lengthened if data for analyses are to be restricted to the years from 2008 onwards only, and particularly so if closure replaces catch as a covariate.

Background

At the time by which the initial set of analyses (in MARAM/IWS/DEC14/Peng/B4) of the island closure feasibility study had to be submitted for the Panel's information, certain data had been made available only a few days beforehand, making it impossible to repeat those analyses including these data updates by that deadline. These data involved corrections to some of the data previously provided on foraging path length and duration, and also extended those data by one year. This document repeats the analyses of MARAM/IWS/DEC14/Peng/B4 using those updated data; this exercise also takes account of a few corrections to past catch data which had occurred as a result of a misunderstanding in datafile exchanges in relation to MARAM/IWS/DEC14/Peng/C1, which contains the datasets agreed for these analyses for presentation to the Panel. Differences between the results of these updated analyses and those in MARAM/IWS/DEC14/Peng/B4 are summarised.

The document then proceeds to provide some responses to comments and results presented in document MARAM/IWS/DEC14/Peng/A3, which presents an alternative method of analysis of data from the island closure feasibility study. Unlike MARAM/IWS/DEC14/Peng/B4, MARAM/IWS/DEC14/Peng/A3 restricts its analysis to data from 2008 onwards only, and treats closure to fishing rather than the size of the catch around an island as the key covariate. To facilitate comparisons between the two approaches so as to be able to respond more effectively, this document

also reports results using the methodology of MARAM/IWS/DEC14/Peng/B4 applied with combinations of this restriction and covariate change.

Updated results of the MARAM/IWS/DEC14/Peng/B4 analyses

The results from applying the methods of MARAM/IWS/DEC14/Peng/B4 to the updated data are given in Appendix A. The Figures provided in that Appendix compare estimates of the fishing effect parameter λ with those from the previous analyses of MARAM/IWS/DEC14/Peng/B4.

The differences in the data used for the two set of analyses have been summarised above. One other point to be clarified, which was inadvertently omitted from MARAM/IWS/DEC14/Peng/B4, concerns the relationship between the means (p) of the response variables listed in document MARAM/IWS/DEC14/Peng/C1, and the response variable F reflected in, for example, equation (1) of MARAM/IWS/DEC14/Peng/B4:

$$\ln(F_{y,i}) = \alpha_y + \beta_i + \lambda_i \frac{C_{y,i,p}}{\bar{C}_{i,p}} + \varepsilon_{y,i} \qquad (1)$$

While in most instances F has been taken to be identical to p, for the active nest proportion response F was set equal to $p/(1–p)$ to maintain a potential unconstrained positive range for F, and for the foraging track related parameters $F = -p$ so that the sign of the λ fishing effect parameter maintains its same meaning throughout these analyses (positive/negative being favourable/unfavourable).
The following more important differences between the results in Appendix A compared to those in MARAM/IWS/DEC14/Peng/B4 are evident for Dassen and Robben Islands:

- For the fixed year effects model, there is a reduction in the excess of positive over negative estimates of λ, but across all the models the change is only by about 2% (Table A.3).
- For the some 16% of the λ estimates that are statistically significant at the 5% level, the proportion that are positive rises from about 80 to 85% (Table A.3).
- For the foraging path length response variable, the precision of the λ estimates deteriorates for the fixed year effects models, but improves for those using survey estimates of prey biomass (Figures A.5 and A.13 respectively). Generally speaking, there is little change for the other response variables.
- There is little change in the results for the power analyses, ***except*** that this drops substantially for the foraging path length and duration variables, which now are estimated to require in excess of 20 years to obtain statistically significant results unless significance has already been demonstrated (Table A.4).

For Bird and St Croix Islands:

- The proportion of positive λ estimates falls from about 50 to 40%, and two of the negative estimates for St Croix Island are now statistically significant at the 5% level (Table A.3).
- Estimates of the time required to obtain results significant at the 5% level remain in excess of 20 years except for the cases where such significance has already been demonstrated (Table A.5).

Responses to MARAM/IWS/DEC14/Peng/A3

For the reader's ease of reference, the material to which a specific response is offered is reproduced, with the quote in question shown in *red italics*, and with the key words on which the response is focused indicated by the use of yellow highlighting. Details of references in those quotations are listed only if necessary.

Data

The following data sets were originally identified by the ICTT as being potentially useful to assess the power of an experiment to determine analyses the impact of island closures: …….(5) maximum foraging distance away from the colony (km); ……. .

This response variable was not amongst those included in document MARAM/IWS/DEC14/Peng/C1 which details the data agreed and available for use in these analyses for presentation to the Panel. This is not to suggest that this variable may not contain useful information, but simply for noting that:

a) this is the reason why no results for this variable have been presented in MARAM/IWS/DEC14/Peng/B4 and the Appendices of this document; and
b) one would expect some "duplication" as these data would be expected to correlate positively with those on foraging path length, though naturally one would also expect non-independence amongst all the other response variables as well, if perhaps not to the same extent.

As the study progressed, it became clear that certain traits originally identified as being "potentially useful" might not be as useful as they first appeared; this was the case for the proportion of active nests to potential nests as well as breeding success (chicks fledged/pair/year or breeding attempt). The proportion of active to potential nests has been called into question as the penguin population has decreased. As African Penguin adult survival has declined (Sherley et al. 2014), it is likely that a greater proportion of birds surviving from year to year would be unable to reunite with their partner from the previous season. It would therefore become harder to distinguish between potential nest sites that represent failed breeding attempts and those that represent sites guarded by a bird unable to reunite with their former mate. These birds may later move and guard additional sites, adding a greater degree of subjectivity to the assessment of potential nests and raising questions over the comparability of this measure over time. Breeding success has not been used in this report as this integrates various components of reproduction (hatching success, chick survival and condition) through the whole season and each of these components may respond to different pressures.

Regarding proportion of active nests, the argument here to the effect that the absence of inclusion of penguin population size at the island as a covariate could bias results seems persuasive, though it is surprising that the point has been raised only at this stage rather than in July when the data sets to be used for this study were agreed. However, the rationale for excluding breeding success (*aka* fledging success) seems to be misguided when viewed in the light of the primary purpose of this exercise. What is important is to try to capture the accumulation of as many of the stages of reproduction as possible, as it is that combination which matters to population trends. Focus on individual components, though unavoidable in some instances, is problematic because observed effects may well be negatively correlated with ones that cannot be observed (for example for whales it is argued that the positive quantifiable impact of an (observable) reduction in the age at maturity may be confounded by a consequent negative impact on the (unobservable) juvenile survival. See also in particular paragraph a) on pg 3 of MARAM/IWS/DEC14/Peng/B2.

Time frame

The time frame of the data is also important. In the analyses that follow, only data from 2008 to 2013 are considered. This covers the time when the manipulation of fishing was in place. Analysing data prior to 2008 is an exploratory analysis rather than one that confirms predictions from an experiment or manipulation, and may result in spurious effects (Anderson et al. 2001). In addition, when analysing long time series relating to penguins and food availability, one needs to be mindful of two ecosystem regime shifts that have taken place in the southern Benguela, the first in the mid-1960s after the first collapse of sardine at the west coast, and the second in the early 2000s, which went along with the change in spatial distribution of small pelagics (Howard et al. 2007, Blamey et al. 2012). Therefore data from pre-2003 may not be directly comparable to data post-2003.

Restricting analyses to data for 2008+ reduces the contrast available to detect the effects of interest which is the primary aim of the whole closure study, so requires compelling motivation, particularly since this is the first time that this has been suggested (the point was not raised at the July meeting which finalised on the data to be used in these studies). Such motivation is not provided by appeal to the Anderson *et al.* reference quoted, which is primarily concerned with the adverse effects of pressures to publish. Those authors are concerned that this leads to the outputs from what amount to data dredging exercises being published, claiming the "discovery" of statistically significant results. The process concerned in this instance reflects neither the "fishing trips" nor undue model complexity which concern Anderson *et al*., as there are few explanatory variables under consideration (only catch/closure and fish abundance), and the hypothesis at issue (related to the extent and direction of the possible impact of fishing close to penguin breeding colonies on their reproductive success) is simple and was established *a priori*.

The fact that ecosystem effects may have occurred during the period for which penguin response variable values are available does not necessarily compromise the use of "pre-shift" data. No reasons are given as to why the shifts suggested might be expected to change the relationship of the impact of fishing on prey close to islands, and through that on penguin responses – the shift might, for example, change the distribution of the annual prey biomass, but that is already factored into all the various analyses that have been presented. Furthermore, if indeed ecosystem shifts have this effect, in circumstances where data over a considerable period are required to determine the fishing impact reliably anyway, the model to determine experimental power would need to be made more complex, both to simulate future ecosystem changes, and to use estimators that include methods such as STARS which seek to identify those changes. The authors of the quotation make no suggestions on how they propose to pursue that approach, which their logic implies to be a necessary part of the feasibility study.

The quantitative implications of restricting to data for 2008+ are presented and discussed further in the following section.

Results

The main aim was to determine the island-specific closure-effect, so the interaction term 'Island' × 'Closure' was included as fixed effect for all response variables. Closure was a categorical variable, as per the design in Table 1.

As mentioned in MARAM/IWS/DEC14/Peng/B13, the fundamental aim of the island closure exercise is not isolation of the closure effect *per se* (this is merely a device to maximise catch contrasts to improve estimation performance); rather it is to estimate the impact of catches close to the islands under investigation on penguin reproductive success. The problems associated with use of closure rather than catch as an explanatory variable are elaborated both in that document and in MARAM/IWS/DEC14/Peng/B10 under Item 16.

Suggesting that shortage of food contributed to the ongoing decline in the African Penguin population, we wanted to test whether penguins breeding on islands that are open to fisheries work harder to provision their brood than do those breeding at islands around which the fisheries are closed. Therefore we hypothesise that the foraging behaviour of breeding African Penguins at 'Closed' islands will respond to the increase in available prey in the surrounding waters and that this in turn will be reflected in a decrease of foraging trip duration, foraging trip range and total distance travelled.

Lesser catch will also increase the prey available, so that this does not constitute a reason to use closure rather than catch as the key covariate in analyses.

To be able to better compare and respond in regard to the consequences of the use of closure rather than catch in this way, as well to those of restricting data to 2008+ years only, together with the

different analysis approaches used in MARAM/IWS/DEC14/Peng/B4 and MARAM/IWS/DEC14/Peng/A3, the results of the former have been repeated here for three further cases:

i) Restriction of catch-based analyses to the years 2008+ only - Appendix B
ii) Replacement of catch by the categorical variable closed/open for all years – Appendix C
iii) Use of the closed/open covariate, but for the years 2008+ only – Appendix D.

Appendix B includes plots comparing estimates of the fishing effect parameter λ with those from Appendix A (i.e. 2008+ results with those for catches for all years). Appendix D shows plots which compare across all four approaches, where catch-based results refer to those for catches made with 10 nm of the island (the region from which fishing is excluded when the island is under closure). The results of Appendices C and D are produced treating catches in equations (1) and (2) of MARAM/IWS/DEC14/Peng/B4 as 0 (closed) or 1 (open), so that values of λ are comparable to those for the catch-based approaches (where they pertain to average catches in the absence of closure). In these circumstances, the fixed year effects model (method (i)) has insufficient information to estimate λ, and hence is excluded from the Tables in Appendices C and D. For those Appendices, the Tables collapse to fewer options as the distance from the island within which catches are considered is no longer relevant. However the "Fish" (species) column still retains relevance as that also pertains to the species to which the biomass series used in the equation (2) approach (methods (iii) and (iv)) applies.

Comparing the various results in these Appendices, the following is evident for Dassen and Robben Islands:

- When catch is the covariate, but the years taken into account are restricted to 2008+, the proportion of positive λ estimates drops from about 75 to 50%. Overall the proportion of results which are statistically significant at the 5% level drops by about 65%, though the proportion of these that are positive remains at about 85% (Table B.3). Power deteriorates for the fledging success response variable in particular (Table B.4).
- If closure replaces catch as the covariate, the proportion of results which are statistically significant at the 5% level drops, but the proportion of such significant results remains at about 30% for the random year effects model (Table C.3).
- For closure as the covariate, if only years from 2008 onwards are considered, changes in results are very similar to those under a similar change when catch is the covariate (Table D.3).
- With closure as the covariate, the power to detect significant effects not already demonstrated decreases substantially, with more than 20 years required in every case (Tables C.4 and D.4).

For the Bird and St Croix Islands (note that here, unlike the situation for the two west coast islands, restricting consideration to the years 2008+ results in the loss of proportionately much less data overall):

- With catch as the covariate, but restricting to the years 2008+, the proportion of positive λ estimates increases back to 50%, but now more are statistically significant at the 5% level (3 positive for Bird Island and 6 negative for St Croix) (Table B.3).
- When closure replaces catch as the covariate, the proportion of positive estimates of λ drops from 40% to 20%, but there is then only 1 (for St Croix) significant at the 5% level (Tables C.3 and D.3).
- Except for the foraging path length response variable with closure as the covariate, over 20 years is estimated to be required to detect significant effects not already demonstrated (Tables A.5, B.5, C.5 and D.5).

Table 1 compares estimates of the standard errors of λ under these different choices for periods of years and covariates. The general pattern (though there are minor exceptions) is clear:

- Appreciably more precise λ estimates result from the use of catch rather than closure as a covariate.
- For Robben and Dassen Islands there is a similar precision improvement from the use of catch data from all years rather than for 2008+ only, but this is not the case for Bird and St Croix Islands (no doubt for the reason given in the previous paragraph).

When such comparisons are made of a response variable basis through inspection of the comparisons in Figures D.1 to D.8, it is evident that:

- For catch as the covariate, using all years rather than 2008+ only results in an appreciable improvement in precision of estimates of λ for all except the fledging success and chick growth response variables.
- Precision improvements in λ estimates are evident for every variable when using catch rather than closure as a covariate.
- When closure is used as a covariate, there are a number of cases where the precision of λ estimates ***decreases*** when the longer time series of data is used. A possible reason for this is that the model is handicapped by having to assign the same effect size across an increasingly wide range of catches (see Figure 1 of MARAM/IWS/DEC14/Peng/B13).

For the foraging response variables, the effect of fishing in MARAM/IWS/DEC14/Peng/A3 is evaluated on the same structural basis as in this document. This enables a direct comparison of results across the two approaches, which is reported in Table 2. The closest approach comparisons available in this Table as those for closure as the response variable, and for the years 2008+. In seven of these eight comparisons, the simpler approach of this document achieves better precision than does the more complex approach of MARAM/IWS/DEC14/Peng/A3.

In summary then:

- The assertion in documents MARAM/IWS/DEC14/Peng/A1 and Peng/A2 that the restriction of the analyses of feasibility study to consideration of annual means for response variable values compromises their results does not stand scrutiny under a direct comparison with results from the more complex and data-intensive estimator a number of the authors of those papers put forward in MARAM/IWS/DEC14/Peng/A3. Probably for the reasons offered in MARAM/IWS/DEC14/Peng/B13, the Peng/A3 approach generally results in estimates of the fishing effect parameter that are less precise.
- Use of closure rather than catch as the covariate generally results in poorer precision and fewer statistically significant estimates of λ.
- When using catch as the covariate, appreciably better precision is generally achieved by including all years in the analyses, rather than restricting analyses to the period from 2008 onwards. In particular, it is the addition of these earlier data which switches an approximately 50:50 mixture of positive: negative λ estimates to a 75:25 preponderance.

The positive effect of closures on the foraging behaviour of African Penguins has been shown in this study (Table 2) and supports previous evidence of benefits from fishing closures to penguins (Sherley et al. submitted, summarised in Annex 4, Pichegru et al. 2010, 2012). ..... The study period for 'Closure' has been too short to allow experimental power to be estimated for all the traits proposed and thus to produce clear-cut results.

While the p-values in this Table 2 for results for Bird and St Croix Islands are generally fairly low, though none are significant at the 5% level, this is not the case for Robben and Dassen Islands where they generally rather high, and the positive/negative estimates for the effective of fishing split 3/7.

Thus these results do not reflect strong evidence for a positive effect of closures on these west coast penguin colonies.

It is unclear why the period of closures is said to be too short to estimate experimental power, as that is done with results reported in Appendix D for the GLM approach of this document for the equivalent situation to that considered in MARAM/IWS/DEC14/Peng/A3. Admittedly the simulations required when using the estimator of MARAM/IWS/DEC14/Peng/A3 would be complex. Nevertheless the primary aim of the feasibility study itself is to assess how long an experiment would need to continue to provide reliable results. Document MARAM/IWS/DEC14/Peng/A3 fails to report the variance estimates needed for input to such a power analysis, and further offers no specification of the simulation studies necessary to carry out a power analysis for the estimators which it proposes. Thus it has failed to address to key first step in this overall process.

Conclusion

In conclusion, this study confirms that fishing closures can benefit African Penguins, thereby contributing to securing the objectives of the Biodiversity Management Plan for the African Penguin (BMP-AP). Combining fishing closures around islands with a suite of other management actions described in the BMP-AP currently implemented will achieve the objectives of halting penguin decline and subsequently increasing their numbers.

As per the comments immediately above, the study has produced some suggestive evidence for the Eastern Cape colonies only. Further it has failed to address the primary aim of the feasibility study itself to ascertain how long an experimental closures programme would need to continue for reliable determination of the impact of fishing in the near vicinity of island colonies on penguin reproductive success.

Table 1: A comparison of average standard error estimates for λ across response variables for different estimation models and choices for the years to be taken into account. Catch-based results relate to catches within 10 nm of the island concerned.

a) Dassen Island

	(i) Fixed year effects	(ii) Random gear effects	(iii) Spawner biomass	(iv) Recruit Biomass
All years – catch	0.35	0.17	0.21	0.20
2008+ - catch	0.71	0.25	0.26	0.28
All years – closure	-	0.27	0.32	0.32
2008+ - closure	-	0.30	0.29	0.33

b) Robben Island

	(i) Fixed year effects	(ii) Random gear effects	(iii) Spawner biomass	(iv) Recruit Biomass
All years – catch	0.34	0.16	0.20	0.18
2008+ - catch	0.64	0.24	0.24	0.29
All years – closure	-	0.27	0.35	0.33
2008+ - closure	-	0.30	0.32	0.37

c) Bird Island

	(i) Fixed year effects	(ii) Random gear effects	(iii) Spawner biomass	(iv) Recruit Biomass
All years – catch	0.17	0.08	0.08	0.09
2008+ - catch	0.12	0.08	0.08	0.08
All years – closure	-	0.12	0.14	0.17
2008+ - closure	-	0.12	0.16	0.17

d) St Croix

	(i) Fixed year effects	(ii) Random gear effects	(iii) Spawner biomass	(iv) Recruit Biomass
All years – catch	0.17	0.11	0.13	0.12
2008+ - catch	0.17	0.11	0.13	0.11
All years – closure	-	0.11	0.14	0.17
2008+ - closure	-	0.12	0.15	0.17

Table 2: Comparisons of estimates with standard errors (in parentheses) for the fishing effect parameter λ for foraging related response variables for which the data have been analysed in ways which provide comparable measures of λ. For the method of MARAM/IWS/DEC14/Peng/A3, standard error estimates have been calculated as 25% of the 95% CI range given in Table 2 of that paper. For the MARAM/IWS/DEC14/Peng/B12 method, results are for the random effects model and correspond to the catch of anchovy and sardine combined for Robben and for Dassen Island, or sardine for Bird and for St Croix Island, and a 10 nm distance from the island concerned where either is respectively pertinent.

a) Dassen Island

Method	Data	Foraging path length	Foraging trip duration
Peng/B12	All years – catch	0.17 (0.24)	0.41 (0.14)
	2008+ catch	0.04 (0.19)	0.35 (0.17)
	All years – closure	0.19 (0.29)	0.45 (0.19)
	2008+ - closure	-0.04 (0.22)	0.38 (0.20)
Peng/A3	2008+ - closure	0.09 (0.28)	0.44 (0.39)

b) Robben Island

Method	Data	Foraging path length	Foraging trip duration
Peng/B12	All years – catch	0.26 (0.24)	0.18 (0.14)
	2008+ catch	0.11 (0.18)	0.07 (0.16)
	All years – closure	0.16 (0.28)	0.07 (0.19)
	2008+ - closure	0.12 (0.23)	-0.03 (0.21)
Peng/A3	2008+ - closure	-0.15 (0.20)	-0.07 (0.25)

c) Bird Island

Method	Data	Foraging path length	Foraging trip duration
Peng/B12	All years – catch	0.01 (0.08)	-0.03 (0.08)
	2008+ catch	0.12 (0.07)	0.01 (0.08)
	All years – closure	0.05 (0.08)	-0.17 (0.15)
	2008+ - closure	0.06 (0.08)	-0.16 (0.16)
Peng/A3	2008+ - closure	-0.10 (0.12)	-0.29 (0.18)

d) St Croix

Method	Data	Foraging path length	Foraging trip duration
Peng/B12	All years – catch	-0.21 (0.10)	-0.13 (0.11)
	2008+ catch	-0.26 (0.10)	-0.13 (0.12)
	All years – closure	-0.39 (0.08)	-0.19 (0.14)
	2008+ - closure	-0.39 (0.08)	-0.20 (0.15)
Peng/A3	2008+ - closure	-0.26 (0.10)	-0.03 (0.19)

Appendix A

Comparison of results for updated data with those for previous data

Table A.1: Residual standard error σ_ε and upper 95% confidence limits $\sigma_{\varepsilon,+95}$ (estimated using a likelihood profile approach) for each penguin response series available for assessing the power of the island closure experiment are listed for the random year effects model for the **updated datasets**. Note that MLE estimates are negatively biased because of the small number of degrees of freedom, but these estimates are unbiased through use of REML. The number of past data points n and the number of model parameters estimated p are indicated for the model. Results are given for the case of total catch within 30 nmi for the Western Cape and sardine catch within 30 nmi for the Eastern Cape.

(a) Dassen and Robben islands

Penguin response	n	p	σ_ε	$\sigma_{\varepsilon,+95}$
Chick condition	11	5	0.212	0.330
Active nest proportion	27	5	0.411	0.541
Fledging success	32	6	0.083	0.107
Chick growth	14	5	0.049	0.072
Foraging path length	14	5	0.281	0.415
Foraging trip duration	14	5	0.205	0.302

(b) St Croix and Bird islands

Penguin response	n	p	σ_ε	$\sigma_{\varepsilon,+95}$
Foraging path length	13	5	0.106	0.158
Foraging trip duration	13	5	0.128	0.191

Table A.2: Fishing effect parameters λ with associated standard errors for (i) fixed year effects, (ii) random year effects, (iii) year effects given by spawner biomass, and (iv) year effects given by recruit biomass for the **updated datasets**. Values significantly different from zero at the 15% and 5% levels are indicated by one and two asterisks respectively. Statistical significance is based on a normal approximation for the random effects model and a two-sided t-test for the other models. Cases where the correlation between the catch and the (recruit or spawning) biomass exceeds $r = 0.7$ are indicated by a †. Some results are left blank in cases where there are no degrees of freedom.

(a) Dassen Island

Penguin response	Fish	Area	λ				s.e			
			(i)	(ii)	(iii)	(iv)	(i)	(ii)	(iii)	(iv)
Chick condition	Sardine	10 nmi	0.10	-0.03	-0.07 †	-0.01	0.26	0.19	0.18	0.22
		20 nmi	0.28	0.07	-0.02	0.07	0.37	0.25	0.25	0.30
		30 nmi	0.42	0.17	0.02	0.08	0.34	0.21	0.24	0.26
	Anchovy	10 nmi	-0.67 *	-0.22 *	0.01	0.01	0.17	0.20	0.23	0.22
		20 nmi	-0.36	-0.15	0.06	0.06	0.23	0.23	0.29	0.27
		30 nmi	-0.97	0.10	0.11	0.13	0.89	0.29	0.33	0.32
	Total	10 nmi	-0.80 *	-0.14	0.03	0.00	0.23	0.22	0.23	0.23
		20 nmi	-0.37	-0.04	0.12	0.07	0.30	0.28	0.31	0.31
		30 nmi	-0.39	0.16	0.25	0.18	1.12	0.37	0.39	0.40
Active nest proportion	Sardine	10 nmi	0.97 *	0.54**	0.29	0.41 *	0.58	0.27	0.31	0.26
		20 nmi	1.39	0.79**	0.66 **	0.68**	1.01	0.27	0.31	0.27
		30 nmi	0.88	0.86**	0.80 **	0.77**	1.14	0.29	0.34	0.30
	Anchovy	10 nmi	0.15	0.15	0.04	0.38	0.38	0.35	0.60	0.47
		20 nmi	0.10	0.23	0.77	0.85	0.42	0.41	0.75	0.58
		30 nmi	0.59	0.59	0.93	0.89	0.91	0.81	1.11	0.88
	Total	10 nmi	0.26	0.31	0.31	0.47	0.37	0.35	0.61	0.47
		20 nmi	0.54	0.90**	1.44 **	1.12**	0.47	0.44	0.65	0.51
		30 nmi	1.11	1.72**	2.06 **	1.50**	0.93	0.69	0.82	0.68
Fledging success	Sardine	10 nmi	0.30**	0.07	0.10 †	0.09	0.09	0.11	0.14	0.13
		20 nmi	0.23	0.09	0.13 †	0.09	0.17	0.12	0.16	0.15
		30 nmi	0.48	0.04	0.19 †	0.13	0.45	0.15	0.20	0.18
	Anchovy	10 nmi	0.13	0.10 *	0.04	0.00	0.09	0.08	0.12	0.14
		20 nmi	0.15	0.12 *	-0.01	-0.04	0.10	0.10	0.14	0.17
		30 nmi	0.37**	0.17 *	0.02	-0.07	0.14	0.11	0.14	0.17
	Total	10 nmi	0.16	0.17 *	0.10	0.05	0.12	0.11	0.14	0.17
		20 nmi	0.24	0.20 *	0.09	0.05	0.15	0.13	0.18	0.21
		30 nmi	0.51 *	0.22 *	0.17	0.08	0.25	0.19	0.24	0.29
Chick growth	Sardine	10 nmi	-	0.11**	0.08	0.10	-	0.06	0.06	0.07
		20 nmi	-	0.15**	0.11 †	0.15 *	-	0.06	0.08	0.07
		30 nmi	-	0.20**	0.23**†	0.20**	-	0.06	0.10	0.07
	Anchovy	10 nmi	-	-0.06	-0.03	-0.05	-	0.07	0.08	0.07
		20 nmi	-	-0.18**	-0.11	-0.15 *	-	0.07	0.10	0.08
		30 nmi	-	-0.17**	-0.15 *	-0.15**	-	0.06	0.08	0.06
	Total	10 nmi	-	0.00	0.01	0.01	-	0.10	0.11	0.11
		20 nmi	-	0.02	0.07	0.02	-	0.16	0.17	0.17
		30 nmi	-	-0.23 *	-0.12	-0.14	-	0.20	0.22	0.21
Foraging path length	Sardine	10 nmi	-0.24	0.09	-0.10	0.09	0.70	0.10	0.10	0.11
		20 nmi	-0.80	0.08	-0.13	0.07	0.75	0.13	0.11	0.13
		30 nmi	-0.63	0.08	-0.12	0.08	0.87	0.12	0.11	0.13
	Anchovy	10 nmi	-0.07	0.03	0.13	0.09	0.43	0.25	0.26	0.27
		20 nmi	-0.27	0.26	0.27	0.24	0.33	0.26	0.26	0.26
		30 nmi	-0.74	0.07	0.15	0.16	0.75	0.27	0.26	0.27
	Total	10 nmi	0.02	0.17	0.11	0.15	0.34	0.24	0.24	0.25
		20 nmi	-0.21	0.25 *	0.17	0.23	0.41	0.23	0.24	0.24
		30 nmi	-0.76	0.17	0.09	0.18	1.09	0.23	0.23	0.23
Foraging trip duration	Sardine	10 nmi	0.31	0.12**	0.08	0.12 *	0.79	0.07	0.10	0.07
		20 nmi	-0.55	0.12 *	0.07	0.12	0.95	0.09	0.11	0.09
		30 nmi	-0.66	0.12 *	0.06	0.12	1.00	0.09	0.11	0.09
	Anchovy	10 nmi	0.07	0.37**	0.39 **	0.36 *	0.42	0.16	0.16	0.17
		20 nmi	-0.04	0.18	0.24	0.22	0.33	0.19	0.20	0.20
		30 nmi	-0.17	-0.05	-0.03	-0.02	0.85	0.20	0.21	0.20
	Total	10 nmi	0.24	0.41**	0.40 **	0.41**	0.33	0.14	0.15	0.15
		20 nmi	0.13	0.26 *	0.24	0.26	0.44	0.17	0.19	0.18
		30 nmi	0.03	0.10	0.07	0.11	1.32	0.17	0.19	0.18

Table A.2: Continued.

(b) Robben Island

Penguin response	Fish	Area	λ				s.e.			
			(i)	(ii)	(iii)	(iv)	(i)	(ii)	(iii)	(iv)
Chick condition	Sardine	10 nmi	-0.11	0.16	-0.04	0.17	0.33	0.17	0.22	0.20
		20 nmi	0.12	0.26	-0.01	0.34	0.48	0.28	0.34	0.33
		30 nmi	0.49	0.37**	0.16 †	0.38	0.60	0.22	0.48	0.24
	Anchovy	10 nmi	0.34 *	-0.02	-0.12	-0.13	0.15	0.17	0.19	0.20
		20 nmi	-0.05	-0.08	-0.06	-0.08	0.21	0.21	0.25	0.28
		30 nmi	-0.61	0.17	0.18	0.23	0.79	0.25	0.27	0.30
	Total	10 nmi	0.44 *	-0.07	-0.14	-0.12	0.18	0.18	0.19	0.19
		20 nmi	-0.04	-0.08	-0.07	-0.07	0.26	0.24	0.26	0.29
		30 nmi	-0.04	0.29	0.34	0.34	0.90	0.29	0.30	0.33
Active nest proportion	Sardine	10 nmi	0.71 *	0.41**	0.16	0.28 *	0.35	0.17	0.19	0.17
		20 nmi	0.84	0.44**	0.25	0.29 *	0.55	0.18	0.22	0.20
		30 nmi	0.70	0.57**	0.38	0.39 *	0.83	0.24	0.29	0.25
	Anchovy	10 nmi	1.02**	0.98**	0.69	0.66 *	0.32	0.29	0.50	0.38
		20 nmi	1.44**	1.37**	1.10 *	1.00**	0.33	0.32	0.60	0.46
		30 nmi	1.41**	1.20**	0.67	0.70	0.63	0.56	0.78	0.61
	Total	10 nmi	1.05**	1.01**	0.73 *	0.92**	0.28	0.27	0.48	0.36
		20 nmi	1.39**	1.40**	1.25**	1.32**	0.35	0.34	0.54	0.41
		30 nmi	1.86**	1.89**	1.29 *	1.43**	0.75	0.59	0.73	0.58
Fledging success	Sardine	10 nmi	0.59**	-0.14**	-0.14**	-0.15**	0.15	0.04	0.05	0.04
		20 nmi	0.27	-0.17**	-0.17**	-0.19**	0.20	0.06	0.07	0.06
		30 nmi	0.30	-0.16**	-0.15 *	-0.19**	0.33	0.07	0.09	0.07
	Anchovy	10 nmi	-0.10	-0.07	-0.03	-0.07	0.10	0.08	0.09	0.10
		20 nmi	0.03	0.01	0.03	-0.03	0.12	0.09	0.11	0.12
		30 nmi	0.37 *	0.14 *	0.08	0.07	0.19	0.13	0.13	0.14
	Total	10 nmi	-0.09	-0.13 *	-0.09	-0.14	0.11	0.08	0.09	0.10
		20 nmi	0.04	-0.10	-0.08	-0.20	0.14	0.11	0.13	0.14
		30 nmi	0.36	-0.06	-0.03	-0.19	0.26	0.16	0.17	0.18
Chick growth	Sardine	10 nmi	-	0.17**	0.07 †	0.18 *	-	0.09	0.14	0.10
		20 nmi	-	0.27**	0.08 †	0.28 *	-	0.16	0.33	0.17
		30 nmi	-	0.23**	0.32 †	0.23 *	-	0.10	0.26	0.11
	Anchovy	10 nmi	-	0.05	0.05 †	0.07 †	-	0.13	0.16	0.15
		20 nmi	-	0.06	0.04	0.14 †	-	0.09	0.17	0.16
		30 nmi	-	-0.04	-0.00	0.08 †	-	0.12	0.15	0.15
	Total	10 nmi	-	0.02	-0.01	0.04 †	-	0.14	0.17	0.16
		20 nmi	-	0.06	0.02	0.09 †	-	0.16	0.19	0.20
		30 nmi	-	0.00	0.05	0.13 †	-	0.18	0.22	0.22
Foraging path length	Sardine	10 nmi	-0.33	0.16 *	-0.12 †	0.15	0.92	0.14	0.13	0.14
		20 nmi	-0.91	0.18 *	-0.12 †	0.17	0.86	0.15	0.14	0.16
		30 nmi	-0.82	0.21 *	-0.13 †	0.19	1.15	0.17	0.16	0.18
	Anchovy	10 nmi	0.14	0.17	0.17	0.25	0.35	0.24	0.26	0.27
		20 nmi	0.17	0.37 *	0.33	0.44	0.30	0.28	0.29	0.30
		30 nmi	-0.45	0.50 *	0.53 *	0.61 *	0.91	0.33	0.33	0.34
	Total	10 nmi	0.08	0.26 *	0.13	0.28	0.28	0.24	0.25	0.25
		20 nmi	0.08	0.43 *	0.31	0.47 *	0.40	0.27	0.28	0.28
		30 nmi	-0.65	0.63**	0.51 *	0.67 *	1.45	0.31	0.32	0.32
Foraging trip duration	Sardine	10 nmi	0.36	0.12 *	0.07 †	0.12	1.04	0.10	0.13	0.10
		20 nmi	-0.66	0.13 *	0.05 †	0.13	1.09	0.11	0.14	0.12
		30 nmi	-0.90	0.15 *	0.05 †	0.14	1.32	0.12	0.16	0.13
	Anchovy	10 nmi	0.27	0.15	0.12	0.16	0.34	0.15	0.16	0.17
		20 nmi	0.45	0.32 *	0.25	0.31	0.30	0.20	0.22	0.23
		30 nmi	0.36	0.44**	0.41 *	0.46 *	1.04	0.24	0.26	0.26
	Total	10 nmi	0.20	0.18 *	0.15	0.19	0.27	0.14	0.15	0.14
		20 nmi	0.43	0.31 *	0.28	0.33 *	0.43	0.20	0.22	0.21
		30 nmi	0.43	0.48**	0.43 *	0.49 *	1.75	0.24	0.26	0.25

Table A.2: Continued.

(c) Bird Island

Penguin response	Fish	Area	λ				s.e.			
			(i)	(ii)	(iii)	(iv)	(i)	(ii)	(iii)	(iv)
Foraging path length	Sardine	10 nmi	0.01	0.01	0.03	0.01	0.15	0.08	0.07	0.09
		20 nmi	0.22	0.05	0.04	0.04	0.23	0.11	0.09	0.11
		30 nmi	0.04	0.03	0.07	0.08	0.22	0.13	0.11	0.15
Foraging trip duration	Sardine	10 nmi	-0.06	-0.03	-0.01	-0.05	0.19	0.08	0.08	0.08
		20 nmi	0.32	0.01	-0.00	-0.01	0.25	0.10	0.11	0.10
		30 nmi	0.03	0.02	0.03	0.02	0.24	0.12	0.12	0.12

(d) St Croix Island

Penguin response	Fish	Area	λ				s.e.			
			(i)	(ii)	(iii)	(iv)	(i)	(ii)	(iii)	(iv)
Foraging path length	Sardine	10 nmi	-0.16	-0.21**	-0.12†	-0.27*	0.15	0.10	0.11	0.12
		20 nmi	-0.27	-0.27**	-0.17†	-0.32*	0.20	0.13	0.13	0.15
		30 nmi	-0.37	-0.47 *	-0.10†	-0.57	0.44	0.34	0.35	0.43
Foraging trip duration	Sardine	10 nmi	-0.16	-0.13 *	-0.04†	-0.14	0.19	0.11	0.14	0.11
		20 nmi	-0.43*	-0.20 *	-0.12†	-0.18	0.21	0.13	0.16	0.13
		30 nmi	-0.67	-0.52 *	-0.31†	-0.42	0.49	0.33	0.40	0.35

Table A.3: Tallies of positive and negative values of λ, those significantly different from zero at the 15% level, and those significantly different from zero at the 5% level for the **updated datasets**. "Both no †" tallies omit instances where the catch-biomass correlation exceeds $r = 0.7$.

(a) Western Cape

		Fixed year effects			Random year effects			Spawner Biomass			Recruit Biomass		
		all	15%	5%	all	15%	5%	all	15%	5%	all	15%	5%
Chick condition	Dassen	3:6	0:2	0:0	4:5	0:1	0:0	7:2	0:0	0:0	8:1	0:0	0:0
	Robben	4:5	2:0	0:0	5:4	1:0	1:0	3:6	0:0	0:0	5:4	0:0	0:0
Active nest proportion	Dassen	9:0	1:0	0:0	9:0	5:0	5:0	9:0	4:0	4:0	9:0	5:0	4:0
	Robben	9:0	7:0	6:0	9:0	9:0	9:0	9:0	4:0	1:0	9:0	8:0	4:0
Fledging success	Dassen	9:0	3:0	2:0	9:0	6:0	0:0	8:1	0:0	0:0	7:2	0:0	0:0
	Robben	7:2	2:0	1:0	2:7	1:4	0:3	2:7	0:3	0:2	1:8	0:3	0:3
Chick growth	Dassen				5:4	3:3	3:2	5:4	1:1	1:0	5:4	2:2	1:1
	Robben				8:1	3:0	3:0	7:2	0:0	0:0	9:0	3:0	0:0
Foraging path length	Dassen	1:8	0:0	0:0	9:0	1:0	0:0	6:3	0:0	0:0	9:0	0:0	0:0
	Robben	4:5	0:0	0:0	9:0	8:0	1:0	6:3	2:0	0:0	9:0	3:0	0:0
Foraging trip duration	Dassen	5:4	0:0	0:0	8:1	6:0	3:0	8:1	2:0	2:0	8:1	3:0	1:0
	Robben	7:2	0:0	0:0	9:0	8:0	2:0	9:0	2:0	0:0	9:0	3:0	0:0
Total	Dassen	27:18	4:2	2:0	44:10	21:4	11:2	43:11	7:1	7:0	46:8	10:2	6:1
	Robben	31:14	11:0	7:0	42:12	30:4	16:3	36:18	8:3	1:2	42:12	17:3	4:3
	Both	58:32	15:2	9:0	86:22	51:8	27:5	79:29	15:4	8:2	88:20	27:5	10:4
	Both no †							66:25	14:4	7:2	82:20	27:5	10:4

(b) Eastern Cape

		Fixed year effects			Random year effects			Spawner Biomass			Recruit Biomass		
		all	15%	5%	all	15%	5%	all	15%	5%	all	15%	5%
Foraging path length	Bird	3:0	0:0	0:0	3:0	0:0	0:0	3:0	0:0	0:0	3:0	0:0	0:0
	St Croix	0:3	0:0	0:0	0:3	0:3	0:2	0:3	0:0	0:0	0:3	0:2	0:0
Foraging trip duration	Bird	2:1	0:0	0:0	2:1	0:0	0:0	1:2	0:0	0:0	1:2	0:0	0:0
	St Croix	0:3	0:1	0:0	0:3	0:3	0:0	0:3	0:0	0:0	0:3	0:0	0:0
Total	Bird	5:1	0:0	0:0	5:1	0:0	0:0	4:2	0:0	0:0	4:2	0:0	0:0
	St Croix	0:6	0:1	0:0	0:6	0:6	0:2	0:6	0:0	0:0	0:6	0:2	0:0
	Both	5:7	0:1	0:0	5:7	0:6	0:2	4:8	0:0	0:0	4:8	0:2	0:0
	Both no †							4:2	0:0	0:0			

Table A.4: The number of additional years' data required to detect a fishing effect significant at the 5% level with **95%** probability is given for each of Dassen and Robben islands for the **updated datasets**, where the true values of λ are assumed to be the random effects model-estimates. If a model-estimated λ value is small (i.e. $|\lambda| < 0.1$) then $\lambda = \pm 0.1$ is assumed for the effect size, where the sign is chosen according to the sign of the model-estimate for λ. A value of 0 indicates that the existing estimate of λ is already significant at the 5% level. C/O indicates future alternating periods of three years of the area being closed and open to fishing; O indicates the area is always open in the future.

			Dassen		Robben	
Response	Fish	Area	C/O	O	C/O	O
Chick condition	Sardine	10 nmi	> 20	> 20	> 20	> 20
		20 nmi	-	> 20	-	> 20
		30 nmi	-	> 20	-	0
	Anchovy	10 nmi	15	> 20	> 20	> 20
		20 nmi	-	> 20	-	> 20
		30 nmi	-	> 20	-	> 20
	Total	10 nmi	> 20	> 20	> 20	> 20
		20 nmi	-	> 20	-	> 20
		30 nmi	-	> 20	-	> 20
Active nest proportion	Sardine	10 nmi	0	0	0	0
		20 nmi	-	0	-	0
		30 nmi	-	0	-	0
	Anchovy	10 nmi	> 20	> 20	0	0
		20 nmi	-	> 20	-	0
		30 nmi	-	> 20	-	0
	Total	10 nmi	> 20	> 20	0	0
		20 nmi	-	0	-	0
		30 nmi	-	0	-	0
Fledging success	Sardine	10 nmi	> 20	> 20	0	0
		20 nmi	-	> 20	-	0
		30 nmi	-	> 20	-	0
	Anchovy	10 nmi	16	13	> 20	> 20
		20 nmi	-	18	-	> 20
		30 nmi	-	4	-	17
	Total	10 nmi	14	10	> 20	> 20
		20 nmi	-	10	-	> 20
		30 nmi	-	> 20	-	> 20
Chick growth	Sardine	10 nmi	0	0	0	0
		20 nmi	-	0	-	0
		30 nmi	-	0	-	0
	Anchovy	10 nmi	1	> 20	1	> 20
		20 nmi	-	0	-	12
		30 nmi	-	0	-	> 20
	Total	10 nmi	1	> 20	1	> 20
		20 nmi	-	> 20	-	> 20
		30 nmi	-	> 20	-	> 20
Foraging path length	Sardine	10 nmi	> 20	> 20	> 20	> 20
		20 nmi	-	> 20	-	> 20
		30 nmi	-	> 20	-	> 20
	Anchovy	10 nmi	> 20	> 20	> 20	> 20
		20 nmi	-	> 20	-	> 20
		30 nmi	-	> 20	-	13
	Total	10 nmi	> 20	> 20	> 20	> 20
		20 nmi	-	> 20	-	20
		30 nmi	-	> 20	-	0
Foraging trip duration	Sardine	10 nmi	0	0	> 20	> 20
		20 nmi	-	> 20	-	> 20
		30 nmi	-	> 20	-	> 20
	Anchovy	10 nmi	0	0	> 20	> 20
		20 nmi	-	> 20	-	20
		30 nmi	-	> 20	-	0
	Total	10 nmi	0	0	> 20	> 20
		20 nmi	-	> 20	-	19
		30 nmi	-	> 20	-	0

Table A.5: The number of additional years' data required to detect a fishing effect significant at the 5% level with **95%** probability is given for each of Bird and StCroix islands for the **updated datasets**, where the true values of λ are assumed to be the random effects model-estimates. If a model-estimated λ value is small (i.e. $|\lambda| < 0.1$) then $\lambda = \pm 0.1$ is assumed for the effect size, where the sign is chosen according to the sign of the model-estimate for λ. A value of 0 indicates that the existing estimate of λ is already significant at the 5% level. C/O indicates future alternating periods of three years of the area being closed and open to fishing; O indicates the area is always open in the future.

			Bird		StCroix	
Response	Fish	Area	C/O	O	C/O	O
Foraging path length	Sardine	10 nmi	> 20	> 20	0	0
		20 nmi	-	> 20	-	0
		30 nmi	-	> 20	-	19
Foraging trip duration	Sardine	10 nmi	> 20	> 20	> 20	> 20
		20 nmi	-	> 20	-	> 20
		30 nmi	-	> 20	-	> 20

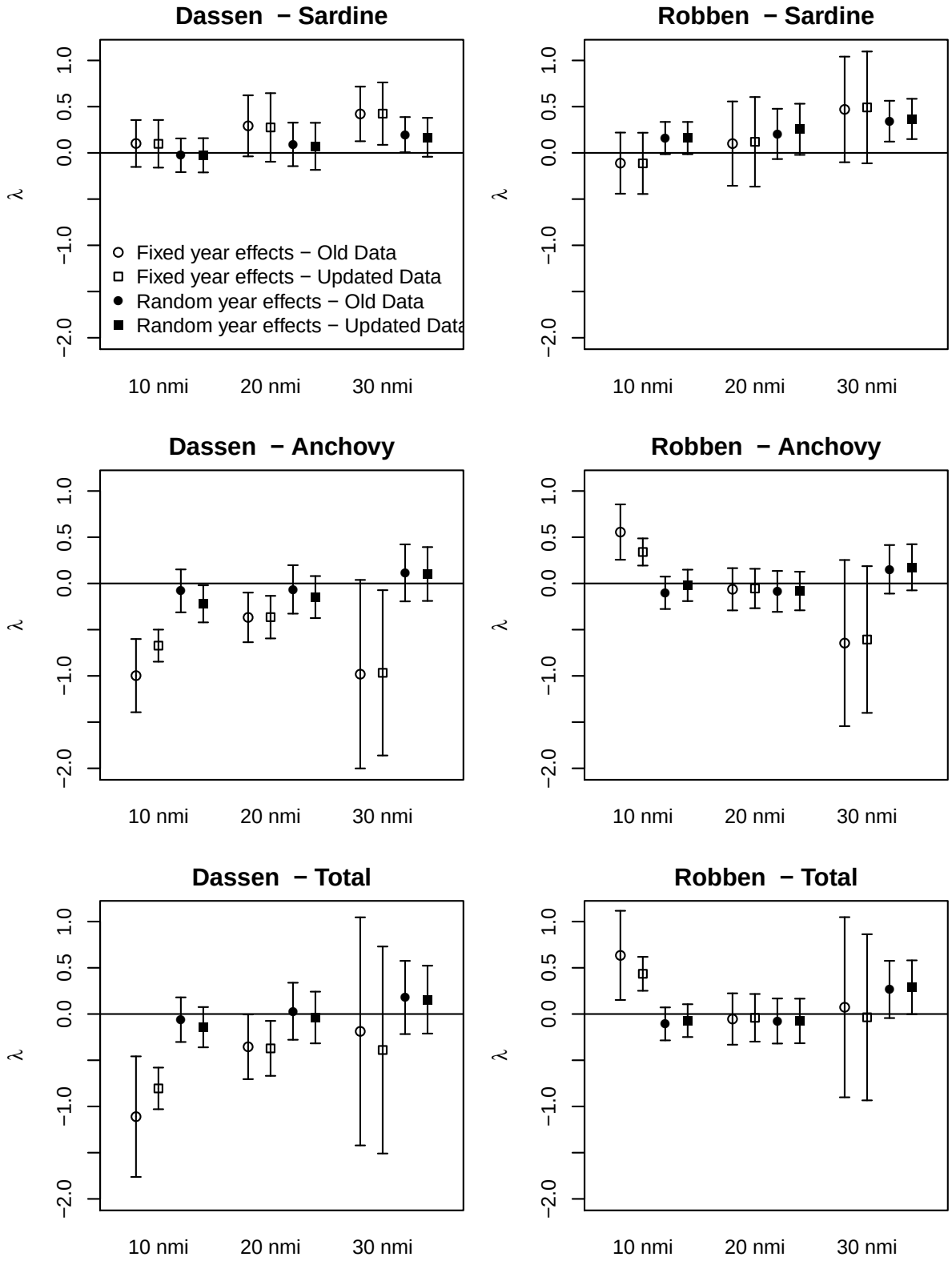

Figure A.1: Dassen and Robben Islands fishing effect parameter estimates: for the **chick condition** response variable. Bars indicate one standard error.

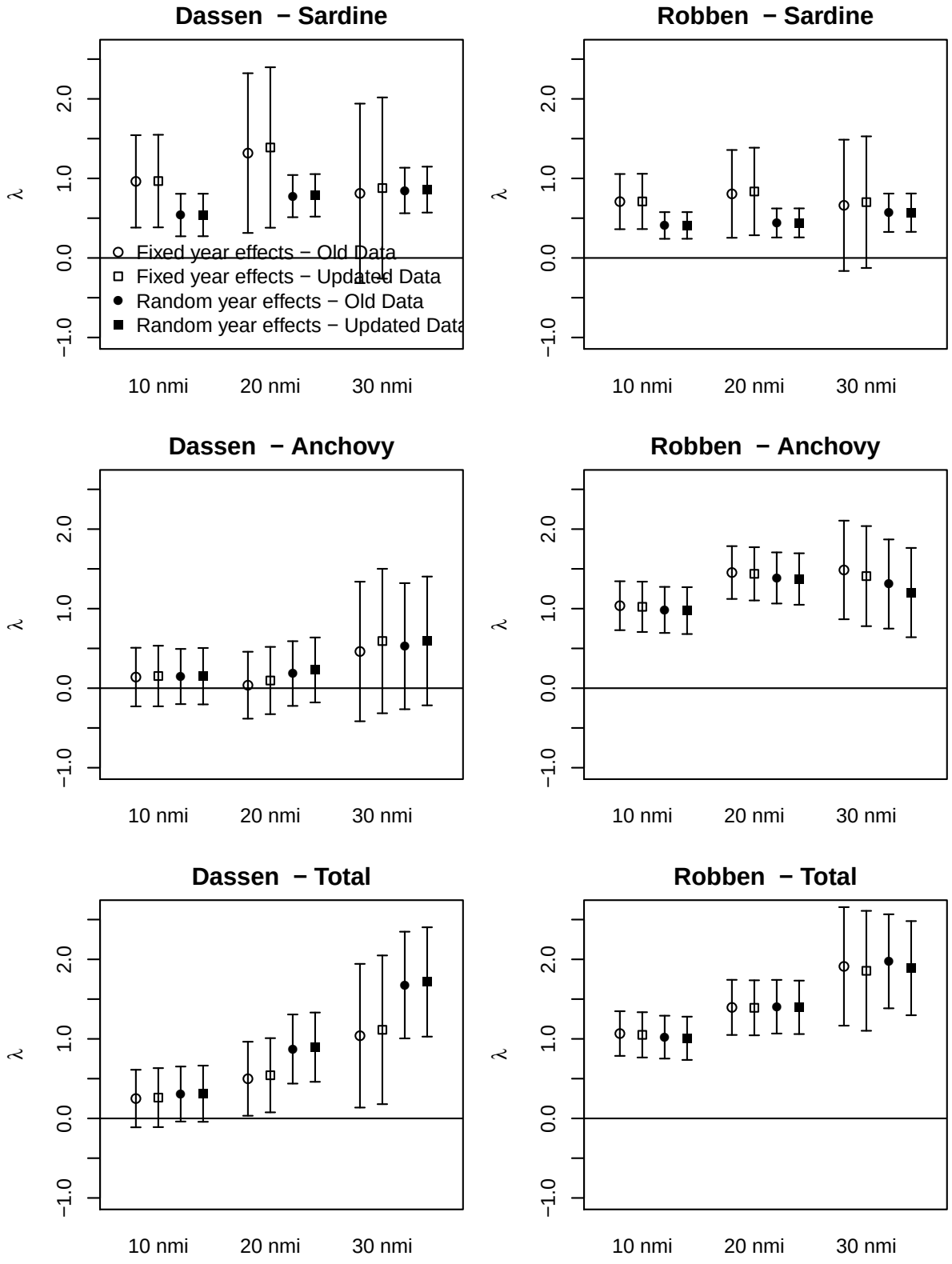

Figure A.2: Dassen and Robben Islands fishing effect parameter estimates: for the **active nest proportion** response variable. Bars indicate one standard error.

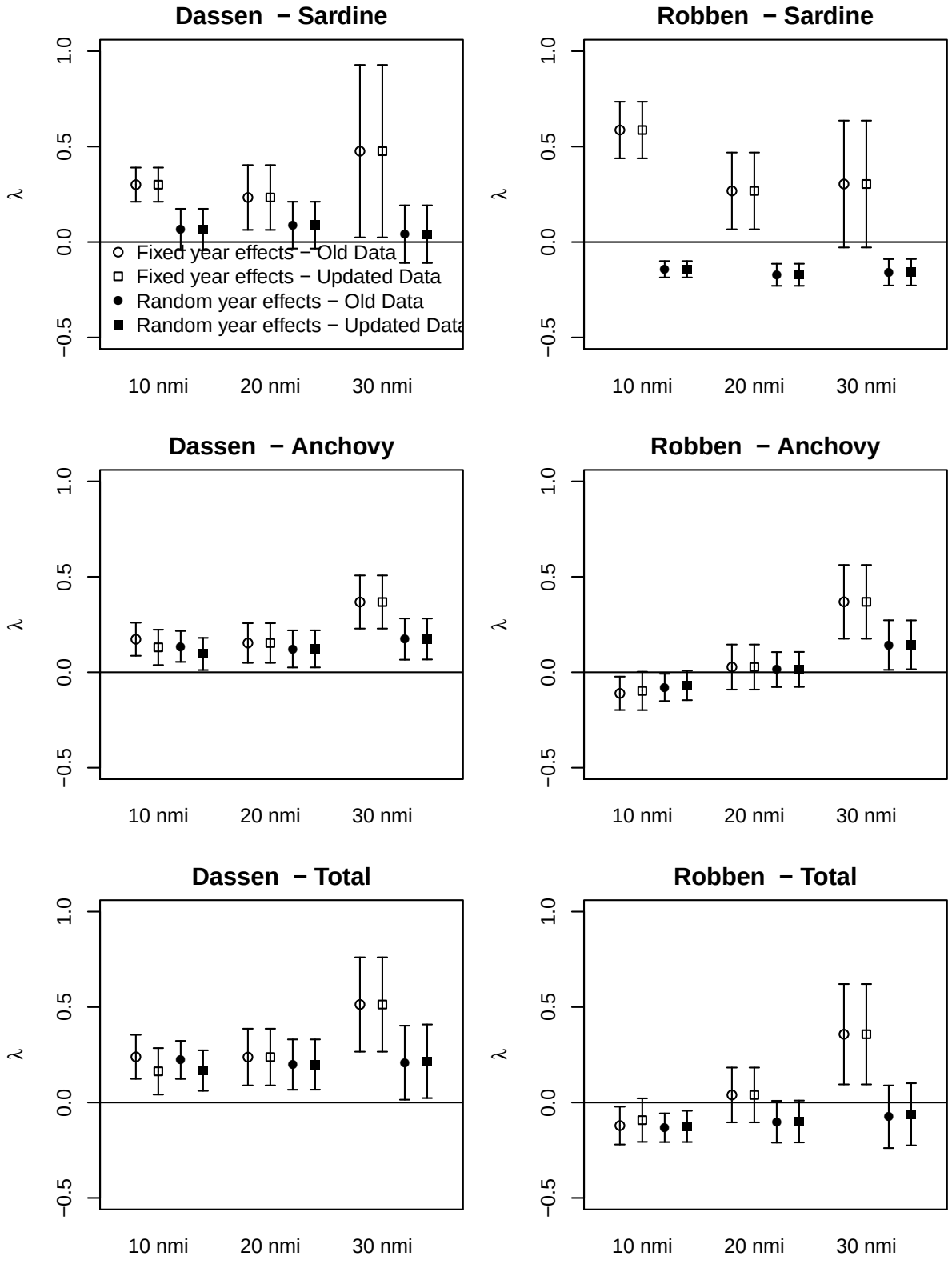

Figure A.3: Dassen and Robben Islands fishing effect parameter estimates: for the **fledging success** response variable. Bars indicate one standard error.

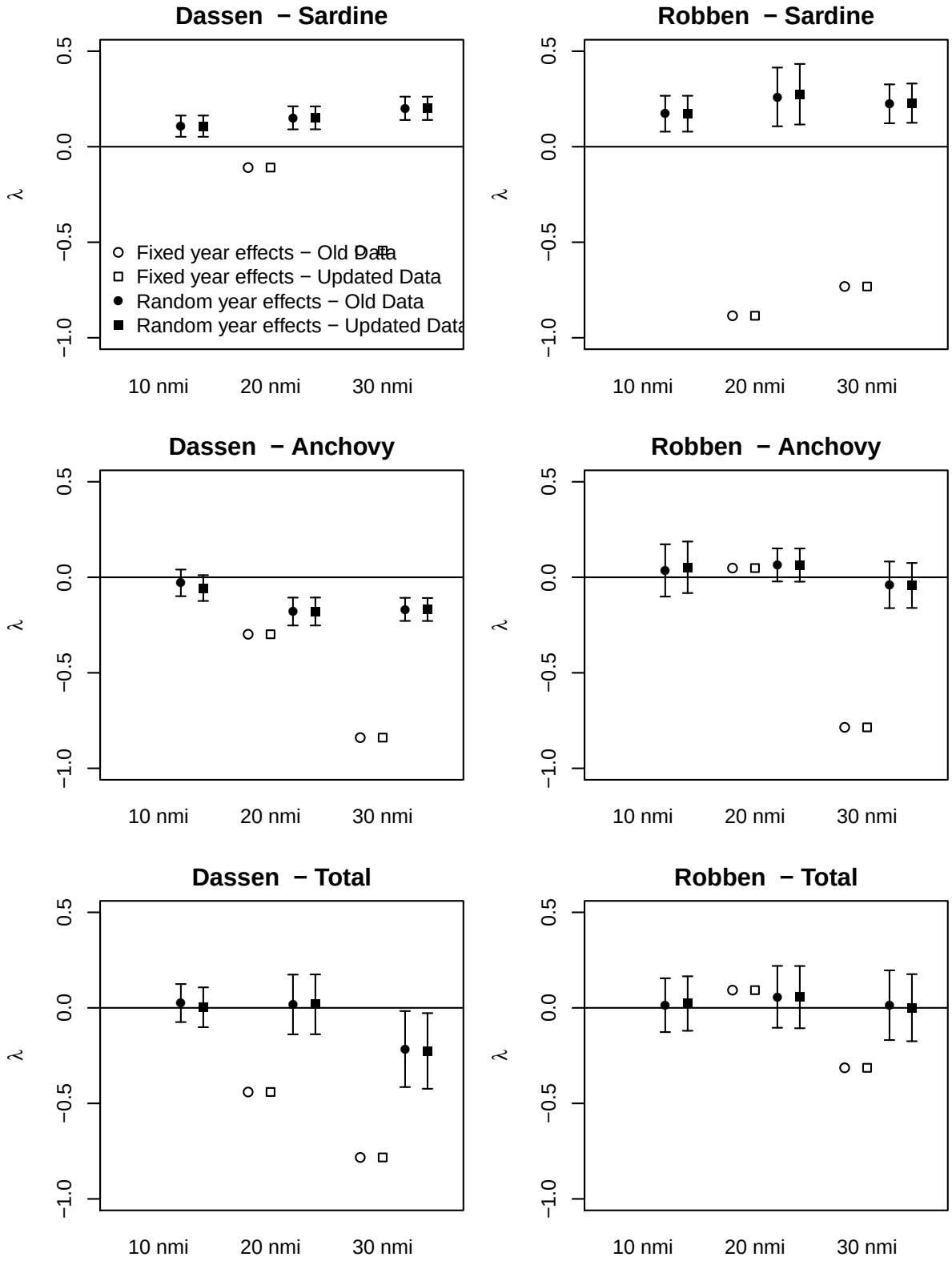

Figure A.4: Dassen and Robben Islands fishing effect parameter estimates: for the **chick growth rate** response variable. Bars indicate one standard error.

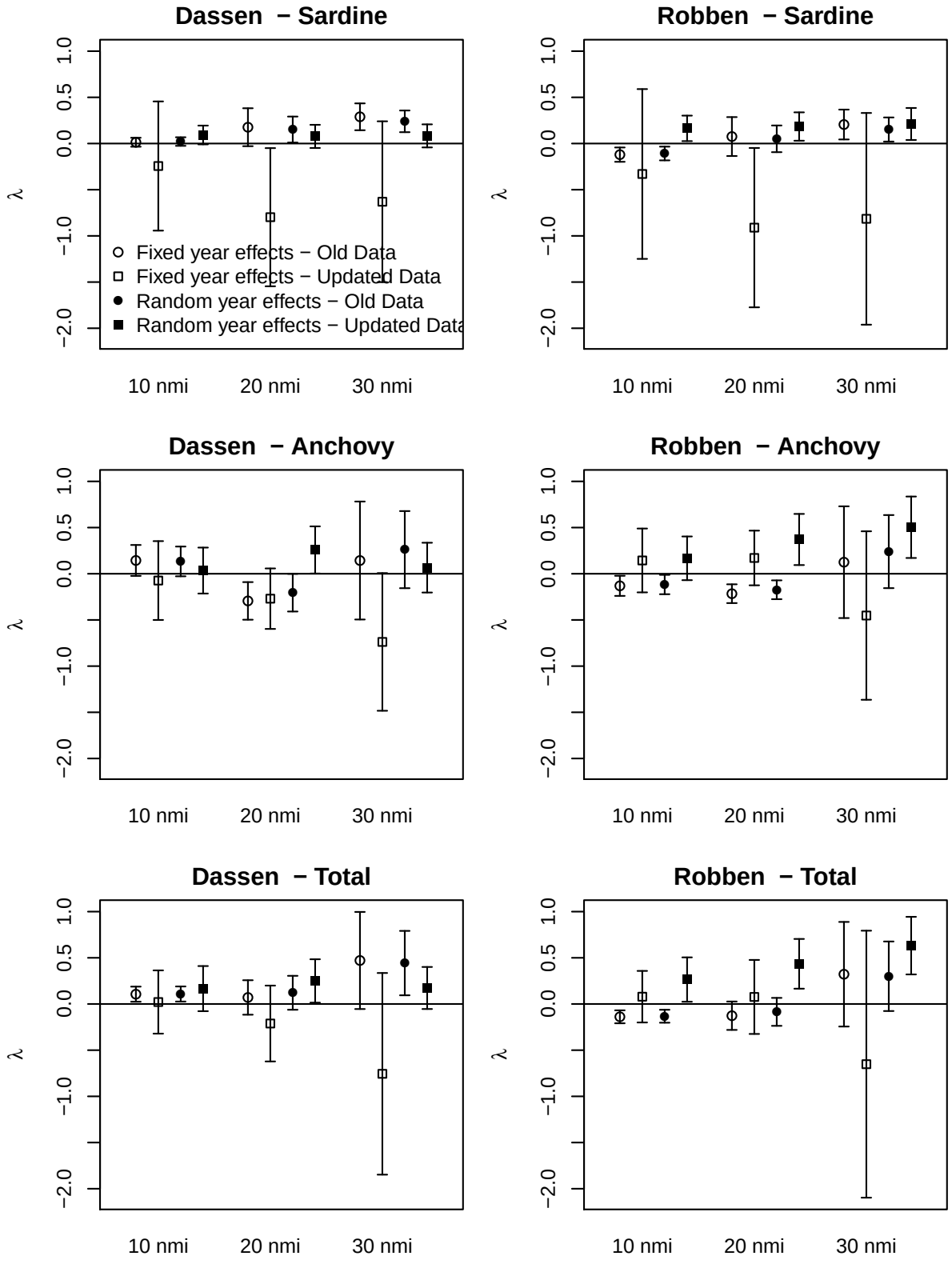

Figure A.5: Dassen and Robben Islands fishing effect parameter estimates: for the **foraging path length** response variable. Bars indicate one standard error.

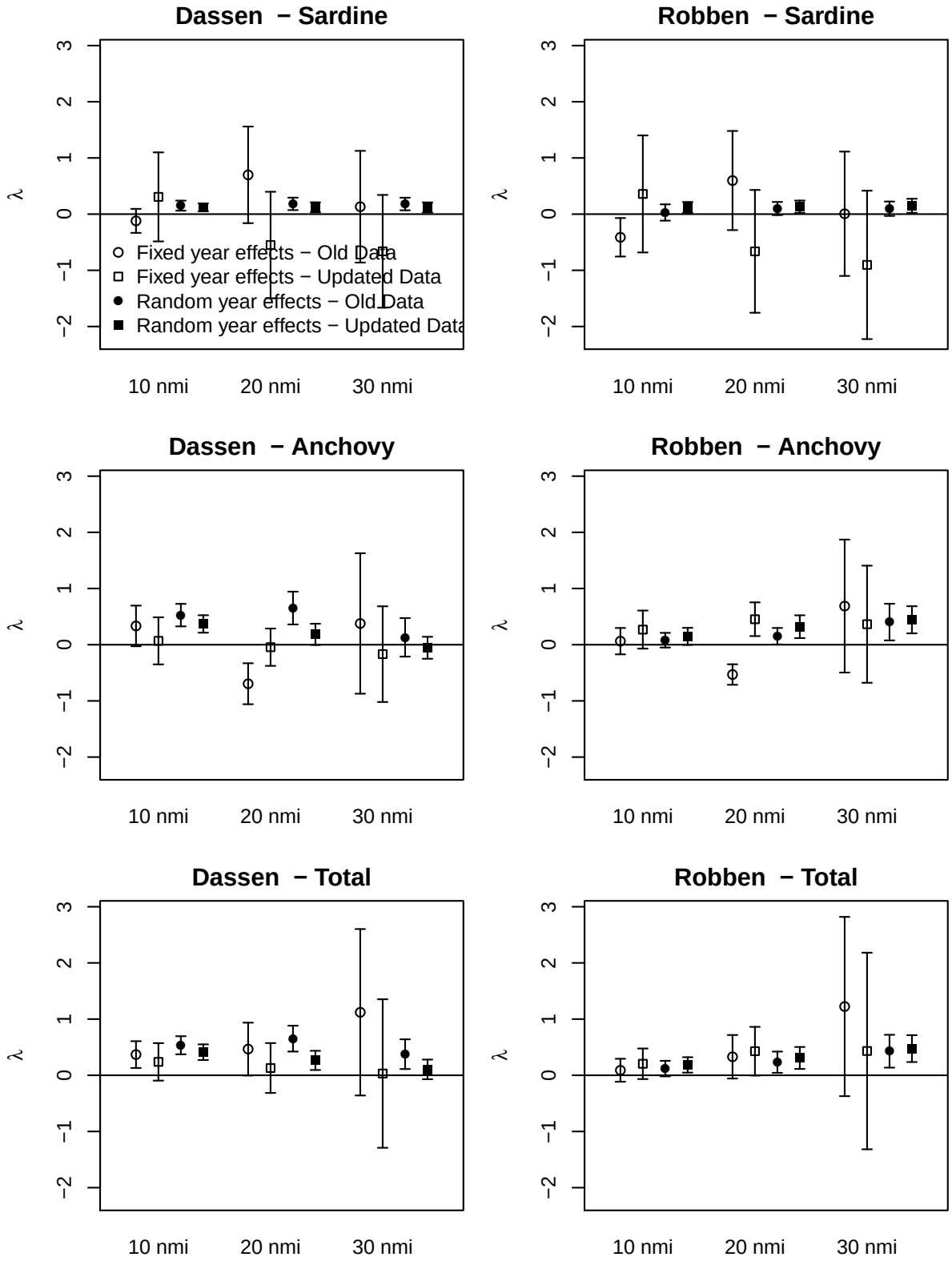

Figure A.6: Dassen and Robben Islands fishing effect parameter estimates: for the **foraging trip duration** response variable. Bars indicate one standard error.

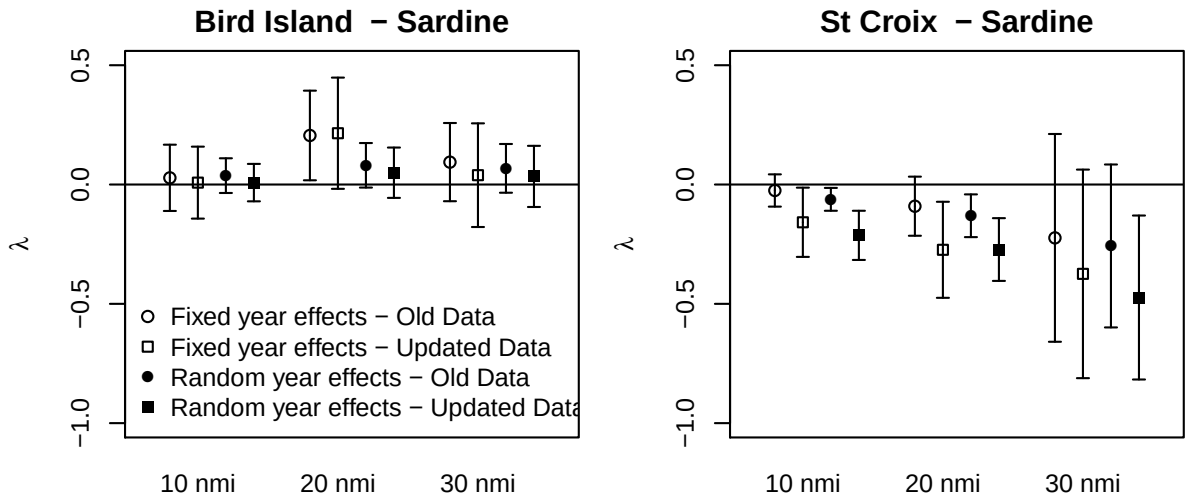

Figure A.7: Bird and St Croix Islands fishing effect parameter estimates: for the **foraging path length** response variable. Bars indicate one standard error.

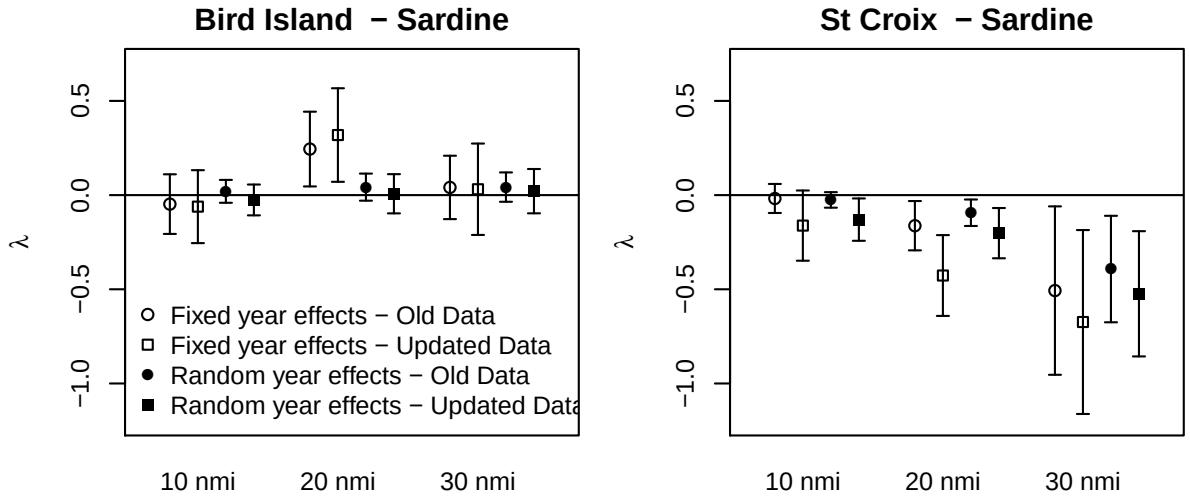

Figure A.8: Bird and St Croix Islands fishing effect parameter estimates: for the **foraging trip duration** response variable. Bars indicate one standard error.

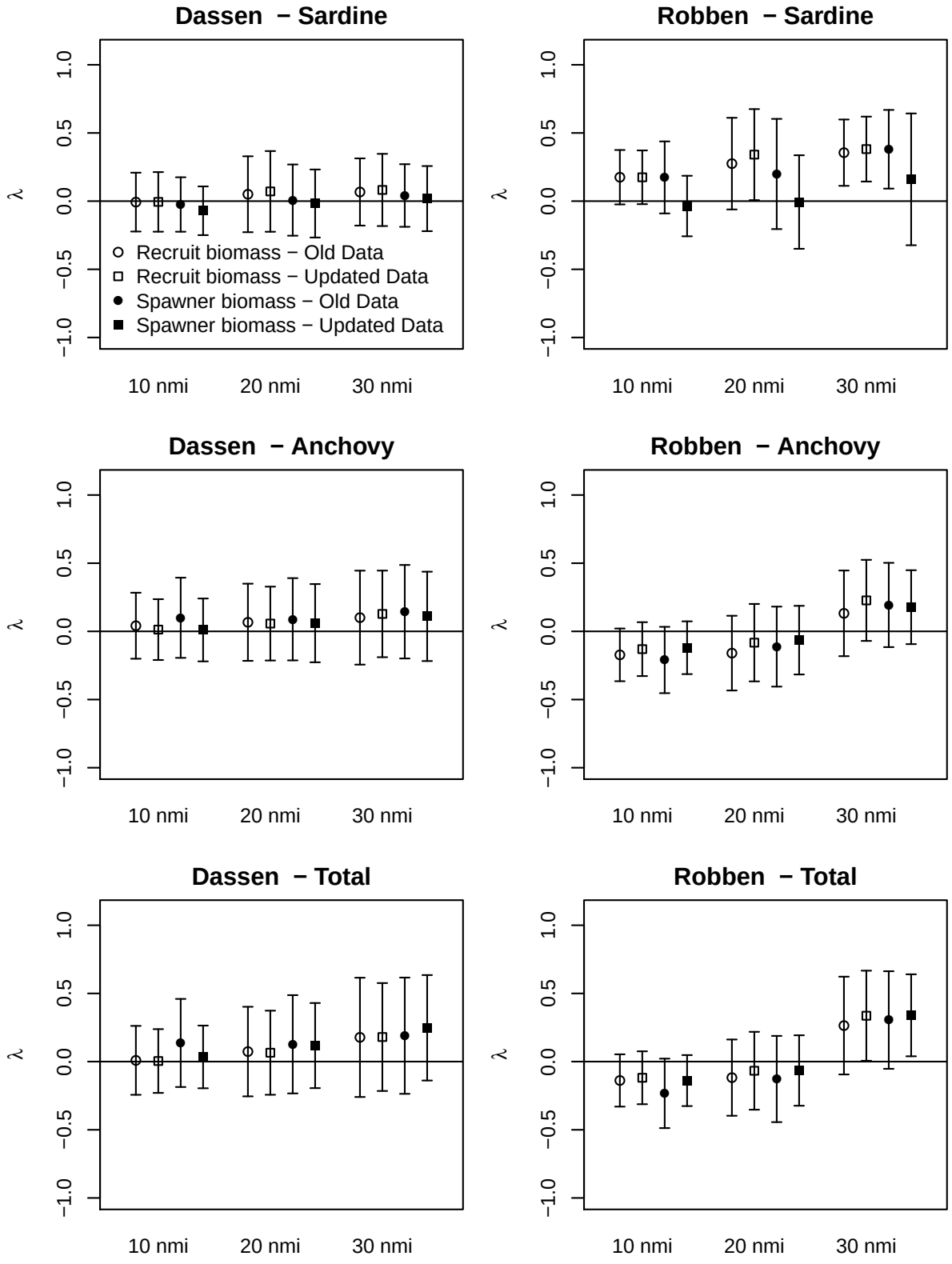

Figure A.9: Dassen and Robben Islands fishing effect parameter estimates: for the **chick condition** response variable. Bars indicate one standard error.

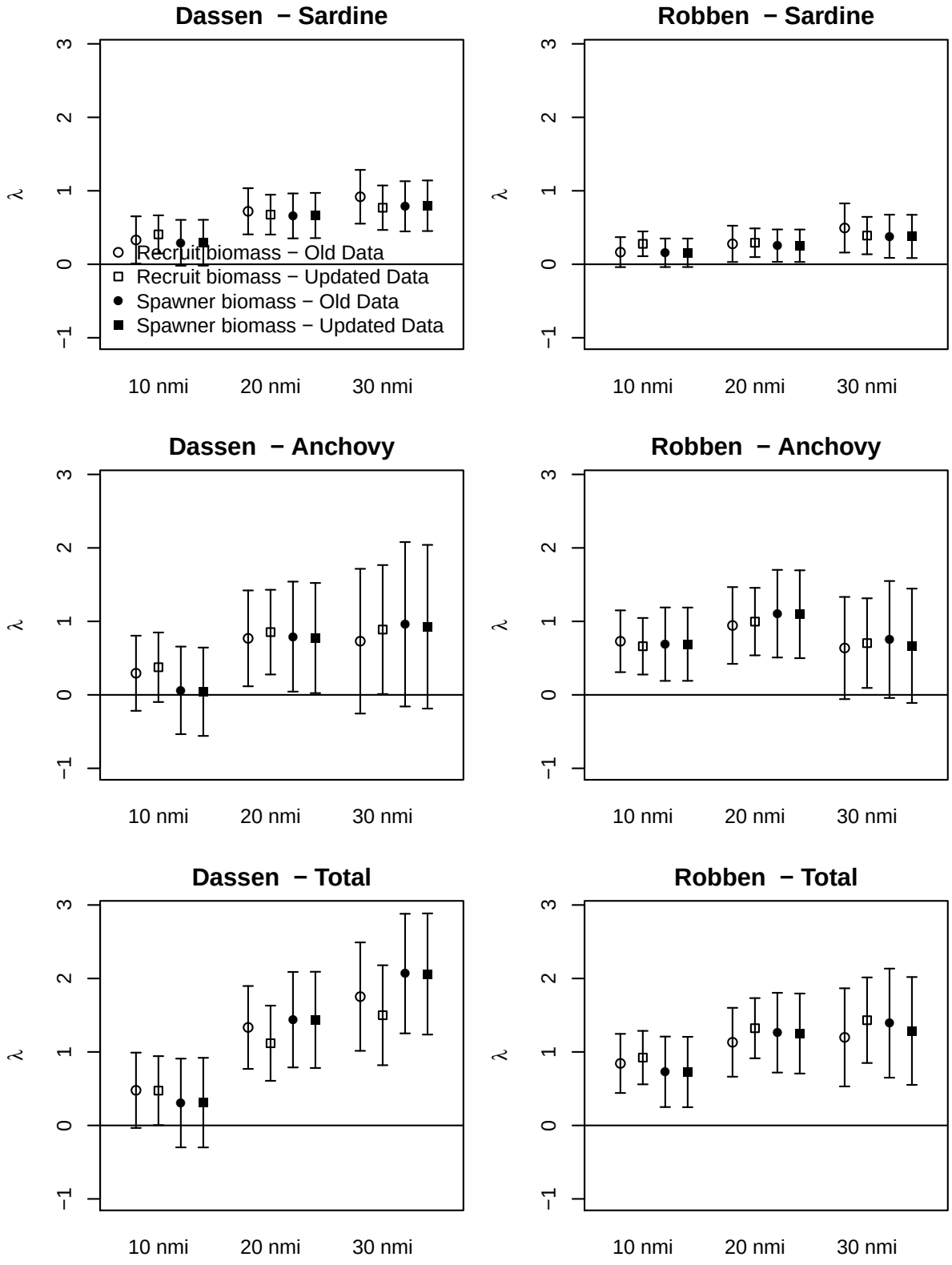

Figure A.10: Dassen and Robben Islands fishing effect parameter estimates: for the **active nest proportion** response variable. Bars indicate one standard error.

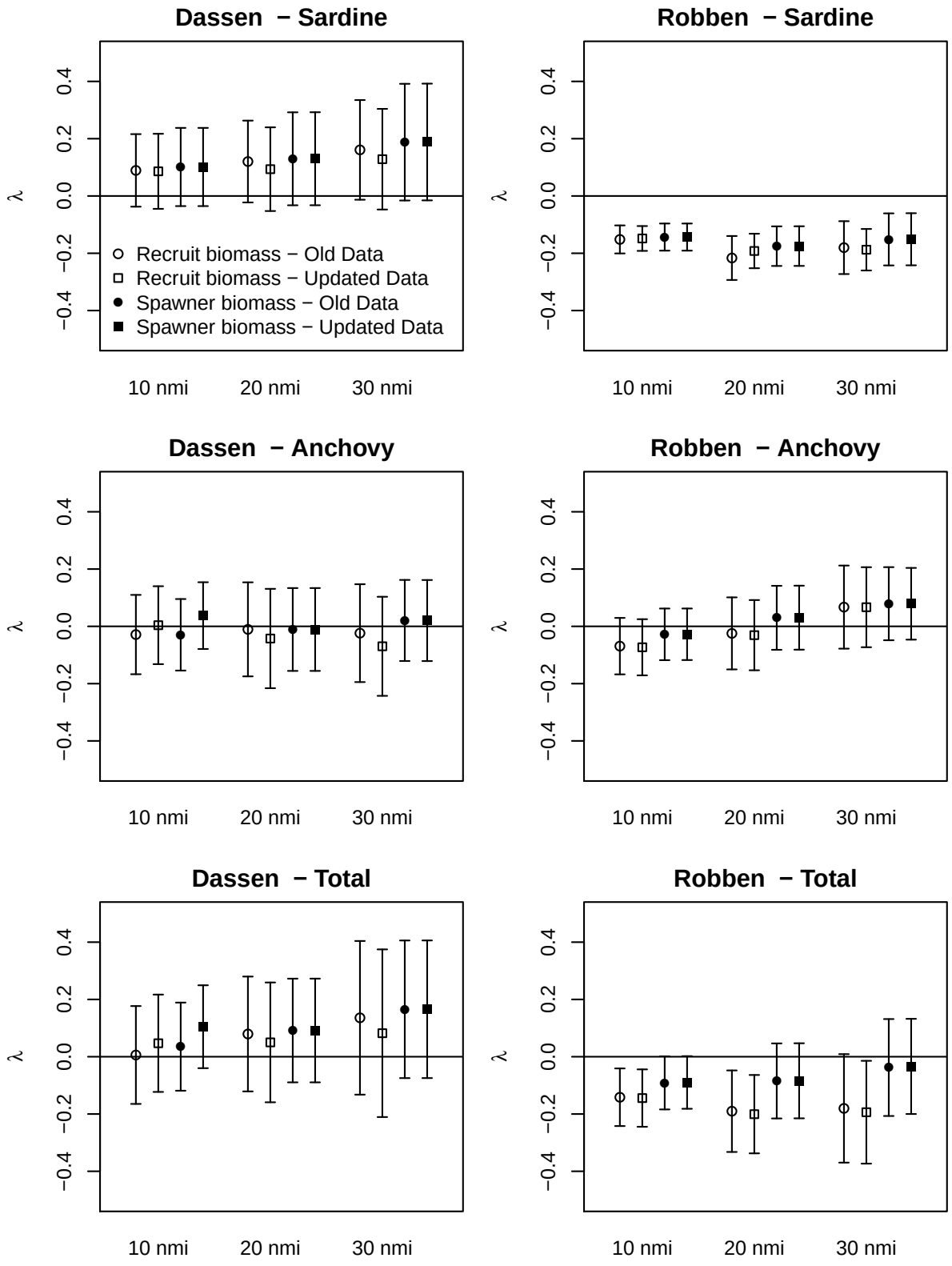

Figure A.11: Dassen and Robben Islands fishing effect parameter estimates: for the **fledging success** response variable. Bars indicate one standard error.

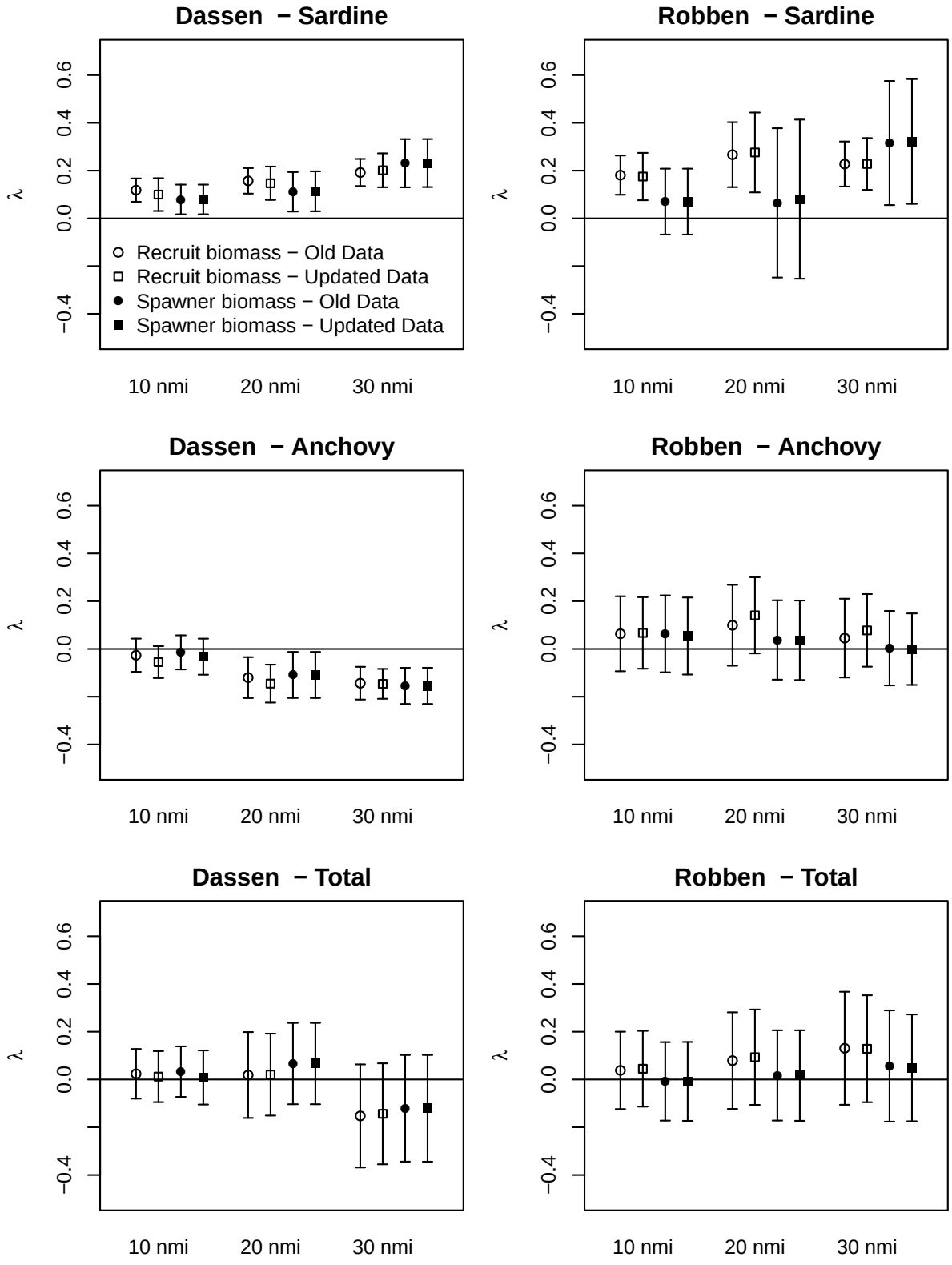

Figure A.12: Dassen and Robben Islands fishing effect parameter estimates: for the **chick growth rate** response variable. Bars indicate one standard error.

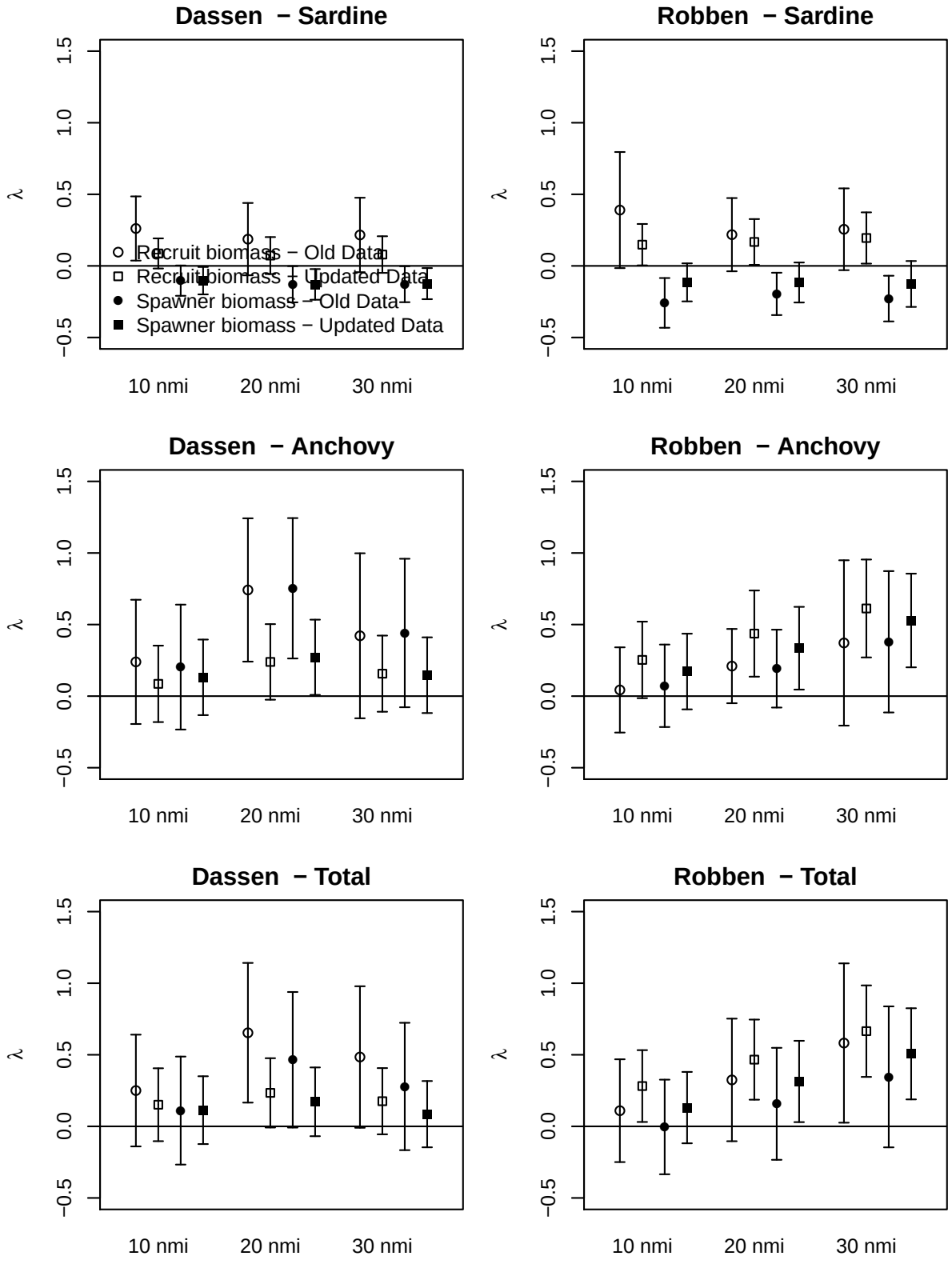

Figure A.13: Dassen and Robben Islands fishing effect parameter estimates: for the **foraging path length** response variable. Bars indicate one standard error.

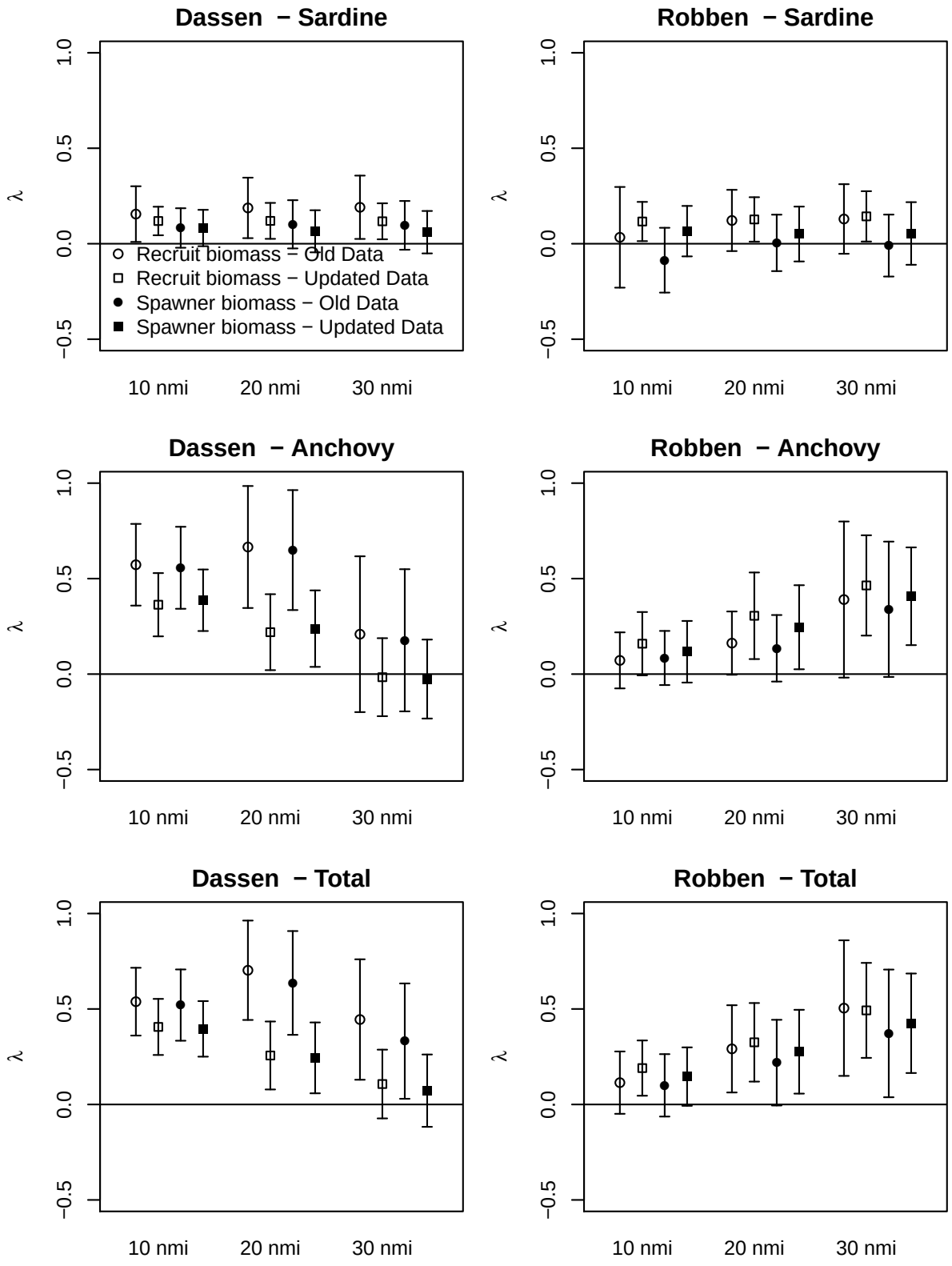

Figure A.14: Dassen and Robben Islands fishing effect parameter estimates: for the **foraging trip duration** response variable. Bars indicate one standard error.

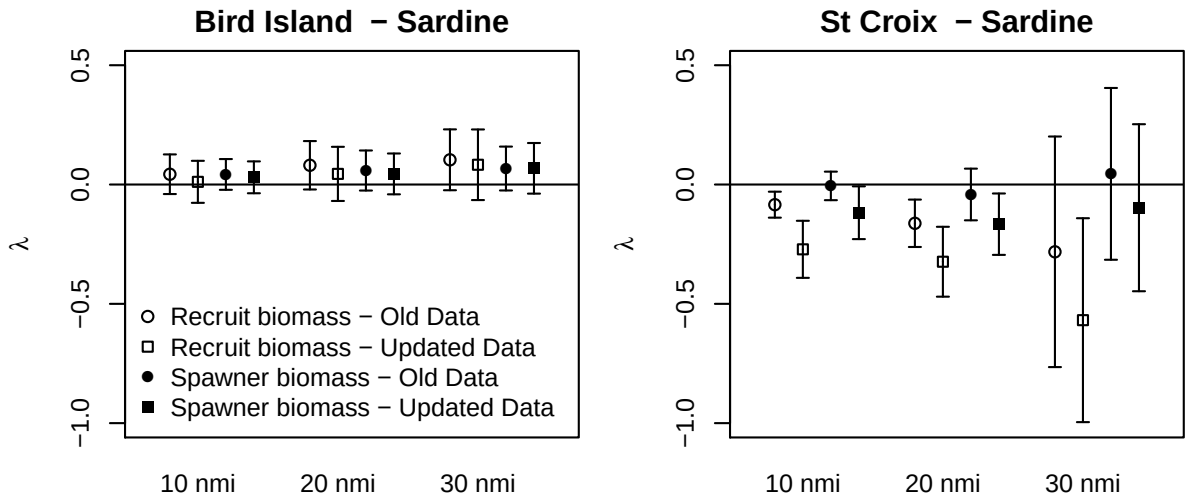

Figure A.15: Bird and St Croix Islands fishing effect parameter estimates: for the **foraging path length** response variable. Bars indicate one standard error.

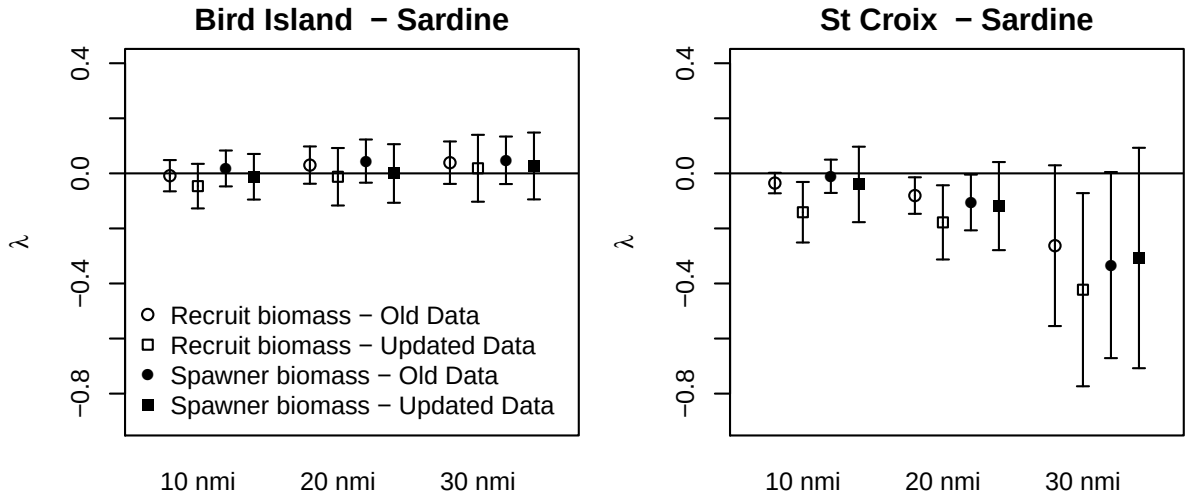

Figure A.16: Bird and St Croix Islands fishing effect parameter estimates: for the **foraging trip duration** response variable. Bars indicate one standard error.

Appendix B

Results for updated data for years restricted to 2008+

Table B.1: Residual standard error σ_ε and upper 95% confidence limits $\sigma_{\varepsilon,+95}$ (estimated using a likelihood profile approach) for each penguin response series available for the **updated datasets from 2008 onwards**, for assessing the power of the island closure experiment are listed for the random year effects model. Note that MLE estimates are negatively biased because of the small number of degrees of freedom, but these estimates are unbiased through use of REML. The number of past data points n and the number of model parameters estimated p are indicated for the model. Results are given for the case of total catch within 30 nmi for the Western Cape and sardine catch within 30 nmi for the Eastern Cape.

(a) Dassen and Robben islands

Penguin response	n	p	σ_ε	$\sigma_{\varepsilon,+95}$
Chick condition	10	5	0.155	0.247
Active nest proportion	10	5	0.702	1.116
Fledging success	9	5	0.069	0.113
Chick growth	8	6	0.060	0.102
Foraging path length	11	5	0.147	0.228
Foraging trip duration	11	5	0.154	0.240

(b) St Croix and Bird islands

Penguin response	n	p	σ_ε	$\sigma_{\varepsilon,+95}$
Foraging path length	12	5	0.153	0.234
Foraging trip duration	12	5	0.142	0.216

Table B.2: Fishing effect parameters λ with associated standard errors for (i) fixed year effects, (ii) random year effects, (iii) year effects given by spawner biomass, and (iv) year effects given by recruit biomass for the **updated datasets from 2008 onwards**. Values significantly different from zero at the 15% and 5% levels are indicated by one and two asterisks respectively. Statistical significance is based on a normal approximation for the random effects model and a two-sided t-test for the other models. Cases where the correlation between the catch and the (recruit or spawning) biomass exceeds $r = 0.7$ are indicated by a †. Some results are left blank in cases where there are no degrees of freedom.

(a) Dassen Island

Penguin response	Fish	Area	λ				s.e.			
			(i)	(ii)	(iii)	(iv)	(i)	(ii)	(iii)	(iv)
Chick condition	Sardine	10 nmi	0.10	-0.01	0.03†	-0.11	0.26	0.17	0.21	0.20
		20 nmi	0.28	0.05	0.06	-0.06	0.37	0.23	0.26	0.29
		30 nmi	0.42	0.09	0.08	-0.03	0.34	0.22	0.24	0.30
	Anchovy	10 nmi	-0.67 *	-0.06	0.00	0.04	0.17	0.17	0.20	0.17
		20 nmi	-0.36	0.06	0.05	0.06	0.23	0.22	0.25	0.22
		30 nmi	-0.97	0.10	0.10	0.10	0.89	0.22	0.25	0.24
	Total	10 nmi	-0.80 *	-0.05	-0.00	0.02	0.23	0.18	0.20	0.18
		20 nmi	-0.37	0.07	0.05	0.06	0.30	0.25	0.28	0.26
		30 nmi	-0.39	0.16	0.16	0.15	1.12	0.28	0.32	0.30
Active nest proportion	Sardine	10 nmi	0.96	-0.12	0.81†	0.22	1.17	0.91	0.69	1.03
		20 nmi	-0.25	-0.35	0.38	-0.31	2.04	1.20	0.96	1.53
		30 nmi	-1.46	-0.58	0.14	-0.73	1.77	1.03	0.88	1.41
	Anchovy	10 nmi	0.35	-0.03	-0.20	0.01	1.90	0.71	0.79	0.81
		20 nmi	0.34	0.27	0.11	0.26	0.86	0.57	0.64	0.62
		30 nmi	4.75	0.81	0.77	0.63	3.99	1.11	1.26	1.24
	Total	10 nmi	0.33	-0.08	-0.25	-0.07	2.29	0.75	0.80	0.84
		20 nmi	0.21	0.23	0.02	0.25	1.01	0.67	0.71	0.71
		30 nmi	2.11	0.88	0.83	0.85	5.23	1.49	1.71	1.65
Fledging success	Sardine	10 nmi	-0.05	-0.01	-0.01†	0.04	0.15	0.10	0.14	0.12
		20 nmi	-0.12	-0.04	-0.05	0.02	0.24	0.13	0.15	0.15
		30 nmi	-0.21	-0.09	-0.10	-0.01	0.27	0.13	0.15	0.17
	Anchovy	10 nmi	-0.57	-0.04	-0.03	-0.06	0.48	0.09	0.08	0.09
		20 nmi	-0.28	-0.20**	-0.12	-0.10	0.13	0.11	0.10	0.12
		30 nmi	-0.14	-0.06	-0.06	0.01	0.92	0.10	0.08	0.09
	Total	10 nmi	-0.60	-0.04	-0.02	-0.04	0.50	0.09	0.08	0.09
		20 nmi	-0.29	-0.17 *	-0.11	-0.09	0.14	0.12	0.11	0.13
		30 nmi	-0.37	-0.11	-0.12	-0.05	0.53	0.13	0.11	0.12
Chick growth	Sardine	10 nmi	-	0.05	0.07†	-0.02	-	0.10	0.15	0.12
		20 nmi	-	-0.01	-0.05	-0.11	-	0.10	0.11	0.07
		30 nmi	-	0.00	-0.04	-0.16	-	0.12	0.12	0.10
	Anchovy	10 nmi	-	0.07	0.05	0.09	-	0.10	0.10	0.10
		20 nmi	-	-0.05	-0.06	-0.07	-	0.13	0.14	0.15
		30 nmi	-	-0.10 *	-0.10	-0.15	-	0.09	0.09	0.10
	Total	10 nmi	-	0.06	0.05	0.07	-	0.10	0.11	0.10
		20 nmi	-	-0.05	-0.05	-0.08	-	0.14	0.15	0.15
		30 nmi	-	-0.13 *	-0.13	-0.20	-	0.12	0.12	0.12
Foraging path length	Sardine	10 nmi	-0.08	-0.17 *	-0.13†	-0.20	0.33	0.13	0.17	0.16
		20 nmi	-0.29	-0.24 *	-0.19	-0.24	0.60	0.15	0.16	0.18
		30 nmi	-0.14	-0.21 *	-0.16	-0.21	0.60	0.15	0.15	0.18
	Anchovy	10 nmi	-0.28	0.05	0.04	0.08	0.68	0.19	0.21	0.20
		20 nmi	-0.32	-0.01	-0.03	-0.01	0.33	0.17	0.19	0.18
		30 nmi	-1.13	-0.02	-0.02	-0.02	0.69	0.13	0.14	0.14
	Total	10 nmi	-0.42	0.04	0.02	0.05	0.77	0.19	0.21	0.21
		20 nmi	-0.43	-0.05	-0.08	-0.05	0.35	0.18	0.20	0.20
		30 nmi	-1.59**	-0.07	-0.08	-0.08	0.24	0.14	0.16	0.16
Foraging trip duration	Sardine	10 nmi	0.12	0.01	0.01†	-0.04	0.38	0.16	0.20	0.19
		20 nmi	-0.40	-0.13	-0.14	-0.17	0.78	0.19	0.22	0.23
		30 nmi	-0.44	-0.14	-0.15	-0.20	0.74	0.18	0.20	0.22
	Anchovy	10 nmi	-0.27	0.34**	0.33*	0.34*	0.59	0.16	0.18	0.18
		20 nmi	-0.14	0.08	0.05	0.08	0.31	0.20	0.22	0.21
		30 nmi	-0.58	-0.16	-0.18	-0.14	0.92	0.16	0.17	0.18
	Total	10 nmi	-0.34	0.35**	0.33*	0.35*	0.68	0.17	0.19	0.19
		20 nmi	-0.19	0.04	0.03	0.07	0.36	0.22	0.24	0.24
		30 nmi	-0.96	-0.22 *	-0.24	-0.20	0.93	0.19	0.20	0.20

Table B.2: Continued.

(b) Robben Island

Penguin response	Fish	Area	λ				s.e.			
			(i)	(ii)	(iii)	(iv)	(i)	(ii)	(iii)	(iv)
Chick condition	Sardine	10 nmi	-0.09	-0.07	-0.06	-0.19 †	0.27	0.17	0.18	0.23
		20 nmi	0.11	-0.01	0.06	-0.17 †	0.43	0.27	0.31	0.42
		30 nmi	0.38	0.05	0.16	-0.09 †	0.46	0.30	0.37	0.50
	Anchovy	10 nmi	0.37 ∗	-0.13	-0.14	-0.21	0.16	0.16	0.18	0.17
		20 nmi	-0.06	-0.02	-0.01	-0.11	0.24	0.22	0.25	0.26
		30 nmi	-0.67	0.34 ∗	0.34	0.33	0.87	0.21	0.23	0.25
	Total	10 nmi	0.47 ∗	-0.13	-0.13	-0.17	0.20	0.16	0.18	0.17
		20 nmi	-0.05	-0.02	-0.01	-0.08	0.28	0.24	0.26	0.26
		30 nmi	-0.04	0.40∗∗	0.40	0.38	0.95	0.23	0.26	0.27
Active nest proportion	Sardine	10 nmi	0.81	0.42	0.40	1.30 †	1.20	0.93	0.60	1.19
		20 nmi	-0.93	-1.36	-0.39	-1.36 †	2.36	1.39	1.15	2.26
		30 nmi	-2.76	-2.28 ∗	-1.03	-3.20 †	2.43	1.41	1.33	2.34
	Anchovy	10 nmi	1.14	1.57∗∗	1.77 ∗	1.55 ∗	1.77	0.67	0.73	0.80
		20 nmi	2.21 ∗	2.66∗∗	2.81∗∗	2.88∗∗	0.89	0.59	0.63	0.73
		30 nmi	5.89	2.23∗∗	2.25 ∗	2.13	3.89	1.08	1.19	1.29
	Total	10 nmi	1.17	1.59∗∗	1.78 ∗	1.64 ∗	2.03	0.67	0.70	0.77
		20 nmi	2.33 ∗	2.79∗∗	2.93∗∗	3.03∗∗	0.97	0.64	0.65	0.73
		30 nmi	3.32	2.42∗∗	2.44 ∗	2.48	4.44	1.26	1.40	1.46
Fledging success	Sardine	10 nmi	0.15	-0.02	-0.02	0.03 †	0.12	0.07	0.08	0.10
		20 nmi	0.11	-0.02	-0.03	0.08 †	0.22	0.11	0.14	0.17
		30 nmi	0.03	-0.01	-0.02	0.12 †	0.26	0.12	0.16	0.19
	Anchovy	10 nmi	0.40	-0.06	-0.04	-0.04	0.38	0.06	0.06	0.07
		20 nmi	0.03	0.01	0.01	0.04	0.09	0.08	0.07	0.09
		30 nmi	-0.03	0.07	0.06	0.14	1.04	0.10	0.08	0.09
	Total	10 nmi	0.43	-0.06	-0.04	-0.05	0.40	0.06	0.06	0.07
		20 nmi	0.07	0.00	-0.00	0.02	0.10	0.09	0.08	0.10
		30 nmi	-0.15	0.08	0.06	0.14	0.49	0.11	0.09	0.10
Chick growth	Sardine	10 nmi	-	0.00	-0.02	0.01	-	0.10	0.13	0.10
		20 nmi	-	-0.35 ∗	-0.50∗†	-0.37 ∗	-	0.22	0.25	0.13
		30 nmi	-	-0.24 ∗	-0.46 †	-0.28 ∗	-	0.21	0.27	0.13
	Anchovy	10 nmi	-	0.00	-0.05 †	-0.06 †	-	0.09	0.12	0.11
		20 nmi	-	0.07	0.04	0.02 †	-	0.11	0.13	0.16
		30 nmi	-	0.11 ∗	0.10	0.04 †	-	0.10	0.10	0.12
	Total	10 nmi	-	0.00	-0.04 †	-0.05 †	-	0.09	0.12	0.11
		20 nmi	-	0.07	0.05	0.01 †	-	0.12	0.13	0.14
		30 nmi	-	0.11 ∗	0.12	0.04 †	-	0.11	0.11	0.11
Foraging path length	Sardine	10 nmi	0.04	0.05	0.05	-0.01 †	0.43	0.19	0.20	0.26
		20 nmi	0.08	0.16	0.24	0.18 †	0.65	0.20	0.21	0.27
		30 nmi	0.23	0.19	0.31	0.18 †	0.82	0.23	0.24	0.32
	Anchovy	10 nmi	0.32	0.11	0.12	0.07	0.54	0.18	0.19	0.20
		20 nmi	0.22	0.30 ∗	0.30	0.27	0.33	0.19	0.21	0.22
		30 nmi	-1.08	0.48∗∗	0.48∗∗	0.46 ∗	0.96	0.18	0.19	0.20
	Total	10 nmi	0.41	0.11	0.12	0.09	0.58	0.18	0.19	0.20
		20 nmi	0.21	0.31 ∗	0.31	0.30	0.31	0.20	0.21	0.22
		30 nmi	-1.42∗∗	0.53∗∗	0.53∗∗	0.52∗∗	0.30	0.19	0.20	0.21
Foraging trip duration	Sardine	10 nmi	0.04	-0.10	-0.10	-0.18 †	0.49	0.22	0.24	0.31
		20 nmi	-0.30	-0.03	-0.05	-0.12 †	0.84	0.25	0.29	0.34
		30 nmi	-0.47	-0.02	-0.05	-0.15 †	1.02	0.29	0.34	0.38
	Anchovy	10 nmi	0.56	0.07	0.07	0.06	0.47	0.16	0.17	0.18
		20 nmi	0.52	0.20	0.21	0.24	0.31	0.23	0.24	0.26
		30 nmi	-0.16	0.38∗∗	0.35	0.40	1.28	0.23	0.23	0.25
	Total	10 nmi	0.61	0.07	0.07	0.06	0.52	0.16	0.17	0.18
		20 nmi	0.52	0.26 ∗	0.21	0.23	0.32	0.24	0.25	0.27
		30 nmi	-0.51	0.40∗∗	0.38	0.42	1.17	0.24	0.25	0.27

Table B.2: Continued.

(c) Bird Island

Penguin response	Fish	Area	λ				s.e.			
			(i)	(ii)	(iii)	(iv)	(i)	(ii)	(iii)	(iv)
Foraging path length	Sardine	10 nmi	0.01	0.12**	0.09	0.11	0.10	0.07	0.06	0.07
		20 nmi	0.16	0.21**	0.16*	0.22*	0.18	0.09	0.09	0.10
		30 nmi	0.03	0.27**	0.19	0.27*	0.17	0.13	0.12	0.14
Foraging trip duration	Sardine	10 nmi	-0.04	0.01	0.01	-0.00	0.13	0.08	0.09	0.08
		20 nmi	0.24	0.09	0.05	0.08	0.19	0.12	0.13	0.12
		30 nmi	0.02	0.12	0.10	0.13	0.19	0.13	0.15	0.13

(d) St Croix Island

Penguin response	Fish	Area	λ				s.e.			
			(i)	(ii)	(iii)	(iv)	(i)	(ii)	(iii)	(iv)
Foraging path length	Sardine	10 nmi	-0.16	-0.26**	-0.15 †	-0.27**	0.14	0.10	0.11	0.10
		20 nmi	-0.27	-0.32**	-0.22*†	-0.32**	0.20	0.11	0.12	0.11
		30 nmi	-0.37	-0.57**	-0.22 †	-0.55	0.44	0.33	0.34	0.36
Foraging trip duration	Sardine	10 nmi	-0.16	-0.13 *	-0.05 †	-0.14	0.19	0.12	0.15	0.12
		20 nmi	-0.43*	-0.23**	-0.14 †	-0.18	0.21	0.13	0.17	0.14
		30 nmi	-0.67	-0.50 *	-0.38 †	-0.41	0.49	0.34	0.43	0.34

Table B.3: Tallies of positive and negative values of λ, those significantly different from zero at the 15% level, and those significantly different from zero at the 5% level for the **updated datasets from 2008 onwards**. "Both no †" tallies omit instances where the catch-biomass correlation exceeds $r = 0.7$.

(a) Western Cape

		Fixed year effects			Random year effects			Spawner Biomass			Recruit Biomass		
		all	15%	5%	all	15%	5%	all	15%	5%	all	15%	5%
Chick condition	Dassen	3:6	0:2	0:0	6:3	0:0	0:0	8:1	0:0	0:0	6:3	0:0	0:0
	Robben	4:5	2:0	0:0	3:6	2:0	1:0	4:5	0:0	0:0	2:7	0:0	0:0
Active nest proportion	Dassen	7:2	0:0	0:0	4:5	0:0	0:0	7:2	0:0	0:0	6:3	0:0	0:0
	Robben	7:2	2:0	0:0	7:2	6:1	6:0	7:2	6:0	2:0	7:2	4:0	2:0
Fledging success	Dassen	0:9	0:0	0:0	0:9	0:2	0:1	0:9	0:0	0:0	3:6	0:0	0:0
	Robben	7:2	0:0	0:0	4:5	0:0	0:0	3:6	0:0	0:0	7:2	0:0	0:0
Chick growth	Dassen				4:5	0:2	0:0	3:6	0:0	0:0	2:7	0:0	0:0
	Robben				7:2	2:2	0:0	4:5	0:1	0:0	5:4	0:2	0:0
Foraging path length	Dassen	0:9	0:1	0:1	2:7	0:3	0:0	2:7	0:0	0:0	2:7	0:0	0:0
	Robben	7:2	0:1	0:1	9:0	4:0	2:0	9:0	2:0	2:0	8:1	2:0	1:0
Foraging trip duration	Dassen	1:8	0:0	0:0	5:4	2:1	2:0	5:4	2:0	0:0	4:5	2:0	0:0
	Robben	5:4	0:0	0:0	6:3	3:0	2:0	6:3	0:0	0:0	6:3	0:0	0:0
Total	Dassen	11:34	0:3	0:1	21:33	2:8	2:1	25:29	2:0	0:0	23:31	2:0	0:0
	Robben	30:15	4:1	0:1	36:18	17:3	11:0	33:21	8:1	4:0	35:19	6:2	3:0
	Both	41:49	4:4	0:2	57:51	19:11	13:1	58:50	10:1	4:0	58:50	8:2	3:0
	Both no †							54:44	10:0	4:0	48:39	8:2	3:0

(b) Eastern Cape

		Fixed year effects			Random year effects			Spawner Biomass			Recruit Biomass		
		all	15%	5%	all	15%	5%	all	15%	5%	all	15%	5%
Foraging path length	Bird	3:0	0:0	0:0	3:0	3:0	3:0	3:0	1:0	0:0	3:0	2:0	0:0
	St Croix	0:3	0:0	0:0	0:3	0:3	0:3	0:3	0:1	0:0	0:3	0:2	0:2
Foraging trip duration	Bird	2:1	0:0	0:0	3:0	0:0	0:0	3:0	0:0	0:0	2:1	0:0	0:0
	St Croix	0:3	0:1	0:0	0:3	0:3	0:1	0:3	0:0	0:0	0:3	0:0	0:0
Total	Bird	5:1	0:0	0:0	6:0	3:0	3:0	6:0	1:0	0:0	5:1	2:0	0:0
	St Croix	0:6	0:1	0:0	0:6	0:6	0:4	0:6	0:1	0:0	0:6	0:2	0:2
	Both	5:7	0:1	0:0	6:6	3:6	3:4	6:6	1:1	0:0	5:7	2:2	0:2
	Both no †							6:0	1:0	0:0			

Table B.4: The number of additional years' data required to detect a fishing effect significant at the 5% level with **95%** probability is given for each of Dassen and Robben islands for the **updated datasets from 2008 onwards**, where the true values of λ are assumed to be the random effects model-estimates. If a model-estimated λ value is small (i.e. $|\lambda| < 0.1$) then $\lambda = \pm 0.1$ is assumed for the effect size, where the sign is chosen according to the sign of the model-estimate for λ. A value of 0 indicates that the existing estimate of λ is already significant at the 5% level. C/O indicates future alternating periods of three years of the area being closed and open to fishing; O indicates the area is always open in the future.

			Dassen		Robben	
Response	Fish	Area	C/O	O	C/O	O
Chick condition	Sardine	10 nmi	> 20	> 20	> 20	> 20
		20 nmi	-	> 20	-	> 20
		30 nmi	-	> 20	-	> 20
	Anchovy	10 nmi	> 20	> 20	> 20	> 20
		20 nmi	-	> 20	-	> 20
		30 nmi	-	> 20	-	> 20
	Total	10 nmi	> 20	> 20	> 20	> 20
		20 nmi	-	> 20	-	> 20
		30 nmi	-	> 20	-	0
Active nest proportion	Sardine	10 nmi	> 20	> 20	> 20	> 20
		20 nmi	-	> 20	-	> 20
		30 nmi	-	> 20	-	20
	Anchovy	10 nmi	> 20	> 20	0	0
		20 nmi	-	> 20	-	0
		30 nmi	-	> 20	-	0
	Total	10 nmi	> 20	> 20	0	0
		20 nmi	-	> 20	-	0
		30 nmi	-	> 20	-	0
Fledging success	Sardine	10 nmi	> 20	> 20	> 20	> 20
		20 nmi	-	> 20	-	> 20
		30 nmi	-	> 20	-	> 20
	Anchovy	10 nmi	> 20	> 20	> 20	> 20
		20 nmi	-	0	-	17
		30 nmi	-	> 20	-	> 20
	Total	10 nmi	> 20	> 20	> 20	> 20
		20 nmi	-	13	-	> 20
		30 nmi	-	> 20	-	> 20
Chick growth	Sardine	10 nmi	> 20	1	1	> 20
		20 nmi	-	> 20	-	> 20
		30 nmi	-	> 20	-	> 20
	Anchovy	10 nmi	1	1	1	1
		20 nmi	-	> 20	-	> 20
		30 nmi	-	> 20	-	> 20
	Total	10 nmi	1	1	1	1
		20 nmi	-	> 20	-	> 20
		30 nmi	-	> 20	-	> 20
Foraging path length	Sardine	10 nmi	> 20	> 20	> 20	> 20
		20 nmi	-	> 20	-	> 20
		30 nmi	-	> 20	-	> 20
	Anchovy	10 nmi	> 20	> 20	> 20	> 20
		20 nmi	-	> 20	-	20
		30 nmi	-	> 20	-	0
	Total	10 nmi	> 20	> 20	> 20	> 20
		20 nmi	-	> 20	-	18
		30 nmi	-	> 20	-	0
Foraging trip duration	Sardine	10 nmi	> 20	> 20	> 20	> 20
		20 nmi	-	> 20	-	> 20
		30 nmi	-	> 20	-	> 20
	Anchovy	10 nmi	0	0	> 20	> 20
		20 nmi	-	> 20	-	> 20
		30 nmi	-	> 20	-	0
	Total	10 nmi	0	0	> 20	> 20
		20 nmi	-	> 20	-	> 20
		30 nmi	-	> 20	-	0

Table B.5: The number of additional years' data required to detect a fishing effect significant at the 5% level with **95%** probability is given for each of Bird and StCroix islands for the **updated datasets from 2008 onwards**, where the true values of λ are assumed to be the random effects model-estimates. If a model-estimated λ value is small (i.e. $|\lambda| < 0.1$) then $\lambda = \pm 0.1$ is assumed for the effect size, where the sign is chosen according to the sign of the model-estimate for λ. A value of 0 indicates that the existing estimate of λ is already significant at the 5% level. C/O indicates future alternating periods of three years of the area being closed and open to fishing; O indicates the area is always open in the future.

			Bird		StCroix	
Response	Fish	Area	C/O	O	C/O	O
Foraging path length	Sardine	10 nmi	0	0	0	0
		20 nmi	-	0	-	0
		30 nmi	-	0	-	0
Foraging trip duration	Sardine	10 nmi	> 20	> 20	> 20	> 20
		20 nmi	-	> 20	-	0
		30 nmi	-	> 20	-	> 20

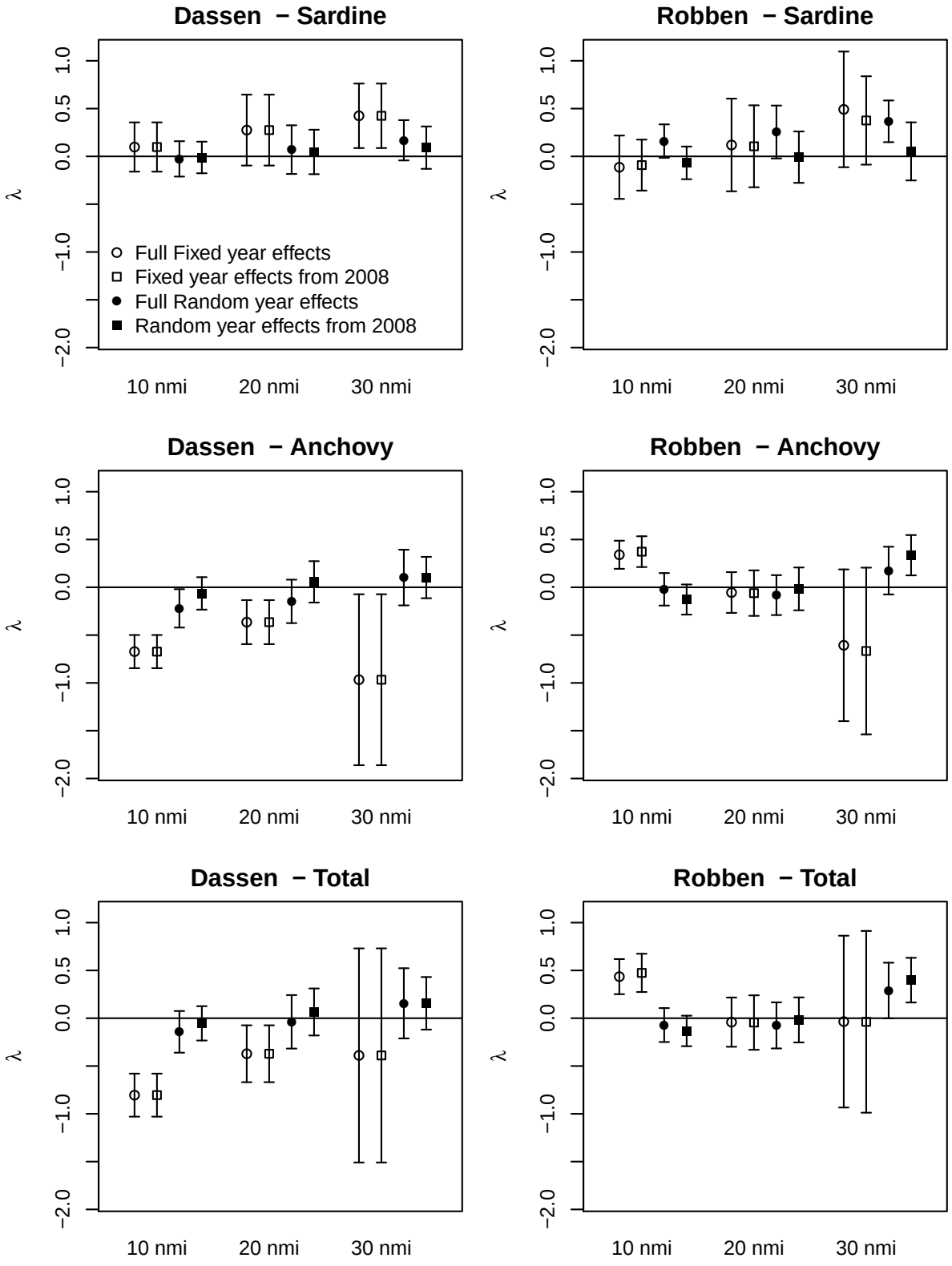

Figure B.1: Dassen and Robben Islands fishing effect parameter estimates: for the **chick condition** response variable for the **updated datasets**. Bars indicate one standard error.

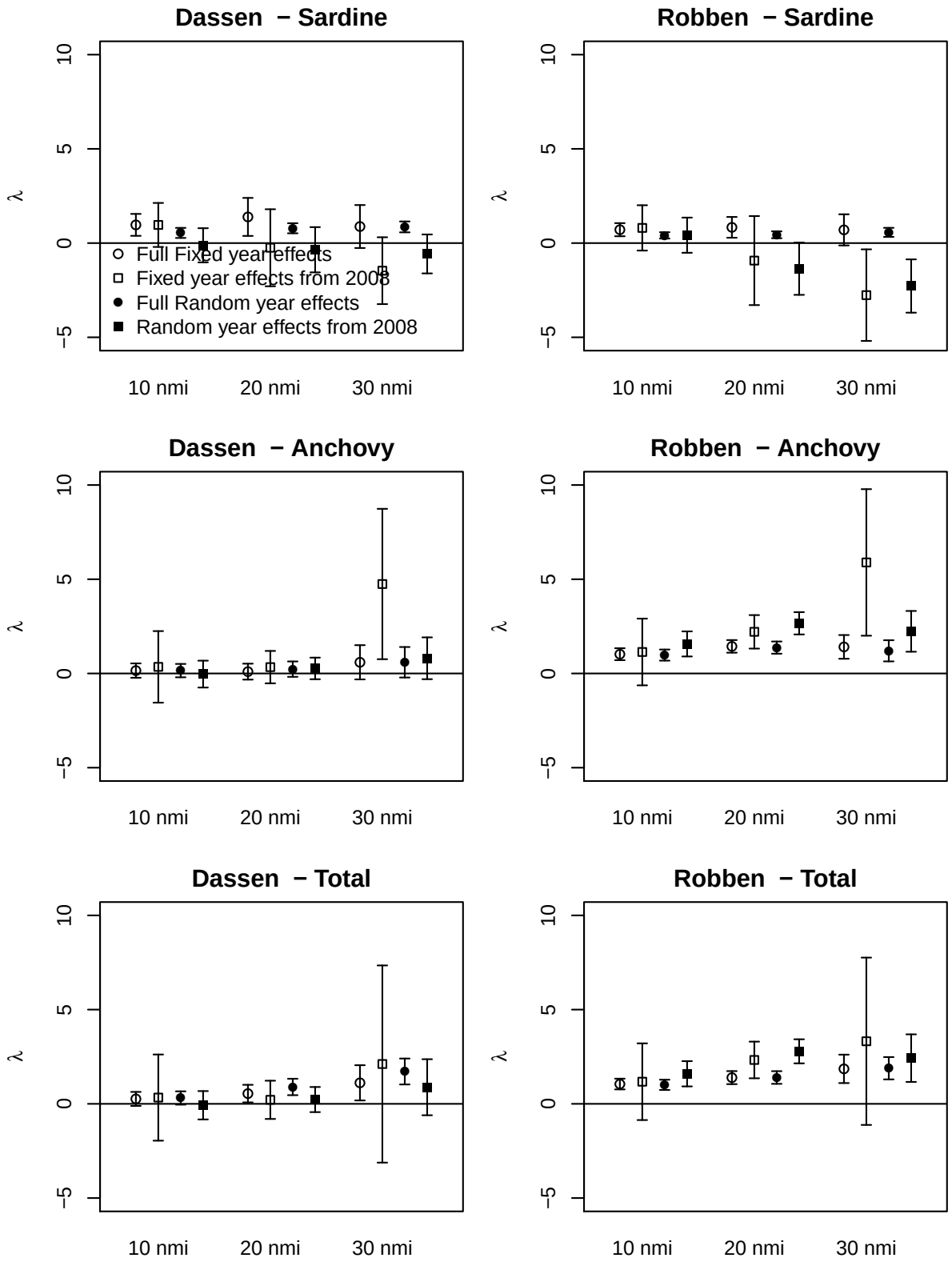

Figure B.2: Dassen and Robben Islands fishing effect parameter estimates: for the **active nest proportion** response variable for the **updated datasets**. Bars indicate one standard error.

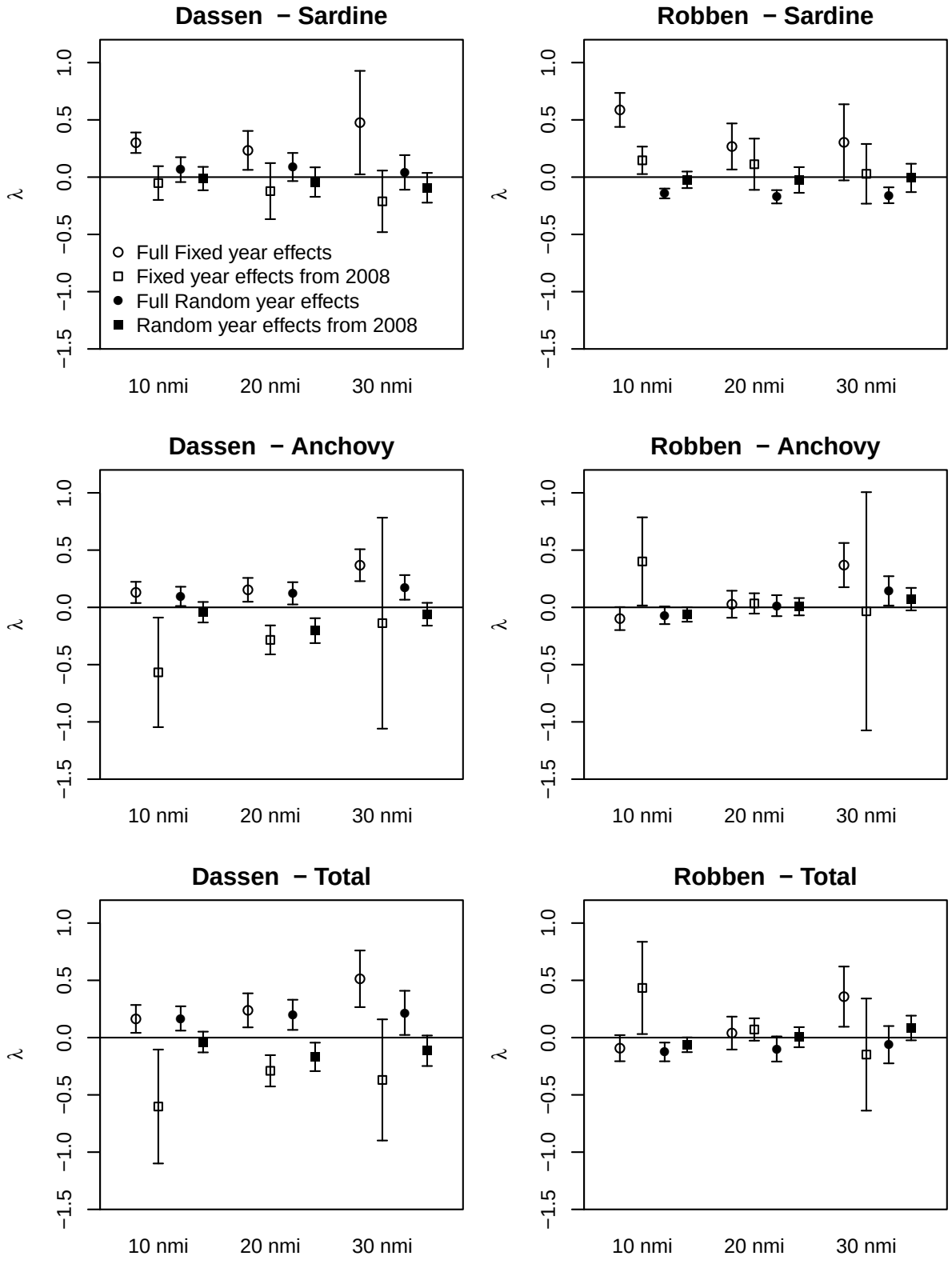

Figure B.3: Dassen and Robben Islands fishing effect parameter estimates: for the **fledging success** response variable for the **updated datasets**. Bars indicate one standard error.

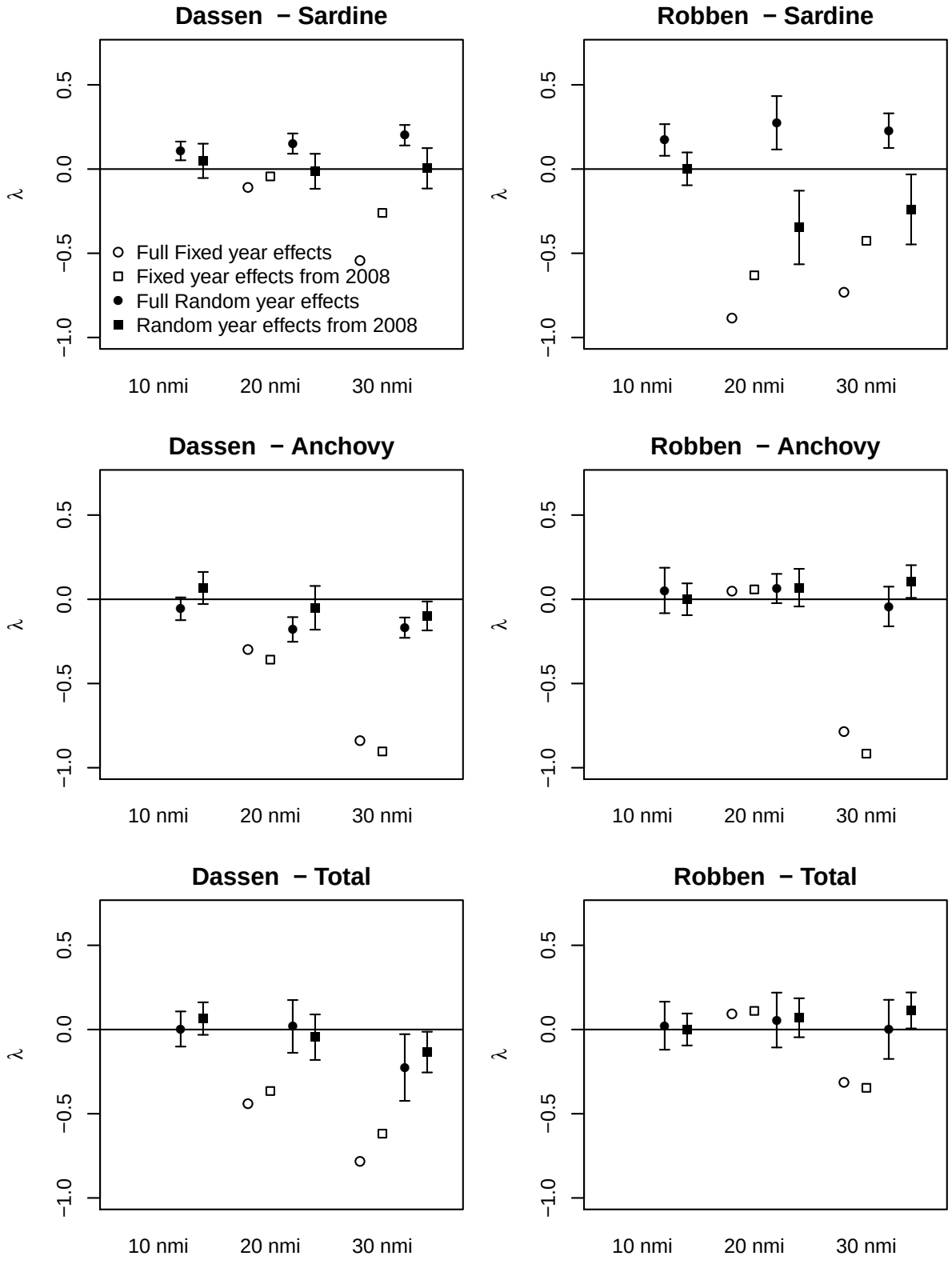

Figure B.4: Dassen and Robben Islands fishing effect parameter estimates: for the **chick growth rate** response variable for the **updated datasets**. Bars indicate one standard error.

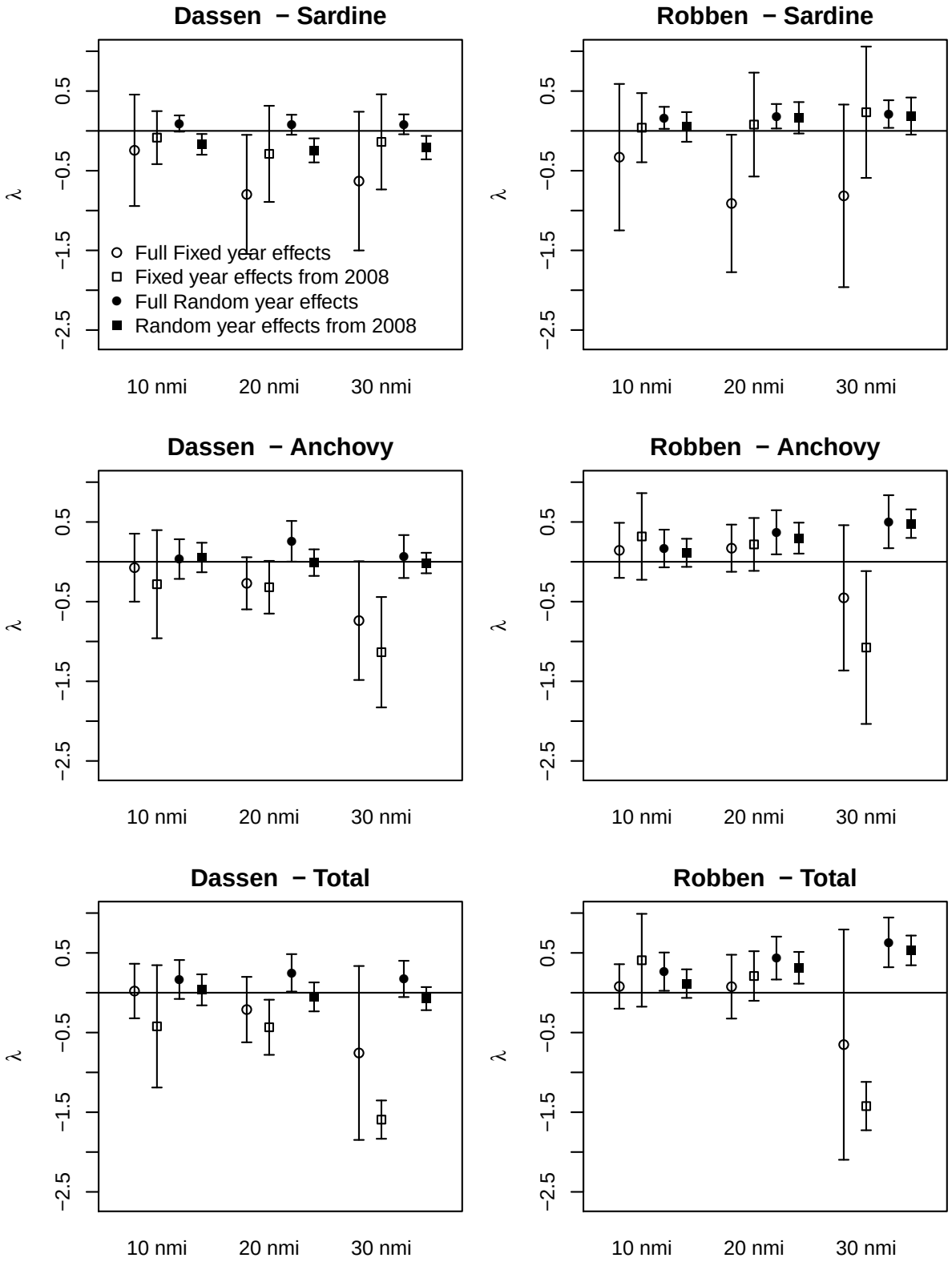

Figure B.5: Dassen and Robben Islands fishing effect parameter estimates: for the **foraging path length** response variable for the **updated datasets**. Bars indicate one standard error.

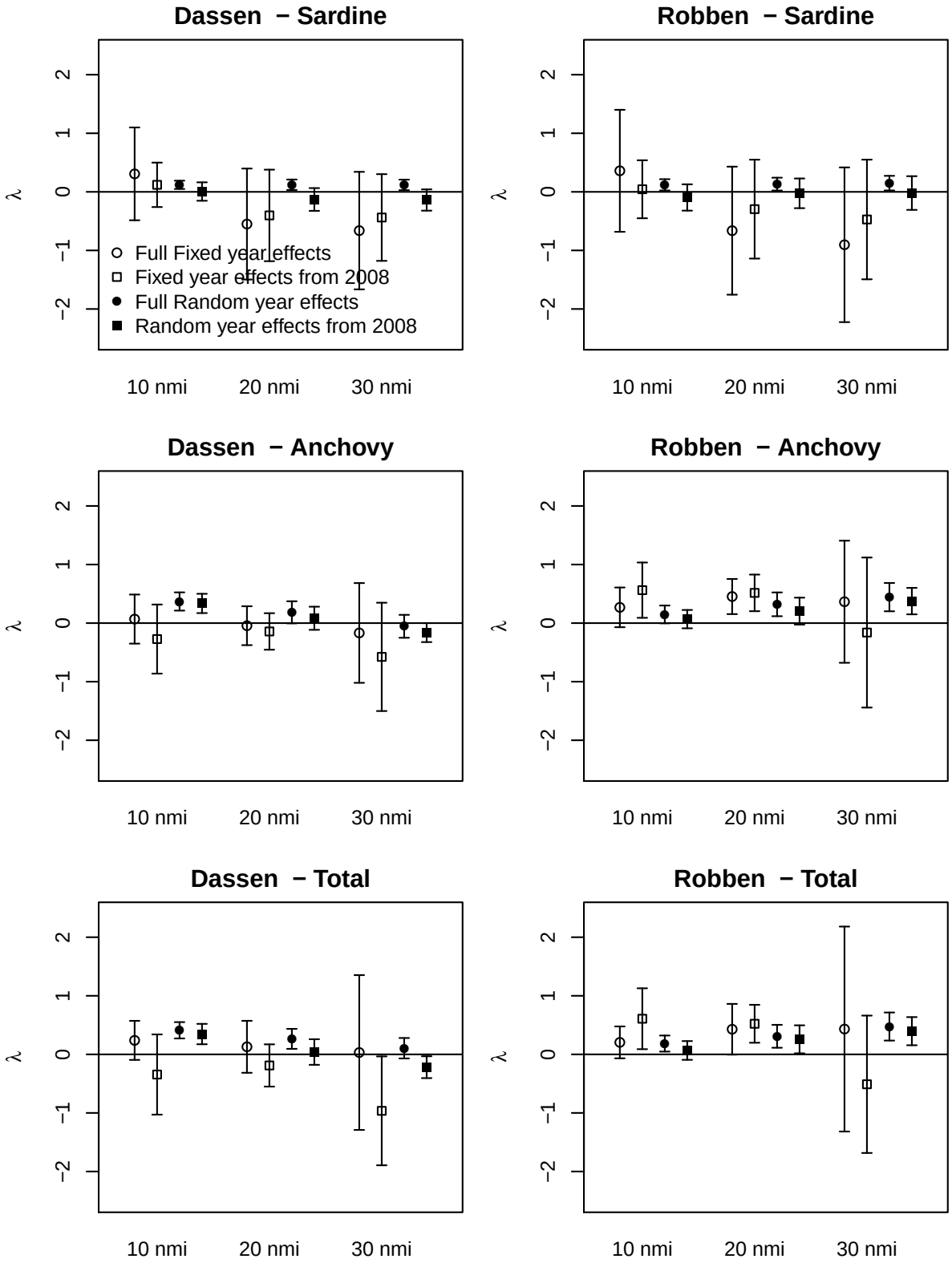

Figure B.6: Dassen and Robben Islands fishing effect parameter estimates: for the **foraging trip duration** response variable for the **updated datasets**. Bars indicate one standard error.

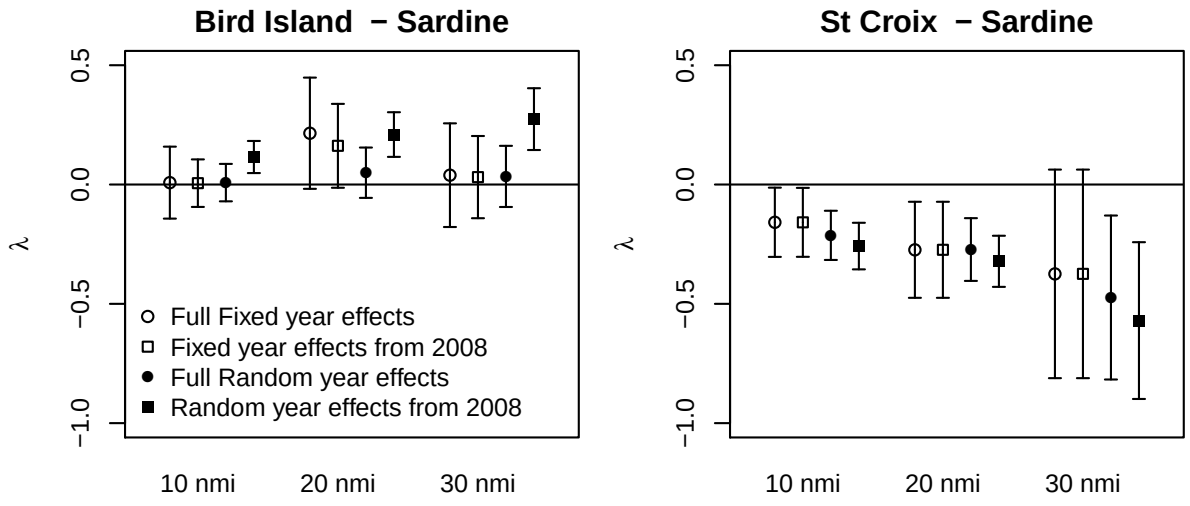

Figure B.7: Bird and St Croix Islands fishing effect parameter estimates: for the **foraging path length** response variable for the **updated datasets**. Bars indicate one standard error.

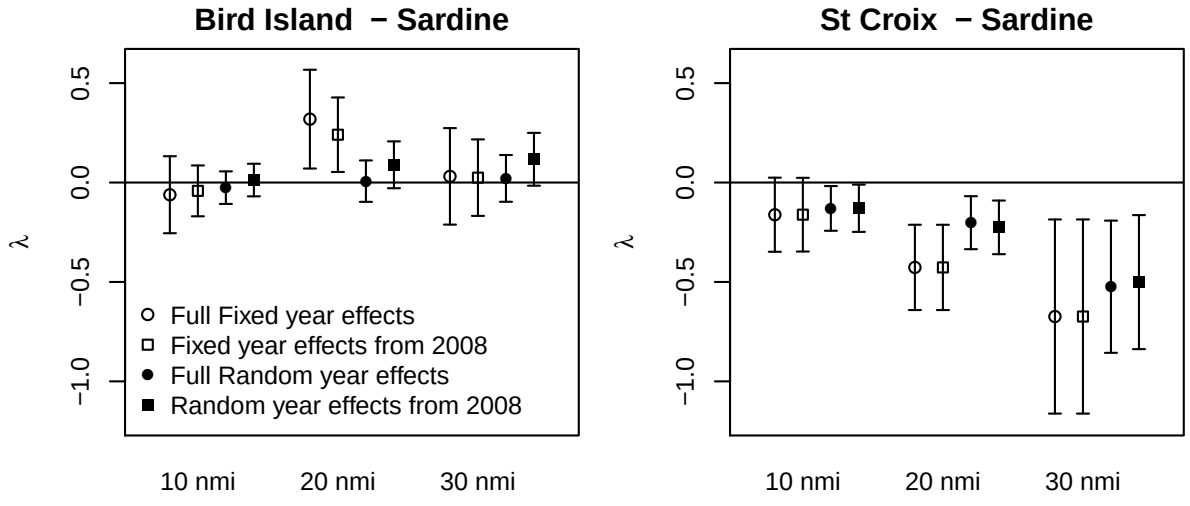

Figure B.8: Bird and St Croix Islands fishing effect parameter estimates: for the **foraging trip duration** response variable for the **updated datasets**. Bars indicate one standard error.

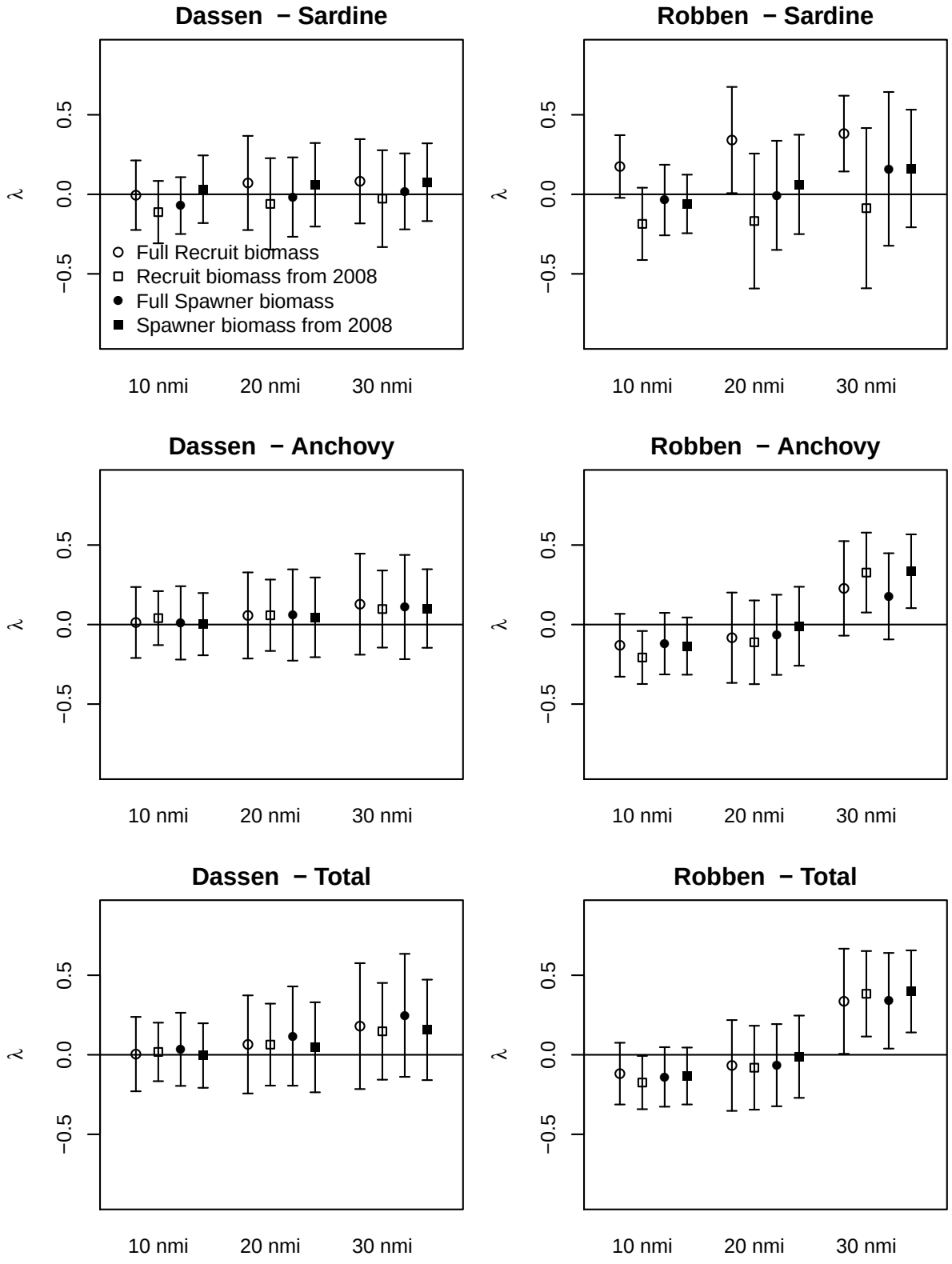

Figure B.9: Dassen and Robben Islands fishing effect parameter estimates: for the **chick condition** response variable for the **updated datasets**. Bars indicate one standard error.

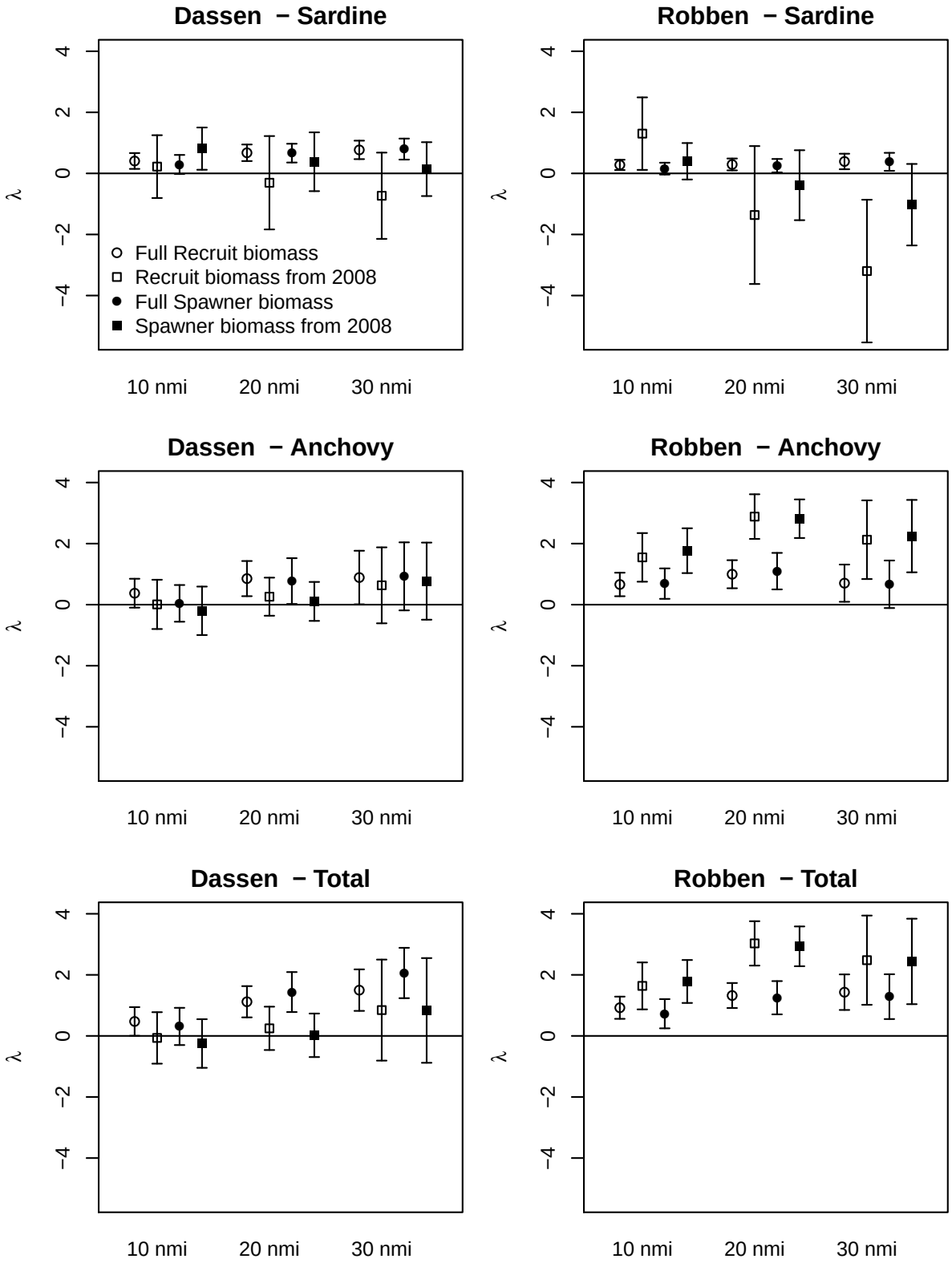

Figure B.10: Dassen and Robben Islands fishing effect parameter estimates: for the **active nest proportion** response variable for the **updated datasets**. Bars indicate one standard error.

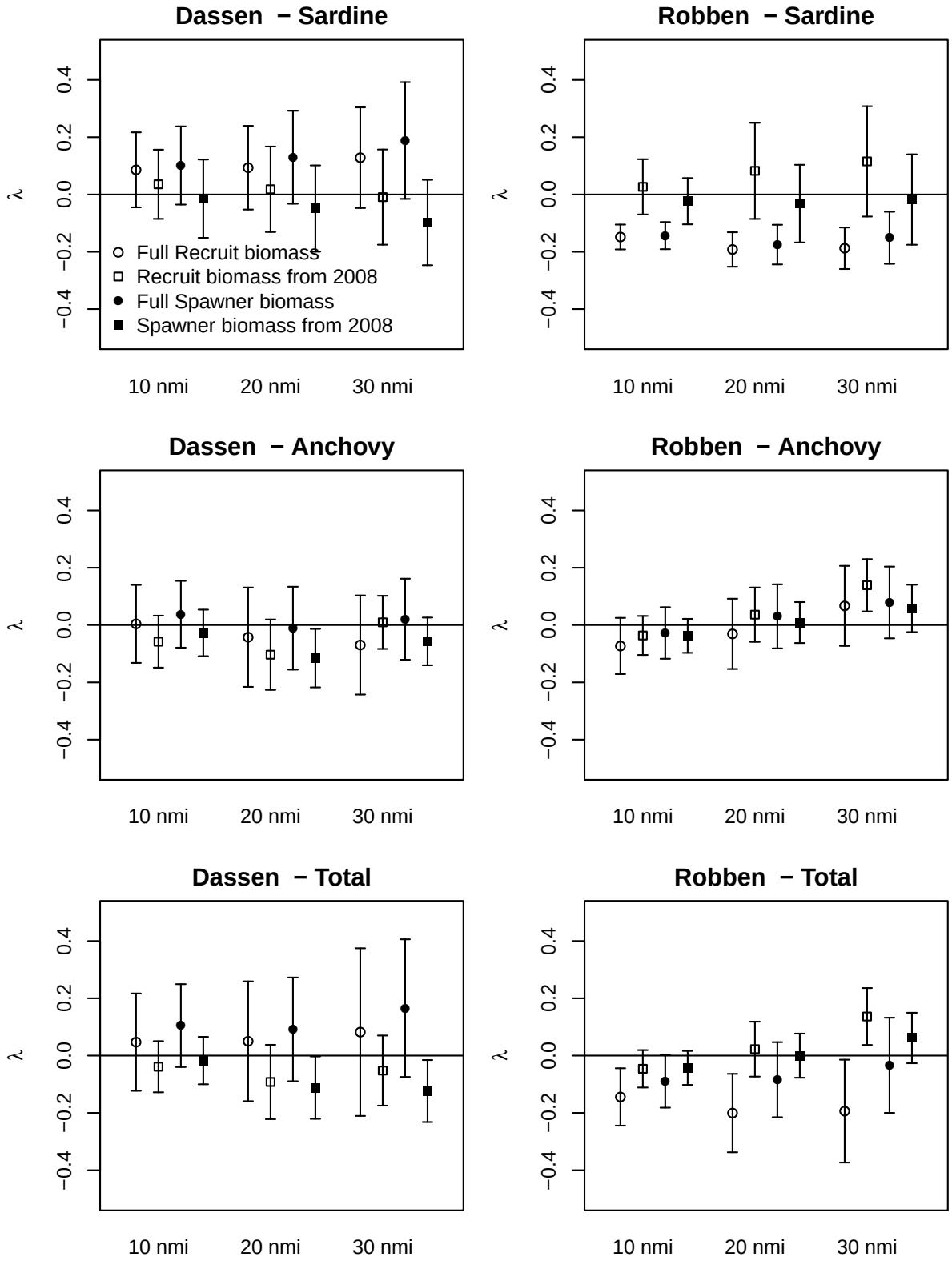

Figure B.11: Dassen and Robben Islands fishing effect parameter estimates: for the **fledging success** response variable for the **updated datasets**. Bars indicate one standard error.

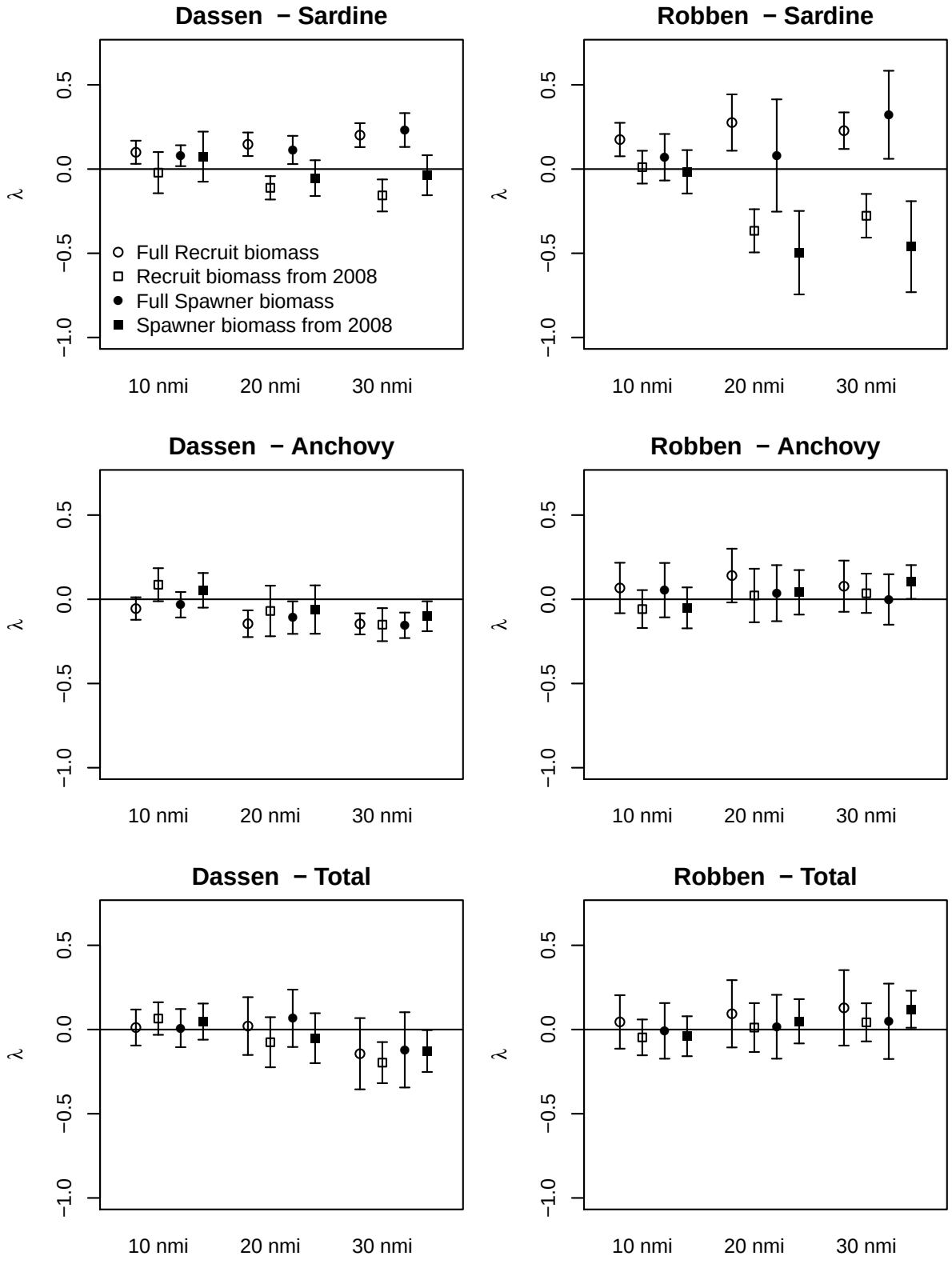

Figure B.12: Dassen and Robben Islands fishing effect parameter estimates: for the **chick growth rate** response variable for the **updated datasets**. Bars indicate one standard error.

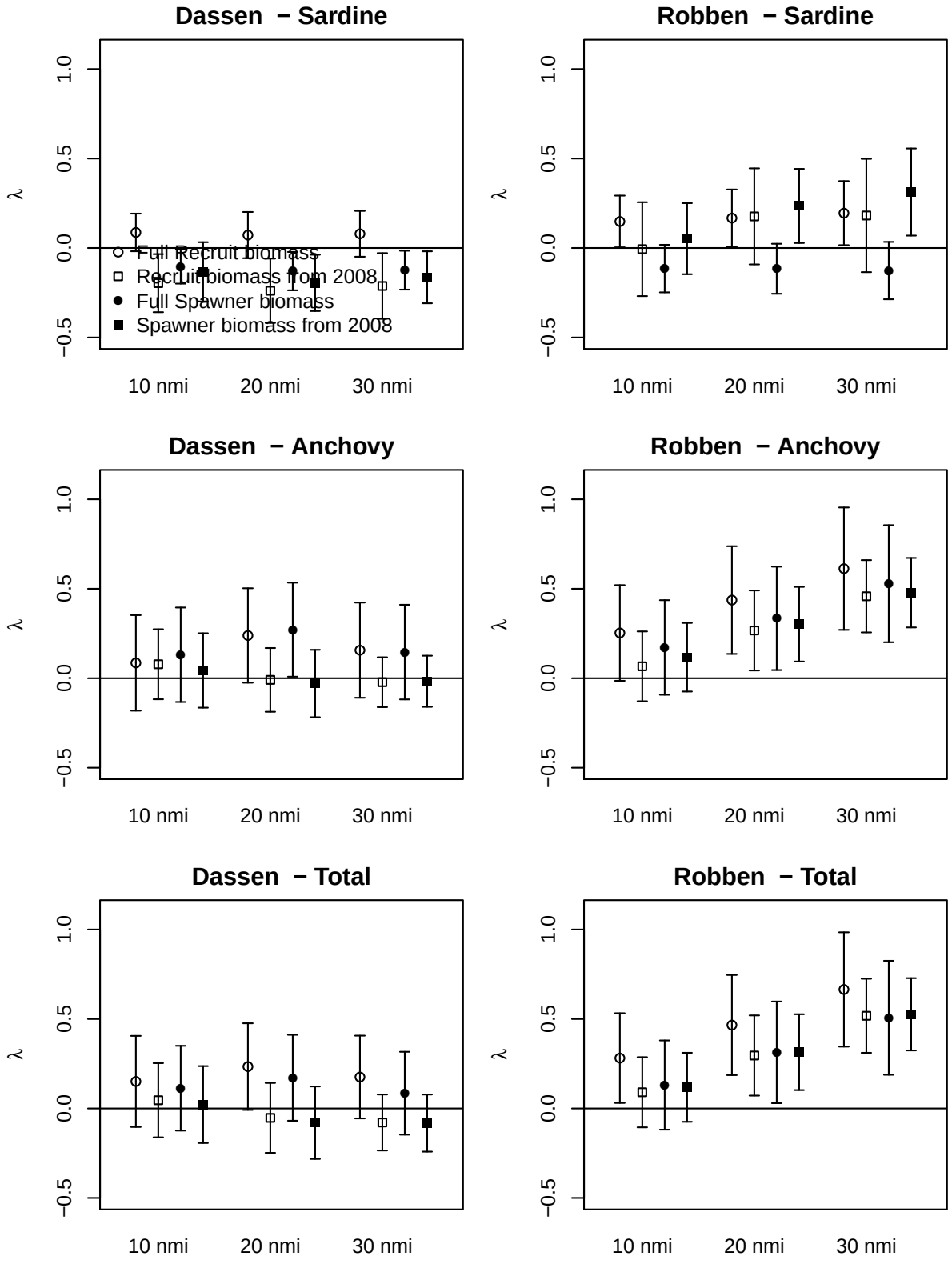

Figure B.13: Dassen and Robben Islands fishing effect parameter estimates: for the **foraging path length** response variable for the **updated datasets**. Bars indicate one standard error.

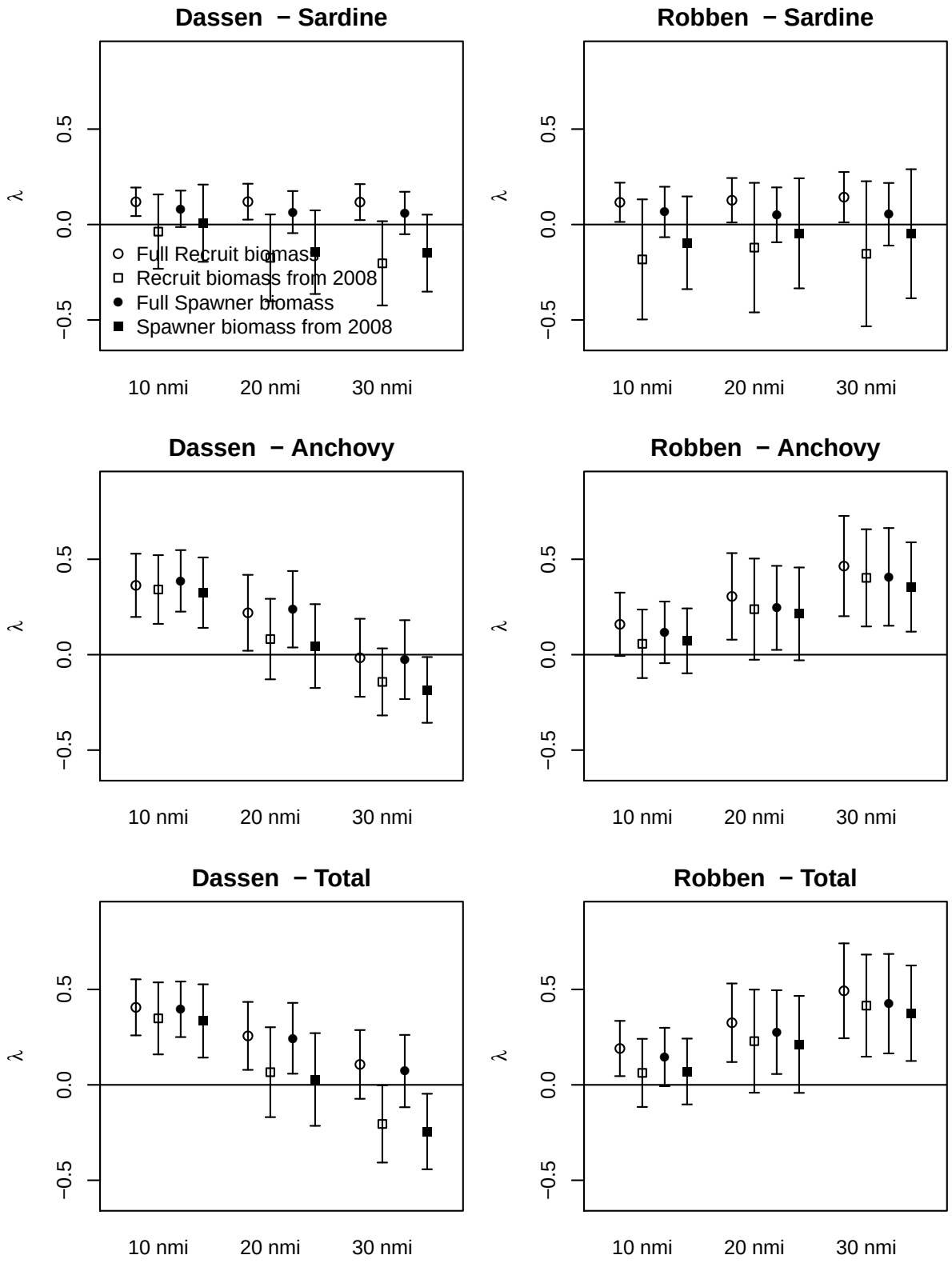

Figure B.14: Dassen and Robben Islands fishing effect parameter estimates: for the **foraging trip duration** response variable for the **updated datasets**. Bars indicate one standard error.

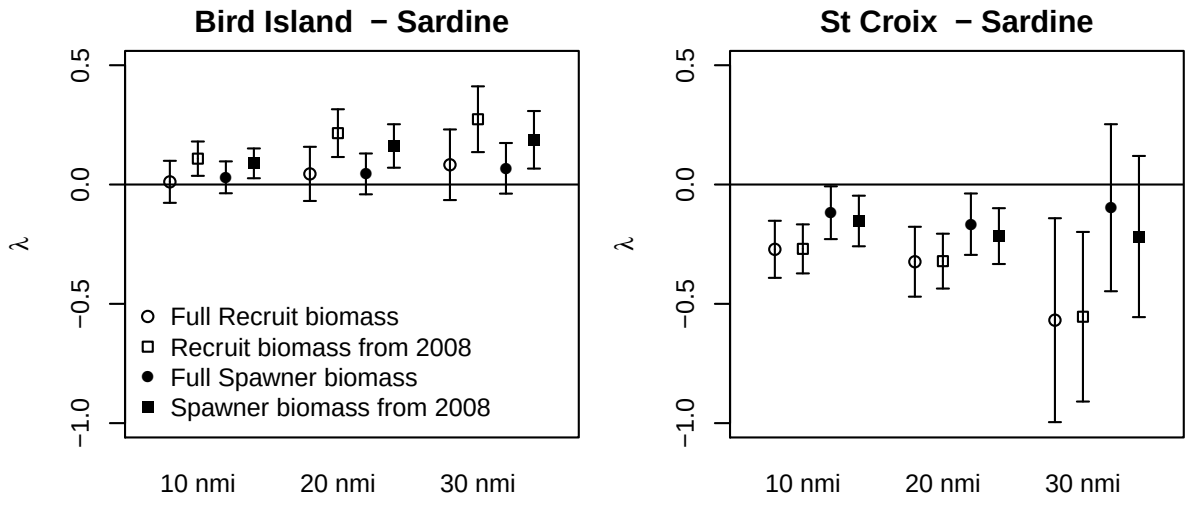

Figure B.15: Bird and St Croix Islands fishing effect parameter estimates: for the **foraging path length** response variable for the **updated datasets**. Bars indicate one standard error.

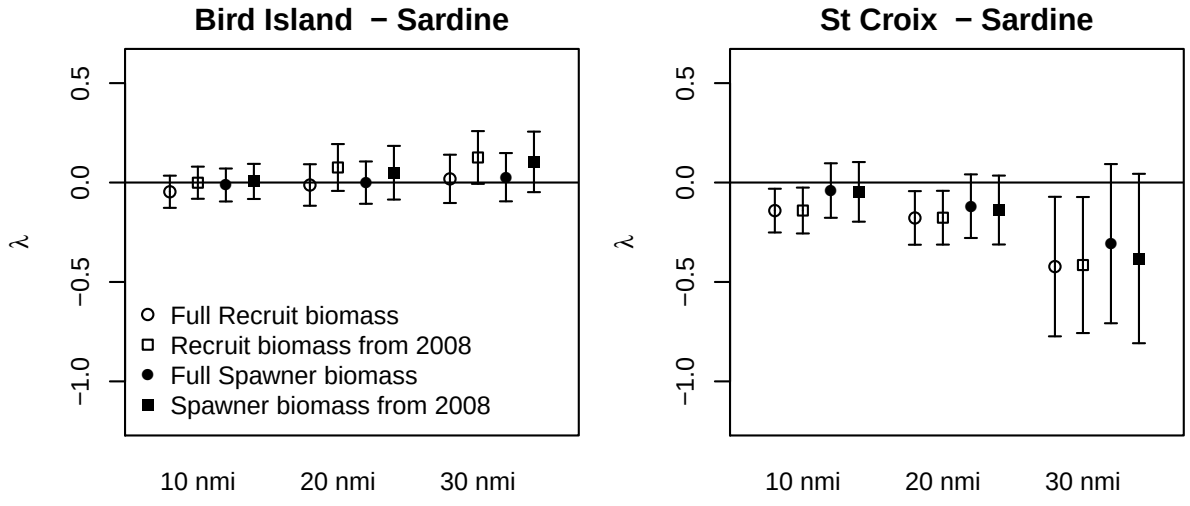

Figure B.16: Bird and St Croix Islands fishing effect parameter estimates: for the **foraging trip duration** response variable for the **updated datasets**. Bars indicate one standard error.

Appendix C

Results for updated data for all years with closure replacing catch as a co-variate

Table C.1: Residual standard error σ_ε and upper 95% confidence limits $\sigma_{\varepsilon,+95}$ (estimated using a likelihood profile approach) for each penguin response series for the **updated datasets for all years when continuous catch co-variate is replaced by the categorical open/closed co-variate for 10nmi** available for assessing the power of the island closure experiment are listed for the random year effects model. Note that MLE estimates are negatively biased because of the small number of degrees of freedom, but these estimates are unbiased through use of REML. The number of past data points n and the number of model parameters estimated p are indicated for the model. Results are given for the case of total catch within 30 nmi for the Western Cape and sardine catch within 30 nmi for the Eastern Cape.

(a) Dassen and Robben islands

Penguin response	n	p	σ_ε	$\sigma_{\varepsilon,+95}$
Chick condition	11	5	0.212	0.330
Active nest proportion	27	5	0.411	0.541
Fledging success	32	6	0.083	0.107
Chick growth	14	5	0.049	0.072
Foraging path length	14	5	0.281	0.415
Foraging trip duration	14	5	0.205	0.302

(b) St Croix and Bird islands

Penguin response	n	p	σ_ε	$\sigma_{\varepsilon,+95}$
Foraging path length	13	5	0.106	0.158
Foraging trip duration	13	5	0.128	0.191

Table C.2: Fishing effect parameters λ with associated standard errors for (i) fixed year effects, (ii) random year effects, (iii) year effects given by spawner biomass, and (iv) year effects given by recruit biomass for the **updated datasets for all years when continuous catch co-variate is replaced by the categorical open/closed co-variate for 10nmi**. Note that the "Fish" effect remains for models (iii) and (iv) because that defines the survey biomass series used and that there are no estimates for model (i) because of inadequate degrees of freedom. Values significantly different from zero at the 15% and 5% levels are indicated by one and two asterisks respectively. Statistical significance is based on a normal approximation for the random effects model and a two-sided t-test for the other models. Cases where the correlation between the catch and the (recruit or spawning) biomass exceeds $r = 0.7$ are indicated by a †. Some results are left blank in cases where there are no degrees of freedom.

(a) Dassen Island

Penguin response	Fish	Area	λ				s.e.			
			(i)	(ii)	(iii)	(iv)	(i)	(ii)	(iii)	(iv)
Chick condition	Sardine	-	-	-0.06	-0.07	-0.02	-	0.25	0.22	0.29
	Anchovy	-	-	-0.06	-0.02	-0.02	-	0.25	0.27	0.28
	Total	-	-	-0.06	-0.01	-0.02	-	0.25	0.26	0.27
Active nest proportion	Sardine	-	-	1.06**	0.04	0.18	-	0.57	0.81	0.80
	Anchovy	-	-	1.06**	0.50	0.70	-	0.57	0.84	0.68
	Total	-	-	1.06**	0.40	0.50	-	0.57	0.83	0.69
Fledging success	Sardine	-	-	0.10	0.12	0.03	-	0.21	0.26	0.27
	Anchovy	-	-	0.10	-0.07	0.09	-	0.21	0.25	0.26
	Total	-	-	0.10	0.01	0.07	-	0.21	0.24	0.26
Chick growth	Sardine	-	-	0.22**	0.16	0.20	-	0.12	0.11	0.14
	Anchovy	-	-	0.22**	0.17	0.16	-	0.12	0.12	0.15
	Total	-	-	0.22**	0.21*	0.19	-	0.12	0.13	0.14
Foraging path length	Sardine	-	-	0.19	-0.05	0.28	-	0.29	0.23	0.30
	Anchovy	-	-	0.19	0.20	0.14	-	0.29	0.31	0.33
	Total	-	-	0.19	0.13	0.15	-	0.29	0.29	0.32
Foraging trip duration	Sardine	-	-	0.45**	0.35*	0.49**	-	0.19	0.20	0.19
	Anchovy	-	-	0.45**	0.45*	0.46 *	-	0.19	0.20	0.22
	Total	-	-	0.45**	0.41*	0.44 *	-	0.19	0.20	0.21

Table C.2: Continued.

(b) Robben Island

Penguin response	Fish	Area	λ				s.e.			
			(i)	(ii)	(iii)	(iv)	(i)	(ii)	(iii)	(iv)
Chick condition	Sardine	-	-	-0.03	-0.11	-0.02	-	0.23	0.22	0.26
	Anchovy	-	-	-0.03	-0.01†	-0.02	-	0.23	0.32	0.29
	Total	-	-	-0.03	-0.15†	-0.02	-	0.23	0.31	0.28
Active nest proportion	Sardine	-	-	1.03**	1.30*	1.33*	-	0.57	0.79	0.80
	Anchovy	-	-	1.03**	1.56*	1.01	-	0.57	0.93	0.70
	Total	-	-	1.03**	1.27	1.03	-	0.57	0.90	0.71
Fledging success	Sardine	-	-	-0.26 *	-0.32	-0.38	-	0.23	0.25	0.25
	Anchovy	-	-	-0.26 *	-0.11	-0.39*	-	0.23	0.26	0.25
	Total	-	-	-0.26 *	-0.09	-0.40*	-	0.23	0.26	0.25
Chick growth	Sardine	-	-	0.11	0.04	0.11	-	0.14	0.13	0.15
	Anchovy	-	-	0.11	0.19†	0.14	-	0.14	0.15	0.15
	Total	-	-	0.11	0.11†	0.12	-	0.14	0.17	0.15
Foraging path length	Sardine	-	-	0.16	0.09	0.32	-	0.28	0.23	0.30
	Anchovy	-	-	0.16	0.16†	0.33	-	0.28	0.38	0.35
	Total	-	-	0.16	0.01†	0.35	-	0.28	0.33	0.34
Foraging trip duration	Sardine	-	-	0.07	0.03	0.14	-	0.19	0.19	0.19
	Anchovy	-	-	0.07	0.03†	0.06	-	0.19	0.24	0.23
	Total	-	-	0.07	-0.01†	0.11	-	0.19	0.22	0.22

Table C.2: Continued.

(c) Bird Island

Penguin response	Fish	Area	λ				s.e.			
			(i)	(ii)	(iii)	(iv)	(i)	(ii)	(iii)	(iv)
Foraging path length	Sardine	-	-	0.05	-0.09	0.07	-	0.08	0.13	0.18
Foraging trip duration	Sardine	-	-	-0.17*	-0.28*	-0.16	-	0.15	0.14	0.15

(d) St Croix Island

Penguin response	Fish	Area	λ				s.e.			
			(i)	(ii)	(iii)	(iv)	(i)	(ii)	(iii)	(iv)
Foraging path length	Sardine	-	-	-0.39**	-0.16	-0.33*	-	0.08	0.13	0.18
Foraging trip duration	Sardine	-	-	-0.19 *	-0.04	-0.19	-	0.14	0.14	0.15

Table C.3: Tallies of positive and negative values of λ, those significantly different from zero at the 15% level, and those significantly different from zero at the 5% level for the **updated datasets for all years when continuous catch co-variate is replaced by the categorical open/closed co-variate for 10nmi**. "Both no †" tallies omit instances where the catch-biomass correlation exceeds $r = 0.7$.

(a) Western Cape

		Fixed year effects			Random year effects			Spawner Biomass			Recruit Biomass		
		all	15%	5%	all	15%	5%	all	15%	5%	all	15%	5%
Chick condition	Dassen				0:3	0:0	0:0	0:3	0:0	0:0	0:3	0:0	0:0
	Robben				0:3	0:0	0:0	0:3	0:0	0:0	0:3	0:0	0:0
Active nest proportion	Dassen				3:0	3:0	3:0	3:0	0:0	0:0	3:0	0:0	0:0
	Robben				3:0	3:0	3:0	3:0	2:0	0:0	3:0	1:0	0:0
Fledging success	Dassen				3:0	0:0	0:0	2:1	0:0	0:0	3:0	0:0	0:0
	Robben				0:3	0:3	0:0	0:3	0:0	0:0	0:3	0:2	0:0
Chick growth	Dassen				3:0	3:0	3:0	3:0	1:0	0:0	3:0	0:0	0:0
	Robben				3:0	0:0	0:0	3:0	0:0	0:0	3:0	0:0	0:0
Foraging path length	Dassen				3:0	0:0	0:0	2:1	0:0	0:0	3:0	0:0	0:0
	Robben				3:0	0:0	0:0	3:0	0:0	0:0	3:0	0:0	0:0
Foraging trip duration	Dassen				3:0	3:0	3:0	3:0	3:0	0:0	3:0	3:0	1:0
	Robben				3:0	0:0	0:0	2:1	0:0	0:0	3:0	0:0	0:0
Total	Dassen				15:3	9:0	9:0	13:5	4:0	0:0	15:3	3:0	1:0
	Robben				12:6	3:3	3:0	11:7	2:0	0:0	12:6	1:2	0:0
	Both				27:9	12:3	12:0	24:12	6:0	0:0	27:9	4:2	1:0
	Both no †							19:9	6:0	0:0			

(b) Eastern Cape

		Fixed year effects			Random year effects			Spawner Biomass			Recruit Biomass		
		all	15%	5%	all	15%	5%	all	15%	5%	all	15%	5%
Foraging path length	Bird				1:0	0:0	0:0	0:1	0:0	0:0	1:0	0:0	0:0
	St Croix				0:1	0:1	0:1	0:1	0:0	0:0	0:1	0:1	0:0
Foraging trip duration	Bird				0:1	0:1	0:0	0:1	0:1	0:0	0:1	0:0	0:0
	St Croix				0:1	0:1	0:0	0:1	0:0	0:0	0:1	0:0	0:0
Total	Bird				1:1	0:1	0:0	0:2	0:1	0:0	1:1	0:0	0:0
	St Croix				0:2	0:2	0:1	0:2	0:0	0:0	0:2	0:1	0:0
	Both				1:3	0:3	0:1	0:4	0:1	0:0	1:3	0:1	0:0
	Both no †												

Table C.4: The number of additional years' data required to detect a fishing effect significant at the 5% level with **95%** probability is given for each of Dassen and Robben islands for the **updated datasets for all years when continuous catch co-variate is replaced by the categorical open/closed co-variate for 10nmi**, where the true values of λ are assumed to be the random effects model-estimates. If a model-estimated λ value is small (i.e. $|\lambda| < 0.1$) then $\lambda = \pm 0.1$ is assumed for the effect size, where the sign is chosen according to the sign of the model-estimate for λ. A value of 0 indicates that the existing estimate of λ is already significant at the 5% level. C/O indicates future alternating periods of three years of the area being closed and open to fishing; O indicates the area is always open in the future.

			Dassen		Robben	
Response	Fish	Area	C/O	O	C/O	O
Chick condition	Sardine	-	> 20	> 20	> 20	> 20
	Anchovy	-	> 20	> 20	> 20	> 20
	Total	-	> 20	> 20	> 20	> 20
Active nest proportion	Sardine	-	0	0	0	0
	Anchovy	-	0	0	0	0
	Total	-	0	0	0	0
Fledging success	Sardine	-	> 20	> 20	> 20	> 20
	Anchovy	-	> 20	> 20	> 20	> 20
	Total	-	> 20	> 20	> 20	> 20
Chick growth	Sardine	-	0	0	> 20	> 20
	Anchovy	-	0	0	> 20	> 20
	Total	-	0	0	> 20	> 20
Foraging path length	Sardine	-	> 20	> 20	> 20	> 20
	Anchovy	-	> 20	> 20	> 20	> 20
	Total	-	> 20	> 20	> 20	> 20
Foraging trip duration	Sardine	-	0	0	> 20	> 20
	Anchovy	-	0	0	> 20	> 20
	Total	-	0	0	> 20	> 20

Table C.5: The number of additional years' data required to detect a fishing effect significant at the 5% level with **95%** probability is given for each of Bird and StCroix islands for the **updated datasets for all years when continuous catch co-variate is replaced by the categorical open/closed co-variate**, where the true values of λ are assumed to be the random effects model-estimates. If a model-estimated λ value is small (i.e. $|\lambda| < 0.1$) then $\lambda = \pm 0.1$ is assumed for the effect size, where the sign is chosen according to the sign of the model-estimate for λ. A value of 0 indicates that the existing estimate of λ is already significant at the 5% level. C/O indicates future alternating periods of three years of the area being closed and open to fishing; O indicates the area is always open in the future.

			Bird		StCroix	
Response	Fish	Area	C/O	O	C/O	O
Foraging path length	Sardine	10 nmi	11	11	0	0
Foraging trip duration	Sardine	10 nmi	> 20	> 20	16	> 20

Appendix D

Results for updated data for years 2008+ with closure replacing catch as a co-variate

Table D.1: Residual standard error σ_ε and upper 95% confidence limits $\sigma_{\varepsilon,+95}$ (estimated using a likelihood profile approach) for each penguin response series available for the **updated datasets from 2008 onwards when continuous catch co-variate is replaced by the categorical open/closed co-variate for 10nmi** for assessing the power of the island closure experiment are listed for the random year effects model. Note that MLE estimates are negatively biased because of the small number of degrees of freedom, but these estimates are unbiased through use of REML. The number of past data points n and the number of model parameters estimated p are indicated for the model. Results are given for the case of total catch within 30 nmi for the Western Cape and sardine catch within 30 nmi for the Eastern Cape.

(a) Dassen and Robben islands

Penguin response	n	p	σ_ε	$\sigma_{\varepsilon,+95}$
Chick condition	10	5	0.155	0.247
Active nest proportion	10	5	0.702	1.116
Fledging success	9	5	0.069	0.113
Chick growth	8	5	0.060	0.102
Foraging path length	11	5	0.147	0.228
Foraging trip duration	11	5	0.154	0.240

(b) St Croix and Bird islands

Penguin response	n	p	σ_ε	$\sigma_{\varepsilon,+95}$
Foraging path length	12	5	0.153	0.234
Foraging trip duration	12	5	0.142	0.216

Table D.2: Fishing effect parameters λ with associated standard errors for (i) fixed year effects, (ii) random year effects, (iii) year effects given by spawner biomass, and (iv) year effects given by recruit biomass for the **updated datasets from 2008 onwards when continuous catch co-variate is replaced by the categorical open/closed co-variate for 10nmi**. Note that the "Fish" effect remains for models (iii) and (iv) because that defines the survey biomass series used and that there are no estimates for model (i) because of inadequate degrees of freedom. Values significantly different from zero at the 15% and 5% levels are indicated by one and two asterisks respectively. Statistical significance is based on a normal approximation for the random effects model and a two-sided t-test for the other models. Cases where the correlation between the catch and the (recruit or spawning) biomass exceeds $r = 0.7$ are indicated by a †. Some results are left blank in cases where there are no degrees of freedom.

(a) Dassen Island

Penguin response	Fish	Area	λ				s.e.			
			(i)	(ii)	(iii)	(iv)	(i)	(ii)	(iii)	(iv)
Chick condition	Sardine	-	-	-0.03	0.08	-0.07	-	0.20	0.24	0.23
	Anchovy	-	-	-0.03	-0.01	0.09	-	0.20	0.23	0.19
	Total	-	-	-0.03	-0.02	0.02	-	0.20	0.23	0.19
Active nest proportion	Sardine	-	-	0.09	0.80	0.16	-	0.96	0.75	1.00
	Anchovy	-	-	0.09	-0.57	-0.37	-	0.96	0.93	1.18
	Total	-	-	0.09	-0.48	-0.41	-	0.96	0.87	1.09
Fledging success	Sardine	-	-	-0.02	-0.01†	0.01	-	0.09	0.13	0.11
	Anchovy	-	-	-0.02	-0.01	-0.05	-	0.09	0.08	0.10
	Total	-	-	-0.02	-0.00	-0.03	-	0.09	0.09	0.09
Chick growth	Sardine	-	-	0.06	0.09†	-0.01	-	0.10	0.14	0.12
	Anchovy	-	-	0.06	0.05	0.09	-	0.10	0.10	0.10
	Total	-	-	0.06	0.04	0.07	-	0.10	0.10	0.10
Foraging path length	Sardine	-	-	-0.04	0.06	-0.02	-	0.22	0.25	0.25
	Anchovy	-	-	-0.04	-0.06	0.01	-	0.22	0.24	0.24
	Total	-	-	-0.04	-0.05	-0.03	-	0.22	0.23	0.24
Foraging trip duration	Sardine	-	-	0.38**	0.47*	0.41*	-	0.20	0.23	0.23
	Anchovy	-	-	0.38**	0.36*	0.42*	-	0.20	0.22	0.22
	Total	-	-	0.38**	0.37*	0.39*	-	0.20	0.21	0.22

Table D.2: Continued.

(b) Robben Island

Penguin response	Fish	Area	λ				s.e.			
			(i)	(ii)	(iii)	(iv)	(i)	(ii)	(iii)	(iv)
Chick condition	Sardine	-	-	-0.17	-0.22	-0.19	-	0.20	0.22	0.22
	Anchovy	-	-	-0.17	-0.19 †	-0.40∗†	-	0.20	0.28	0.23
	Total	-	-	-0.17	-0.17 †	-0.34 †	-	0.20	0.27	0.23
Active nest proportion	Sardine	-	-	1.61∗∗	0.97	1.97 ∗	-	0.96	0.69	0.97
	Anchovy	-	-	1.61∗∗	2.66∗†	1.72 †	-	0.96	1.14	1.41
	Total	-	-	1.61∗∗	2.63∗†	1.98 †	-	0.96	1.04	1.31
Fledging success	Sardine	-	-	-0.06	-0.07	-0.05	-	0.09	0.10	0.09
	Anchovy	-	-	-0.06	0.03 †	0.00 †	-	0.09	0.10	0.11
	Total	-	-	-0.06	0.02 †	-0.01 †	-	0.09	0.10	0.10
Chick growth	Sardine	-	-	0.00	-0.02	0.01	-	0.10	0.13	0.10
	Anchovy	-	-	0.00	-0.05 †	-0.06 †	-	0.10	0.12	0.11
	Total	-	-	0.00	-0.04 †	-0.05 †	-	0.10	0.12	0.11
Foraging path length	Sardine	-	-	0.12	0.05	0.14	-	0.23	0.25	0.27
	Anchovy	-	-	0.12	0.18 †	0.02 †	-	0.23	0.28	0.29
	Total	-	-	0.12	0.18	0.05 †	-	0.23	0.27	0.30
Foraging trip duration	Sardine	-	-	-0.03	-0.09	0.01	-	0.21	0.22	0.24
	Anchovy	-	-	-0.03	0.03 †	-0.13 †	-	0.21	0.26	0.27
	Total	-	-	-0.03	0.03	-0.08 †	-	0.21	0.25	0.27

Table D.2: Continued.

(c) Bird Island

Penguin response	Fish	Area	λ				s.e.			
			(i)	(ii)	(iii)	(iv)	(i)	(ii)	(iii)	(iv)
Foraging path length	Sardine	-	-	0.06	-0.07	0.13	-	0.08	0.15	0.18
Foraging trip duration	Sardine	-	-	-0.16	-0.30∗	-0.13	-	0.16	0.16	0.16

(d) St Croix Island

Penguin response	Fish	Area	λ				s.e.			
			(i)	(ii)	(iii)	(iv)	(i)	(ii)	(iii)	(iv)
Foraging path length	Sardine	-	-	-0.39∗∗	-0.17	-0.34∗	-	0.08	0.14	0.18
Foraging trip duration	Sardine	-	-	-0.20 ∗	-0.03	-0.19	-	0.15	0.15	0.16

Table D.3: Tallies of positive and negative values of λ, those significantly different from zero at the 15% level, and those significantly different from zero at the 5% level for the **updated datasets from 2008 onwards when continuous catch co-variate is replaced by the categorical open/closed co-variate for 10nmi**. "Both no †" tallies omit instances where the catch-biomass correlation exceeds $r = 0.7$.

(a) Western Cape

		Fixed year effects			Random year effects			Spawner Biomass			Recruit Biomass		
		all	15%	5%	all	15%	5%	all	15%	5%	all	15%	5%
Chick condition	Dassen				0:3	0:0	0:0	1:2	0:0	0:0	2:1	0:0	0:0
	Robben				0:3	0:0	0:0	0:3	0:0	0:0	0:3	0:1	0:0
Active nest proportion	Dassen				3:0	0:0	0:0	1:2	0:0	0:0	1:2	0:0	0:0
	Robben				3:0	3:0	3:0	3:0	2:0	0:0	3:0	1:0	0:0
Fledging success	Dassen				0:3	0:0	0:0	0:3	0:0	0:0	1:2	0:0	0:0
	Robben				0:3	0:0	0:0	2:1	0:0	0:0	1:2	0:0	0:0
Chick growth	Dassen				3:0	0:0	0:0	3:0	0:0	0:0	2:1	0:0	0:0
	Robben				3:0	0:0	0:0	0:3	0:0	0:0	1:2	0:0	0:0
Foraging path length	Dassen				0:3	0:0	0:0	1:2	0:0	0:0	1:2	0:0	0:0
	Robben				3:0	0:0	0:0	3:0	0:0	0:0	3:0	0:0	0:0
Foraging trip duration	Dassen				3:0	3:0	3:0	3:0	3:0	0:0	3:0	3:0	0:0
	Robben				0:3	0:0	0:0	2:1	0:0	0:0	1:2	0:0	0:0
Total	Dassen				9:9	3:0	3:0	9:9	3:0	0:0	10:8	3:0	0:0
	Robben				9:9	3:0	3:0	10:8	2:0	0:0	9:9	1:1	0:0
	Both				18:18	6:0	6:0	19:17	5:0	0:0	19:17	4:1	0:0
	Both no †							12:12	3:0	0:0	14:10	4:0	0:0

(b) Eastern Cape

		Fixed year effects			Random year effects			Spawner Biomass			Recruit Biomass		
		all	15%	5%	all	15%	5%	all	15%	5%	all	15%	5%
Foraging path length	Bird				1:0	0:0	0:0	0:1	0:0	0:0	1:0	0:0	0:0
	St Croix				0:1	0:1	0:1	0:1	0:0	0:0	0:1	0:1	0:0
Foraging trip duration	Bird				0:1	0:0	0:0	0:1	0:1	0:0	0:1	0:0	0:0
	St Croix				0:1	0:1	0:0	0:1	0:0	0:0	0:1	0:0	0:0
Total	Bird				1:1	0:0	0:0	0:2	0:1	0:0	1:1	0:0	0:0
	St Croix				0:2	0:2	0:1	0:2	0:0	0:0	0:2	0:1	0:0
	Both				1:3	0:2	0:1	0:4	0:1	0:0	1:3	0:1	0:0
	Both no †												

Table D.4: The number of additional years' data required to detect a fishing effect significant at the 5% level with **95%** probability is given for each of Dassen and Robben islands for the **updated datasets from 2008 onwards when continuous catch co-variate is replaced by the categorical open/closed co-variate for 10nmi**, where the true values of λ are assumed to be the random effects model-estimates. If a model-estimated λ value is small (i.e. $|\lambda| < 0.1$) then $\lambda = \pm 0.1$ is assumed for the effect size, where the sign is chosen according to the sign of the model-estimate for λ. A value of 0 indicates that the existing estimate of λ is already significant at the 5% level. C/O indicates future alternating periods of three years of the area being closed and open to fishing; O indicates the area is always open in the future.

			Dassen		Robben	
Response	Fish	Area	C/O	O	C/O	O
Chick condition	Sardine	-	> 20	> 20	> 20	> 20
	Anchovy	-	> 20	> 20	> 20	> 20
	Total	-	> 20	> 20	> 20	> 20
Active nest proportion	Sardine	-	> 20	> 20	0	0
	Anchovy	-	> 20	> 20	0	0
	Total	-	> 20	> 20	0	0
Fledging success	Sardine	-	> 20	> 20	> 20	> 20
	Anchovy	-	> 20	> 20	> 20	> 20
	Total	-	> 20	> 20	> 20	> 20
Chick growth	Sardine	-	> 20	> 20	> 20	> 20
	Anchovy	-	> 20	> 20	> 20	> 20
	Total	-	> 20	> 20	> 20	> 20
Foraging path length	Sardine	-	> 20	> 20	> 20	> 20
	Anchovy	-	> 20	> 20	> 20	> 20
	Total	-	> 20	> 20	> 20	> 20
Foraging trip duration	Sardine	-	0	0	> 20	> 20
	Anchovy	-	0	0	> 20	> 20
	Total	-	0	0	> 20	> 20

Table D.5: The number of additional years' data required to detect a fishing effect significant at the 5% level with **95%** probability is given for each of Bird and StCroix islands for the **updated datasets from 2008 onwards when continuous catch co-variate is replaced by the categorical open/closed co-variate for 10nmi**, where the true values of λ are assumed to be the random effects model-estimates. If a model-estimated λ value is small (i.e. $|\lambda| < 0.1$) then $\lambda = \pm 0.1$ is assumed for the effect size, where the sign is chosen according to the sign of the model-estimate for λ. A value of 0 indicates that the existing estimate of λ is already significant at the 5% level. C/O indicates future alternating periods of three years of the area being closed and open to fishing; O indicates the area is always open in the future.

			Bird		StCroix	
Response	Fish	Area	C/O	O	C/O	O
Foraging path length	Sardine	10 nmi	11	9	0	0
Foraging trip duration	Sardine	10 nmi	> 20	> 20	14	19

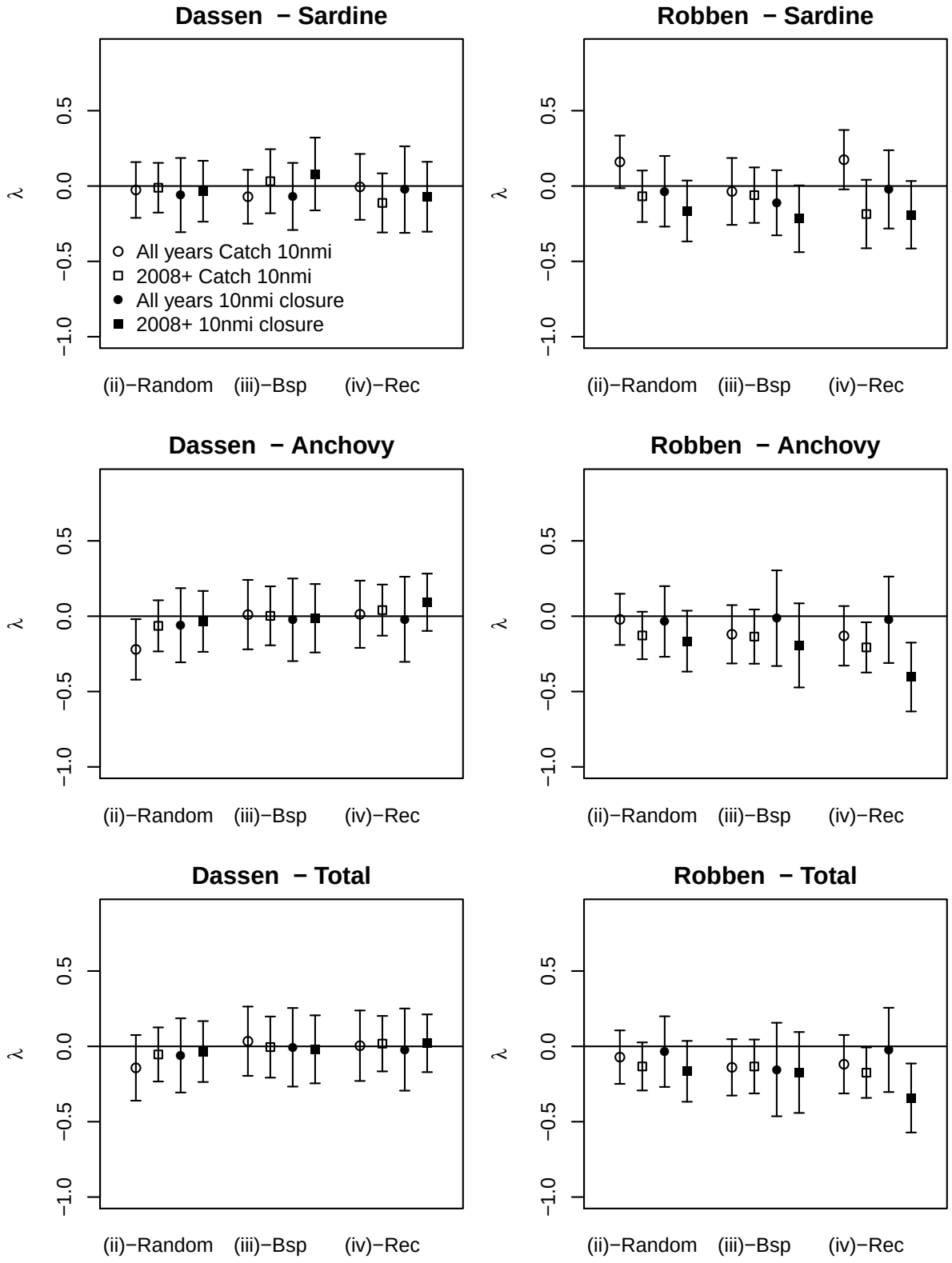

Figure D.1: Dassen and Robben Islands fishing effect parameter estimates: for the **chick condition** response variable for the **updated datasets for methods (ii), (iii) and (iv) for all combinations of all years vs 2008+ only and catch within 10nmi vs closed/open from Appendices A-D**. Bars indicate one standard error.

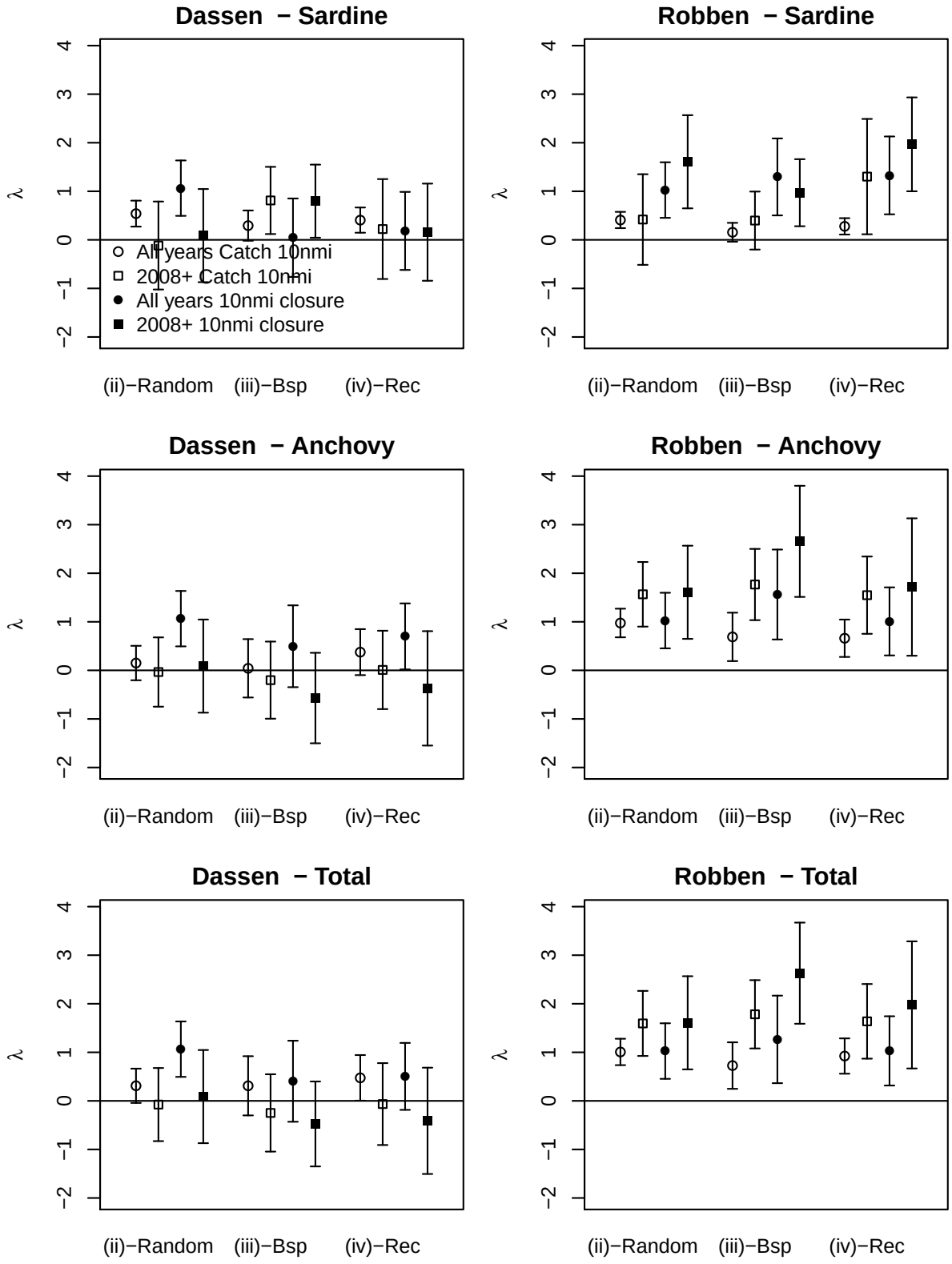

Figure D.2: Dassen and Robben Islands fishing effect parameter estimates: for the **active nest proportion** response variable for the **updated datasets for methods (ii), (iii) and (iv) for all combinations of all years vs 2008+ only and catch within 10nmi vs closed/open from Appendices A-D**. Bars indicate one standard error.

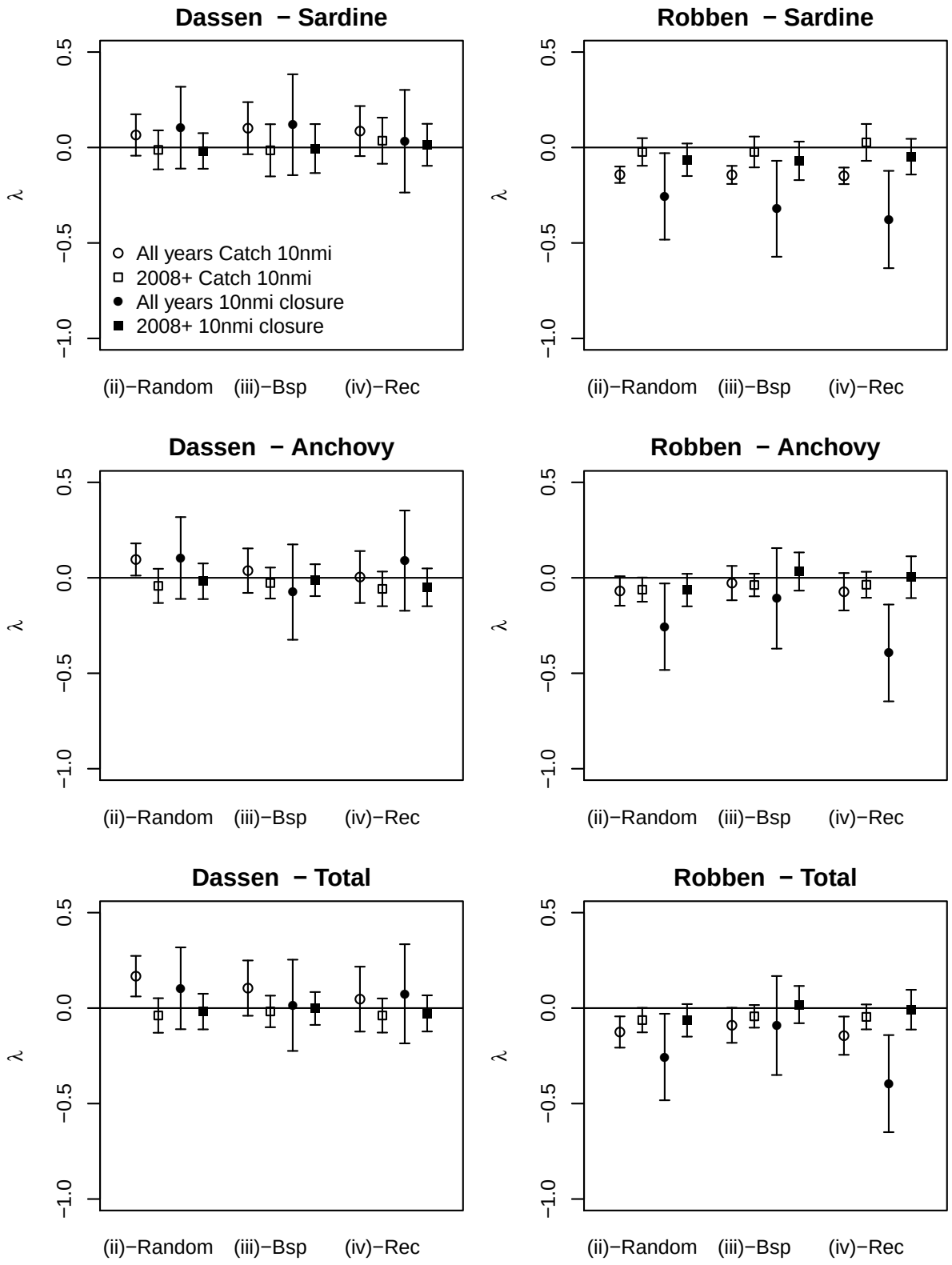

Figure D.3: Dassen and Robben Islands fishing effect parameter estimates: for the **fledging success** response variable for the **updated datasets for methods (ii), (iii) and (iv) for all combinations of all years vs 2008+ only and catch within 10nmi vs closed/open from Appendices A-D**. Bars indicate one standard error.

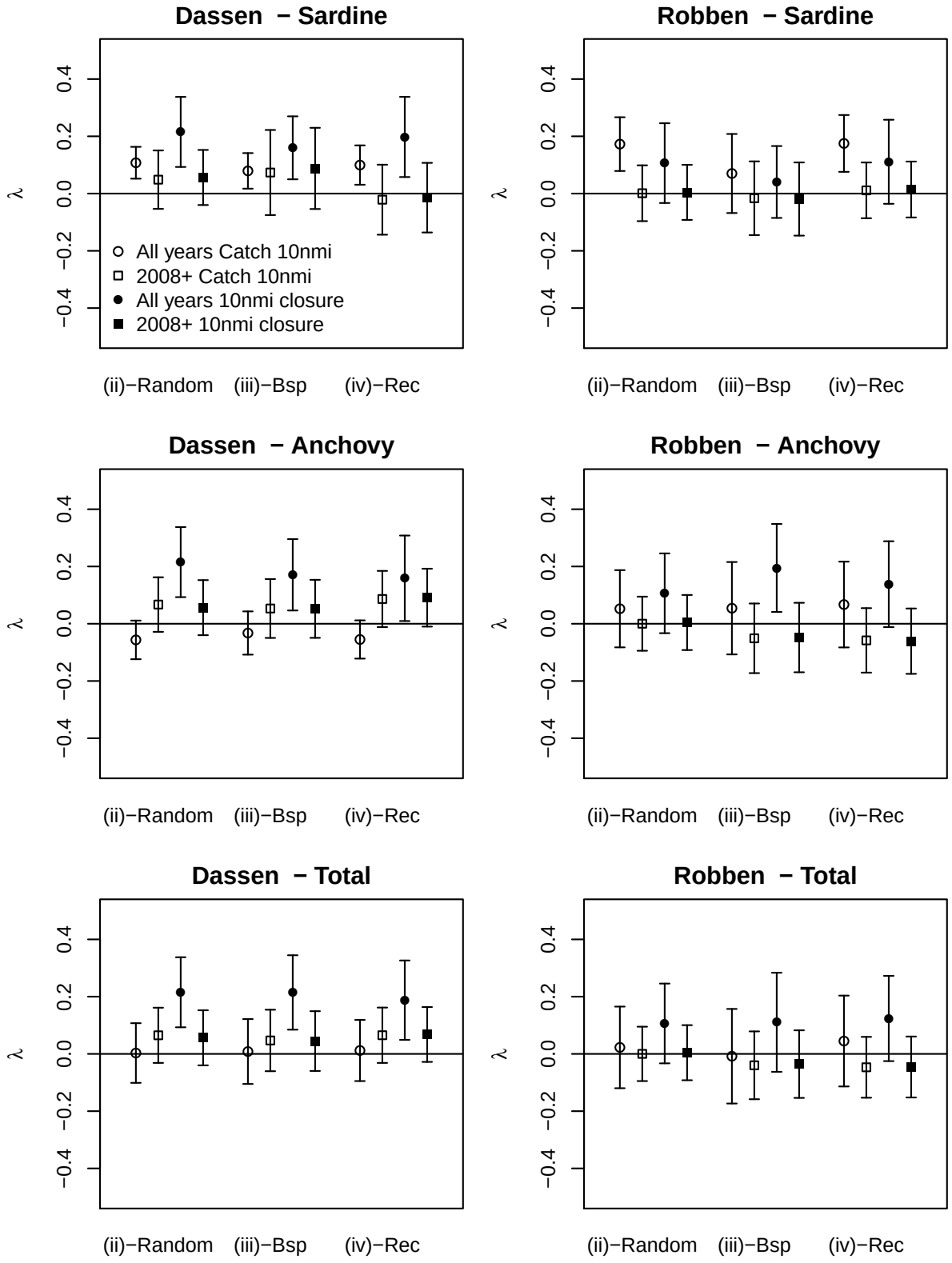

Figure D.4: Dassen and Robben Islands fishing effect parameter estimates: for the **chick growth rate** response variable for the **updated datasets for methods (ii), (iii) and (iv) for all combinations of all years vs 2008+ only and catch within 10nmi vs closed/open from Appendices A-D**. Bars indicate one standard error.

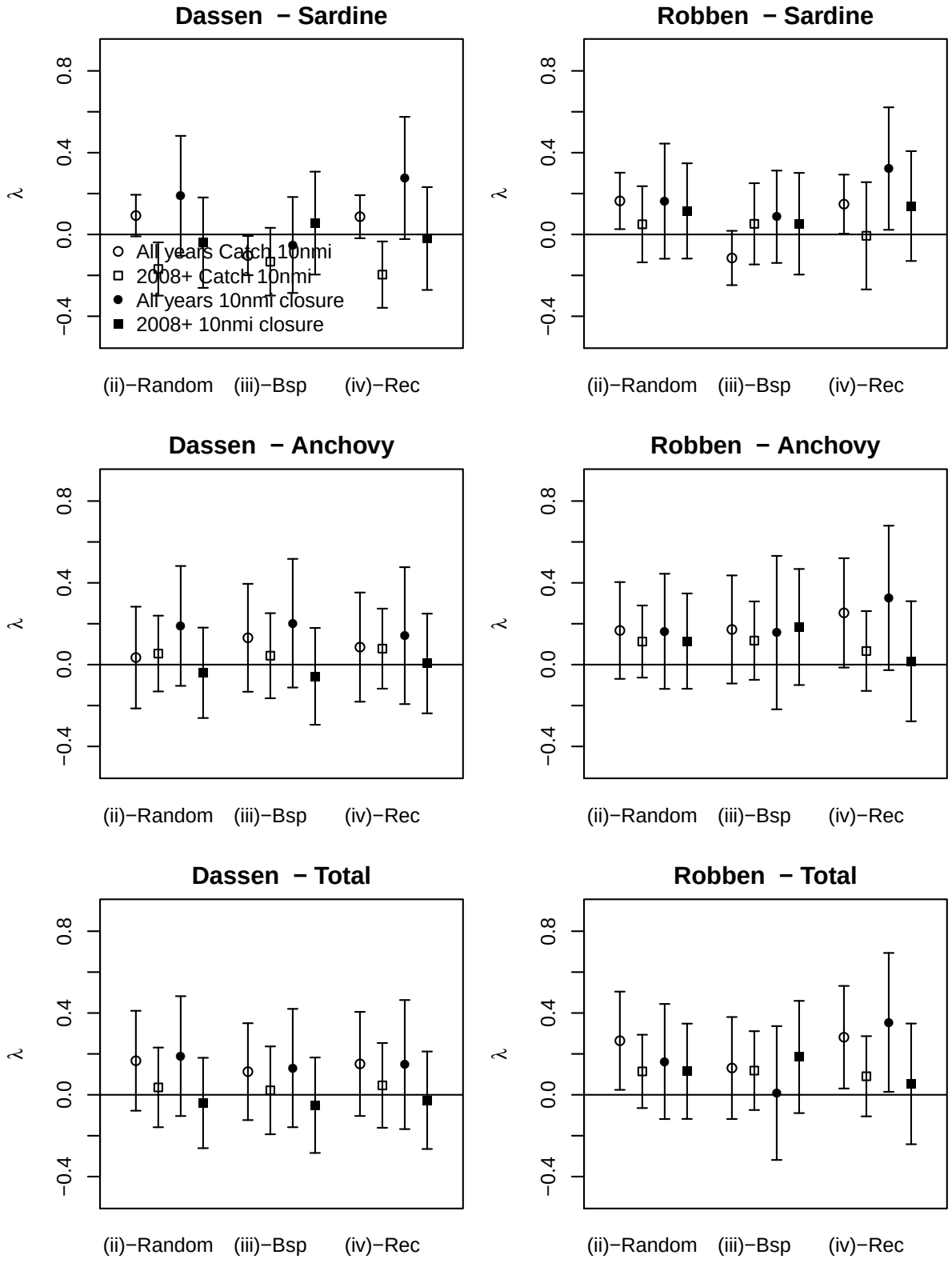

Figure D.5: Dassen and Robben Islands fishing effect parameter estimates: for the **foraging path length** response variable for the **updated datasets for methods (ii), (iii) and (iv) for all combinations of all years vs 2008+ only and catch within 10nmi vs closed/open from Appendices A-D**. Bars indicate one standard error.

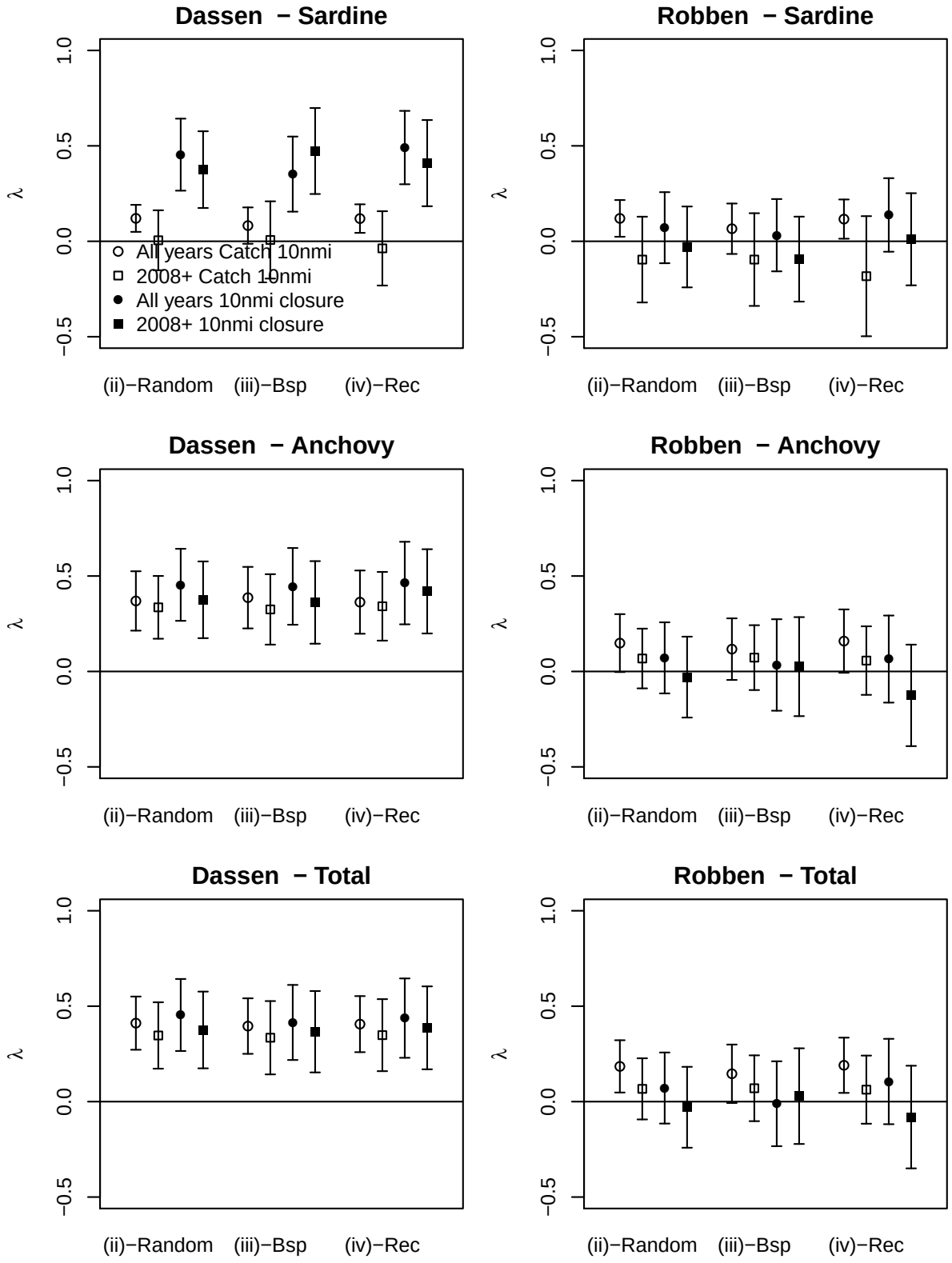

Figure D.6: Dassen and Robben Islands fishing effect parameter estimates: for the **foraging trip duration** response variable for the **updated datasets for methods (ii), (iii) and (iv) for all combinations of all years vs 2008+ only and catch within 10nmi vs closed/open from Appendices A-D**. Bars indicate one standard error.

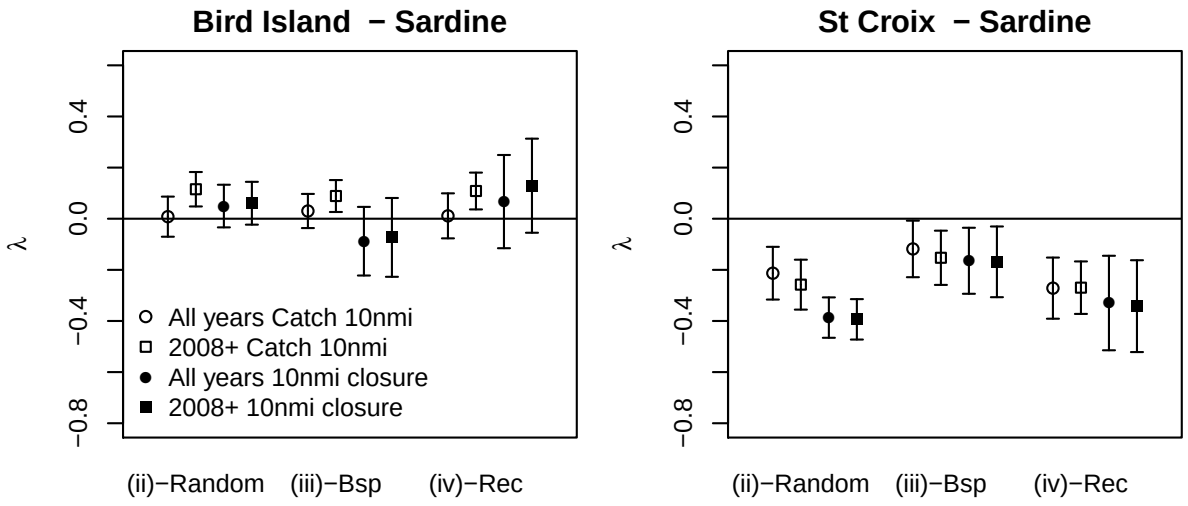

Figure D.7: Bird and St Croix Islands fishing effect parameter estimates: for the **foraging path length** response variable for the **updated datasets for methods (ii), (iii) and (iv) for all combinations of all years vs 2008+ only and catch within 10nmi vs closed/open from Appendices A-D**. Bars indicate one standard error.

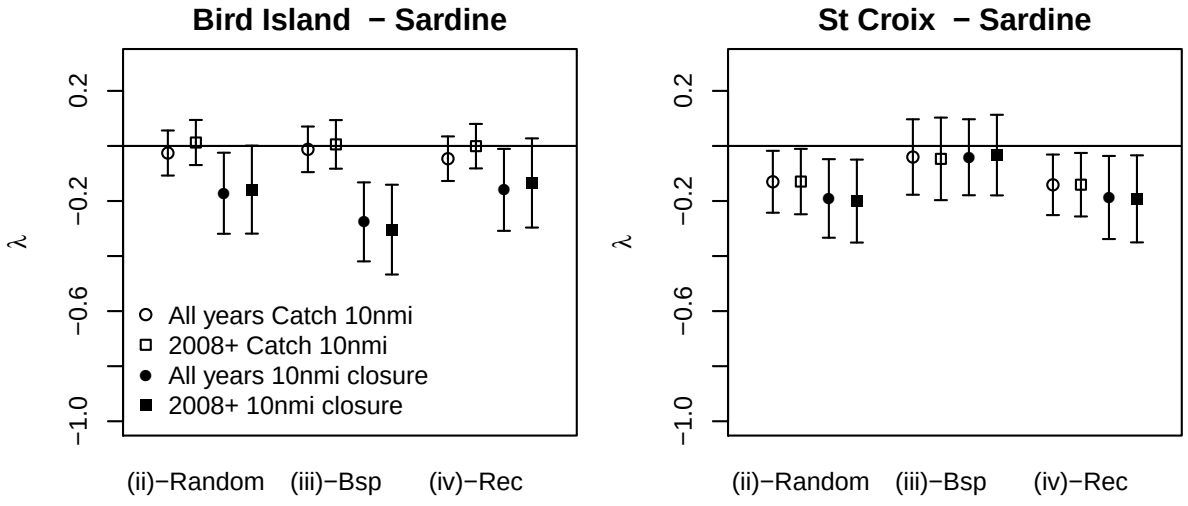

Figure D.8: Bird and St Croix Islands fishing effect parameter estimates: for the **foraging trip duration** response variable for the **updated datasets for methods (ii), (iii) and (iv) for all combinations of all years vs 2008+ only and catch within 10nmi vs closed/open from Appendices A-D**. Bars indicate one standard error.