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# Potential SLAs for West Greenland fin whales testing against the agreed evaluation trials

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INTERNATIONAL WHALING COMMISSION

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# Potential *SLA*s for West Greenland fin whales testing against the agreed evaluation trials

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## ABSTRACT

This paper presents four potential *SLA*s for West Greenlandic fin whales. The proposed *SLAs* are based on a weighted-average interim *SLA* which uses all abundance estimates, but earlier abundance estimates are down-weighted compared to more recent ones. An adjustment to the multiplier of the abundance estimate in the interim *SLA* is applied which depends on the trend of the abundance indices. Three candidate *SLA*s are tuned to achieve 1.0, 0.9 and 0.8 for the conservation statistic (D10) at the lower 5 percentile for the Influx hypothesis trial GF34-1B with a MSYR1+ of 1% and the middle need envelope (B). The fourth *SLA* attempts to provide near complete satisfaction of the conservation performance criterion and meet need satisfaction for all evaluation trials excluding the Influx hypothesis trials. To achieve a lower 5 percentile of the D10 statistic of one for the GF34-1B trial, the lower 5 percentile of need satisfaction (N9 over 20 and 100 years) is never met (*SLA*1.0). Dropping the D10 statistic to 0.8 for this trial improves need satisfaction by all other trials without sacrificing conservation performance (except for Influx hypothesis trials at $MSYR_{1+}$= 1%).

## INTRODUCTION

This paper provides results from the application of the software developed by Andre Punt for the West Greenland fin whale trials, as reported in IWC (2018). The *SLA*s considered are of the form previously proposed by Brandão (2017) and Brandão and Butterworth (2015a, 2015b). Brandão (2017) applied a restriction of which abundance indices would be used by the *SLA*s to account for unrealistically low abundance estimates. With the updated abundance estimates now available for West Greenlandic fin whales, this filter is no longer used by the proposed *SLA*s.

Three *SLA*s considered here are tuned to achieve the conservation performance criterion (D10) of 1.0, 0.9 and 0.8 at the lower 5 percentile for the GF34-1B trial which assumes the Influx hypothesis with an $MSYR_{1+}$ of 1% and a need envelope of B (see Appendix A). The fourth *SLA* is tuned so that the lower 5 percentile of the D10 statistic is mostly one or above and need satisfaction at the lower 5 percentile is mostly met by all evaluation trials, but not including the Influx hypothesis trials. Results for the *SLA*s considered are shown for all evaluation trials, including the Influx hypothesis trials.

## *SLA*s CONSIDERED

Four *SLA*s are considered in this paper. Results for a further SLA, the interim *SLA* (*SLA*I) which formed part of the 'reference *SLA*s' as given in IWC (2012) are also shown here for comparison purposes.

*SLA*I: Interim *SLA* which sets the *Strike Limit* as the lesser of need and $0.02\hat{N}e^{-1.645CV}$, where $\hat{N}$ is the most recent estimate of abundance and *CV* is the coefficient of variation of $\hat{N}$.

*SLA*1.0: Weighted-average *SLA* which uses all the abundance estimates and replaces $\hat{N}$ and *CV* in *SLA*I by:

$$\hat{N} = \exp\left[\sum_i \frac{0.9^{t_i} \ln N_i}{CV_i^2} \Big/ \sum_i \frac{0.9^{t_i}}{CV_i^2}\right] \tag{1}$$

$$CV = \sqrt{\sum_i \frac{0.9^{2t_i}}{CV_i^2}} \Big/ \sum_i \frac{0.9^{t_i}}{CV_i^2} \tag{2}$$

where $N_i$ is the *i*th estimate of abundance, $CV_i$ is the coefficient of variation of $N_i$, and $t_i$ is the time (in years) between when the *i*th estimate of abundance was obtained and the first year of the block for which a *Strike Limit* is needed. The 0.02 multiplier applied to $\hat{N}$ as in *SLA*1 is adjusted by a function of the observed trend of the abundance indices, so that the *Strike Limit* is set as the lesser of need and $\varphi f\left(\beta^*\right)\hat{N}e^{-1.645CV}$, where

$$f\left(\beta^*\right) = \alpha + (1-\alpha)\frac{1}{1+e^{\left(\beta^*-\bar{\beta}\right)/\delta}},$$

where

$\beta^* = \hat{\beta} - \lambda s_{\hat{\beta}}$, where $\hat{\beta}$ is the negative of the slope of the log-linear regression applied to the abundance indices, $s_{\hat{\beta}}$ is the standard error of the slope coefficient and $\lambda$ is a control parameter, and $\alpha, \bar{\beta}, \varphi$ and $\delta$ are further control parameters. The function $f\left(\beta^*\right)$ is calculated only if there are more than three abundance indices; otherwise it is set to 1.

For this variant a lower 5 percentile for **D10 of 1.0** is achieved for the GF34-1B trial, with the following values chosen for the control parameters:
$\alpha = 0.7, \bar{\beta} = 0.001, \delta = 0.008, \varphi = 0.0042$ and $\lambda = 1$.

*SLA*0.9: Variant of *SLA*1.0 described above but a lower 5 percentile for **D10 of 0.9** is achieved for the GF34-1B trial. In this variant the control parameters are set to:
$\alpha = 0.7, \bar{\beta} = 0.001, \delta = 0.008, \varphi = 0.0085$ and $\lambda = 1$.

*SLA*0.8: Variant of *SLA*1.0 described above but a lower 5 percentile for **D10 of 0.8** is achieved for the GF34-1B trial. In this variant the control parameters are set to:
$\alpha = 0.2, \bar{\beta} = 0.001, \delta = 0.008, \varphi = 0.017$ and $\lambda = 1$.

*SLA*0.65: Variant of *SLA*1.0 described above but tuned so that the lower 5 percentile of the D10 statistic is mostly 1 or above and need satisfaction is mostly met for the lower 5 percentile by all evaluation trials, but not including the Influx hypothesis trials. The application of this *SLA* to the GF34-1B trial obtained a lower 5 percentile of the D10 statistic of 0.65. In this variant the control parameters are set to:

$\alpha = 0.7, \bar{\beta} = 0.001, \delta = 0.008$ and $\lambda = 1$. For this *SLA*, the control parameter $\varphi$ has been defined as $\varphi = \begin{cases} 0.02 & \text{on or before 2038} \\ 0.03 & \text{after 2038} \end{cases}$.

## RESULTS AND DISCUSSION

Table 1 gives a summary of the results in terms of conservation performance (defined by the D10 statistic: relative increase of 1+ population size: $P_T/P_0$, where *P* is the size of the total 1+ population), the need satisfaction criteria (defined by the N9 statistic: Average need satisfaction given by $\frac{1}{T}\sum_{t=0}^{T-1}\frac{C_t}{Q_t}$, where *C* is catch and *Q* is the need) and the proportion of times that each *SLA* achieves need satisfaction (N9 over 20 and 100 years) above 0.75 at the lower 5 percentile for the evaluation trials (including the Influx hypothesis trials) for the *SLAs* considered. Further statistics are reported in Table 1 that were not given previously: the maximum value as well as the average of the lower 5 percentile of the D10 statistic over all evaluation trials. Note that Appendix A gives details of all the trials and need envelopes considered. Table 2 reports similar results but trials with the high need scenario C are omitted from the computations.

To achieve a lower 5 percentile of the D10 statistic of one for the GF34-1B trial, the lower 5 percentile of need satisfaction (N9 over 20 and 100 years) is never met (*SLA*1.0). Dropping the D10 statistic to 0.8 for this trial improves need satisfaction by all other trials without sacrificing conservation performance (except for Influx hypothesis trials at $MSYR_{1+}$= 1%). Appendix B shows plots for a) population trajectories for the Influx hypothesis trials (both for the lower 5 percentile and the median value) for the proposed *SLA*s, b) Zeh plots for the Influx hypothesis trials and c) plots of catches, need envelopes and abundance estimates for 10 realisations of the GF34-1B trial for each of the *SLA*s considered.

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**Table 1.** Proportion of times that each *SLA* meets the conservation performance and need satisfaction (over 20 and 100 years) criteria for various subsets of the 68 evaluation trials (including the Influx hypothesis trials) for West Greenland fin whales, the minimum lower 5 percentile of the conservation performance and the mean of the lower 5 percentile need satisfaction (over 20 and 100 years) and of the conservation performance.

**(a) Results by MSY rate**

| | Interim | *SLA* 1.0 | *SLA* 0.9 | *SLA* 0.8 | *SLA* 0.65 |
|---|---|---|---|---|---|
| **MSYR1+ = 1% (15 trials)** | | | | | |
| Conservation performance (D10) | 0.80 | 0.93 | 0.80 | 0.80 | 0.80 |
| Mean conservation performance (D10) | 1.17 | 1.24 | 1.20 | 1.16 | 1.12 |
| Minimum D10 value | 0.62 | 0.96 | 0.75 | 0.57 | 0.33 |
| Mean Need satisfaction 20 yrs | 0.80 | 0.41 | 0.70 | 0.88 | 0.89 |
| Mean Need satisfaction 100 yrs | 0.74 | 0.32 | 0.54 | 0.78 | 0.85 |
| Proportion Need satisfaction 20 yrs | 0.80 | 0.00 | 0.20 | 1.00 | 1.00 |
| Porportion Need satisfaction 100 yrs | 0.47 | 0.00 | 0.00 | 0.67 | 0.87 |
| | | | | | |
| **MSYR1+=2.5% (33 trials)** | | | | | |
| Conservation performance (D10) | 0.97 | 1.00 | 1.00 | 0.97 | 0.91 |
| Mean conservation performance (D10) | 1.17 | 1.18 | 1.17 | 1.16 | 1.16 |
| Minimum D10 value | 0.97 | 1.04 | 1.00 | 0.96 | 0.91 |
| Mean Need satisfaction 20 yrs | 0.85 | 0.48 | 0.70 | 0.92 | 0.92 |
| Mean Need satisfaction 100 yrs | 0.84 | 0.45 | 0.69 | 0.89 | 0.94 |
| Proportion Need satisfaction 20 yrs | 1.00 | 0.00 | 0.15 | 1.00 | 1.00 |
| Porportion Need satisfaction 100 yrs | 0.97 | 0.00 | 0.36 | 0.97 | 1.00 |
| | | | | | |
| **MSYR1+=4% (17 trials)** | | | | | |
| Conservation performance (D10) | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Mean conservation performance (D10) | 1.08 | 1.08 | 1.08 | 1.07 | 1.07 |
| Minimum D10 value | 1.02 | 1.03 | 1.03 | 1.02 | 1.02 |
| Mean Need satisfaction 20 yrs | 0.92 | 0.49 | 0.75 | 0.98 | 0.98 |
| Mean Need satisfaction 100 yrs | 0.88 | 0.50 | 0.75 | 0.94 | 0.96 |
| Proportion Need satisfaction 20 yrs | 1.00 | 0.00 | 0.41 | 1.00 | 1.00 |
| Porportion Need satisfaction 100 yrs | 1.00 | 0.00 | 0.53 | 1.00 | 1.00 |
| | | | | | |
| **MSYR1+ = 7% (3 trials)** | | | | | |
| Conservation performance (D10) | 1.00 | 1.00 | 1.00 | 0.67 | 0.67 |
| Mean conservation performance (D10) | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Minimum D10 value | 1.00 | 1.00 | 1.00 | 0.99 | 0.99 |
| Mean Need satisfaction 20 yrs | 0.94 | 0.48 | 0.73 | 0.99 | 0.99 |
| Mean Need satisfaction 100 yrs | 0.81 | 0.35 | 0.58 | 0.86 | 0.91 |
| Proportion Need satisfaction 20 yrs | 1.00 | 0.00 | 0.33 | 1.00 | 1.00 |
| Porportion Need satisfaction 100 yrs | 0.67 | 0.00 | 0.00 | 1.00 | 1.00 |

**(b) Results by need envelope**

| | Interim | *SLA* 1.0 | *SLA* 0.9 | *SLA* 0.8 | *SLA* 0.65 |
|---|---|---|---|---|---|
| **Need Scenario A (26 trials)** | | | | | |
| Conservation performance (D10) | 0.96 | 1.00 | 0.96 | 0.96 | 0.96 |
| Mean conservation performance (D10) | 1.15 | 1.16 | 1.15 | 1.15 | 1.15 |
| Minimum D10 value | 0.93 | 1.00 | 0.96 | 0.93 | 0.90 |
| Mean Need satisfaction 20 yrs | 0.88 | 0.49 | 0.75 | 0.95 | 0.95 |
| Mean Need satisfaction 100 yrs | 0.88 | 0.53 | 0.77 | 0.93 | 0.96 |
| Proportion Need satisfaction 20 yrs | 1.00 | 0.00 | 0.42 | 1.00 | 1.00 |
| Porportion Need satisfaction 100 yrs | 1.00 | 0.00 | 0.77 | 1.00 | 1.00 |
| | | | | | |
| **Need Scenario B (26 trials)** | | | | | |
| Conservation performance (D10) | 0.96 | 1.00 | 0.96 | 0.96 | 0.92 |
| Mean conservation performance (D10) | 1.13 | 1.15 | 1.14 | 1.13 | 1.12 |
| Minimum D10 value | 0.80 | 1.00 | 0.90 | 0.80 | 0.65 |
| Mean Need satisfaction 20 yrs | 0.86 | 0.46 | 0.71 | 0.93 | 0.93 |
| Mean Need satisfaction 100 yrs | 0.82 | 0.40 | 0.65 | 0.88 | 0.92 |
| Proportion Need satisfaction 20 yrs | 0.96 | 0.00 | 0.12 | 1.00 | 1.00 |
| Porportion Need satisfaction 100 yrs | 0.89 | 0.00 | 0.04 | 0.96 | 1.00 |
| | | | | | |
| **Need Scenario C (16 trials)** | | | | | |
| Conservation performance (D10) | 0.88 | 0.94 | 0.94 | 0.81 | 0.75 |
| Mean conservation performance (D10) | 1.12 | 1.18 | 1.14 | 1.12 | 1.09 |
| Minimum D10 value | 0.62 | 0.96 | 0.75 | 0.57 | 0.33 |
| Mean Need satisfaction 20 yrs | 0.83 | 0.43 | 0.67 | 0.89 | 0.90 |
| Mean Need satisfaction 100 yrs | 0.75 | 0.31 | 0.52 | 0.79 | 0.86 |
| Proportion Need satisfaction 20 yrs | 0.88 | 0.00 | 0.13 | 1.00 | 1.00 |
| Porportion Need satisfaction 100 yrs | 0.56 | 0.00 | 0.00 | 0.69 | 0.88 |

**Table 2.** Proportion of times that each *SLA* meets the conservation performance and need satisfaction (over 20 and 100 years) criteria for various subsets of the 52 evaluation trials (including the Influx hypothesis trials but **excluding the high need trials**) for West Greenland fin whales, the minimum lower 5 percentile of the conservation performance and the mean of the lower 5 percentile need satisfaction (over 20 and 100 years) and of the conservation performance.

**(a) Results by MSY rate**

| | **Interim** | ***SLA* 1.0** | ***SLA* 0.9** | ***SLA* 0.8** | ***SLA* 0.65** |
|---|---|---|---|---|---|
| **MSYR1+ = 1% (10 trials)** | | | | | |
| Conservation performance (D10) | 0.80 | 1.00 | 0.80 | 0.80 | 0.80 |
| Mean conservation performance (D10) | 1.19 | 1.25 | 1.22 | 1.18 | 1.16 |
| Minimum D10 value | 0.80 | 1.00 | 0.90 | 0.80 | 0.65 |
| Mean Need satisfaction 20 yrs | 0.81 | 0.43 | 0.72 | 0.88 | 0.90 |
| Mean Need satisfaction 100 yrs | 0.77 | 0.36 | 0.59 | 0.82 | 0.88 |
| Proportion Need satisfaction 20 yrs | 0.90 | 0.00 | 0.20 | 1.00 | 1.00 |
| Porportion Need satisfaction 100 yrs | 0.70 | 0.00 | 0.00 | 0.90 | 1.00 |
| | | | | | |
| **MSYR1+=2.5% (24 trials)** | | | | | |
| Conservation performance (D10) | 1.00 | 1.00 | 1.00 | 1.00 | 0.96 |
| Mean conservation performance (D10) | 1.17 | 1.18 | 1.18 | 1.17 | 1.17 |
| Minimum D10 value | 1.01 | 1.05 | 1.03 | 1.00 | 0.98 |
| Mean Need satisfaction 20 yrs | 0.86 | 0.49 | 0.72 | 0.93 | 0.93 |
| Mean Need satisfaction 100 yrs | 0.87 | 0.49 | 0.73 | 0.92 | 0.95 |
| Proportion Need satisfaction 20 yrs | 1.00 | 0.00 | 0.17 | 1.00 | 1.00 |
| Porportion Need satisfaction 100 yrs | 1.00 | 0.00 | 0.50 | 1.00 | 1.00 |
| | | | | | |
| **MSYR1+=4% (16 trials)** | | | | | |
| Conservation performance (D10) | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Mean conservation performance (D10) | 1.08 | 1.08 | 1.08 | 1.08 | 1.07 |
| Minimum D10 value | 1.02 | 1.03 | 1.03 | 1.02 | 1.02 |
| Mean Need satisfaction 20 yrs | 0.93 | 0.49 | 0.75 | 0.98 | 0.98 |
| Mean Need satisfaction 100 yrs | 0.89 | 0.51 | 0.76 | 0.94 | 0.96 |
| Proportion Need satisfaction 20 yrs | 1.00 | 0.00 | 0.44 | 1.00 | 1.00 |
| Porportion Need satisfaction 100 yrs | 1.00 | 0.00 | 0.56 | 1.00 | 1.00 |
| | | | | | |
| **MSYR1+ = 7% (2 trials)** | | | | | |
| Conservation performance (D10) | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Mean conservation performance (D10) | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Minimum D10 value | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 |
| Mean Need satisfaction 20 yrs | 0.95 | 0.49 | 0.74 | 1.00 | 1.00 |
| Mean Need satisfaction 100 yrs | 0.84 | 0.39 | 0.64 | 0.90 | 0.93 |
| Proportion Need satisfaction 20 yrs | 1.00 | 0.00 | 0.50 | 1.00 | 1.00 |
| Porportion Need satisfaction 100 yrs | 1.00 | 0.00 | 0.00 | 1.00 | 1.00 |

## APPENDIX A

### List of evaluation trials

| Trial | Description | Conditioning |
|---|---|---|
| **GF01-4A** | $MSYR_{1+}$ = 4%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67 | Yes [1-4] |
| **GF01-4B** | $MSYR_{1+}$ = 4%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67 | 1-4 |
| **GF01-4C** | $MSYR_{1+}$ = 4%; need scenario C; survey frequency = 105; historic survey bias = 1; future survey CVs 0.38/0.67 | 1-4 |
| **GF01-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67 | Yes [1-2] |
| **GF01-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67 | 1-2 |
| **GF01-2C** | $MSYR_{1+}$ = 2.5%; need scenario C; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67 | 1-2 |
| **GF01-1A** | $MSYR_{1+}$ = 1%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67 | Yes [1-1] |
| **GF01-1B** | $MSYR_{1+}$ = 1%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67 | 1-1 |
| **GF01-1C** | $MSYR_{1+}$ = 1%; need scenario C; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67 | 1-1 |
| **GF01-7A** | $MSYR_{1+}$ = 7%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67 | Yes [1-7] |
| **GF01-7B** | $MSYR_{1+}$ = 7%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67 | 1-7 |
| **GF01-7C** | $MSYR_{1+}$ = 7%; need scenario C; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67 | 1-7 |
| **GF02-4A** | $MSYR_{1+}$ = 4%; need scenario A; survey frequency = 5; historic survey bias = 1; future survey CVs 0.38/0.67 | 1-4 |
| **GF02-4B** | $MSYR_{1+}$ = 4%; need scenario B; survey frequency = 5; historic survey bias = 1; future survey CVs 0.38/0.67 | 1-4 |
| **GF02-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 5; historic survey bias = 1; future survey CVs 0.38/0.67 | 1-2 |
| **GF02-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 5; historic survey bias = 1; future survey CVs 0.38/0.67 | 1-2 |
| **GF02-2C** | $MSYR_{1+}$ = 2.5%; need scenario C; survey frequency = 5; historic survey bias = 1; future survey CVs 0.38/0.67 | 1-2 |
| **GF03-4A** | $MSYR_{1+}$ = 4%; need scenario A; survey frequency = 15; historic survey bias = 1; future survey CVs 0.38/0.67 | 1-4 |
| **GF03-4B** | $MSYR_{1+}$ = 4%; need scenario B; survey frequency = 15; historic survey bias = 1; future survey CVs 0.38/0.67 | 1-4 |
| **GF03-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 15; historic survey bias = 1; future survey CVs 0.38/0.67 | 1-2 |
| **GF03-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 15; historic survey bias = 1; future survey CVs 0.38/0.67 | 1-2 |
| **GF03-2C** | $MSYR_{1+}$ = 2.5%; need scenario C; survey frequency = 15; historic survey bias = 1; future survey CVs 0.38/0.67 | 1-2 |
| **GF03-1A** | $MSYR_{1+}$ = 1%; need scenario A; survey frequency = 15; historic survey bias = 1; future survey CVs 0.38/0.67 | 1-1 |

| | | |
|---|---|---|
| **GF03-1B** | $MSYR_{1+}$ = 1%; need scenario B; survey frequency = 15; historic survey bias = 1; future survey CVs 0.38/0.67 | 1-1 |
| **GF03-1C** | $MSYR_{1+}$ = 1%; need scenario C; survey frequency = 15; historic survey bias = 1; future survey CVs 0.38/0.67 | 1-1 |
| **GF04-4A** | $MSYR_{1+}$ = 4%; need scenario A; survey frequency = 10; historic survey bias = 0.8; future survey CVs 0.38/0.67 | Yes [4-4] |
| **GF04-4B** | $MSYR_{1+}$ = 4%; need scenario B; survey frequency = 10; historic survey bias = 0.8; future survey CVs 0.38/0.67 | 4-4 |
| **GF04-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 0.8; future survey CVs 0.38/0.67 | Yes [4-2] |
| **GF04-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 10; historic survey bias = 0.8; future survey CVs 0.38/0.67 | 4-2 |
| **GF05-4A** | $MSYR_{1+}$ = 4%; need scenario A; survey frequency = 10; historic survey bias = 1.2; future survey CVs 0.38/0.67 | Yes [5-4] |
| **GF05-4B** | $MSYR_{1+}$ = 4%; need scenario B; survey frequency = 10; historic survey bias = 1.2; future survey CVs 0.38/0.67 | 5-4 |
| **GF05-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1.2; future survey CVs 0.38/0.67 | Yes [5-2] |
| **GF05-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 10; historic survey bias = 1.2; future survey CVs 0.38/0.67 | 5-2 |
| **GF06-4A** | $MSYR_{1+}$ = 4%; need scenario A; survey frequency = 10; historic survey bias = 1; 3 episodic events | 1-4 |
| **GF06-4B** | $MSYR_{1+}$ = 4%; need scenario B; survey frequency = 10; historic survey bias = 1; 3 episodic events; future survey CVs 0.38/0.67 | 1-4 |
| **GF06-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; 3 episodic events; future survey CVs 0.38/0.67 | 1-2 |
| **GF06-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 10; historic survey bias = 1; 3 episodic events; future survey CVs 0.38/0.67 | 1-2 |
| **GF06-2C** | $MSYR_{1+}$ = 2.5%; need scenario C; survey frequency = 10; historic survey bias = 1; 3 episodic events; future survey CVs 0.38/0.67 | 1-2 |
| **GF06-1A** | $MSYR_{1+}$ = 1%; need scenario A; survey frequency = 10; historic survey bias = 1; 3 episodic events; future survey CVs 0.38/0.67 | 1-1 |
| **GF06-1B** | $MSYR_{1+}$ = 1%; need scenario B; survey frequency = 10; historic survey bias = 1; 3 episodic events; future survey CVs 0.38/0.67 | 1-1 |
| **GF06-1C** | $MSYR_{1+}$ = 1%; need scenario C; survey frequency = 10; historic survey bias = 1; 3 episodic events; future survey CVs 0.38/0.67 | 1-1 |
| **GF07-4A** | $MSYR_{1+}$ = 4%; need scenario A; survey frequency = 10; historic survey bias = 1; stochastic events every 5 years; future survey CVs 0.38/0.67 | 1-4 |
| **GF07-4B** | $MSYR_{1+}$ = 4%; need scenario B; survey frequency = 10; historic survey bias = 1; stochastic events every 5 years; future survey CVs 0.38/0.67 | 1-4 |
| **GF07-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; stochastic events every 5 years; future survey CVs 0.38/0.67 | 1-2 |
| **GF07-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 10; historic survey bias = 1; stochastic events every 5 years; future survey CVs 0.38/0.67 | 1-2 |
| **GF08-4A** | $MSYR_{1+}$ = 4%; need scenario A; survey frequency = 10; historic survey bias = 1; asymmetric environmental stochasticity (depletion = 0.3) ; future survey CVs 0.38/0.67 | Yes [1-4,8-4] |
| **GF08-4B** | $MSYR_{1+}$ = 4%; need scenario B; survey frequency = 10; historic survey bias = 1; asymmetric environmental stochasticity (depletion = 0.3) ; future survey CVs 0.38/0.67 | 8-4 |
| **GF08-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; asymmetric environmental stochasticity (depletion = 0.3) ; future survey CVs 0.38/0.67 | Yes [1-2,8-2] |
| **GF08-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 10; historic survey bias = 1; asymmetric environmental stochasticity (depletion = 0.3) ; future survey CVs 0.38/0.67 | 8-2 |

| | | |
|---|---|---|
| **GF08-2C** | $MSYR_{1+}$ = 2.5%; need scenario C; survey frequency = 10; historic survey bias = 1; asymmetric environmental stochasticity (depletion = 0.3) ; future survey CVs 0.38/0.67 | 8-2 |
| **GF08-1A** | $MSYR_{1+}$ = 1%; need scenario A; survey frequency = 10; historic survey bias = 1; asymmetric environmental stochasticity (depletion = 0.3) ; future survey CVs 0.38/0.67 | Yes [1-1,8-1] |
| **GF08-1B** | $MSYR_{1+}$ = 1%; need scenario B; survey frequency = 10; historic survey bias = 1; asymmetric environmental stochasticity (depletion = 0.3) ; future survey CVs 0.38/0.67 | 8-1 |
| **GF08-1C** | $MSYR_{1+}$ = 1%; need scenario C; survey frequency = 10; historic survey bias = 1; asymmetric environmental stochasticity (depletion = 0.3) ; future survey CVs 0.38/0.67 | 8-1 |
| **GF09-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.33/0.62 | 1-2 |
| **GF09-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.33/0.62 | 1-2 |
| **GF09-2C** | $MSYR_{1+}$ = 2.5%; need scenario C; survey frequency = 10; historic survey bias = 1; future survey CVs 0.33/0.62 | 1-2 |
| **GF10-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.43/0.72 | 1-2 |
| **GF10-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.43/0.72 | 1-2 |
| **GF10-2C** | $MSYR_{1+}$ = 2.5%; need scenario C; survey frequency = 10; historic survey bias = 1; future survey CVs 0.43/0.72 | 1-2 |

## List of robustness trials

| Trial | Description | Conditioning |
|---|---|---|
| **GF21-4A** | $MSYR_{1+}$ = 4%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; linear decrease in *K* in future | 1-4 |
| **GF21-4B** | $MSYR_{1+}$ = 4%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; linear decrease in *K* in future | 1-4 |
| **GF21-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; linear decrease in *K* in future | 1-2 |
| **GF21-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; linear decrease in *K* in future | 1-2 |
| **GF22-4A** | $MSYR_{1+}$ = 4%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; linear increase in *M* in future | 1-4 |
| **GF22-4B** | $MSYR_{1+}$ = 4%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; linear increase in *M* in future | 1-4 |
| **GF22-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; linear increase in *M* in future | 1-2 |
| **GF22-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; linear increase in *M* in future | 1-2 |
| **GF23-4A** | $MSYR_{1+}$ = 4%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; strategic surveys | 1-4 |
| **GF23-4B** | $MSYR_{1+}$ = 4%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; strategic surveys | 1-4 |
| **GF23-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; strategic surveys | 1-2 |

| | | |
|---|---|---|
| **GF23-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; strategic surveys | 1-2 |
| **GF25-4A** | $MSYR_{1+}$ = 4%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; p=0.5; (Propn generated from beta(1,9) | Y[25-4] |
| **GF25-4B** | $MSYR_{1+}$ = 4%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; p=0.5; (Propn generated from beta(1,9) | 25-4 |
| **GF25-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; p=0.5; (Propn generated from beta(1,9) | Y[25-2] |
| **GF25-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67;; p=0.5; (Propn generated from beta(1,9) | 25-2 |
| **GF26-4A** | $MSYR_{1+}$ = 4%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; p=0. 189; (Propn generated from beta(2,8) | Y[26-4] |
| **GF26-4B** | $MSYR_{1+}$ = 4%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67;; p=0.189; (Propn generated from beta(2,8) | 26-4 |
| **GF26-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; p=0. 189; (Propn generated from beta(2,8) | Y[26-2] |
| **GF26-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; p=0. 189; (Propn generated from beta(2,8) | 26-2 |
| **GF27-4A** | $MSYR_{1+}$ = 4%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; p=0. 811; (Propn generated from beta(2,8) | Y[27-4] |
| **GF27-4B** | $MSYR_{1+}$ = 4%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; p=0.811; (Propn generated from beta(2,8) | 27-4 |
| **GF27-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; p=0. 811; (Propn generated from beta(2,8) | Y[27-2] |
| **GF27-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; p=0. 811; (Propn generated from beta(2,8) | 27-2 |
| **GF28-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.2/0.5 | 1-2 |
| **GF28-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.2/0.5 | 1-2 |
| **GF29-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.2/0.5; p=0.5; (Propn generated from beta(1,9) | 25-2 |
| **GF29-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.2/0.5; p=0.5; (Propn generated from beta(1,9) | 25-2 |
| **GF30-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; population drop of 50% in 0 years | 1-2 |
| **GF30-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; population drop of 50% in 0 years | 1-2 |
| **GF31-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; population drop of 50% in 35 years | 1-2 |
| **GF31-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; population drop of 50% in 35 years | 1-2 |
| **GF32-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; population drop of 80% in 0 years | 1-2 |
| **GF32-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; population drop of 80% in 0 years | 1-2 |
| **GF33-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; population drop of 80% in 35 years | 1-2 |
| **GF33-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; population drop of 80% in 35 years | 1-2 |
| **GF34-1A** | $MSYR_{1+}$ = 1%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; Influx hypothesis; *K* prior of U[0, 6000] | Y[34-1] |

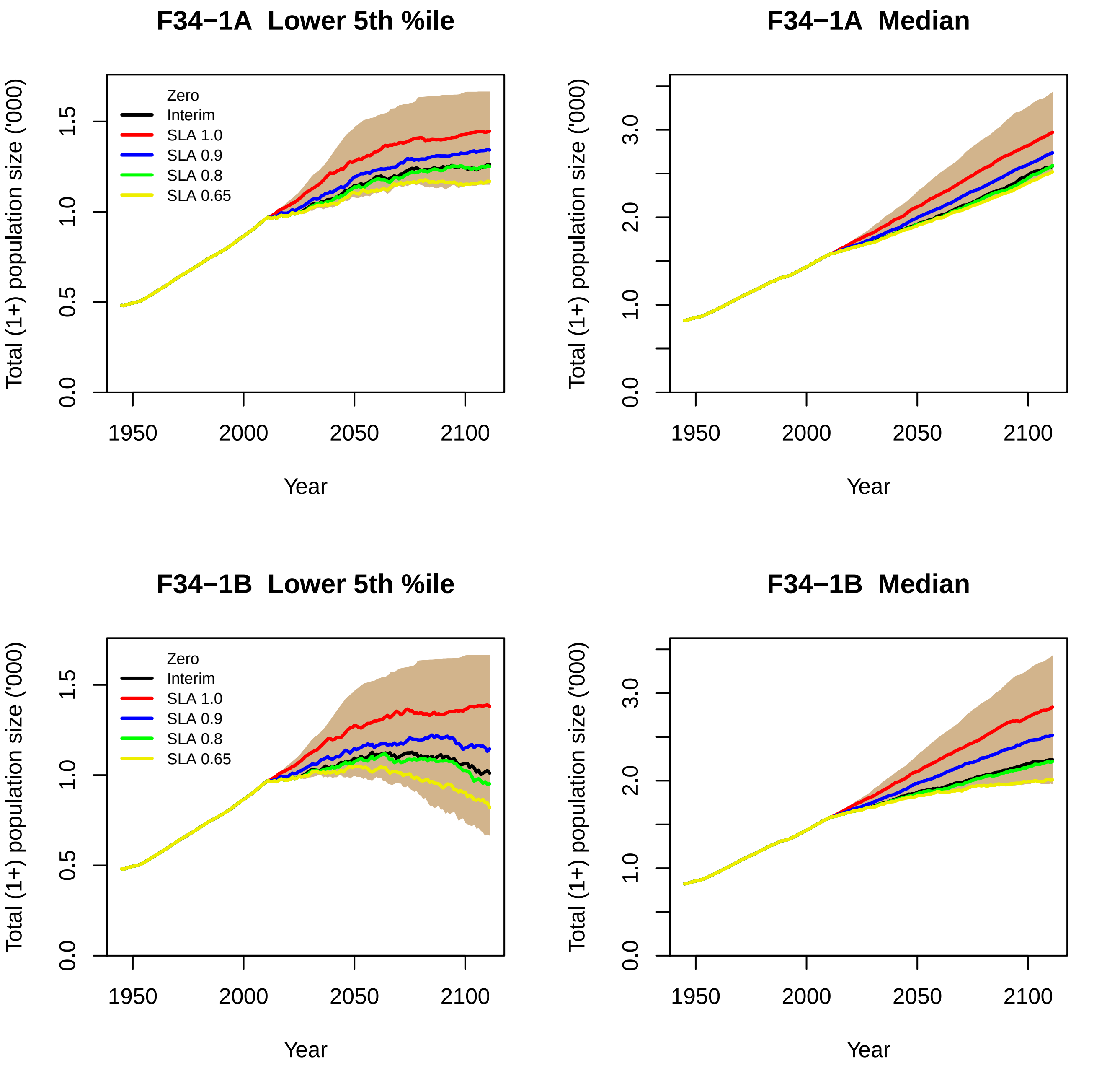
| | | |
|---|---|---|
| **GF34-1B** | $MSYR_{1+}$ = 1%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; Influx hypothesis; *K* prior of U[0, 6000] | 34-1 |
| **GF35-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; Influx hypothesis; *K* prior of U[0, 6000] | Y[35-2] |
| **GF35-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; Influx hypothesis; *K* prior of U[0, 6000] | 35-2 |
| **GF36-2A** | $MSYR_{1+}$ = 2.5%; need scenario A; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; Influx hypothesis; *K* prior of U[0, 9000] | Y[36-2] |
| **GF36-2B** | $MSYR_{1+}$ = 2.5%; need scenario B; survey frequency = 10; historic survey bias = 1; future survey CVs 0.38/0.67; Influx hypothesis; *K* prior of U[0, 9000] | 36-2 |

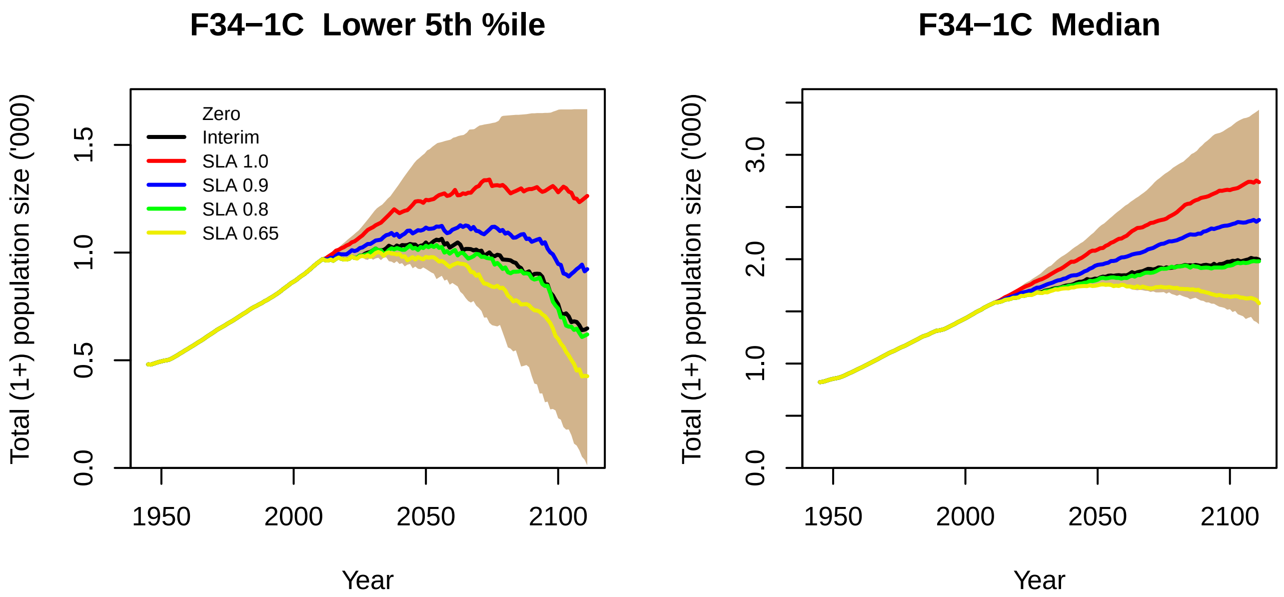
**Description of the different need scenarios (see IWC, 2015b, Table 5) for fin whales off West Greenland.**

| Need scenario | Description |
|---|---|
| **A** | 19 -> 19 over 100 years |
| **B** | 19 -> 38 over 100 years |
| **C** | 19 -> 57 over 100 years |

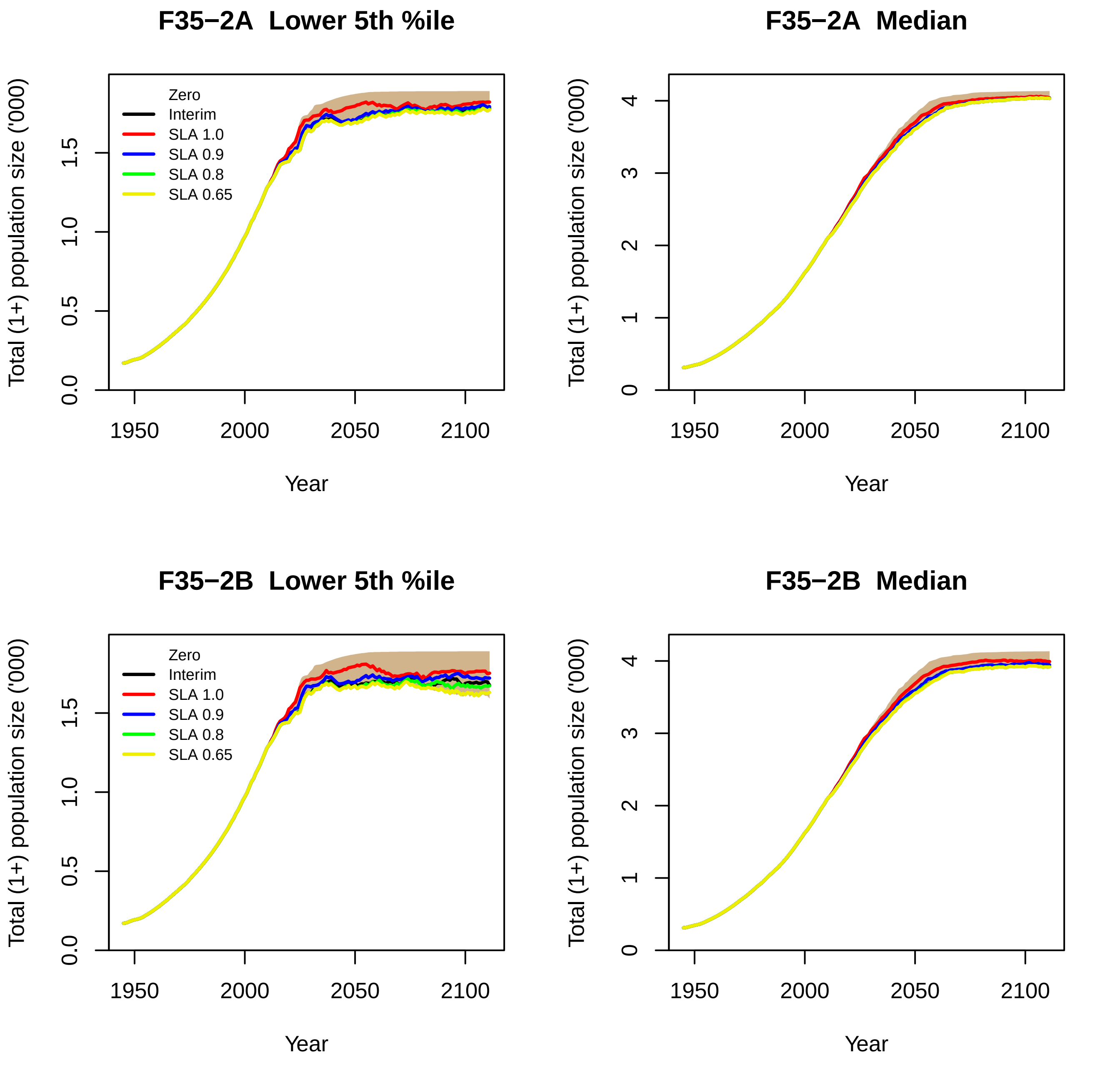
## APPENDIX B

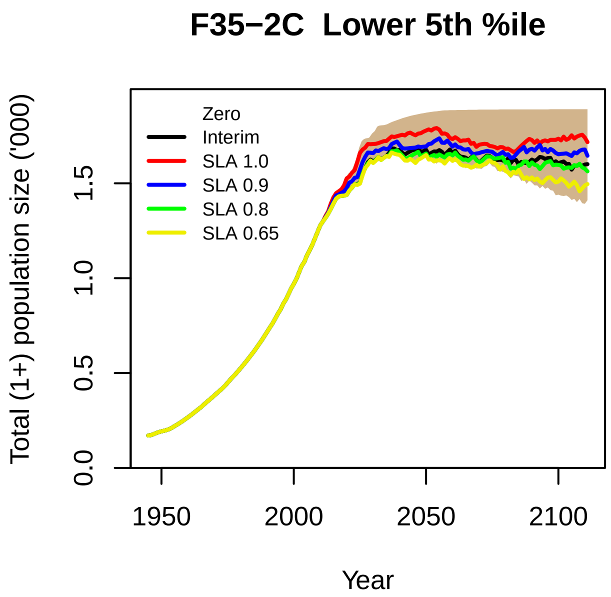
## Summary plots for the Influx hypothesis trials

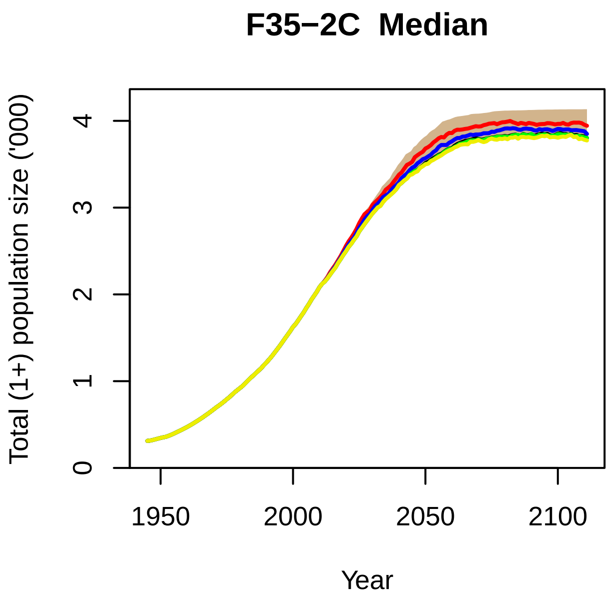

F34−1A Lower 5th %ile
F34−1A Median
F34−1B Lower 5th %ile
F34−1B Median
Total (1+) population size ('000)
Year
Zero
Interim
SLA 1.0
SLA 0.9
SLA 0.8
SLA 0.65
0.0
0.5
1.0
1.5
2.0
3.0
1950
2000
2050
2100

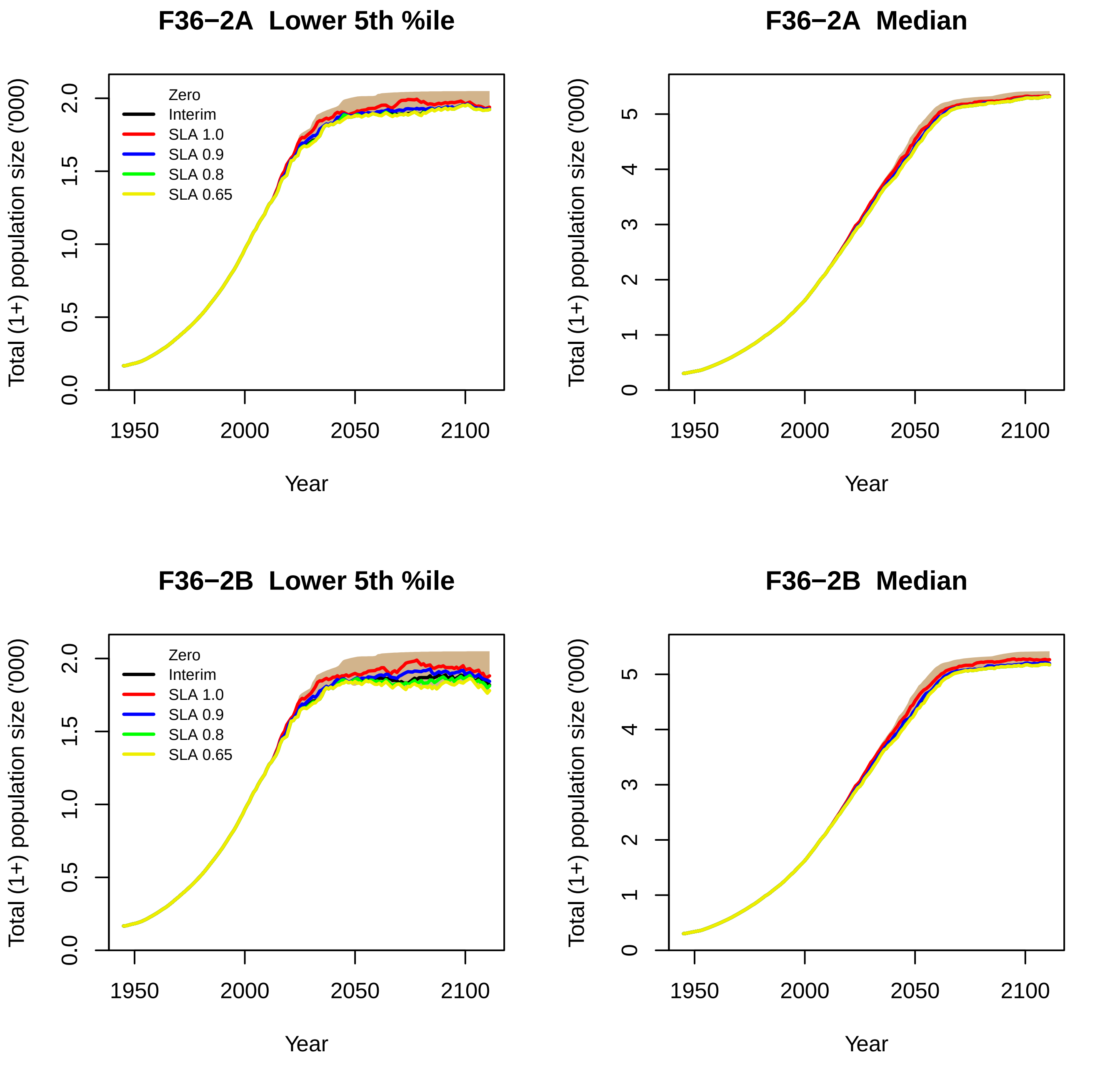


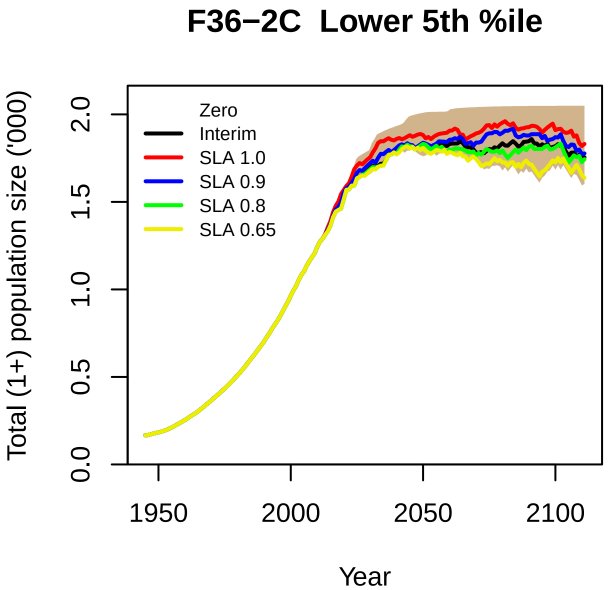
F34−1C Lower 5th %ile
F34−1C Median
Total (1+) population size ('000)
Year
Zero
Interim
SLA 1.0
SLA 0.9
SLA 0.8
SLA 0.65
0.0
0.5
1.0
1.5
1.0
2.0
3.0
1950
2000
2050
2100


F35−2A Lower 5th %ile
F35−2A Median
F35−2B Lower 5th %ile
F35−2B Median
Zero
Interim
SLA 1.0
SLA 0.9
SLA 0.8
SLA 0.65
Total (1+) population size ('000)
Year
1950
2000
2050
2100
0.0
0.5
1.0
1.5
0
1
2
3
4

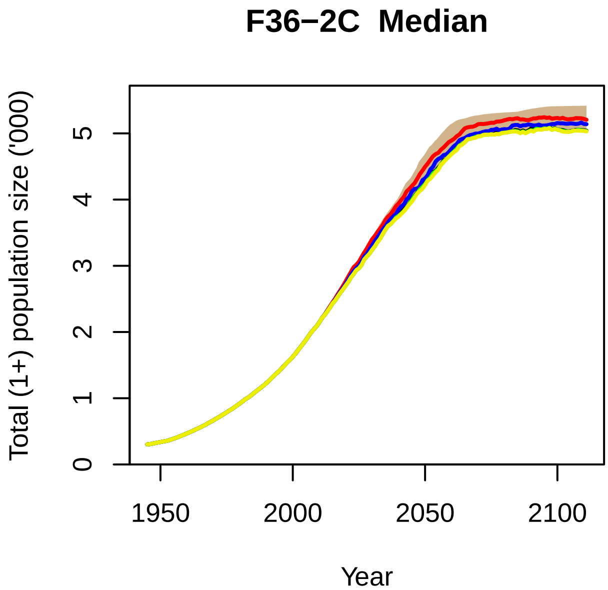

F35−2C Lower 5th %ile
Zero
Interim
SLA 1.0
SLA 0.9
SLA 0.8
SLA 0.65
Total (1+) population size ('000)
0.0
0.5
1.0
1.5
1950
2000
2050
2100
Year


F35−2C Median
Total (1+) population size ('000)
0
1
2
3
4
1950
2000
2050
2100
Year

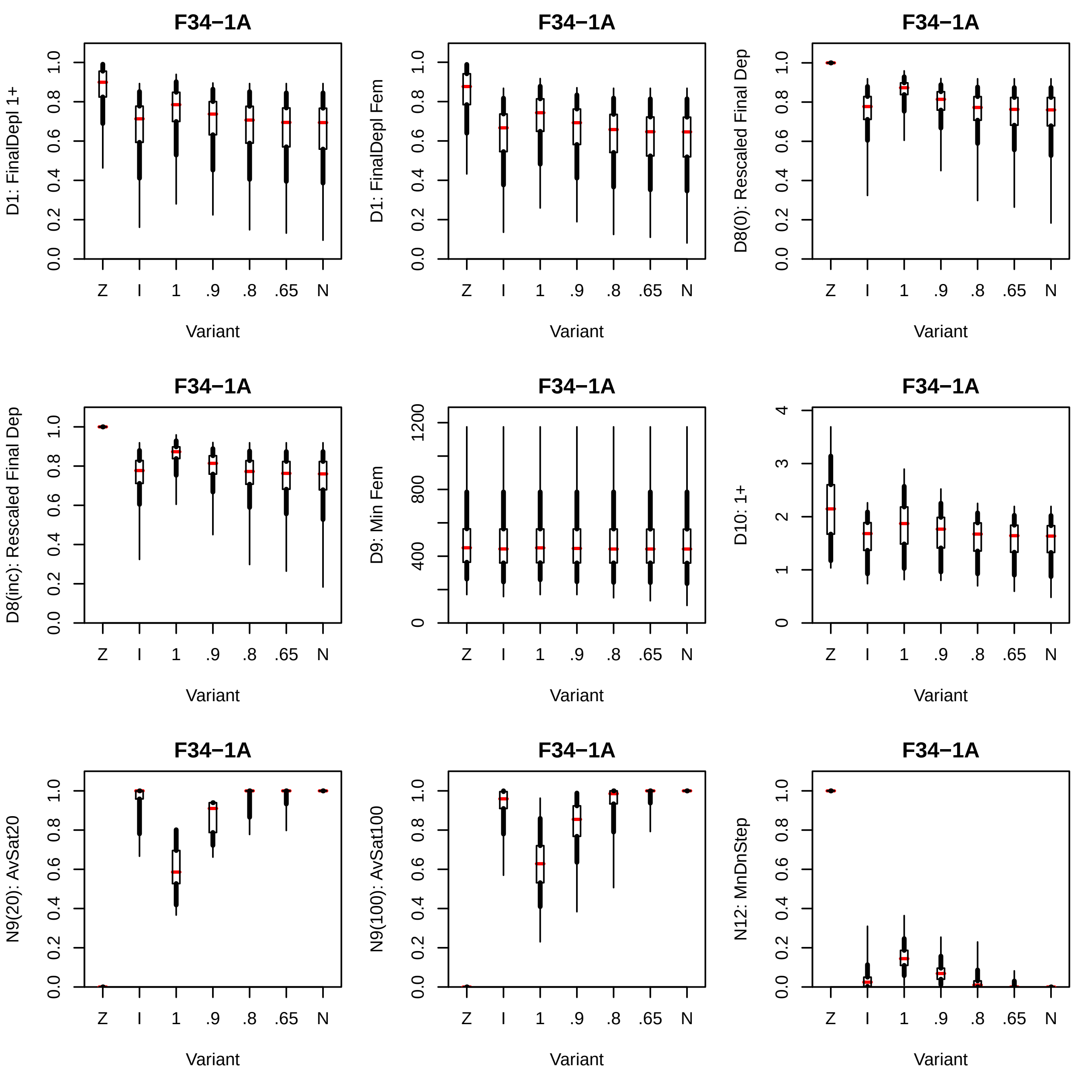

F36−2A Lower 5th %ile
F36−2A Median
F36−2B Lower 5th %ile
F36−2B Median
Total (1+) population size ('000)
Year
Zero
Interim
SLA 1.0
SLA 0.9
SLA 0.8
SLA 0.65
0.0
0.5
1.0
1.5
2.0
0
1
2
3
4
5
1950
2000
2050
2100

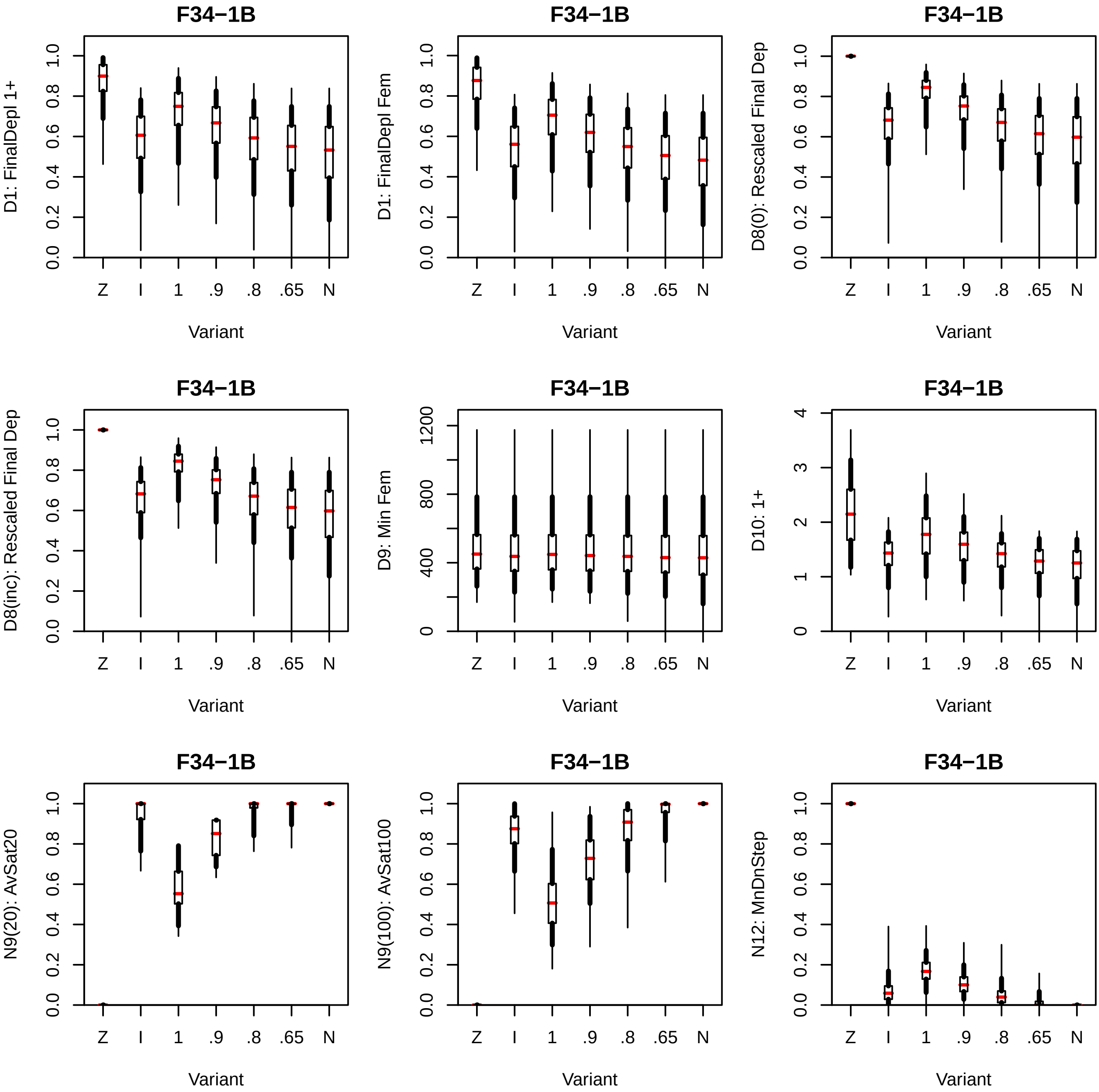


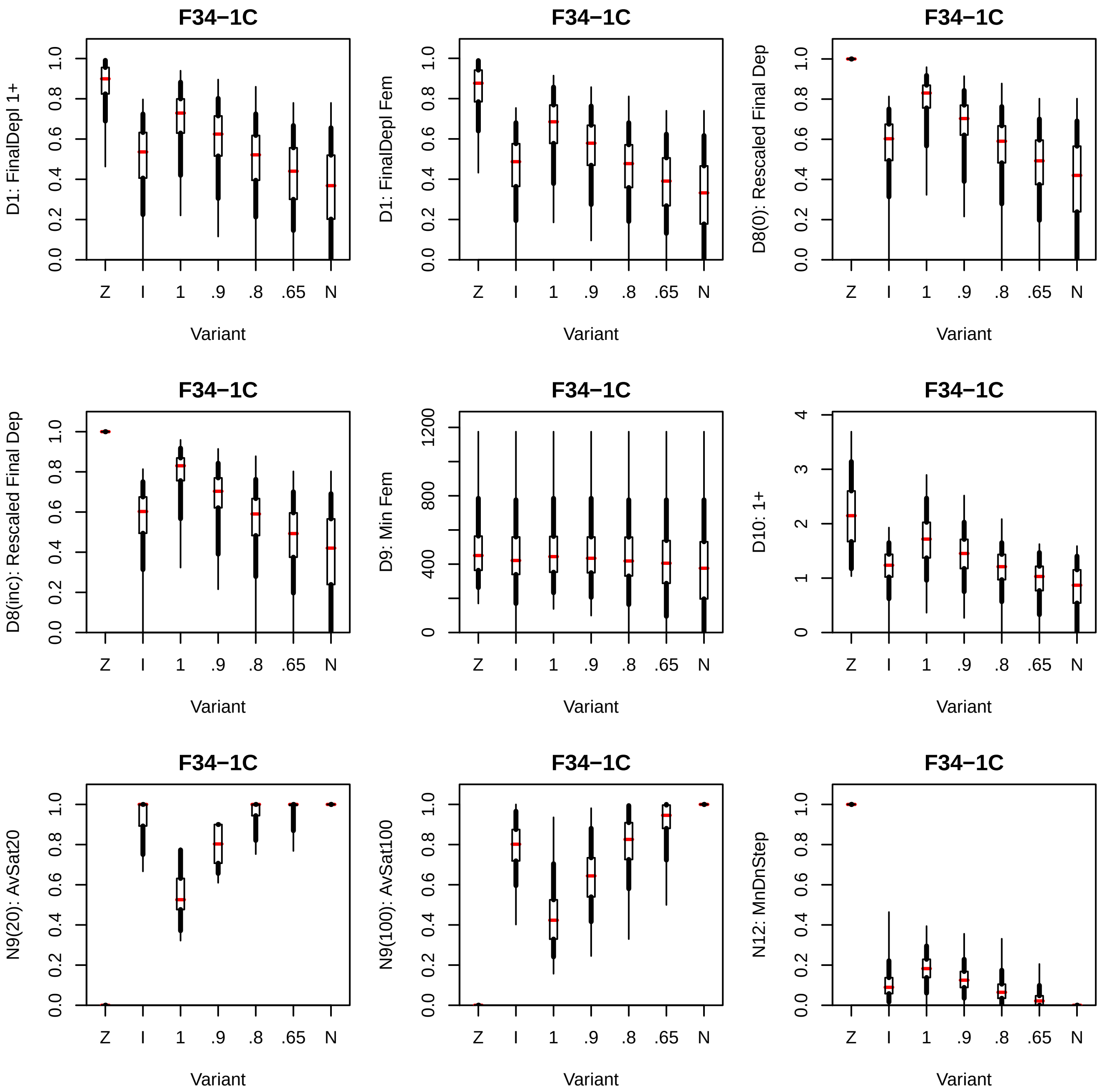
F36−2C Lower 5th %ile
Total (1+) population size ('000)
0.0
0.5
1.0
1.5
2.0
1950
2000
2050
2100
Year
Zero
Interim
SLA 1.0
SLA 0.9
SLA 0.8
SLA 0.65

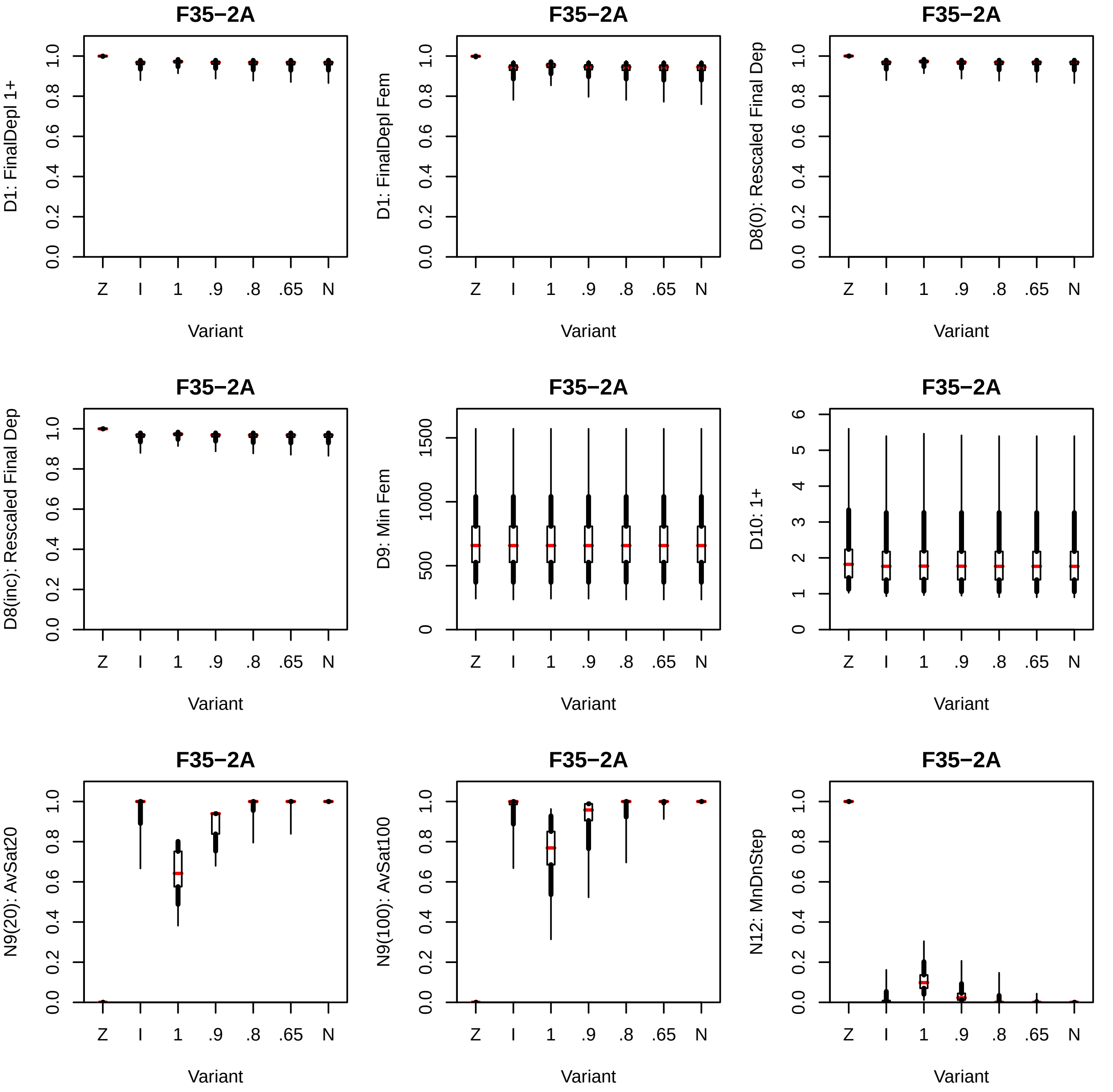



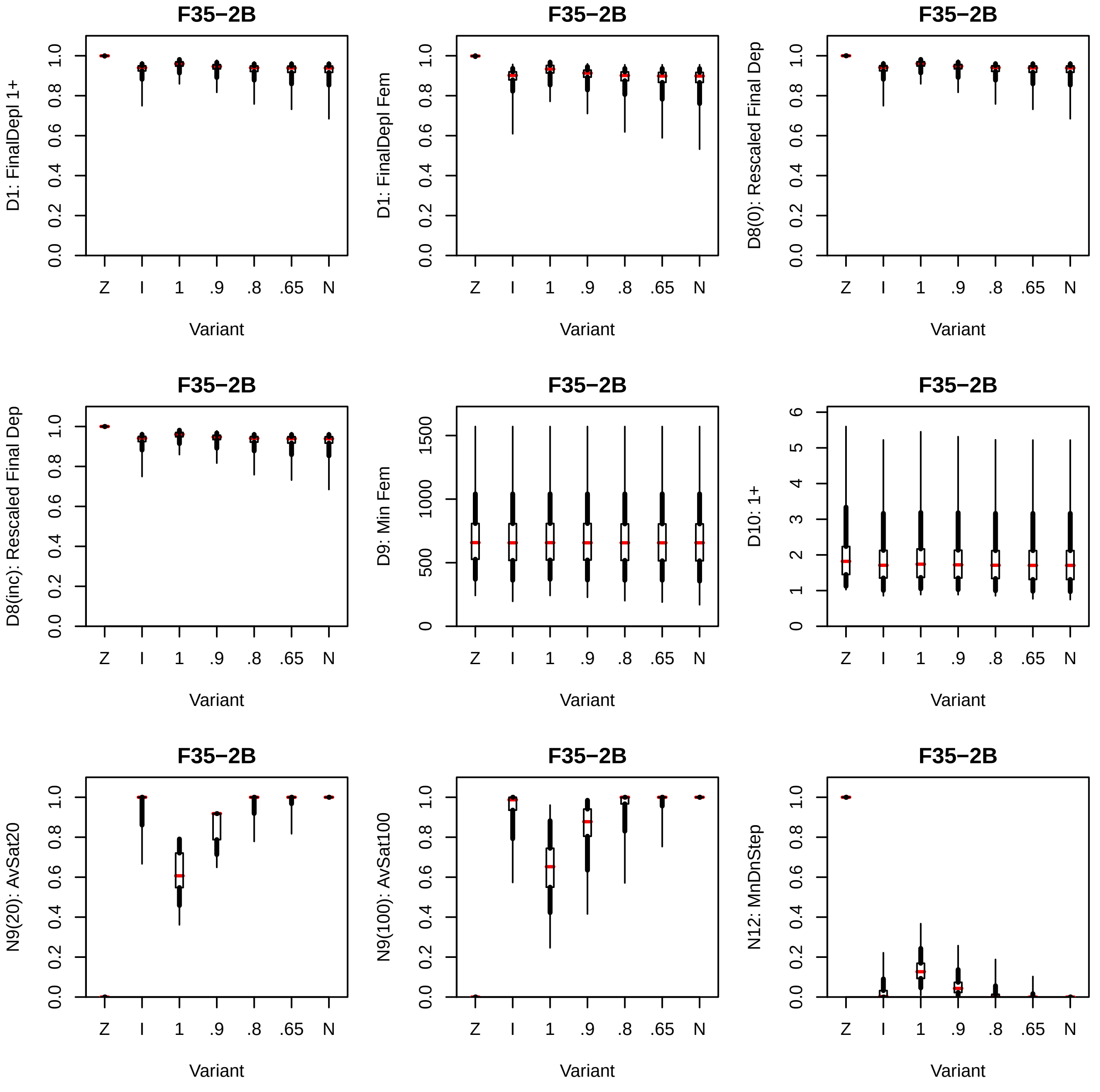
F36−2C Median
Total (1+) population size ('000)
0
1
2
3
4
5
1950
2000
2050
2100
Year

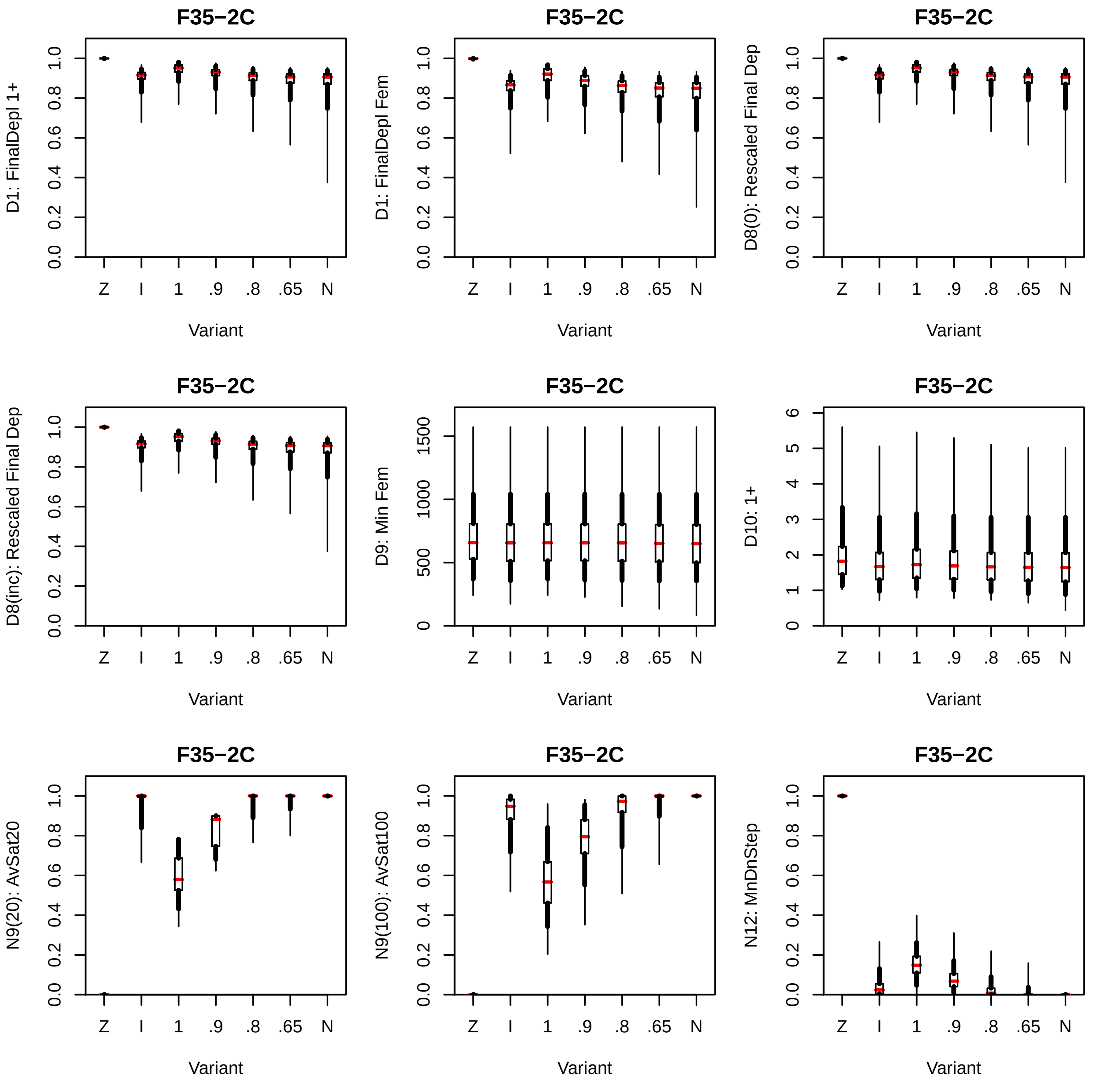

F34−1A
D1: FinalDepl 1+
D1: FinalDepl Fem
D8(0): Rescaled Final Dep
D8(inc): Rescaled Final Dep
D9: Min Fem
D10: 1+
N9(20): AvSat20
N9(100): AvSat100
N12: MnDnStep
0.0 0.2 0.4 0.6 0.8 1.0
0 400 800 1200
0 1 2 3 4
Z I 1 .9 .8 .65 N
Variant

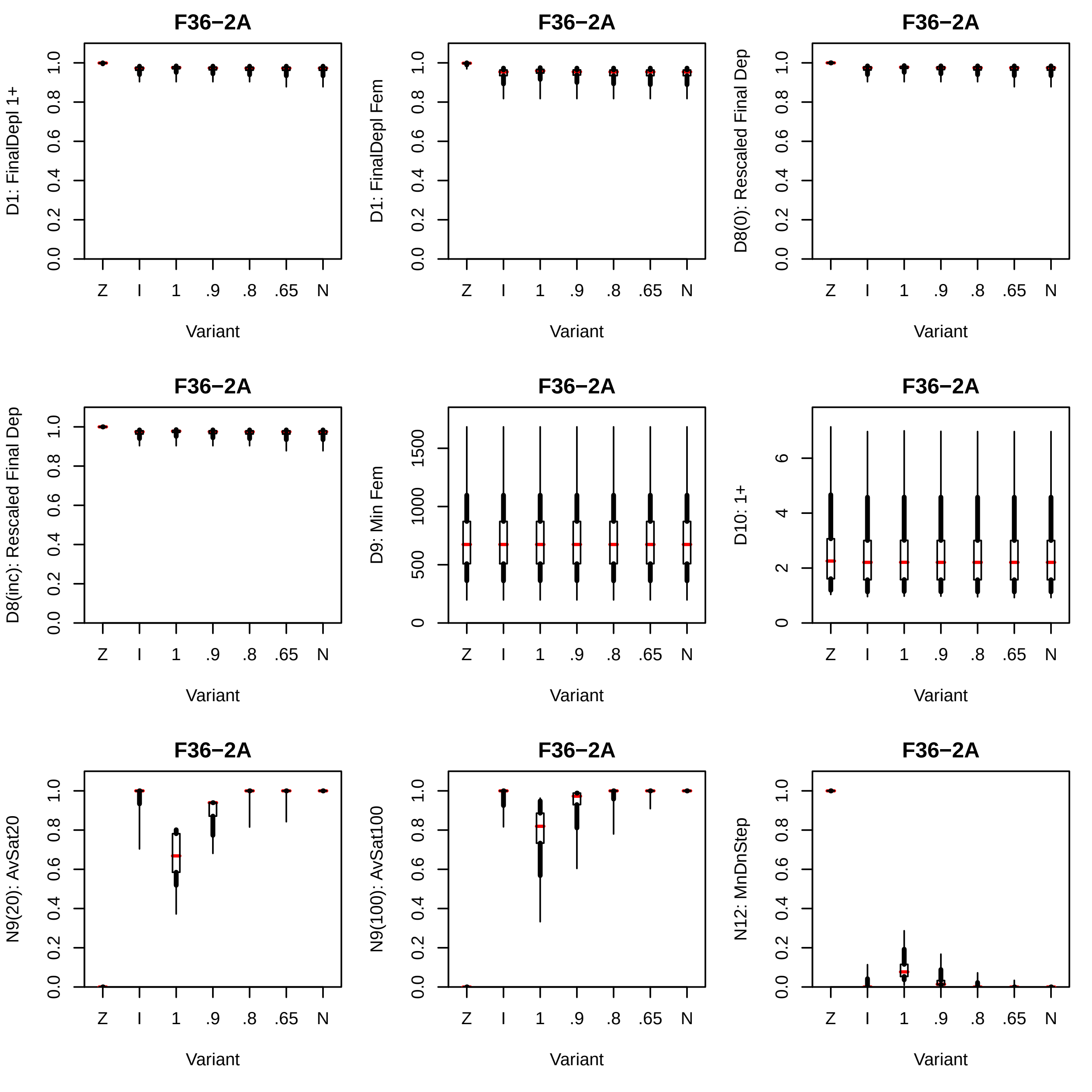

F34−1B
D1: FinalDepl 1+
F34−1B
D1: FinalDepl Fem
F34−1B
D8(0): Rescaled Final Dep
F34−1B
D8(inc): Rescaled Final Dep
F34−1B
D9: Min Fem
F34−1B
D10: 1+
F34−1B
N9(20): AvSat20
F34−1B
N9(100): AvSat100
F34−1B
N12: MnDnStep
Z I 1 .9 .8 .65 N
Variant

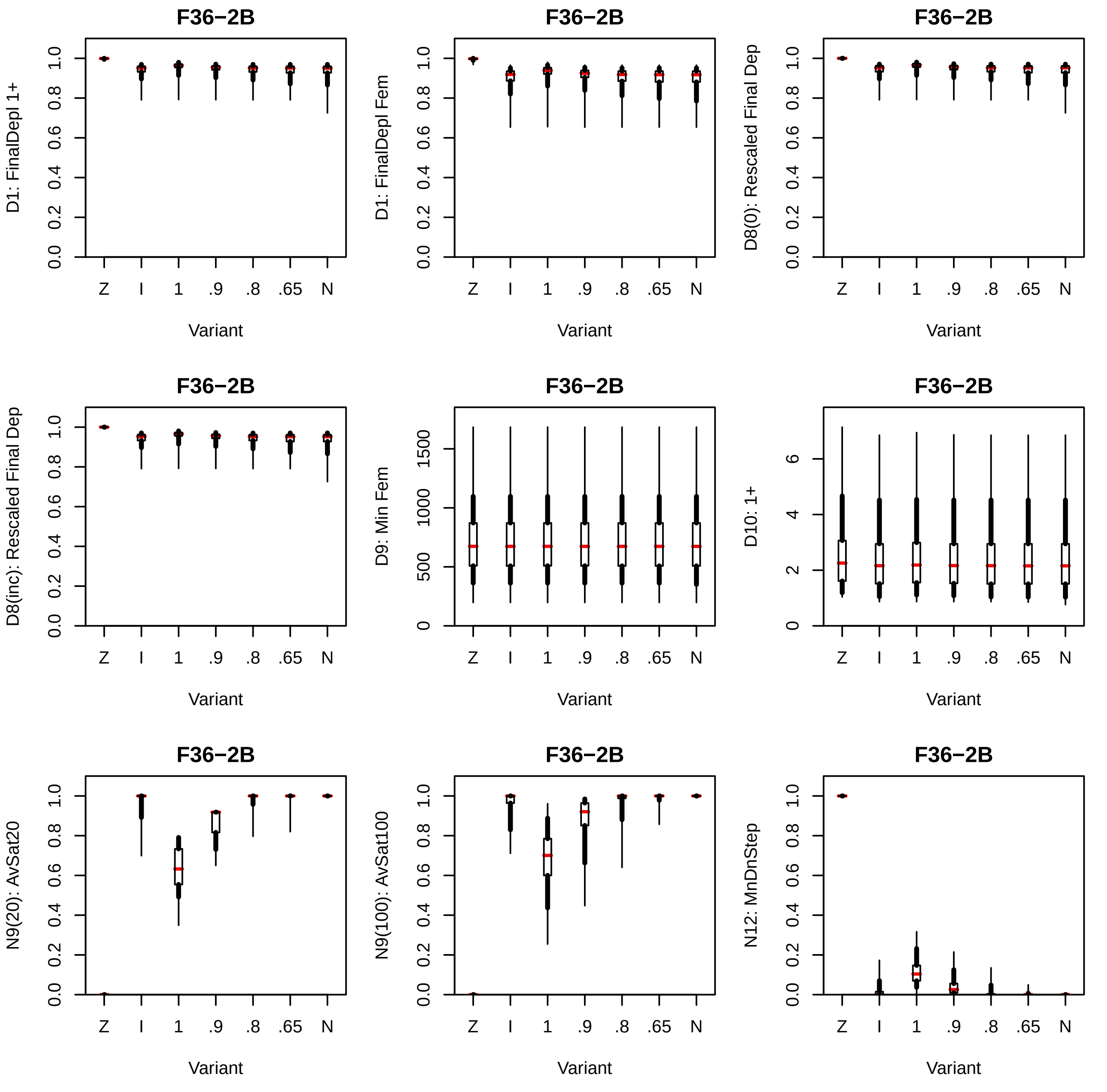

F34−1C
D1: FinalDepl 1+
D1: FinalDepl Fem
D8(0): Rescaled Final Dep
D8(inc): Rescaled Final Dep
D9: Min Fem
D10: 1+
N9(20): AvSat20
N9(100): AvSat100
N12: MnDnStep
Z
I
1
.9
.8
.65
N
Variant

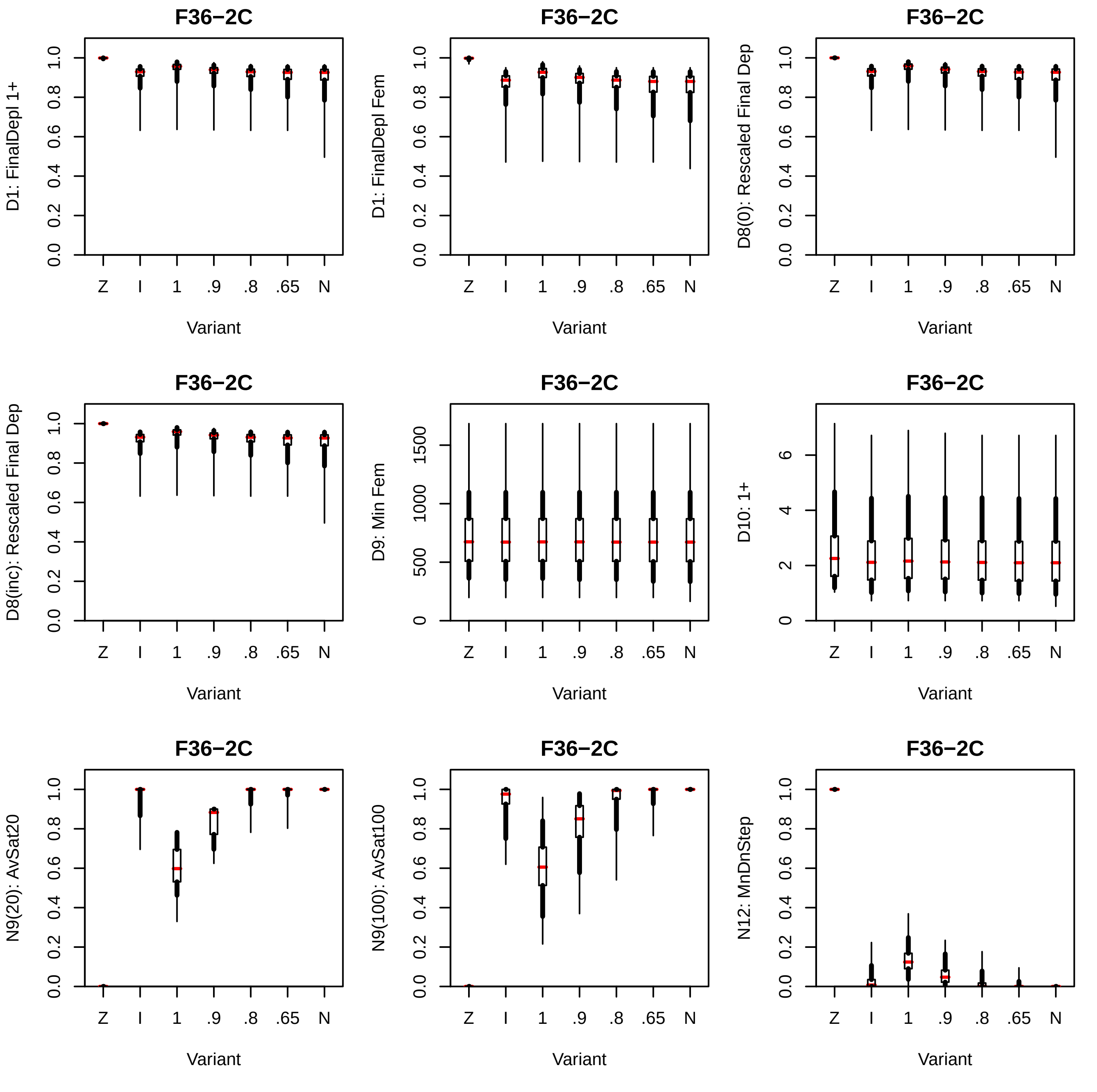

F35−2A
D1: FinalDepl 1+
D1: FinalDepl Fem
D8(0): Rescaled Final Dep
D8(inc): Rescaled Final Dep
D9: Min Fem
D10: 1+
N9(20): AvSat20
N9(100): AvSat100
N12: MnDnStep
0.0
0.2
0.4
0.6
0.8
1.0
0
500
1000
1500
1
2
3
4
5
6
Z
I
1
.9
.8
.65
N
Variant

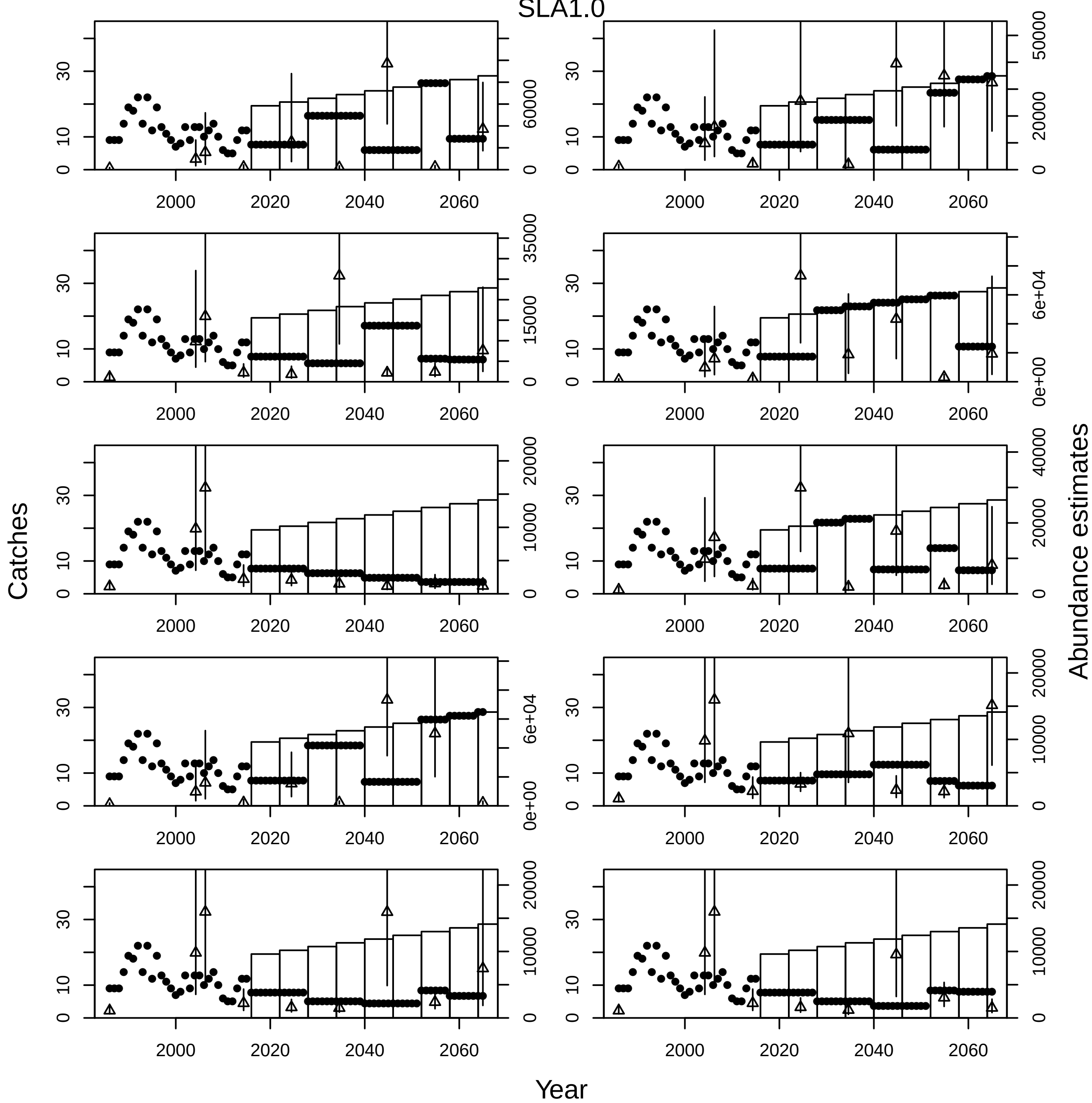

F35−2B
D1: FinalDepl 1+
0.0 0.2 0.4 0.6 0.8 1.0
Z I 1 .9 .8 .65 N
Variant
F35−2B
D1: FinalDepl Fem
0.0 0.2 0.4 0.6 0.8 1.0
Z I 1 .9 .8 .65 N
Variant
F35−2B
D8(0): Rescaled Final Dep
0.0 0.2 0.4 0.6 0.8 1.0
Z I 1 .9 .8 .65 N
Variant
F35−2B
D8(inc): Rescaled Final Dep
0.0 0.2 0.4 0.6 0.8 1.0
Z I 1 .9 .8 .65 N
Variant
F35−2B
D9: Min Fem
0 500 1000 1500
Z I 1 .9 .8 .65 N
Variant
F35−2B
D10: 1+
0 1 2 3 4 5 6
Z I 1 .9 .8 .65 N
Variant
F35−2B
N9(20): AvSat20
0.0 0.2 0.4 0.6 0.8 1.0
Z I 1 .9 .8 .65 N
Variant
F35−2B
N9(100): AvSat100
0.0 0.2 0.4 0.6 0.8 1.0
Z I 1 .9 .8 .65 N
Variant
F35−2B
N12: MnDnStep
0.0 0.2 0.4 0.6 0.8 1.0
Z I 1 .9 .8 .65 N
Variant

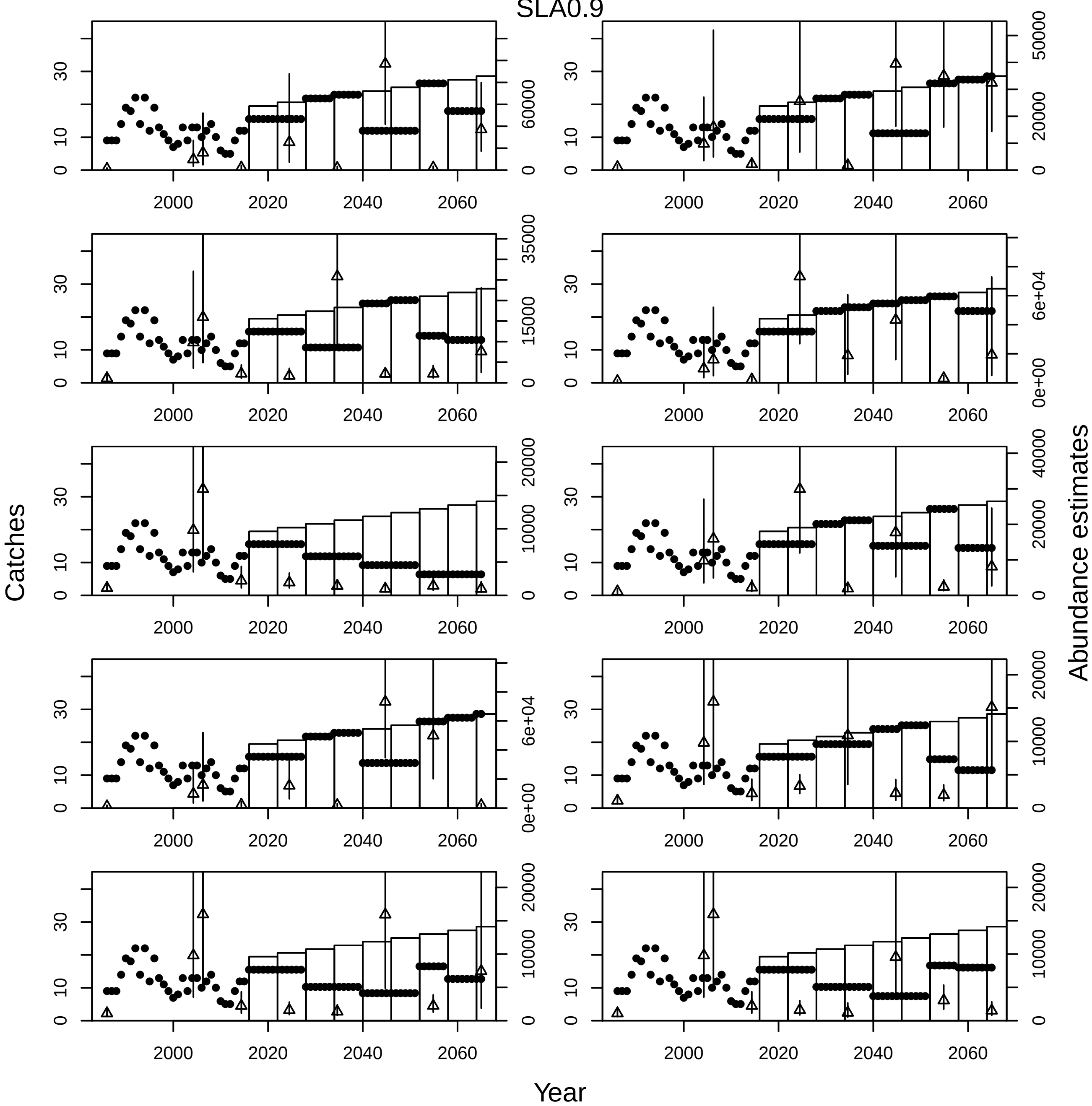

F35−2C
D1: FinalDepl 1+
D1: FinalDepl Fem
D8(0): Rescaled Final Dep
D8(inc): Rescaled Final Dep
D9: Min Fem
D10: 1+
N9(20): AvSat20
N9(100): AvSat100
N12: MnDnStep
Variant
Z
I
1
.9
.8
.65
N

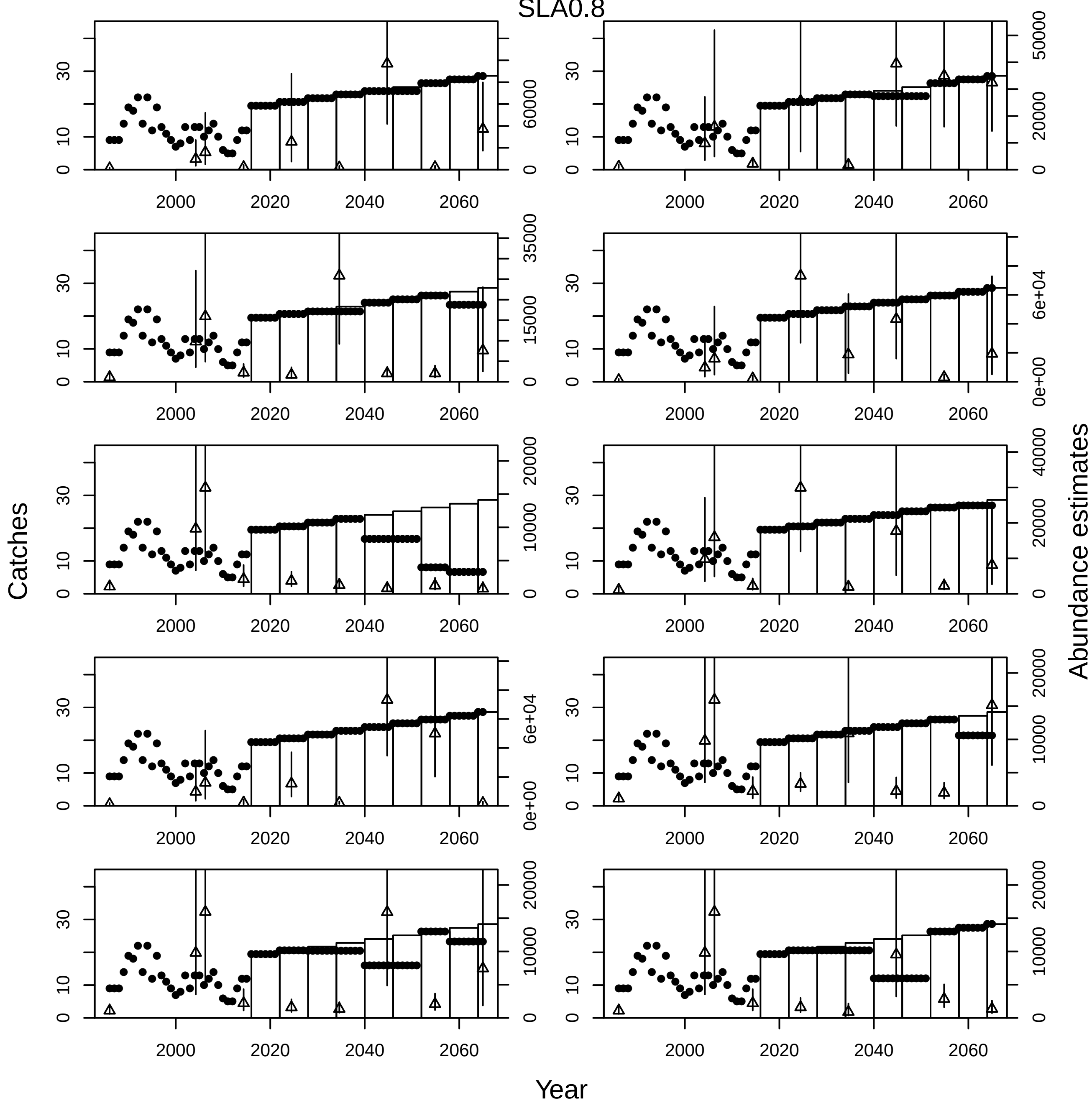

F36−2A
D1: FinalDepl 1+
D1: FinalDepl Fem
D8(0): Rescaled Final Dep
D8(inc): Rescaled Final Dep
D9: Min Fem
D10: 1+
N9(20): AvSat20
N9(100): AvSat100
N12: MnDnStep
Variant
Z
I
1
.9
.8
.65
N
0.0
0.2
0.4
0.6
0.8
1.0
0
500
1000
1500
2
4
6


F36−2B
D1: FinalDepl 1+
F36−2B
D1: FinalDepl Fem
F36−2B
D8(0): Rescaled Final Dep
F36−2B
D8(inc): Rescaled Final Dep
F36−2B
D9: Min Fem
F36−2B
D10: 1+
F36−2B
N9(20): AvSat20
F36−2B
N9(100): AvSat100
F36−2B
N12: MnDnStep
Z I 1 .9 .8 .65 N
Variant

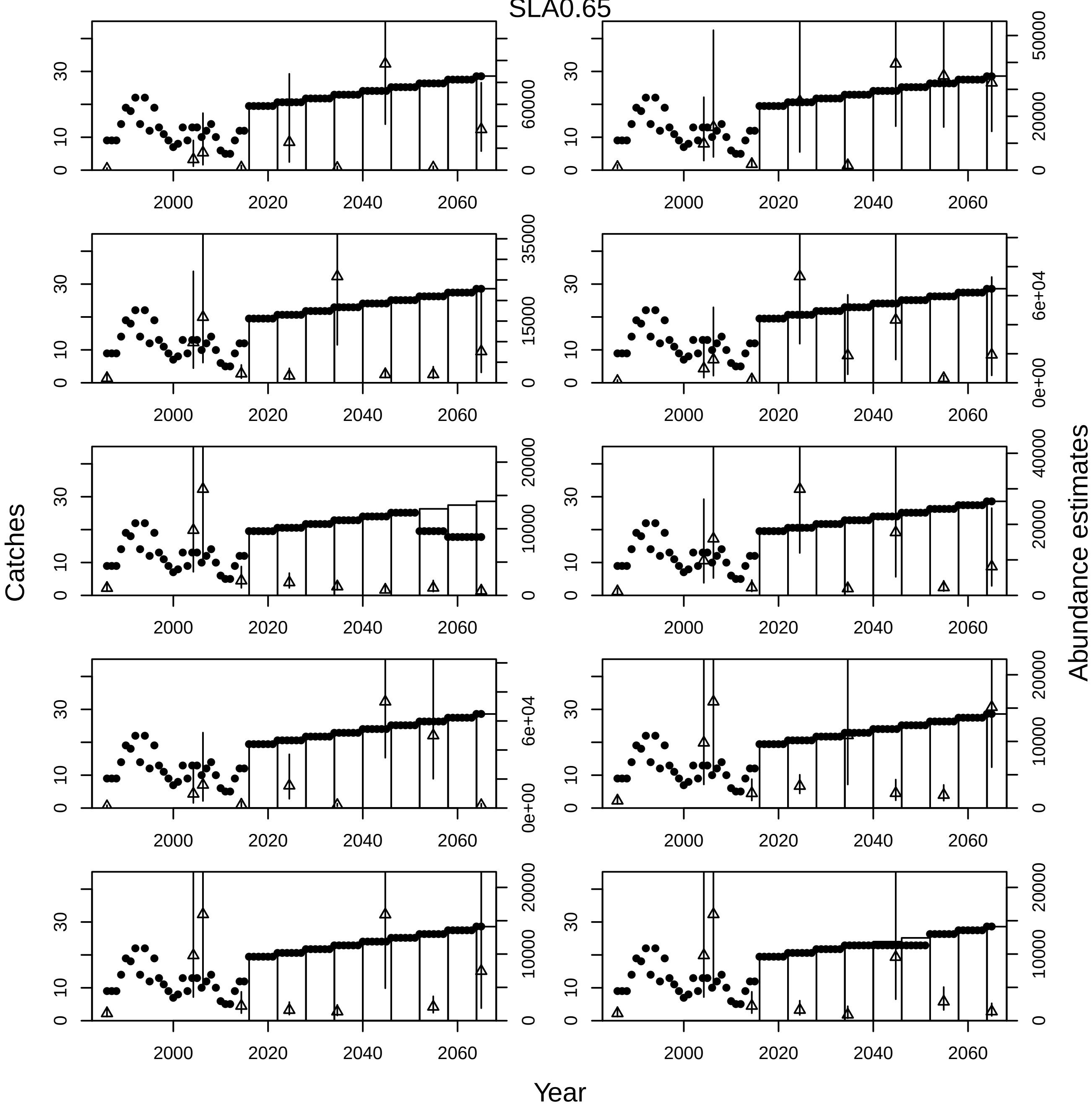

F36−2C
D1: FinalDepl 1+
D1: FinalDepl Fem
D8(0): Rescaled Final Dep
D8(inc): Rescaled Final Dep
D9: Min Fem
D10: 1+
N9(20): AvSat20
N9(100): AvSat100
N12: MnDnStep
Z
I
1
.9
.8
.65
N
Variant


SLA1.0
Catches
Abundance estimates
Year
2000
2020
2040
2060
0
10
30
60000
50000
20000
35000
15000
6e+04
0e+00
40000
20000
10000


SLA0.9
Catches
Abundance estimates
Year
2000
2020
2040
2060
0
10
30
60000
50000
20000
35000
15000
6e+04
0e+00
40000
10000



SLA0.8
Catches
Abundance estimates
Year
2000
2020
2040
2060
0
10
30


SLA0.65
Catches
Abundance estimates
Year