Simulation trials for the Revised Management Procedure, including comparisons for when density dependence acts on fecundity or natural mortality — Part 2.

KELLI F. JOHNSON AND ANDRÉ E. PUNT

School of Aquatic & Fishery Sciences, University of Washington, Box 355020, Seattle, WA 98195-5020, USA
Contact e-mail aepunt@uw.edu

ABSTRACT

Two variants of the Catch Limit Algorithm, *CLA* (the original *CLA* adopted by the Commission, and an alternative version produced by Norway) are evaluated using the trials identified by the Scientific Committee as well as additional trials that consider density-dependence on natural mortality rather than on fecundity, and additional ways in which environmental change could impact whale dynamics. Results are shown for 100- and 300-year projection periods, and are summarized by 'Zeh-plots'.

INTRODUCTION

The Revised Management Procedure (RMP) of the International Whaling Commission (IWC) (IWC, 2012) represents a rigorously-tested mechanism to provide risk-averse advice regarding catch limits for baleen whales. The catch limit algorithm (*CLA*), the process used to calculate area-specific catch limits, represents a major component of the RMP. This paper summarizes the results of the extended set (Tables 1 and 2) of results comparing the original *CLA* adopted by the Commission and the alternate tuning proposed by Norway that were not included in the initial comparison (Johnson and Punt, 2015b).

METHODS

Trials structure

All trials necessary for the evaluation of a RMP (IWC, 2007) were conducted for 100-year and 300-year projection periods when density-dependence acts on fecundity or natural mortality (Johnson and Punt, 2015a) and whether MSYR pertains to the total (1+) or mature female component of the population. Results from 400 simulations for each trial are summarized using 'Zeh plots', using the following notation:

A. 100-year projections using the currently-adopted *CLA*;
B. 300-year projections using the currently-adopted *CLA*;
C. 100-year projections using the alternative *CLA* tuning proposed by Norway; and
D. 300-year projections using the alternative *CLA* tuning proposed by Norway.

'Zhe plots' show how total catch (TC; 5th %ile, median, and 95th %ile), final population size (*Pf;* 5th %ile, median, and 95th %ile), lowest population size (*Pmin;* 5%, 10%,and 25%), and average annual catch variation (AAV) change as aspects of the trials are changed (Tables 1, 2, and 3). Results are not shown for the relative recovery statistic, the realized protection level, and the continuing catch statistic owing to difficulties in defining these statistics when natural mortality is changing over time. Population sizes are scaled by *K*, except when *K* varies. In these cases, the final population size and lowest population size over the distribution are scaled by the population size resulting if no catch is taken in the management period.

RESULTS

'Zeh plots' are shown for for $MSYR_{1+} = 1\%$ and $MSYR_{mat} = 4\%$, as these choices were selected during the MSYR review. Figures show results for 100- and 300-year projections for the currently-adopted *CLA* (A and B, respectively) and 100- and 300-year projections implementing the tuning proposed by Norway (C and D, respectively).

ACKNOWLEDGEMENTS

This work was partially supported by the IWC. Cherry Allison is thanked for providing the control program as well as the lists of trials to be conducted.

REFERENCES

International Whaling Commission (IWC). 2007. Report of *Catch Limit Algorithm* (*CLA*) trials group. J. Cetacean Res. Manage. 9(Suppl): 110–13.

Johnson, K. F., and Punt, A. E. 2015a. A note on density-dependent natural mortality in Catch Limit Algorithm trials. Paper SC/66a/RMP1 presented to the IWC Scientific Committee, May 2015, San Diego, USA. 15 pp. [Paper available from the Office of this Journal].

Johnson, K. F., and Punt, A. E. 2015b. Simulation trials for the Revised Management Procedure, including comparisons for when density dependence acts on fecundity or natural mortality — Part 1.. Paper SC/66a/RMP10 presented to the IWC Scientific Committee, May 2015, San Diego, USA. 25 pp. [Paper available from the Office of this Journal].

Table 1
Full set of trials that should be conducted if a proposal were to be made for a revision to the *CLA*.

	Description	$MSYR$	1%	4%	Figure
T.1	Age structured model, maturity = 7 yr				
	D=Development (initial population $0.99K$)		T1-D1	T1-D4	1b
	R=Rehabilitation (initial population $0.30K$)		T1-R1	T1-R4	1a-upper
	S=Sustainable (initial population $0.60K$)		T1-S1	T1-S4	1a-lower
	initial population $0.20K$		T1-T1	T1-T4	2
	initial population $0.40K$		T1-F1	T1-F4	3
T.2	Survey Bias 0.5		T2-D1	T2-D4	4-lower
			T2-R1	T2-R4	4-upper
T.3	Survey Bias 1.5		T3-D1	T3-D4	5b
			T3-R1	T3-R4	5a-upper
			T3-S1	T3-S4	5a-lower
T.4	Initial Population size $P_0 = 0.05K$		T4-R1	T4-R4	6
T.5	25 years of protection prior to management		T5-R1	T5-R4	7
T.6	Historic error in catch ($1/2$ true catch)		T6-R1	T6-R4	8
T.7	Age at maturity = 10 yr		T7-D1	T7-D4	9-lower
			T7-R1	T7-R4	9-upper
T.9	Episodic events: 2% yearly chance that population is halved		T9-D1	T9-D4	Not included
			T9-R1	T9-R4	Not included
T.10	$MSYL = 40\%$		T10-D1	T10-D4	Failed
			T10-R1	T10-R4	Failed
T.11	$MSYL = 80\%$		T11-D1	T11-D4	10-lower
			T11-R1	T11-R4	10-upper
T.12A	K doubles over management period		T12A-D1	T12A-D4	11-lower
			T12A-R1	T12A-R4	11-upper
T.12B	K halves over management period		T12B-D1	T12B-D4	12-lower
			T12B-R1	T12B-R4	12-upper
T.13	33 year cycle in $MSYR(141)$		T13-D1		Not included
			T13-R1		13
	33 year cycle in $MSYR(414)$		T13-D4		Not included
			T13-R4		13
T.15	Survey every 10 years		T15-D1	T15-D4	14-lower
			T15-R1	T15-R4	14-upper
T.16	$MSYR$ declines to $1/2$ its initial value		T16-D1	T16-D4	15
T.17	K & $MSYR$ declines to $1/2$ its initial value		T17-D1	T17-D4	16

Table 2
Additional trials for evaluating the variants of the *CLA*.

	Description	MSYR	1%	4%	Figure
T.18	$MSYR$ doubles over the management period		T18-D1	T18-D4	17b
			T18-R1	T18-R4	17-upper
			T18-S1	T18-S4	17-lower
T.19	$MSYR$ and K decrease by half over the management period		T19-D1	T19-D4	18b
			T19-R1	T19-D4	18-upper
			T19-S1	T19-S4	18-lower
T.20	2% yearly chance population is halved & survey bias of 1.5		T20-D1	T20-D4	19b
			T20-R1	T20-R4	19a-upper
			T20-S1	T20-S4	19a-lower

Table 3
Specification of the *CLA* variants.

Parameter	**Alt**	**Original**
PROBABILITY LEVEL (PPROB)	0.50	0.40
MIN MSY % (PYMIN)	0.00	0.00
MAX MSY % (PYMAX)	0.05	0.05
DEPLETION MIN (DTMIN)	0.00	0.00
DEPLETION MAX (DTMAX)	1.00	1.00
BIAS MIN (PBMIN)	0.00	0.00
BIAS MAX (PBMAX)	1.67	1.67
SCALE FACTOR (PSCALE)	4.00	4.00
PHASEOUT PERIOD (PHASET)	8.00	8.00
PHASEOUT PROPORTION (PHASEP)	0.20	0.20
ASSESSMENT CYCLE (PCYCLE)	5.00	5.00
INTERNAL PROTECTION LEVEL	0.54	0.54
CATCH CONTROL SLOPE (PSLOPE)	4.72	3.00
ACCURACY TOLERANCE (ACCTOL)	0.00	0.00
NOFRULE	8.00	8.00

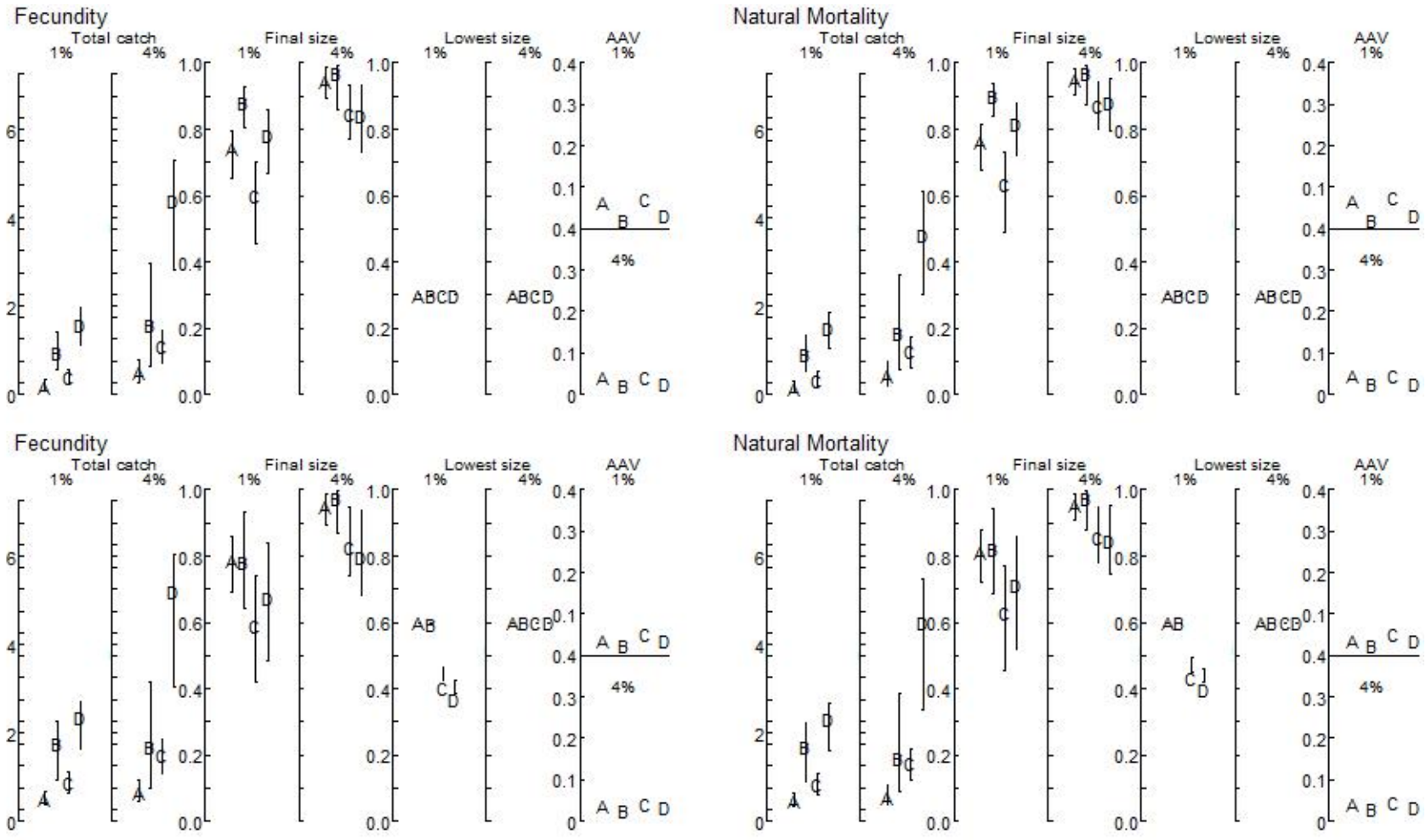

Figure 1(a): Zeh plots for the base-case model (A = 100-year current, B = 300-year current, C = 100-year alternate, and D = 300-year alternate) when initial depletion is 30% (upper panel) and 60% (lower panel). Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).

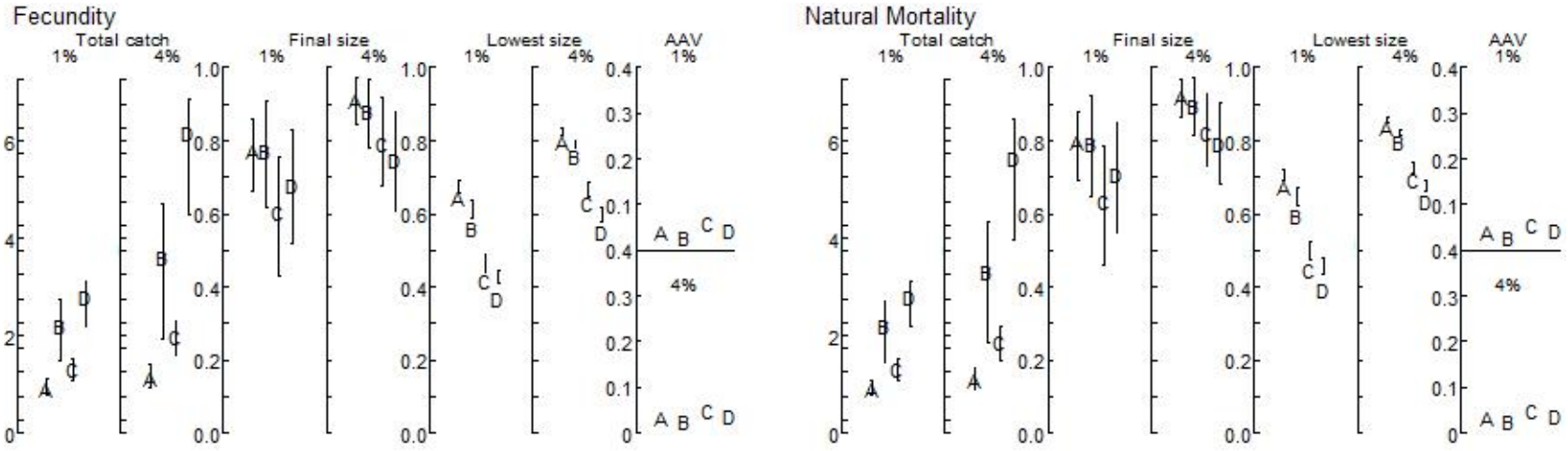

Figure 1(b): Zeh plots for the base-case model (A = 100-year current, B = 300-year current, C = 100-year alternate, and D = 300-year alternate) when initial depletion is 99%. Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).

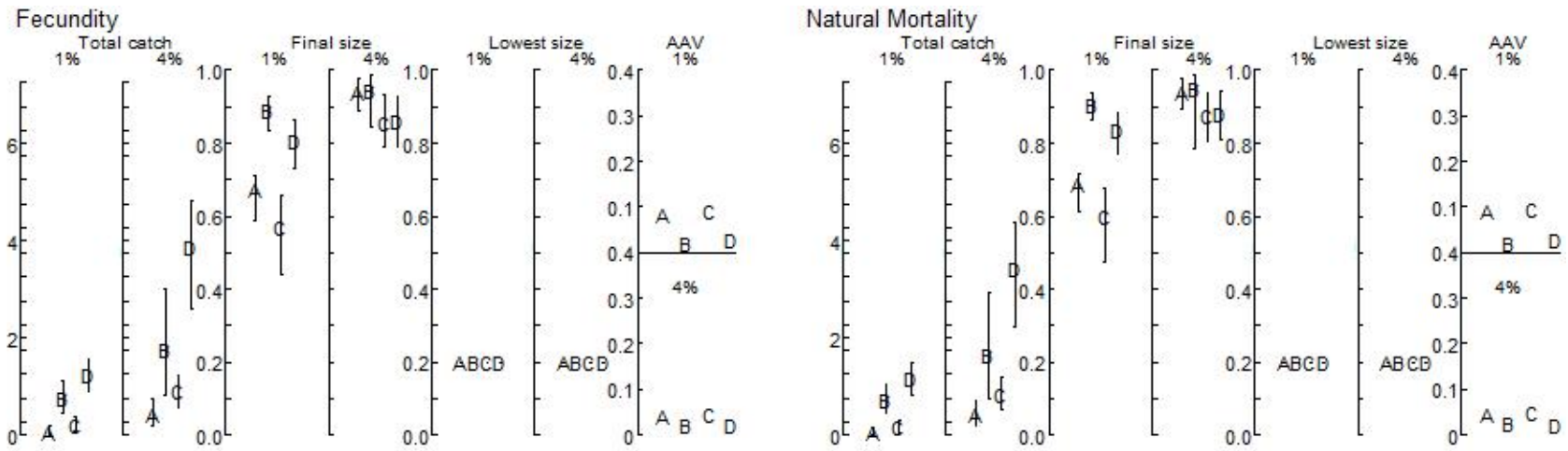

Figure 2: Zeh plots for trial T1-T [P_0 = 0.2] (A = 100-year current, B = 300-year current, C = 100-year alternate, and D = 300-year alternate) when initial depletion is 20%. Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).

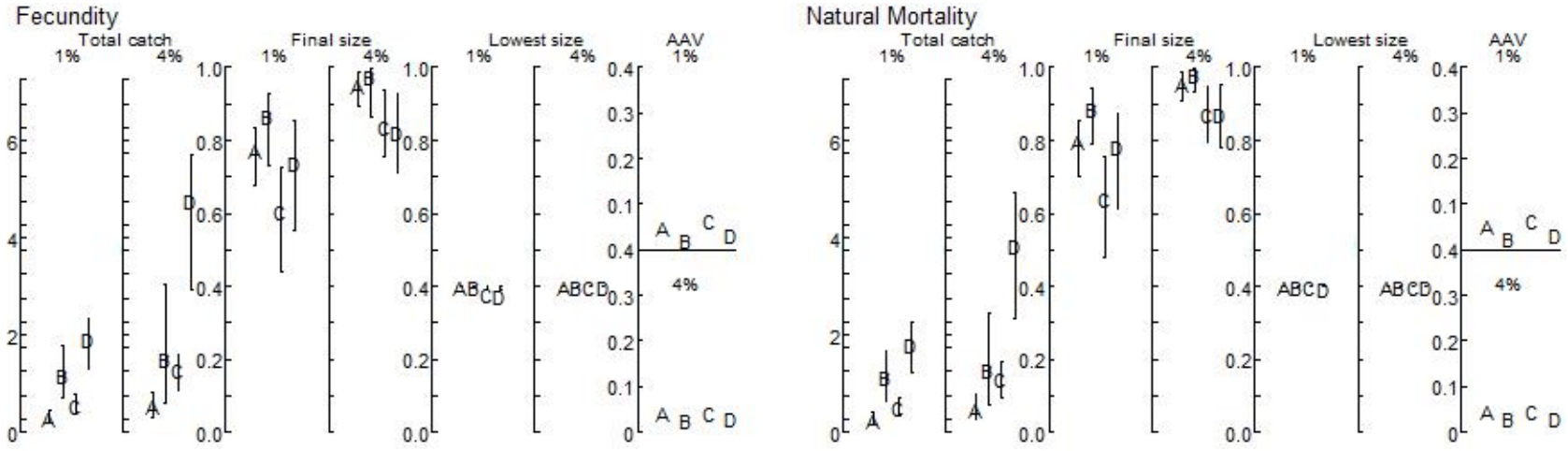

Figure 3: Zeh plots for trial T1-F [P_0 = 0.4] (A = 100-year current, B = 300-year current, C = 100-year alternate, and D = 300-year alternate) when initial depletion is 40%. Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).

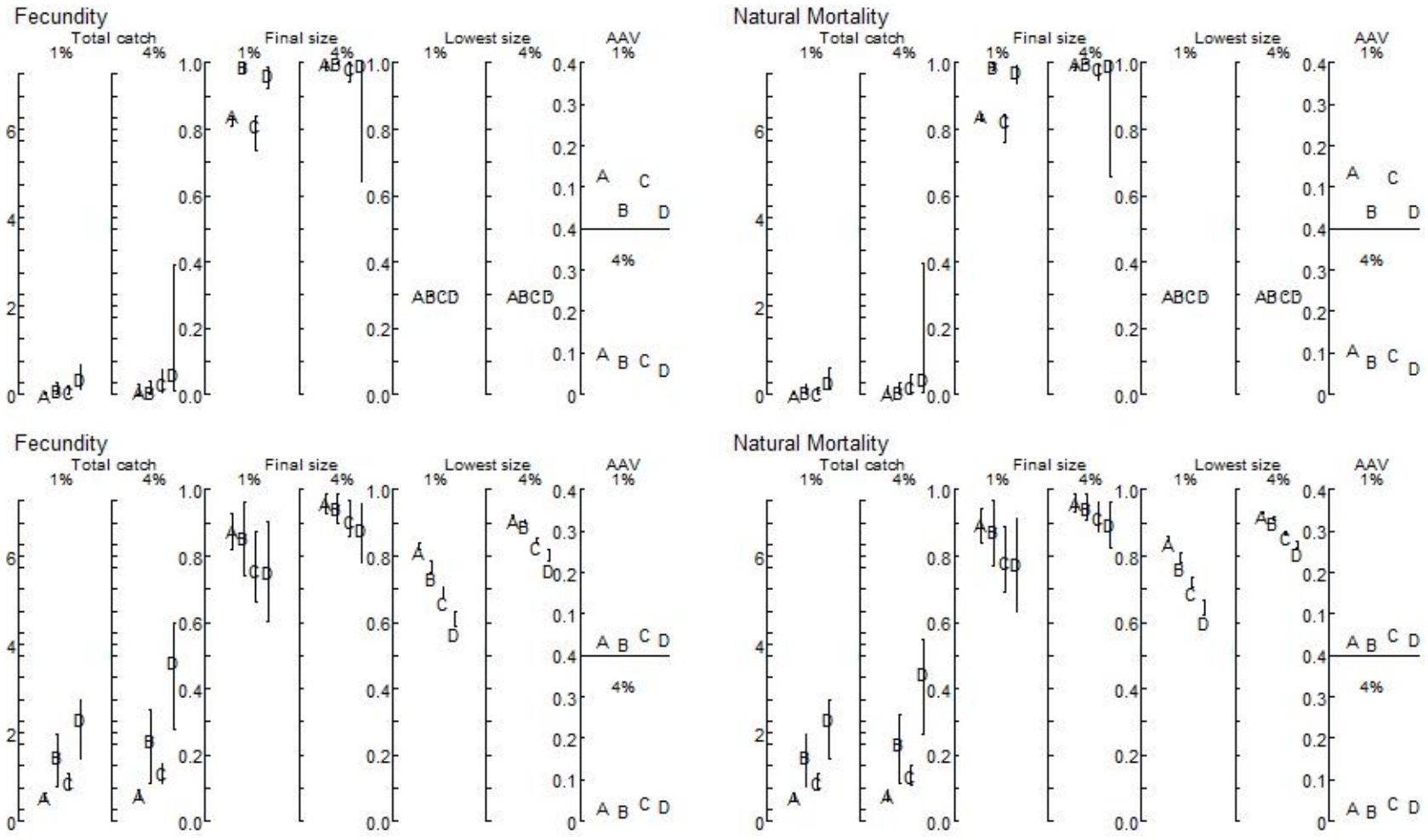

Figure 4: Zeh plots for trial T2 [survey bias = 0.5] (A = 100-year current, B = 300-year current, C = 100-year alternate, and D = 300-year alternate) when initial depletion is 30% (upper panel) and 99% (lower panel). Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).

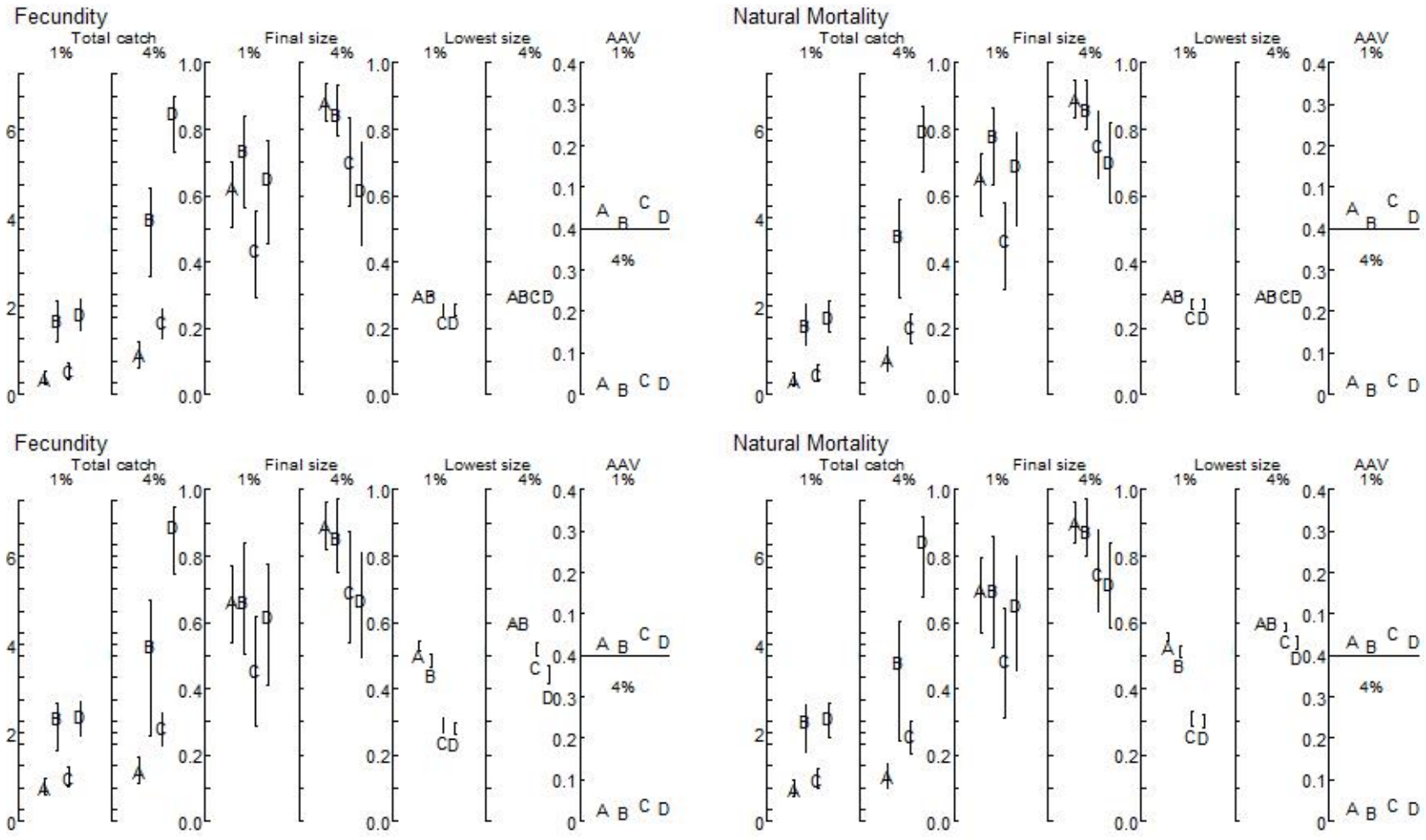

Figure 5(a): Zeh plots for trial T3 [survey bias = 1.5] (A = 100-year current, B = 300-year current, C = 100-year alternate, and D = 300-year alternate) when initial depletion is 30% (upper panel) and 60% (lower panel). Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).

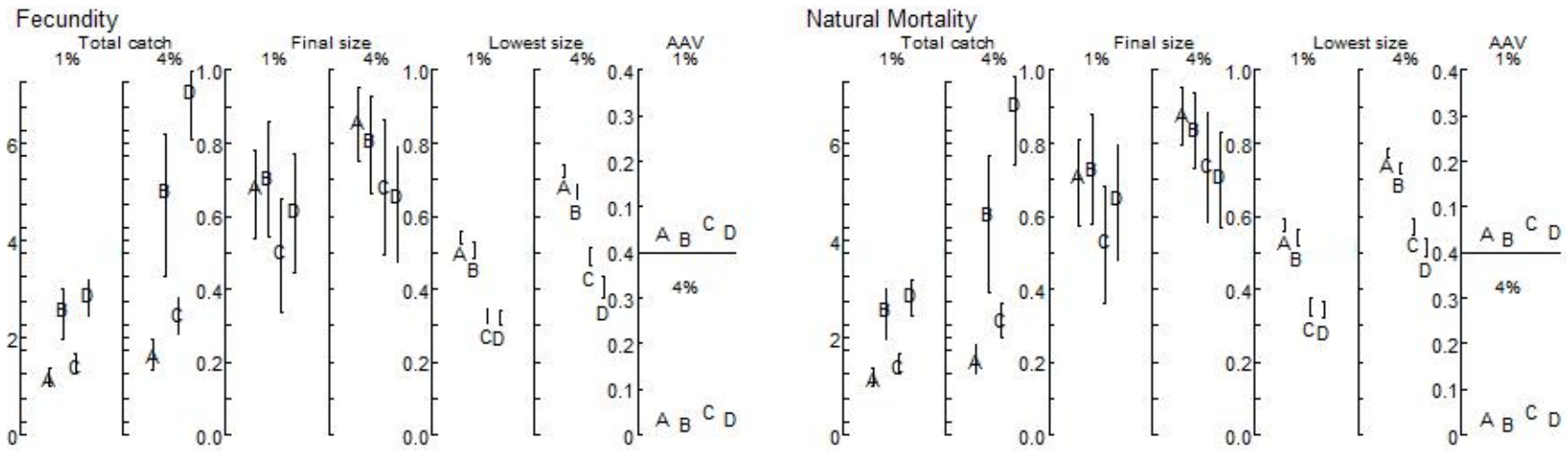

Figure 5(b): Zeh plots for trial T3 [survey bias = 1.5] (A = 100-year current, B = 300-year current, C = 100-year alternate, and D = 300-year alternate) when initial depletion is 99%. Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).

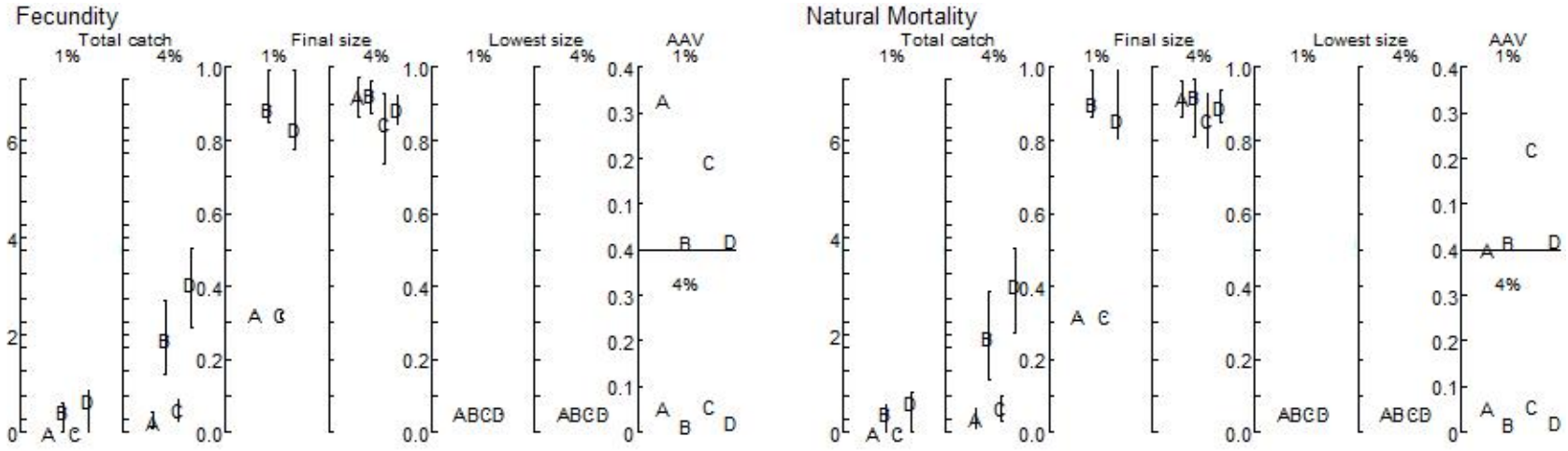

Figure 6: Zeh plots for trial T4 [P_0 = 0.05] (A = 100-year current, B = 300-year current, C = 100-year alternate, and D = 300-year alternate) when initial depletion is 5%. Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).

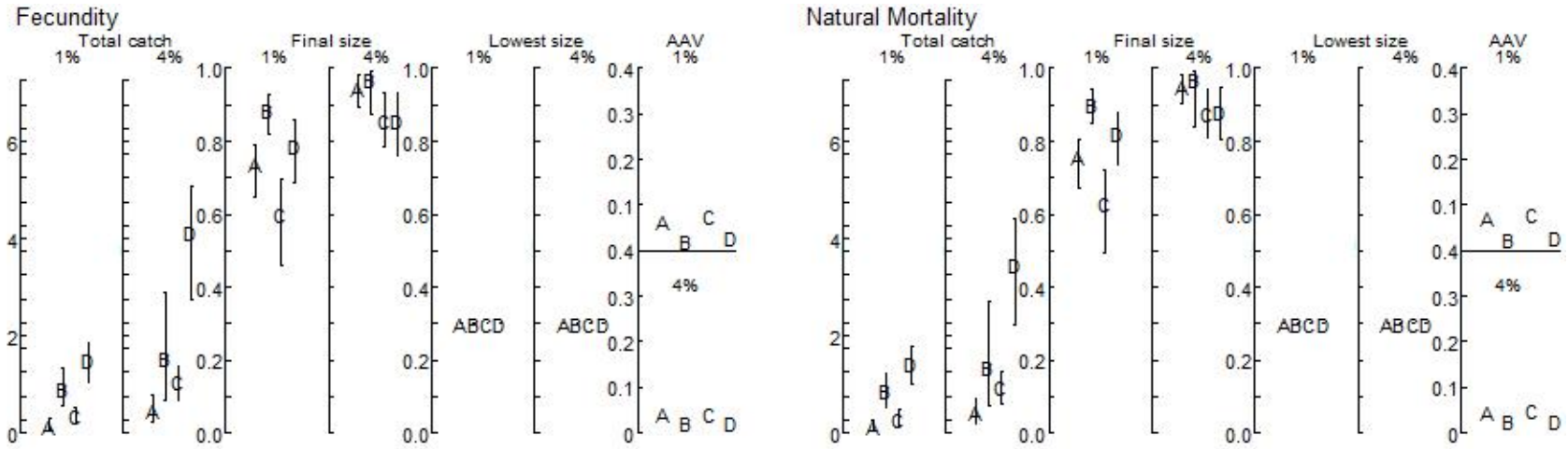

Figure 7: Zeh plots for trial T5 [years of protection = 25] (A = 100-year current, B = 300-year current, C = 100-year alternate, and D = 300-year alternate) when initial depletion is 30%. Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).

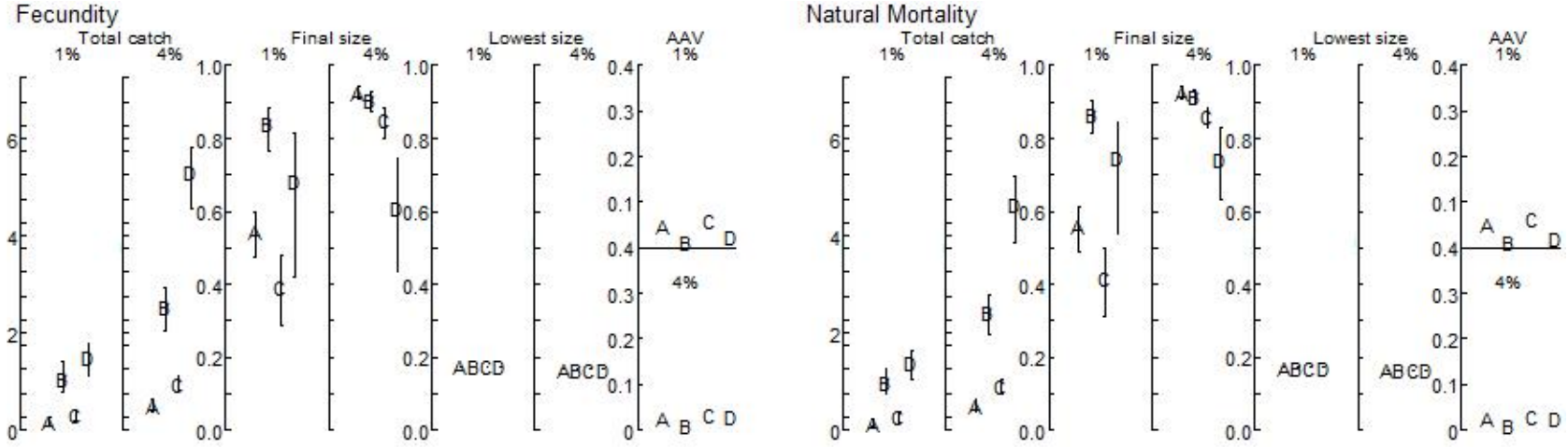

Figure 8: Zeh plots for trial T6 [1/2 true catch] (A = 100-year current, B = 300-year current, C = 100-year alternate, and D = 300-year alternate) when initial depletion is 30%. Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).

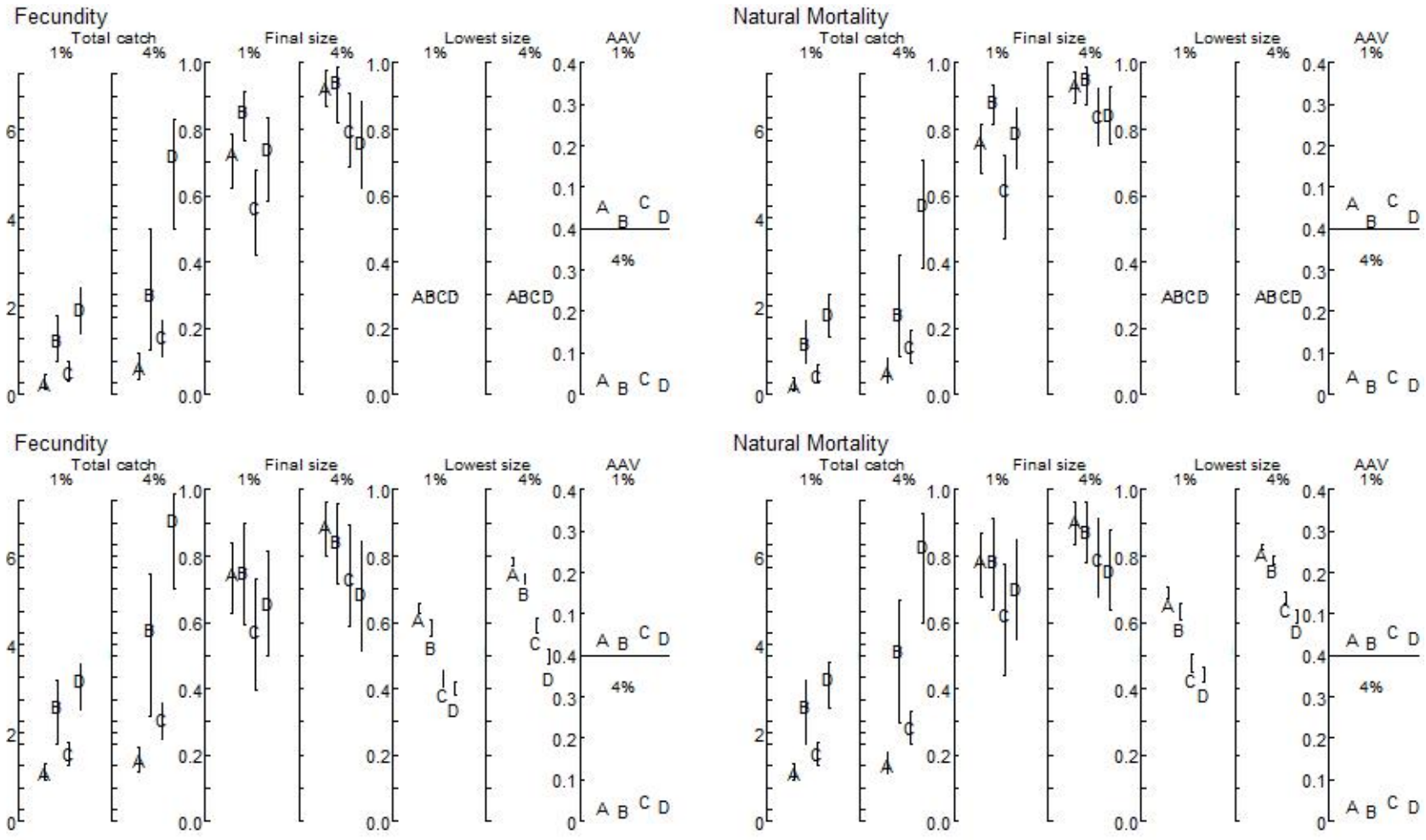

Figure 9: Zeh plots for trial T7 [age at maturity = 10] (A = 100-year current, B = 300-year current, C = 100-year alternate, and D = 300-year alternate) when initial depletion is 30% (upper panel) and 99% (lower panel). Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).

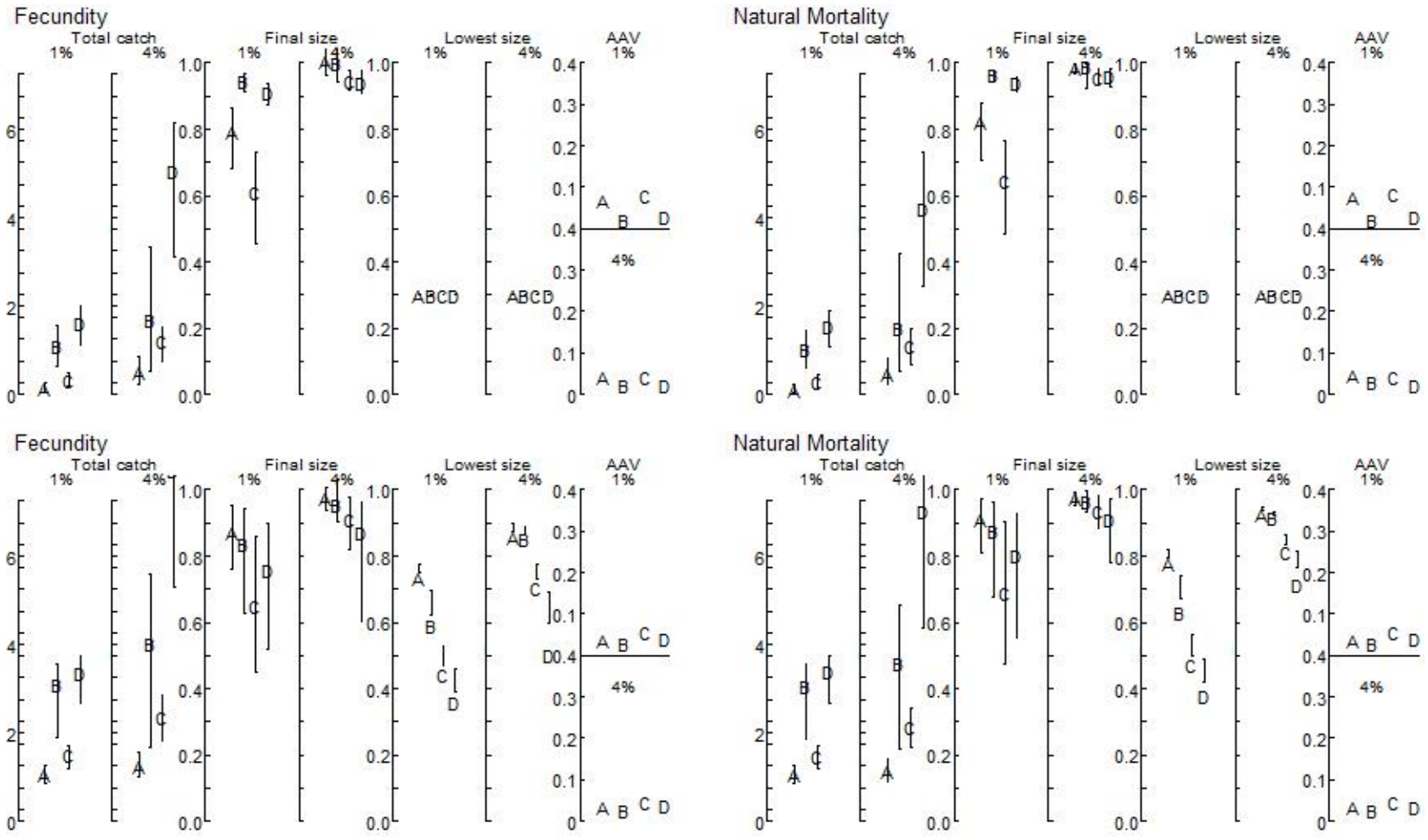

Figure 10: Zeh plots for trial T11A [MSYL = 80%] (A = 100-year current, B = 300-year current, C = 100-year alternate, and D = 300-year alternate) when initial depletion is 30% (upper panel) and 99% (lower panel). Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).

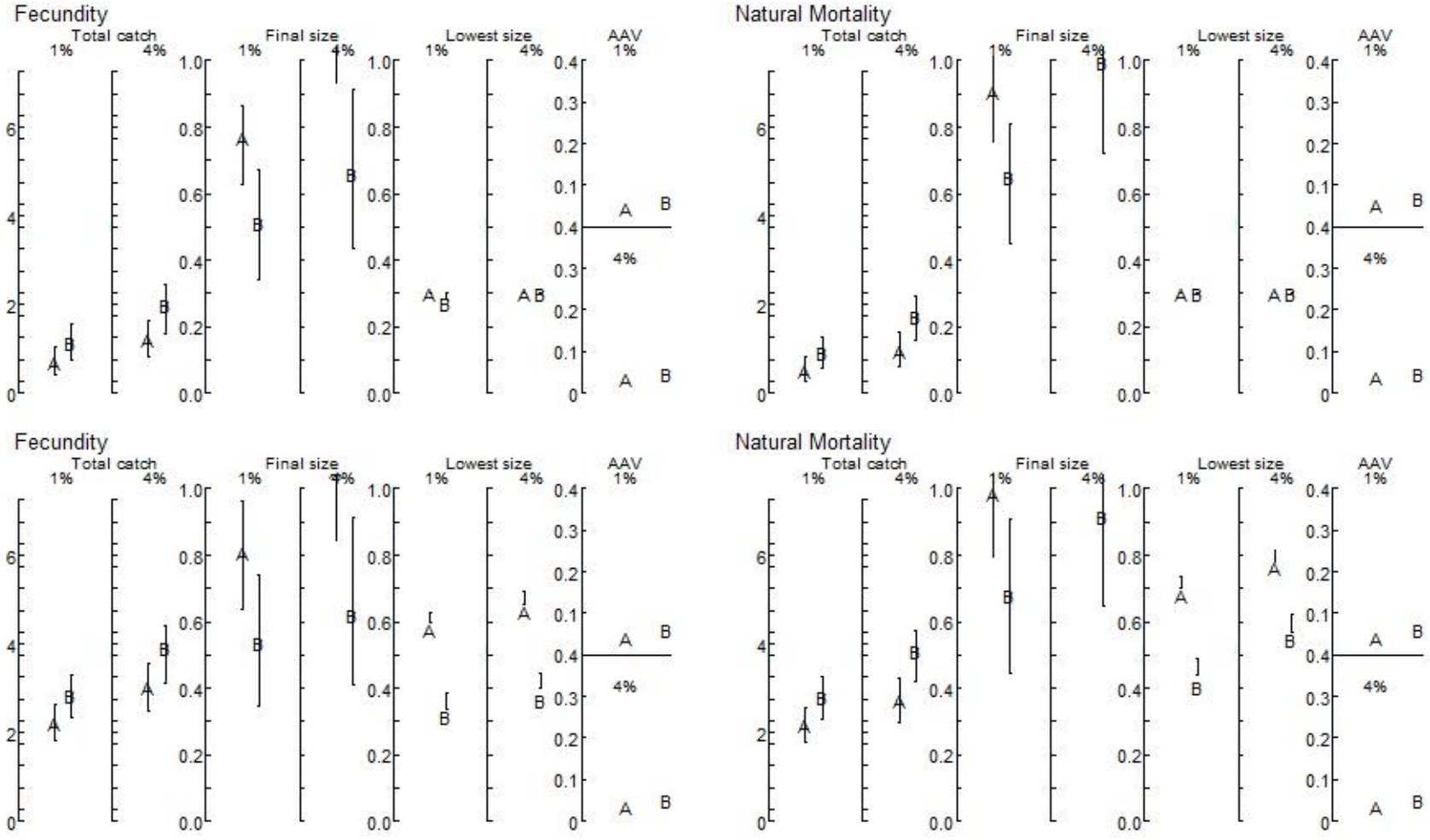

Figure 11: Zeh plots for trial T12A [linear change to $2K$ over management period] (A = 100-year current and B = 100-year alternate) when initial depletion is 30% (upper panel) and 99% (lower panel). Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).

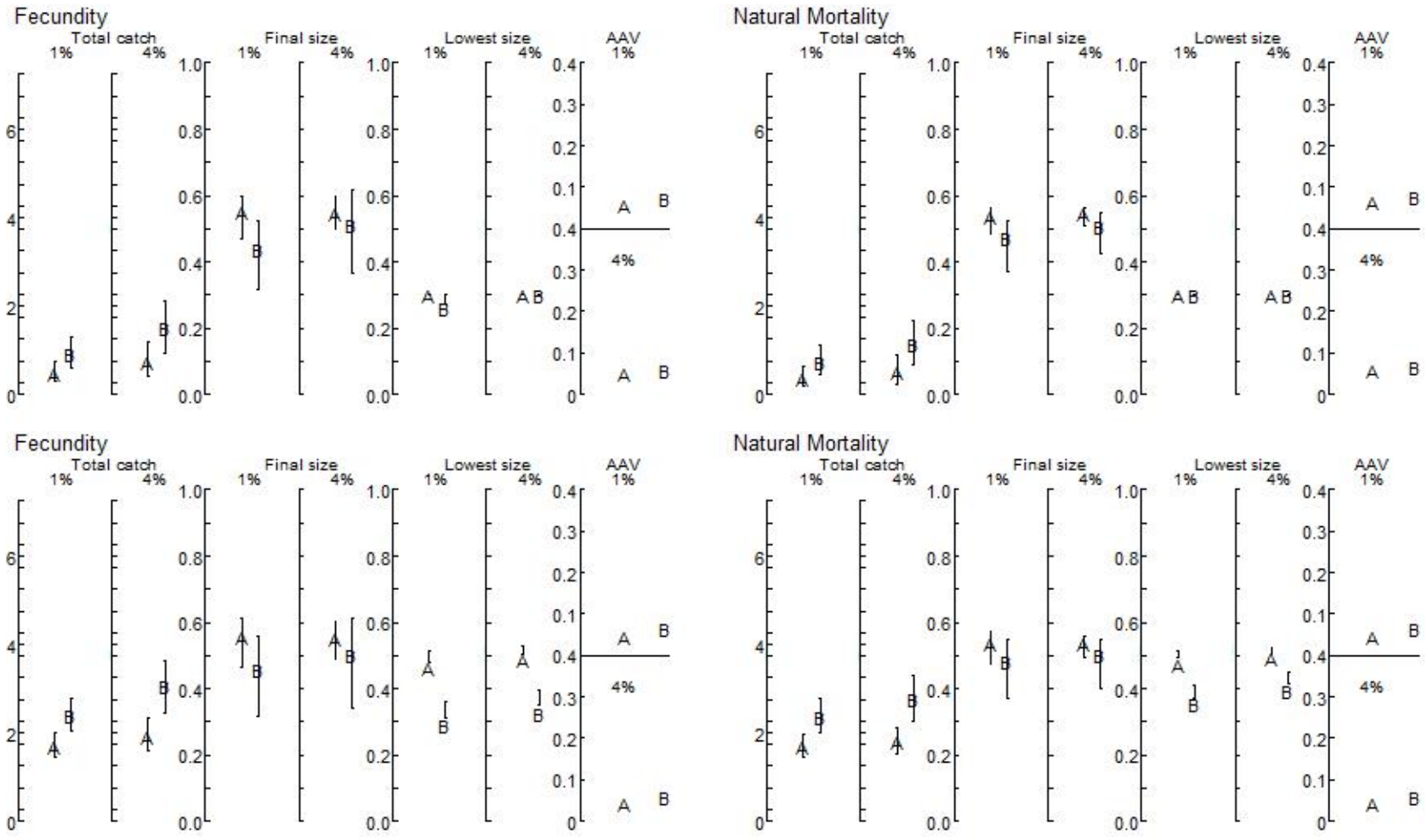

Figure 12: Zeh plots for trial T12B [linear change to $0.5K$ over management period] (A = 100-year current and B = 100-year alternate) when initial depletion is 30% (upper panel) and 99% (lower panel). Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).

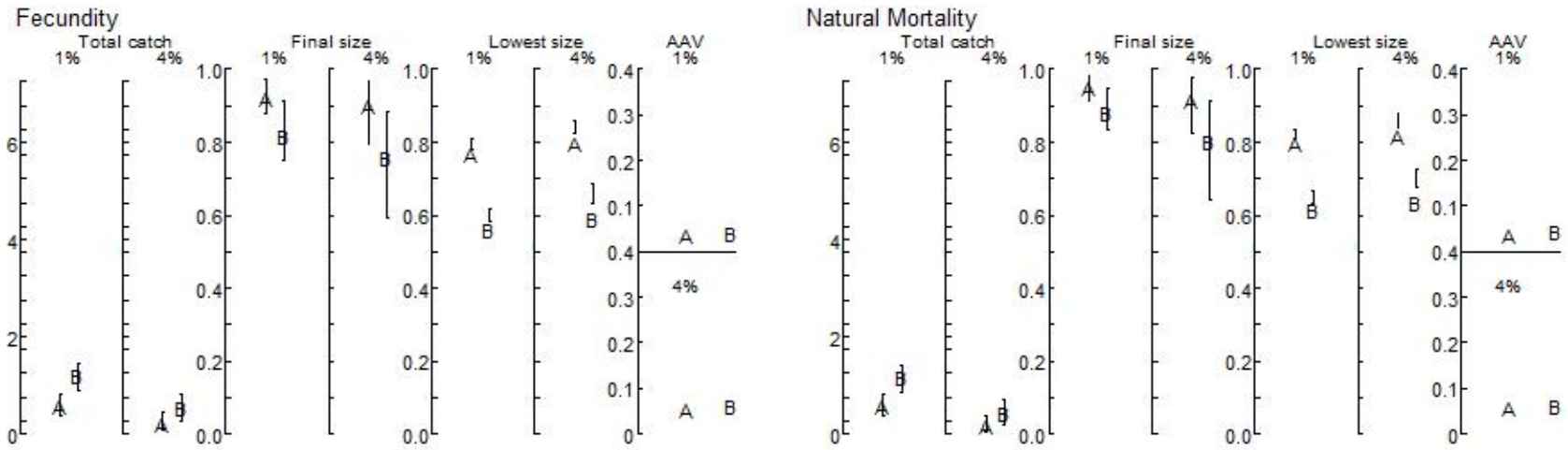

Figure 13: Zeh plots for trial 13 [33 year cycle in $MSYR$ (141) and (414)] (A = 100-year current, B = 300-year current, C = 100-year alternate, and D = 300-year alternate) when initial depletion is 30% .Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).

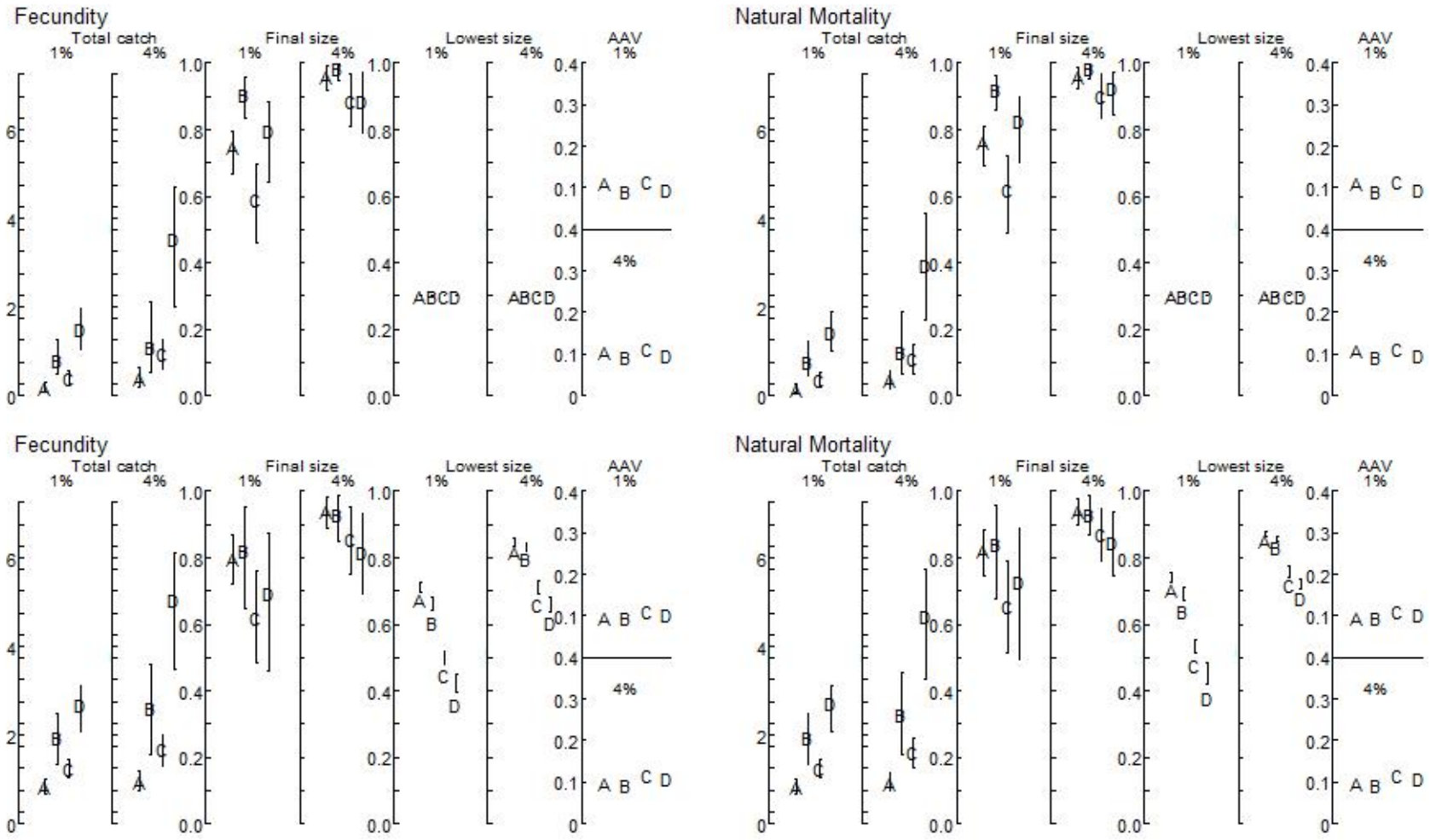

Figure 14: Zeh plots for trial 15 [survey every 10 years] (A = 100-year current, B = 300-year current, C = 100-year alternate, and D = 300-year alternate) when initial depletion is 30% (upper panel) and 99% (lower panel). Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).

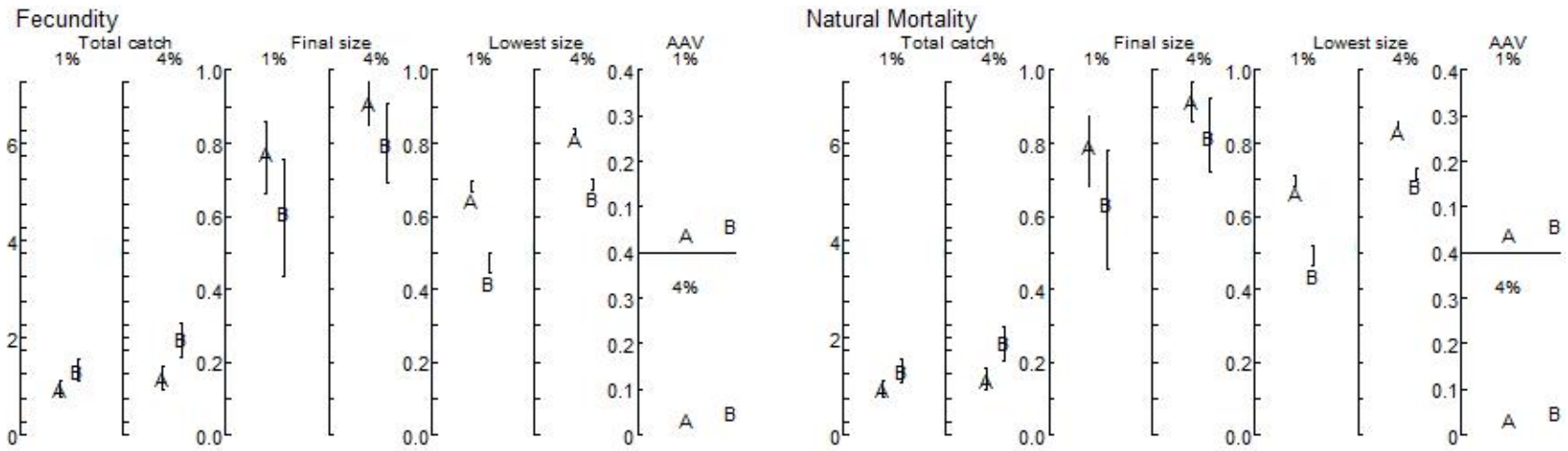

Figure 15: Zeh plots for trial 16 [linear change to $0.5MSYR$] (A = 100-year current and B = 100-year alternate) when initial depletion is 99%. Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).

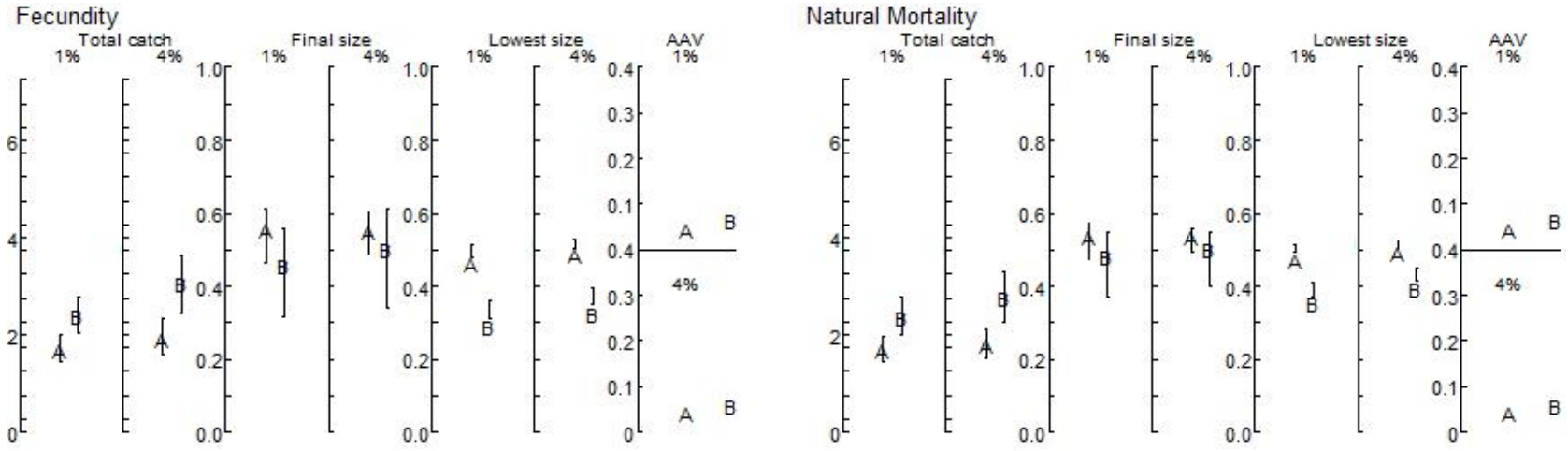

Figure 16: Zeh plots for trial 17 [linear change to $0.5MSYR$ and $0.5K$] (A = 100-year current and B = 100-year alternate) when initial depletion is 99%. Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).

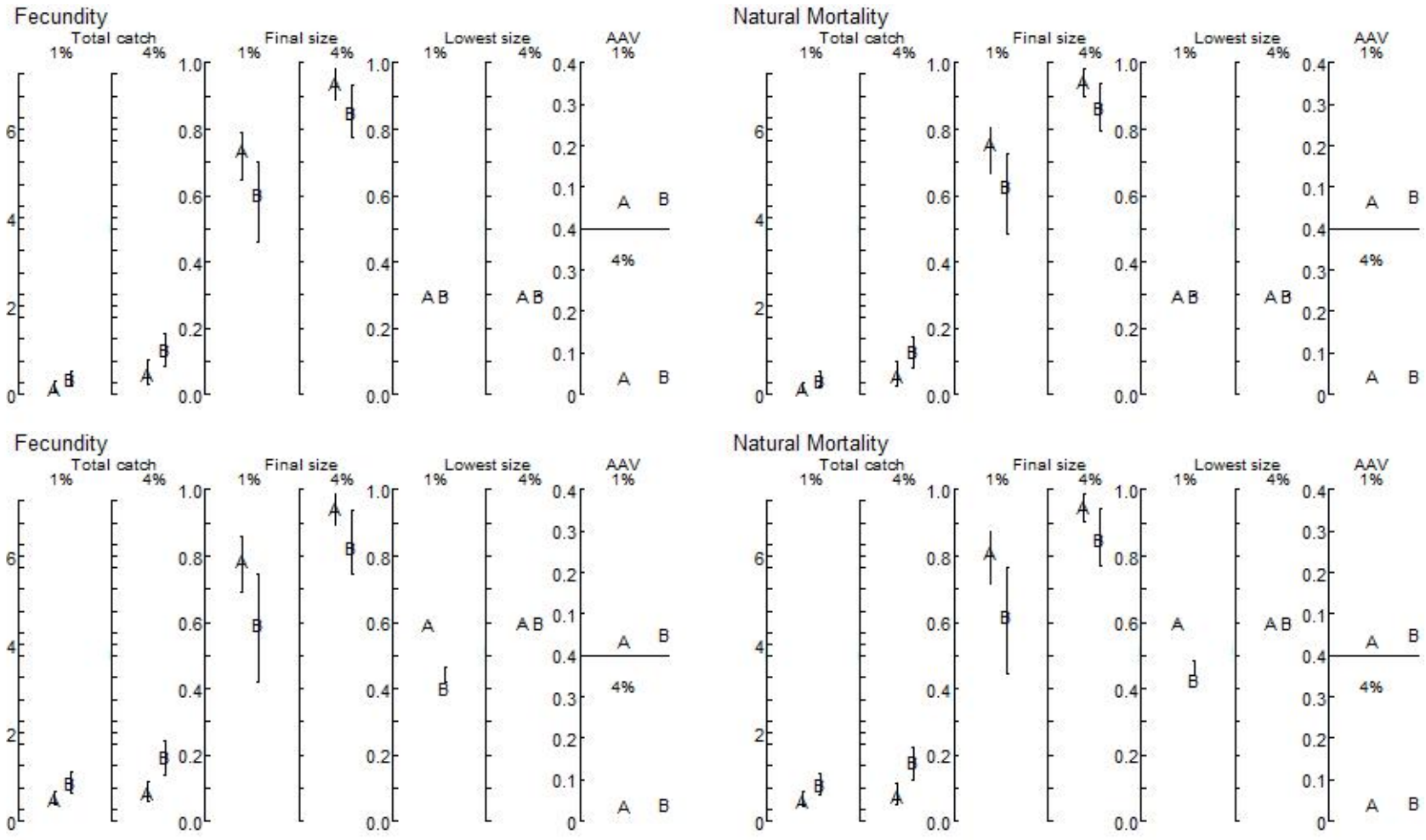

Figure 17(a): Zeh plots for trial T18 [linear change to $2MSYR$] (A = 100-year current and B = 100-year alternate) when initial depletion is 30% (upper panel) and 60% (lower panel). Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).

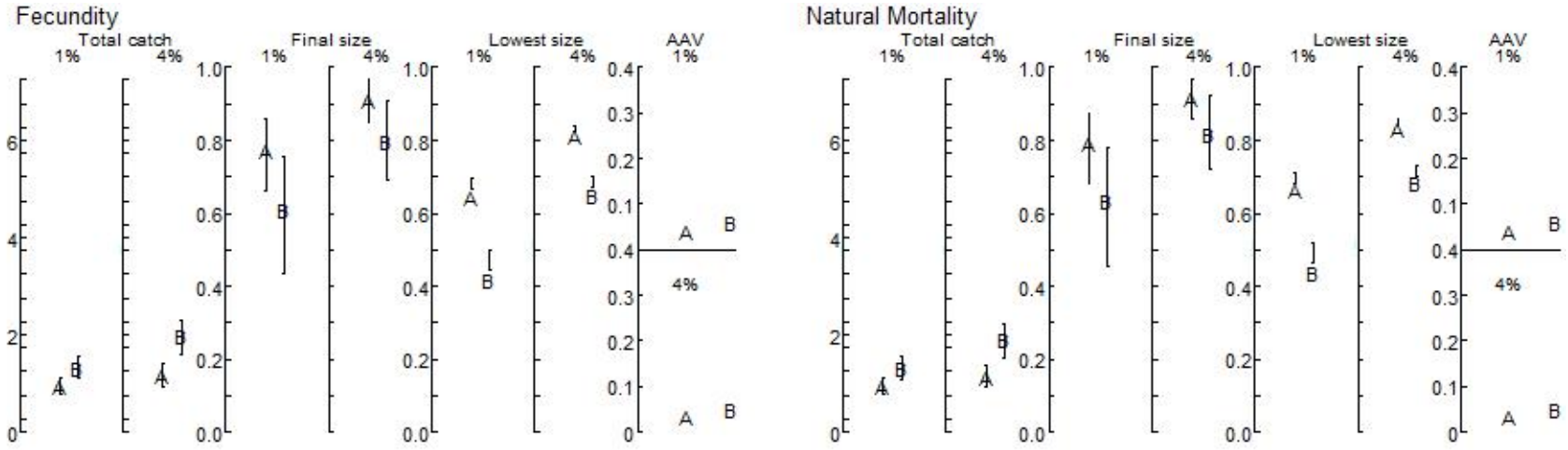

Figure 17(b): Zeh plots for trial T18 [linear change to $2MSYR$] (A = 100-year current and B = 100-year alternate) when initial depletion is 99%. Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).

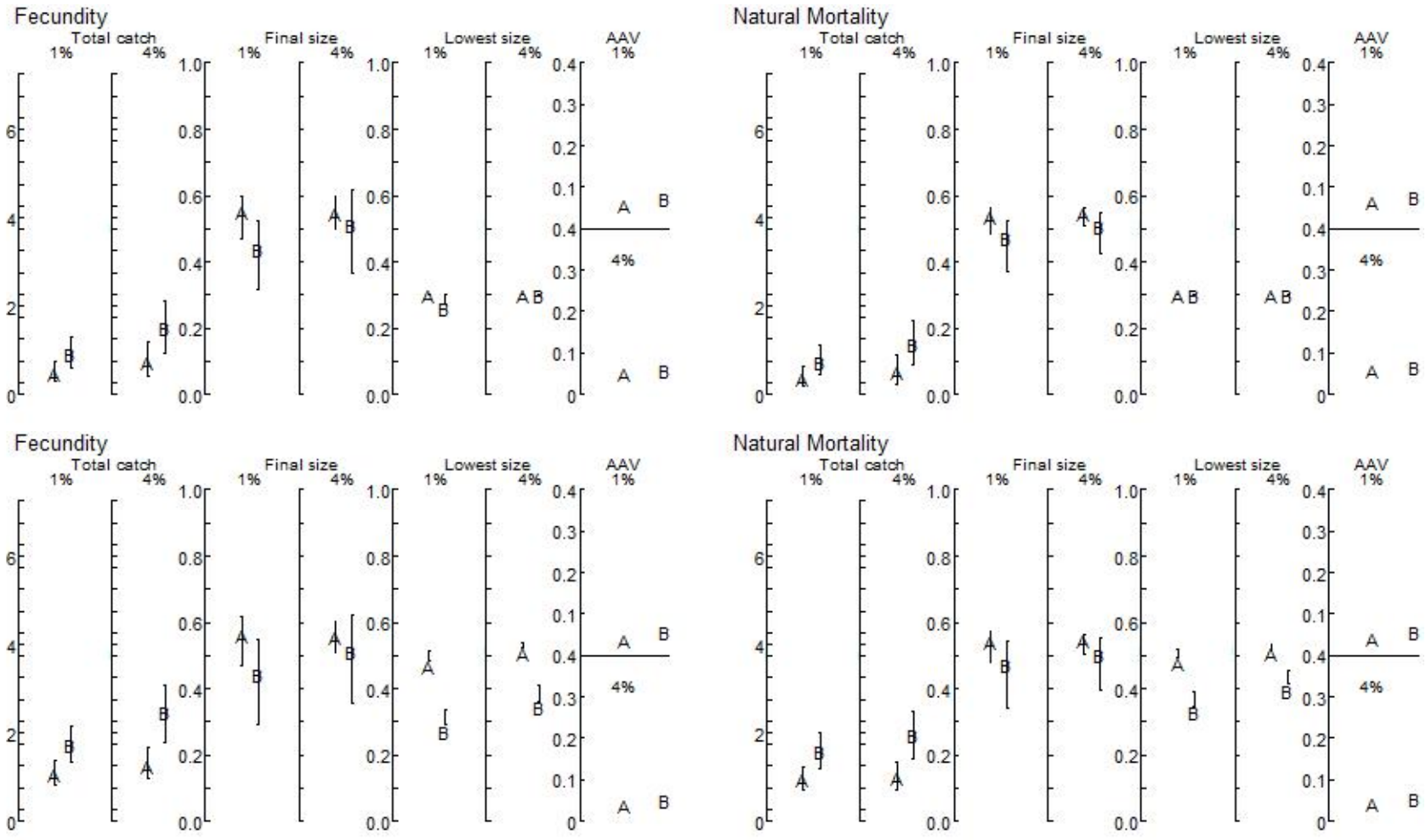

Figure 18(a): Zeh plots for trial T19 [linear change to $0.5MSYR$ and $0.5K$] (A = 100-year current and B = 100-year alternate) when initial depletion is 30% (upper panel) and 60% (lower panel). Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).

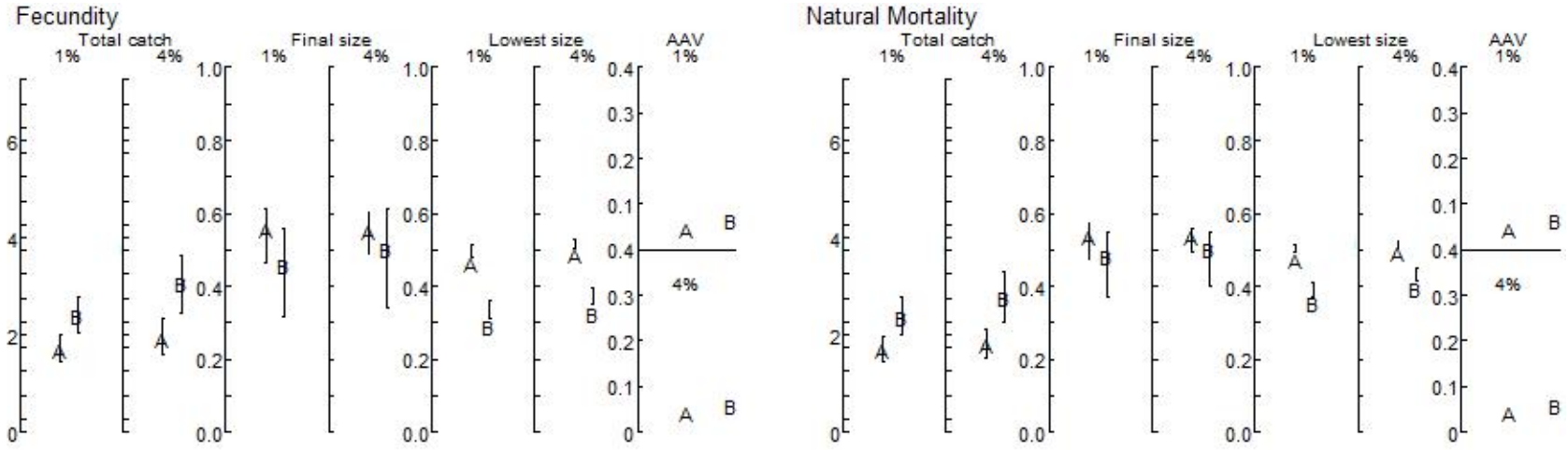

Figure 18(b): Zeh plots for trial T19 [linear change to $0.5MSYR$ and $0.5K$] (A = 100-year current and B = 100-year alternate) when initial depletion is 99%. Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).

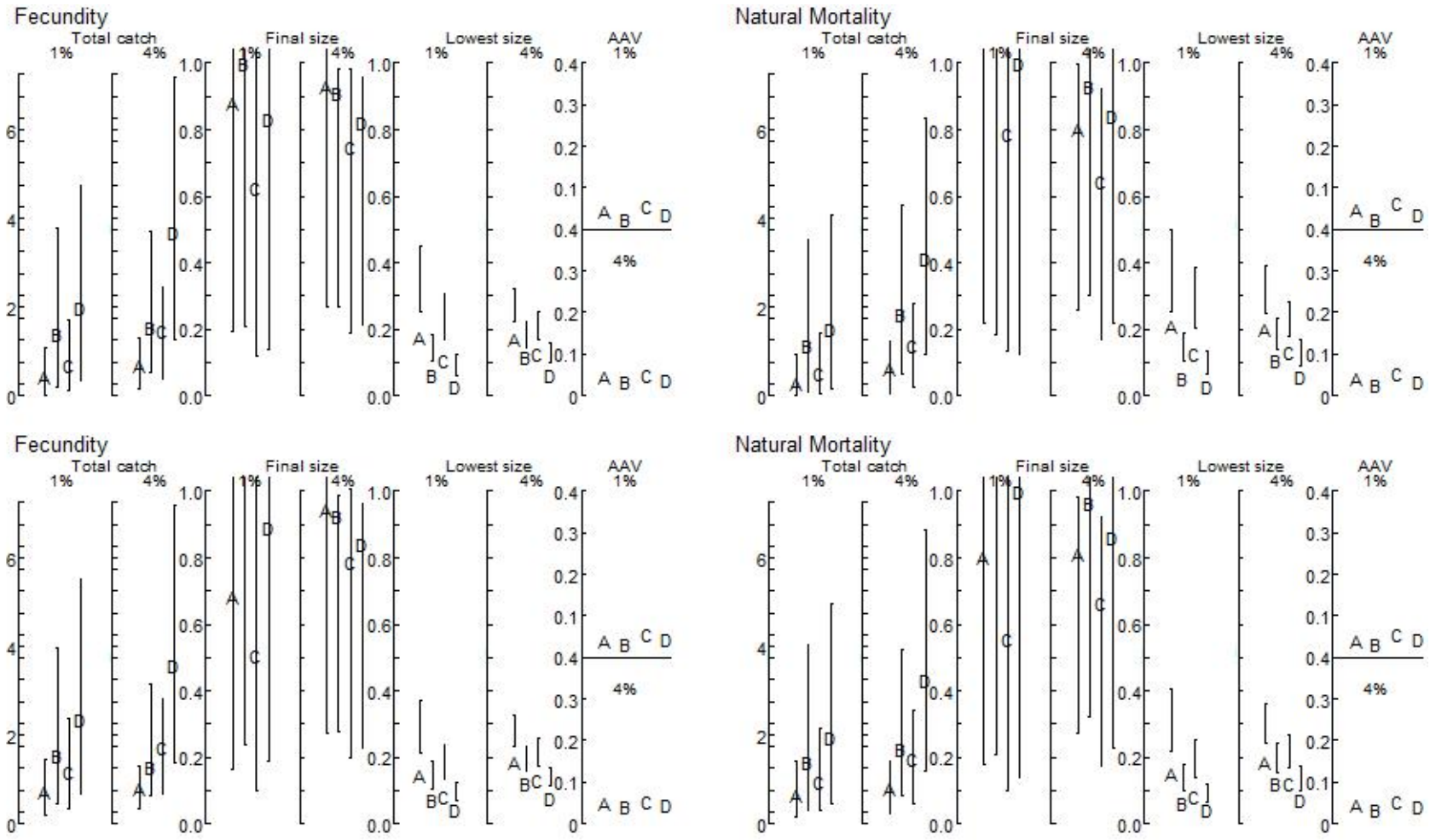

Figure 19(a): Zeh plots for trial T20 [Episodic events and survey bias = 1.5] (A = 100-year current, B = 300-year current, C = 100-year alternate, and D = 300-year alternate) when initial depletion is 30% (upper panel) and 60% (lower panel). Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).

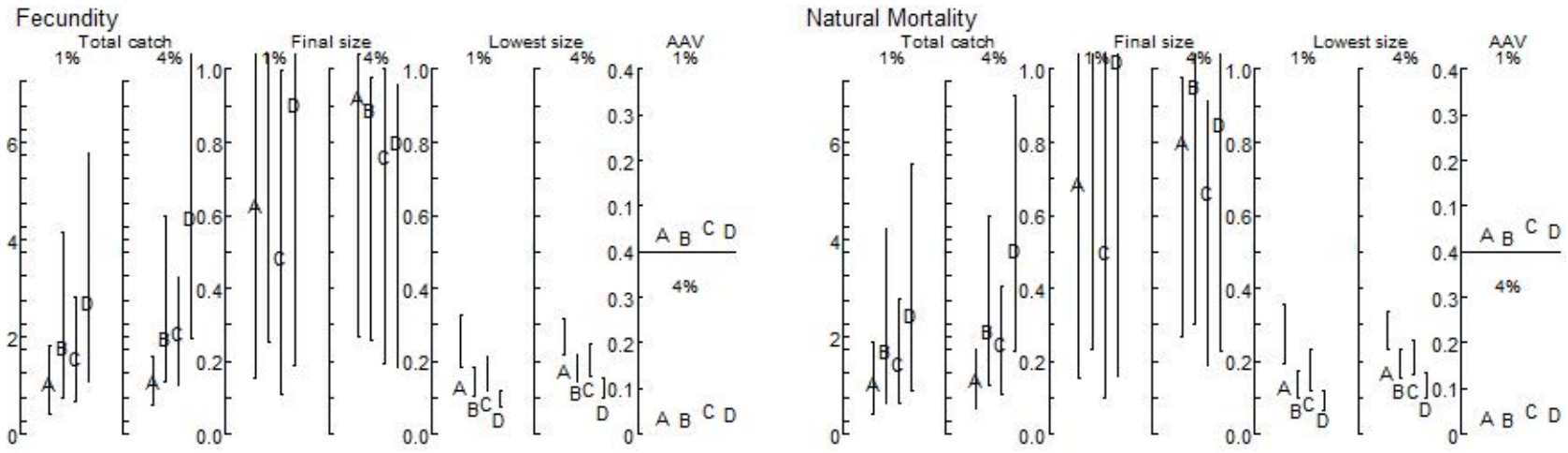

Figure 19(b): Zeh plots for trial T20 [Episodic events and survey bias = 1.5] (A = 100-year current, B = 300-year current, C = 100-year alternate, and D = 300-year alternate) when initial depletion is 99%. Results are shown when density-dependence impacts fecundity (left panel) and when it impacts natural mortality (right panel).