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Simulation trials for the Revised Management Procedure, including comparisons for when density dependence acts on fecundity or natural mortality Part 1.

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INTERNATIONAL WHALING COMMISSION

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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 projection periods of 100 and 300 years, and are summarized by tables of performance statistics and 'response curves'.

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. The *CLA* was developed based on a set of simulation trials that explored the performance of candidate *CLAs* given uncertainty in population dynamics and demographic parameters. Before any changes can be made to the established RMP, results from an agreed upon list of *CLA* trials must be used to highlight differences in performance between the established procedure and the suggested replacement (IWC, 2007).

Norway stated at the 2004 meeting that it intended to develop and propose a change to the *CLA* of the RMP. Norway also proposed that the Maximum Sustained Yield Rate (MSYR) should refer to the 1^+ component of the population (with $MSYR_{1+} = 1\%$ as the minimum) instead of the mature component. The revised tuning mechanism and some simulation results were presented at the 2006 meeting, and these were discussed extensively. The Scientific Committee established two working groups at the 2006 meeting, which led to the MSYR review, completed in 2013 (IWC, 2013), and the *CLA* group, which specified trials and diagnostic plots for testing amendments to the *CLA* (IWC, 2007). Revised results (Aldrin and Huseby, 2007) were presented to the Committee in 2007. However, the MSYR review had not been completed so no decision was made at that time. The MSYR review was completed in 2013 and it concluded that the lower bound for MSYR in trials should be $MSYR_{1+} = 1\%$.

METHODS

Trials structure

The Scientific Committee agreed on a set of trials that should be conducted if a proposal were to be made for a revision to the *CLA*, to highlight the differences in performance of the procedures (IWC, 2007; Table 1). IWC (2007) also proposed that 'response curve plots' be produced for MSY rates of 1%, 1.5%, and 4% and the following scenarios:

a. initial depletion of $0.05K$, $0.1K$, $0.2K$, $0.3K$ (R trials), $0.4K$, $0.5K$, $0.6K$ (S trials), $0.8K$, and $0.99K$ (D trials);

b. unreported catch level (for initial depletion levels of 0.3*K*, 0.6*K*, and 0.99*K*), where the reported catch is either 100%, 80%, 60%, 40%, 20%, or 1% of the true catch; and
c. positive bias in survey estimates (for initial depletion levels of 0.3*K*, 0.6*K*, and 0.99*K*): No bias (1.0), 1.2, 1.4, 1.6, 1.8, and 2.0.

Table 2 lists additional trials developed to further evaluate the performance of the *CLA* when the parameters determining the dynamics of the population are changing over time. Cooke (1995) conducted additional trials to evaluate the performance of the *CLA* in the face of marked changes in productivity. However, the code used to conduct those trials is not part of the agreed control program so additional coding would be required were the Committee interested in seeing results of such trials.

The tables of results and the response curve plots show how total catch, final population size, lowest population size, and average annual catch variation (AAV) change as aspects of the trials are changed. 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 (*Pf*) and lowest population size over the distribution (*Pmin*) are scaled by the population size resulting if no catch is taken in the management period. The reported statistics are as follows:

a. Total catch (TC) distribution: (a) median, (b) 5th %ile, (c) 96th %ile, and (d) mean;
b. *Pf* distribution: (a) median, (b) 5th %ile, and (c) 96th %ile;
c. *Pmin* distribution: (a) median, (b) 5th %ile, and (c) 96th %ile; and
d. AAV distribution: median.

All trials are conducted for 100-year and 300-year projection periods when density-dependence acts on fecundity or natural mortality (Johnson and Punt, 2015) and whether MSYR pertains to the total (1+) or mature female component of the population. For consistency, MSYL and the density-dependence component are assumed to pertain to the same population component as that to which MSYR pertains. As suggested by IWC (2007), all trials are based on 400 replicates.

Implementation

All simulations used MANTST, a FORTRAN program, which is available from the IWC Secretariat. MANTST version 15, used here, has several options, where options for a single base trial are shown in Table 3.

Catch Limit Algorithms

Table 4 lists the specifications for the two *CLA* variants considered. Note that this paper refers to *CLA* variants for ease of presentation even though the current Commission-adopted set of parameters is 'the *CLA*'.

RESULTS

Table 5 lists the values for the performance statistics for the two *CLA* variants for the six base-case trials (T1-D1, T1-D4, T1-S1, T1-S4, T1-R1, T1-R4) for the two simulation lengths, for whether MSYR pertains to the total (1+) or mature female components of the population and the two choices for density-dependence. The median final depletion for trial F2-T1-D1 [density-dependence acts on fecundity, MSYR pertains to mature female component of the population, $MSYR_{mat}$=1%, and initial depletion = 0.99] was used as the basis for tuning of the current *CLA*. This value is 0.723 for 100 years for the 'original' (i.e. adopted) version of the *CLA*. This value differs from 0.72 because the tuning of the *CLA* was based on a much larger number of replicates than 400. Over a 300-year projection period, the median final depletion for the 'original' *CLA* is 0.764. The median final depletion for this version of the

CLA is marginally higher when density-dependence acts on natural mortality. The median final depletion of the 'alternative' *CLA* is consistently lower than that of the 'original' *CLA* (as expected from Table 4). The median final depletion for the 'alternative' *CLA* for trial F1-T1-D1 [density-dependence acts on fecundity, MSYR pertains to 1+ component of the population, $MSYR_{1+}$=1%, and initial depletion = 0.99] is 0.681 over a 300- year projection period, which reflects how the 'alternative' *CLA* was tuned.

The results for $MSYR_{1+} = 1\%$ and $MSYR_{mat} = 4\%$ are the focus for additional analyses as these choices were selected during the MSYR review. Figures 1 and 2 respectively show response curve plots for the low depletion set for initial depletion (0.05*K*, 0.1*K*, 0.2*K*, 0.3*K*, 0.4*K*, and 0.5*K*), and for the full set depletion set (0.05K, 0.2*K*, 0.4*K*, 0.6*K*, 0.8*K*, and 0.99*K*). Figure 3 shows response curve plots for different levels of reported historical catch (100%, 80%, 60%, 40%, 20%, or 1%) while Figure 4 shows response curve plots for different levels of survey bias (No bias (1.0), 1.2, 1.4, 1.6, 1.8, and 2.0).

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

	Description	Trial	
	$MSYR_{mat}$	1%	4%
T.1	Age structured model, maturity = 7 yr		
	D=Development (initial population $0.99K$)	T1-D1	T1-D4
	R=Rehabilitation (initial population $0.30K$)	T1-R1	T1-R4
	S=Sustainable (initial population $0.60K$)	T1-S1	T1-S4
	initial population $0.20K$	T1-T1	T1-T4
	initial population $0.40K$	T1-F1	T1-F4
T.2	Survey Bias 0.5	T2-D1	T2-D4
		T2-R1	T2-R4
T.3	Survey Bias 1.5	T3-D1	T3-D4
		T3-R1	T3-R4
		T3-S1	T3-S4
T.4	Initial Population size $P_0 = 0.05K$	T4-R1	T4-R4
T.5	25 years of protection prior to management	T5-R1	T5-R4
T.6	Historic error in catch ($1/2$ true catch)	T6-R1	T6-R4
T.7	Age at maturity = 10 yr	T7-D1	T7-D4
		T7-R1	T7-R4
T.9	Episodic events: 2% yearly chance that population is halved	T9-D1	T9-D4
		T9-R1	T9-R4
T.10	$MSYL = 40\%$	T10-D1	T10-D4
		T10-R1	T10-R4
T.11	$MSYL = 80\%$	T11-D1	T11-D4
		T11-R1	T11-R4
T.12A	K doubles over management period	T12A-D1	T12A-D4
		T12A-R1	T12A-R4
T.12B	K halves over management period	T12B-D1	T12B-D4
		T12B-R1	T12B-R4
T.13	33 year cycle in $MSYR(141)$	T13-D1	
		T13-R1	
	33 year cycle in $MSYR(414)$	T13-D4	
		T13-R4	
T.15	Survey every 10 years	T15-D1	T15-D4
		T15-R1	T15-R4
T.16	$MSYR$ declines to $1/2$ its initial value	T16-D1	T16-D4
T.17	K & $MSYR$ declines to $1/2$ its initial value	T17-D1	T17-D4

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

	Description		Trial	
		$MSYR_{mat}$	1%	4%
T.18	$MSYR$ doubles over the management period		T18-D1	T18-D4
			T18-R1	T18-R4
			T18-S1	T18-S4
T.19	$MSYR$ and K decrease by half over the management period		T19-D1	T19-D4
			T19-R1	T19-D4
			T19-S1	T19-S4
T.20	Episodic events: 2% yearly chance that population is halved and survey bias of 1.5		T20-D1	T20-D4
			T20-R1	T20-R4
			T20-S1	T20-S4
T.21	Episodic events (2% yearly chance that population is halved), survey bias of 1.5, and coefficient of variation of 0.2		T.21-D1	T.21-D4

Table 3
An example data file used to run a single trial with 400 simulations, when density-dependence acts on fecundity through the 1+ population.

RANDOM PARAMETERS OPTION	OPTRAN	0
VARIABLE BIAS OPTION	OPTB	0
REPORTED CATCH OPTION	OPTC	0
PRODUCTION MODEL OPTION	OPTMOD	5
P>K BIRTH CALCULATION OPTION	OPTDK	0
DENSITY-DEPENDENCE TYPE	OPTDT	0
STOCHASTICITY OPTION	OPTDET	0
SURVEY COSTS OPTION	OPTSUR	0
No. OF TRIALS	NTRIAL	400
No. OF YEARS IN SIMULATION	NYEAR	100
No. OF YEARS OF PREMANAGEMENT CATCH	NPCAT	30
YEARS OF PREMANAGEMENT PROTECTION	NPPROT	0
TRUE MSYL(1)	MSYL	0.4
TRUE MSY RATE(1)	MSYR1	0.025
PREMANAGEMENT DEPLETION (1)	DEPL	0.3
CHANGING K OPTION	K99	0
CHANGING MSYR OPTION	MSYR99	0
CHANGING MSYR STEP	ISTEP	0
MATURITY PARAMETER	MAT1	7
MATURITY SIGMA	MSIG	1.2
RECRUITMENT PARAMETER	REC1	7
RECRUITMENT SIGMA	RSIG	1.2
MORTALITY PARAMETER 1	MORT1	0.04
MORTALITY PARAMETER 2	MORT2	0.07
MORTALITY FUNCTION	MORTIP	-1
MAXIMUM AGE	MAXAGE	20
MINIMUM AGE OF MATURITY	MINMAT	0
EPIDEMIC RATE	ERATE	0
COMPONENTS (0=EXPLOITABLE; 1=TOTAL1+; 2=MATURE)		
MSYR COMPONENT	OPTF	1
MSYL COMPONENT	OPTMSYL	1
DENSITY-DEPENDENT COMPONENT	OPTDD	1
FREQUENCY OF ABUNDANCE ESTIMATES	IFREQ	5
YEAR OF LAST SURVEY	ENDSUR	100
YEAR CV CHANGES	IYRCV	100
BIAS IN ABUNDANCE ESTIMATES	BIAS0	1
CV OF CV ESTIMATES (1st)	CV1EST	0.2
PROCESS ERROR PARAMETER	ETA	1
MINIMUM No. OF DEGREES OF FREEDOM	DOFMIN	5
STARTING VALUE FOR A	INITA	0.2
STARTING VALUE FOR Z	INITZ	0.2
DEPLETION (0:SINGLE VALUE;1:READ IN)	OPTDPL	0

Table 4
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

Table 5.
Values for the performance statistics for the base-case trials.

(a) 100-year projections

Trial	Original CLA											Alternative CLA										
	Total catch				Final population size			Lowest population size			AAV	Total catch				Final population size			Lowest population size			AAV
	Med	5%	96%	Mean	Med	5%	96%	5%	10%	25%		Med	5%	96%	Mean	Med	5%	96%	5%	10%	25%	
F1-T1-R1	0.171	0.077	0.318	0.182	0.743	0.65	0.797	0.3	0.3	0.3	0.063	0.376	0.219	0.573	0.382	0.6	0.456	0.703	0.3	0.3	0.3	0.073
F1-T1-S1	0.508	0.373	0.683	0.516	0.788	0.689	0.86	0.6	0.6	0.6	0.036	0.882	0.642	1.107	0.882	0.59	0.421	0.743	0.401	0.423	0.464	0.051
F1-T1-D1	0.917	0.771	1.097	0.924	**0.773**	0.66	0.857	0.644	0.659	0.69	0.040	1.311	1.078	1.533	1.308	**0.605**	0.431	0.757	0.417	0.442	0.491	0.059
F1-T1-R4	0.47	0.241	0.813	0.491	0.957	0.895	0.993	0.3	0.3	0.3	0.050	1.18	0.748	1.599	1.183	0.861	0.771	0.957	0.3	0.3	0.3	0.049
F1-T1-S4	0.602	0.422	0.887	0.625	0.953	0.895	0.990	0.6	0.6	0.6	0.040	1.493	1.03	1.863	1.478	0.839	0.753	0.956	0.6	0.6	0.6	0.045
F1-T1-D4	1.137	0.921	1.389	1.142	0.904	0.838	0.964	0.794	0.811	0.83	0.035	1.992	1.607	2.352	1.989	0.797	0.704	0.907	0.646	0.670	0.698	0.048
F2-T1-R1	0.095	0.034	0.199	0.103	0.616	0.543	0.66	0.3	0.3	0.3	0.082	0.234	0.132	0.377	0.244	0.497	0.385	0.578	0.297	0.3	0.3	0.090
F2-T1-S1	0.441	0.328	0.598	0.448	0.713	0.612	0.782	0.568	0.58	0.6	0.039	0.716	0.538	0.926	0.724	0.52	0.366	0.645	0.349	0.366	0.410	0.056
F2-T1-D1	0.872	0.740	1.044	0.877	**0.723**	0.608	0.805	0.597	0.619	0.652	0.042	1.185	0.998	1.396	1.191	**0.545**	0.388	0.681	0.376	0.4	0.449	0.061
F2-T1-R4	0.493	0.258	0.798	0.508	0.945	0.892	0.986	0.3	0.3	0.3	0.041	1.113	0.724	1.453	1.108	0.848	0.772	0.935	0.3	0.3	0.3	0.043
F2-T1-S4	0.647	0.454	0.915	0.664	0.952	0.896	0.99	0.6	0.6	0.6	0.037	1.518	1.094	1.839	1.5	0.829	0.74	0.946	0.6	0.6	0.6	0.043
F2-T1-D4	1.144	0.929	1.399	1.151	0.913	0.843	0.972	0.796	0.814	0.835	0.035	1.968	1.595	2.305	1.966	0.793	0.676	0.917	0.628	0.649	0.685	0.048
M1-T1-R1	0.143	0.056	0.288	0.154	0.764	0.675	0.814	0.3	0.3	0.3	0.067	0.329	0.182	0.518	0.338	0.634	0.488	0.732	0.3	0.3	0.3	0.077
M1-T1-S1	0.471	0.34	0.650	0.481	0.814	0.722	0.879	0.6	0.6	0.6	0.038	0.834	0.6	1.066	0.836	0.631	0.456	0.772	0.433	0.451	0.493	0.052
M1-T1-D1	0.914	0.770	1.095	0.922	**0.798**	0.691	0.877	0.675	0.691	0.719	0.040	1.308	1.076	1.531	1.306	**0.637**	0.461	0.785	0.446	0.473	0.523	0.058
M1-T1-R4	0.467	0.208	0.828	0.489	0.972	0.932	0.996	0.3	0.3	0.3	0.051	1.119	0.678	1.533	1.116	0.915	0.854	0.975	0.3	0.3	0.3	0.050
M1-T1-S4	0.515	0.327	0.816	0.535	0.977	0.939	0.997	0.6	0.6	0.6	0.047	1.329	0.876	1.734	1.329	0.912	0.845	0.981	0.6	0.6	0.6	0.048
M1-T1-D4	1.122	0.909	1.368	1.127	0.942	0.898	0.980	0.864	0.878	0.891	0.034	1.981	1.6	2.349	1.98	0.871	0.803	0.944	0.748	0.766	0.789	0.048
M2-T1-R1	0.079	0.023	0.183	0.089	0.635	0.562	0.677	0.3	0.3	0.3	0.086	0.214	0.116	0.355	0.224	0.523	0.41	0.601	0.3	0.3	0.3	0.093
M2-T1-S1	0.408	0.303	0.560	0.419	0.73	0.632	0.792	0.579	0.592	0.6	0.041	0.689	0.508	0.899	0.693	0.546	0.386	0.668	0.371	0.387	0.43	0.057
M2-T1-D1	0.863	0.735	1.033	0.87	**0.737**	0.628	0.816	0.617	0.639	0.67	0.042	1.181	0.994	1.396	1.186	**0.570**	0.406	0.7	0.397	0.422	0.473	0.061
M2-T1-R4	0.432	0.204	0.746	0.449	0.95	0.902	0.984	0.3	0.3	0.3	0.046	0.97	0.614	1.316	0.973	0.873	0.801	0.943	0.3	0.3	0.3	0.047
M2-T1-S4	0.557	0.371	0.825	0.574	0.955	0.908	0.987	0.6	0.6	0.6	0.040	1.318	0.911	1.64	1.309	0.858	0.781	0.948	0.6	0.6	0.6	0.045
M2-T1-D4	1.092	0.89	1.331	1.096	0.921	0.864	0.970	0.838	0.848	0.862	0.035	1.855	1.495	2.177	1.849	0.824	0.729	0.926	0.692	0.710	0.739	0.049

(b) 300-year projections

Trial	Original CLA											Alternative CLA										
	Total catch				Final population size			Lowest population size			AAV	Total catch				Final population size			Lowest population size			AAV
	Med	5%	96%	Mean	Med	5%	96%	5%	10%	25%		Med	5%	96%	Mean	Med	5%	96%	5%	10%	25%	
F1-T1-R1	0.957	0.574	1.392	0.962	0.881	0.807	0.929	0.3	0.3	0.3	0.022	1.564	1.108	1.956	1.559	0.782	0.665	0.858	0.3	0.3	0.3	0.031
F1-T1-S1	1.76	0.937	2.265	1.7	0.782	0.642	0.932	0.593	0.6	0.6	0.023	2.362	1.633	2.7	2.299	0.675	0.484	0.839	0.369	0.387	0.425	0.036
F1-T1-D1	2.223	1.47	2.727	2.19	**0.771**	0.615	0.908	0.56	0.589	0.638	0.030	2.789	2.174	3.103	2.734	**0.681**	0.519	0.83	0.366	0.408	0.447	0.044
F1-T1-R4	0.964	0.4	2.081	1.087	0.988	0.929	1	0.3	0.3	0.3	0.037	3.794	1.918	5.231	3.669	0.874	0.73	0.968	0.3	0.3	0.3	0.032
F1-T1-S4	1.272	0.639	2.887	1.468	0.982	0.867	0.999	0.6	0.6	0.6	0.030	4.936	2.331	6.091	4.605	0.822	0.719	0.965	0.6	0.6	0.6	0.033
F1-T1-D4	3.553	1.903	4.675	3.461	0.873	0.786	0.965	0.766	0.779	0.799	0.026	6.348	4.278	7.403	6.159	0.755	0.64	0.879	0.595	0.617	0.649	0.036
F2-T1-R1	0.577	0.346	0.862	0.583	0.886	0.813	0.929	0.3	0.3	0.3	0.029	0.891	0.627	1.145	0.894	0.789	0.673	0.862	0.297	0.3	0.3	0.041
F2-T1-S1	1.301	0.765	1.775	1.296	0.797	0.593	0.922	0.542	0.565	0.586	0.025	1.544	1.151	1.887	1.533	0.725	0.514	0.852	0.33	0.355	0.392	0.041
F2-T1-D1	1.822	1.283	2.215	1.801	**0.764**	0.589	0.907	0.517	0.552	0.601	0.033	2.073	1.681	2.383	2.063	**0.708**	0.527	0.844	0.348	0.378	0.426	0.049
F2-T1-R4	1.595	0.649	2.969	1.663	0.968	0.858	0.994	0.3	0.3	0.3	0.024	4.373	2.811	5.315	4.232	0.842	0.732	0.932	0.3	0.3	0.3	0.026
F2-T1-S4	1.68	0.73	3.148	1.811	0.974	0.867	0.997	0.6	0.6	0.6	0.027	5.196	3.047	6.035	4.947	0.8	0.68	0.939	0.598	0.6	0.6	0.032
F2-T1-D4	3.615	1.945	4.704	3.512	0.88	0.781	0.969	0.758	0.778	0.8	0.026	6.151	4.47	6.834	5.966	0.747	0.606	0.879	0.549	0.578	0.619	0.036
M1-T1-R1	0.901	0.531	1.33	0.906	0.900	0.84	0.939	0.3	0.3	0.3	0.022	1.496	1.043	1.85	1.482	0.815	0.72	0.877	0.3	0.3	0.3	0.031
M1-T1-S1	1.68	0.89	2.23	1.62	0.822	0.685	0.941	0.6	0.6	0.6	0.023	2.315	1.585	2.671	2.247	0.712	0.518	0.86	0.399	0.421	0.46	0.036
M1-T1-D1	2.224	1.463	2.72	2.188	**0.795**	0.647	0.921	0.594	0.622	0.670	0.030	2.797	2.179	3.112	2.741	**0.708**	0.55	0.85	0.393	0.437	0.477	0.044
M1-T1-R4	1.031	0.383	2.988	1.215	0.991	0.834	1	0.3	0.3	0.3	0.037	3.689	1.961	4.956	3.566	0.921	0.716	0.98	0.3	0.3	0.3	0.031
M1-T1-S4	0.958	0.476	2.071	1.084	0.994	0.97	1	0.6	0.6	0.6	0.037	4.194	1.917	5.771	3.982	0.915	0.823	0.985	0.6	0.6	0.6	0.034
M1-T1-D4	3.507	1.883	4.639	3.422	0.921	0.863	0.979	0.846	0.856	0.87	0.026	6.339	4.248	7.426	6.157	0.841	0.757	0.925	0.703	0.729	0.755	0.036
M2-T1-R1	0.543	0.321	0.82	0.551	0.890	0.824	0.932	0.3	0.3	0.3	0.029	0.873	0.606	1.128	0.875	0.799	0.697	0.868	0.3	0.3	0.3	0.040
M2-T1-S1	1.194	0.713	1.716	1.213	0.834	0.623	0.927	0.563	0.58	0.6	0.026	1.51	1.117	1.853	1.507	0.743	0.542	0.857	0.351	0.376	0.413	0.041
M2-T1-D1	1.781	1.257	2.186	1.767	**0.779**	0.613	0.912	0.541	0.575	0.623	0.033	2.081	1.676	2.379	2.064	**0.723**	0.548	0.851	0.369	0.397	0.447	0.049
M2-T1-R4	1.397	0.576	2.717	1.465	0.971	0.872	0.993	0.3	0.3	0.3	0.027	3.626	2.25	4.609	3.528	0.879	0.797	0.951	0.3	0.3	0.3	0.026
M2-T1-S4	1.412	0.653	2.873	1.546	0.977	0.881	0.997	0.6	0.6	0.6	0.028	4.486	2.518	5.465	4.297	0.845	0.746	0.952	0.6	0.6	0.6	0.032
M2-T1-D4	3.319	1.867	4.337	3.254	0.896	0.815	0.972	0.799	0.813	0.832	0.026	5.636	3.951	6.444	5.479	0.792	0.683	0.902	0.637	0.661	0.691	0.037

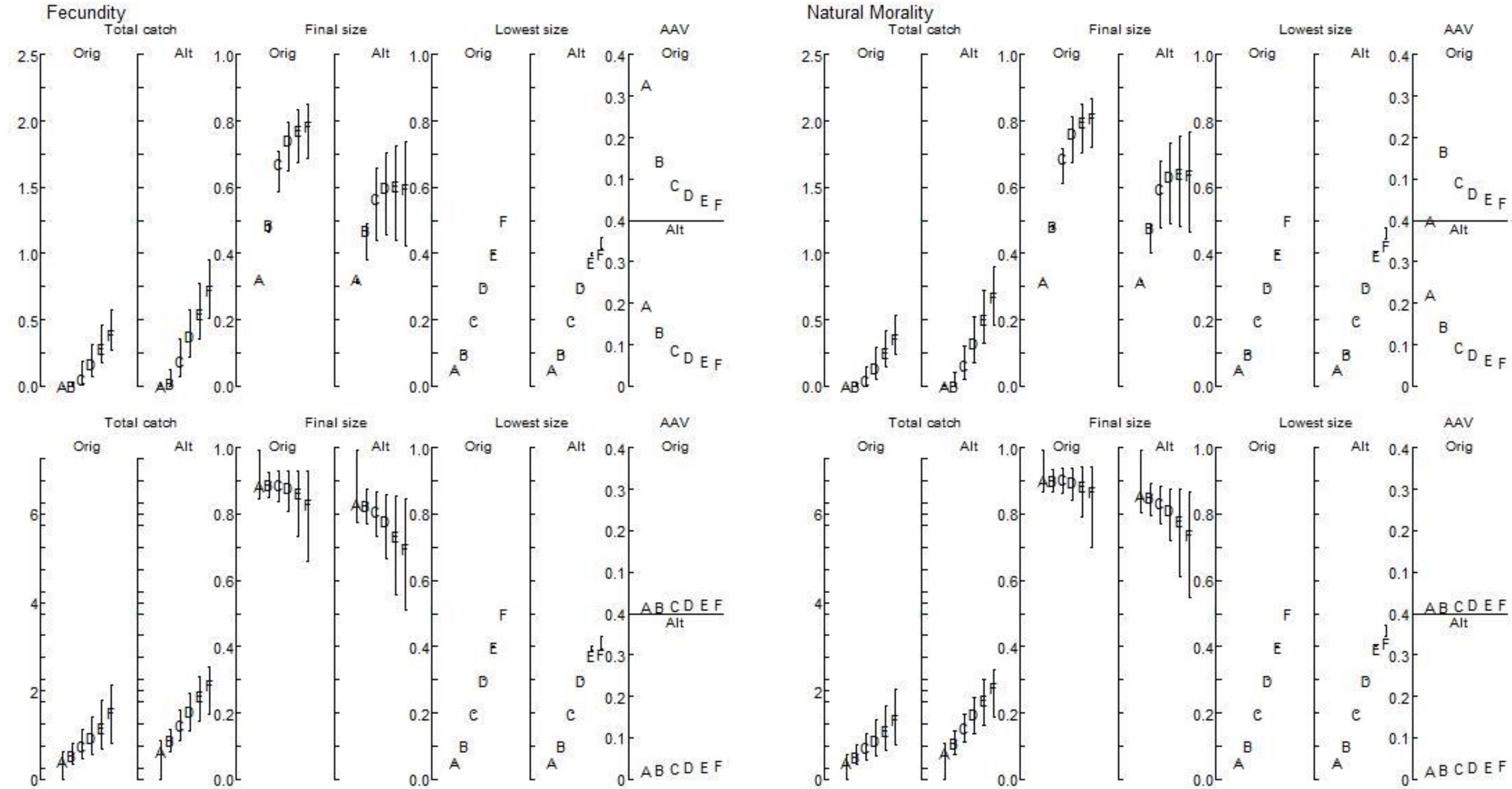

Figure 1(a). Response curve plots for the low depletion set (0.05*K*, 0.1*K*, 0.2*K*, 0.3*K*, 0.4*K*, and 0.5*K*) when $MSYR_{1+}$ = 1% for 100-year (top row) and 300-year projections (bottom row). Results are shown when density-dependence impacts fecundity in the left panel and when it impacts natural mortality in the right panel.

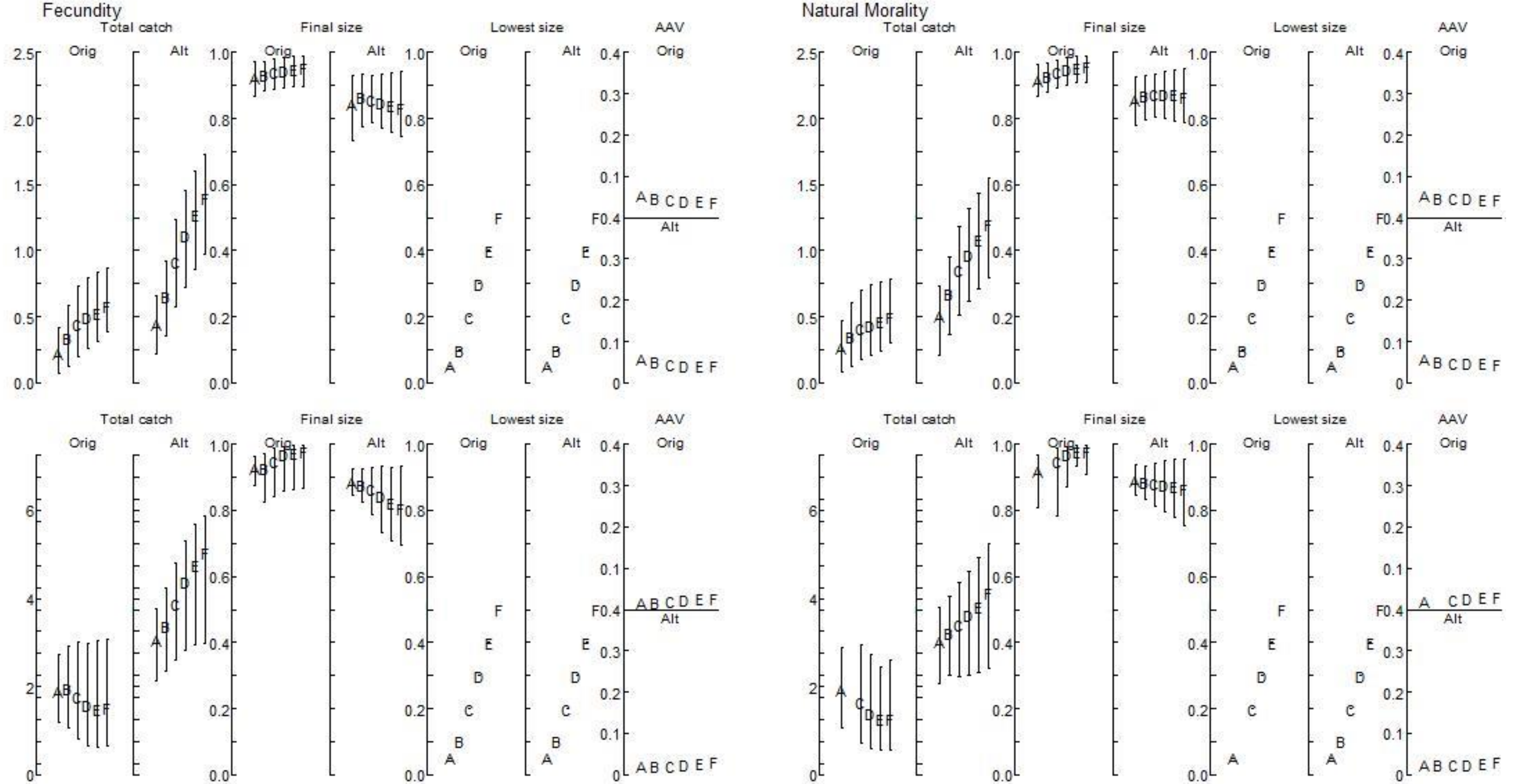

Figure 1(b). Response curve plots for the low depletion set (0.05*K*, 0.1*K*, 0.2*K*, 0.3*K*, 0.4*K*, and 0.5*K*) when $MSYR_{mat}$ = 4% for 100-year (top row) and 300-year projections (bottom row). Results are shown when density-dependence impacts fecundity in the left panel and when it impacts natural mortality in the right panel.

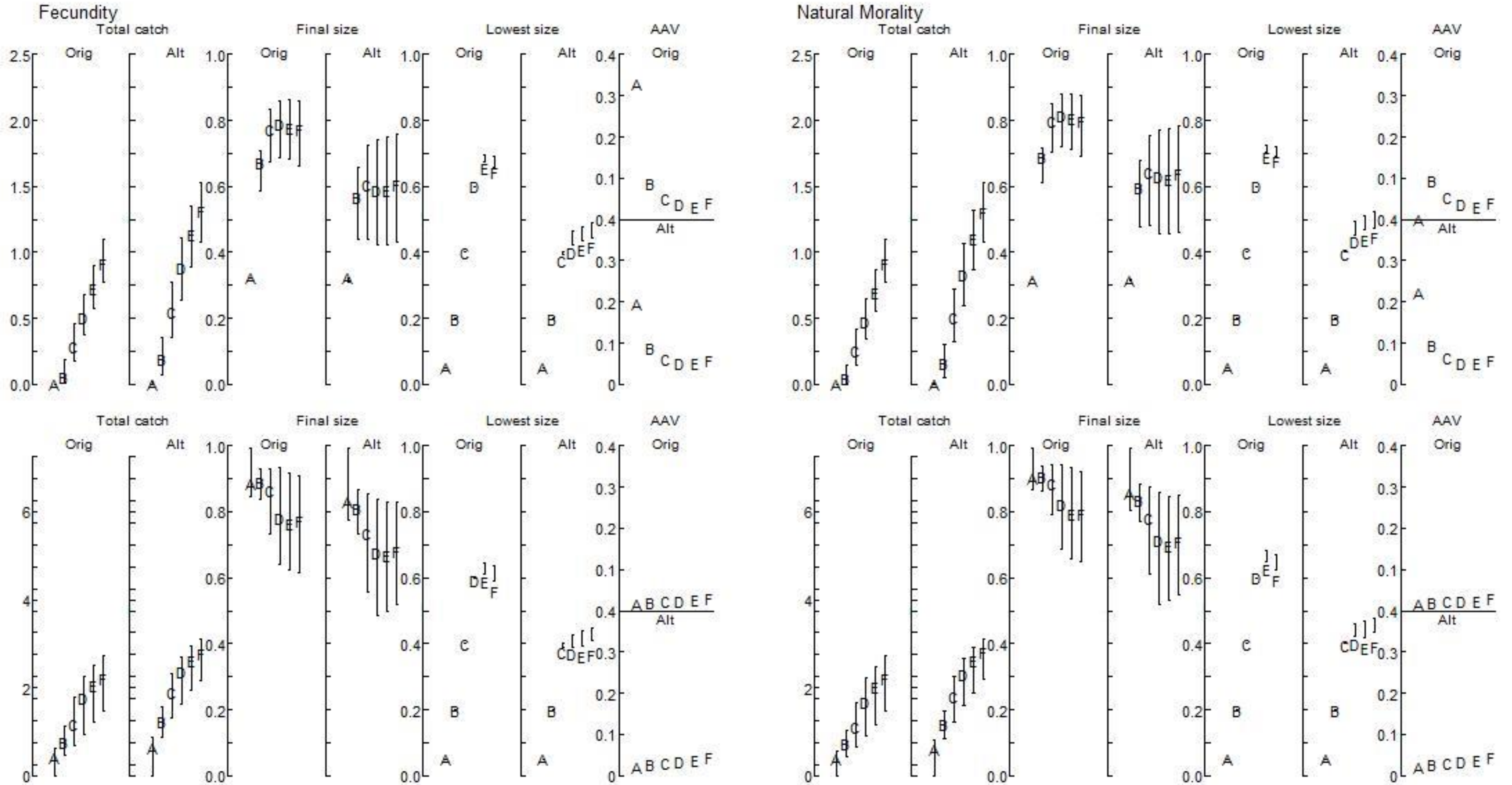

Figure 2(a). Response curve plots for the full depletion set (0.05*K*, 0.2*K*, 0.4*K*, 0.6*K*, 0.8*K*, and 0.99*K*) when $MSYR_{1+}$ = 1% for 100-year (top row) and 300-year projections (bottom row). Results are shown when density-dependence impacts fecundity in the left panel and when it impacts natural mortality in the right panel.

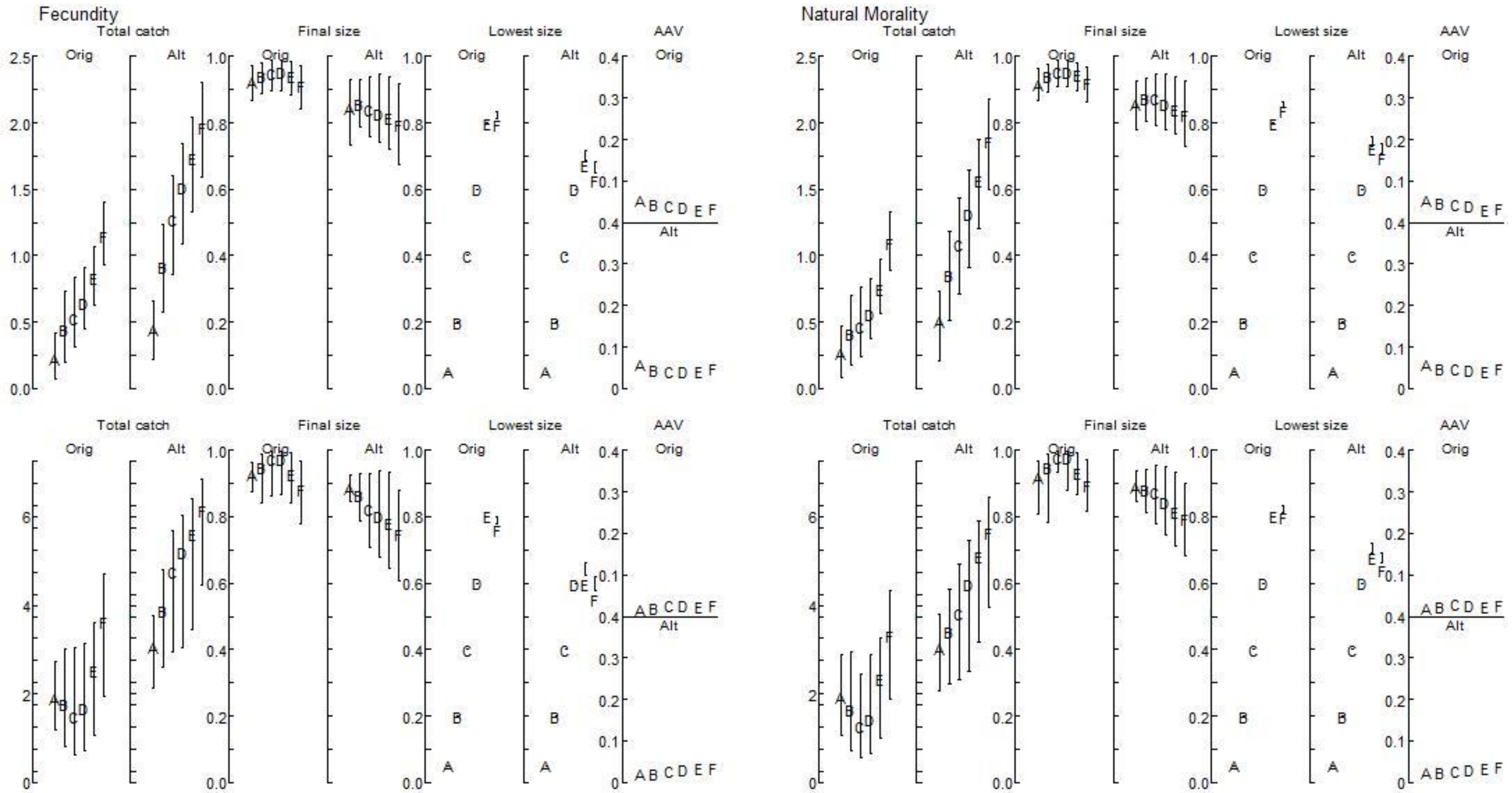

Figure 2(b). Response curve plots for the full depletion set (0.05*K*, 0.2*K*, 0.4*K*, 0.6*K*, 0.8*K*, and 0.99*K*) when $MSYR_{mat}$ = 4% for 100-year (top row) and 300-year projections (bottom row). Results are shown when density-dependence impacts fecundity in the left panel and when it impacts natural mortality in the right panel.

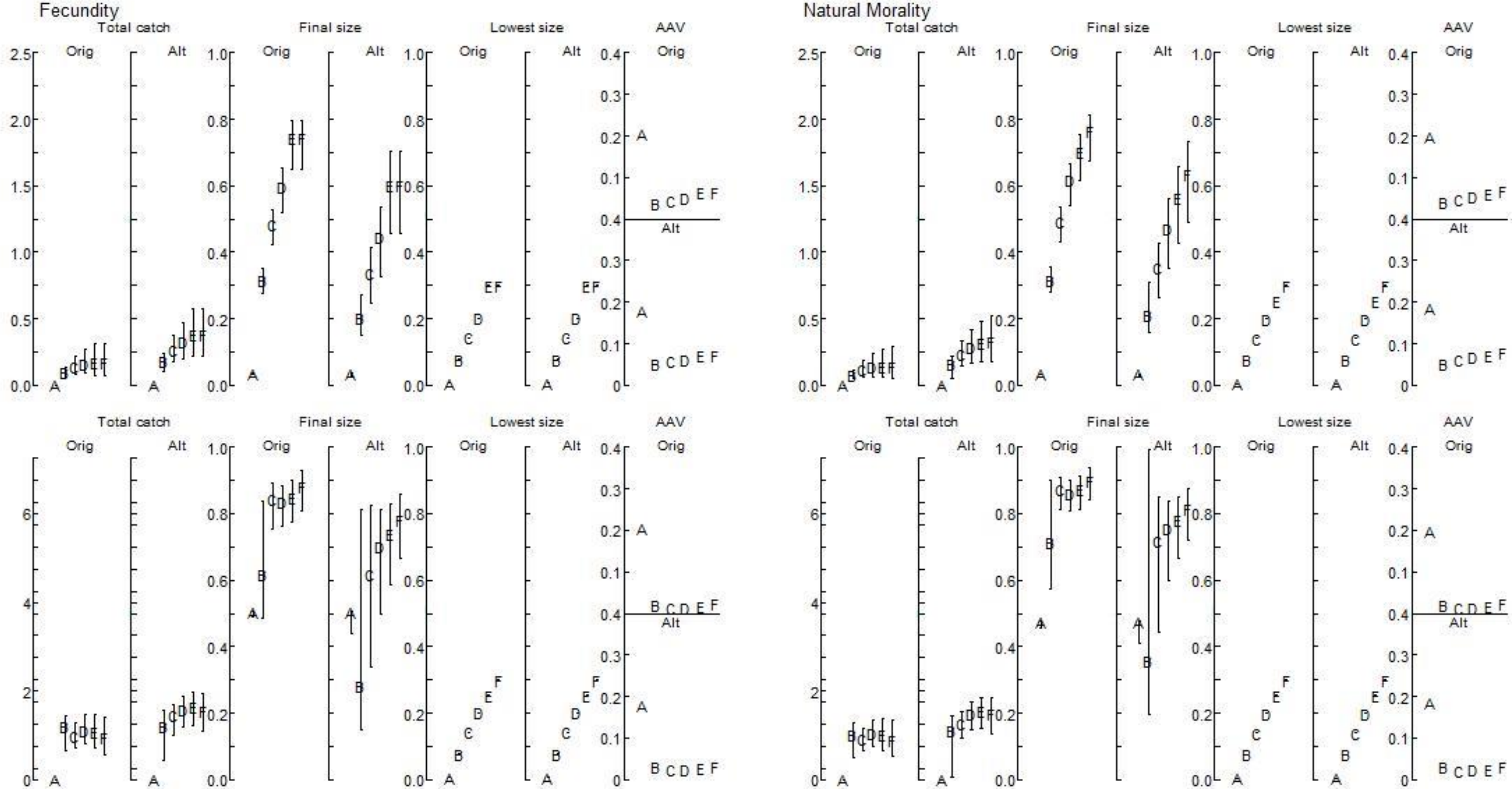

Figure 3(a). Response curve plots for unreported catch level (1%C_t, 20%C_t, 40%C_t, 60%C_t, 80%C_t, and 100%C_t) when MSYR$_{1+}$ = 1% and an initial depletion of 0.3K for 100-year (top row) and 300-year projections (bottom row). Results are shown when density-dependence impacts fecundity in the left panel and when it impacts natural mortality in the right panel.

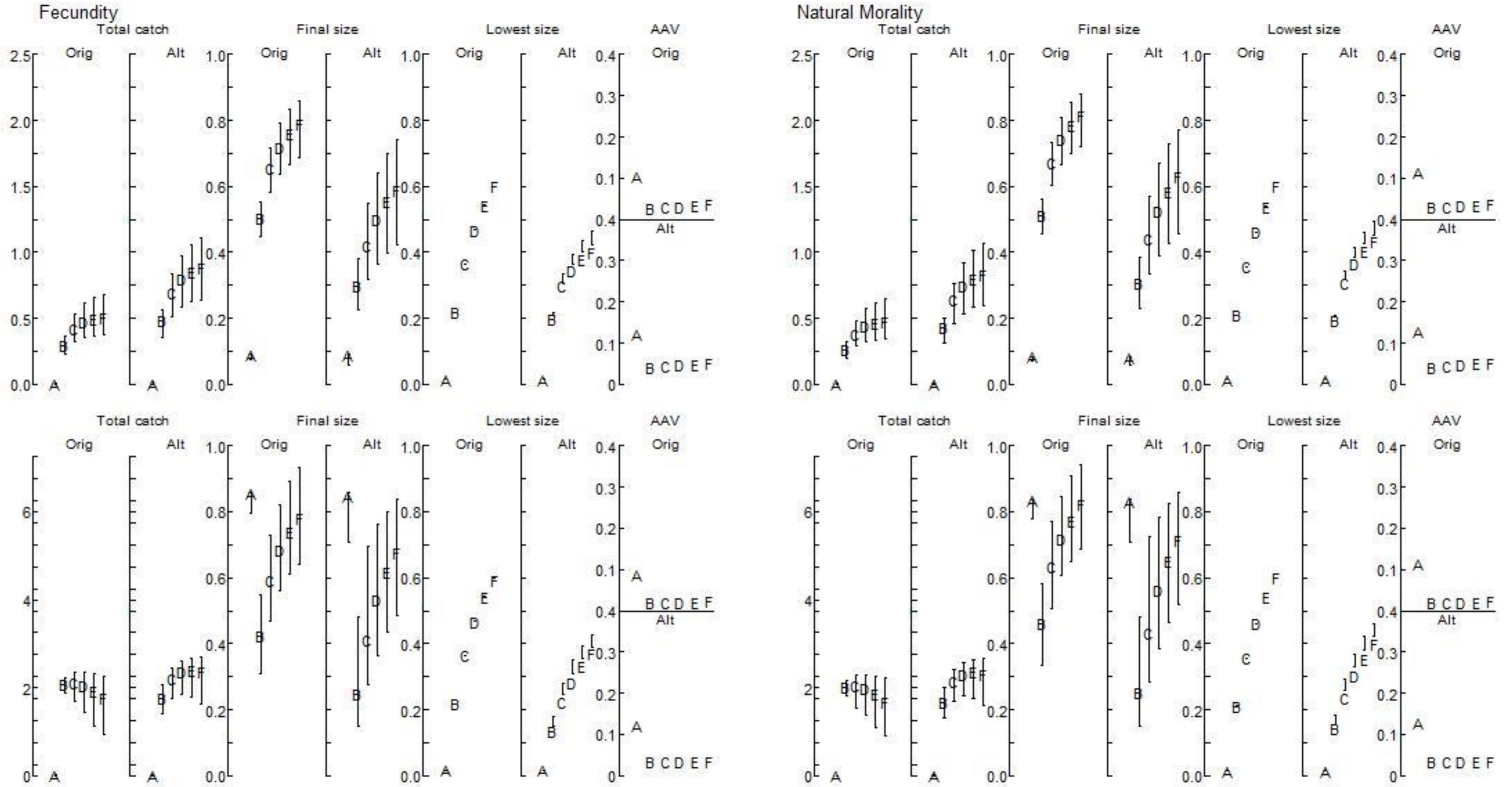

Figure 3(b). Response curve plots for unreported catch level (1%C_t, 20%C_t, 40%C_t, 60%C_t, 80%C_t, and 100%C_t) when $MSYR_{1+}$ = 1% and an initial depletion of 0.6*K* for 100-year (top row) and 300-year projections (bottom row). Results are shown when density-dependence impacts fecundity in the left panel and when it impacts natural mortality in the right panel.

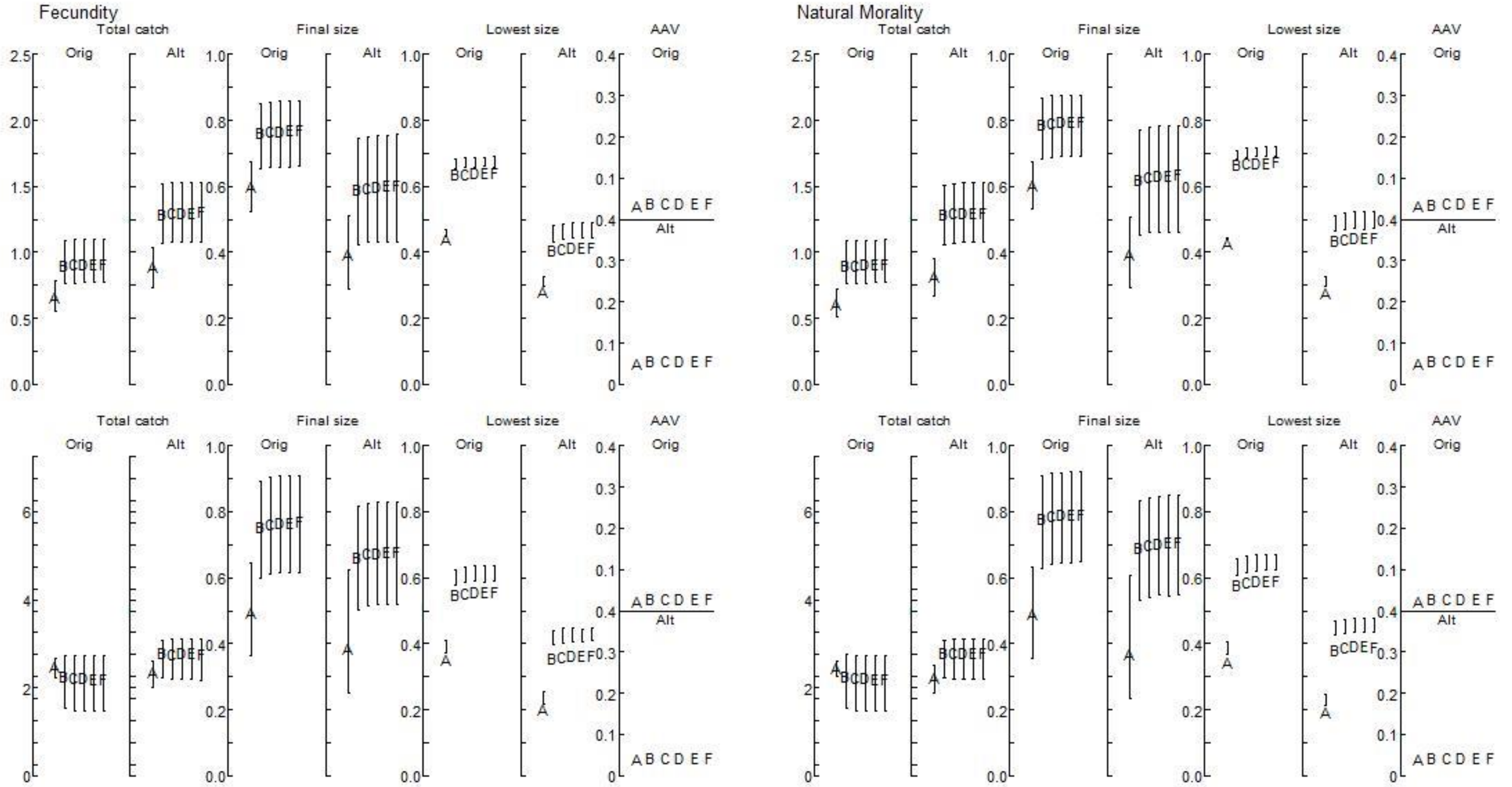

Figure 3(c). Response curve plots for unreported catch level (1%C_t, 20%C_t, 40%C_t, 60%C_t, 80%C_t, and 100%C_t) when $MSYR_{1+}$ = 1% and an initial depletion of 0.99K for 100-year (top row) and 300-year projections (bottom row). Results are shown when density-dependence impacts fecundity in the left panel and when it impacts natural mortality in the right panel.

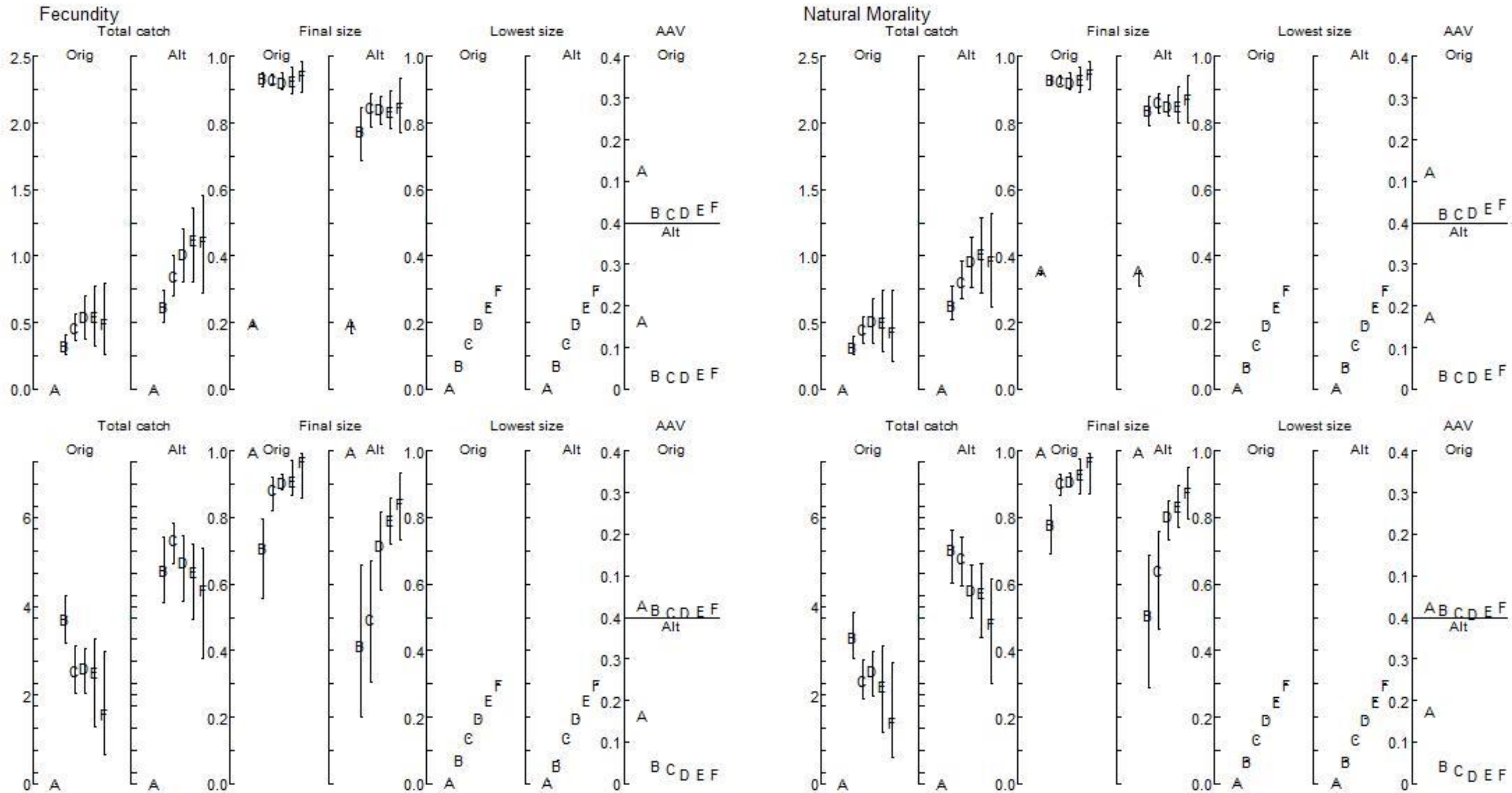

Figure 3(d). Response curve plots for unreported catch level (1%C_t, 20%C_t, 40%C_t, 60%C_t, 80%C_t, and 100%C_t) when $MSYR_{mat}$ = 4% and an initial depletion of 0.3K for 100-year (top row) and 300-year projections (bottom row). Results are shown when density-dependence impacts fecundity in the left panel and when it impacts natural mortality in the right panel.

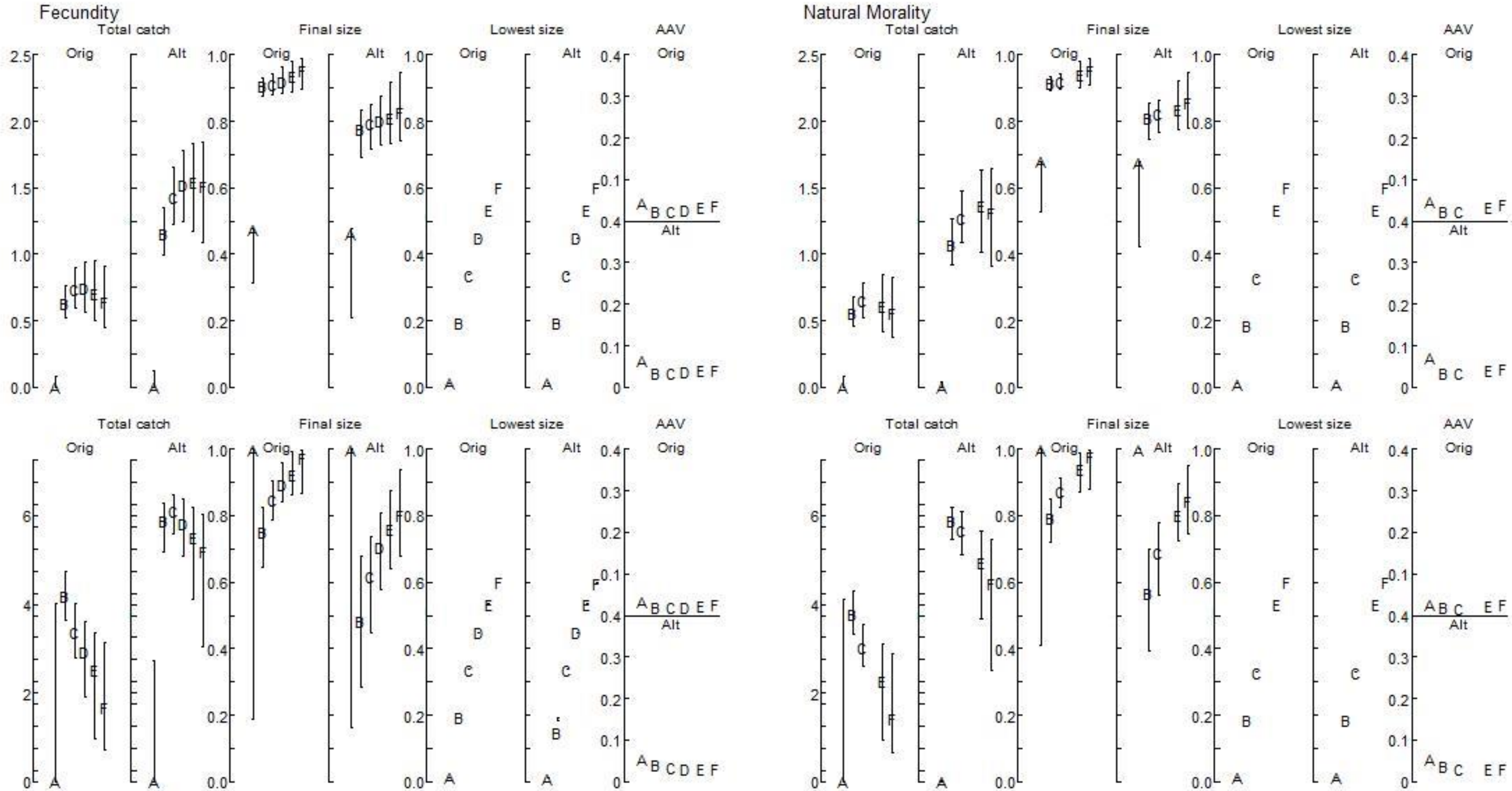

Figure 3(e). Response curve plots for unreported catch level (1%C_t, 20%C_t, 40%C_t, 60%C_t, 80%C_t, and 100%C_t) when $MSYR_{mat}$ = 4% and an initial depletion of 0.6K for 100-year (top row) and 300-year projections (bottom row). Results are shown when density-dependence impacts fecundity in the left panel and when it impacts natural mortality in the right panel.

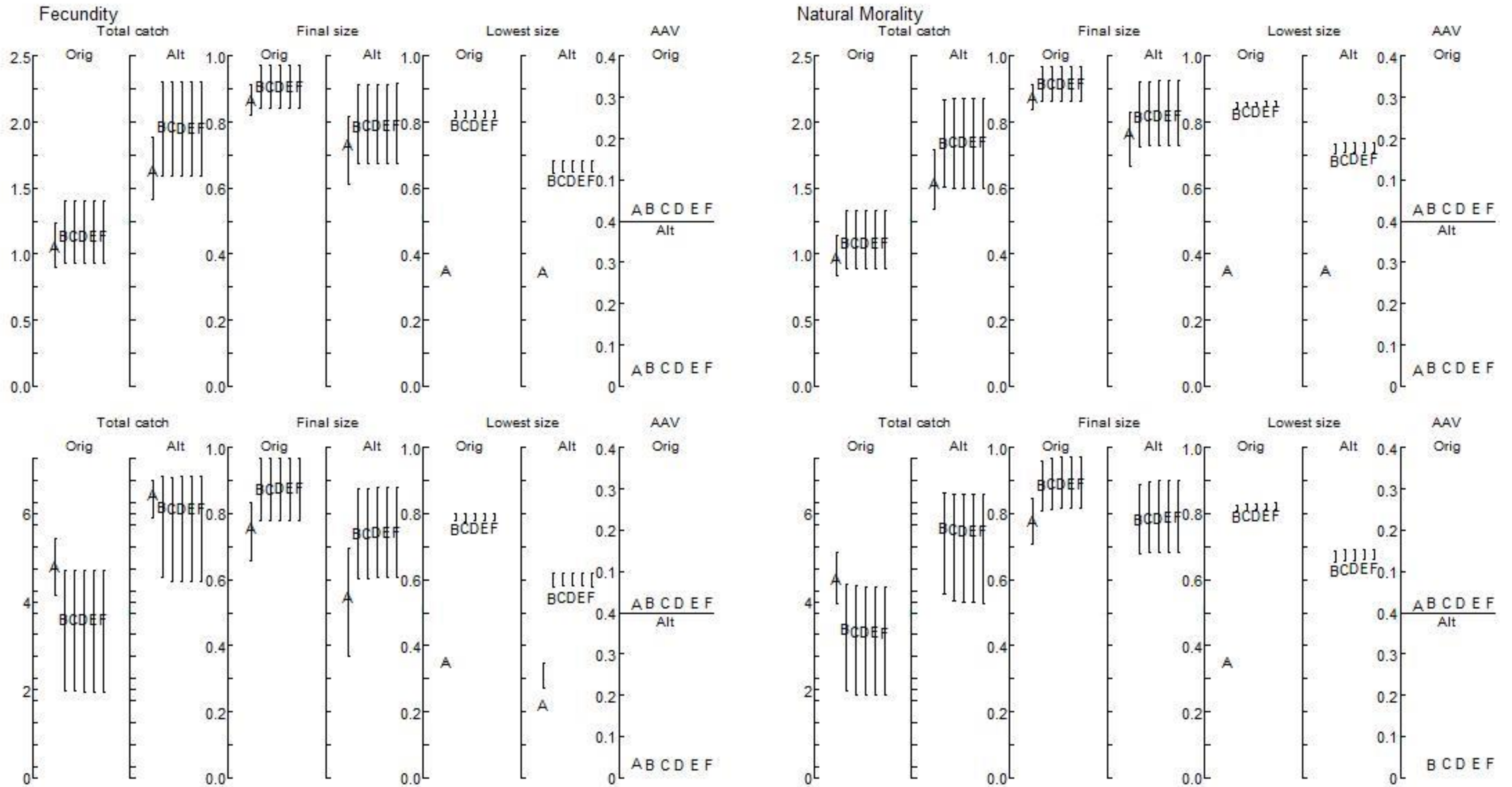

Figure 3(f). Response curve plots for unreported catch level (1%C_t, 20%C_t, 40%C_t, 60%C_t, 80%C_t, and 100%C_t) when $MSYR_{mat}$ = 4% and an initial depletion of 0.99K for 100-year (top row) and 300-year projections (bottom row). Results are shown when density-dependence impacts fecundity in the left panel and when it impacts natural mortality in the right panel.

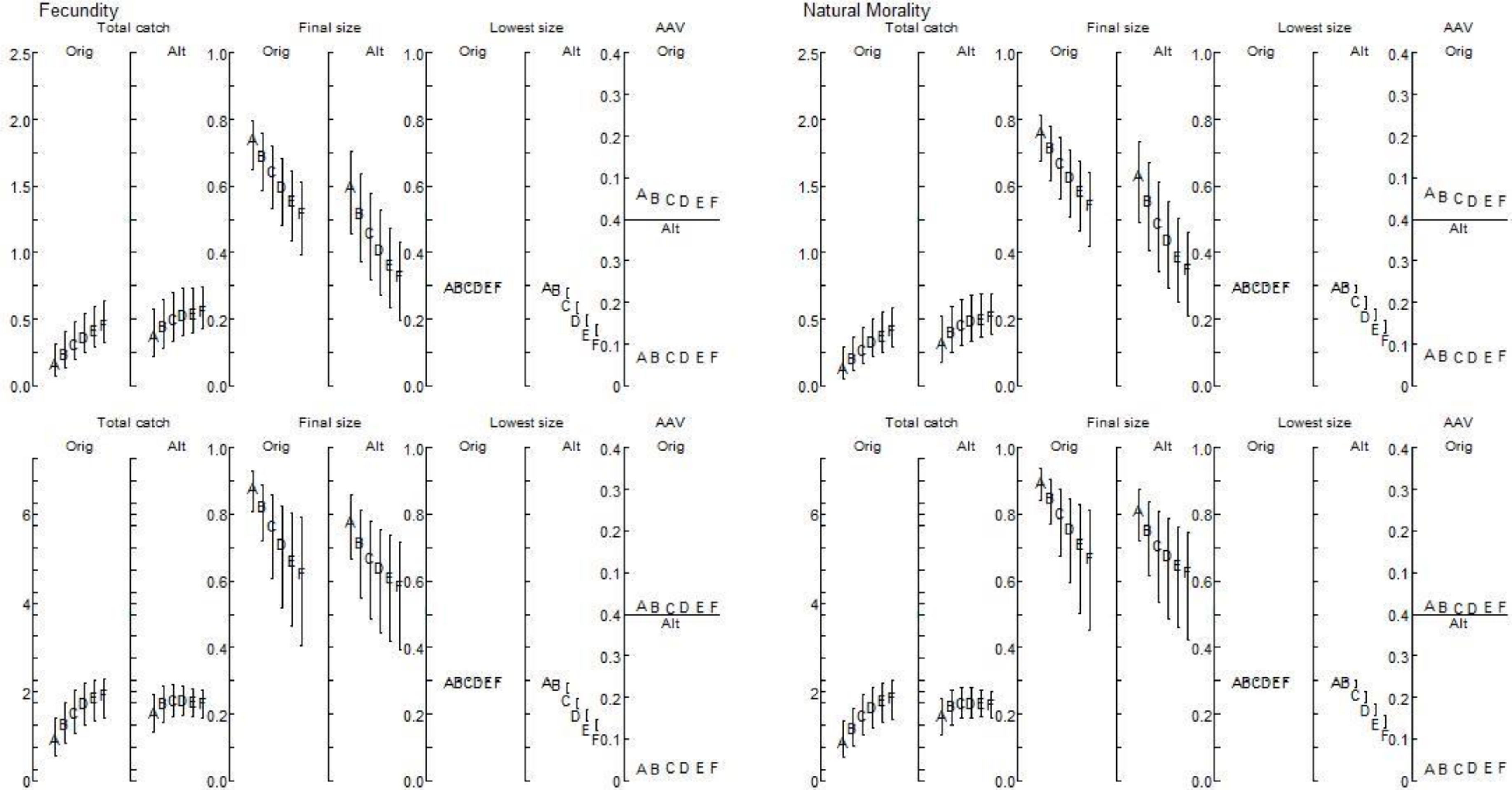

Figure 4(a). Response curve plots for positive survey bias (1.0, 1.2, 1.4, 1.6, 1.8, and 2.0) when $MSYR_{1+}$ = 1% and an initial depletion of 0.3*K* for 100-year (top row) and 300-year projections (bottom row). Results are shown when density-dependence impacts fecundity in the left panel and when it impacts natural mortality in the right panel.

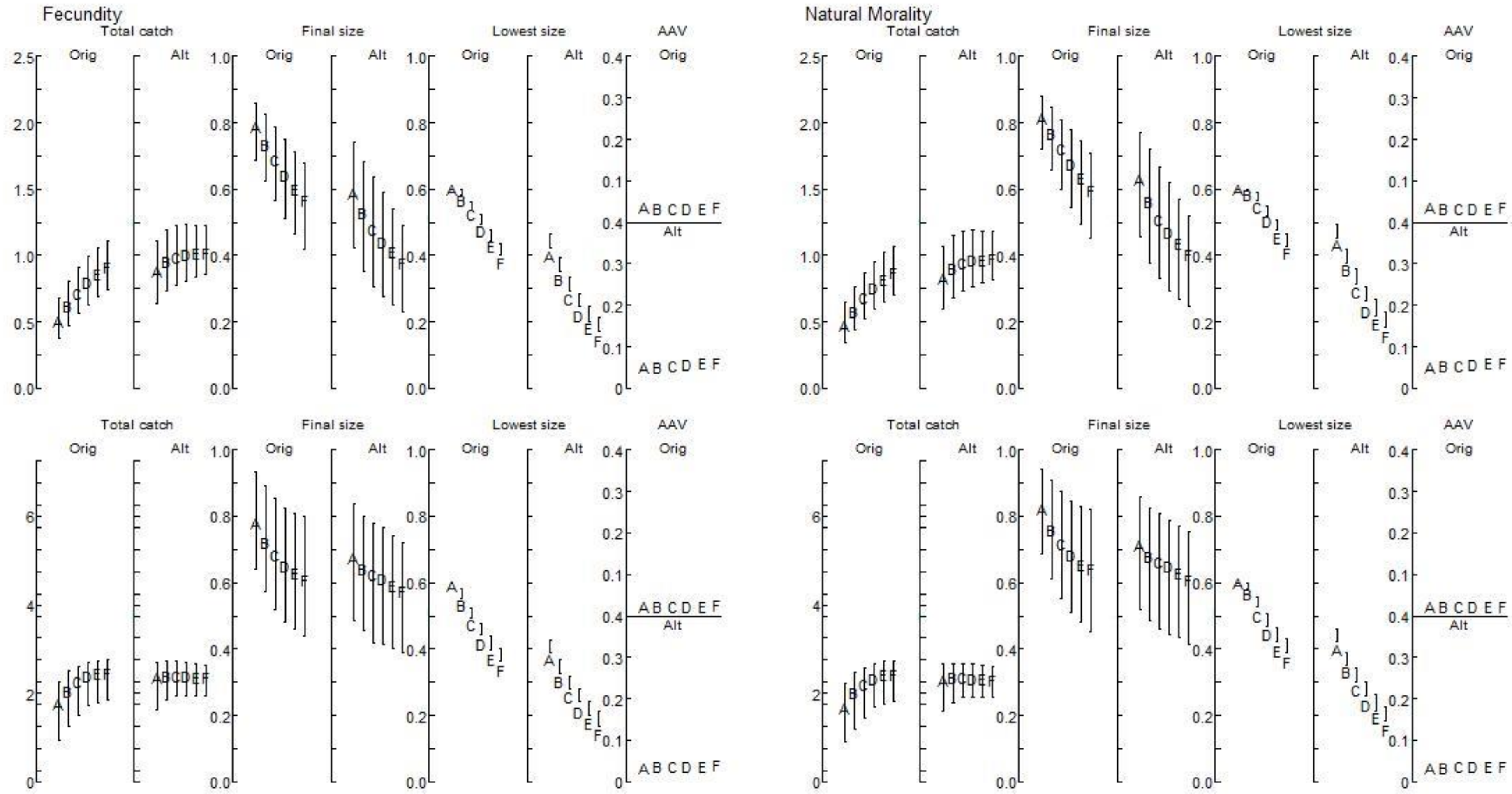

Figure 4(b). Response curve plots for positive survey bias (1.0, 1.2, 1.4, 1.6, 1.8, and 2.0) when $MSYR_{1+}$ = 1% and an initial depletion of 0.6*K* for 100-year (top row) and 300-year projections (bottom row). Results are shown when density-dependence impacts fecundity in the left panel and when it impacts natural mortality in the right panel.

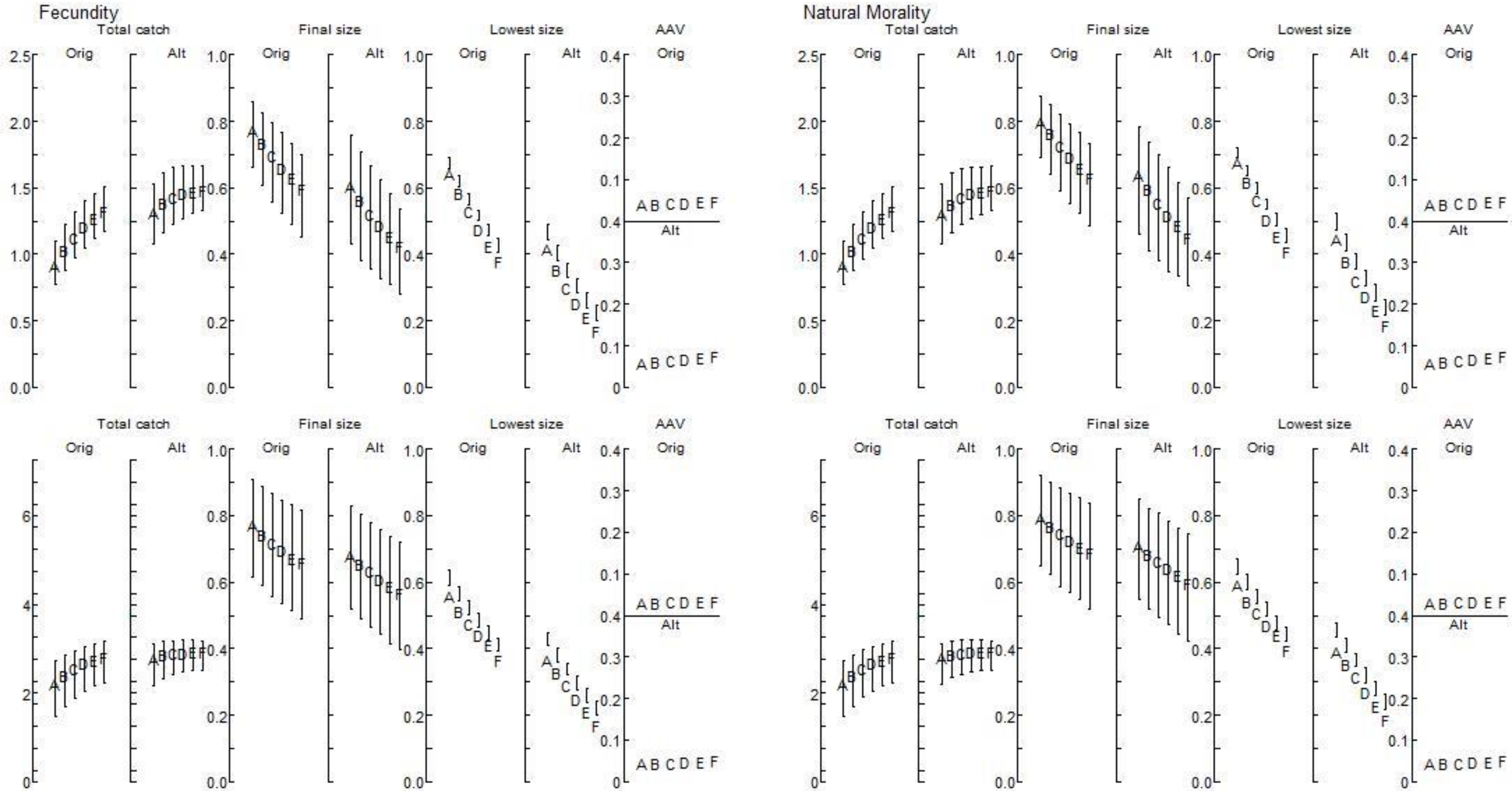

Figure 4(c). Response curve plots for positive survey bias (1.0, 1.2, 1.4, 1.6, 1.8, and 2.0) when $MSYR_{1+}$ = 1% and an initial depletion of 0.99K for 100-year (top row) and 300-year projections (bottom row). Results are shown when density-dependence impacts fecundity in the left panel and when it impacts natural mortality in the right panel.

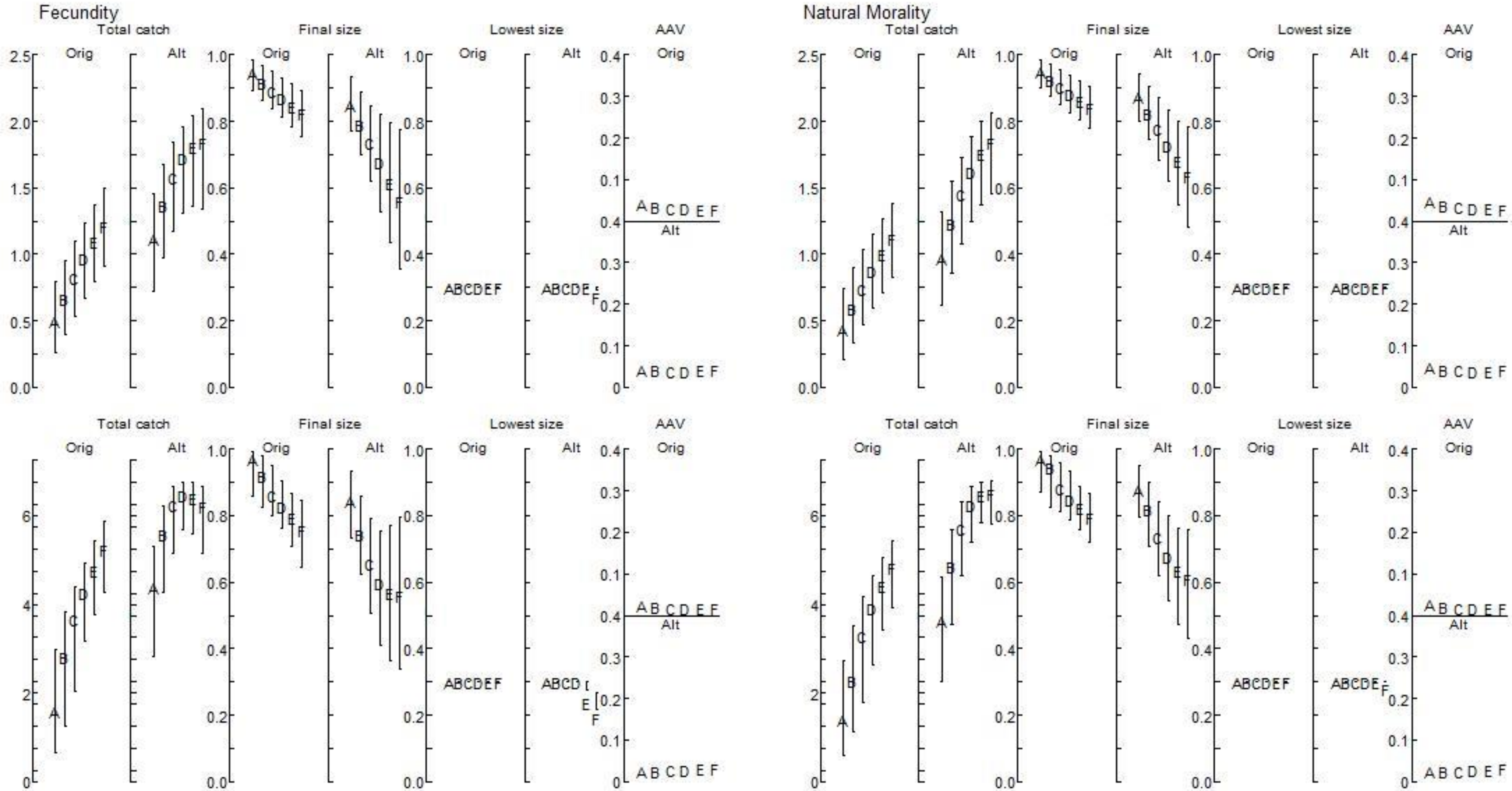

Figure 4(d). Response curve plots for positive survey bias (1.0, 1.2, 1.4, 1.6, 1.8, and 2.0) when $MSYR_{mat}$ = 4% and an initial depletion of 0.3*K* for 100-year (top row) and 300-year projections (bottom row). Results are shown when density-dependence impacts fecundity in the left panel and when it impacts natural mortality in the right panel.

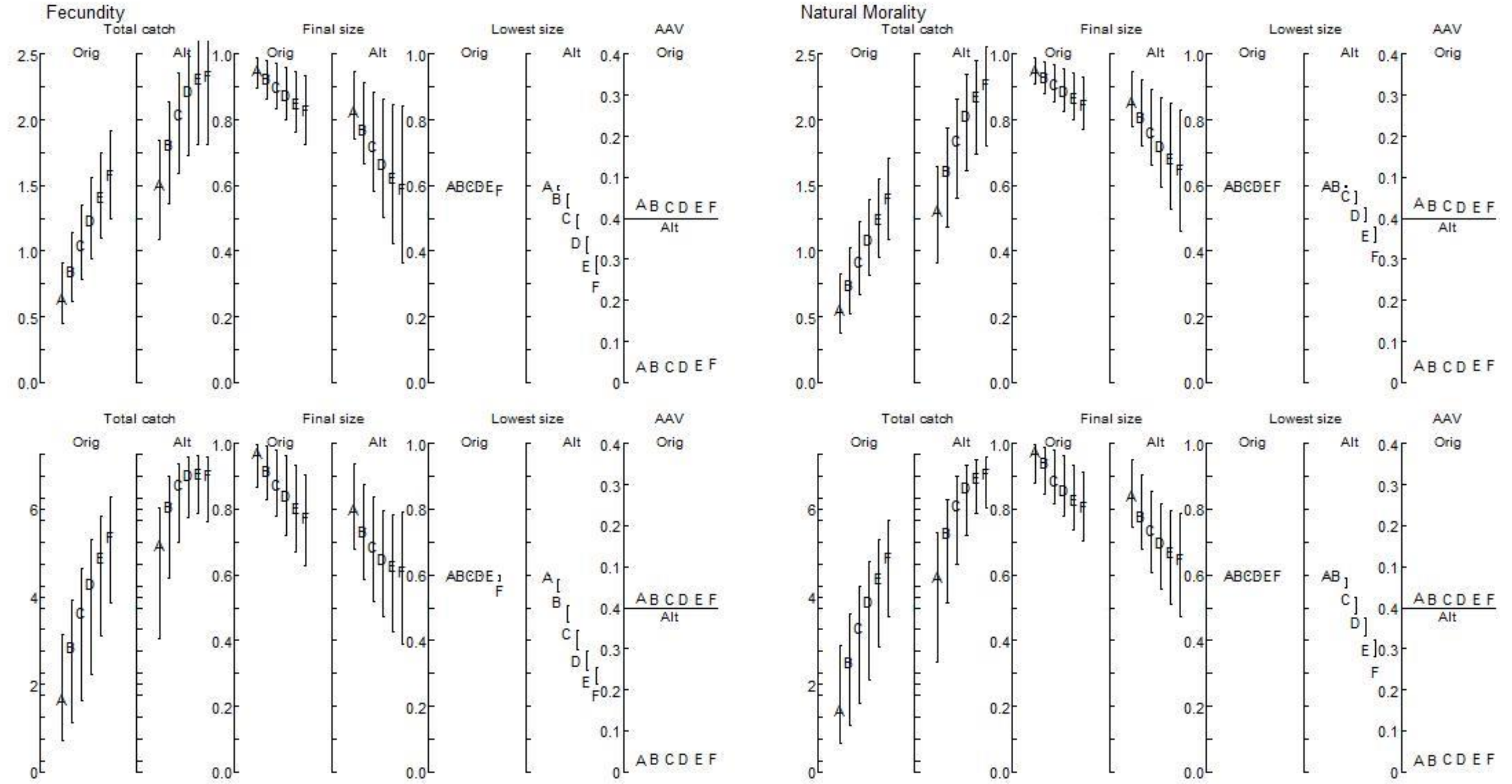

Figure 4(e). Response curve plots for positive survey bias (1.0, 1.2, 1.4, 1.6, 1.8, and 2.0) when $MSYR_{mat}$ = 4% and an initial depletion of 0.6K for 100-year (top row) and 300-year projections (bottom row). Results are shown when density-dependence impacts fecundity in the left panel and when it impacts natural mortality in the right panel.

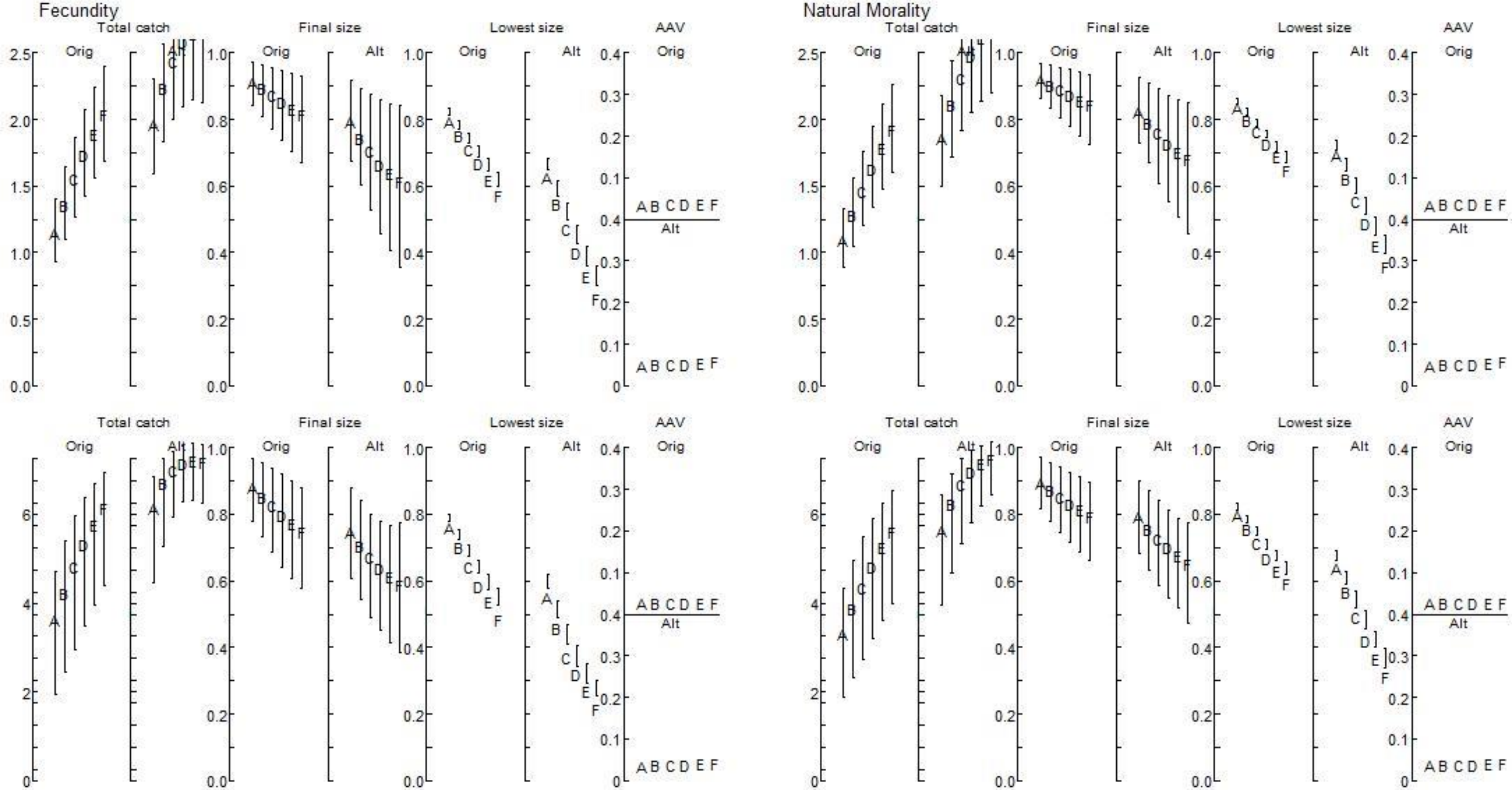

Figure 4(f). Response curve plots for positive survey bias (1.0, 1.2, 1.4, 1.6, 1.8, and 2.0) when $MSYR_{mat}$ = 4% and an initial depletion of 0.99*K* for 100-year (top row) and 300-year projections (bottom row). Results are shown when density-dependence impacts fecundity in the left panel and when it impacts natural mortality in the right panel.