10.1071/MF23004

Marine and Freshwater Research

Supplementary Material

Assessing the use of environmental flows and stocking for the persistence of a flow-dependent spawner in a drying climate

Daniel J. Stoessel[A,*], *Jian Yen*[A], *and Charles R. Todd*[A]

[A]Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, 123 Brown Street, Heidelberg, Vic. 3084, Australia.

[*]Correspondence to: Daniel J. Stoessel Arthur Rylah Institute for Environmental Research, Department of Environment, Land, Water and Planning, 123 Brown Street, Heidelberg, Vic. 3084, Australia Email: daniel.stoessel01@gmail.com

Australian bass matrix population model

Our model was based on an existing Leslie matrix model of estuary perch population dynamics (Stoessel *et al*. 2022). This existing model considered the abundances of females in each of 40 age classes, accounting for the effects of environmental and demographic stochasticity, negative density dependence, and streamflow and productivity on spawning and survival of early life stages (eggs and larvae) (Stoessel *et al*. 2022). Female estuary perch are assumed to reproduce annually from 3 years of age, with reproductive output limited by female abundances (i.e., males are assumed to be present in sufficient numbers).

We altered or extended the model of Stoessel *et al*. (2022) in several ways:

1. Include an additional 10 adult female age classes (50 in total).
2. Increase female maturity to 4 years of age.
3. Adjust density dependence to include negative effects of high densities on reproductive output.
4. Include the effects of water temperature on Australian bass spawning.
5. Add parameters to include the effects of stocking in population simulations.

Model description

Defining $\mathbf{n_t}$ as a column vector of population abundances (50 age classes) in year t and $\mathbf{A}$ as a (pre-breeding) Leslie matrix of vital rates, the model had the following structure:

$$\mathbf{n_t} = \mathbf{A}\ \mathbf{n_{t-1}}$$

This model was updated on an annual time step (focusing on water years, July–June), and included environmental and demographic stochasticity. Environmental stochasticity introduced Gaussian variation into survival estimates and Poisson variation into reproduction estimates, with standard deviations for survival equal to 0.5 of its mean value. Environmental stochasticity was defined on a logit scale for survival to ensure values between zero and one. Demographic stochasticity introduced Poisson variation into reproductive outputs and Binomial variation into survival outcomes (with current abundances in each age class as the number of trials).

Parameter estimation and the sensitivity of model outputs to parameter uncertainty are described in Stoessel *et al*. (2022). The matrix **A** had non-zero values on the lower diagonal (survival from one age class to the next) and in the first row (reproduction and survival to age 1). Survival values were estimated from empirical data and survival of ages 1–40 followed the following equation, where s_i is survival from age class i to i + 1 and p_i is the relative frequency of individuals surviving to age class i + 1:

$$p_i = 1020.23 \times i^{-1.16} - 13.5,\ i = 1, \ldots, 40$$

$$s_i = p_i \div p_{i-1}$$

We extended these values to 41–50 year age classes by linearly interpolating survival at age 40 to an assumed survival rate of 0 for 50 year-old individuals. Maximum reproductive output was estimated from empirical data and was defined as:

$$R_i^{max} = 0.5\ s_e\ s_l\ s_f\ z\ s_{temp} \exp(-49.8 \times \log(384.69 \times (1 - \exp(-0.19\ (i + 2.27)))))$$

where s_e, s_l, and s_f are survival of eggs (0.5), larvae (0.0061) and fingerlings (0.1226) respectively, z is a constant that reflects the proportion of females breeding in each year (0.85), and s_{temp} is a proportional change in survival due to variation in discharge and water temperature during the spawning period (described below).

Negative density dependence (d) was included with a Beverton–Holt model to capture reductions in fecundity under high adult densities, so that realised reproductive output was:

$$R_i = R_i^{max} \div (1 + R_i^{max}\, n_{ad} \div \mathrm{K})$$

where n_{ad} is the total abundance of reproductive females and K is the adult female carrying capacity. Adult female carrying capacity was set to 10000 individuals based on estimated habitable reach length of 50 km, maximum densities of ~400 individuals per km and an ~50:50 sex ratio (Stoessel *et al*. 2020).

Reproductive output was dependent on annual discharge and water temperatures (outlined in main text). The effects of discharge on reproductive output are described in Stoessel *et al*. (2017) and include a requirement for high spring flows as a migration cue prior to spawning, the mortality of eggs under very high flows, and a requirement for high flows to stimulate productivity that supports survival of larvae. The effects of water temperature were based on empirical results in Stoessel *et al*. (2022), with reproductive output modified by the following factor:

$$s_{temp} = 0.5 + 3 \times (-0.01 \times (x_{temp} - 14)^2)$$

which represents a peak in reproductive output at water temperatures of 14°C and declines at higher or lower water temperatures. We set s_{temp} to 0 (no reproductive output) at temperatures below 10°C or above 18°C.

We initiated population trajectories with values drawn randomly from a Poisson distribution with a separate mean in each age class. We assumed the Snowy River population of Australian bass was at half of its carrying capacity, and set the mean of the Poisson distribution by dividing this value (5000 individuals) among age classes according to the steady-state age distribution (leading right eigenvector) of the average population matrix. The effects of stocking were included through the direct addition of recruits in any given year, with an assumption that survival of stocked fingerlings matches that of the wild population (0.1226) and a 50:50 sex ratio.

Computational details

The population model described above is included as a template in the aae.pop.templates R package (ver. 0.0.0.9001, see https://github.com/aae-stats/aae.pop.templates). We simulated population dynamics in the aae.pop R package (ver. 0.0.0.9002, see https://aae-stats.github.io/aae.pop/). The aae.pop package aims to support flexible development of matrix population models that include a range of demographic processes and is described at https://aae-stats.github.io/aae.pop/. All simulations were run in R (ver. 4.1.0, R Foundation for Statistical Computing, Vienna, Austria, see https://www.r-project.org/) on a Dell Inc. Precision 7540 laptop with an Intel i7-9850H CPU (2.60 GHz) 16 GB of RAM running Windows 10 Enterprise.

Table S1. Probability of population persistence and expected minimum population size (EMPS) under all combinations of management interventions for all climate change scenarios.

Climate change scenario	First management intervention	Second management intervention	Probability of population persistence	EMPS
Historical (post-1975)	None		0	109
	Env. water (2 small)		0.005	531
	Stocking (10000)		0.042	863
	Env. water (3 small)		0.136	802
	Env. water (3 large every 5 years)		0.6	1054
	Env. water (2 small)	Stocking (10000)	0.991	1299
	Stocking (15000)		0.996	1238
	Env. water (2 small)	Stocking (15000)	1	1704
	Env. water (3 large every 5 years)	Stocking (10000)	1	1875
	Env. water (3 small)	Stocking (10000)	1	2083
	Env. water (3 large every 3 years)		1	2106
	Env. water (3 large every 5 years)	Stocking (15000)	1	2264
	Stocking (30000)		1	2328
	Env. water (3 small)	Stocking (15000)	1	2669
	Env. water (2 small)	Stocking (30000)	1	2814
	Env. water (3 large every 3 years)	Stocking (10000)	1	2921
	Env. water (3 small)	Stocking (30000)	1	3088
	Env. water (3 large every 3 years)	Stocking (15000)	1	3311
	Env. water (3 large every 5 years)	Stocking (30000)	1	3412
	Env. water (3 large every 2 years)		1	3472
	Stocking (50000)		1	3761
	Env. water (2 small)	Stocking (50000)	1	4270
	Env. water (3 large every 2 years)	Stocking (10000)	1	4341
	Env. water (3 large every 3 years)	Stocking (30000)	1	4419
	Env. water (3 small)	Stocking (50000)	1	4618
	Env. water (3 large every 2 years)	Stocking (15000)	1	4744
	Env. water (3 large every 5 years)	Stocking (50000)	1	4847
	Env. water (3 large every 3 years)	Stocking (50000)	1	5776
	Env. water (3 large every 2 years)	Stocking (30000)	1	5784
	Env. water (2 large)		1	6546

Climate change scenario	First management intervention	Second management intervention	Probability of population persistence	EMPS
	Env. water (3 large every 2 years)	Stocking (50000)	1	7052
	Env. water (2 large)	Stocking (10000)	1	7290
	Env. water (2 large)	Stocking (15000)	1	7868
	Env. water (2 large)	Stocking (30000)	1	8772
	Env. water (3 large)		1	8945
	Env. water (2 large)	Stocking (50000)	1	9361
	Env. water (3 large)	Stocking (10000)	1	9503
	Env. water (3 large)	Stocking (15000)	1	9814
	Env. water (3 large)	Stocking (30000)	1	10516
	Env. water (3 large)	Stocking (50000)	1	11284
Post-1997	None		0	24
	Env. water (2 small)		0	266
	Env. water (3 small)		0	403
	Stocking (10000)		0	763
	Env. water (3 large every 5 years)		0.258	888
	Env. water (2 small)	Stocking (10000)	0.541	1022
	Stocking (15000)		0.939	1123
	Env. water (3 small)	Stocking (10000)	0.968	1255
	Env. water (3 large every 5 years)	Stocking (10000)	0.999	1714
	Env. water (2 small)	Stocking (15000)	1	1475
	Env. water (3 small)	Stocking (15000)	1	1624
	Env. water (3 large every 3 years)		1	1897
	Env. water (3 large every 5 years)	Stocking (15000)	1	2128
	Stocking (30000)		1	2202
	Env. water (2 small)	Stocking (30000)	1	2580
	Env. water (3 large every 3 years)	Stocking (10000)	1	2732
	Env. water (3 large every 3 years)	Stocking (15000)	1	3105
	Env. water (3 large every 5 years)	Stocking (30000)	1	3285
	Env. water (3 large every 2 years)		1	3343
	Env. water (3 small)	Stocking (30000)	1	3393
	Stocking (50000)		1	3605
	Env. water (2 small)	Stocking (50000)	1	4017
	Env. water (3 large every 3 years)	Stocking (30000)	1	4096
	Env. water (3 large every 2 years)	Stocking (10000)	1	4111
	Env. water (3 small)	Stocking (50000)	1	4308

Climate change scenario	First management intervention	Second management intervention	Probability of population persistence	EMPS
	Env. water (3 large every 2 years)	Stocking (15000)	1	4598
	Env. water (3 large every 5 years)	Stocking (50000)	1	4662
	Env. water (3 large every 3 years)	Stocking (50000)	1	5630
	Env. water (3 large every 2 years)	Stocking (30000)	1	5662
	Env. water (2 large)		1	6661
	Env. water (3 large every 2 years)	Stocking (50000)	1	6921
	Env. water (2 large)	Stocking (10000)	1	7205
	Env. water (2 large)	Stocking (15000)	1	7887
	Env. water (2 large)	Stocking (30000)	1	8719
	Env. water (3 large)		1	8890
	Env. water (3 large)	Stocking (10000)	1	9531
	Env. water (2 large)	Stocking (50000)	1	9691
	Env. water (3 large)	Stocking (15000)	1	9719
	Env. water (3 large)	Stocking (30000)	1	10473
	Env. water (3 large)	Stocking (50000)	1	11207
RCP4.5 (low)	None		0	153
	Env. water (2 small)		0	503
	Stocking (10000)		0.173	922
	Env. water (3 small)		0.207	862
	Env. water (3 large every 5 years)		0.504	1014
	Env. water (2 small)	Stocking (10000)	0.989	1322
	Env. water (3 large every 3 years)		0.999	1936
	Stocking (15000)		1	1303
	Env. water (2 small)	Stocking (15000)	1	1674
	Env. water (3 small)	Stocking (10000)	1	1718
	Env. water (3 large every 5 years)	Stocking (10000)	1	1838
	Env. water (3 small)	Stocking (15000)	1	1992
	Env. water (3 large every 5 years)	Stocking (15000)	1	2243
	Stocking (30000)		1	2415
	Env. water (3 large every 3 years)	Stocking (10000)	1	2776
	Env. water (2 small)	Stocking (30000)	1	2819
	Env. water (3 large every 2 years)		1	3039
	Env. water (3 large every 3 years)	Stocking (15000)	1	3181
	Env. water (3 small)	Stocking (30000)	1	3209

Climate change scenario	First management intervention	Second management intervention	Probability of population persistence	EMPS
	Env. water (3 large every 5 years)	Stocking (30000)	1	3413
	Stocking (50000)		1	3838
	Env. water (3 large every 2 years)	Stocking (10000)	1	4050
	Env. water (2 small)	Stocking (50000)	1	4263
	Env. water (3 large every 3 years)	Stocking (30000)	1	4361
	Env. water (3 large every 2 years)	Stocking (15000)	1	4435
	Env. water (3 large every 5 years)	Stocking (50000)	1	4861
	Env. water (3 small)	Stocking (50000)	1	4998
	Env. water (2 large)		1	5507
	Env. water (3 large every 2 years)	Stocking (30000)	1	5547
	Env. water (3 large every 3 years)	Stocking (50000)	1	5686
	Env. water (2 large)	Stocking (10000)	1	6030
	Env. water (2 large)	Stocking (15000)	1	6715
	Env. water (3 large every 2 years)	Stocking (50000)	1	6900
	Env. water (3 large)		1	7856
	Env. water (2 large)	Stocking (30000)	1	7998
	Env. water (3 large)	Stocking (10000)	1	8631
	Env. water (2 large)	Stocking (50000)	1	8967
	Env. water (3 large)	Stocking (15000)	1	9002
	Env. water (3 large)	Stocking (30000)	1	9801
	Env. water (3 large)	Stocking (50000)	1	10733
RCP4.5 (medium)	None		0	53
	Env. water (2 small)		0	391
	Stocking (10000)		0	786
	Env. water (3 small)		0.001	560
	Env. water (3 large every 5 years)		0.017	598
	Env. water (2 small)	Stocking (10000)	0.837	1119
	Stocking (15000)		0.962	1147
	Env. water (3 large every 3 years)		0.976	1505
	Env. water (3 small)	Stocking (10000)	0.992	1315
	Env. water (3 large every 5 years)	Stocking (10000)	0.995	1466
	Env. water (2 small)	Stocking (15000)	1	1500
	Env. water (3 small)	Stocking (15000)	1	1696
	Env. water (3 large every 5 years)	Stocking (15000)	1	1896
	Stocking (30000)		1	2218

Climate change scenario	First management intervention	Second management intervention	Probability of population persistence	EMPS
	Env. water (3 large every 3 years)	Stocking (10000)	1	2396
	Env. water (2 small)	Stocking (30000)	1	2616
	Env. water (3 large every 2 years)		1	2666
	Env. water (3 large every 3 years)	Stocking (15000)	1	2778
	Env. water (3 small)	Stocking (30000)	1	2889
	Env. water (3 large every 5 years)	Stocking (30000)	1	3060
	Stocking (50000)		1	3607
	Env. water (3 large every 2 years)	Stocking (10000)	1	3610
	Env. water (3 large every 3 years)	Stocking (30000)	1	3983
	Env. water (3 large every 2 years)	Stocking (15000)	1	4005
	Env. water (2 small)	Stocking (50000)	1	4051
	Env. water (2 large)		1	4226
	Env. water (3 small)	Stocking (50000)	1	4308
	Env. water (3 large every 5 years)	Stocking (50000)	1	4480
	Env. water (3 large every 2 years)	Stocking (30000)	1	5019
	Env. water (3 large every 3 years)	Stocking (50000)	1	5346
	Env. water (2 large)	Stocking (10000)	1	5421
	Env. water (2 large)	Stocking (15000)	1	5783
	Env. water (3 large every 2 years)	Stocking (50000)	1	6557
	Env. water (2 large)	Stocking (30000)	1	6682
	Env. water (3 large)		1	7143
	Env. water (3 large)	Stocking (10000)	1	7718
	Env. water (3 large)	Stocking (15000)	1	8101
	Env. water (2 large)	Stocking (50000)	1	8360
	Env. water (3 large)	Stocking (30000)	1	9137
	Env. water (3 large)	Stocking (50000)	1	10119
RCP4.5 (high)	None		0	8
	Env. water (2 small)		0	36
	Env. water (3 small)		0	83
	Env. water (3 large every 5 years)		0	220
	Stocking (10000)		0	711
	Env. water (2 small)	Stocking (10000)	0	777
	Env. water (3 small)	Stocking (10000)	0.089	884
	Env. water (3 large every 3 years)		0.464	994

Climate change scenario	First management intervention	Second management intervention	Probability of population persistence	EMPS
	Env. water (3 large every 5 years)	Stocking (10000)	0.57	1027
	Stocking (15000)		0.821	1063
	Env. water (2 small)	Stocking (15000)	0.982	1175
	Env. water (3 large every 2 years)		0.999	1767
	Env. water (3 small)	Stocking (15000)	1	1370
	Env. water (3 large every 5 years)	Stocking (15000)	1	1455
	Env. water (3 large every 3 years)	Stocking (10000)	1	1943
	Stocking (30000)		1	2102
	Env. water (3 small)	Stocking (30000)	1	2256
	Env. water (2 small)	Stocking (30000)	1	2329
	Env. water (3 large every 3 years)	Stocking (15000)	1	2363
	Env. water (2 large)		1	2402
	Env. water (3 large every 5 years)	Stocking (30000)	1	2616
	Env. water (3 large every 2 years)	Stocking (10000)	1	2785
	Env. water (2 large)	Stocking (10000)	1	3260
	Env. water (3 large every 2 years)	Stocking (15000)	1	3315
	Stocking (50000)		1	3456
	Env. water (3 large every 3 years)	Stocking (30000)	1	3516
	Env. water (2 small)	Stocking (50000)	1	3635
	Env. water (3 small)	Stocking (50000)	1	3840
	Env. water (2 large)	Stocking (15000)	1	4006
	Env. water (3 large every 5 years)	Stocking (50000)	1	4050
	Env. water (3 large every 2 years)	Stocking (30000)	1	4437
	Env. water (3 large every 3 years)	Stocking (50000)	1	4993
	Env. water (3 large)		1	5037
	Env. water (2 large)	Stocking (30000)	1	5481
	Env. water (3 large every 2 years)	Stocking (50000)	1	5793
	Env. water (3 large)	Stocking (10000)	1	6240
	Env. water (3 large)	Stocking (15000)	1	6495
	Env. water (2 large)	Stocking (50000)	1	6978
	Env. water (3 large)	Stocking (30000)	1	7652
	Env. water (3 large)	Stocking (50000)	1	8839
RCP8.5 (low)	None		0	116
	Env. water (2 small)		0	406

Climate change scenario	First management intervention	Second management intervention	Probability of population persistence	EMPS
	Env. water (3 small)		0.015	642
	Env. water (3 large every 5 years)		0.051	704
	Stocking (10000)		0.081	888
	Env. water (2 small)	Stocking (10000)	0.928	1176
	Env. water (3 large every 3 years)		0.99	1536
	Stocking (15000)		0.998	1262
	Env. water (3 large every 5 years)	Stocking (10000)	0.999	1603
	Env. water (2 small)	Stocking (15000)	1	1536
	Env. water (3 small)	Stocking (10000)	1	1665
	Env. water (3 small)	Stocking (15000)	1	1756
	Env. water (3 large every 5 years)	Stocking (15000)	1	2016
	Env. water (3 large every 2 years)		1	2301
	Stocking (30000)		1	2373
	Env. water (3 large every 3 years)	Stocking (10000)	1	2408
	Env. water (2 small)	Stocking (30000)	1	2672
	Env. water (3 large every 3 years)	Stocking (15000)	1	2825
	Env. water (3 small)	Stocking (30000)	1	2998
	Env. water (3 large every 5 years)	Stocking (30000)	1	3205
	Env. water (3 large every 2 years)	Stocking (10000)	1	3227
	Env. water (2 large)		1	3548
	Env. water (3 large every 2 years)	Stocking (15000)	1	3769
	Stocking (50000)		1	3805
	Env. water (3 large every 3 years)	Stocking (30000)	1	4004
	Env. water (2 small)	Stocking (50000)	1	4155
	Env. water (3 small)	Stocking (50000)	1	4394
	Env. water (2 large)	Stocking (10000)	1	4424
	Env. water (3 large every 5 years)	Stocking (50000)	1	4639
	Env. water (3 large every 2 years)	Stocking (30000)	1	4895
	Env. water (2 large)	Stocking (15000)	1	5021
	Env. water (3 large every 3 years)	Stocking (50000)	1	5438
	Env. water (3 large)		1	5996
	Env. water (3 large every 2 years)	Stocking (50000)	1	6295
	Env. water (2 large)	Stocking (30000)	1	6300

Climate change scenario	First management intervention	Second management intervention	Probability of population persistence	EMPS
	Env. water (3 large)	Stocking (10000)	1	6887
	Env. water (3 large)	Stocking (15000)	1	7152
	Env. water (2 large)	Stocking (50000)	1	7689
	Env. water (3 large)	Stocking (30000)	1	8060
	Env. water (3 large)	Stocking (50000)	1	9190
RCP8.5 (medium)	None		0	19
	Env. water (2 small)		0	88
	Env. water (3 small)		0	114
	Env. water (3 large every 5 years)		0	215
	Stocking (10000)		0	736
	Env. water (3 large every 3 years)		0.014	573
	Env. water (2 small)	Stocking (10000)	0.021	846
	Env. water (3 small)	Stocking (10000)	0.095	894
	Env. water (3 large every 2 years)		0.431	982
	Env. water (3 large every 5 years)	Stocking (10000)	0.653	1050
	Env. water (2 large)		0.657	1098
	Stocking (15000)		0.894	1088
	Env. water (2 small)	Stocking (15000)	0.997	1224
	Env. water (3 large every 3 years)	Stocking (10000)	0.999	1501
	Env. water (3 small)	Stocking (15000)	1	1265
	Env. water (3 large every 5 years)	Stocking (15000)	1	1456
	Env. water (3 large every 2 years)	Stocking (10000)	1	1923
	Env. water (3 large every 3 years)	Stocking (15000)	1	1951
	Stocking (30000)		1	2132
	Env. water (2 large)	Stocking (10000)	1	2161
	Env. water (2 small)	Stocking (30000)	1	2318
	Env. water (3 small)	Stocking (30000)	1	2380
	Env. water (3 large every 2 years)	Stocking (15000)	1	2442
	Env. water (3 large every 5 years)	Stocking (30000)	1	2576
	Env. water (2 large)	Stocking (15000)	1	2710
	Env. water (3 large)		1	2962
	Env. water (3 large every 3 years)	Stocking (30000)	1	3177
	Stocking (50000)		1	3502
	Env. water (3 large every 2 years)	Stocking (30000)	1	3638
	Env. water (2 small)	Stocking (50000)	1	3728

Climate change scenario	First management intervention	Second management intervention	Probability of population persistence	EMPS
	Env. water (3 small)	Stocking (50000)	1	3819
	Env. water (2 large)	Stocking (30000)	1	4001
	Env. water (3 large)	Stocking (10000)	1	4003
	Env. water (3 large every 5 years)	Stocking (50000)	1	4065
	Env. water (3 large)	Stocking (15000)	1	4498
	Env. water (3 large every 3 years)	Stocking (50000)	1	4659
	Env. water (3 large every 2 years)	Stocking (50000)	1	5155
	Env. water (2 large)	Stocking (50000)	1	5675
	Env. water (3 large)	Stocking (30000)	1	5713
	Env. water (3 large)	Stocking (50000)	1	7250
RCP8.5 (high)	None		0	2
	Env. water (2 small)		0	4
	Env. water (3 small)		0	7
	Env. water (3 large every 5 years)		0	34
	Env. water (3 large every 3 years)		0	121
	Env. water (3 large every 2 years)		0	122
	Env. water (2 large)		0	137
	Env. water (3 large)		0	459
	Stocking (10000)		0	690
	Env. water (2 small)	Stocking (10000)	0	705
	Env. water (3 small)	Stocking (10000)	0	727
	Env. water (3 large every 5 years)	Stocking (10000)	0.004	799
	Env. water (3 large every 3 years)	Stocking (10000)	0.303	950
	Env. water (2 large)	Stocking (10000)	0.345	968
	Env. water (3 large every 2 years)	Stocking (10000)	0.417	986
	Stocking (15000)		0.687	1032
	Env. water (2 small)	Stocking (15000)	0.772	1052
	Env. water (3 small)	Stocking (15000)	0.873	1080
	Env. water (3 large every 5 years)	Stocking (15000)	0.972	1158
	Env. water (2 large)	Stocking (15000)	0.999	1373
	Env. water (3 large)	Stocking (10000)	0.999	1407
	Env. water (3 large every 3 years)	Stocking (15000)	1	1366
	Env. water (3 large every 2 years)	Stocking (15000)	1	1378
	Env. water (3 large)	Stocking (15000)	1	1844
	Stocking (30000)		1	2045

Climate change scenario	First management intervention	Second management intervention	Probability of population persistence	EMPS
	Env. water (3 small)	Stocking (30000)	1	2082
	Env. water (2 small)	Stocking (30000)	1	2085
	Env. water (3 large every 5 years)	Stocking (30000)	1	2243
	Env. water (3 large every 3 years)	Stocking (30000)	1	2518
	Env. water (2 large)	Stocking (30000)	1	2545
	Env. water (3 large every 2 years)	Stocking (30000)	1	2559
	Env. water (3 large)	Stocking (30000)	1	3093
	Stocking (50000)		1	3394
	Env. water (2 small)	Stocking (50000)	1	3434
	Env. water (3 small)	Stocking (50000)	1	3455
	Env. water (3 large every 5 years)	Stocking (50000)	1	3672
	Env. water (3 large every 3 years)	Stocking (50000)	1	3967
	Env. water (3 large every 2 years)	Stocking (50000)	1	4020
	Env. water (2 large)	Stocking (50000)	1	4030
	Env. water (3 large)	Stocking (50000)	1	4638

Management interventions are described in Table 1 in the main text. All management interventions were applied under each climate change scenario.

References

Stoessel DJ, Morrongiello JR, Raadik TA, Lyon JP, Nicol MD (2018) Determinants of year class strength and growth of estuary perch *Macquaria colonorum* in a highly regulated system. *Marine and Freshwater Research* **69**(11), 1663–1673.

Stoessel DJ, Van Rooyen AR, Beheregaray LB, Raymond SM, Van Wyk B, Haddy J, Lieschke J, Weeks AR (2020) Population genetic structure of estuary perch (*Percalates colonorum* Gunther) in south-eastern Australia. *Marine and Freshwater Research* **72**(2), 263-274.

Stoessel D, Todd CR, Brown T, Koehn JD, Walsh C, van der Meulen D, Williams J, Birleson M (2022) Assessing outcomes of environmental flows for an estuary-dependent fish species using a novel stochastic population model approach. *Estuaries and Coasts* **45**, 2040–2058.