

Modelling temperature impacts on fish growth using a growth model with reproductive costs: can we reproduce the temperature-size rule?

Asta Audzijonyte, Egle Jakubavičiūtė, Max Lindmark, Shane A. Richards

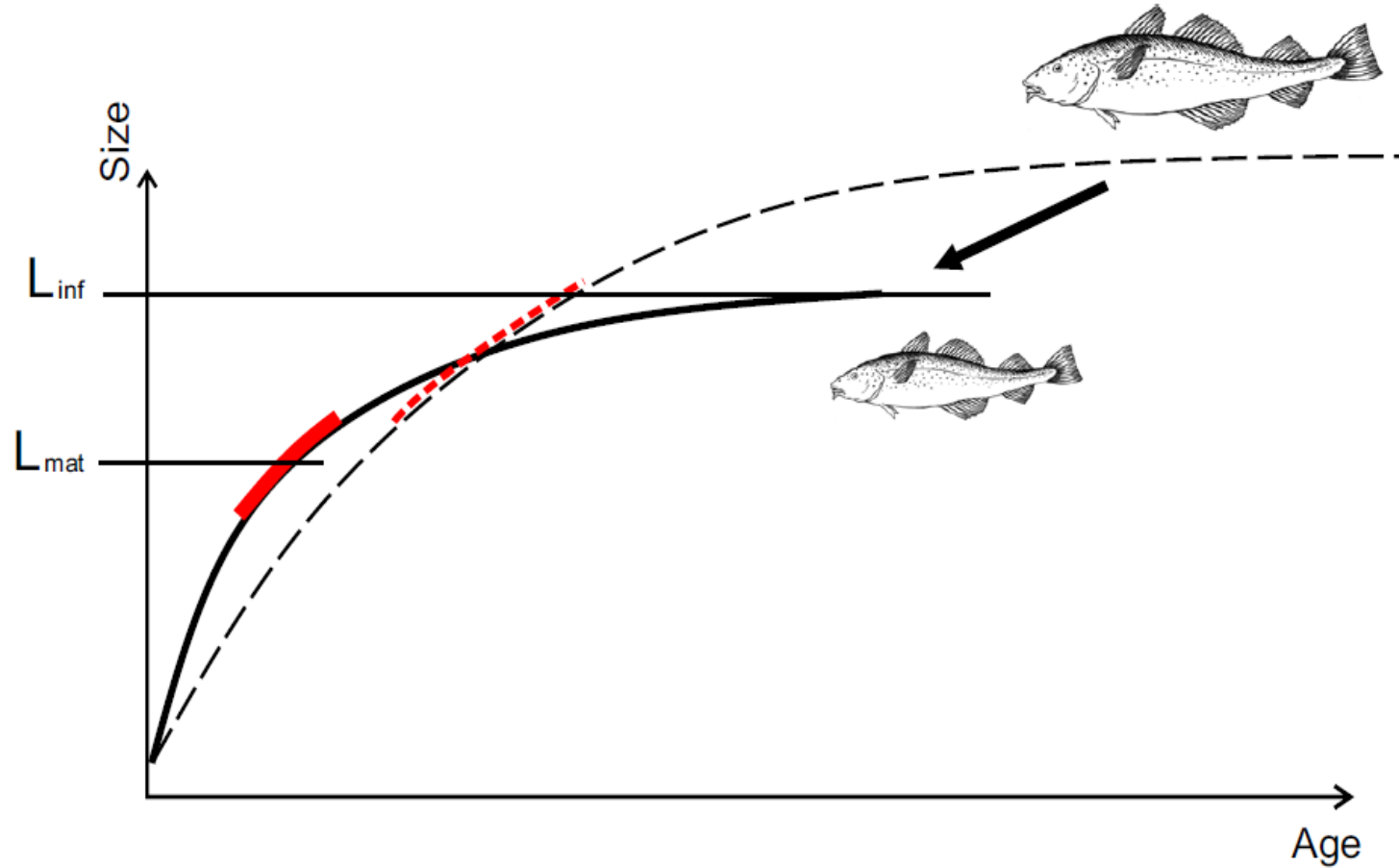
Nature Research Centre, Lithuania

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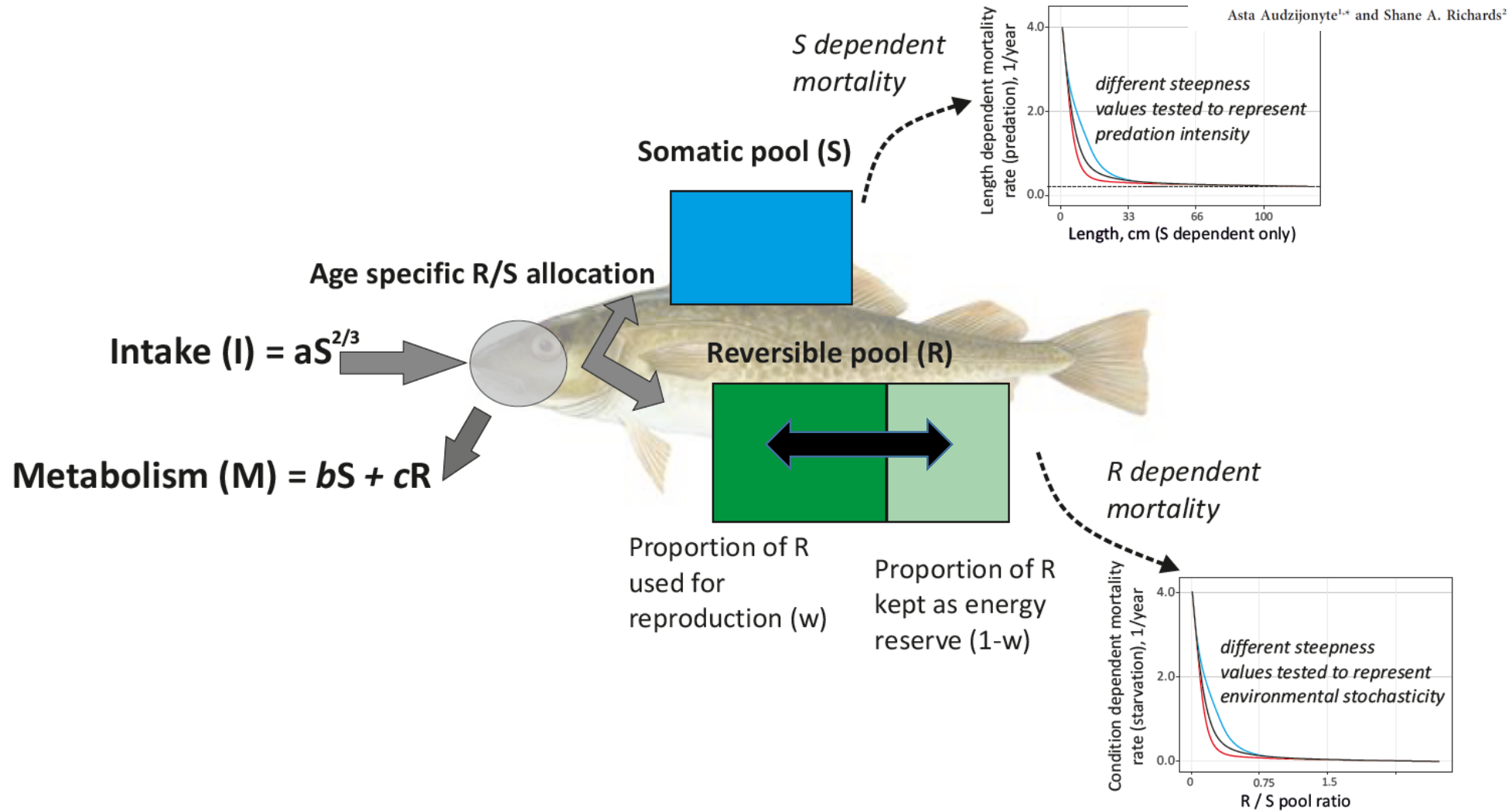
Can we explain temperature-size rule mechanistically?
Can we model it?



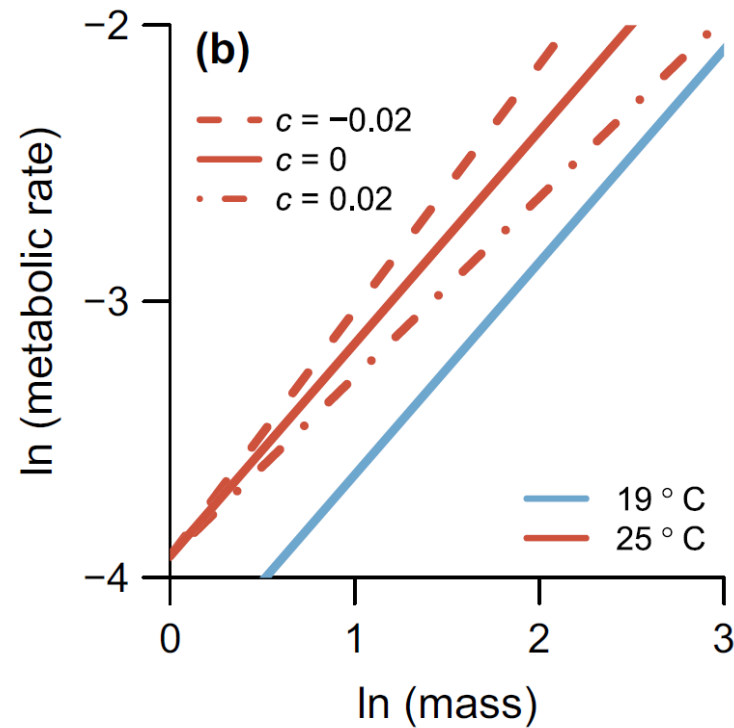
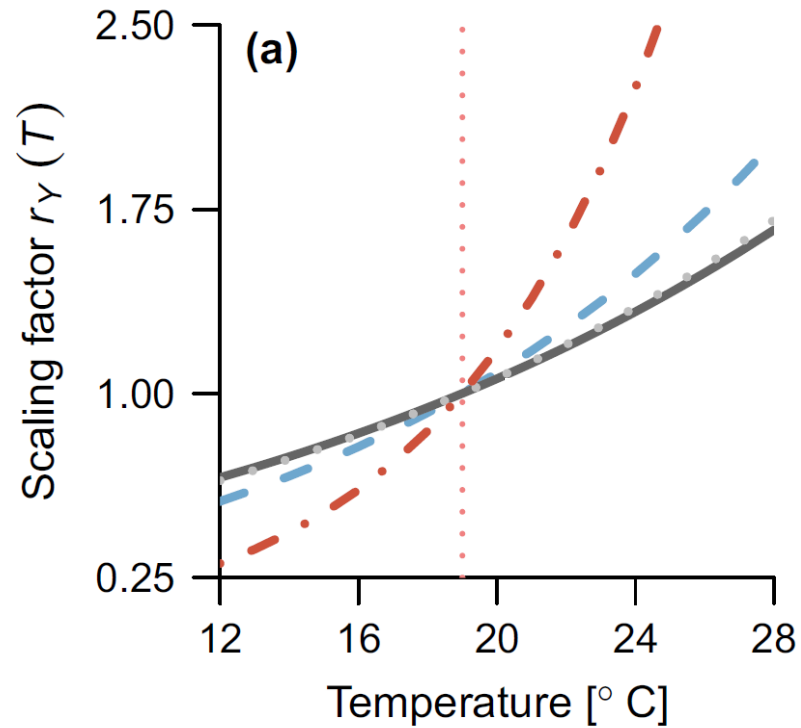
Model with EMERGENT maturation size and age

The Energetic Cost of Reproduction and Its Effect on Optimal Life-History Strategies

Asta Audzijonyte^{1,*} and Shane A. Richards²

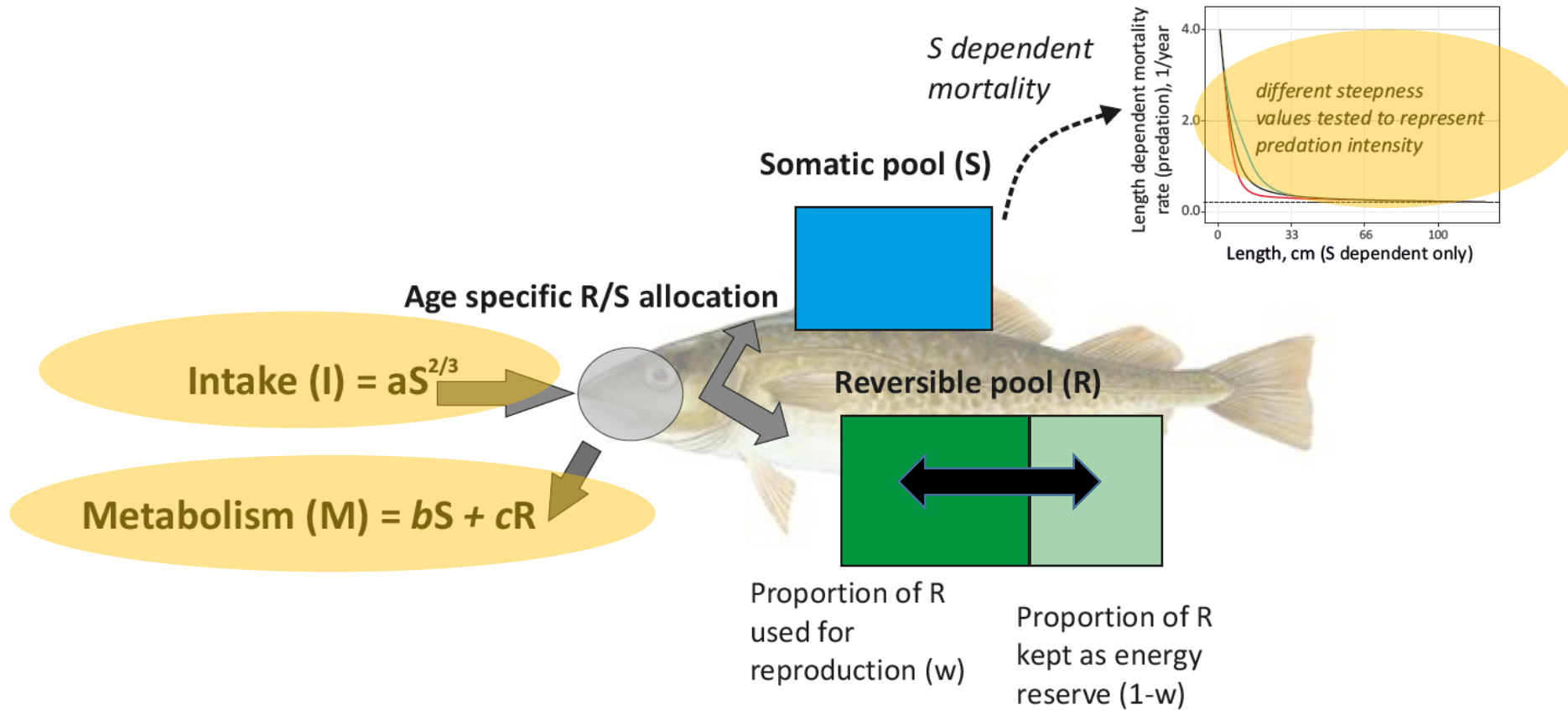


Adding temperature. Temperature speeds up life processes



This speeding up might be size dependent

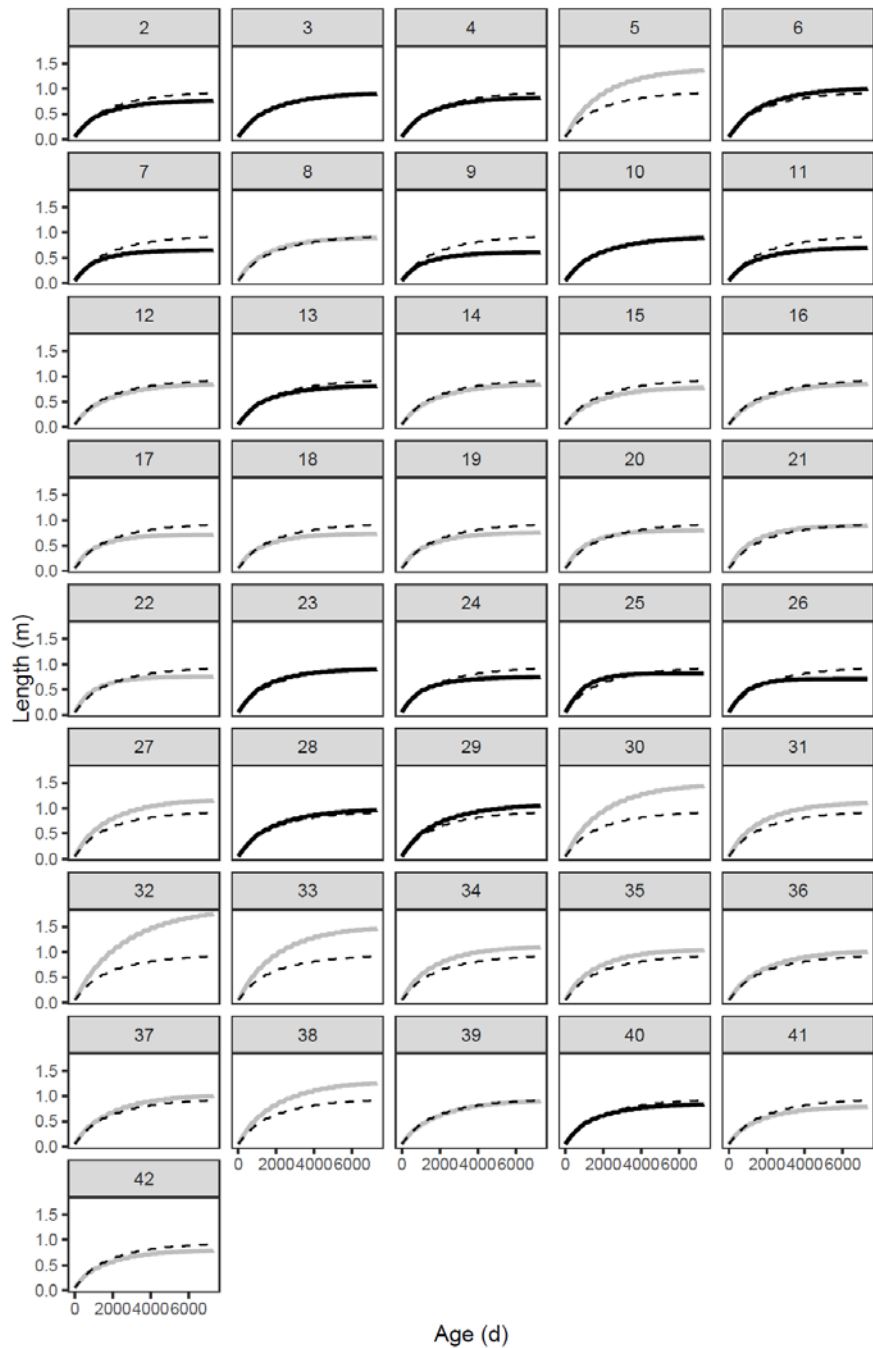
Temperature can affect intake, metabolism and mortality



42 scenarios of different parameter combinations

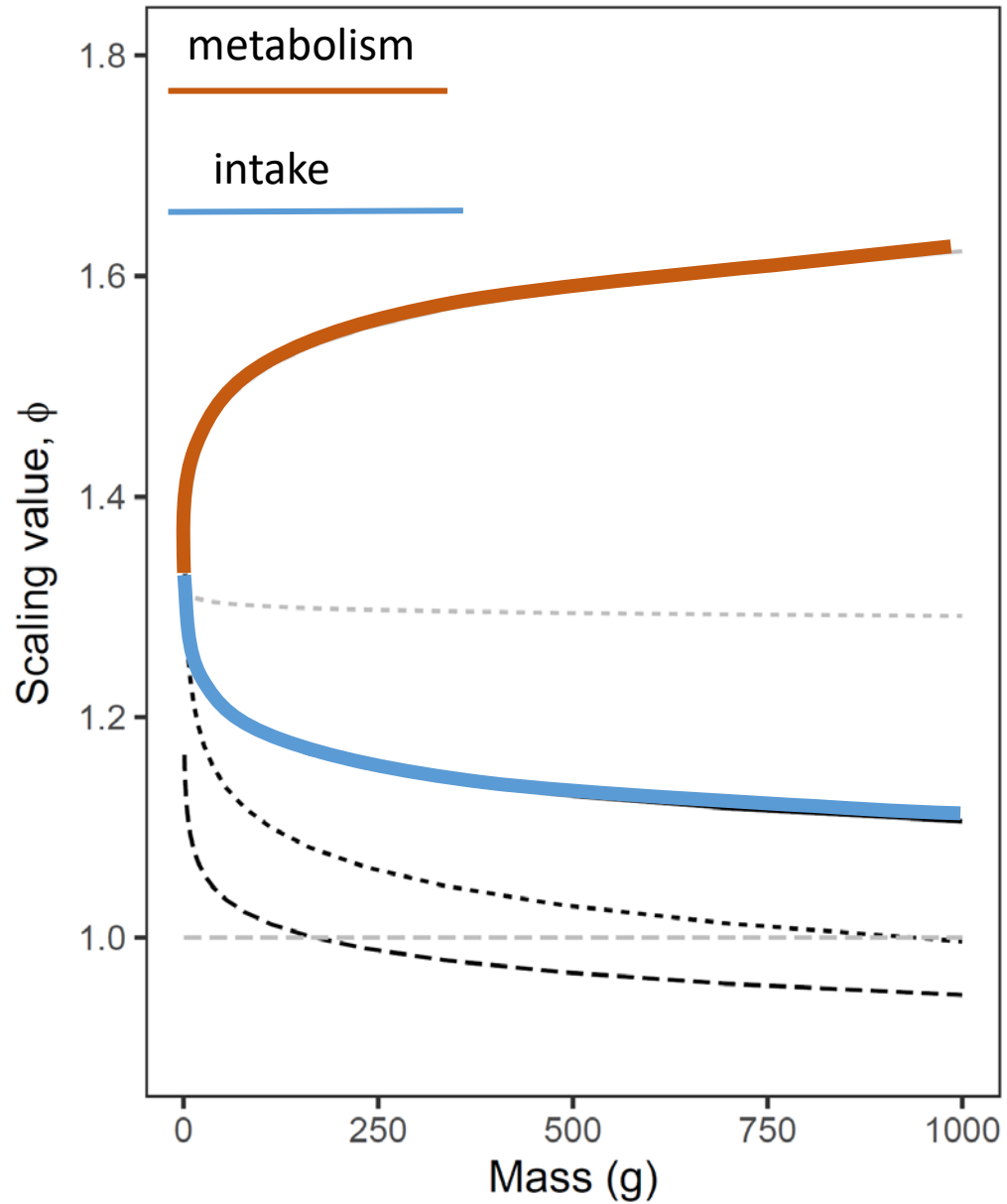
Name	Mat age	Mat wgt	Wgt 1y	Wgt 5y	Wgt 10y	Wgt 15y	Spawn 3y	Fitness	E_M	E_I	A_M	A_I	Z_P	$M_{P,min}$
Life-history responses in baseline scenario														
Base (1)	3	632	99	3026	6860	9063	150	314	0	0	0	0	8	0.2
Scenario group I: Original TSR explanation – metabolism activation energy is higher: $E_M > E_I$														
I-1 (2)	3	0.83	0.94	0.77	0.66	0.61	0.91	0.58	0.7	0	0	0	8	0.2
I-2 (3)	3	1.02	1.04	1.01	0.98	0.97	1.09	1.03	0.15	0.05	0	0	8	0.2
I-3 (4)	3	0.96	1.05	0.91	0.80	0.75	1.13	0.84	0.6	0.1	0	0	8	0.2
Group Ia: Metabolism activation energy is higher, combined with different temperature-size interactions														
I-4 (5)	2	1.12	2.34	2.93	3.22	3.30	4.28	7.41	0.7	0.63	0	0.01	8	0.2
I-5 (6)	3	1.28	1.14	1.33	1.34	1.32	1.56	1.66	0.7	0.01	0	0.01	8	0.2
I-6 (7)	3	0.73	0.93	0.62	0.46	0.39	0.95	0.38	0.7	0.01	0.01	0	8	0.2
I-7 (8)	2	0.64	1.67	1.22	1.07	0.99	1.88	1.74	0.7	0.63	0	-0.005	8	0.2
I-8 (9)	3	0.58	0.81	0.48	0.36	0.32	0.64	0.22	0.7	0.01	0	-0.01	8	0.2
I-9 (10)	3	0.95	0.97	0.94	0.94	0.95	0.90	0.89	0.7	0.01	-0.01	0	8	0.2
I-10 (11)	3	0.65	0.82	0.58	0.50	0.46	0.58	0.32	0.7	0.01	-0.01	-0.01	8	0.2
Group Ib: Metabolism activation energy is higher, combined with increased mortality														
I-11 (12)	2	0.41	1.06	0.85	0.83	0.81	1.53	0.23	0.15	0.05	0	0	8	0.4
I-12 (13)	3	0.97	1.05	0.90	0.78	0.72	1.24	0.21	0.6	0.1	0	0	8	0.4
Scenario group II: Life-history explanation - increased mortality only														
II-1 (14)	2	0.42	1.02	0.86	0.82	0.80	1.49	0.02	0	0	0	0	4	0.2

Dashed line is baseline, solid line is scenario



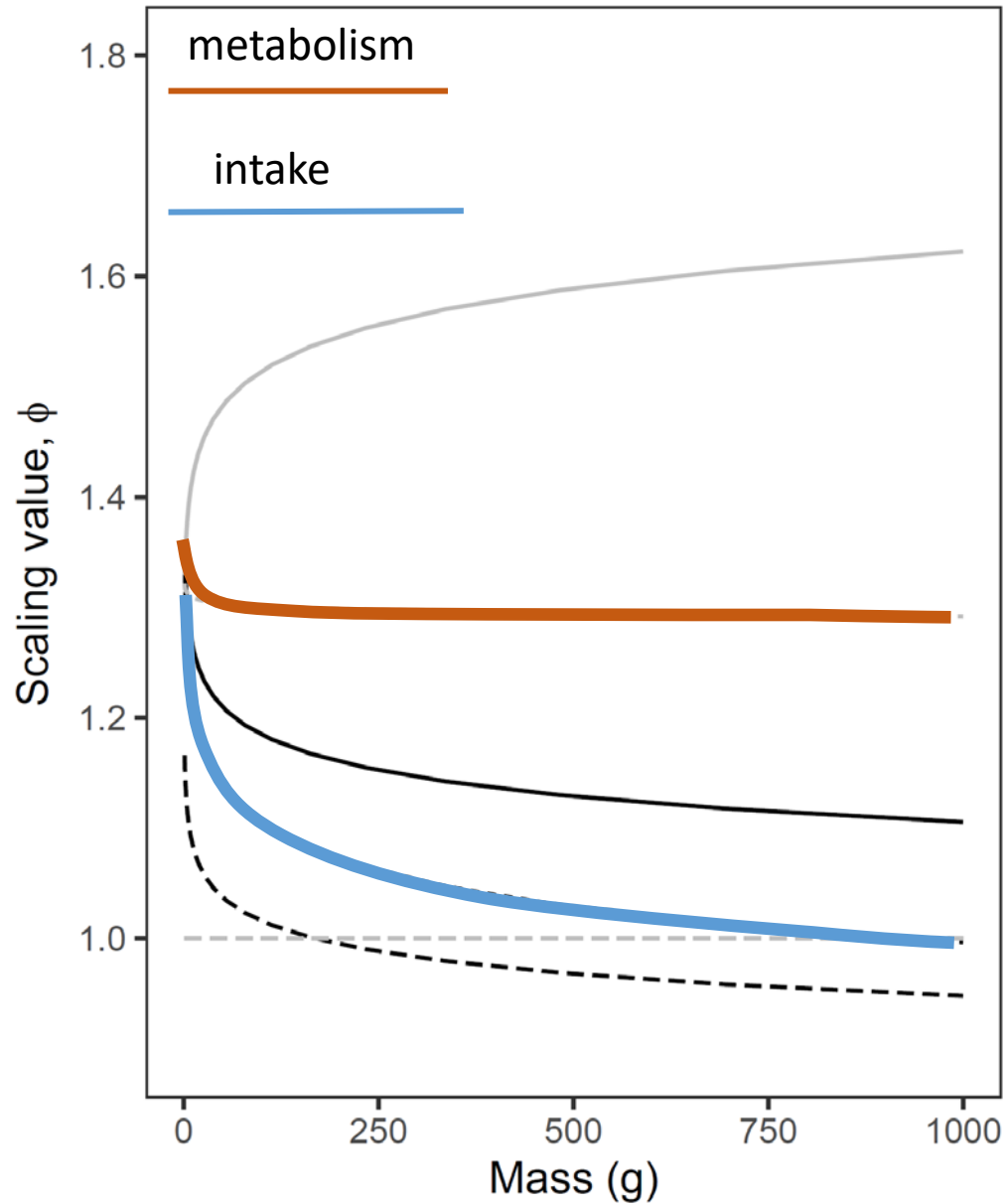
42 emergent growth and maturation curves

Age at maturation (y)
— 2
— 3



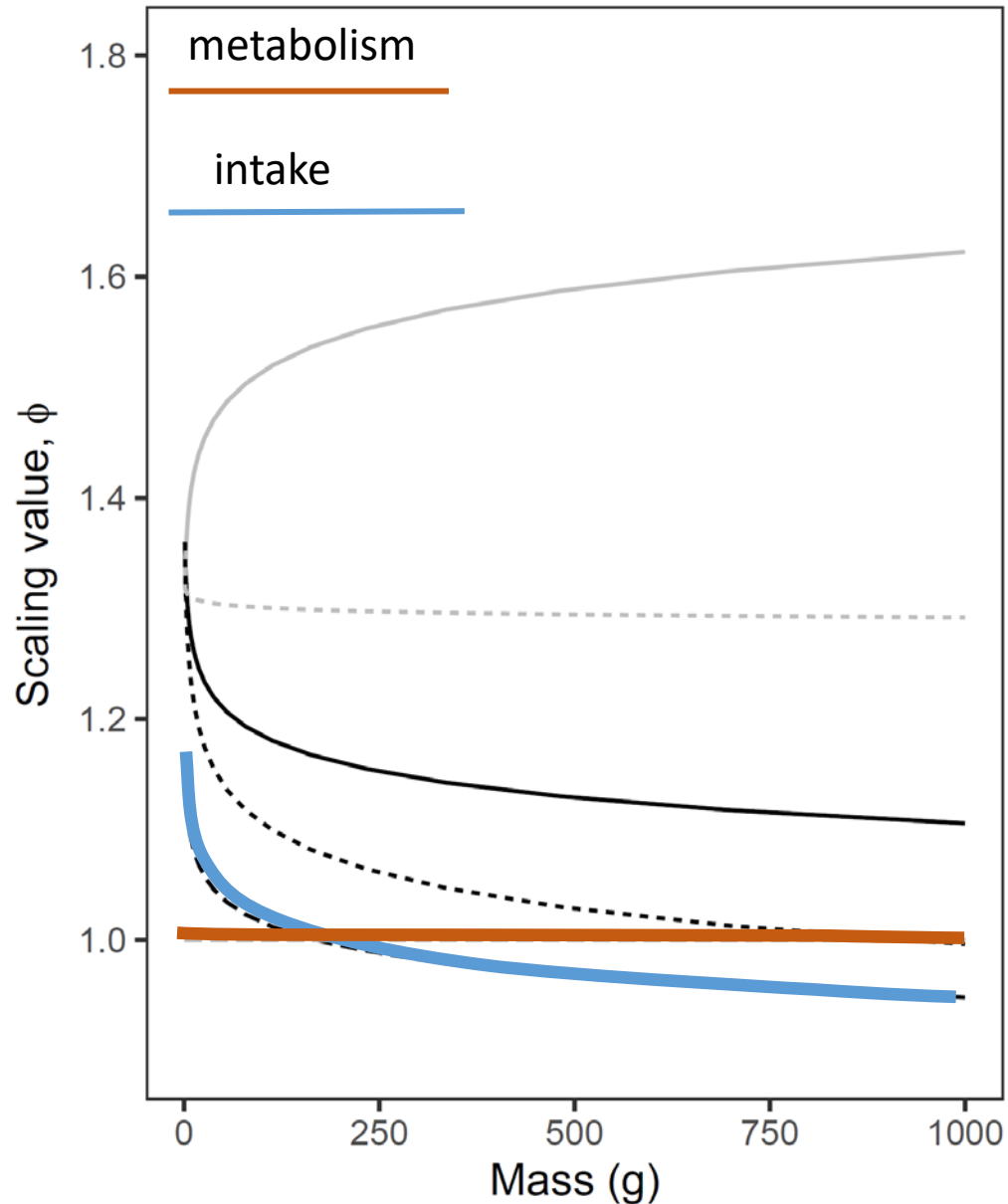
Two main ways how TSR can emerge

1. Metabolism increases more with size than intake



Two main ways how TSR can emerge

1. Or at least metabolism decreases with size slower than intake

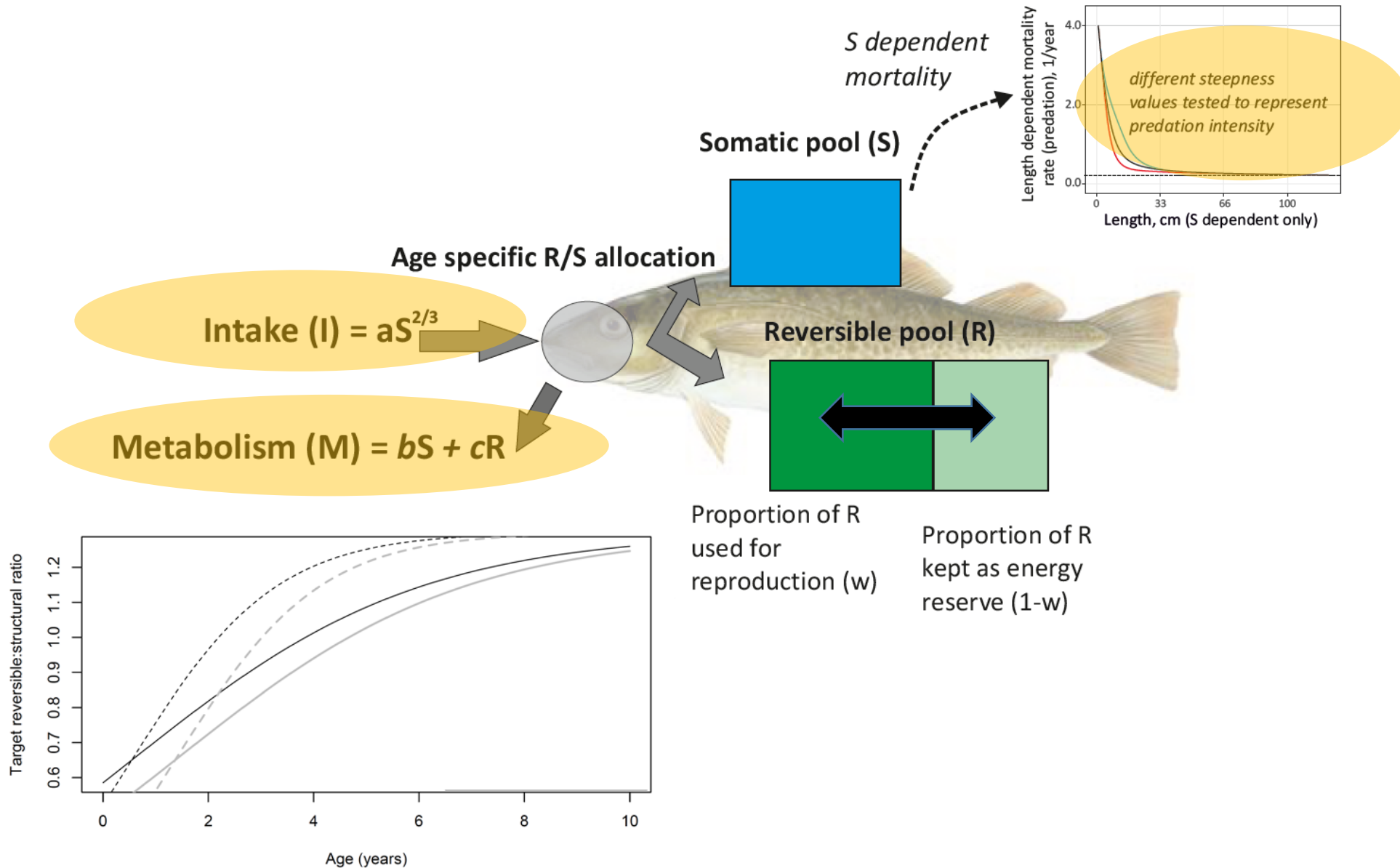


Two main ways how TSR can emerge

2. Metabolism does not increase, but relative intake rate decreases in large fish + mortality increases

Wootton et al. 2022, Ecol. Letters – TSR observed without increased baseline metabolic rate

In each case life-history optimisation is important



Take home & significance

Temperature – size rule growth is likely to be caused by a combination of **physiological processes related to food or oxygen intake and use**

AND

life-history optimisation of energy allocation between growth, reproduction and other processes

To understand how it works we need cross-disciplinary research and dialogue

Publication accepted in The Biological Bulletin special issue “An oxygen perspective on climate change”

Play with the model yourself!

github.com/astaudzi/TSRmodel

Supplementary Material to Audzijonyte & Richards: "The energetic cost of reproduction and its effect on optimal life-history strategies"

To run the model optimisation the Excel add-in "Solver" is required. The optimized parameters are shown in orange (r, abar and w). To explore optimal allocation and emergent life-history, modify blue parameter and run optimization using Solver (Data -> Solver).
 Solver should maximise the fitness by changing r, abar and w and adhering to the condition that of 0.01>w>0.99. Further explanations on parameters are given in Table 1 of the manuscript. NOTE - mortality is expressed in daily (not yearly!) values
 NOTE - the r and abar values given below are multiplied by 1000 and 0.01 respectively to improve Solver efficiency, because optimised values should be around 1. In the equation 1 of the manuscript abar is reflected in days at which allocation to R is half the maximum
 To find the optimal solution multiple starting points of w must be tested. In particular for higher fishing rates, higher w values (w>0.8) might need to be used as initial starting points!

Parameter	Value	Age	Breed	Lambda	Structure	Reserve	Total	FishLength	Lambda observed	FishMort	NatMort	StarvMort	MortRate	MortProb	StillAlive	Assimilated Intake	Maintenanc e cost	Net Intake	Rneed	Sneed	Intake Rmax	Reserves Rmax	Intake Smax	Intake reserves used	Reserves reserves used	Intake structure used	Net intake remaining	
weight at age 0	1	1	F												1	0.0961732	0.00262435	0.09354895	0	0	0.08419405	0.25326492	0.03118267	0	0	0	0.093548946	
Structure/reserve allocation strategy	lambda_min	0	2	F																							0.095090436	
	lambda_max	1.3	3	F																							0.097383166	
Intake scaling	l0	0.1	4	F																							0.09700638	
	l1	0.66667	5	F																							0.102042753	
Structure maintenance	cS	0.003	6	F																							0.104409414	
Reserve maintenance	cR	0.0003	7	F																							0.10680052	
Efficiency of structure syn	eS	0.33333	8	F																							0.109215975	
Efficiency of reserve syn	eR	0.9	9	F																							0.111655679	
Reproduction cost	r0	6	10	F																							0.114119534	
	r1	0.6	11	F																							0.116607443	
Shape parameter for len	l	5787	12	F																							0.119119306	
Natural mortality	MPmin	0.00137	Daily rate	13	F																						0.121655027	
	MPmax	0.01644	Daily rate	14	F																						0.124214506	
	zP	8	15	F																							0.126252	
Starvation mortality	MCmax	0.01096	Daily rate	16	F																						0.085252	
	zC	6	17	F																							0.00097706	
Fishing mortality	MFmax	0	Daily rate	18	F																						0.01182959	
	Lbar	0.3	19	F																							0.01175989	
	zF	20	20	F																							0.85331	
	r (optimized)	3.41	multiplied by 10	21	F																						0.12950327	
	abar (optimized)	2.48	multiplied by 0.0	22	F																						0.00410519	
	w (optimized)	0.821		23	F																						0.12539808	
	Fitness	35.0358	maximise this	24	F																						0.00106522	
	Mean age	0.34		25	F																						0	
	Age first rep	2		26	F																						0	
	Mass at F R	776.26		27	F																						0.11285827	
	Mass at 1 y	154.57		28	F																						0.40715063	
	Mass at 5 y	3685.07		29	F																						0.04179894	
	Mass at 10	7896.61		30	F																						0.00106522	
	Mean weight	889.38		31	F																						0	
Ambient temperature	Temp	285		33	FALSE	0.4221	1.93937091	0.81671544	2.75608635	0.06946016	0.4211239																0.124214506	
reference temp, in Kelvin	Tref	283		34	FALSE	0.42307	1.9904601	0.84016385	2.83062395	0.07006482	0.4220953																0.085252	
metabolim activation er	ea_met	0.55		35	FALSE	0.42404	2.04240204	0.86407466	2.9064767	0.07066905	0.42306786																0.00097706	
intake activation energy	ea_int	0.63		36	FALSE	0.42502	2.09520242	0.88845295	2.98365538	0.07127286	0.42404158																0.01182959	
botzman constant	k_boltz	8.62E-05		37	FALSE	0.42599	2.14886695	0.91330382	3.06217077	0.07187624	0.42501646																0.01175989	
emergent metabolism s	met_scalar	1.17		38	FALSE	0.42697	2.20340124	0.93863238	3.14203362	0.0724792	0.42599249																0.85331	
emergent intake scalar	intake_scalar	1.20		39	FALSE	0.42795	2.25881093	0.96444375	3.22325468	0.07308173	0.42696666																0.12950327	
				40	FALSE	0.42893	2.31510158	0.99074306	3.30584464	0.07368383	0.42794798																0.00410519	
size dependency of met	ca_met	0		41	FALSE	0.42991	2.37227875	1.01753546	3.38981421	0.0742855	0.42892744																0.12539808	
size dependency of intal	ca_int	0		42	FALSE	0.43089	2.43034794	1.04482612	3.47517406	0.07488675	0.42990804																0.00106522	
				43	FALSE	0.43187	2.48931463	1.07262021	3.56193484	0.075488757	0.43088977																	0
				44	FALSE	0.43286	2.54918427	1.10092922	3.65010719	0.07608796	0.43187263																	0.124214506

Reproductive cost versus R and S weight

Fish length (m)

Reserve:Structure ratio

Net intake (g d-1)

Fish mass (g)

Daily probability of mortality

Mortality components

Survivorship

Spawning mass (g)

Expected fitness components (g)



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