Supplemental information

Invariant gametogenic response of dominant infaunal bivalves from the Arctic under ambient and near-future climate change conditions

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Table S1. Summary of the station data for the collection of *A. crenata* and *B. glacialis* in the Barents Sea during Research Cruise JR16006 (2017) and JR17007 (2018), RRS James Clark Ross. Event numbers are from the ship log listed in the associated cruise reports (listed at end of supplementary material). All timings are in GMT.

	Event	Station	Date (ddmmyy)	Latitude (^o N)			Longitude (°E)			Time		Trawl		
Cruise				Start	Bottom	End	Start	Bottom	End	time	at bottom	End time	duration (mins)	Depth (m)
JR16006	134	B13	170717	74.50878	74.50799	74.50219	29.98888	29.98968	29.99543	9.58	10.08	10.43	15	-
JR16006	135	B13	170717	74.50083	74.49983	74.49402	30.00348	30.00336	30.00338	11.00	11.12	11.47	15	359
JR16006	136	B13	170717	74.49341	74.49235	74.48652	30.00430	30.00335	30.00349	11.56	12.09	12.42	15	360
JR16006	137	B13	170717	74.49939	74.49899	74.49257	29.99641	29.99650	29.99644	13.07	13.12	13.53	15	363
JR17007	113	B17	180718	81.27922	81.27922	81.27979	29.34515	29.34460	29.26345	10:12	10:13	11:21	5	340
JR17007	115	B17	180718	81.27939	81.27938	81.27885	29.33728	29.33635	29.28820	12:58	13:00	13:46	15	344
JR17007	116	B17	180718	81.27882	81.27876	81.27847	29.28686	29.27970	29.24346	14:05	14:15	14:42	15	339
JR17007	118	B17	180718	81.28354	81.28332	81.28297	29.35273	29.33683	29.30954	16:15	16:32	16:51	15	339
JR17007	120	B17	180718	81.28397	81.28388	81.28342	29.34701	29.34098	29.30313	18:26	18:36	19:05	15	354
JR17007	121	B17	180718	81.28394	81.28310	81.27740	29.34459	29.34406	29.34019	19:36	19:46	20:14	15	350
JR17007	122	B17	180718	81.28475	81.28415	81.27814	29.33391	29.33843	29.38193	20:45	20:56	21:33	25	340
JR17007	172	B16	220718	80.11647	80.11562	80.10993	30.04722	30.05017	30.06896	17:39	17:48	18:27	15	282
JR17007	173	B16	220718	80.11593	80.11504	80.10932	30.04600	30.04885	30.06622	18:47	18:57	19:41	15	292
JR17007	174	B16	220718	80.11518	80.11409	80.10897	30.04508	30.04837	30.06422	19:56	20:06	20:48	15	292

Table S2. Biometric data for *A. crenata* and *B. glacialis* used for histological examination. Sex was derived from histology only, blanks were not selected for histology, '?' denotes no observed reproductive tissue. Shell morphology measured as described by Oliver et al. 2020. Shell length refers to maximum anterior – posterior length, shell height refers to dorsal-ventral length, tumitidy refers to maximum inflation of articulated valves.

Climate treatment	Species	Individual Number	Shell length (mm)	Shell height (mm)	Tumidity (mm)	Weight (g)	Tissue Weight (g)	Sex (derived from histology)
Ambient	A. crenata	1	26.08	20.62	11.70	4.7912	0.5243	
Ambient A. crenata		2	24.23	20.64	11.81	4.8780	0.4968	
Ambient	A. crenata	3	30.01	23.47	13.26	8.0734	0.9910	
Ambient	A. crenata	4	24.85	19.43	10.72	3.8639	0.4726	male
Ambient	A. crenata	5	27.23	22.78	12.55	5.8938	0.9295	female
Ambient	A. crenata	6	26.74	21.82	12.85	6.7128	0.7903	
Ambient	A. crenata	7	31.13	24.80	14.85	9.2388	0.9954	
Ambient	A. crenata	8	28.25	23.13	12.16	5.7086	0.7991	male
Ambient	A. crenata	9	22.33	20.50	12.24	4.8359	0.4657	male
Ambient	A. crenata	10	24.83	18.99	13.10	5.0705	0.5133	female
Ambient	A. crenata	11	30.90	24.58	12.70	7.2276	0.9488	female
Ambient	A. crenata	12	24.19	18.70	12.00	3.9199	0.4781	female
Ambient	A. crenata	13	28.07	23.48	11.73	6.2795	0.8536	female
Ambient	A. crenata	14	28.31	23.95	13.26	7.2243	0.9377	
Ambient	A. crenata	15	22.26	19.32	11.77	4.1813	0.4110	
Ambient	A. crenata	16	23.76	19.71	13.62	5.3101	0.5551	
Ambient	A. crenata	17	28.13	21.51	12.19	6.1445	0.8262	female
Ambient	A. crenata	18	24.59	19.30	11.62	5.0616	0.6066	male
Ambient	A. crenata	19	30.56	25.38	13.24	8.5249	1.0709	male
Ambient	A. crenata	20	25.27	19.65	11.59	4.6062	0.5611	female
Ambient	A. crenata	21	25.86	21.60	11.32	5.2941	0.6657	male
Ambient	A. crenata	22	24.70	21.12	11.55	4.7138	0.5445	male
Ambient	A. crenata	23	24.23	21.75	12.25	5.2979	0.5750	
Ambient	A. crenata	24	22.45	18.74	10.62	3.5231	0.4338	male
Ambient	A. crenata	25	26.78	22.85	13.06	6.8733	1.0372	male
Ambient	A. crenata	26	25.89	21.70	12.95	5.7507	0.9381	
Ambient	A. crenata	27	21.86	17.04	10.51	3.0989	0.6022	female
Ambient	A. crenata	28	24.04	19.93	13.11	5.1734	0.4225	male
Ambient	A. crenata	29	22.41	18.16	11.81	3.7170	0.4600	
Ambient	A. crenata	30	26.89	21.65	13.11	6.5487	0.7703	female
Future	A. crenata	31	26.24	21.42	11.24	5.1028	0.5584	
Future	A. crenata	32	24.73	20.75	12.25	4.7755	0.5865	female
Future	A. crenata	33	27.18	25.47	11.92	6.1647	0.7505	
Future	A. crenata	34	22.27	18.16	13.17	4.5070	0.4094	
Future	A. crenata	35	31.73	25.77	13.05	8.2354	1.1233	male
Future	A. crenata	36	25.45	19.73	12.14	4.8464	0.3826	male
Future	A. crenata	37	25.52	20.65	11.57	5.1645	0.5678	male

Future	A. crenata	38	30.05	22.16	12.16	6.2068	0.9342	female
Future	A. crenata	40	24.73	19.77	11.64	4.8244	0.5613	
Future	A. crenata	41	24.28	19.46	11.37	4.2691	0.4995	female
Future	A. crenata	42	23.68	18.63	10.78	3.7062	0.3881	male
Future	A. crenata	43	24.69	19.06	11.16	4.5022	0.4682	female
Future	A. crenata	44	27.21	21.72	11.31	4.9745	0.5848	male
Future	A. crenata	45	24.11	20.34	10.61	4.2926	0.5481	male
Future	A. crenata	46	21.22	18.76	10.80	3.3664	0.4090	
Future	A. crenata	47	26.17	21.13	11.54	4.4923	0.4912	male
Future	A. crenata	48	25.91	19.91	12.33	5.2749	0.7398	male
Future	A. crenata	49	30.93	25.21	14.60	8.8061	1.0533	female
Future	A. crenata	50	28.81	25.01	11.98	6.8988	0.8043	female
Future	A. crenata	51	23.51	17.73	10.41	3.6716	0.4810	male
Future	A. crenata	52	27.15	21.75	12.06	6.1726	0.6944	
Future	A. crenata	53	28.22	22.19	13.51	6.7903	0.7383	male
Future	A. crenata	54	25.86	20.70	11.44	5.0540	0.5501	male
Future	A. crenata	55	25.31	20.52	12.02	5.3860	0.5247	
Future	A. crenata	56	25.99	21.76	11.65	5.0335	0.7250	?
Future	A. crenata	57	22.95	19.43	9.73	3.5654	0.4188	
Future	A. crenata	58	26.64	19.63	12.80	5.1186	0.8253	
Future	A. crenata	59	29.83	23.60	11.77	6.5804	0.9868	
Future	A. crenata	60	26.21	20.83	11.87	5.5369	0.6253	female
Ambient	B. glacialis	1	18.94	14.44	9.28	1.4553	0.5051	male
Ambient	B. glacialis	2	21.77	15.17	10.16	1.6878	0.3563	male
Ambient	B. glacialis	3	24.33	17.18	10.24	2.0013	0.5293	female
Ambient	B. glacialis	4	21.95	16.04	10.05	1.9207	0.7017	female
Ambient	B. glacialis	5	20.61	15.18	9.53	1.2287	0.2934	male
Ambient	B. glacialis	6	22.88	16.76	10.94	2.1913	0.6582	male
Ambient	B. glacialis	7	19.7	15.51	10.49	1.6905	0.3804	female
Ambient	B. glacialis	8	20.02	14.21	8.67	1.3375	0.3883	female
Ambient	B. glacialis	9	22.66	16.1	9.91	1.702	0.4128	male
Ambient	B. glacialis	10	20.92	14.93	8.97	1.394	0.5566	male
Ambient	B. glacialis	11	21.45	16.23	9.67	1.180	0.518	female
Ambient	B. glacialis	12	22.22	15.65	10.25	1.7629	0.5087	male
Ambient	B. glacialis	13	22.02	17.72	10.82	1.5811	0.4957	male
Ambient	B. glacialis	14	19.94	15.2	8.86	1.3373	0.3123	female
Ambient	B. glacialis	15	22.78	17.29	10.15	1.9303	0.6623	male
Ambient	B. glacialis	16	20.72	15.04	9.14	1.149	0.523	female
Ambient	B. glacialis	17	21.09	15.83	9.72	1.15921	0.637	female
Ambient	B. glacialis	18	21.42	16.04	9.71	1.6733	0.601	male
Ambient	B. glacialis	19	21.21	15.3	9.46	1.4968	0.5244	male
Ambient	B. glacialis	20	21.83	15.1	9.19	1.4901	0.4787	female
Ambient	B. glacialis	21	20.77	15.5	9.92	1.391	0.6635	female
Ambient	B. glacialis	22	22.18	17.46	10.62	1.9518	0.5913	male
Ambient	B. glacialis	23	21.52	16.35	9.39	1.5997	0.5277	male
Ambient	B. glacialis	24	21.2	15.92	8.61	1.5003	0.5543	male

Table S3. Summary of sediment particle size statistics given by the default GRADISTAT output (Blott & Pye, 2001). Mean, sorting, skewness, kurtosis, the percentage of sample less than 63 μ m and total organic carbon are presented for (a) 2017, cruise JCR16006 and (b) 2018, cruise JCR17007. Superscripts provide descriptive terminology as outlined by Blott & Pye (2001). <u>Mean, \bar{x} :</u> fs, fine silt; ms, medium silt; cs, coarse silt; vcs, very coarse silt. <u>Sorting, σ :</u> ps, poorly sorted; vps, very poorly sorted. <u>Skewness, *Sk*</u>: sy, symmetrical; vfsk, very fine skewed; fsk, fine skewed; csk, coarse skewed. <u>Kurtosis, *K*</u>: mk, mesokurtic; lk, leptokurtic; pk, platykurtic. Data from Solan et al. 2020, obtained on the same research cruise and station occupancy date.

Station	Event numbe r	Mean (x̄, µm)	Sorting (σ, μm)	Skewness (Sk, μm)	Kurtosis (K, μm)	Sample <63 µm (%)	Total organic carbon (TOC, %)	Sediment name
(a) JCR16006								
B13	331	22.27 ^{ms}	27.28 ^{ps}	2.080 ^{sy}	7.131 ^{mk}	90.902	6.777	Medium silt
B13	332	24.47 ^{ms}	35.53 ^{ps}	2.993 ^{sy}	14.17 ^{mk}	89.783	7.205	Very fine sandy medium silt
B13	333	40.47 ^{cs}	66.83 ^{vps}	3.426 ^{sy}	17.12 ^{mk}	82.298	6.229	Very fine sandy coarse silt
B13	334	25.12 ^{ms}	29.33 ^{ps}	1.743 ^{sy}	5.276 ^{mk}	88.010	6.748	Very fine sandy coarse silt
(b) JCR17007								
B16	189	33.29 ^{ms}	69.49 ^{ps}	4.736 ^{sy}	29.43 ^{lk}	89.361	5.643	Very fine sandy medium silt
B16	190	32.66 ^{ms}	64.63 ^{ps}	4.509 ^{sy}	27.51 [⊮]	88.799	6.229	Very fine sandy medium silt
B16	191	51.71 ^{cs}	102.0 ^{vps}	3.276 ^{csk}	14.27 ^{lk}	82.795	6.231	Very fine sandy medium silt
B16	192	40.31 ^{ms}	91.13 ^{ps}	4.174 ^{csk}	21.56 ^{lk}	87.475	6.024	Very fine sandy medium silt
B17	134	28.46 ^{ms}	55.14 ^{ps}	5.079 ^{sy}	34.27 ^{mk}	91.254	6.250	Medium silt
B17	135	22.01 ^{ms}	29.75 ^{ps}	3.682 ^{sy}	20.59 ^{mk}	94.024	6.101	Medium silt
B17	136	23.49 ^{ms}	40.14 ^{ps}	5.252 ^{sy}	39.00 ^{mk}	93.434	6.209	Medium silt
B17	137	32.07 ^{ms}	50.59 ^{ps}	4.045 ^{sy}	23.70 ^{mk}	88.540	6.271	Very fine sandy coarse silt

	Species	Egg size	Mean egg size	Location	Reference
i)	Astarte borealis	150 - 200 µm	-	Greenland	Thorsen 1936
	Astarte elliptica	150 - 200 µm	-	Baltic Sea	Von Oertzen 1972
	Astarte sulcata	150 – 200 µm	-	North Atlantic	Saleuddin 1964
	Digitaria digitaria	150 – 180 μm	-	Strait of Gibraltar	Marina et al. 2020
ii)	Astarte crenata	36.23 – 281.21 μm	129.33 µm ± 38.71 SD, n = 1200	Barents Sea	Personal observation
	Astarte crenata	46.96 – 185.08 µm	122.61 µm ± 24.01 SD, n = 500	Ambient Treatment	This study
	Astarte crenata	44.61 – 181.93 µm	122.48 µm ± 22.84 SD, n = 500	Future Treatment	This Study
iii)	Bathyarca glacialis	39.60 – 144.77 μm	96.77 μm ± 14.36 SD, n = 500	Ambient Treatment	This Study
	Bathyarca glacialis	35.07 – 144.90 µm	95.03 μm ± 18.57 SD, n = 500	Future Treatment	This Study

Table S4. Known egg sizes and locations of i) Astartidae; ii) Astarte crenata in this study; iii) Bathyarca glacialis from this study

Figure S1. Cumulative sediment particle size distributions (n = 4) for stations (a) B13 in 2017, (b) B16 in 2018 and (c) B17 in 2018. Data from Solan et al. 2020, obtained on the same research cruise and station occupancy date.



Figure S2. Summary of periodic seawater measurements in aquaria under ambient (black) and near-future (grey) conditions for (a) *B. glacialis* and (b) *A. crenata.* Temperature (°C), Salinity, pH_{NBS} and total alkalinity (AT, µmol kgSW⁻¹) were measured directly from each aquarium and were used to calculate dissolved organic carbon (DIC, µmol kgSW⁻¹), pCO_2^{SW} (µAtm), saturation states for calcite (Ω Calcite) and aragonite (Ω Aragonite), bicarbonate (HCO₃, µmol kgSW⁻¹) and carbonate (CO₃, µmol kgSW-1) using CO₂calc (Robbins et al. 2010). Error bars represent standard deviation.





(b)

Figure S3. Classification of the experimental conditions for (a) Astarte crenata and (b) Bathyarca glacialis from the Barents Sea under ambient (open circles; 1 - 2°C, ~400 ppm [CO₂]) and near-future (open triangles; 3 - 5°C, ~550 ppm [CO₂]) scenarios shows a clear separation between treatment groups. Non-metric two-dimensional (nMDS) representations of euclidean similarity matrices based on 10 water and carbonate chemistry parameters (temperature, salinity, pH, total alkalinity, HCO₃, CO₃, pCO₂, calcite, aragonite and DIC) are presented. Dimensionality representation stress values (k=2) are (a) 0.0080 and (b) 0.0198.



(b)

Figure S4. Individual oocyte size frequency histograms for *Astarte crenata* maintained in ambient (top) and future (bottom) conditions. Statistically significant associations were found between individual females and oocyte size frequencies in each treatment (Ambient $x^2 = 143.17$, d.f. = 28, p < 0.0001; Future $x^2 = 97.263$, d.f. = 24, p < 0.0001).



Figure S5. Individual oocyte size frequency histograms for *Bathyarca glacialis* maintained in ambient (top) and future (bottom) conditions. Statistically significant associates were found between individual females in each treatment (Ambient $x^2 = 172.86$, d.f. = 20, p < 0.0001; Future $x^2 = 119.43$, d.f. = 20, p < 0.0001).



Supplemental references

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Cruise reports for this research programme can be obtained from the British Oceanographic Data Centre at:

https://www.bodc.ac.uk/resources/inventories/cruise_inventory/results/

Cottier FR. 2017 RRS James Clark Ross cruise, JR16006

Solan M. 2018 RRS James Clark Ross cruise, JR17007

Barnes D. 2019 RRS James Clark Ross cruise, JR18006 (not included in the present contribution, but listed here as it forms the third and final cruise of this research programme)

Ends.