UK Ocean Acidification Research Programme
Benthic Acidification

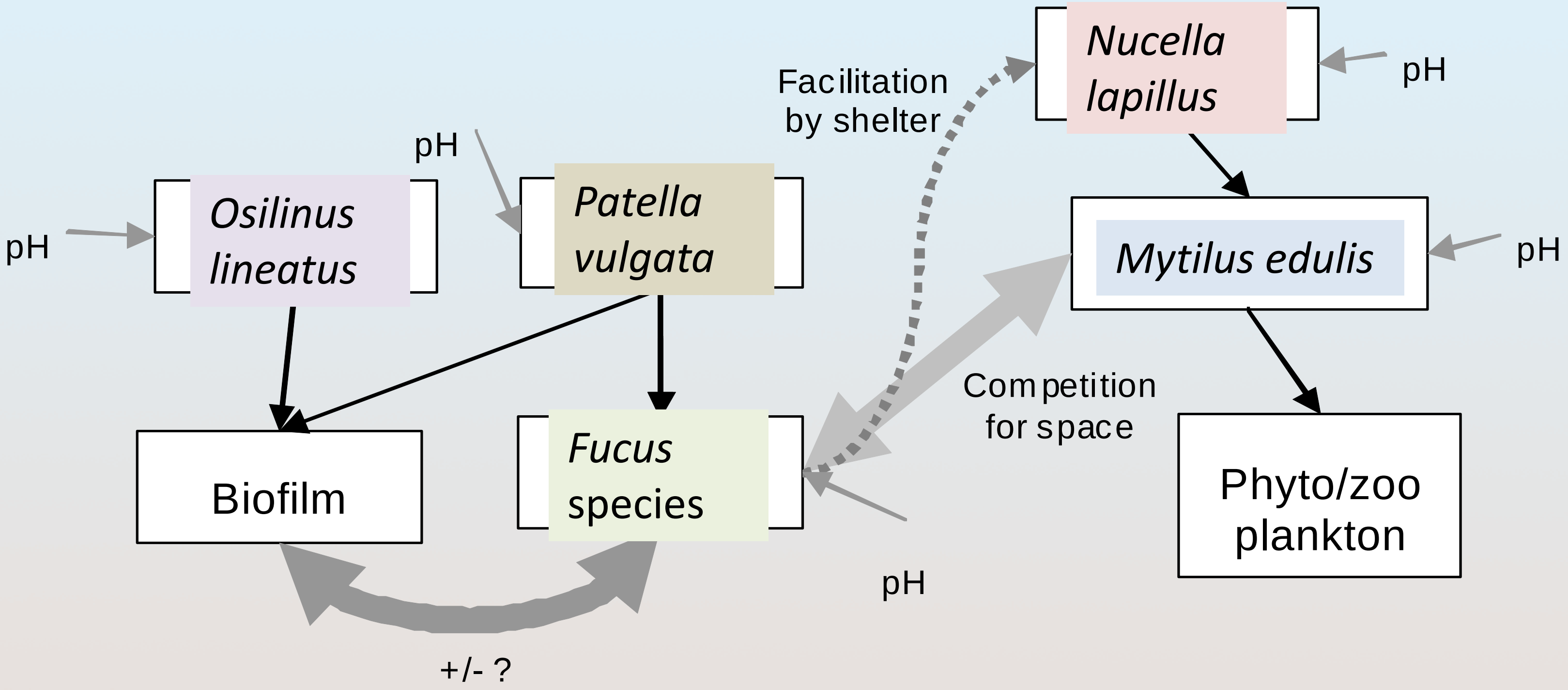
Population effects of OA in intertidal gastropods: *Nucella lapillus* and *Osilinus lineatus*

Nova Mieszkowska (MBA) and Michael T. Burrows (SAMS)

Thanks to Tania Hurley (MBA) for support

defra
NATURAL ENVIRONMENT RESEARCH COUNCIL
DEPARTMENT OF ENERGY & CLIMATE CHANGE
Living With Environmental Change

UK rocky shore species interactions



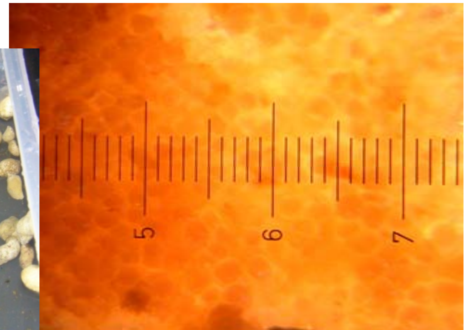
Experimental manipulations of temperature and CO2….

Task 1.3. Compare the vulnerability of different life stages and model the implications for population dynamics (Mike Burrows, SAMS)

- H0: Elevated CO2 x temperature will have no significant impact on the long-term sustainability of marine invertebrate populations

Experiments

- 18 month microcosm exposure experiment at the MBA, CO_2 (380, 750, 1000ppm × temperature (L4 monthly SST, SST +4°C)
  - *Osilinus lineatus, Nucella lapillus* gonad development and spawning time



UK Ocean Acidification Research Programme
Benthic Acidification

…Combined with published data…

6 C. J. Feare:

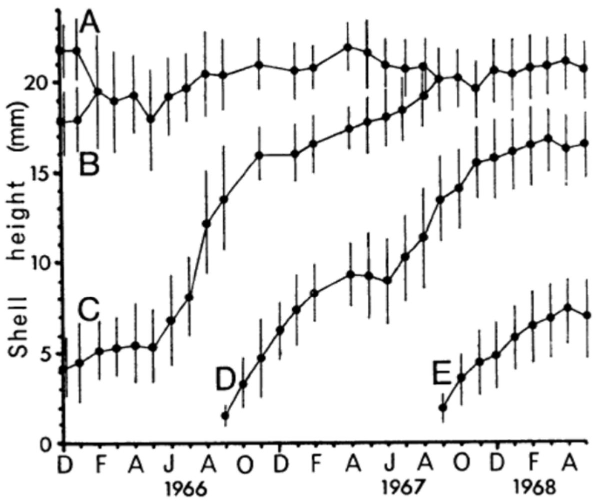
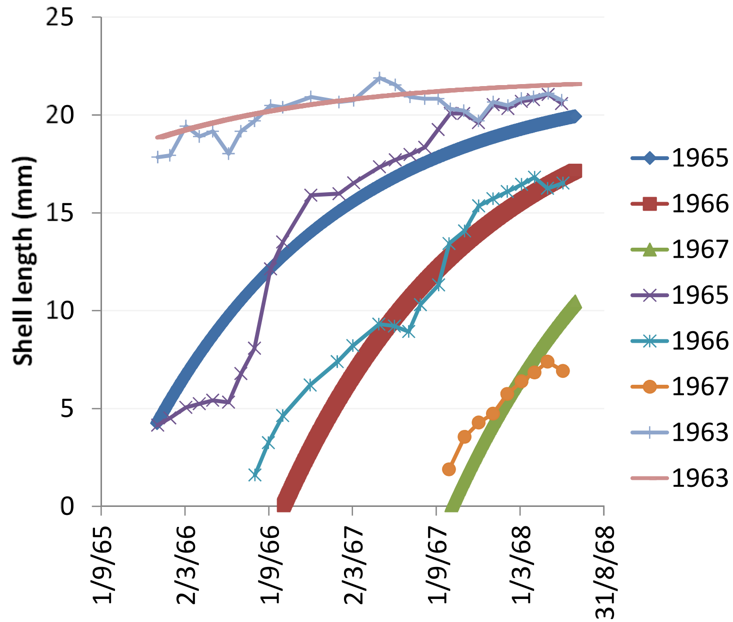


Fig. 2. The mean monthly shell heights and their standard deviations for each age group from December 1965 to May 1968. *A* 1963 group and older; *B* 1964 group; *C* 1965 group; *D* 1966 group; *E* 1967 group



$$L_t = L_\infty\left(1 - e^{-K(t-t_0)}\right)$$

… to make population models

Age based model for *Nucella*

Survival

Fecundity

Nucella lapillus

Exposed shore populations **Survivorship** From Feare 197(from Etter 1989 A function of sx (size) **Fecundity** from Etter 198(fx

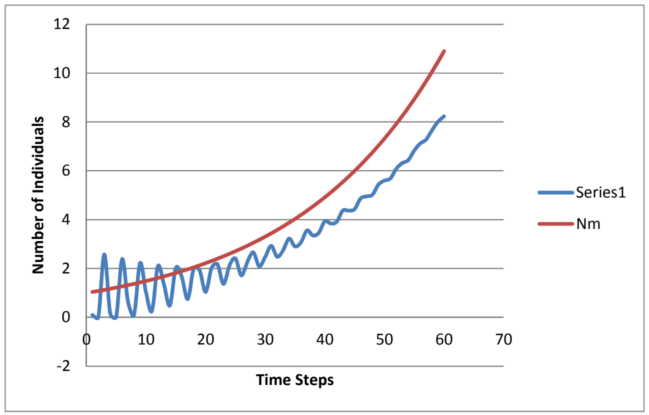
From Feare 1970 and Etter 1989

Stage	Age, x	Cumulative survival lx	Size (mm) sx	No eggs per capsule	No capsule per year	sexually mature	fertile	fij mx	lxmx	xlxmx	e-rxlxmx	e-rxlx	Vx	***12-month step model*** Age (months), x	**Survival probabilities** Pij	**Fecundity** fij	Survivorsh lx
0	1	1	2	19.5	22	0	1	0	0	0	0	1.000E+00	1	0	0.06	0	1
12	2	0.06	14	19.5	22	0	1	0	0.00000	0	0.000E+00	6.000E-02	19	12	0.06	0	0.06
24	3	0.0036	17	19.5	22	0.6	1	257.4	0.92664	2.77992	9.266E-01	3.600E-03	316	24	0.12	257.4	0.0036
36	4	0.000432	19	19.5	22	1	1	429	0.18533	0.741312	1.853E-01	4.320E-04	485	36	0.12	429	0.000432
48	5	0.00005184	20	19.5	22	1	1	429	0.02224	0.111197	2.224E-02	5.184E-05	463	48	0.08	429	5.18E-05
60	6	4.1472E-06	21	19.5	22	1	1	429	0.00178	0.010675	1.779E-03	4.147E-06	429	60	0.08	429	4.15E-06
				19.5	22		1										

Transition Matrix

Age, months To	From 0	12	24	36	48	60+
0	0.0000	0.0000	**257.4000**	**429.0000**	**429.0000**	**429.0000**
12	**0.0600**	0	0	0	0	0
24	0	**0.0600**	0	0	0	0
36	0	0	**0.1200**	0	0	0
48	0	0	0	**0.1200**	0	0
60+	0	0	0	0	**0.0800**	**0.0800**

Age time (x12month)	0	12	24	36	48	60	Sum1+	1 Nm
1	0	0	0	0	0	0.1	0.1	1.0406122
2	42.9	0	0	0	0	0	0	1.0828738
3	0	2.574	0	0	0	0	2.574	1.1268517
4	0	0	0.15444	0	0	0	0.15444	1.1726156
5	39.75286	0	0	0.0185328	0	0	0.018533	1.2202382
6	7.950571	2.38517136	0	0	0.002223936	0	2.387395	1.2697948
7	0.954069	0.477034272	0.143110282	0	0	0.000178	0.620322	1.3213639
8	36.91291	0.057244113	0.028622056	0.017173234	0	0	0.103039	1.3750275
9	14.73463	2.214774718	0.003434647	0.003434647	0.002060788	0	2.223705	1.4308704
10	3.24162	0.884078076	0.132886483	0.000412158	0.000412158	0.000165	1.017954	1.4889812



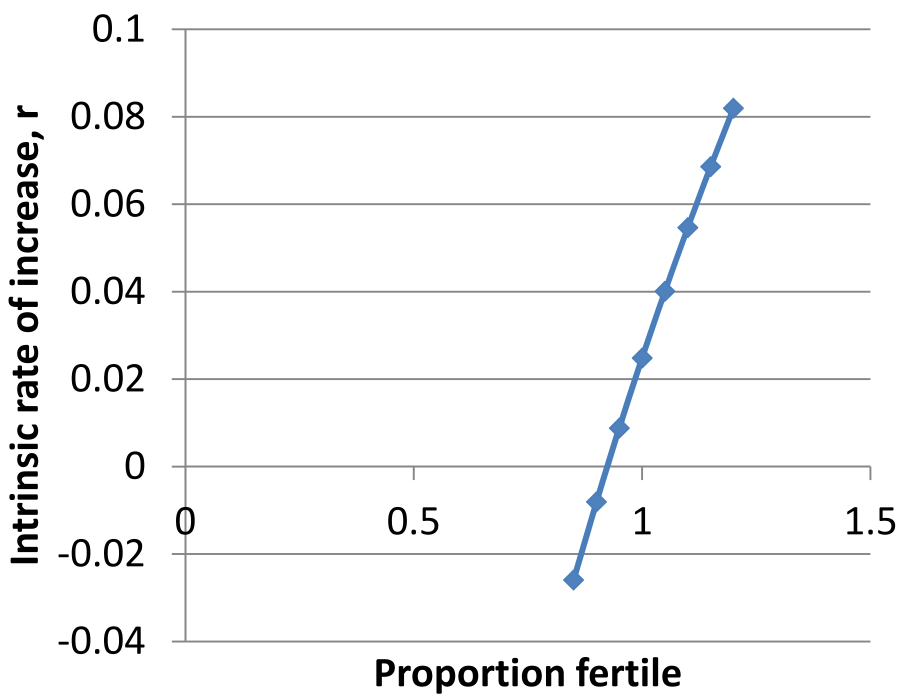
Number at age

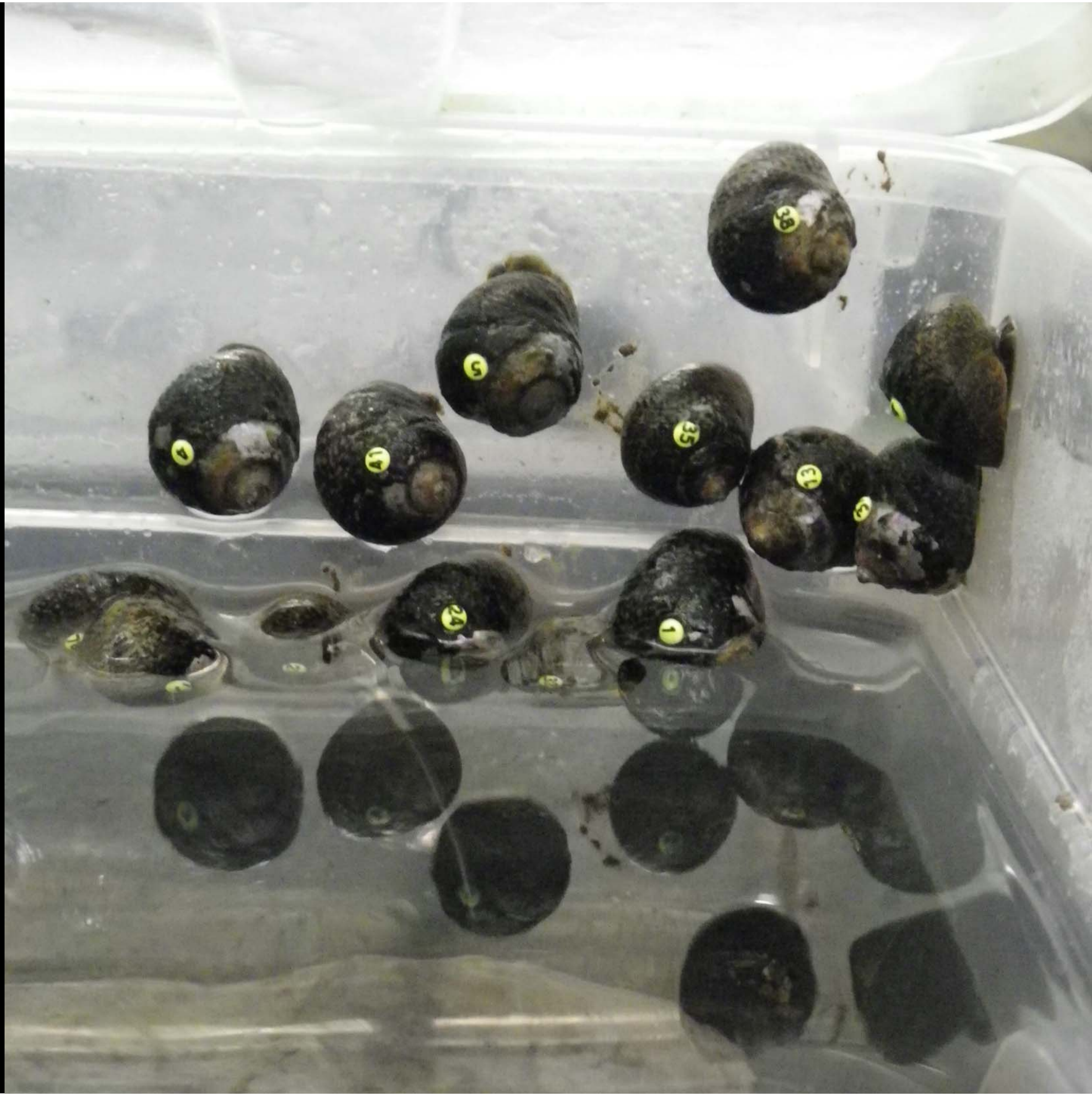
Population growth or decline

…to determine likely population effects

Euler Lotka equation

$$\sum_{x=1}^{\infty} e^{-rx} F_x L_x = 1$$





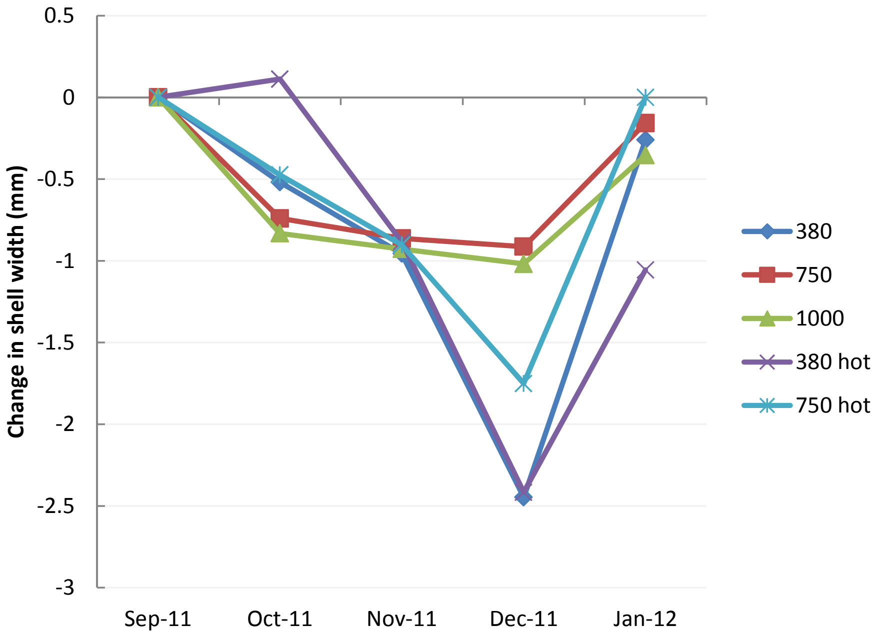
Shell dimensions

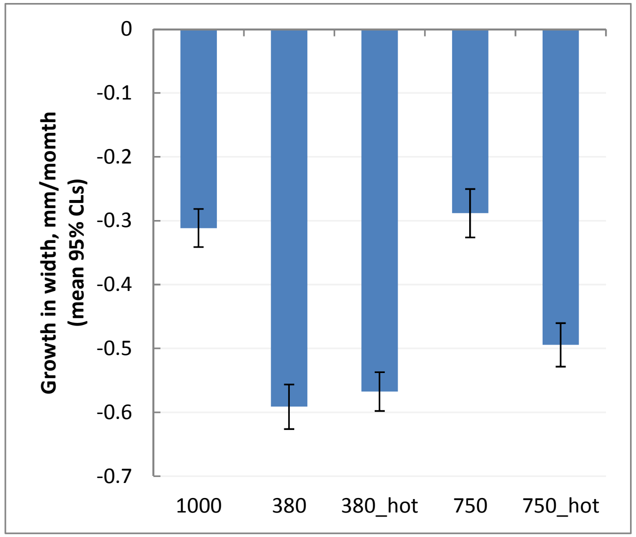
width

height

(*Gibbula umbilicalis*)

Osilinus lineatus – shell width



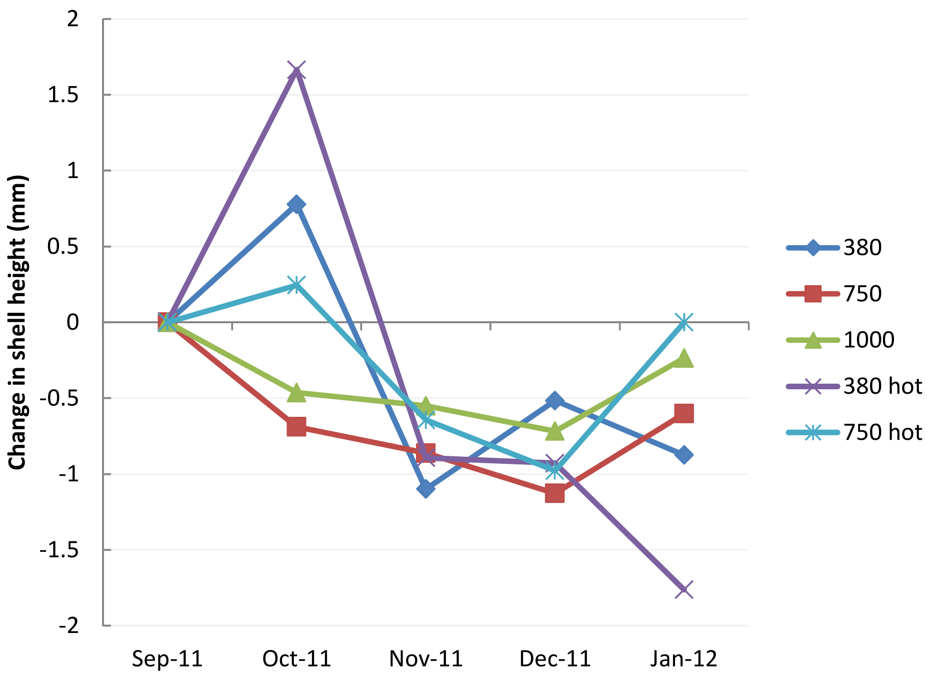


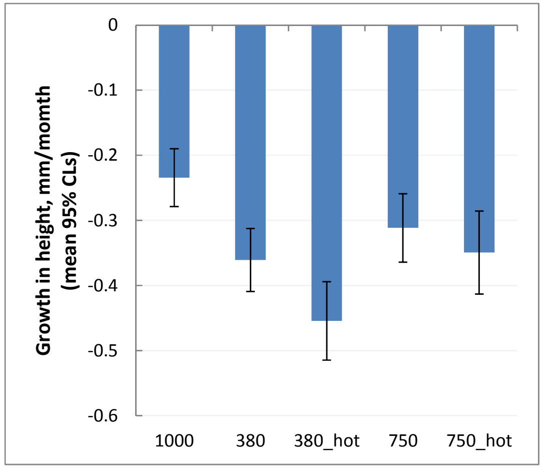
Width loss similar at 380 ambient and ‘hot’, but > in ‘hot’ at 750

Source	*DF*	*F Value*	*Pr > F*	*Error*
Treat	4	24.15	**<.0001**	
Tank(Treat)	15	3.12	**<.0001**	Tank(Treat)
Excluding 1000ppm				
CO2	1	34.78	**<.0001**	Tank(CO2*Te
Temp	1	8.30	**0.014**	Tank(CO2*Te
CO2*Temp	1	13.79	**0.003**	Tank(CO2*Te
Tank(CO2*Temp)	12	3.33	**<.0001**	
Excluding above ambient (1000 vs 750 vs 380)				
CO2	2	69.39	**<.0001**	Tank(CO2)
Tank(CO2)	9	1.38	0.195	

- Shells lose width in all treatments over the first four months, but greater at increased temps and 380
- A strong reversal in month five

Osilinus lineatus – shell height



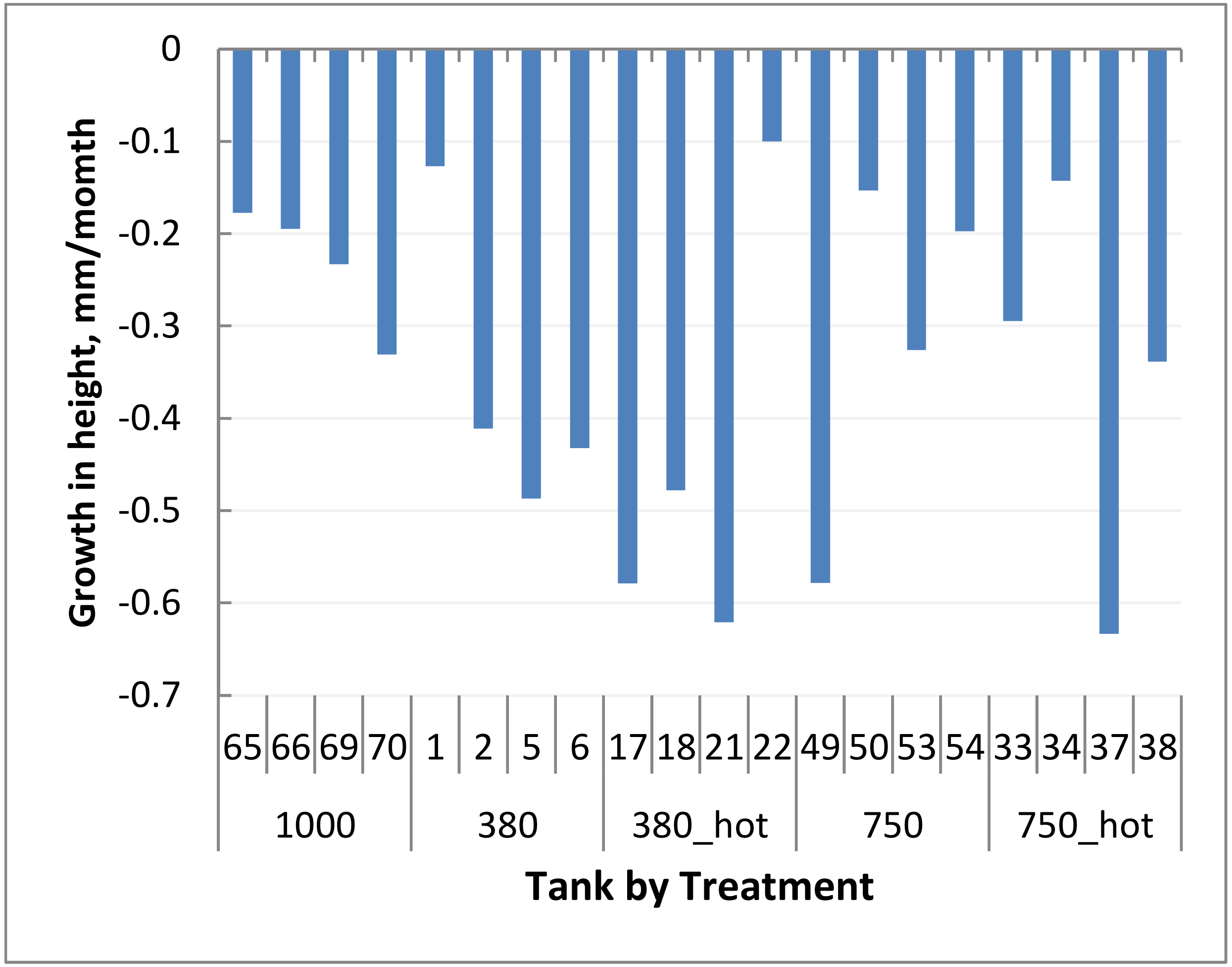


Height loss > at 380 and 'hot'
Tank differences significant

Source	*DF*	*F Value*	*Pr > F*	*Error*
Treat	4	0.76	0.566	Tank(Treat)
Tank(Treat)	15	12.24	**<.0001**	
Excluding 1000ppm				
CO2	1	7.37	**0.007**	Tank(CO2*Te
Temp	1	5.11	**0.024**	Tank(CO2*Te
CO2*Temp	1	0.63	0.429	Tank(CO2*Te
Tank(CO2*Temp)	12	14.16	**<.0001**	
Excluding above ambient (1000 vs 750 vs 380)				
CO2	2	0.77	0.491	Tank(CO2)
Tank(CO2)	9	10.12	**<.0001**	

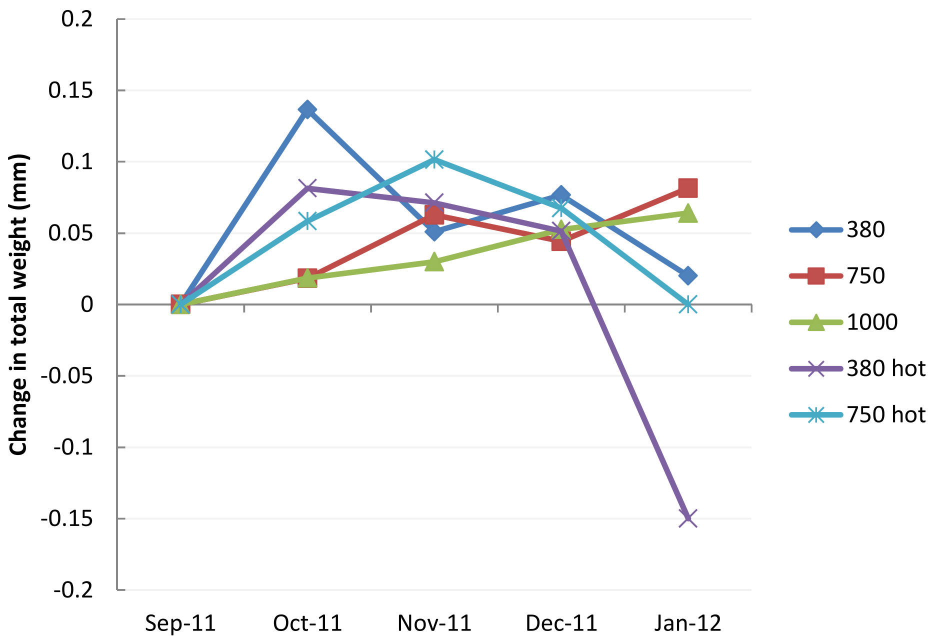
- Shells initially increase in length at 380, but decrease at 750 and 100
- Initial increase in length lost after 2 months

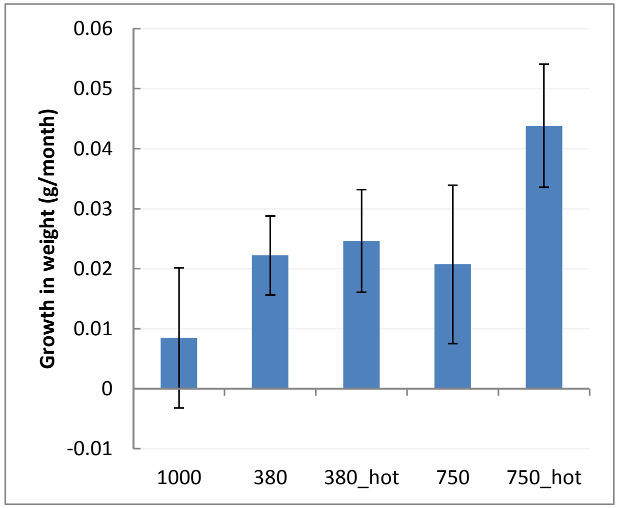
Osilinus lineatus – shell height



Tank by Treatment differences significant

Osilinus lineatus – weight change

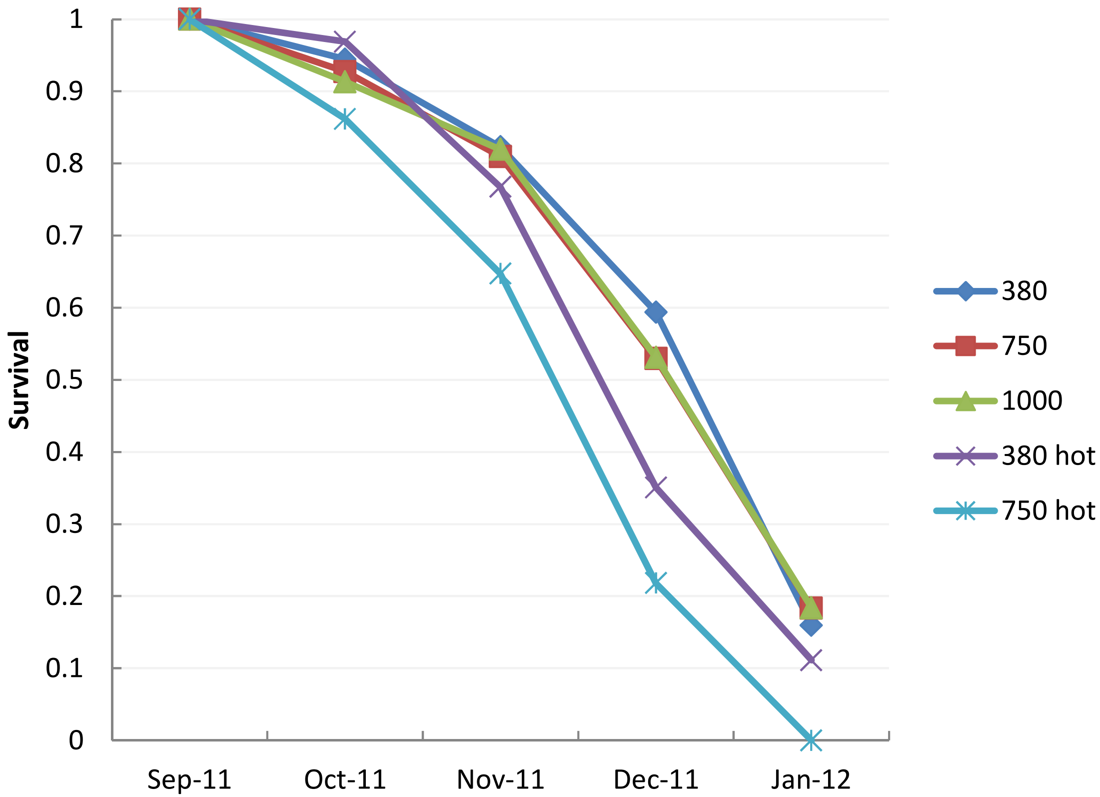




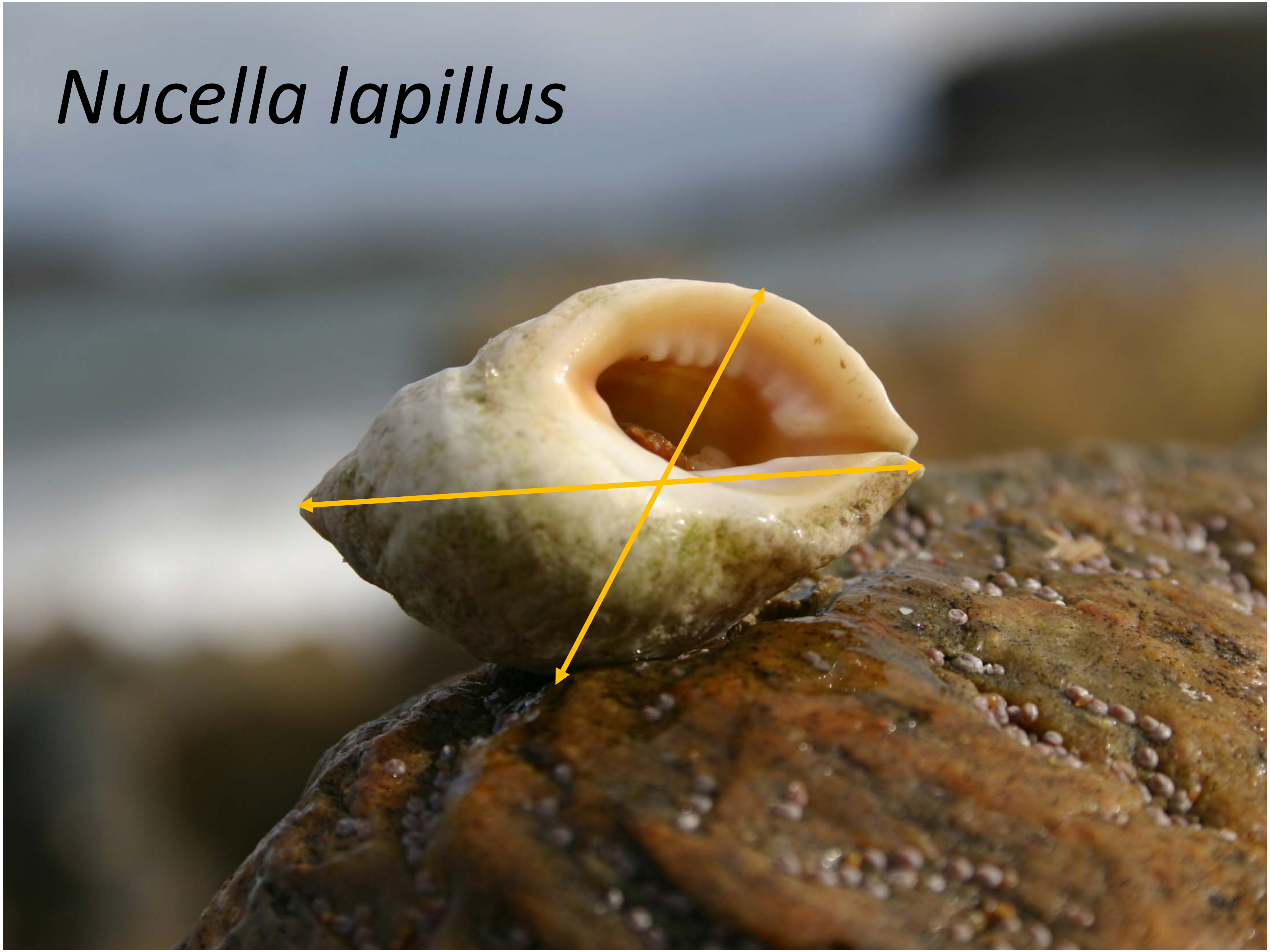
Source	*DF*	*F Value*	*Pr > F*	*Error*
Treat	4	2.34	0.103	Tank(Treat)
Tank(Treat)	15	2.19	**0.005**	
Excluding 1000ppm				
CO2	1	1.70	0.216	Tank(CO2*Te
Temp	1	3.49	0.087	Tank(CO2*Te
CO2*Temp	1	2.85	0.117	Tank(CO2*Te
Tank(CO2*Temp)	12	1.56	0.097	
Excluding above ambient (1000 vs 750 vs 380)				
CO2	2	0.79	0.483	Tank(CO2)
Tank(CO2)	9	2.49	**0.008**	

- Weight increase initially faster at 380, and less at 750 and 100
- Weight gain reversed in Dec 11 and Jan 12

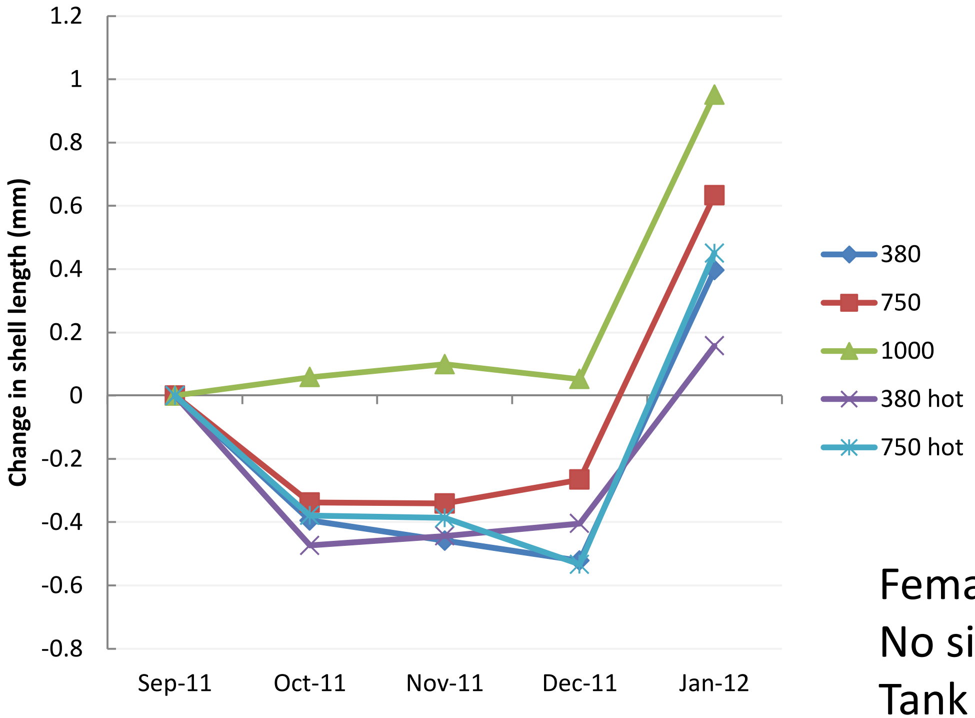
Osilinus lineatus – survival

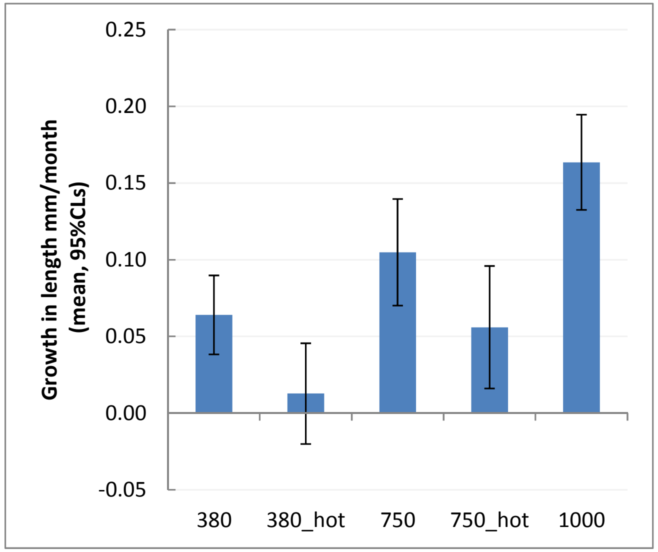


- Survival declines rapidly beyond three months
- Survival least in high temperature treatments


Nucella lapillus

Nucella lapillus – shell length



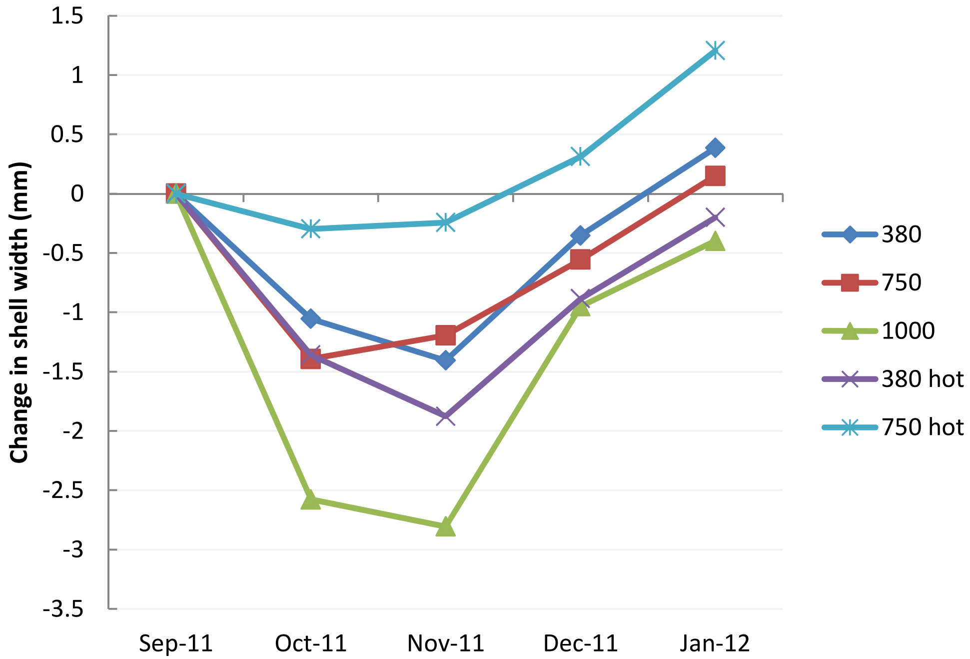


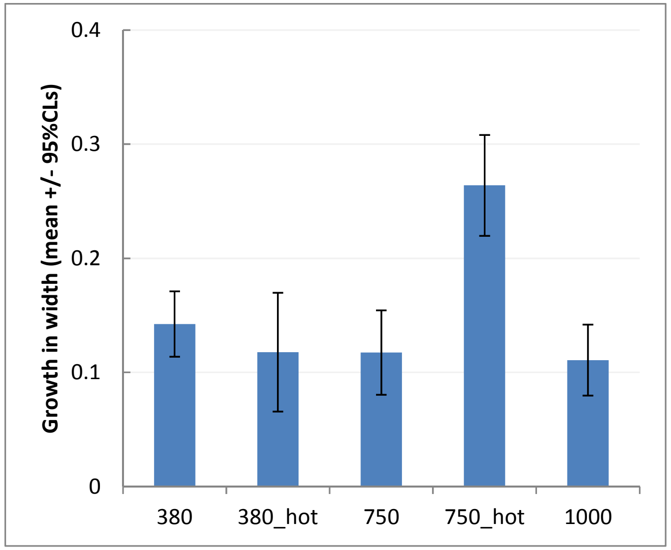
Female growth > Male
No significant differences among treatments
Tank differences significant

- Shells decrease in length in all but 1000 then increase after month 4
- Increase greater in 750 and 1000

Source	DF	F Value	Pr > F	Error
Treatment	4	2.81	0.064	Tank(Trt)
Sex	1	4.98	**0.041**	Sex*Tank(Trt)
Treatment*Sex	4	0.94	0.469	Sex*Tank(Trt)
Tank(Treatment)	15	3.28	**<.0001**	Residual
Sex*Tank(Treatment)	15	1.75	**0.038**	Residual

Nucella lapillus – shell width



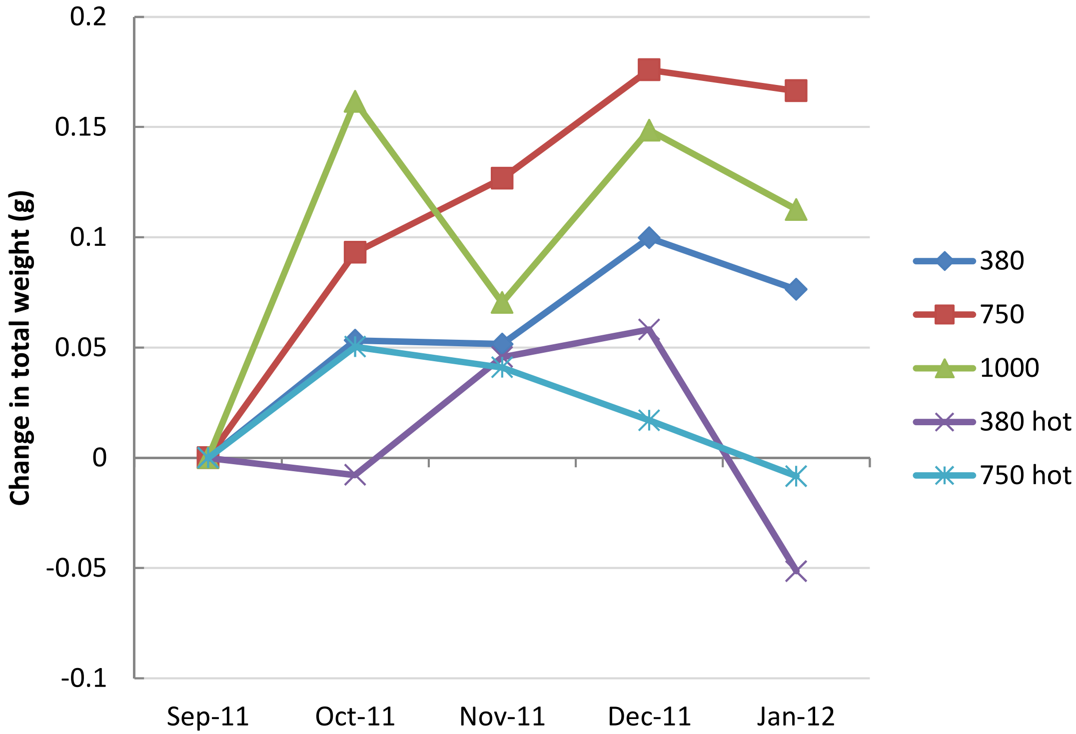


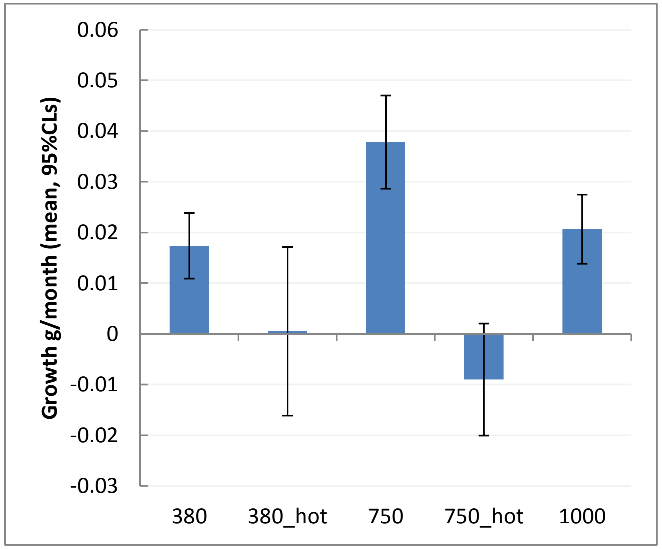
No significant differences among treatments
Tank differences significant

- Shells lose width in all treatments over the first three months, then gain steadily
- Loss greatest in 1000, but least in 750 hot

Source	*DF*	*F Value*	*Pr > F*	*Error*
Treatment	4	1.08	0.402	Tank(Trt)
Sex	1	2.28	0.152	Sex*Tank(Trt)
Treatment*Sex	4	0.38	0.821	Sex*Tank(Trt)
Tank(Treatment)	15	11.46	**<.0001**	Residual
Sex*Tank(Treatment)	15	2.27	**0.004**	Residual

Nucella lapillus – weight change



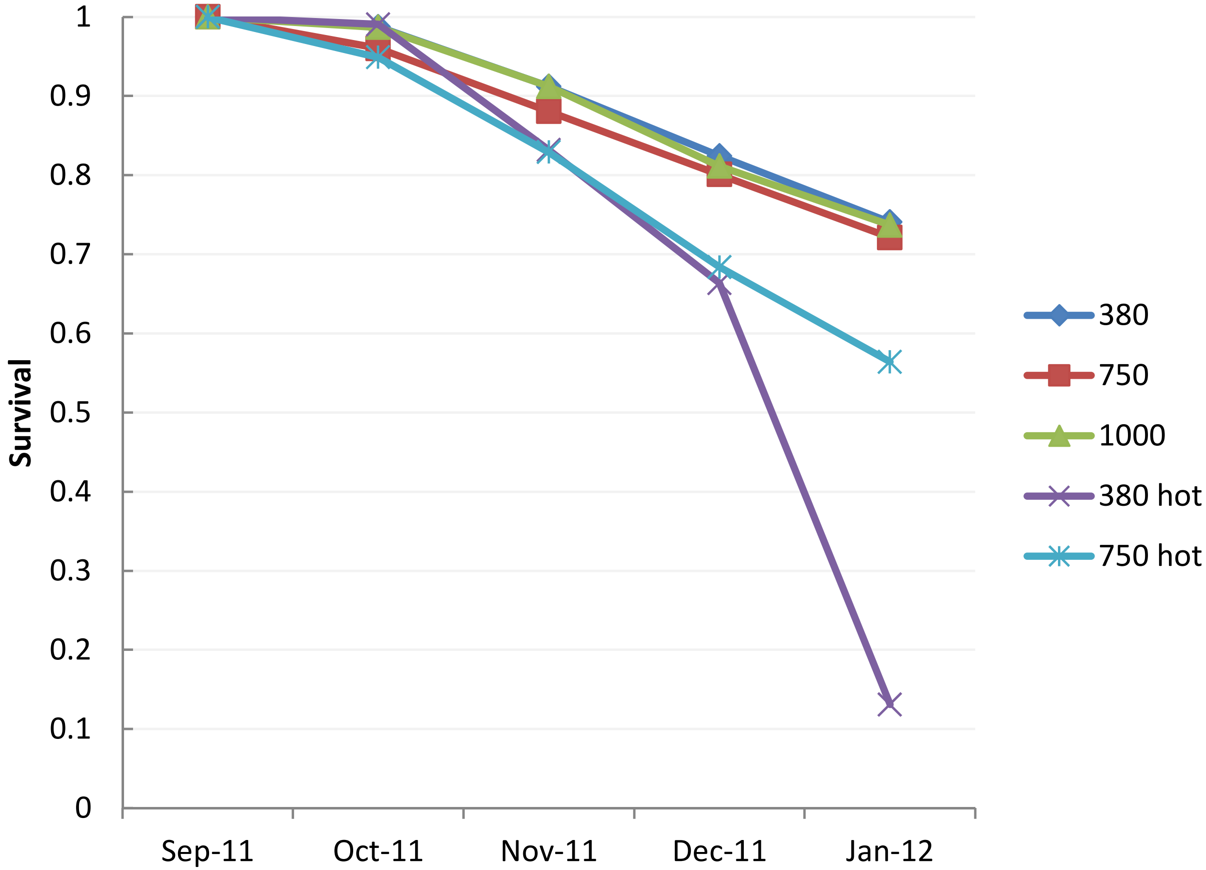


'Hot' < Ambient (P=0.003)
CO_2 significant (ex 'hot' P=0.032)

- Nucella increase in weight
- Increase greater in lower temperature treatments

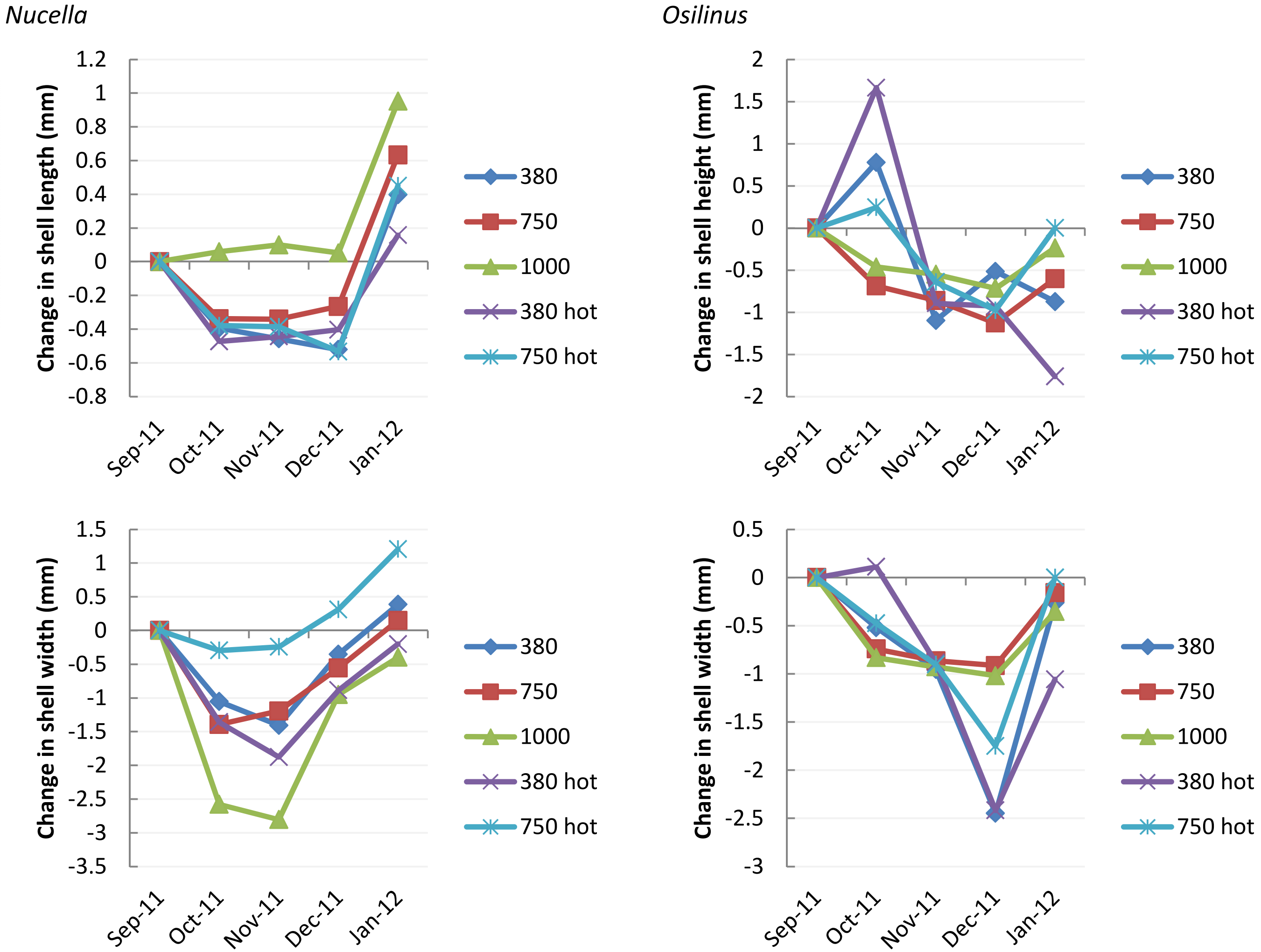
Source	*DF*	*F Value*	*Pr > F*	*Error*
Treatment	4	8.48	**0.001**	Tank(Trt)
Sex	1	10.23	**0.006**	Sex*Tank(Trt)
Treatment*Sex	4	1.31	0.310	Sex*Tank(Trt)
Tank(Treatment)	15	1.76	**0.037**	Residual
Sex*Tank(Treatment)	15	0.6	0.877	Residual

Nucella lapillus – survival



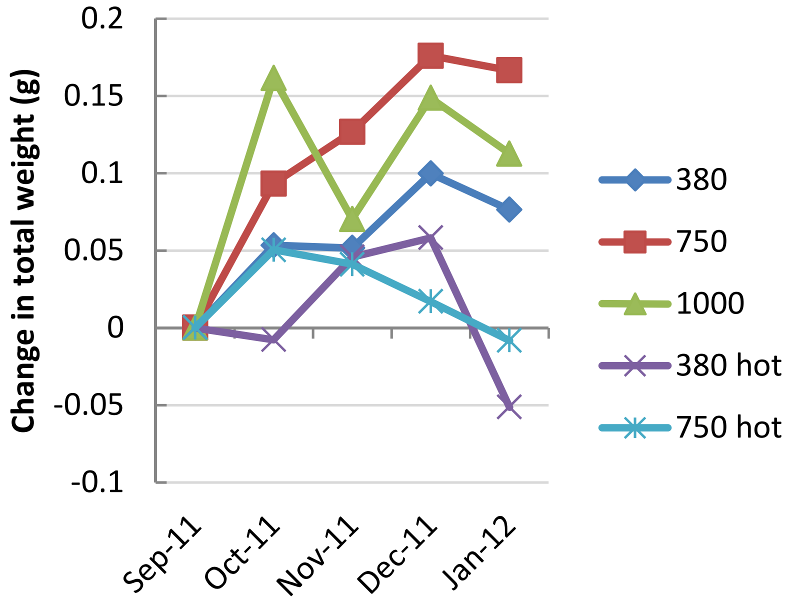
- Survival declines steadily over the period
- Survival least in high temperature treatments

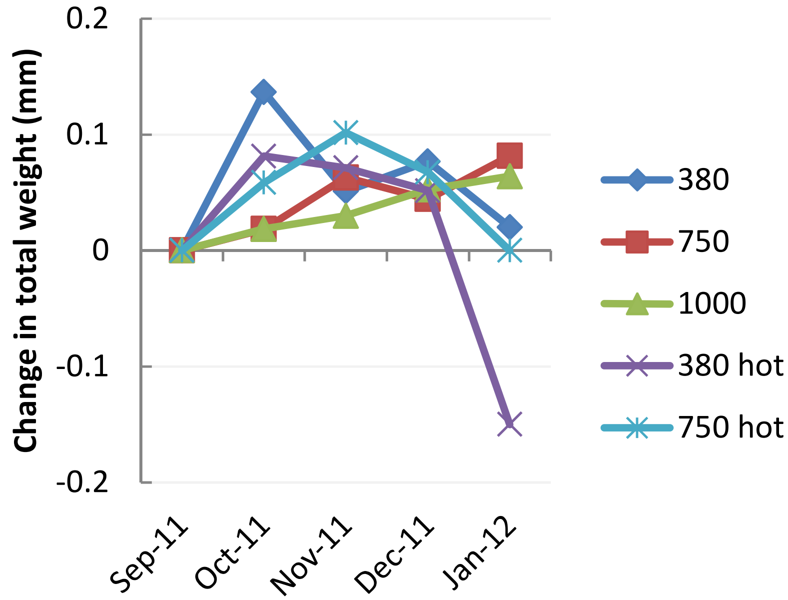
Change in shell size



- Time-dependent response in both species

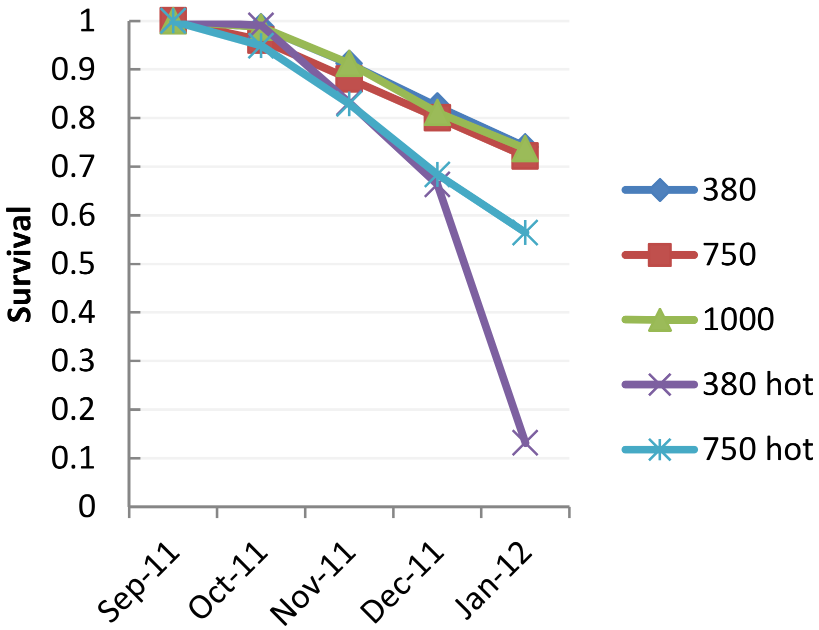
Change in weight

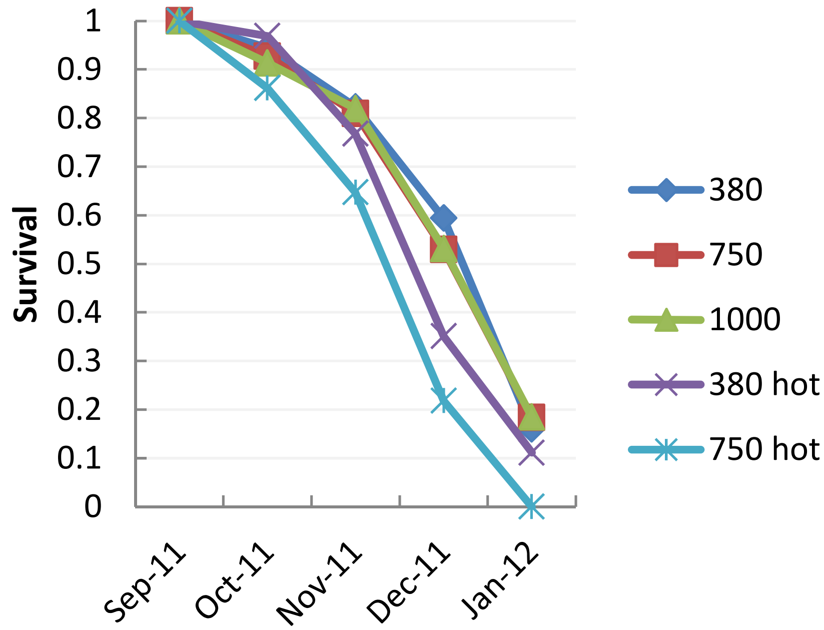




- Weight gain in both species
- Eventual weight loss in increased temperatures
- Weight gain best at ambient temperatures

Survival





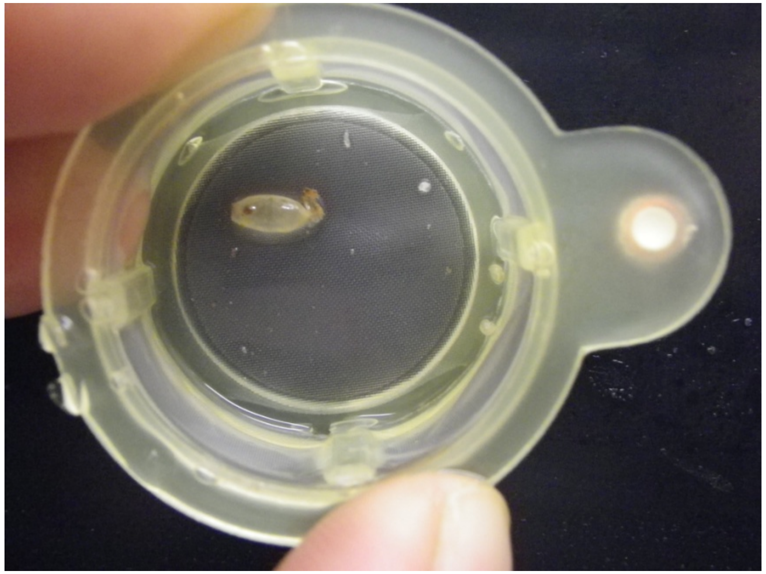
- *Nucella* survive better than *Osilinus*
- Poorest survival in increased temperatures
- Survival least where weight loss occurs

UK Ocean Acidification Research Programme
Benthic Acidification

Summary, so far

- Both *Osilinus* and *Nucella* show negative shell growth but weight gain in mesocosms
  - *Osilinus* more negative growth in width and height at 380ppm than 750 and 1000ppm, and more negative in height at 380 and +4°C
  - *Nucella* gain less weight in +4°C and most at 750ppm
  - Initial loss of size is reversed after 5 months
- Survival of both species lowest in +4°C treatments

Short-term (2mo) effects on *Nucella* hatchlings



Field collected capsules
Treatments
380, 380 +4, 750, 750+4, 1000, 1000 +4

Lab-collected capsules from adults in mesocosm treatments – reintroduced into original treatments

Length, width, calcification, weight, survival

Next steps

- Shorter term experiments on juveniles
  - Hatched and developed in mesocosms
- Incorporating mesocosm findings into population models
  - Growth, fecundity and survival