

# Supporting online material for ‘Primary productivity controls on opportunistic bivalves during Early Jurassic oceanic deoxygenation’

Bryony A. Caswell and Angela L. Coe

## 1. Methods

### Supplementary information on field data collection

Shell size and abundance data for the epifaunal bivalves *Pseudomytiloides dubius* and *Bositra radiata* (Fig. DR2) were collected from the shallowly dipping and laterally extensive foreshore exposures along the north Yorkshire coast, UK at Port Mulgrave (54°32′48.64″N 00°45′59.50″W), Kettleness (54°31′50.56″N 00°43′12.25″W), Saltwick Bay (54°31′15.84″N 00°35′15.68″W), Hawsker Bottoms (54°27′29.89″N 00°33′25.62″W) and Ravenscar (54°24′23.37″N 00°29′19.03″W) and (Fig. DR1). Data were collected during seven weeks of fieldwork spanning a two year period. Almost all fieldwork was undertaken in late autumn to early spring after stormy conditions and/ or spring tides in order to maximize the amount and freshness of the foreshore exposures.

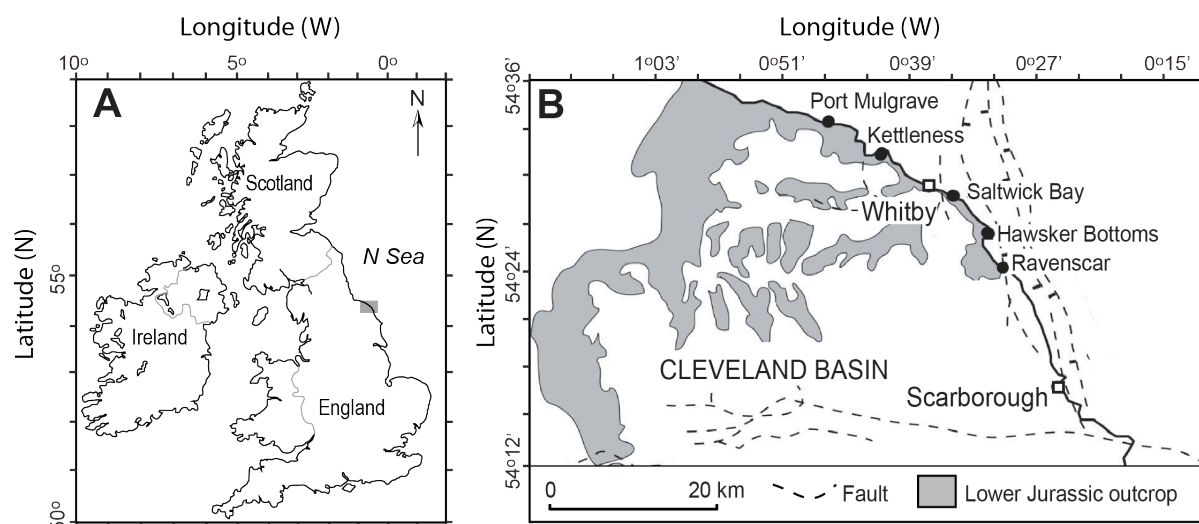


Figure DR1. Field study area. A: Map of the UK. Grey box shows area covered by B. B: Map of the Cleveland Basin showing the Lower Jurassic outcrop, fault lines, and the five field study sites on the Yorkshire coast: Hawsker Bottoms, Port Mulgrave, Kettleness, Saltwick Bay, Hawsker Bottoms and Ravenscar (figure modified from Rawson and Wright (1995)).

The stratigraphic positions of the sampled bedding planes were recorded at 0.5 cm resolution with respect to known stratigraphic datums (e.g. bed boundaries of Howarth, 1992) based on the graphic log of Kemp *et al.* (2005) and Kemp (2006). Care was taken to ensure data were from one stratigraphic level by removing overlying clay laminae and fossils to expose a single lamina. Each stratigraphic level was interpreted to represent one temporal point and thus one time averaged population. Quadrats (20 cm x 20 cm) were marked out and multiple high-resolution images were taken (e.g. Fig. DR2A). From these photographs bivalve abundance was determined and shell size (length and surface area) measured using image analysis (ImageJ 1.41i, National Institute of Health). At stratigraphic levels where the density of *P. dubius* was 24 individuals or less the abundance was recorded but the shells were not measured.

Data were collected at the highest resolution that their stratigraphic occurrences would allow over the main interval of the event (-3.71 m to 5.8 m), and at a roughly decimetre scale stratigraphic resolution above and below this. The resulting average stratigraphic resolution is summarized in Table DR1, and true heights are provided in Figure DR2. It is noteworthy that previous biotic studies through the OAE are at a 10–50 fold (Little, 1996) lower stratigraphic resolution and at any one stratigraphic level have a mean sample size 13-24 fold lower (Morten and Twitchett, 2009) than this study.

TABLE DR1: RESOLUTION OF THE FIELD COLLECTED DATA

Ammonite zone(s)	Ammonite subzones	Height (m)	Mean (range) strat. resolution (cm)
<u>Bivalve abundance data</u>			
<i>Dactylioceras</i> ( <i>Orthodactylites</i> ) <i>tenuicostatum</i> (Young & Bird)	<i>Protogrammoceras</i> ( <i>Paltarpites</i> ) <i>paltum</i> Buckman to <i>D. (O.) semicelatum</i> (Simpson)	-14 to 0	11.0 (0.1–91)
<i>Harpoceras falciferum</i> (J. Sowerby)	<i>H. falciferum</i> and <i>Cleviceras exaratum</i> (Young & Bird)	0 to 16	4.5 (0.1–73)
<i>H. falciferum</i> to <i>Hildoceras bifrons</i> Bruguier	<i>H. falciferum</i> and <i>D. commune</i> (J. Sowerby)	16 to 35	11.0 (0.2–508)
<u>Bivalve size data</u>			
<i>D. tenuicostatum</i> to <i>H. falciferum</i>	<i>D. (O.) semicelatum</i> to <i>H. falciferum</i>	-3.71 to 21.37	11.0 (0.2–87)

Note: zero datum is the base of bed 33 of Howarth (1992; Fig. DR3)



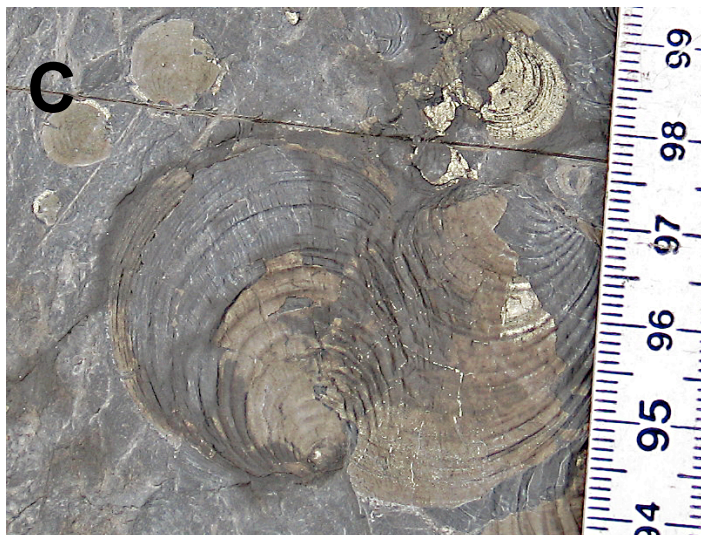
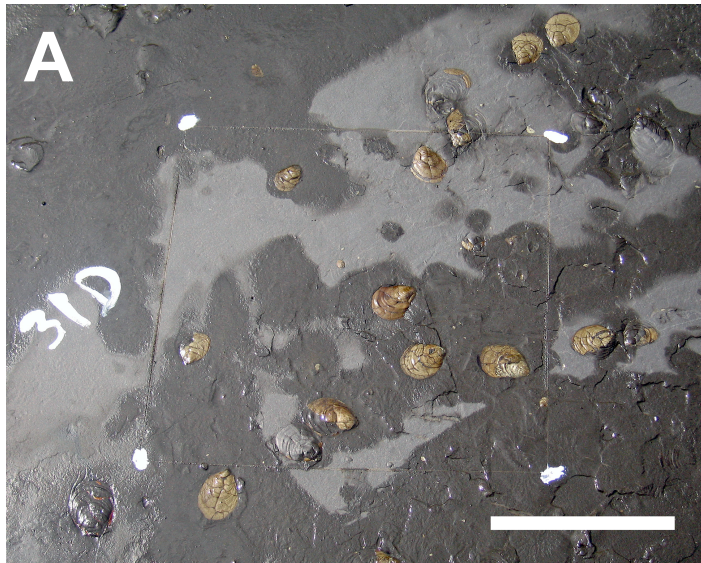


Figure DR2. The two dominant bivalve species found in the strata representing the Toarcian OAE near Whitby, Yorkshire, UK. A: *Pseudomytiloides dubius* specimens in a 20 cm x 20 cm quadrat from 2.05 m below the middle of bed 35 (the Whalestone Nodules) at Port Mulgrave; scale bar is 10 cm. B: Close up of A; scale bar is 4 cm. C: *Bositra radiata* from 132 cm below the middle of bed 33 (the Canon Ball Nodules) at Port Mulgrave; scale in centimetres.

## **Supplementary information on data analyses**

All statistical analyses (linear and multiple regressions, and non-parametric tests) were performed on SPSS v. 20 (<http://www-01.ibm.com/support/docview.wss?uid=swg24029274>) except for reduced major axis regressions that were performed with Past.exe (Hammer et al., 2001).

### **Multiple regression**

Results from multiple regression were analysed for multicollinearity (variance inflation factors), autocorrelation (Durbin-Watson), and the influence of extreme cases (leverage values, Cooks distance, Mahalanobis distances, DFBeta statistics, and covariance ratios). Residuals were inspected for heteroscedasticity, non-linearity and non-normal distributions (Kolmogorov-Smirnov). Results were found to meet all of these assumptions.

### **Weibull distribution**

Survivorship data for populations may be compared using the Weibull frequency distribution (Weibull, 1939; Pinder et al., 1978). The Weibull frequency distribution is widely used in engineering as a component time to failure model and is considered an appropriate model of animal survivorship (Pinder et al., 1978). The distributions of the survivorship data were fitted to the Weibull distribution using least sum of squares linear regression and the fit was tested with an ANOVA. For distributions that fit the Weibull distribution (ANOVA,  $p < 0.05$ ) the Weibull shape parameter ( $\beta$ ) was determined from the slope of the regression line. The parameter may take several forms: If  $\beta > 1$  individuals probability of mortality increases with age; if  $\beta < 1$  the probability of mortality decreases with age; and if  $\beta = 1$  there is a constant probability of death. The Weibull shape parameter was used to compare survivorship patterns between bivalve populations (Fig. DR3).

## **2. Additional details on statistical results**

Bivalve size data were compared using non-parametric statistical tests (Tables DR2 and DR3). Median shell size of both species significantly differed between populations ( $p < 0.001$ : Table DR2). *Post hoc* comparisons of

individual populations were made using critical values and significant differences are shown on Fig. DR3. Median shell size significantly differed ( $p < 0.001$ ) between data when grouped into Interval 2 and Interval 3, and between data grouped into periods of increasing and decreasing  $\delta^{13}\text{C}_{\text{org}}$  (Table DR3).

Linear regressions were performed with raw, 3 point moving average, and per ~75cm Milankovitch cycle averaged bivalve size data (Table DR4). All correlations were significant ( $p < 0.005$ ) and the strongest relationships were found for size data averaged per 75 cm Milankovitch cycle (equivalent to precession or obliquity). Stronger coefficients of determination were found for maximum rather than mean shell size because it is less variable (Table DR4).

Linear regressions of *P. dubius* shell size were performed with geochemical proxies for seawater temperature ( $\delta^{18}\text{O}$  and Mg/Ca; Bailey et al., 2003) and paleoproductivity ( $\delta^{15}\text{N}$ ; Jenkyns et al., 2001) that are predicted to influence bivalve shell size directly or indirectly (e.g. the impact of seawater temperature change on paleoproductivity; Gomez and Goy, 2011). However, these regressions were not significant (Table DR5). This is highly likely to be a function of the lower stratigraphic resolution of these proxy data.

TABLE DR2. RESULTS OF STATISTICAL COMPARISONS OF MEDIAN SHELL SIZE

Statistical Test	Test statistic	Significance level (p)	n
<i>P. dubius</i> shell size*			
Kruskal-Wallis	7465	<0.001	186
Jonkheere-Terpstra <sup>†</sup>	27.19	<0.001	186
Median test	5393	<0.001	186
<i>B. radiata</i> shell size*			
Kruskal-Wallis	1996	<0.001	35
Jonkheere-Terpstra <sup>†</sup>	10.95	<0.001	35
Median test	1341	<0.001	35

Note: n = sample size; p<0.05 indicates a significant difference.  
 \*Size data are shell surface area (mm<sup>2</sup>) for raw data see Fig. DR 2  
<sup>†</sup>Positive values indicate trend is increasing values with stratigraphic height.

TABLE DR3. MANN WHITNEY U TEST RESULTS

Statistical Comparison	Test statistic	n	Significance level (p)
<i>B. radiata</i> shell size*			
Decreasing versus Increasing $\delta^{13}\text{C}_{\text{org}}$	-9.99	6162	<0.001
<i>P. dubius</i> shell size*			
Interval 2 versus Interval 3	-27.85	29673	<0.001

Note: tests compare medians; n = sample size; p<0.05 indicates significant difference.  
 \*Size data are shell surface area (mm<sup>2</sup>)

109

TABLE DR4. RESULTS OF LINEAR REGRESSIONS FOR *P. dubius* SIZE

Proxy	Coefficient of determination					
	Mean shell surface area			Max shell surface area		
	Raw	3 pt.	Mkv.	Raw	3 pt. ma	Mkv. av.
[Mo]	0.10	0.27	0.39	0.18	0.36	0.62
$\delta^{98/95}\text{Mo}$	0.12	0.27	0.37	0.16	0.29	0.40
TOC/P	0.09	0.25	0.32	0.11	0.20	0.38
n	185	93	35	185	93	35

Note: all significant at  $p < 0.005$ ; Mk. av. = Milankovitch average; 3 pt. ma = 3 point moving average; n = sample size.

110

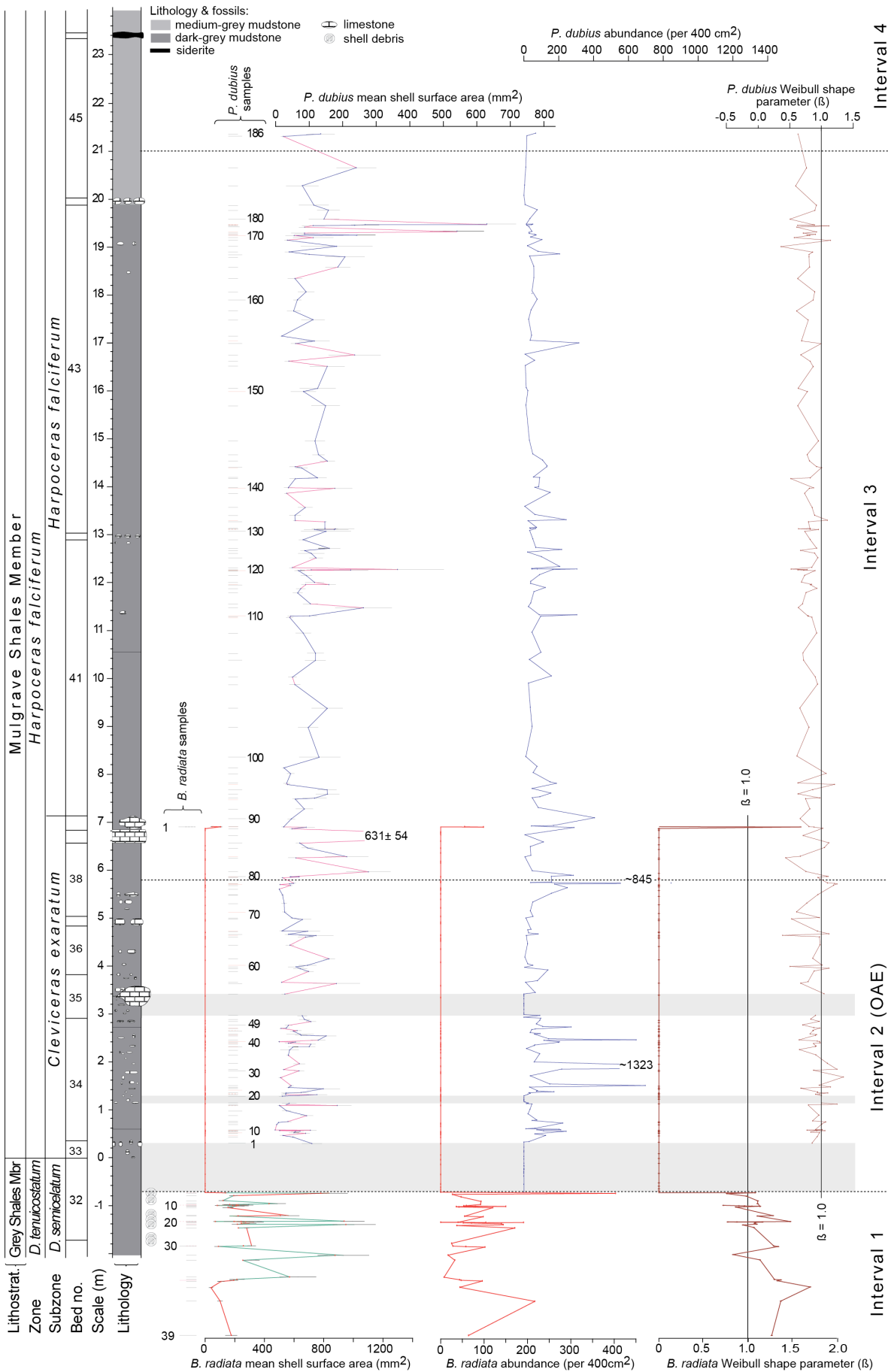
111

TABLE DR5. RESULTS OF REGRESSION OF *P. dubius* SIZE WITH OTHER PROXIES

Geochemical proxy	R <sup>2</sup>	Significance level (p)
N-isotopes ( $\delta^{15}\text{N}$ )	0.076	0.386
O-isotopes ( $\delta^{18}\text{O}$ )	0.100	0.142
Mg/Ca	0.014	0.581

Note: Data are mean shell surface area averaged per ~75 cm Milankovitch cycle (n=23);  $p < 0.05$  indicates significant result

112



113

114

Figure DR3 (previous page). Stratigraphic log for part of the Toarcian of Yorkshire showing mean shell surface area (with 95% CI), shell abundance (within 400 cm<sup>2</sup>), and  $\beta$  the Weibull shape parameter for *P. dubius* (blue and pink lines; the pink part indicating significantly different medians of the two adjacent points) and *B. radiata* (red and green lines with the green part indicating significantly different medians). For the Weibull shape parameter 10 of the 221 stratigraphic levels are not plotted because  $\beta$  could not be calculated. Data are from the 221 stratigraphic levels sampled; sample points are numbered 1–186 for *P. dubius* (level 50 does not exist) and 1–39 for *B. radiata* (levels 17, 24 and 25 do not exist). Stratigraphic log from Kemp *et al.* (2005) and Kemp (2006); ammonite zones and bed numbers from Howarth (1992). Dashed black horizontal lines show the position of intervals 1–4 of Pearce *et al.* (2008); horizontal gray bands indicate the very poorly fossiliferous intervals (Caswell *et al.* 2009). Ammonite subzones: *D. tenuico.* = *Dactylioceras tenuicostatum* Subzone; *D. semi.* = *D. semicelatum* Subzone.

### 3. Background to *Mulinia lateralis* a modern analogue for *Pseudomytiloides dubius*

*Mulinia lateralis* (Say) is a small (~15 mm shell length; e.g. fig. 13, Pl. 24 of Tunnell *et al.* (2010) and Rosenberg (2013)) widely distributed shallow infaunal suspension-feeding bivalve that appears, based on our study, to be a good modern analogue for *P. dubius*. *Mulinia lateralis* inhabits soft muddy substrates similar to those inferred for *P. dubius* during the Toarcian. *Mulinia lateralis* occurs in high abundances in anoxic conditions in areas such as Chesapeake Bay (Dauer *et al.*, 1992), and Long Island Sound, USA (Sanders, 1956) where densities of up to 21,000 individuals per m<sup>-2</sup> have been reported (Santos and Simon, 1980). This is comparable to *P. dubius* that we record at densities up to 12,500 individuals per m<sup>2</sup>. Occurrences of *M. lateralis* are sporadic and its distribution shows large spatial and temporal variation (e.g. it is observed in very high densities one year but absent the next) (Sanders, 1956; Levinton, 1970; Holland *et al.*, 1977). This distribution pattern has been identified for several highly opportunistic species from the geologic record (Levinton, 1970). The present study shows that abrupt large shifts in the size of *P. dubius* populations occurred during the Toarcian OAE, and suggests that *P. dubius* was also highly opportunistic and could rapidly respond to favourable environmental conditions.

*Mulinia lateralis* is an opportunist that is able to colonise areas rapidly because it has very fast growth rates and generation times (as short as 60 days; Calabrese, 1970) and high fecundity ~3-4 million eggs produced per female (Calabrese, 1969). The population structure of *P. dubius* (Fig. DR5)

and *M. lateralis* (Fig. DR4B) are indicative of high recruitment and juvenile mortality, and thus for *P. dubius* it is likely that generation times were also fast. This life history would have enabled *P. dubius* to colonise the seafloor rapidly when palaeoenvironmental conditions became suitable. Several factors influence bivalve growth including food supply, temperature, salinity, and oxygen; and of these the most important is food supply (e.g. Gosling, 2003).

Some extant bivalves that inhabit anoxic environments have chemosymbionts, e.g. the Mytilidae, Solemyidae, Lucinidae, Thyasiridae and Vesicomyidae. Determining whether an extinct species had chemosymbionts is difficult because little evidence is preserved on the shell. Some studies use features on the internal shell surface (Taylor and Glover, 2000) and others use stable isotope composition (e.g. CoBabe, 1991), but the Toarcian bivalve shell material is not suitable for these analyses. Although chemosymbiosis cannot be excluded for the Toarcian species this life habit seems highly unlikely because neither of the Toarcian species has modern relatives, below the order level, with adaptations for chemosymbiosis. Additionally, we have shown that the Toarcian bivalves decrease in size and abundance when conditions were at their worst (as shown by the geochemical proxy data; Fig. 1) whereas we would predict that if the Toarcian bivalves used chemosymbionts they would be larger and more abundant under these conditions. The present day opportunist *M. lateralis* does not have chemosymbionts but it is well adapted to deoxygenated environments (discussed in detail below). Similar to *M. lateralis* we propose that the Toarcian bivalves had adaptations that enabled them to inhabit deoxygenated environments.

Despite its high abundance in anoxic conditions *M. lateralis* has low tolerance to anoxia compared with other bivalve species that inhabit muddy substrates (Shumway et al., 1983). During anoxia, unlike other bivalves that close their valves and decrease their activity to conserve energy *M. lateralis* maintain near normal activity levels and continue to feed (Shumway et al., 1983). This requires that they switch to anaerobic metabolism, but this is energetically less efficient and so requires a greater energy supply (Shumway and Newell, 1984). *Mulinia lateralis* has high filtration rates  $\sim 100 \text{ ml h}^{-1}$  to



support its high energy demands (Shumway and Newell, 1984). Shumway and Newell (1984) suggest that this species is adapted to short term fluctuating anoxia and exploiting conditions where food supply is very high such as during phytoplankton blooms. Unlike other bivalve species *M. lateralis* cannot breakdown stored proteins (Shumway and Newell, 1984), and therefore during periods of low food availability large populations of *M. lateralis* can no longer be supported, and mass mortalities occur. Chalemwart et al. (1991) showed that *M. lateralis* can efficiently assimilate bacterial biomass, and thus cyanobacteria could constitute an important food source for this species if present in high quantities. Although we cannot study the metabolism of *P. dubius* because it is extinct the relationship we find between N<sub>2</sub>-fixing primary productivity and *P. dubius* body-size in this study strongly suggests it may also have been adapted to exploit cyanobacterial and/or algal blooms under fluctuating anoxia.

Within the high-density Toarcian *P. dubius* populations (Figs 1A–B) competition for resources would have been high, and the body size abundance relationships for *P. dubius* populations indicates that smaller individuals utilised resources more efficiently. A smaller body size may have been advantageous because of the larger surface area to volume ratio. For example, Shumway et al. (1983) showed that small individuals of *M. lateralis* had a larger gill surface area to body size ratio than larger individuals.

Shumway et al. (1983) suggested that *M. lateralis* is a poor competitor that only flourishes when other species are absent, and this is attributed to its low tolerance of repeated burial in soft sediments. *P. dubius* also only occurs in any significant numbers in monospecific pavements during the Toarcian OAE and therefore it appears that it was probably also a poor competitor. It may also, like *M. lateralis*, have required very high food supply and so only occurred where phytoplankton blooms were frequent. Furthermore, *P. dubius* may have had preference for a particular food source(s) as shown for several present day filter feeding bivalve species by Shumway et al. (1985).

#### **4. Additional information on bivalve population structure**

Positively skewed size frequency distributions are common for present day marine bivalve populations that broadcast spawn and have high juvenile



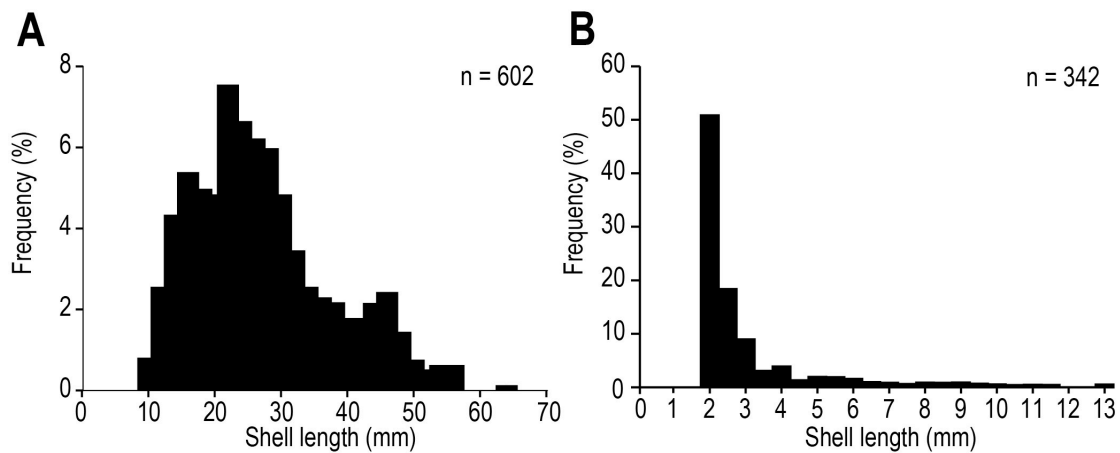
mortality. However, patterns vary from positively to negatively skewed between different populations. The size structure of two present day suspension feeding bivalve populations, *Mya arenaria* and *Mulinia lateralis* are shown (Fig. DR4) for comparison with those from the Toarcian (Figs DR5–7). Both of these present day species inhabit de-oxygenated environments but they have very different life history strategies.

*Mya arenaria* has a deep infaunal life habit within reducing environments where it attains oxygen from the overlying oxygenated seawater via its long siphons. *Mya arenaria* is considered to have an equilibrium life history strategy (Fig. DR4A). It has a relatively long life span ~20 years and reaches sexual maturity after 2 years. This is reflected by its larger body size and the moderately positively skewed and multimodal population size distribution indicating that multiple cohorts were present (with a modal size of 25 mm shell length) and 99% of individuals attained shell lengths greater than 10 mm (Fig. DR4A).

In contrast, *M. lateralis* (discussed in DR Section 3) is an opportunistic species (Fig. DR4B) with a tenfold shorter life span (2 years) and twelvefold faster generation time (2 months) than *M. arenaria*. The size distribution of a time averaged *M. lateralis* population (Fig. DR4B) is strongly positively skewed suggesting high recruitment and juvenile mortality. Only one size cohort exists and less than 50% of individuals in the population attained a shell length greater than 2 mm (Fig. DR4B).

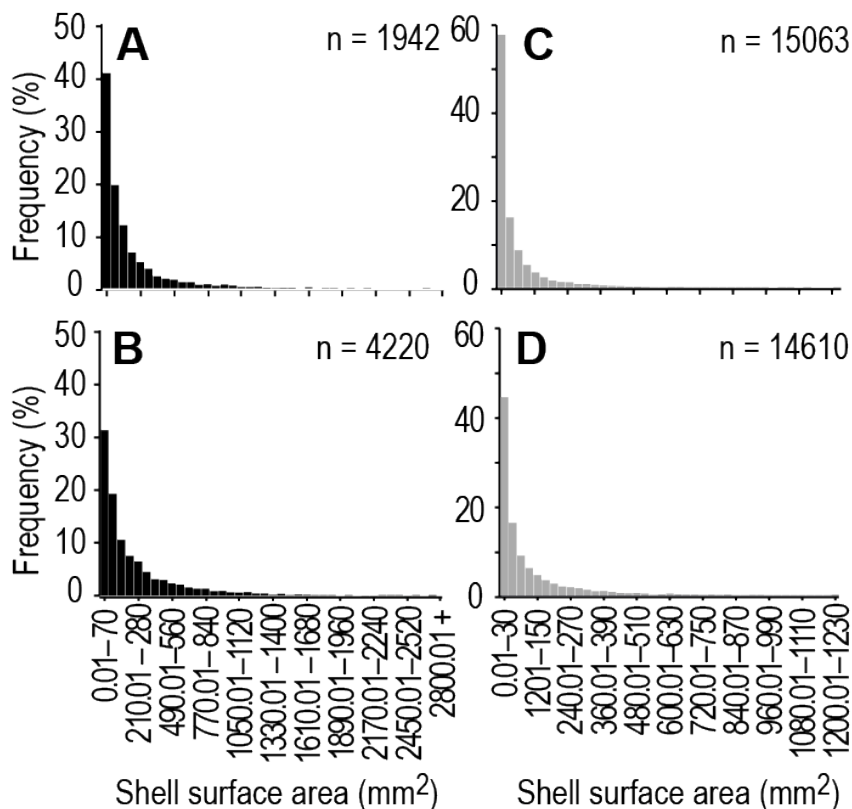
Both Toarcian bivalve species had unimodal strongly positively skewed SFDs (Fig. DR5). Individual *B. radiata* SFDs (i.e. the uncombined SFDs) showed that multimodal distributions were more frequent when  $\delta^{13}\text{C}_{\text{org}}$  was decreasing within a cycle as opposed to  $\delta^{13}\text{C}_{\text{org}}$  increasing (Fig. DR7). Additionally, more of the *P. dubius* SFDs (per Milankovitch cycle, Fig. DR6) were multimodal during Interval 3 compared with Interval 2.

248



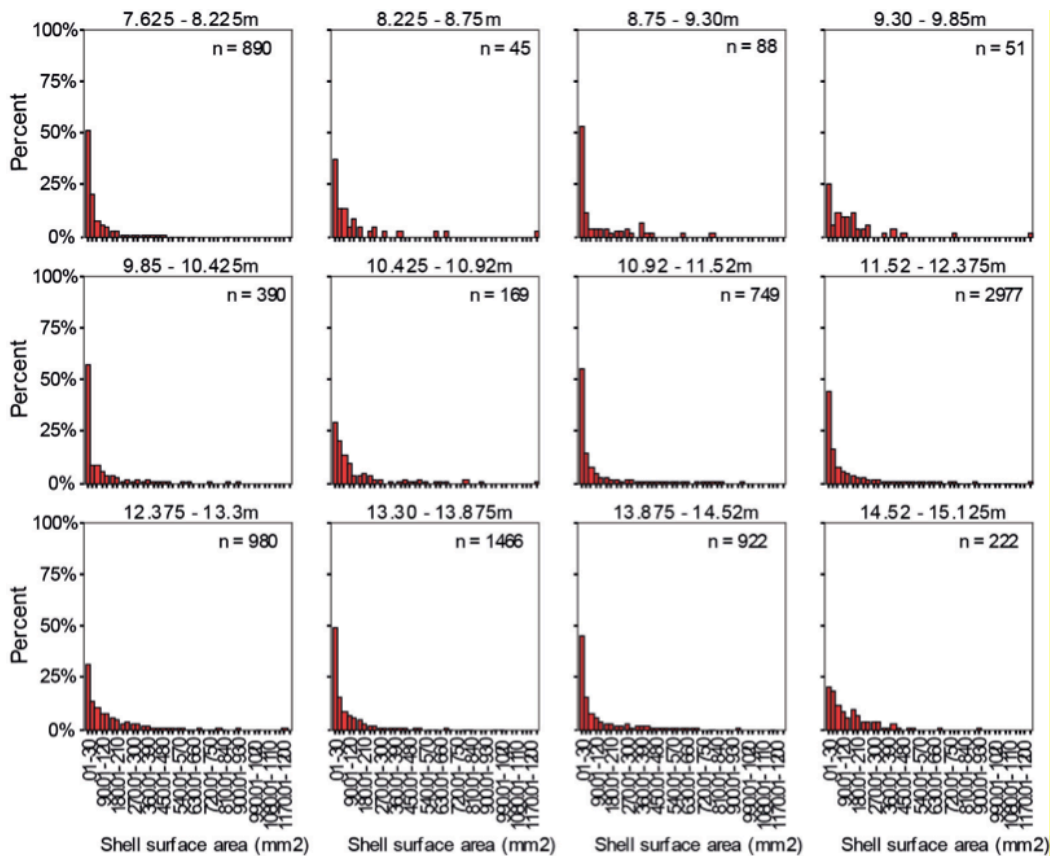
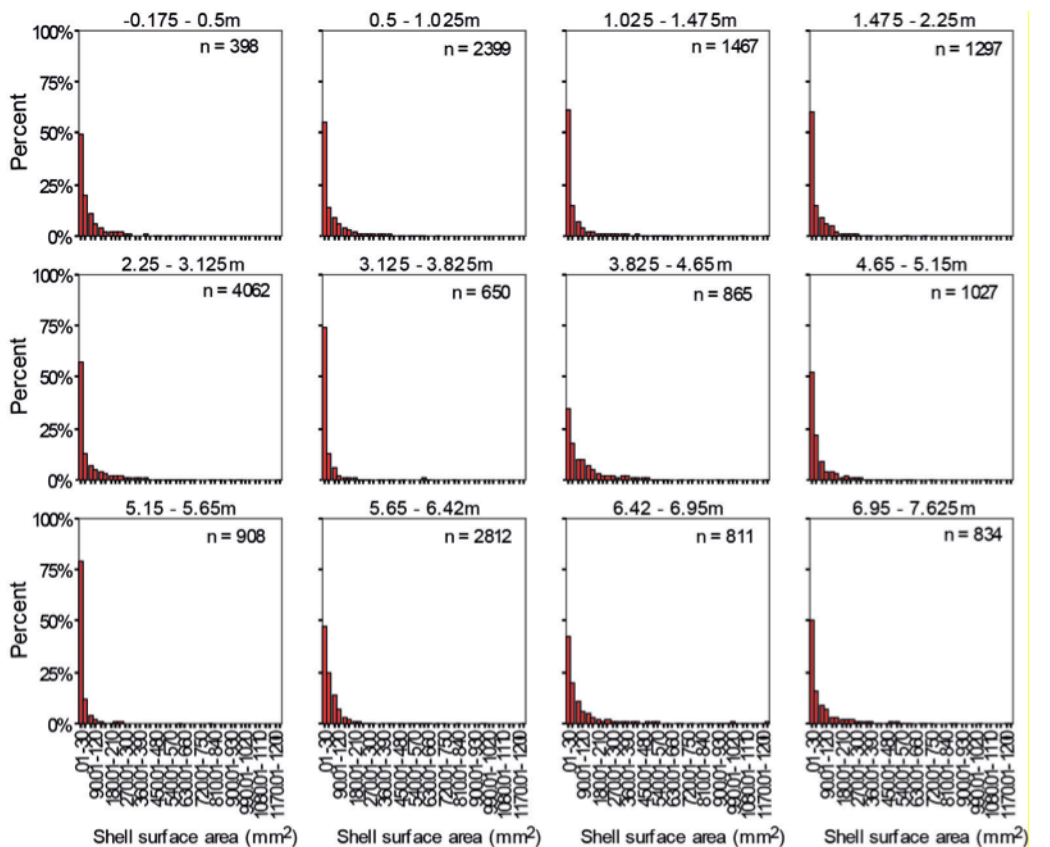
249

250 Figure DR4. Example length frequency distributions (LFDs) for populations of present day  
 251 bivalves with equilibrium (A) and opportunistic life histories (B). A: *Mya arenaria* LFDs  
 252 compiled from several samples collected intertidally at East Passage, Nova Scotia in 1987  
 253 (data re-plotted from Emerson et al. (1988)). B: LFD of a time averaged population of *Mulinia*  
 254 *lateralis* collected subtidally from Long Island Sound, Connecticut, USA (data re-plotted from  
 255 Levinton and Bambach (1970)). The absence of shells < 0.5 mm and 1 mm in length results  
 256 from the sieve size used for sampling *M. arenaria* and *M. lateralis*, respectively.  
 257



258

259 Figure DR5. Size frequency distributions for all Toarcian samples within particular  
 260 stratigraphic levels combined showing percent frequency of shells within 41 size categories.  
 261 A: *B. radiata* (gray) when  $\delta^{13}C_{org}$  are increasing; and B: decreasing. C: *P. dubius* (black) from  
 262 Intervals 2; and D: *P. dubius* from Interval 3.  
 263



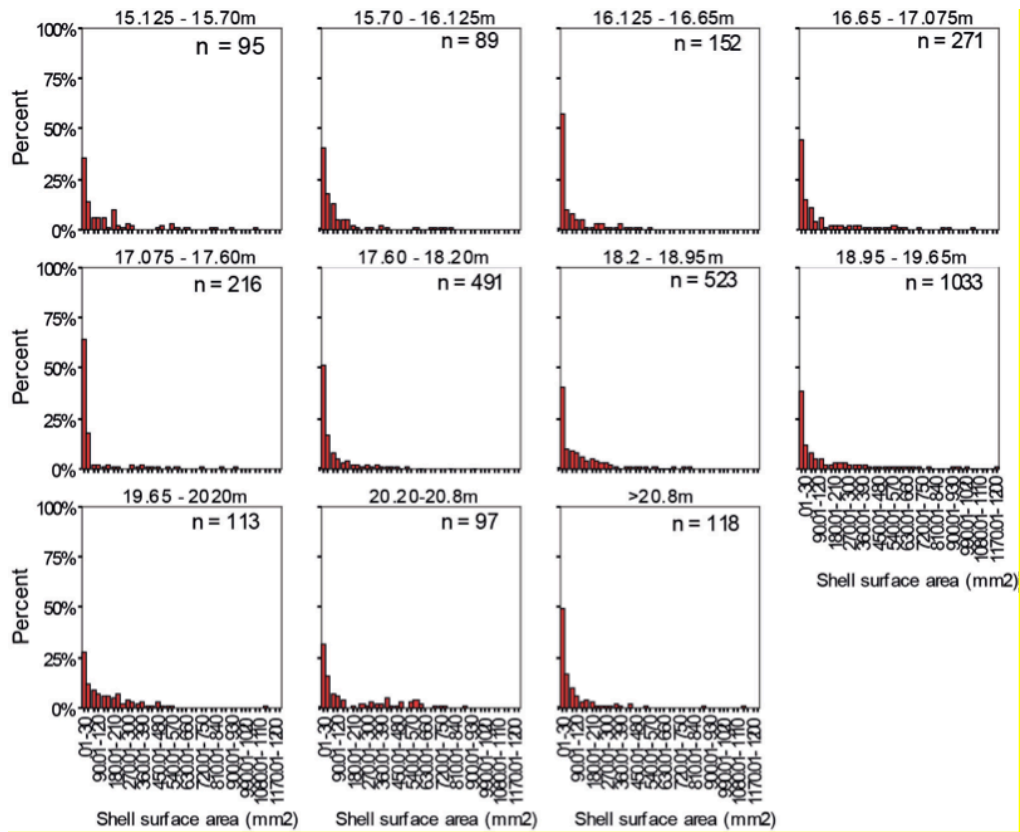
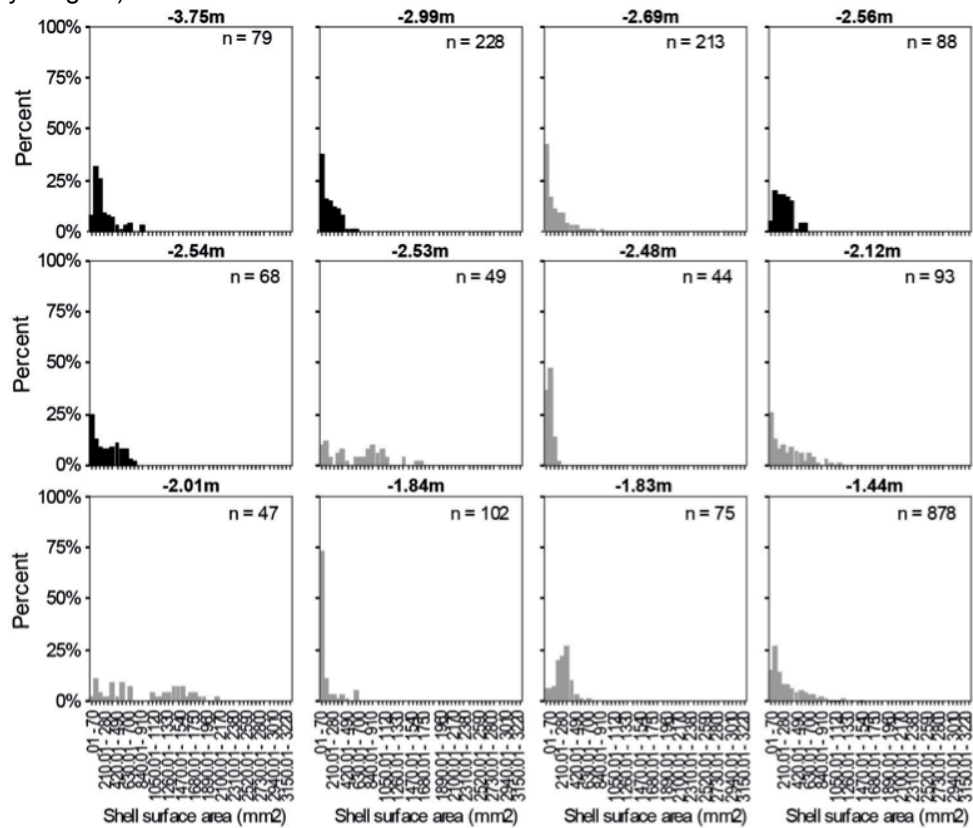


Figure DR6. Size frequency distributions of *P. dubius* for data combined per ~75 cm Milankovitch cycle. Plots show the percentage of shells in each 30 mm<sup>2</sup> (surface area) size category; stratigraphic heights of each Milankovitch cycle are shown (from oldest to youngest).



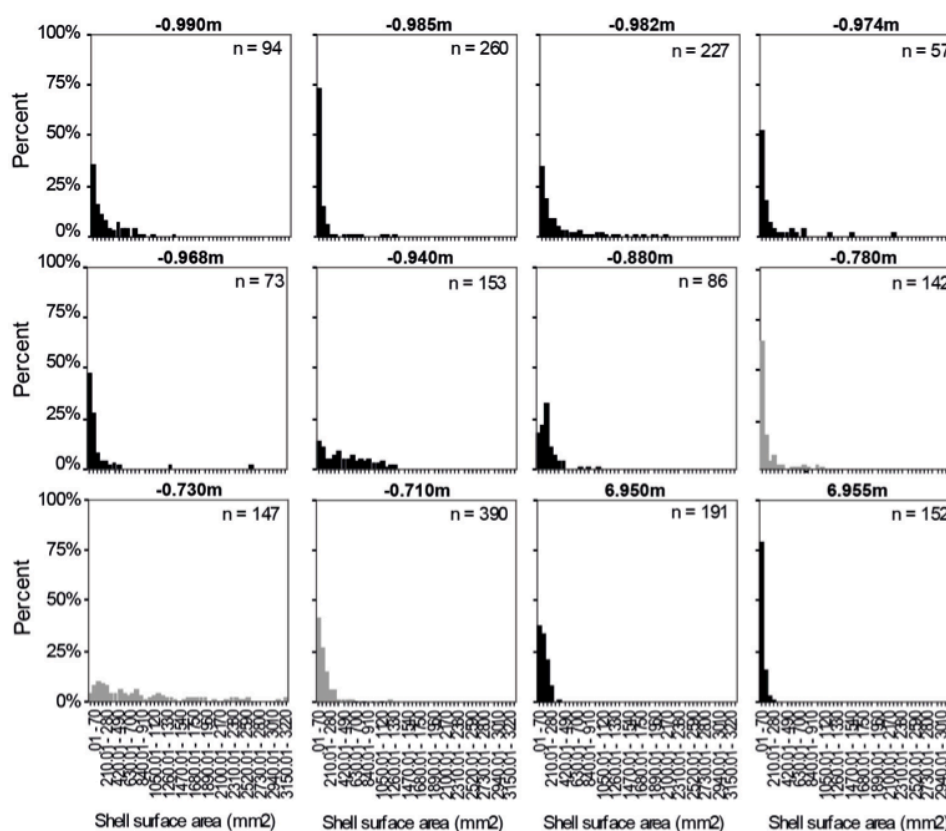
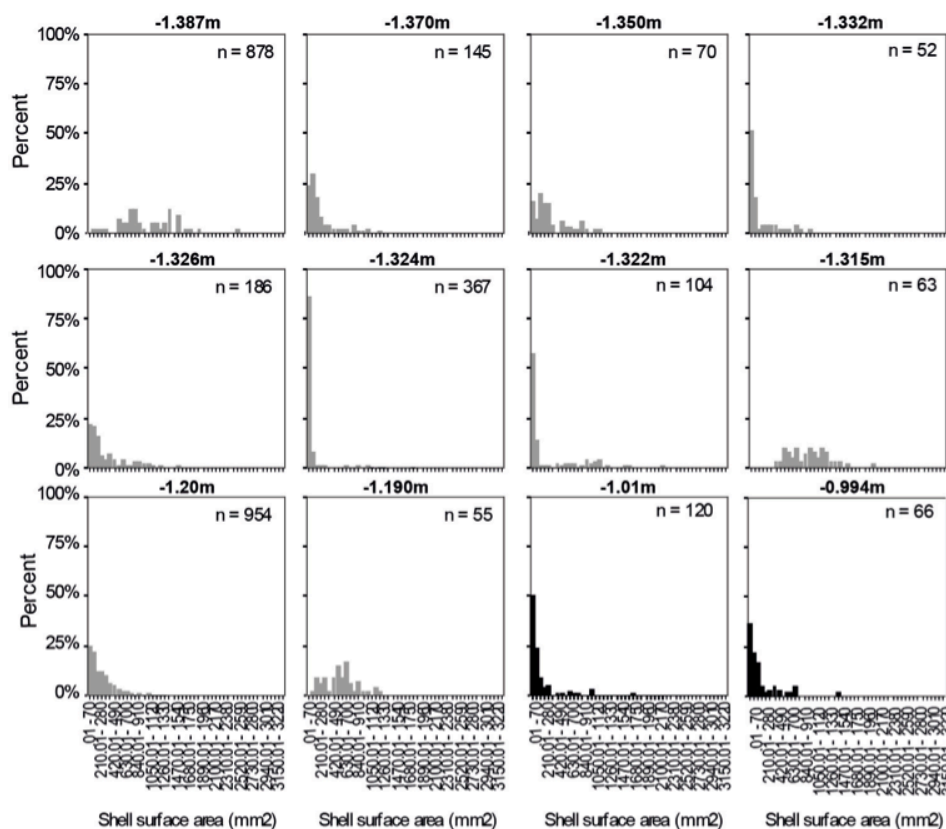


Figure DR7. Size frequency distributions for 36 *B. radiata* populations when  $\delta^{13}\text{C}_{\text{org}}$  was increasing (black) and when  $\delta^{13}\text{C}_{\text{org}}$  was decreasing (gray). Plots show percentage of shells in each 70 mm<sup>2</sup> size (surface area) category. Stratigraphic heights (m) are shown for each population (ordered from oldest to youngest).

## 5. References

- Bailey, T.R., Rosenthal, Y., McArthur, J.M., van de Schootbrugge, B., and Thirlwall, M.F., 2003, Paleooceanographic changes of the Late Pliensbachian-Early Toarcian interval: a possible link to the genesis of an Oceanic Anoxic Event: *Earth and Planetary Science Letters*, v. 212, p. 307–320, doi:10.1016/S0012-821X(03)00278-4.
- Calabrese, A., 1969, *Mulinia lateralis*, molluscan fruit fly? *Proceedings of the Natural Shellfish Association*, v. 59, p. 65–66.
- Calabrese, A., 1970, Reproductive cycle of the coot clam, *Mulinia lateralis* (Say), in *Long Island Sound: Veliger*, v. 12, p. 265–269.
- Chalemwart, K., Jacobsen, T.R., and Lutz, R.A., 1991, Assimilation of bacteria by the dwarf surf clam *Mulinia lateralis* (Bivalvia: Mactridae). *Marine Ecology Progress Series*, v. 71, p. 27–35.
- CoBabe, E.A., 1991, Lucinid bivalve evolution and the detection of chemosymbiosis in the fossil record. Unpublished PhD thesis, Harvard University.
- Dauer, D.M., Rodi Jr., A.J., Ranasinghe, A., 1992, Effects of low dissolved oxygen events on the macrobenthos of the lower Chesapeake Bay: *Estuaries*, v. 15, p. 384–391, doi:10.2307/1352785.
- Emerson, C.W., Minchinton, T.E., and Grant, J., 1988, Population structure, biomass, and respiration of *Mya arenaria* L. on temperate sandflat: *Journal of Experimental Marine Biology and Ecology*, v. 115, p. 99–111, doi: 10.1016/0022-0981(88)90096-2.
- Gómez, J.J., and Goy, A., 2011. Warming-driven mass extinction in the Early Toarcian (Early Jurassic) of northern and central Spain. Correlation with other time-equivalent European sections. *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 308, p.176–195, doi:10.1016/j.palaeo.2011.04.018.
- Gosling, E., 2003, *Bivalve Molluscs: biology, ecology, and culture*: Oxford, UK, Blackwell Science, 456 p.
- Hammer, Ø., Harper, D.A.T., and Ryan, P.D., 2001, PAST: Palaeontological Statistics Software Package for Education and Data Analysis: *Palaeontologia Electronica*, v. 4, p.1–9.
- Holland, A.F.K., Mountford, N.K., and Mihursky, J.A., 1977, Temporal

- 315 variation in the upper bay mesohaline benthic communities. I. The 9-m  
316 mud habitat. *Chesapeake Science*, v. 18, p. 370–378, doi:  
317 10.2307/1350592.
- 318 Howarth, M.K., 1992, The Ammonite family Hildoceratidae in the Lower  
319 Jurassic of Britain: Monograph of the Palaeontographical Society, v.  
320 586, p. 1-106.
- 321 Jenkyns, H.C., Gröcke, D.R., and Hesselbo, S.P., 2001, Nitrogen isotope  
322 evidence for water mass denitrification during the early Toarcian  
323 (Jurassic) oceanic anoxic event: *Paleoceanography*, v. 16, p. 593–603,  
324 doi:10.1029/2000PA000558.
- 325 Kemp, D.B., Coe, A.L., Cohen, A.S., and Schwark, L., 2005, Astronomical  
326 pacing of methane release in the Early Jurassic period: *Nature*, v. 437,  
327 p. 396–399, doi:10.1038/nature04037.
- 328 Kemp, D.B., 2006, Astronomical forcing during the early Toarcian and Late  
329 Triassic; Implications for the cause and duration of global  
330 environmental change and stratigraphic correlation. Unpublished PhD  
331 Thesis, The Open University, Milton Keynes.
- 332 Levinton, J.S., 1970, The palaeoecological significance of opportunistic  
333 species: *Lethaia*, v. 3, p. 69-78, doi: 10.1111/j.1502-  
334 3931.1970.tb01264.x.
- 335 Levinton, J.S., and Bambach, R., 1970, Some ecological aspects of bivalve  
336 mortality patterns: *American Journal of Science*, v. 268, p. 97–112,  
337 doi:10.2475/ajs.268.2.97.
- 338 Little, C.T.S., 1996, The Pliensbachian-Toarcian (Lower Jurassic) extinction  
339 event, *in* Ryder, G., Fastovsky, D., and Gartner, S., eds. *The*  
340 *Cretaceous-Tertiary event and other catastrophes in Earth history:*  
341 *Geological Society of America, Special Papers 307*, p. 505–512,  
342 doi:10.1130/0-8137-2307-8.505.
- 343 Morten, S.D., and Twitchett, R.J., 2009, Fluctuations in the body size of  
344 marine invertebrates through the Pliensbachian-Toarcian extinction  
345 event: *Palaeogeography, Palaeoclimatology, Palaeoecology*, v. 284, p.  
346 29–38, doi: 10.1016/j.palaeo.2009.08.023.
- 347 Pinder, J.E., Wiener, J.G., and Smith, M.H., 1978, The Weibull distribution: A  
348 new method of summarizing survivorship data: *Ecology*, v. 59, p. 175–

- 179, doi:10.2307/1936645.
- Rawson, P.F., and Wright, J.K., 1995, Jurassic of the Cleveland Basin, north Yorkshire, *in*: Taylor, P.D. ed Field geology of the British Jurassic: Geological Society, London, 173-208.
- Sanders, H.L., 1956, Oceanography of Long Island Sound. X. The biology of marine bottom communities: Bulletin Bingham Oceanographic Collection, v. 15, p. 138–153.
- Santos, S.L., and Simon, J.L., 1980, Response of soft-bottom benthos to annual catastrophic disturbance in a South Florida estuary: Marine Ecology Progress Series, v. 3, p. 347–355.
- Shumway, S.E., Scott, T.M., and Shick, J.M., 1983, The effects of anoxia and hydrogen sulphide on survival, activity and metabolic rate in the coot clam, *Mulinia lateralis* (Say): Journal of Experimental Marine Biology and Ecology, v. 71, p. 135–146, doi:10.1016/0022-0981(93)90069-Z.
- Shumway, S.E., and Newell, R.C., 1984, Energy resource allocation in *Mulinia lateralis* (Say), an opportunistic bivalve from shallow water sediments: Ophelia, v. 23, p. 101–118, doi: 10.1080/00785326.1984.10426607.
- Shumway, S.E., Cucci, T.L., Newell, R.C., and Yentsch, C.M., 1985, Particle selection, ingestion, and absorption in filter-feeding bivalves: Journal of Experimental Marine Biology and Ecology, v. 91, p. 77–92, doi:10.1016/0022-0981(85)90222-9.
- Stickney, A.P., and Stringer, L.D., 1957, A study of the invertebrate bottom fauna of Greenwich Bay, Rhoad Island. Ecology, v. 38, p. 111–112, doi:10.2307/1932133.
- Taylor, J.D., & Glover, E.A. 2000. Functional anatomy, chemosymbiosis and evolution of the Lucinidae, *in*: Harper, E.M., Taylor, J.D., and Crame, A., eds, The evolutionary biology of the Bivalvia: Geological Society of London Special Publication, v. 117, p. 283–296.
- Theede, H., Ponat, A., Hiroki, K., and Schlieper, C., 1969, Studies on the resistance of marine bottom invertebrates to oxygen-deficiency and hydrogen sulphide: Marine Biology, v. 2, p. 325–337, doi:10.1007/BF0035712.
- Tunnell Jr., J.W., Andrews, J., Barrera, N.C., and Moretzsohn, F., 2010, Encyclopedia of Texas seashells: Identification, ecology, distribution



- 383           and history: Texas, US, Texas A&M University Press, 512 p.
- 384   Rosenberg, G., (2013). *Mulinia lateralis* (Say, 1822). Accessed through: the
- 385           World Register of Marine Species at <http://www.marinespecies.org> on
- 386           19.07.2013.
- 387   Weibull, W.A., 1939, A statistical theory of the strength of materials. Imgenoirs
- 388           Vetenskaps Akademien Handlingar, v. 151, p. 1-45.