

We would like to thank Jelle Bijma for his constructive and timely review of our paper. Below we have copied his comments and provide a response (in red) and propose changes to the manuscript. Following the useful advice from the second reviewer we have analysed the shell fluxes in separate size classes. This revealed that lunar periodicity is in fact present in at least one size fraction in almost all species analysed here. These new findings lead to considerable changes in the revised manuscript. We will append a revised version with all changes highlighted to our response to the second reviewer.

Review by Jelle Bijma

This paper uses high resolution sediment trap flux data to demonstrate the lunar based reproduction cycle of many species of planktonic Foraminifera. It addresses relevant scientific questions within the scope of BG. Although, the paper does not present novel concepts, ideas or data, it confirms earlier papers and convincingly demonstrates a lunar based reproduction cycle in many species of planktonic Foraminifera. The scientific methods and assumptions are valid and most of it is clearly outlined. The authors give proper credit to related work and clearly indicate their own contribution. The title clearly reflects the contents of the paper and the abstract provides a concise and complete summary. The overall presentation is well structured and clear, and the language fluent and precise. There are a few concepts in the method section that require clarification.

Overall, I rate the scientific significance and quality, as well as the presentation as excellent. Below are some general and more specific comments. Please forgive me when this is "Bijma et al. biased", but we have been looking into planktonic foraminiferal population dynamics at depth (one of the papers you missed: Bijma and Hemleben, 1994).

general comments

Except for the first four comments, which I think should be addressed, the rest is cosmetics. Up to the authors. Great paper!

1. The fluxes considered in this study are based on the TOTAL numbers in the size fraction >150 μm . However, total numbers may not be the most sensitive parameter to demonstrate the TIMING of reproduction within the lunar cycle. This can be demonstrated using data on *G. sacculifer*. Bijma et al. (1990; fig. 1) show that the lowest and highest TOTAL abundance are reached between 3-7 days after full moon and about 8 days before full moon, respectively. However, juvenile mortality is very high and an exponential decrease in abundance towards later ontogenetic stages ("larger size fractions") can be observed (see fig. 2 in Bijma and Hemleben, 1994). In fact, the most abundant size fraction in the standing stock in Bijma et al, 1994 is between 100-200 μm (table 2). As a result, the abundance in this size fraction determines the total abundance of *G. sacculifer*. However, in this species gametogenesis is very rare below 250 μm and the percentage of mature specimens, i.e. those that can undergo gametogenesis, increases exponentially between 300 to 400 μm (Bijma and Hemleben, 1994). Hence, the peak of maximum abundance does not coincide with the reproduction event but rather with the result of a reproduction event that must have occurred earlier. Therefore, the reproduction event itself is shifted in time by as much as it takes for the population to grow from zygote to ca. 150 μm plus the time required for this size fraction to settle to 700m water depth (where the sediment trap is placed). For the most abundant fraction (100-200 μm), the settling velocity is less than 170m/day (Bijma et al., 1994), resulting in a delay of more than 4 days to a trap at 700m. We don't know how long it takes for a zygote to grow to 150 μm but a week seems a reasonable educated guess. Hence, the timing of the reproduction event would be about 11 days before the flux arrives in the trap. I suggest that the authors include something along these lines.

The reviewer makes a valid point with regard to the phasing between abundance and reproduction. However, sediment traps do not register abundance in the water column, but the export flux of dead specimens. Since gametogenesis concludes the life of planktonic foraminifera, the timing of the export flux thus closely tracks reproduction, at least for the specimens that have gone through a complete life cycle.

We have now stressed this point on page 8, line 10-12.

2. A lunar based flux could not be demonstrated for all forams under consideration. However, it seems realistic to assume that ALL planktonic foraminifera must have mechanisms to synchronize their reproduction in time and space! Asexual reproduction has never been observed in planktonic foraminifera. Based on the fact that, in almost 40 years of culture studies, only gametogenesis has

been observed, the assumption that they can only reproduce sexually seems very reasonable. At average densities of ca. 10 specimens/m³, and realizing that the gametes of these protists have a limited life-time of ca. 24 hours, during which they do not get dispersed that far from the parent cell, there simply is no other way to explain the dominance of planktonic Foraminifera in pelagic sediments than by a strategy of simultaneous gamete release at a defined point in space and time.

We agree, which is also the reason why we refrained from stating that lunar reproduction was absent in these species in the original submission. However, we have now analysed size fractionated flux data and find lunar periodicity in the one or more size classes in 11 species present in the Gulf of Mexico. These new analyses thus confirm the hypothesis that lunar synchronised reproduction characterises (many species of) planktonic foraminifera.

3. In the method section, please explain the concept of "Nyquist frequency". Further, it was unclear to me how the authors "linearly detrended and normalised to unit variance"? Could you please rephrase? With regard to REDFIT, the authors state "which takes reddening of spectrum due to memory effects into account". It would be good to spend a few words on what that means.

The Nyquist frequency is half the sampling rate; we have replaced this with the average resolution of the time series. To further improve clarity we have added a reference that explains the wavelet transform and changed the section. It now reads (changes in italics):

'The average sampling resolution of the time series is ~9 days, which is more than sufficient to resolve lunar cyclicity (period 29.5 days), but insufficient to resolve semi-lunar cycles. Each size-specific time series was analysed by the mid date of the collection interval. Prior to analysis linear trends in the data were removed and all fluxes were normalised to unit variance. Spectral analysis was performed in R using REDFIT (Bunn, 2008; R core team, 2013; Schulz and Mudelsee, 2002), which uses a first-order autoregressive (AR1) process to account for memory effects associated with autocorrelation in the a time series to estimate spectral peak significance. To estimate the temporal patterns of spectral power in the lunar frequency band, continuous Morlet wavelet transform was performed on linearly interpolated data (7 day resolution) using the dplR package (Bunn, 2008; Rioul and Vetterli, 1991).'

4. In the figure caption of Fig. 3 the authors state: "Raw shell flux (grey) overlain with the squared power of continuous Morlet wave transform at the lunar frequency (black)." This should be explained in the main text : What is "the squared power of continuous Morlet wave transform at the lunar frequency"?

Please see our response to the comment above for the changes that will be made to the methodology section. The figure caption has been simplified and now reads:

'Temporal expression of lunar periodicity in shell flux of G. siphonifera (for other species see Fig. S2). Raw shell flux (grey) overlain with the squared spectral power at the lunar frequency (estimated using continuous Morlet wave transformation, see Material and methods; black). Lunar periodicity tends to be more expressed (have higher power) when fluxes are higher.'

5. All ontogenetic stages within a life cycle of planktonic Foraminifera are found at any time and every depth, and understanding what the majority of the population does, in space and time, can best be resolved by looking at the residuals of the relative frequencies of size classes as a function of time and depth (see Bijma and Hemleben, 1994). If it can be done easily, I suggest to add an additional plot based on Fig. 1 by overlaying the residuals of the fluxes on a lunar basis, i.e. one lunar cycle on the x-axis (1-29.5 days) and average the residuals of six years of lunar months on the y-axis (i.e. the average of each day within a lunar month, normalized to the total flux of that month). I'm not sure if this will improve a conclusion with regard to the timing of maximum flux but it may be worth a try and might even help to resolve semi-lunar cycles (G. ruber; G. siphonifera type 1 and 2?).

The method used by Bijma & Hemleben (1994) applies to plankton net observations and cannot be applied directly to sediment trap data as these do not provide information on the depth distribution of the foraminifera. Nevertheless, we have looked at the residual fluxes, but this does not improve upon the simple method of peak counting which we have applied. We therefore prefer to use the original figure.

Resolving semi-lunar cycles is unfortunately not possible given the resolution of the time series.

6. If possible, it would be interesting to separate the fluxes of *G. trilobus* and *G. sacculifer sensu stricto*. Bijma and Hemleben (1994) found that reproduction of the “sac-like” morphotype was linked to new moon whereas “trilobus” seemed to peak around full moon.

This would indeed be interesting, but unfortunately, we have not separated *G. trilobus* and *G. quadrilobatus* from *G. sacculifer* for the purposes of our census counts.

7. When the authors talk about *G. siphonifera*, can you specify if this is type I or II (see Huber et al., 1997 and Bijma et al., 1998).

As Bijma et al. (1998) and Huber et al. (1997) point out, it is difficult to differentiate between Type I and Type II morphotypes of *G. siphonifera* using empty tests found in sediment traps (as opposed to living specimens used in these studies). The morphometric differences are subtle, and attempting to classify them is likely to prove quite subjective, so we chosen not to attempt differentiation.

8. The authors state that “In *G. siphonifera* the ratio is >1 , indicating that the lunar cycle has a larger amplitude than the annual/seasonal cycle. This clearly highlights the importance of lunar periodicity on shell flux variability.” Maybe it is worth mentioning that therefore this species may be best suited to provide the best annual mean geochemical data for paleo reconstructions (as opposed to species that experience stronger seasonal variability).

It is true that this is the case for *G. siphonifera* in the gulf of Mexico, but Fig. 1 also shows that the its shell flux is far from even throughout the year. Moreover, there is no such thing as a ‘fixed seasonality’, in fact flux-weighted temperature offsets in this species vary between -2.5 and 4°C (Jonkers and Kučera, 2015). It would therefore be misleading to suggest that *G. siphonifera* (or any other species) ‘is best suited to provide the best annual mean geochemical data for paleo reconstructions’. In addition, the geochemistry of this species is significantly affected by differences between type I and II, which are nearly impossible to distinguish in the sediment (Bijma et al., 1998; Huber et al., 1997) and very little geochemical calibration work has been published on *G. siphonifera* up to this point, also arguing against *G. siphonifera* providing the ‘best annual mean geochemical data’. We therefore refrain from including such a statement.

9. Several times in the discussion, the authors refer to the fact “that lunar periodicity on the shell flux at a site also exhibits substantial temporal variability in amplitude.”. I assume that this might be due to temporal differences in mortality during ontogeny (i.e. between the different size classes) which affects the contribution of each size class to the total number of shells collected every week in the trap cups (cf. my first comment).

This simply reflects the fact that the total flux also exhibits variation at other frequencies, such as annual or semi-annual cycles and indeed reflects temporal differences in reproductive success.

Technical corrections

1) Page 7; line 14: “and Be, 1984) and differences settling time between the two species are unlikely....” should be “and Be, 1984) and differences in settling time between the two species are unlikely”.

Addressed.

2) In the caption of Fig. 2 it is stated that “The horizontal black line indicates the 6 dB bandwidth”. I do not see this black line?

We have added to the figure caption that the bar is in the upper left panel.

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