Temporal variability of live (stained) benthic foraminiferal faunas in a river-dominated shelf – Faunal response to rapid changes of the river influence (Rhône prodelta, NW Mediterranean)

Response to the Anonymous Referee #2

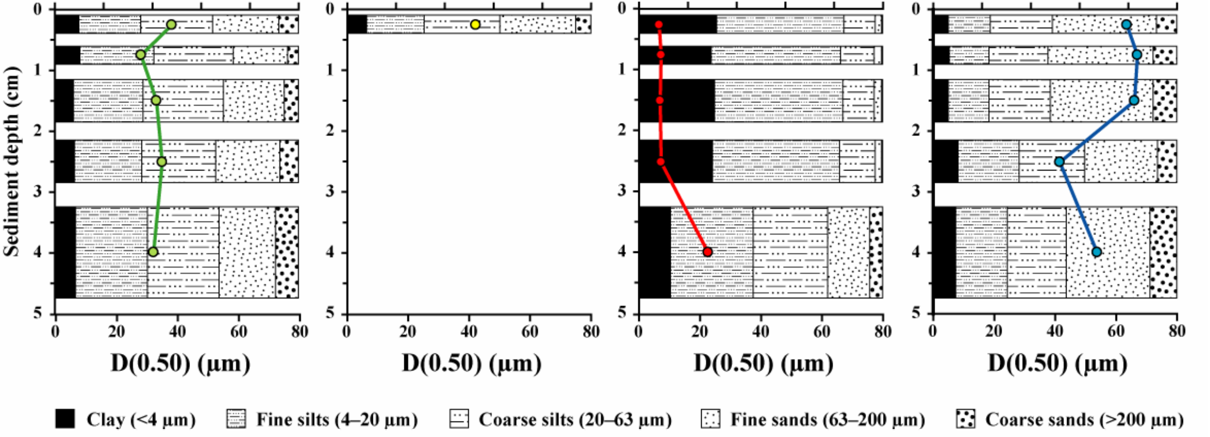
We thank the Anonymous Referee#2 for his/her review. Interestingly, some comments made by the Reviewer#2 are very close to the Reviewer#1's suggestions. Also, some of our responses have taken into account these complementary comments in order to improve our paper.
Please find our answers to the review below (abbreviations are RC: referee comment; AC: author comment).

RC The authors try to discuss about food inputs at prodeltaic environments. Exactly, it is important that phytodetritus deposition takes place after spring bloom. Opportunistic species certainly gather on seasonal phytodetrital layers. This is quite reasonable result. But, hydrological and sedimentological environments also should give quite strong influences to benthic foraminiferal communities. I ask to the authors that they should pay attention to changes in sediment characters among samples, in particular to silt-clay size fractions. Because, river transports quite a lot of clay fractions to the sea. Clay fractions should deposit on prodeltaic areas with forming sedimentary patches on sediment surface. Patchy distribution of these clayey sediments should give strong influences to benthic foraminifera, as detrital organic matters in finer fractions should be different from coarser fractions.

AC We agree with this suggestion. Grain size analyses were performed at both stations in the top 5 cm of sediment for April 2007, May 2008 and December 2008. However, only the top half-centimetre was analysed for September 2007 (see Figure 1). Nevertheless, supplementary analyses will be performed to get the complete grain size profile down to 5 cm depth at both stations for this sampling period.
Compared to station N, Station A displays important changes of grain-size distribution. (D(0.50) = 6.7–67.1 µm). At this site, largest differences are observed between May and December 2008, when both samplings were performed few days to weeks after major floods. In May, the top 3 cm of sediment are composed of 82–84% of clay and fine silts (<20 µm); this layer corresponds to the "*flood deposit constituted by very light liquid mud*" already discussed in the paper (page 9050, lines 27-28). Below, clay and fine silts contribution decreases down to 47%.
In December 2008, we observe 51–53% of sand (>63 µm) in the top 2 cm of the core. This coarse layer was also noticed in the discussion and will now be referred as "*an approximately 2 cm-thick surficial deposit of sandy sediments*" (page 9052, lines 3-4). This coarse sediment is likely related to strong reworking processes (winnowing of fine sediments, deposition of coarse particles) induced by flood and/or wave-induced bottom currents. Despite significant sedimentary differences between May and December 2008, organic carbon and labile organic compounds show quite similar contents in the top half-centimetre of both periods. Similarly, when considering the two other sampling periods (April and September 2007), very close dissolved oxygen uptake values are recorded in the silty (D(0.50) = 38.5 µm) and in the sandy sediments (D(0.50) = 63.7 µm) of April 2007 and December 2008, respectively. On the contrary, sediments with similar grain size characteristics (i.e., April and September 2007: D(0.50) = 38.5–42.1

µm) present quite different DOU. Therefore, no clear correlation exists between sediment grain size, organic matter content and bio-geochemical processes related to its mineralisation. It seems “logical” when you consider that most geochemical processes occur in unsteady states in such river-dominated environment.

(a) Station A



(b) Station N

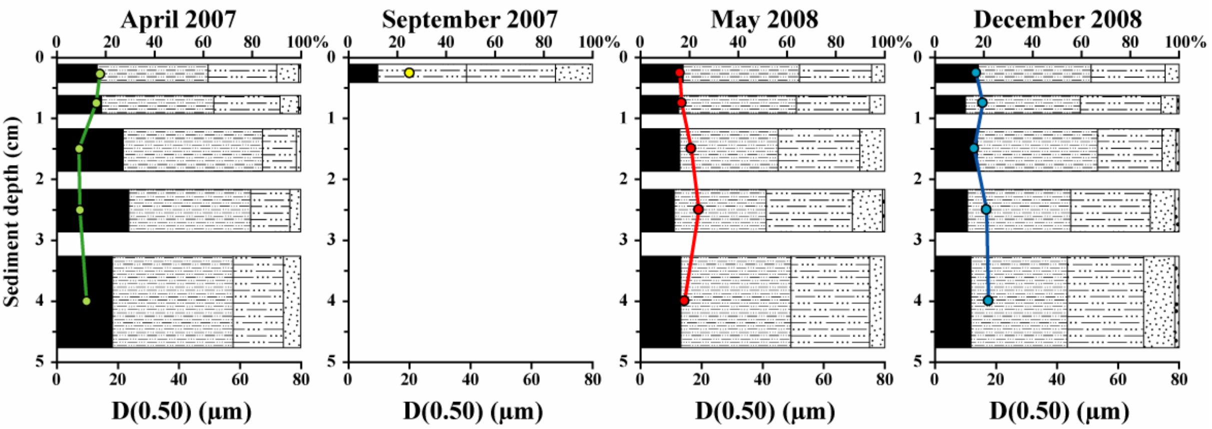


Figure 1: Sediment composition along the top 5 cm of the cores at both Stations A (a) and N (b) Horizontal bars represent clay, fine silts, coarse silts, fine sands and coarse sands contributions. Curves correspond to sediment median diameter D(0.50) for each sediment interval.

RC The authors try to refer Goineau et al., 2011b for discussing about patchy distributions of foraminiferal faunas. However, the paper is not appeared yet. The authors should also discuss patch topics in this manuscript, as we cannot refer the manuscript.

AC We have submitted a revised version of this paper to the Journal of Foraminiferal Research on 10th November 2011. Nevertheless, if we do not get its final acceptance before submitting a revised version of the present study in Biogeosciences, we will follow the Reviewer 2’s suggestion. In that case, we would refer to “Unpublished data” instead of “submitted”. In addition, we propose the following modifications in the text:

1. To remove from the introduction the textual part referring to the above-mentioned submitted paper (page 9036, lines 17-23);

2. To reformulate the introductive part of the discussion (page 9048, lines 10-17).
"*Foraminiferal datasets from ecological studies are usually established on the basis of one sample (i.e., core) per investigated station. Only few studies dealing with shelf environments (Buzas, 1968; Hohenegger et al., 1989, 1993; Buzas and Gibson, 1990; Silva et al., 1996; Swallow, 2000; Buzas et al., 2002; Morvan et al., 2006) have investigated the spatial dynamics of benthic foraminifera at a small spatial scale (<1 km). In these papers, small-scale (decimetric to decametric) spatial variability of benthic foraminiferal faunas exists and is generally explained by a patchy distribution of organic detritus at the seafloor. In our study area, unpublished data show that absolute abundances of major foraminiferal taxa at a single site may present a significantly patchy distribution at a decimetric scale. However, the variability of foraminiferal percentages (i.e. relative abundances) is not significant. Since our temporal survey of benthic foraminiferal faunas was performed with only one core per investigated site and per sampling period, the following discussion is based on percentage data of the major species.*"

3. To reformulate the text on page 9055 between lines 10 and 13.
"*It is assumed that, in shelf environments, local accumulation of food particles in decimetric depressions can favour the growth of the most opportunistic taxa (e.g. N. turgida) by enhanced reproduction and growth (Buzas, 1968; Hohenegger et al., 1989, 1993; Buzas and Gibson, 1990; Silva et al., 1996; Swallow, 2000; Buzas et al., 2002; Morvan et al., 2006)*".

RC Faunal compositions of benthic foraminifera strongly change in time to time. The authors mainly use percentage data. But, absolute numbers in unit volume should show important information about life cycle and/or life history of each species.

AC As explained above, an unpublished work (submitted to Journal of Foraminiferal Research) performed in the Rhône prodelta has put into evidence a significantly patchy distribution of foraminiferal faunas (in both 63–150 µm and >150 µm size fractions) at a decimetric scale when absolute densities are used. For instance, in the 63–150 µm sized-fauna, these data show total absolute densities ranging between ~5070 and ~10370 ind./100 cm² in four cores sampled at a single site (distance between replicates from 16 to 66 cm). Based on these observations, we have considered that variations in absolute abundances between different sampling periods are partially informative and may lead to misinterpretation.

RC The authors stress that growth speed of some benthic species are extremely high. There are many investigations in terms of growth rate of benthic foraminifera. Please discuss carefully about growth of foraminiferal populations. Except for newly-born juvenile specimens, most of benthic foraminifera add new chambers a couple of days intervals. Growth rates should also be different from single-chambered species and multi-chambered species. Please carefully discuss about this point.

AC In our paper, we already tried to discuss carefully about reproduction and growth rates of benthic foraminifera for May and December 2008 sampling periods, when supposed pioneer faunas are observed at Station A few days to weeks after a flood event.
In May (2 days after the beginning of a flood), ~7500 individuals of *Leptohalysis scottii* (multi-chambered agglutinated taxon) are in place. As explained in our

discussion, "*culture experiments performed on sediments sampled in the northern Adriatic Sea near the Po outlet (32 m water depth) by Ernst et al. (2002) showed that L. scottii could enlarge its population by 80% in the three weeks following a simulated physical disturbance consisting in a gentle mixing of the sediment. [In our study,] it seems therefore unlikely that more than 7000 individuals/100 cm², most of them adults or pre-adults found in the >150 µm size fraction, were produced in only 2 days, in an environment impoverished in OM*" (page 9051, lines 13-19).

In December 2008, Cathalot et al. (2010) showed at a station close to the river mouth (45 m depth) that ~10 cm of soft mud were removed by a flood occurring 3 weeks before sampling. Therefore, similar processes likely occurred at our shallower Station A, removing also living foraminiferal faunas in place before the flood. Three weeks after this major disturbance, ~2000 individuals of *Ammonia tepida* (multi-chambered calcareous species) and ~400 specimens of *Psammosphaera fusca* (single-chambered agglutinated taxon) inhabit a newly-deposited flood layer.

Numerous culture experiments in laboratory conditions have focused on reproduction and growth rates of foraminiferal species from shelf environment (e.g., Bradshaw, 1955, 1957, 1961; Goldstein and Moodley, 1993; Stouff et al., 1999; Barras et al., 2009). Their results show that reproduction rates of *Ammonia tepida* and *Bulimina marginata*, two multi-chambered calcareous taxa, are constrained by sea water temperature, the quantity/quality of food supplies, but also the size of the starting pool of juveniles. For instance, Bradshaw (1955, 1957, 1961) reported a growth rate for *A. tepida* ranging from 4 to 84 µm/10 days. A more recent study by Stouff et al. (1999) reported that already calcified juveniles of *A. tepida* could form a third chamber within 24 hours after their release from the reproduction cyst, and a fourth chamber within a few hours. In our study, we assume that "*A. tepida and P. fusca may have colonised the newly deposited organic-rich flood deposit, profiting from their high tolerance for high-energy conditions*" (page 9052, lines 17-19). ~30% of the observed *A. tepida* were juvenile specimens (between 63 and 150 µm). According to culture experiments results presented above, it seems possible that this juvenile population was produced during the three weeks (~20 days) between the flood and time of sampling. This assumption can also be made for the pioneer opportunistic species *P. fusca*. Since this species produces only one chamber constituted by lithic elements, its reproduction and growth rates may be relatively fast (Kaminski, 1985; Kaminski et al., 1995; Fontanier et al., 2008).

RC It is a pity that the authors did not use down core foraminiferal community data, even though they have analysed up to 5 cm in down cores. Responses of benthic foraminifera to environmental changes should be different from infaunal species to epifaunal species.

AC Mojtahid et al. (2010) have published a study on benthic foraminiferal microhabitats in the Rhône prodelta. Their results show the difficulty in this area to divide benthic foraminiferal microhabitats into shallow, intermediate and deep infaunal taxa. Indeed, the oxygen penetration depth is very shallow in the whole prodelta (<1 cm), and most foraminifera live in the topmost centimetre of the sediment. Nevertheless, they distinguish two vertical distributional patterns: (1) "predominantly superficial taxa" that occur with a strong maximum in the oxygenated layer of the sediment and (2) "potentially/predominantly infaunal taxa" which are found deeper in the sediment in considerable densities.

Moreover, the Rhône prodelta is characterised by important sediment deposition rates and organic carbon fluxes, leading to a deep sediment surface mixed layer in the whole prodelta (i.e., ~7–10 cm depth; Miralles et al., 2005). Considering these dynamic conditions and the lack of clear vertical distribution patterns of benthic foraminiferal faunas (Mojtahid et al., 2010), we decided not to present this parameter in our study. Nevertheless, we followed the Reviewer 1's suggestions and decided to present the vertical distribution of the living faunas of Station A in May 2008 and in December 2008, when sampling was performed during/after flood events. For more details, please refer to our answers to Reviewer 1's comments.

RC Colonisation of benthic foraminifera on specific sediment, for instance, flood deposits may take place with several different mechanisms. Down slope transportation with dense clayey flow is one of important mechanisms at deltaic environments. In the case, it may remain some fabrics in sediments. If the authors measure sediment fabrics for every core, it may be important to show these data.

AC Unfortunately, no measurements of sediment fabrics have been performed on any core or at any station. Nevertheless, we have porosity data which have already been published by Cathalot et al. (2010). In this last paper, the authors show that porosity decreases gradually with depth with relatively high values in the top 2 mm of sediment (i.e. 0.85–0.9). Station N shows constant porosity profiles with time, contrary to Station A located at the river outlet. According to the authors, these variations in porosity profiles are linked to large changes in grain size between the different sampling periods (D(0.50) = 6.7–63.7 µm), and so to the Rhône River regime (i.e. nor mal to flood conditions). Considering these conclusions, and as proposed by Reviewer 2' in his/her first comment, we think that data on sediment granularity would be more suitable and give more interesting information for our study.

RC There are many ecological observations for shallow water benthic foraminifera, such as food preferences, growth rates and reproduction cycles. The authors are requested to introduce these observational data into discussions for establishment of ecosystem modelling about prodelta-dwelled benthic foraminiferal community.

AC In our submitted paper, we wrote syntheses at the end of discussion sections dealing with foraminiferal faunas of both Stations A and N. The aim was to give the main trends put in evidence for foraminiferal composition at each study site, i.e. the main factors visibly influencing population dynamics.

Also, we propose a figure (Figure 2, see on the next page) to illustrate and strengthen the synthesis for Station A, i.e. the study site were clear and obvious variations in both environmental conditions and foraminiferal faunal composition were observed over the four sampling periods.

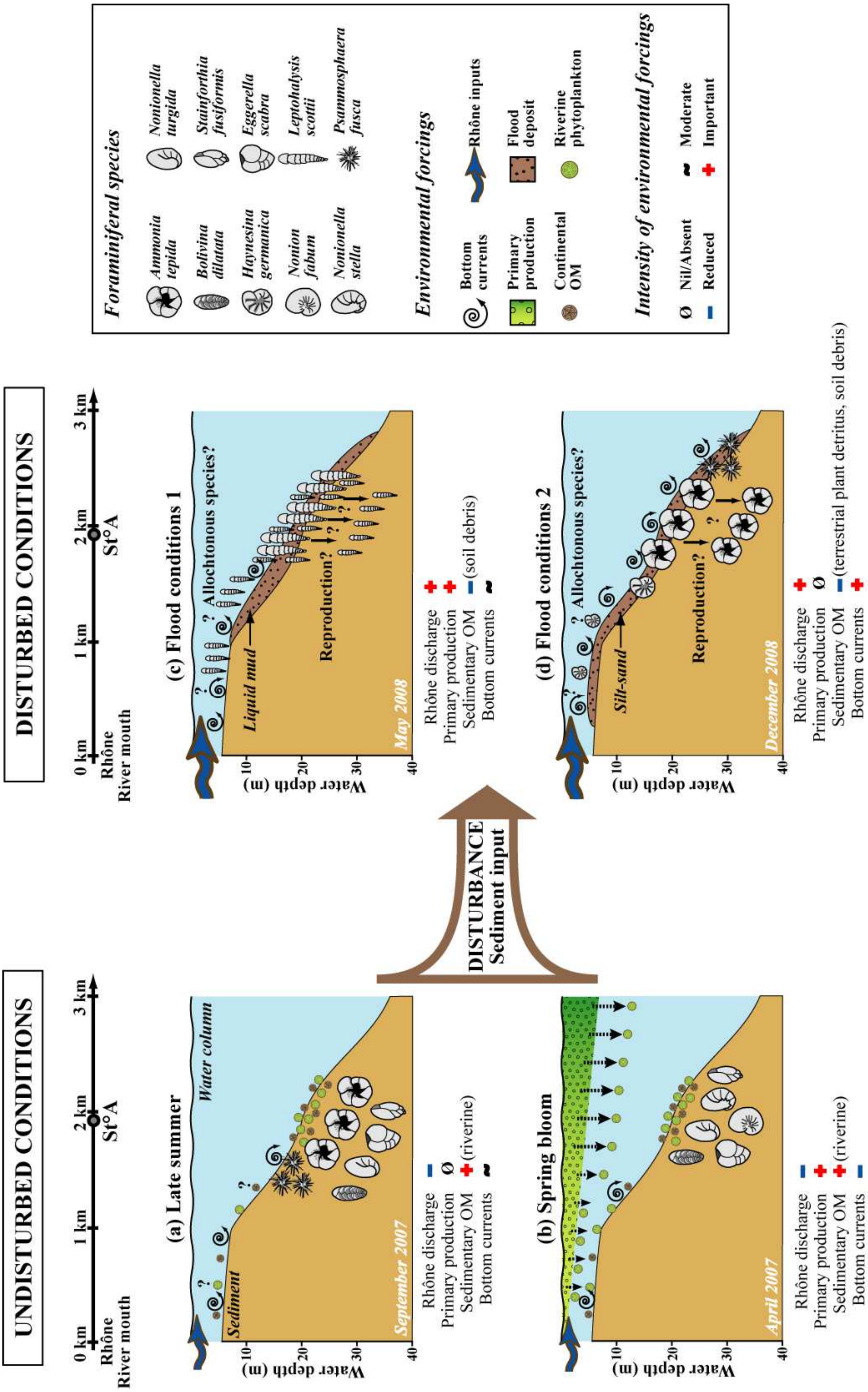


Figure 2: Synthetic picture of the processes influencing the foraminiferal faunal composition during the four investigated periods at the shallowest Station A.

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