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Small mollusks and big cooling

Molluskan response to the Eocene-Oligocene Transition

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General Background

The early Eocene was a relatively warm period during with large numbers of tropic and warm-water biotas. Global surface temperature decreased through the Middle Eocene and into the Late Eocene by 4 to 5 degrees (Prothero et al, 1994). At the end of the Late Eocene a much more rapid cooling took place, the Eocene Oligocene transition (EOT). During the EOT a stepwise increase in $\delta^{18}O$ occurred (Lear et al, 2008). The buildup to the most positive oxygen isotope values took two steps, each of 40 kyr and with a 200 kyr interval. The first increase in $\delta^{18}O$ was caused by cooling and the second by an increase in ice volume and a drop in sea level. After the EOT, $\delta^{18}O$ had increased by 1‰ and the temperature had dropped by 4 degrees (Pearson & Coxall, 2007). The Eocene Oligocene boundary (EOB) itself is defined by the extinction of the foraminifer Hantkeninia, which went extinct during the 200 kyr interval (Berggen et al, 1995). Also, re-organization of continents coincide with changes in ocean circulation and the thermal isolation of Antarctica(Pearson & Coxall, 2007). These changes might have caused the increase in oceanic mixing and higher nutrient availability. During the Eocene several extinction events can be distinguished, one at the end of the Middle Eocene, one during the Late Eocene and one during the EOT (Hansen et al., 1987). This research focuses on the EOT extinction. Some of these EOT extinctions have already been described, for example the extinction of certain planktonic foraminifera (Cotton & Pearson, 2011) and certain nanofossils (Dunkley Jones et al, 2008). The response of mollusks to the EOT however has not been extensively studied.

Specific Background

Mollusks provide a unique insight into environmental conditions due to their specific life habits, feeding and reproduction (Hansen et al., 2004). However, little detail is known about their exact response during the EOT. Few complete shallow water EOT sections exist due to the sea level fall, which is associated with an increased ice volume in Antarctica, which led to subsequent erosion. Deep-water sections are even more rare or have not been investigated for mollusks. Additionally, many of those that do exist do not contain a well preserved mollusk fauna. The mollusk record across the EOT therefore remains patchy with the majority of studies based on North American localities (Prothero et al, 2003). In 2009, three drill sites, part of the Tanzania Drilling Program (TDP), span the EOT and contain a diverse, well-preserved deep-water mollusk fauna. The Tanzania Drilling Project is an enterprise to recover and investigate Cretaceous-Paleogene sediments for climatic and paleontological research (Bown et al., 2008). The mollusk fossils from these three cores have been used in this project to reconstruct mollusk response to the EOT at high resolution (Bown et al., 2008).

Methods

During the Tanzanian Drilling Project three sites (11, 12 and 17, figure 1) were drilled to recover EOT sediments (Pearson et al., 2008). They were within 3 kilometers from each other (TDP 11 — UTM 37L; 560250 8983211; TDP 12 — UTM 37L; 560222 8981309; TDP 17 — UTM 37L; 560539 8984483; Nicholas et al., 2006, For detailed information on the TDP cores; Nicholas et al, 2006.) The lithology of these sites consists of clay-rich, hemipelagic sediments which contain exceptionally well preserved calcareous fossils. The cores contain a wide variety of mollusk shells. Apart from the mollusks, the site has already been extensively studied. Pearson et al (2008) studied the same cores (11, 12 and 17) and they have generated an age model using biostratigraphic datums and geochemical tie-points. (5) This model can be used to look at the mollusk ranges and tie them to climatic events.

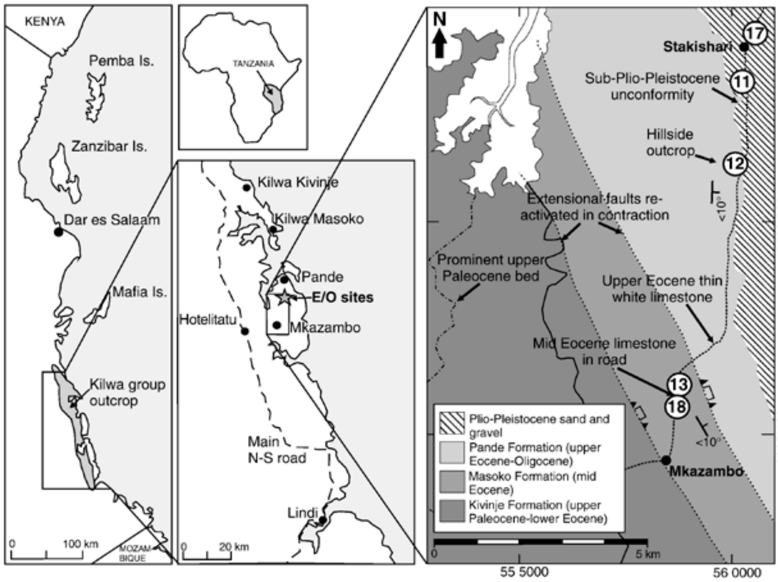


Figure 1. The location and geological maps of the Tanzanian Drilling Project EOB sites 11, 12 and 17. Additional sites in the area are also shown (picture from: Cotton, 2011)

The hemiplegic clays were washed down with a 63 micrometer sieve and the residues dried (Pearson et al, 2008). The samples from the TDP cores were packaged in plastic bags containing an identification code (TDP core section). These samples were filtered using a 500 micrometer sieve. Using a microscope, any present fossil mollusks were transferred to a plastic microscopic slide. The resulting 188 fossil depth assemblages were sorted into different morphotypes and, if possible, identified up to genus level. The identifications were made under the guidance of F.P. Wesselingh (Naturalis). No literature exists on Paleogene deep-water mollusks to my knowledge and identifications were not able to carry out to species level. Counts of mollusks through the cores were carried out.

Data analysis

A sample rarefaction (figure 10, addendum) was computed using PAST ver. 2.17c and this revealed that the sample sizes were too small; too small to get a comparison between depths, (data not shown). Using the rarefaction, minimal sample size should be at least 100. To reach this amount, data was binned for each 10 meter composite depth (mcd). This resulted in nine consecutive samples ranging from 40 to 120 mcd.

NMDS

On the species x 10mcd sample database we first performed a non-metric multidimensional scaling (NMDS). The nine binned samples were analyzed using PAST, using the Bray-Curtis distance measure (df=8). Depth in the core and the Oxygen isotope as an indicator for temperature were used for the environmental variables.

Total mollusk abundance

Total abundance of mollusks was plotted for each 10mcd bins

Biodiversity

To account for the possible change in biodiversity two diversities were measured with the x10 mcd sample database; the standing diversity (amount of mollusk species found at each depth interval) and the range-through diversity (amount of mollusk species found at each depth interval + species that are present both before and after the interval). However, due to unequal sample size, no additional statistics were possible.

Functional groups, ANOVA

To investigate functional group turnover, the mollusks were grouped together. This resulted in five functional groups (chemosymbiont, herbivore detrivore, parasite, carnivore and filter feeder) and one rest group (unknown). These groups were then compared to each other and their combined total was set at 100% for each of the nine binned samples. Afterwards, three groups would be compared to each other; the three Eocene samples (100-120), earliest Oligocene (70-90) and later Oligocene (40-60) and for each functional group. Comparing these two factors, depth and functional group, was done using an Analysis of Variance (ANOVA)(H0; no interaction between depth and functional group). To analyze the interaction, the interaction table was calculated. This was all done using IBM SPSS Statistics 21.

Functional groups, species details

Seven highly abundant species were selected for a detailed analysis. These seven contain four herbivore detrivore species, two carnivore species and one filter feeder. They were adjusted for the amount of sediment sampled, so they now are all ‘specimen found per centimeter composite depth’. They were combined with the $\delta^{18}O$ isotope data from the same cores (Lear et al, 2008), which is the $\delta^{18}O$ response over the EOT. Using this response, the isotope stepd (temperature drop and the sea level drop) could be shown.

Results

1-species identified

The three TDP cores conveyed a total of 188 depth samples with 89 mollusk morphotypes, 20 bivalves and 69 gastropods. A total of 58 gastropod and 19 bivalves species were identified.

2-Mollusk reaction to the EOT

The depth binned data with three Eocene data points (mcd 120-100) and six Oligocene, subdivided in three earliest Oligocene (mcd 70-90) and three later Oligocene data points (mcd 40-60), reveal a grouping of the three periods (figure 2). On the right, the three Eocene samples are grouped together. On the top left, the three earliest Oligocene are close together and on the bottom left the later Oligocene. This first data indicates that there is a response by the mollusks during the EOT. The stress value of 0,08088 indicates a good representation.

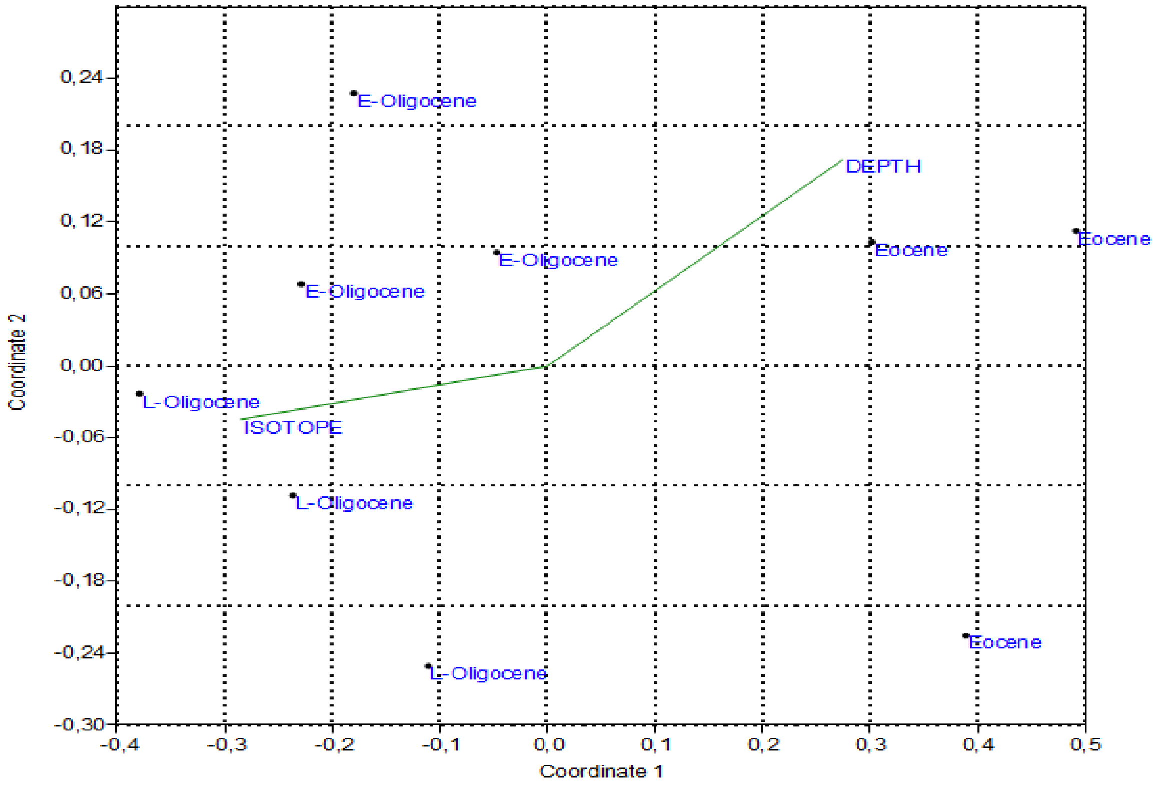


Figure 2. Non-metric multidimensional scaling (NMDS) with three groups, Eocene, Early Oligocene and Late Oligocene. The two variables are DEPTH (40, 50, 60, …, 120 mcd) and ISOTOPE (average δ^{18}O at each depth; -2.35, -2.30, -2.17,… -2.98). The three groups can be sorted; Eocene in the right, Early-Oligocene in the top left and Late Oligocene in the bottom left. The stress value is 0,08088. (PAST output)

3-Total number of specimens

The total number of mollusks found is shown in figure 3. The amount of mollusks that were found differs over time, or mcd. From 130 to 200 mcd the amount of specimens found was extremely low, at around 10 specimens every ten meters or one specimen per meter. After 130 mcd the mollusks became more abundant, rising to around 300 per 10 meters. Around the EOB I found less specimens, just over one hundred. Immediately after the EOB they returned to more than 300 specimens. At 60 mcd the amount peaked at approximately 550 specimen. However, due to unequal sampling, no statistics were possible.

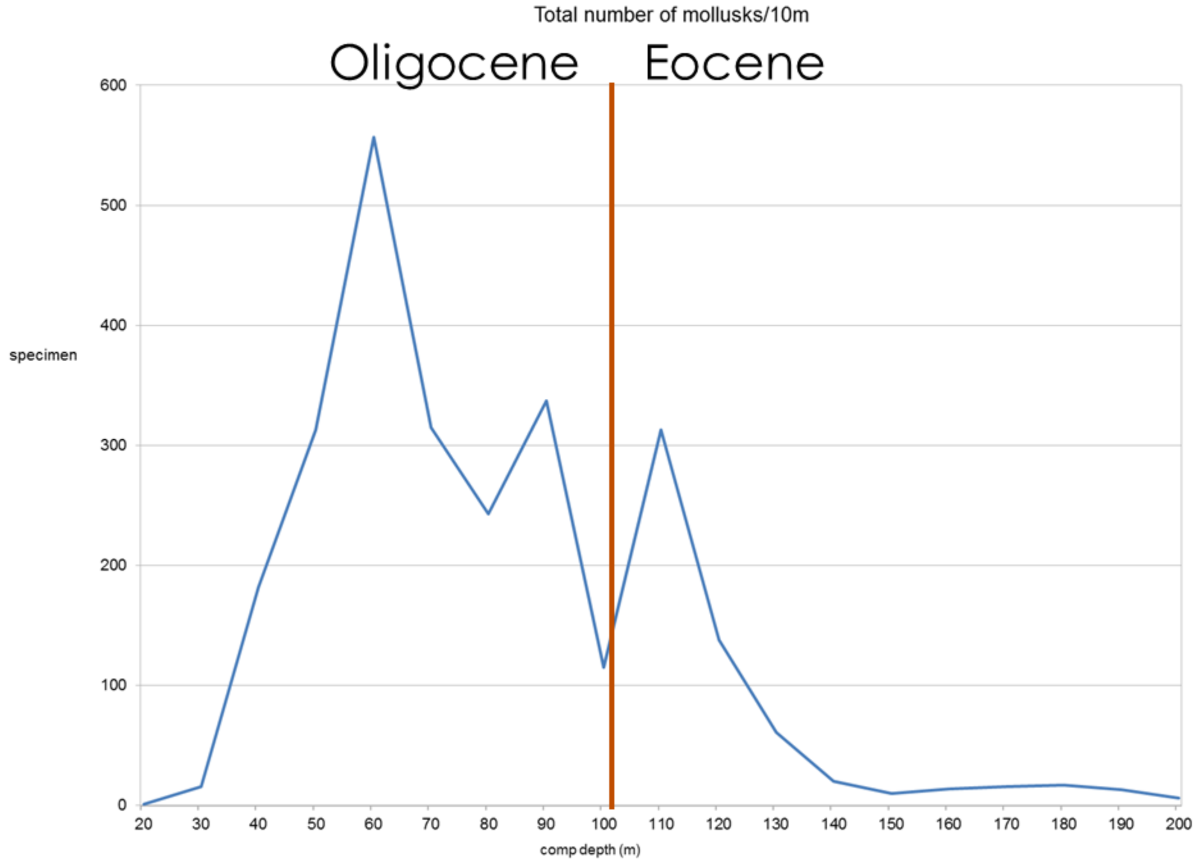
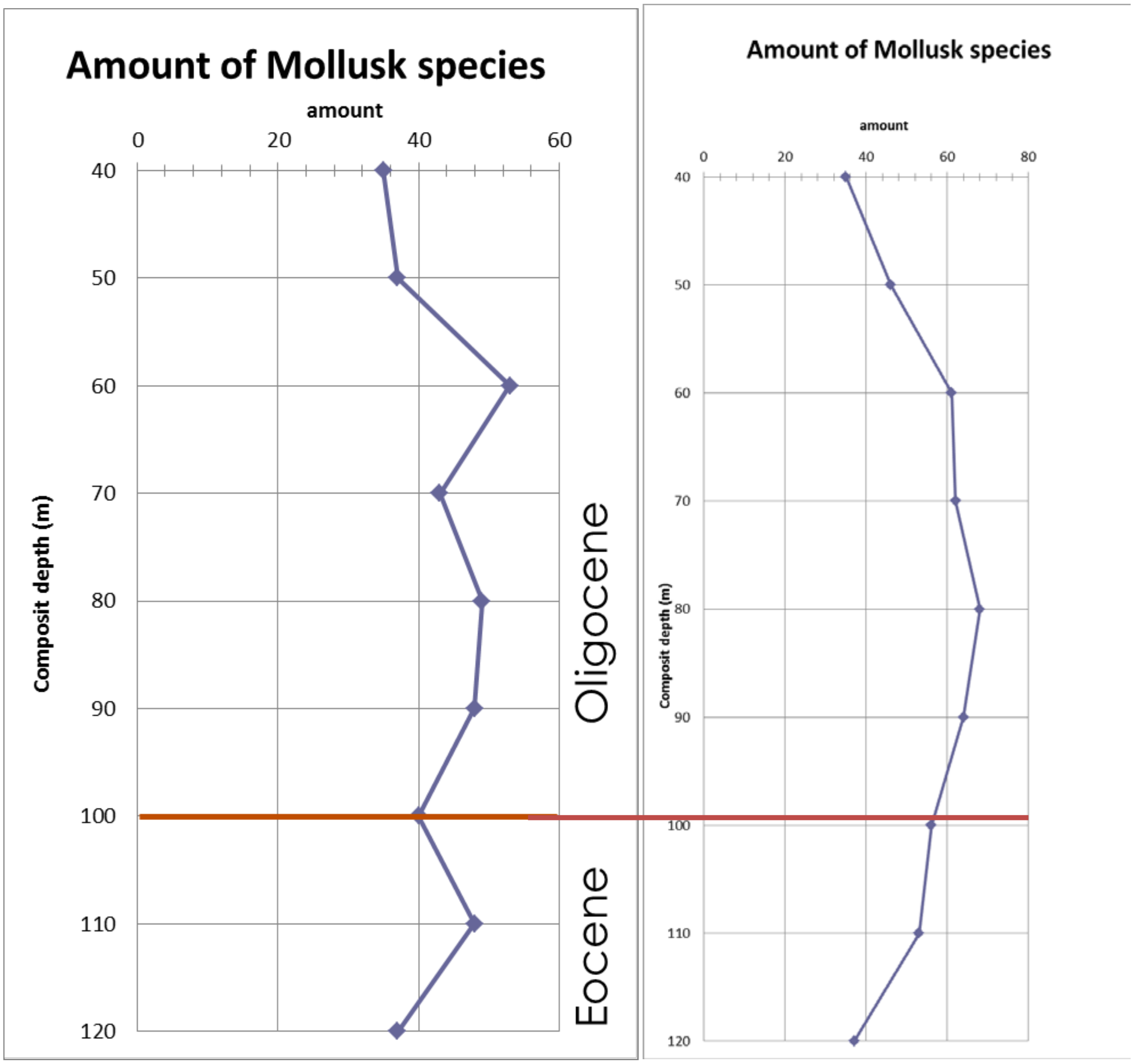


Figure 3. Graph showing the total amount of Mollusks found in different depth intervals (10 mcd). The red line indicate the EOB, with the Oligocene on the left and the Eocene on the right. (Excel output)

4-Diversity

Figure 4 (left) depicts the Mollusk standing biodiversity during the EOT. A first glance reveals a slight peak at 60 mcd and a minor decline at 100 mcd, the EOB (102 mcd). The outer data points, at 120 mcd and 40 mcd are also lower. The highest biodiversity was found at 60 mcd, with just over fifty mollusk species. However, the biodiversity shows no discernable pattern over time and the number of species is consistently over 30 and averages around 45 different species. Figure 4(right) shows the range-through diversity. This data shows a peak at the center, at 80 mcd and a gradual decline towards the ends, 40 mcd and 120 mcd. The range-through diversity shows no discernable pattern either.



Standing diversity

Range-through diversity

Figure 4. Graphs showing the total number of species found in different depth intervals (10 mcd), left is standing diversity, right is range through diversity. The red line indicates the EOB and the lower part is the Eocene and the top part the Oligocene. (Excel output)

5-Response of functional groups

The identified mollusk species were grouped into five different functional groups, based on their feeding strategies. The five categories are chemosymbiont (CB), herbivore detrivore (HD), parasite (P), carnivore (C) and filter feeder (F). The unidentified species compose the sixth category unknown (U). The Herbivore Detrivore group increase from 30 to 40 percent when it crosses the EOB (figure 5). This result is almost significant (p=0,051, figure 6, A) and is significant when we compare the Eocene with the Late Oligocene (p=0,034, figure 6, B). In contrast, the Parasite group plunges when it crosses the EOB (p=0,016, figure 6, C), dropping from 25 percent to just over 10 % in the early Oligocene and just under 10% in the later Oligocene. The filter feeders show little response over the EOB, but during the Oligocene they rise. This increase is almost significant (p=0,074, figure 6, D).

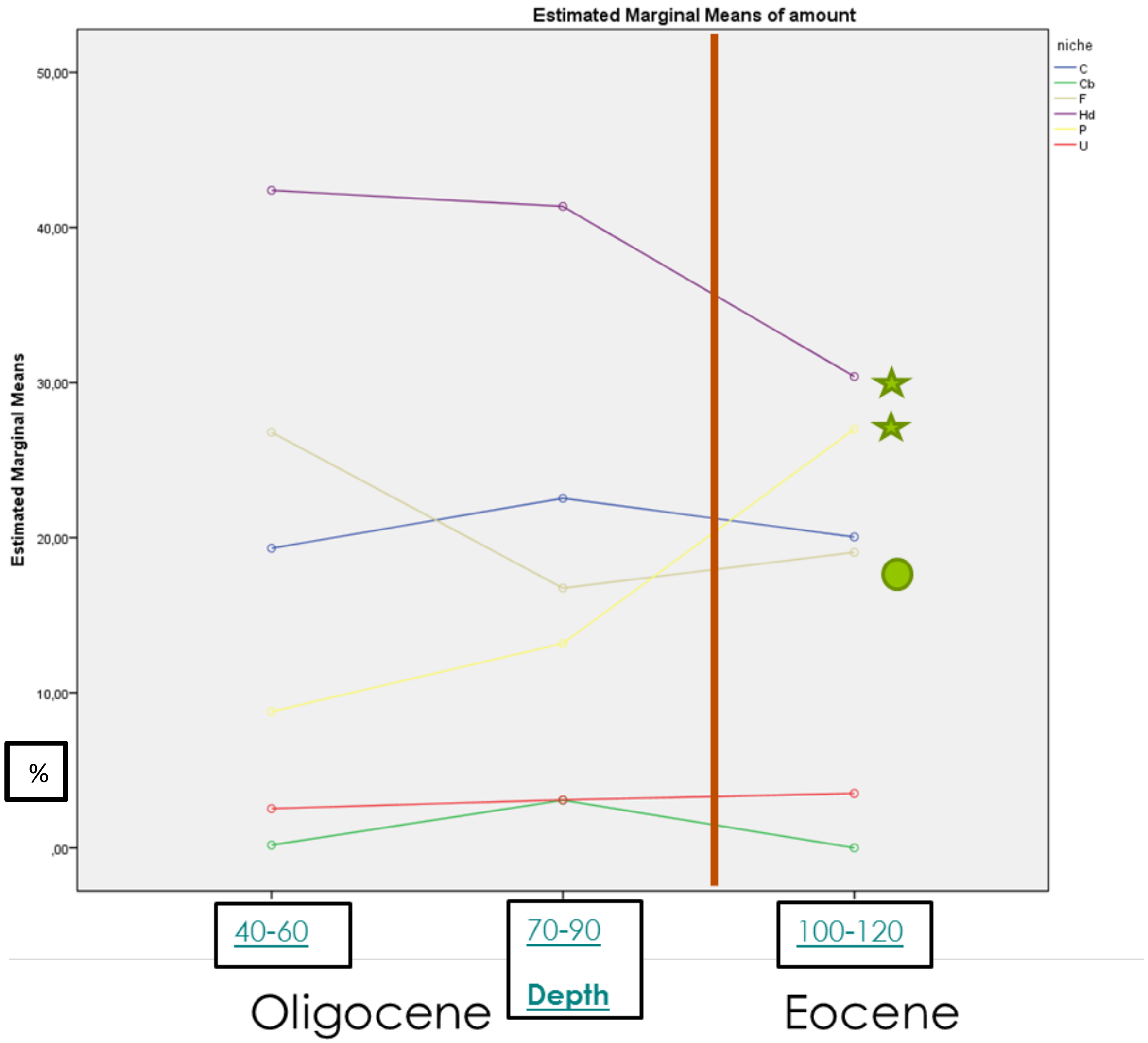
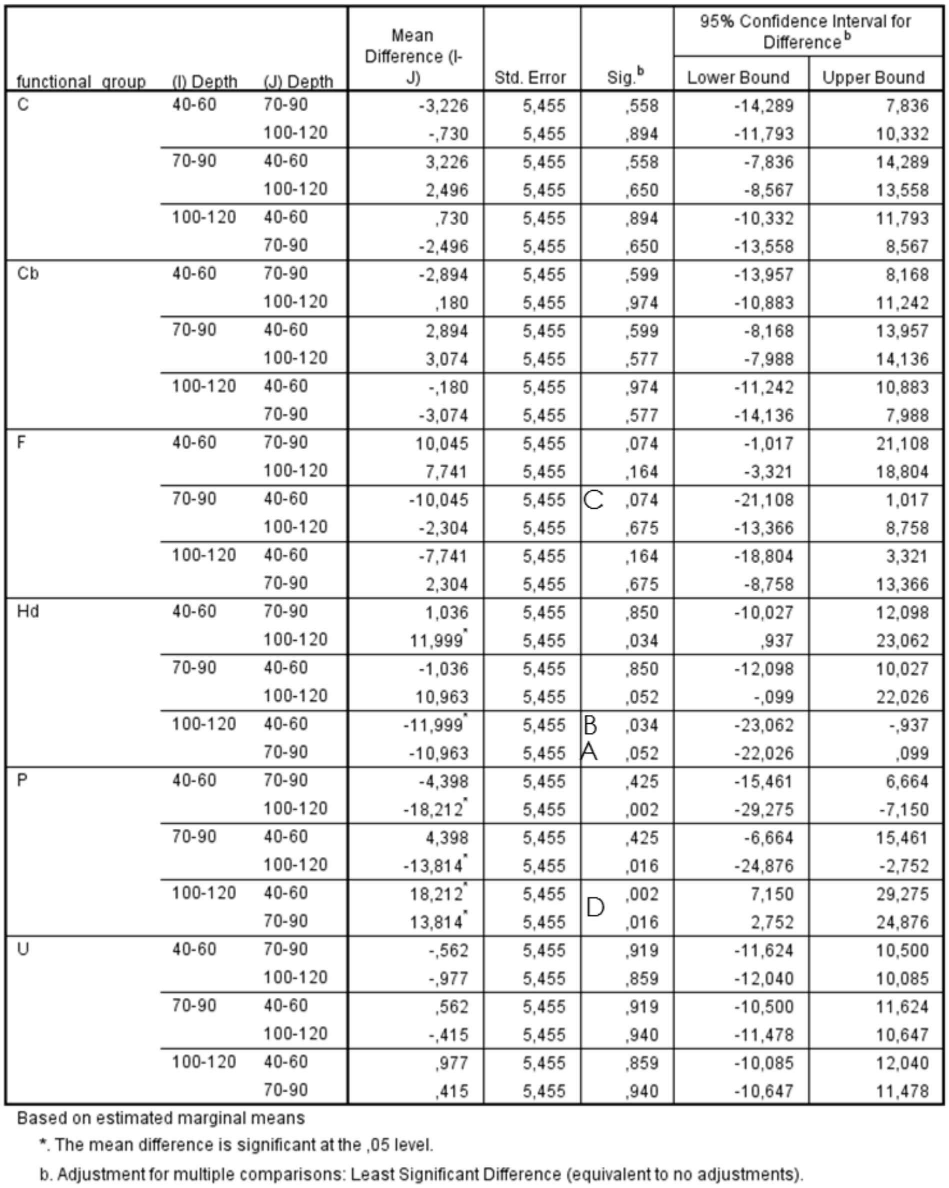


Figure 5. Graphs showing the response of five functional groups of Mollusks during the EOT. The five functional groups are carnivore (C, Blue), chemosymbiont (Cb, green), filter feeder (F, brown), herbivore detrivore (HD, Purple) and parasite (P, Yellow). The last group is unknown (U, Red). The vertical red line indicates the EOB, with on the left the Oligocene and on the right the Eocene. Stars indicate a significant response(p<0.05) and circles indicate an almost significant response (p<0,10). Data is in percentages and binned for each thirty meters. (SPSS output)



functional_group	(I) Depth	(J) Depth	Mean Difference (I-J)	Std. Error	Sig.[b]	95% Confidence Interval for Difference[b]	
						Lower Bound	Upper Bound
C	40-60	70-90	-3,226	5,455	,558	-14,289	7,836
		100-120	-,730	5,455	,894	-11,793	10,332
	70-90	40-60	3,226	5,455	,558	-7,836	14,289
		100-120	2,496	5,455	,650	-8,567	13,558
	100-120	40-60	,730	5,455	,894	-10,332	11,793
		70-90	-2,496	5,455	,650	-13,558	8,567
Cb	40-60	70-90	-2,894	5,455	,599	-13,957	8,168
		100-120	,180	5,455	,974	-10,883	11,242
	70-90	40-60	2,894	5,455	,599	-8,168	13,957
		100-120	3,074	5,455	,577	-7,988	14,136
	100-120	40-60	-,180	5,455	,974	-11,242	10,883
		70-90	-3,074	5,455	,577	-14,136	7,988
F	40-60	70-90	10,045	5,455	,074	-1,017	21,108
		100-120	7,741	5,455	,164	-3,321	18,804
	70-90	40-60	-10,045	5,455	C ,074	-21,108	1,017
		100-120	-2,304	5,455	,675	-13,366	8,758
	100-120	40-60	-7,741	5,455	,164	-18,804	3,321
		70-90	2,304	5,455	,675	-8,758	13,366
Hd	40-60	70-90	1,036	5,455	,850	-10,027	12,098
		100-120	11,999*	5,455	,034	,937	23,062
	70-90	40-60	-1,036	5,455	,850	-12,098	10,027
		100-120	10,963	5,455	,052	-,099	22,026
	100-120	40-60	-11,999*	5,455	B ,034	-23,062	-,937
		70-90	-10,963	5,455	A ,052	-22,026	,099
P	40-60	70-90	-4,398	5,455	,425	-15,461	6,664
		100-120	-18,212*	5,455	,002	-29,275	-7,150
	70-90	40-60	4,398	5,455	,425	-6,664	15,461
		100-120	-13,814*	5,455	,016	-24,876	-2,752
	100-120	40-60	18,212*	5,455	D ,002	7,150	29,275
		70-90	13,814*	5,455	,016	2,752	24,876
U	40-60	70-90	-,562	5,455	,919	-11,624	10,500
		100-120	-,977	5,455	,859	-12,040	10,085
	70-90	40-60	,562	5,455	,919	-10,500	11,624
		100-120	-,415	5,455	,940	-11,478	10,647
	100-120	40-60	,977	5,455	,859	-10,085	12,040
		70-90	,415	5,455	,940	-10,647	11,478

Based on estimated marginal means

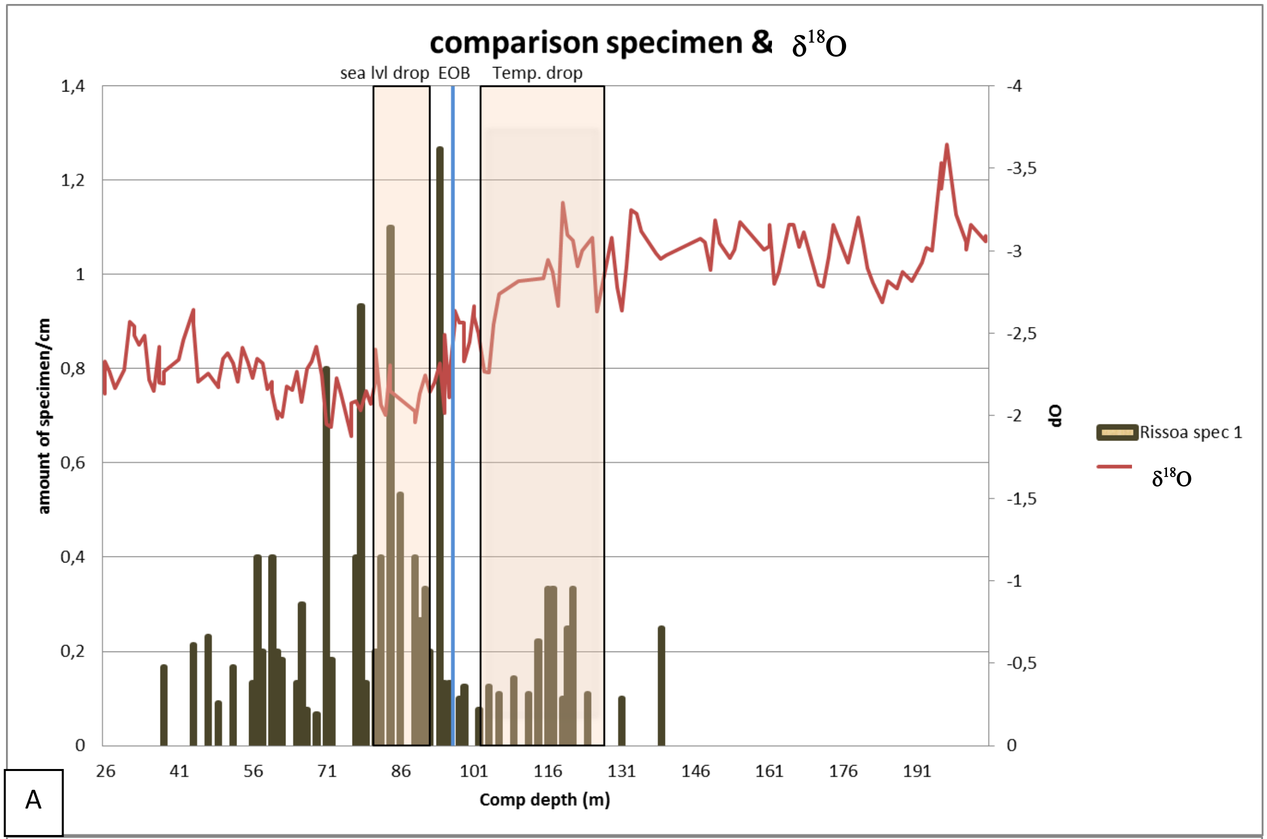
*. The mean difference is significant at the ,05 level.

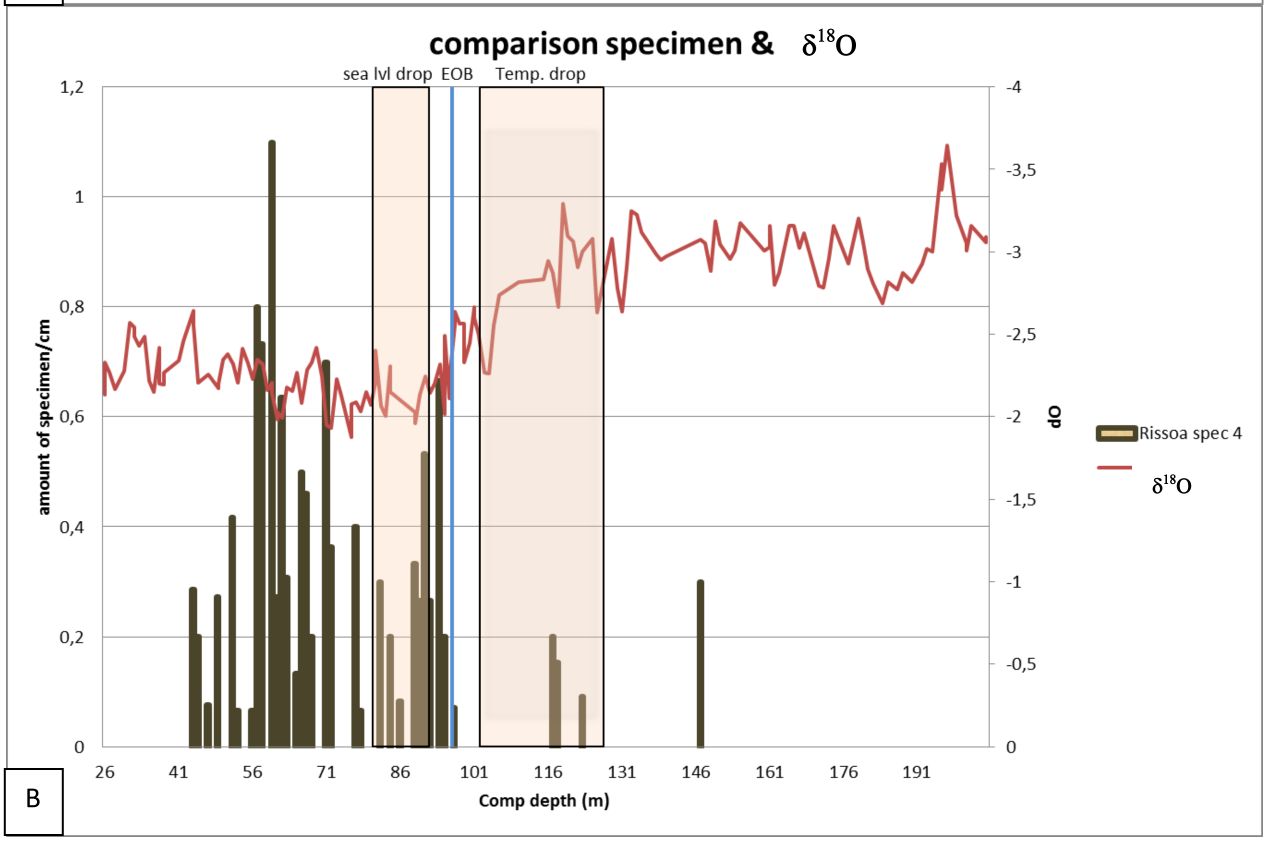
b. Adjustment for multiple comparisons: Least Significant Difference (equivalent to no adjustments).

Figure 6. Analysis of Variance (ANOVA) showing the comparisons between the depth intervals for each Functional Group. Almost significant differences are indicated with A (Hd difference between 10-12 and 7-9) and C (F difference between 7-9 and 4-6). Significant differences (<0.05) are indicated with B (Hd difference between 10-12 and 4-6) and D (P difference between 10-12 and 4-6). Data is binned for each thirty meters. (SPSS output)

6-Functional group response

Seven highly abundant (>100 specimen) species, four from the herbivore detrivore group, two from the carnivore group and one from the filter feeder group, were examined in detail. They are all plotted next to the high resolution ΔO_2 *isotope record* (Lear et al, 2008) *to compare them with the events of the EOT. These events include the cooling period and the sea level drop.* Three of the herbivore detrivore species, both *Rissoa* species (1 and 4) and *Teinostoma* have a very similar pattern (figure 7, ABC). They are all present in the Eocene in relatively low numbers and only *Rissoa* spec. 1 is consistently present though the temperature decrease. It is only after the EOB that they start to become more abundant. The fourth HD species, *Bittium* has a dissimilar pattern (figure 7, D). They are present at deeper stratigraphic depths and they are highly abundant right before the EOB, during the main temperature decrease . After the EOB, they are still present, but their numbers have decreased dramatically.


comparison specimen & $\delta^{18}O$
sea lvl drop
EOB
Temp. drop
1,4
1,2
1
0,8
0,6
0,4
0,2
0
amount of specimen/cm
-4
-3,5
-3
-2,5
-2
-1,5
-1
-0,5
0
dO
26
41
56
71
86
101
116
131
146
161
176
191
Comp depth (m)
Rissoa spec 1
$\delta^{18}O$
A


comparison specimen & $\delta^{18}O$
sea lvl drop
EOB
Temp. drop
1,2
1
0,8
0,6
0,4
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0
amount of specimen/cm
-4
-3,5
-3
-2,5
-2
-1,5
-1
-0,5
0
dO
26
41
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86
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176
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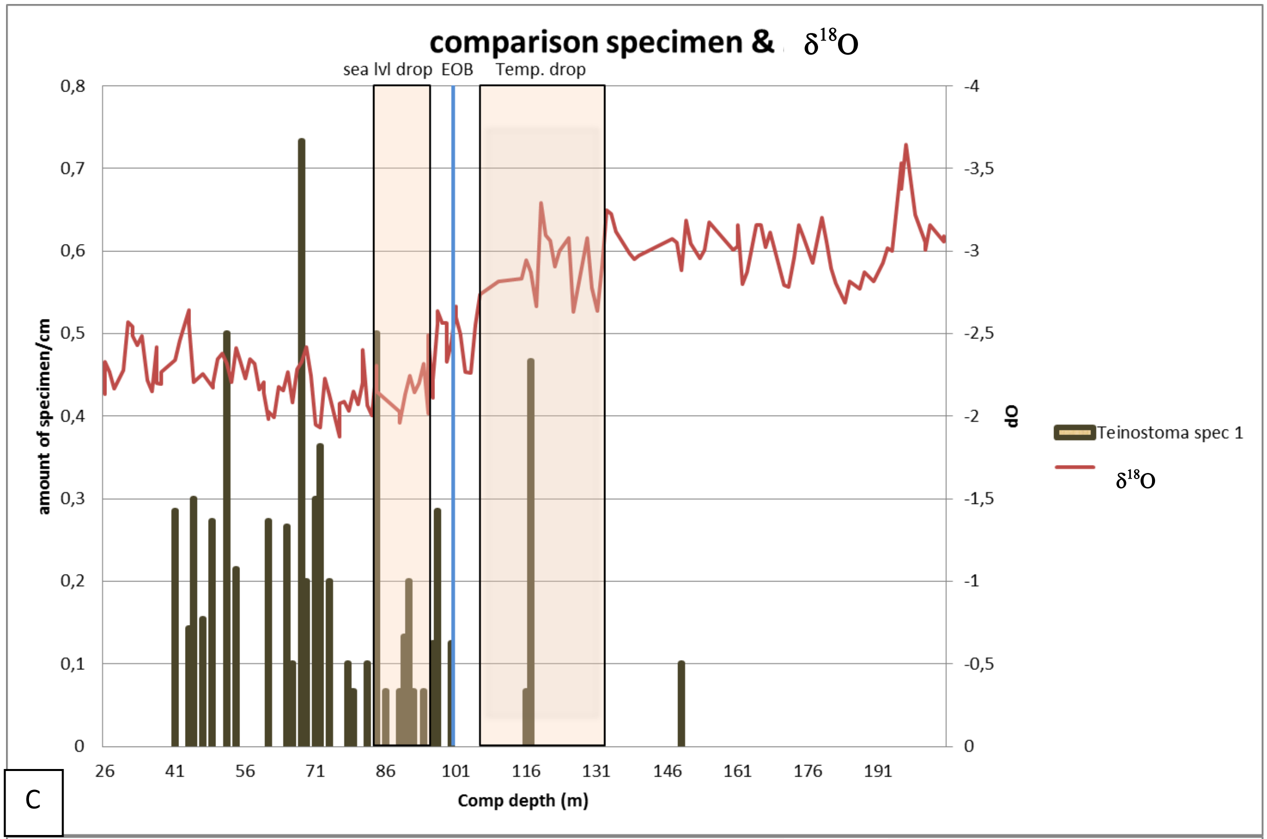
Comp depth (m)
Rissoa spec 4
$\delta^{18}O$
B


comparison specimen & δ18O
sea lvl drop
EOB
Temp. drop
0,8
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0,4
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amount of specimen/cm
-4
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-2
-1,5
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dO
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41
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71
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101
116
131
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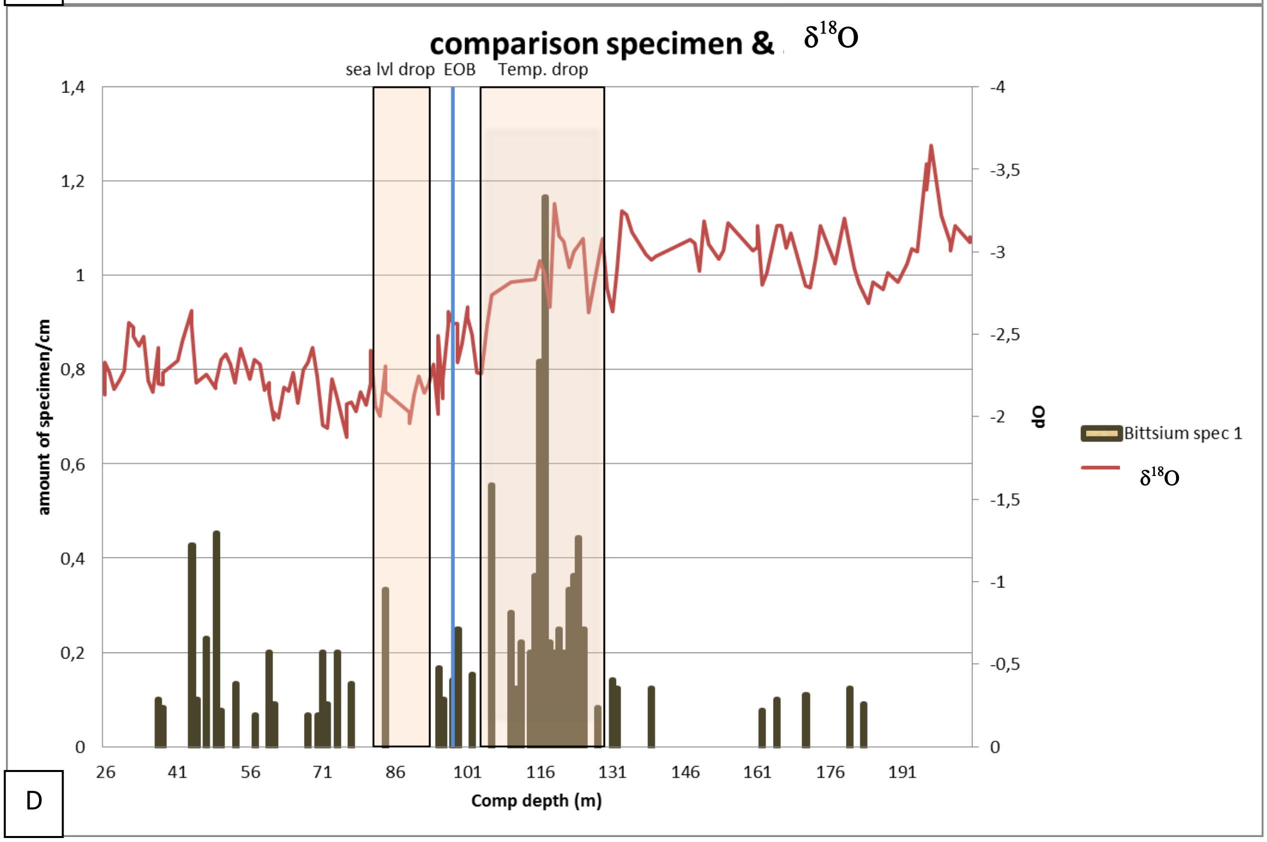
161
176
191
Comp depth (m)
Teinostoma spec 1
δ18O
C


comparison specimen & δ18O
sea lvl drop
EOB
Temp. drop
1,4
1,2
1
0,8
0,6
0,4
0,2
0
amount of specimen/cm
-4
-3,5
-3
-2,5
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-1,5
-1
-0,5
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dO
26
41
56
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86
101
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131
146
161
176
191
Comp depth (m)
Bittsium spec 1
δ18O
D

Figure 7. Bar charts showing the herbivore detrivore response to the EOT. Four different species are shown; Rissoa *spec. 1 (A),* Rissoa *spec. 4 (B),* Teinostoma *(C) and* Bittium *(D). Bars show the amount of specimen found at different depths (corrected for depth interval) .The red line indicates the* $\delta^{18}O$ *change over the EOT. The blue line indicates the EOB. The right orange square indicates the first isotope drop, associated with temperature drop and the left orange square indicates the second, associated with a sea level drop. (Excel output)*

Kelliella, a filter feeder, shows a similar pattern to the three HD species. It is present before the EOB and is abundant after. This increase does not occur immediately after the EOB however, but after the sea level drop. This delay is similar to delay found in the overall filter feeder group (figure 8).

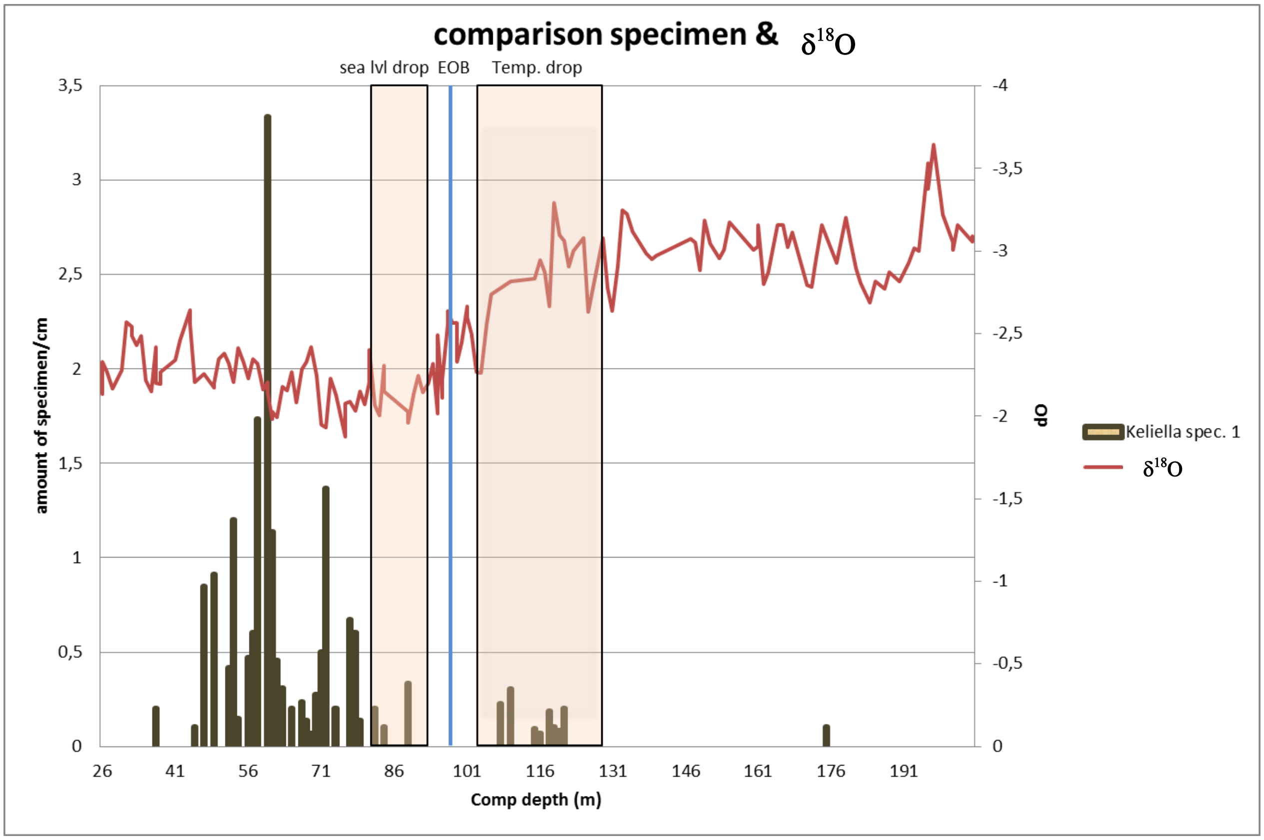

Figure 8. Bar chart showing filter feeder (F) response to the EOT. The depicted species is Kelliella*. Bars show the amount of specimen found at different depths (corrected for depth interval) .The red line indicates the* $\delta^{18}O$ *change over the EOT. The blue line indicates the EOB. The right orange square indicates the first isotope drop, associated with temperature drop and the left orange square indicates the second, associated with a sea level drop. (Excel output)*

The two carnivore species, *Limacina* and *Turridae*, also have different patterns over the EOT (figure 9). *Limacina* is very abundant before the EOB, during the temperature drop. They show a slow decline during the EOT. The other carnivore species, *Turridae*, is almost absent before the EOB, but right after the boundary they increase in numbers.

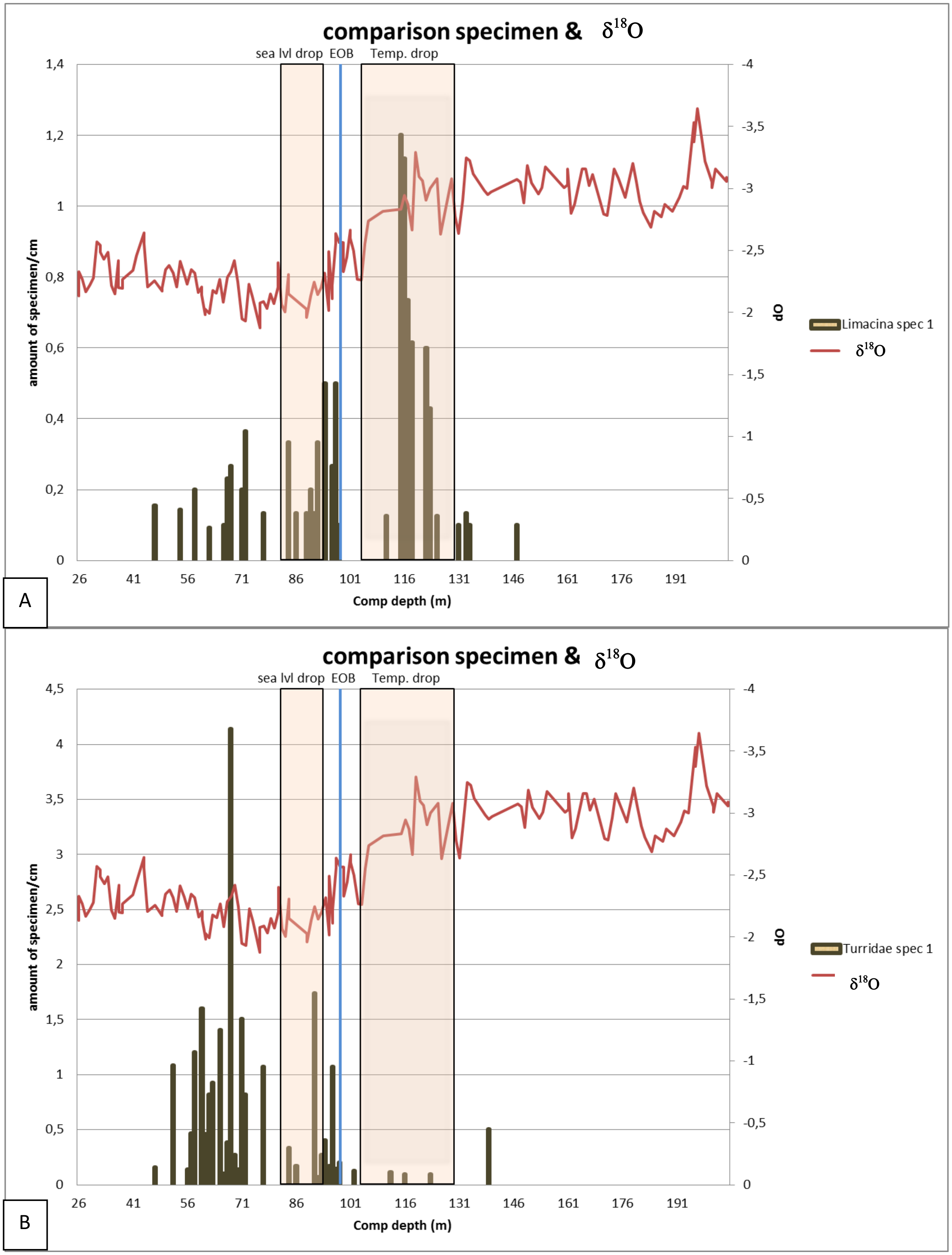

Figure 9. Bar charts showing carnivore response to the EOT. Two different species are shown; Limacina

(A) and Turridae *(B). Bars show the amount of specimen found at different depths (corrected for depth interval) .The red line indicates the* $\delta^{18}O$ *change over the EOT. The blue line indicates the EOB. The right orange square indicates the first isotope drop, associated with temperature drop and the left orange square indicates the second, associated with a sea level drop. (Excel output)*

Discussion

1-Biodiversity

The EOT is well known for its rapid decline in global temperature. However, bottom water temperatures measured from $\delta^{18}O$ of benthic foraminifera do not show such a dramatic shift and remain fairly constant, between 18 and 20°C (Lear et al, 2008). As the molluscs are also living in the bottom water could this be a reason that no decline in mollusk biodiversity was detected in this study. In contrast, calcareous nanofossils from the same cores did respond with a decline in biodiversity (Dunkley Jones et al, 2008). This might be due to the different living habitats of mollusks and the nanofossils. While the majority of the mollusks identified/found lived in the deeper waters, the calcareous nanofossils lived in the surface waters. The surface-waters are more susceptible to changing temperatures, and during the EOT the surface water temperature decreased by at least two degrees. (Lear et al, 2008). Previous research on mollusk responses to the EOT do show a correlation with temperature changes, but they are also shallow-marine molluscan faunas (Prothero et al, 2003).

2-early Eocene depletion

Mollusk densities in the 130-200 mcd interval were low (figure 3). Possibly, deep marine mollusks had a very low presence in the area during this time period. In Baja California, Mexico and West coast of the United States they found mostly shallow-water mollusks from Paleocene through middle Eocene (Prothero et al, 2003). Their increase after 130 mcd, which coincides with the temperature drop of the EOT (Lear et al , 2008), is noteworthy. However, stable deep water temperatures could rule out a temperature-dependent explanation of this sudden increase in mollusk population. A possible rationalization of this increase in specimens might be an increase in nutrient availability due to ocean mixing and circulation changes (Pearson & Coxall, 2007).

3-Functional Group Turnover

The Mollusk population shows a clear and significant turnover in some of their functional groups. The most noteworthy is the increase in the herbivore detrivore group. This group is the largest of them all, increasing from thirty to over forty percent of the total population. The detailed examination of some of the herbivore detrivore species indicates a different reaction of some species within the group. For instance, *Bittium* shows a different trend to the overall group response over the EOB; This species is abundant before the EOB and decreases afterwards. Whilst the other herbivore detrivore species, both *Rissoa* specs and *Teinostoma*, show an increase right after the EOB and are not abundant before. A possible explanation is a difference in feeding strategies. While *Bittium* has a mostly detritus feeding strategy, *Rissoa* feeds on algae. This indicates more eutrophic feeding strategies in the Oligocene (Anderson et al, 2002) and oligotrophic in the late Eocene: "…differences in epiphyte biomass seem to support the notion that eutrophic conditions would favor food webs based in algae, whereas oligotrophy would favor sea grass detritus…" (Gacia et al, 2009). This is further backed by findings of algal limestones above the EOB (Adams et al., 1986). In the same time period, a similar decline is found in oligotrophic foraminifera (Pearson, 2008) and a turnover from in calcareous nanofossils favoring oligotrophic conditions to those favoring more nutrient rich conditions.(Dunkley Jones et al, 2008).

The filter feeder species *Kelliella* seems to represent its group well, by increasing after the sea level drop. Even though it is not a significant increase group-wise, a delayed increase of this group, compared to the herbivore detrivore group, is interesting. It indicates a latent increase of planktonic species. Another explanation might be a possible impact of the sea level drop on the accessibility of planktonic species. However, it is debatable whether a drop of no more than 100 meters would have an impact on deep water fauna composition (Pearson & Coxall, 2007).

The statistical analysis indicates no increase or decrease in numbers of the carnivore group. However, detailed examination of two carnivore species, *Limacina* and *Turridae* do indicate a response by this group. This response can be explained by a possible turnover of their prey species, a further indication that deep water fauna is affected by the EOT. In contrast to the carnivore group, the parasite group did show a significant difference; a decline over the EOT. This might be explained as follows. The decline of the Parasite group is only in ratio to the other mollusk species. Their absolute response however is much less severe and their numbers actually remains rather constant during the EOT. This deep water Parasite group might not be affected by the EOT, and its species not correlated with cooling or eutrophication. However, low amounts of Parasite specimens mean the response and explanation remain uncertain

4-Response

Deep marine Mollusk species respond to the EOT. The results found in this research do not indicate a swift, rapid turnover. Gastropod extinctions in the US Gulf were found to be up to 97% and bivalve species to 89% (Hansen et al, 1987; Prothero et al, 1994). It might have taken several million years for the Eocene species to reach this extinction level. This is in sheer contrast to the larger benthic foraminifera (LBF) that had a rapid extinction (Cotton & Pearson, 2011). Previous mollusk research also take a longer mollusk extinction period in consideration (Prothero et al, 2003). Exact comparisons are difficult, because all mollusk research on the EOT I could find was on shallow marine species and temperature changes and shelf area have more impact there than on deep marine fauna (Lear et al, 2008).

Conclusion

The results from this paper align with the concept that there were gradual extinctions and speciations and that deep-water species increase over the EOT because of the changing currents and nutrient enrichment (Pearson & Coxall, 2007). Deep-water Mollusks seem to have very little response to the cooling of the EOT.

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Addendum

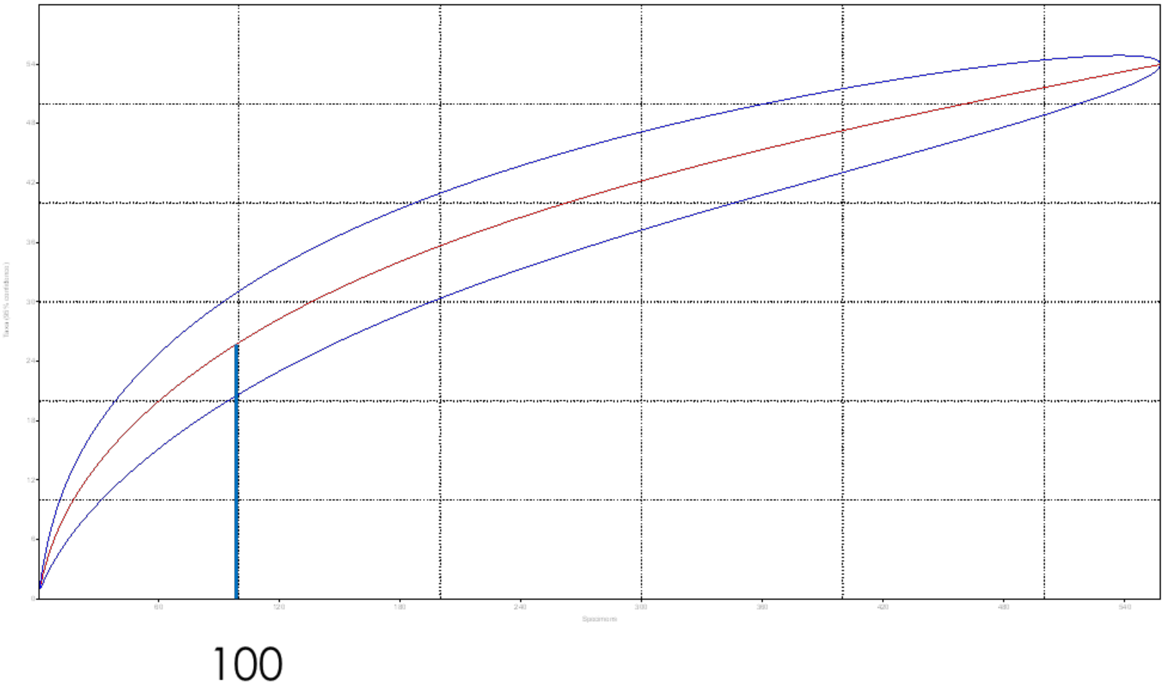


Figure 10. Rarefaction of mollusk species

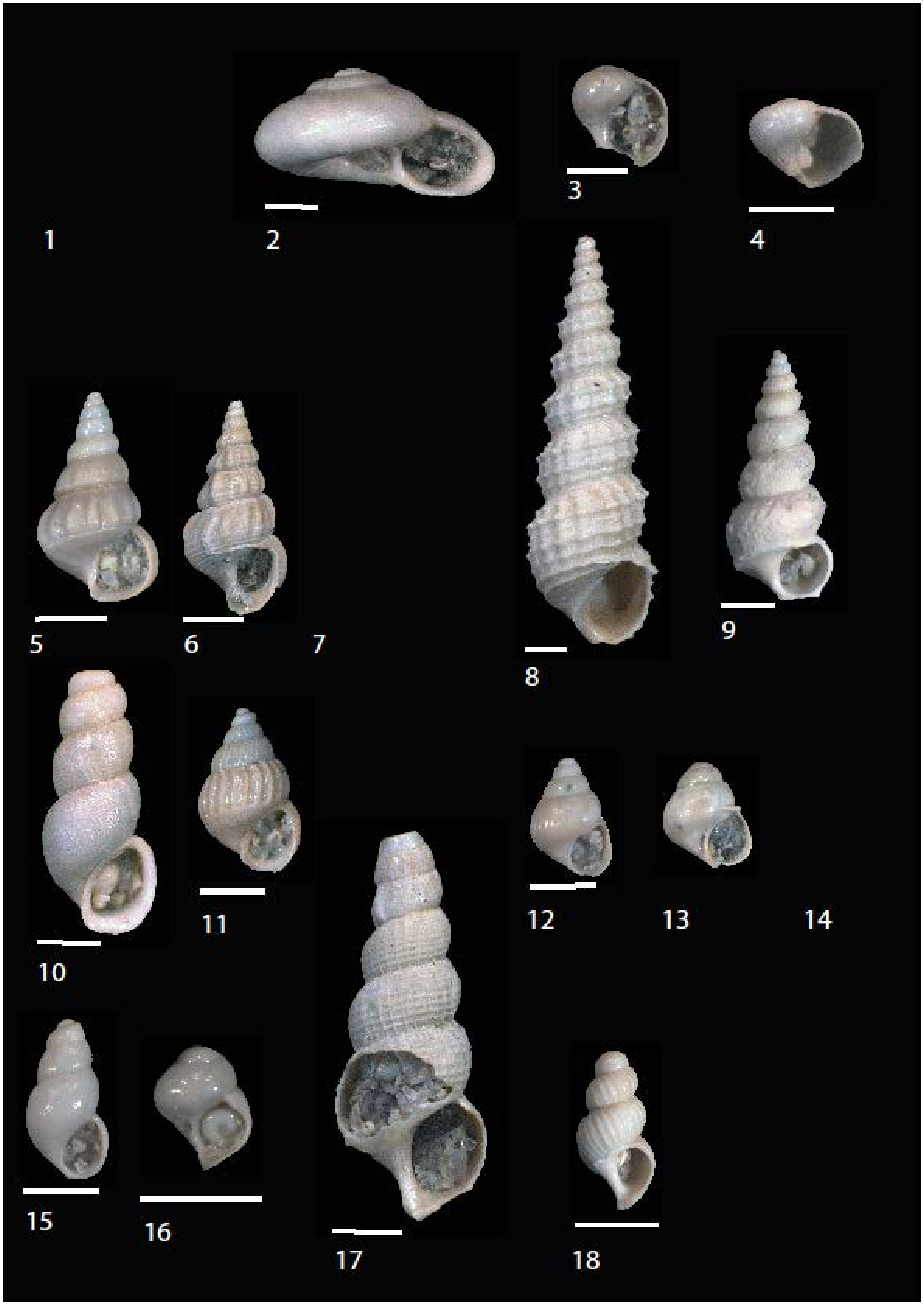
Table 1: list of mollusks found, their morphotypes, identification and corresponding group. Number correspond to plates.

No.	Species identification	Functional group	Characteristics of morphotypes
	Gastropods		
1	Vetigastropoda spec. 1	Hd	Specimen with a small spire. It has a clear pattern of axial and spiral costae.
2	Teinostoma spec. 1	Hd	Large specimen with a small spire and broad width (usually >2mm). They are usually very pale in color.
3	?Skenea spec. 1	Hd	Specimen with deep sutures and a small or non-existing spire.
4	Naticidae spec. 1	C	Round specimen with a large aperture. They have a small, almost non-existing spire.
5	Plesiotrochus spec. 1	Hd	Specimen with defining axial costae on all but the first three whorls. They sometimes show spiral threads and have deep sutures.
6	Pleisotrochus spec. 2	Hd	Specimen with defining axial costae on all but the first three whorls. They sometimes show spiral threads and have deep sutures. More defined than spec. 1
7	Plesiotrochus spec.2	Hd	Specimen with defining axial costae on all but the first three whorls. They sometimes show spiral threads and have deep sutures. Probably the same as 6.
8	Bittium spec. 1	Hd	Specimen with defining axial and spiral costae on all, but the first two whorls and they have deep sutures.
9	Scaliola spec. 1	Hd	Smooth specimen with very deep sutures. Sometimes, they have sand attached to them.
10	Iravadia spec. 1	Hd	Specimen with very fine spiral and axial threads. They have quite a flat apex, deep sutures and a big outer lip.
11	Rissoa spec .1	Hd	Small specimen with axial costae. They have small sutures.
12	Rissoa spec. 2	Hd	Alternative *Rissoa* with less defined and more abundant axial costae.
13	Rissoa spec. 3	Hd	Alternative *Rissoa* with less defined and more abundant axial costae. They have broad whorls.
14	Rissoa spec. 4	Hd	Alternative *Rissoa* with less defined and more abundant axial costae.
15	Rissoa spec. 5	Hd	Alternative *Rissoa* without axial costae (Small smooth rissoa).
16	Rissoa spec. 6	Hd	Alternative *Rissoa* without axial costae (Small smooth rissoa) with broad whorls.
17	Acirsa spec. 1	P	Specimen with clearly defined axial and spiral costae on all but the first two whorls.
18	Epitoniidae Spec. 1	P	Small specimen with axial threads on the first whorl and spiral ones on all the other whorls.
19	Triphora s.l. spec.1	P	Left winding specimen with two rows of round nodes on all but the first three whorl. They have small sutures and

			a small aperture.
20	Triphora s.l. spec.2	P	Alternate smaller *Triphora* without nodes and two rows of spiral costae.
21	Eulima spec. 1	P	Very smooth and shining specimen with almost no sutures. They are usually quite large (>2mm)
22	Eulima spec. 2	P	Alternate larger and broader *Eulima* with a rounder aperture.
23	Eulima spec. 3	P	Alternate Eulima with a skewed columella.
24	Eulima spec. 4	P	Alternate Eulima with defined sutures
25	Cypraeidae spec. 1	C	Round specimen with a fine raster of interconnected and fine nodes.
26	Typhis spec. 1	C	Specimen with hollow spines, usually broken off, on all but the first three whorls. They have a large aperture with a siphonal canal.
27	Buccinoidae spec .1?	C	Large specimen (>2mm) with nodes and spiral threads on all but the first two whorls. They have a large aperture and a siphonal canal.
	Buccinoidae spec .2	C	No photo. Buccinoidae with broader whorls
28	Mitra spec .1	C	Specimen with several columellar plicae and well defined axial costae on all but the first whirl.
29	Marginellidae spec. 1	C	Specimen with large whorls and a relatively small width. They have a small spire and have a round shape.
30	Conus spec .1	C	Large specimen with large whorls and a relatively small width. They are very straight, have small nodes and fine spiral threads and a siphonal canal.
31	Turridae spec. 1	C	Large specimen (>2mm) with clearly defining axial costae on all but the first two whorls and a siphinal canal.
32	Ringicula spec.1	C	Specimen with defining columellar plicae and thick outer lip. They have spiral threads .
33	Ringicula spec. 2	C	Alternative *Ringicula* with a small spire, longer columellar lip and finer spiral threads. They lack the thick outer lip.
34	Ringicula spec. 3	C	Alternative *Ringicula* with finer spiral threads and without the thick outer lip.
35	Ringicula spec. 4	C	Alternative small *Ringicula* without the thick lip.
36	Ringicula spec. 5	C	Alternative small *Ringicula* without the thick lip. (slightly thicker than 35)
37	Chrysallida spec 1	P	Specimen with axial costae and a ridge at the top of each whorl. They also have a deep sutural canal.
38	Odostomia s.l. spec. 1	P	Smooth specimen with a single columellar plait (tooth) and a reversed nuclear whorl.
39	Odostomia s.l. spec. 2	P	Alternative *Odostomia* with larger and rounder whorls
40	Odostomia s.l. spec. 3	P	Alternative very straight *Odostomia.*
41	Odostomia s.l. spec. 4	P	Alternative smaller *Odostomia* with straight sides
42	Odostomia s.l. spec. 5	P	Alternative smaller *Odostomia* with straight sides and a more rectangular aperture.
43	Turbonilla s.l. spec.1	P	Specimen with axial ridges and a reversed nuclear whorl. They have little variation in whorl width.

	Turbonilla s.l. spec. 2	P	No photo. *Turbonilla* with broad whorls
44	Eulimella s.l. spec. 1	P	Specimen with a reversed nuclear whorl and a smooth surface. They have almost no sutures.
45	Eulimella s.l. spec. 2	P	Alternative smaller *Eulimella* with more defined sutures and less whorls. They have a more oval-shaped aperture.
46	Eulimella s.l. spec. 3	P	Alternative elongated *Eulimella* with longer whorls and slightly more defined sutures. They have a more oval-shaped aperture.
47	Eulimella s.l. spec. 4	P	Alternative smaller *Eulimella.*
48	Eulimella s.l. spec. 5	P	Alternative smaller *Eulimella* with more defined sutures and a ridge at the top of each whorl. They have a more oval-shaped aperture.
49	Syrnola spec. 1	P	Specimen with small sutures and straight whorls. They have spiral threads.
50	Phasianema s.l. spec.1	P	Small specimen with small whorls, fine spiral threads and a large aperture.
51	Phasianema s.l. spec.2	P	Alternative *Phasianema* with almost no spire and a larger aperture.
52	Retusa s.l. spec. 1	C	Specimen without a spire and with a long siphonal canal.
53	Retusa s.l. spec. 2	C	Alternative *Retusa* with a short siphonal canal.
54	Roxania spec.1;	C	Specimen are planispiral and, almost, isotrophic in shape. They are smooth and have a large aperture.
55	Roxania s.l. spec. 2	C	Alternative large *Roxania* with clear spiral threads.
56	Pteropoda spec. 1	C	Pteropoda
57	Limacina spec. 1	C	Left winding specimen with a smooth surface and a small spire.
58	Limacina spec. 2	C	Alternative *Limacina* with a larger spire.
59	Gastropoda indet	U	Specimen with a small spire and a large aperture. They have axial and spiral costae.
60	Gastropoda indet.	U	Specimen with rounded whorls and a ridge right above the suture. Aperture is square-shaped.
61	Gastropoda indet.	U	Specimen with almost no sutures and a fine, interconnected pattern of ridges. They have a large squar-shaped aperture.
62	Gastropoda indet.	U	Specimen with two spiral costae on all but the first two whorls. They have a large aperture.
63	Gastropoda indet	U	Specimen with two spiral costae on all but the first two whorls. They have a reversed nuclear whorl.
64	Gastropoda indet.	U	Specimen have fine spiral threads and a large aperture. Spire is small.
65	Gastropoda indet.	U	Specimen have only one whorl in the spire. They have a relatively big aperture.
66	Gastropoda indet	U	Specimen have a single carinate spiral ridge and a siphonal canal.
67	Gastropoda indet	U	Specimen have a large first whorl and a siphonal canal.
68	Gastropoda indet	U	Specimen have fine spiral threads, a small pointy spire

			and a large aperture.
69	Gastropoda indet.	U	Specimen have a round shape and a small spire.
	Bivalves		
1	Nucula spec. 1	F	Taxodont specimen with teeth on one side. Growth lines are faintly present.
2	Leda spec. 1	F	Taxodont species with two rows of teeth. Growth lines are clearly visible.
3	Leda spec. 2	F	Alternative *Leda* with a more rounded shell and less, more pronounced growth lines.
4	Leda spec. 3	F	Alternative *Leda* with a more rounded shell and less, more pronounced growth lines, but not as round as spec. 2.
5	Sarepta spec 1	F	Taxodont specimen with an elongated shell and visible growth lines.
6	Arca s.l. spec. 1	F	Taxodont species with posterior growth. Clearly visible defining radial ribs.
7	Propeamussiidae spec. 1	F	Specimen with a smooth, shining and flat surface and nine radial ridges on the inside.
8	Propeamussiidae spec. 2	F	Alternate *Propeamussiidae* with seven radial ridges.
9	Lucina s.l. spec. 1	CB	Heterodont circular specimen with clear growth lines and a posterior growth.
10	Myrthea spec. 1	CB	Heterodont specimen with a thick shell. They have clear visible ridges on the shell.
	Myrthea spec. 2	CB	Define
11	Pleuromeris spec. 1	F	Round specimen with distinct radial ribs.
12	Pleuromeris spec. 2	F	Alternate *Pleuromeris* with a triangular shape.
13	Parvicardium spec. 1	F	Heterodont specimen with shallow radial rids. They have a obliquely oval shape.
14	Kelliella spec. 1	F	Specimen with a round shape and shining surface with visible growth lines.
15	Vermoedelijk Kelliella spec. 1 controleren juvenile en adult (nummer 6)	F	Alternative small *Kelliella* (<0,5 mm)
16	Veneridae spec. 1	F	Heterodont specimen with an oval shape and visible growth lines.
17	Veneridae spec. 2	F	Alternative small *Veneridae.*
18	Varicorbula spec. 1	F	Very large specimen with thich shell and visible growth lines.
19	Cardiomya spec. 1	C	Specimen with defining axial ribs
20	Bivalvia spec. 1	U	Specimen with a triangular shape and small radial ridges between growth lines.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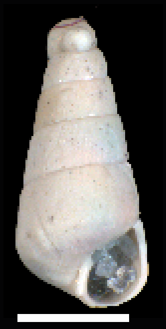
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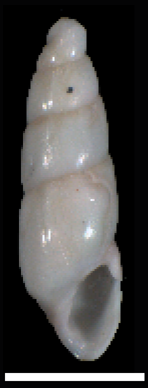
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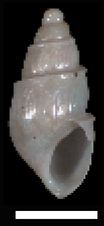
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