The impact of the Messinian Salinity Crisis on marine biota

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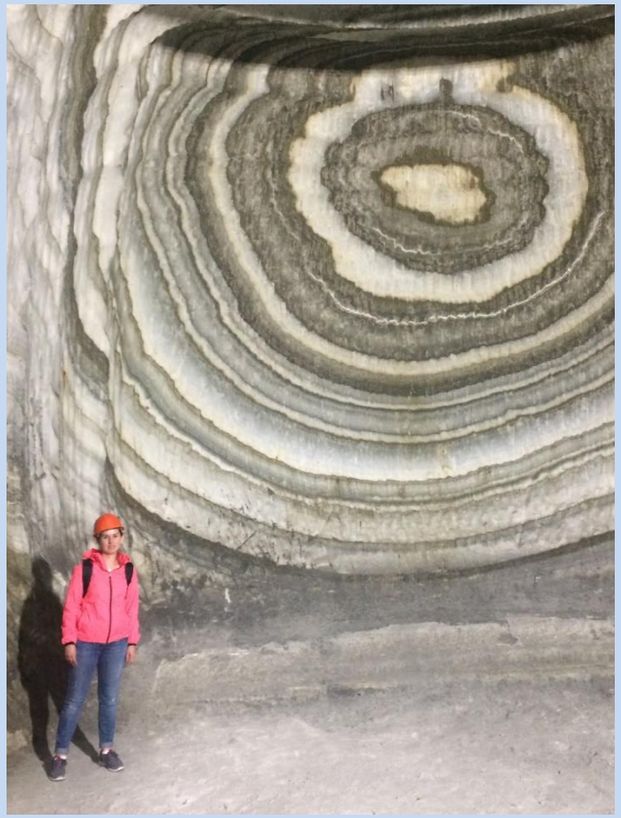

Messinian evaporites in Realmonte salt mine, Sicily

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Messinian Salinity Crisis

The greatest paleoenvironmental perturbation (5.97-5.33 Ma) of the Mediterranean involved:

- **Evaporite deposition** across the Mediterranean, today both onshore and as a 1-3-km thick halite layer on the deepest parts of the basin
- Possible mechanisms involve the Mediterranean turning **freshwater or desiccating**
- The crisis ended with the **Zanclean flood**, the reconnection of the Mediterranean with the Atlantic

HYPOTHESES

METHODS

Messinian Salinity Crisis

salinity and temperature fluctuations + stratification + isolation

diversity

biomass

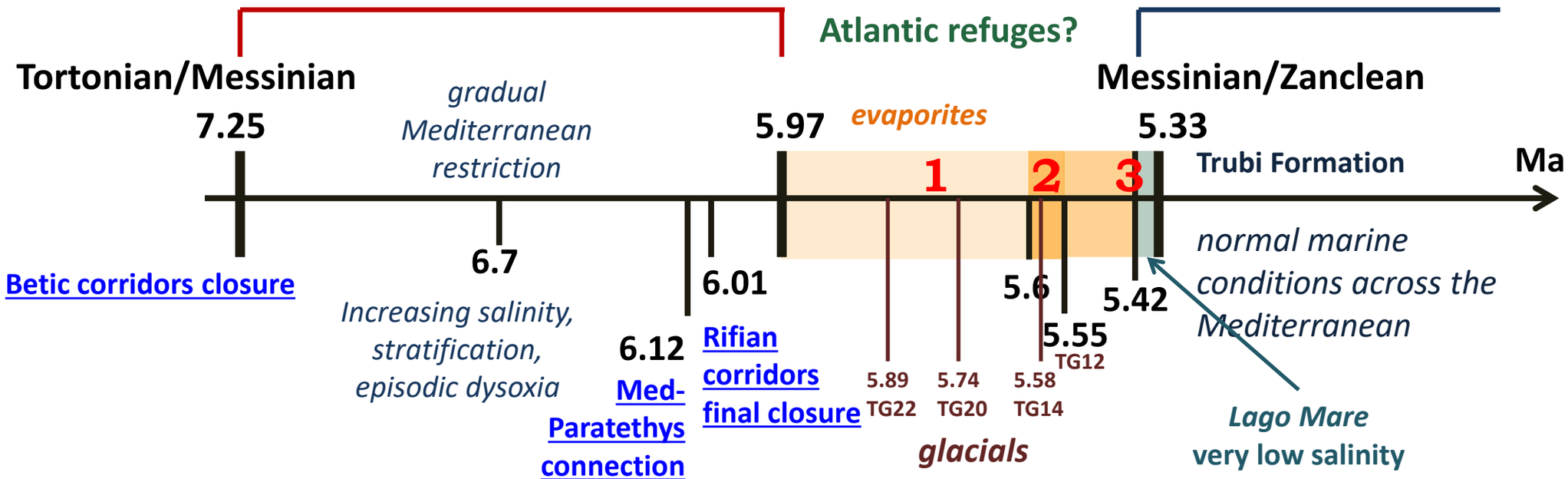
~~deep-water taxa~~

Zanclean Flood

diversity ⬆

biomass ⬆

Atlantic deep-water taxa



INTRO

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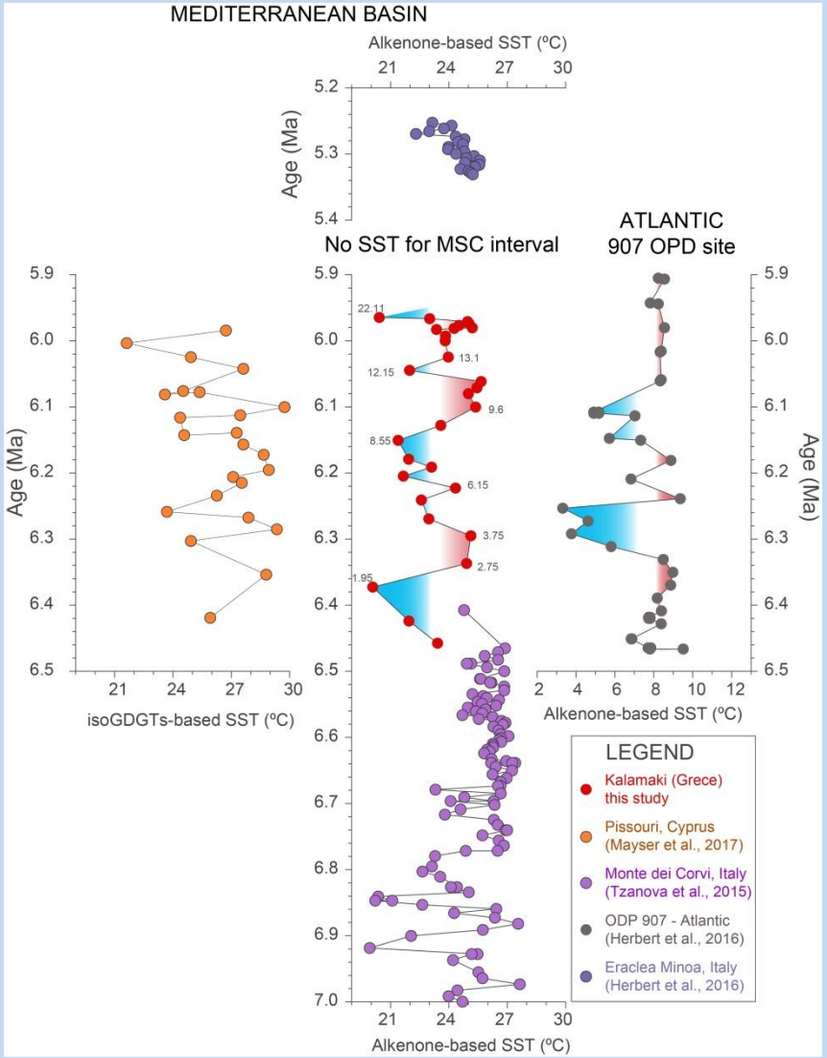
What was the Messinian Ecological Crisis?

The interval from the Tortonian/Messinian boundary (7.25 Ma) until the end of the Messinian Salinity Crisis (5.33 Ma) was characterized by:

- **Temperature decreasing trend** (global cooling)
- Gradual **Mediterranean isolation** brought salinity and temperature fluctuations, stratification
- Evaporites meant **uninhabitable sea bottoms** for most organisms during MSC



Sea surface temperature variations in the Mediterranean during the Messinian (Vasiliev et al. 2019)

Our aim is to *quantify the impact* of the Messinian Ecological Crisis on marine biota

This is important because:

- The Messinian Salinity Crisis has been hypothesized as the starting point for the evolution of Mediterranean marine ecosystems, but this has never been tested
- Intense climatic and oceanographic changes during the Messinian Ecological Crisis offer an opportunity to study the effect of such events on marine organisms

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HYPOTHESES
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Scientific questions

Q1: Was there a ***drop in diversity*** in the pre-evaporitic Messinian?

Q2: Was there a ***taxonomic change*** in the composition of the marine fauna?

Q3: Was the present-day ***west-to-east decreasing gradient*** in species richness established before or after the Messinian?

Hypotheses

- The gradual restriction of the Mediterranean, and therefore the isolation at least of the deep-water organisms, coupled with intense temperature and salinity fluctuations and stratification of the waters would lead to a drop in species richness in the pre-evaporitic Messinian.
- Regardless of whether the Mediterranean desiccated or turned freshwater, the very presence of evaporites would mean that the conditions would be unfavorable for pre-crisis organisms. Therefore, we hypothesize that mostly Atlantic species re-inhabited the basin in the Zanclean.
- The eastern Mediterranean ecosystem before the crisis was a relic of its former glory as biodiversity hotspot. We hypothesize that the west-to-east gradient commenced in the Zanclean because the Atlantic became its only source of species.

What do we need?

- Updated fossil record, which means:
    1. Revised identifications
    2. Checked stratigraphic placement
- Robust statistical methods

- The fossil record is in many cases fragmented and outdated.
- Older studies especially were not combined with detailed biostratigraphy, meaning that the stratigraphic placement of the records was too broad or even wrong.
- Expert opinion is absolutely necessary to assemble, evaluate, and revise the fossil record.

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Approach

- **Review and revise** marine fossil record of Tortonian, pre-evaporitic Messinian (7.25-5.97 Ma), and Zanclean
- Examine **temporal and spatial changes in diversity** at the genus and species levels
- Discuss endemism and adaptations
- Consider functional traits, such as depth, climate and substratum preferences of each group

INTRO

HYPOTHESES

Messinian Mediterranean: one sea, three ecological regions

1) Western Mediterranean
2) Eastern Mediterranean
3) Po Plain- Northern Adriatic

During the Messinian, the Mediterranean was separated in at least three sub-basins with independent water base levels and freshwater budgets.

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Studied taxonomic groups

- Marine mammals
- Sharks and rays
- Teleost fishes
- Ostracods
- Bivalves
- Gastropods
- Scaphopods
- Chitons
- Echinoids
- Bryozoans
- Brachiopods
- Corals
- Benthic foraminifera
- Planktonic foraminifera
- Calcareous nannoplankton
- Diatoms
- Dinoflagellates

Some organisms are simply not preserved!

Statistical methods

For each group and all together:

- **classic rarefaction** (=individual-based rarefaction; subsampling at 80%)
- **alpha diversity** (diversity within each region)
- **gamma diversity** (diversity of entire Mediterranean)
- **beta diversity** for temporal and spatial comparisons distinguishing between *spatial species turnover* (=species replacement) and *nestedness* (=species loss)

- Subsampling at 80% of the smallest sample size within the comparison was done to remove the effect of differences in sampling effort
- Beta diversity (Whittaker 1960): the extent of change in community composition among sites
- species loss refers to loss from one area relative to the other
- Following, all comparison plots show dissimilarity between the respective faunas, increasing from 0 to 1

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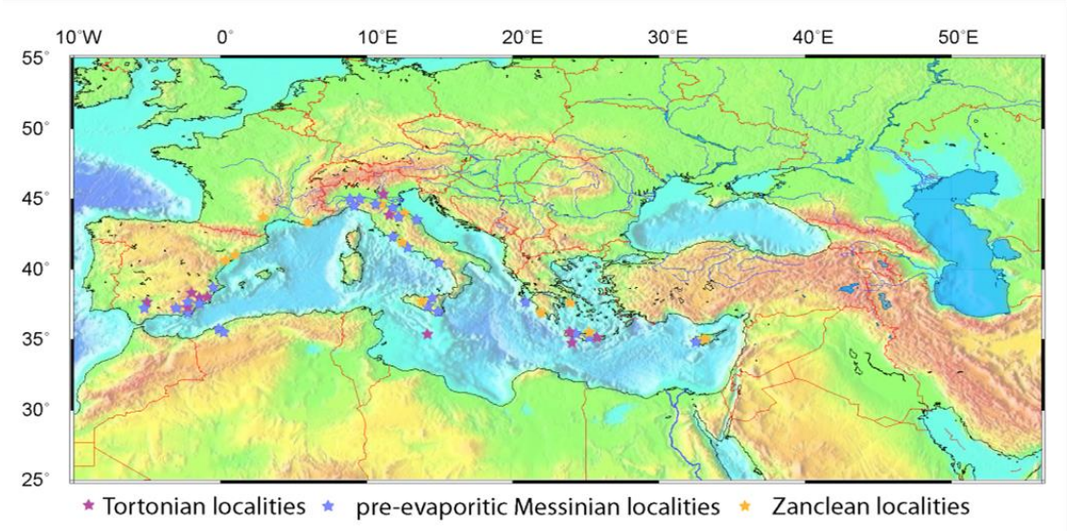
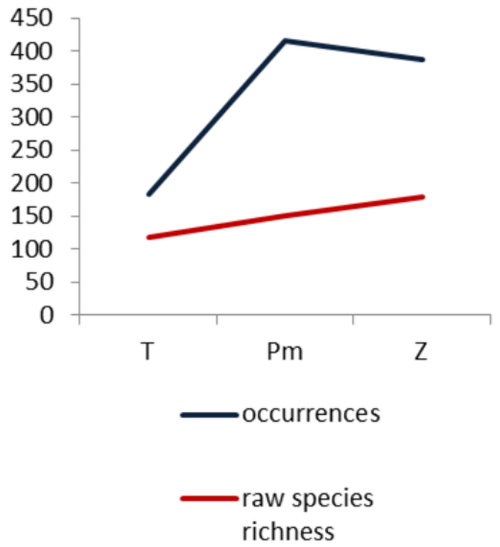
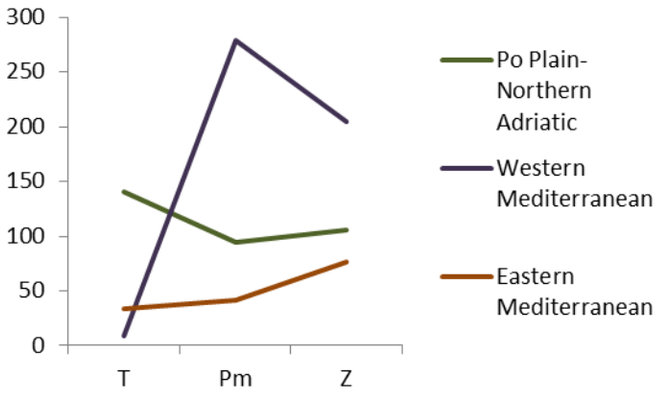
Teleost fishes





Number of species occurrences in the Tortonian (T), pre-evaporitic Messinian (Pm), and Zanclean (Z)



Number of occurrences and number of species recorded in each time slice

There is a clear sampling bias in favor of northern Mediterranean localities.

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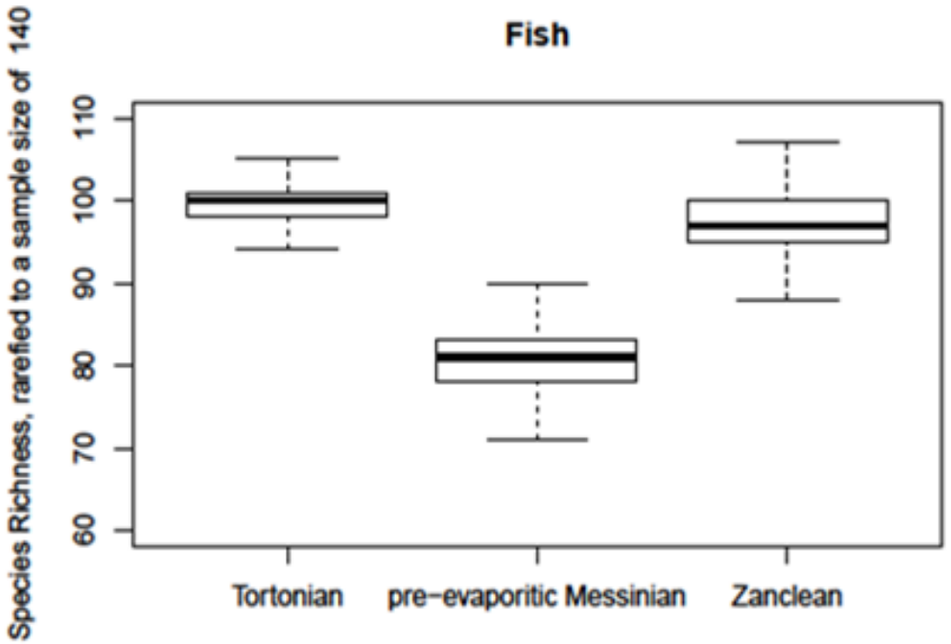
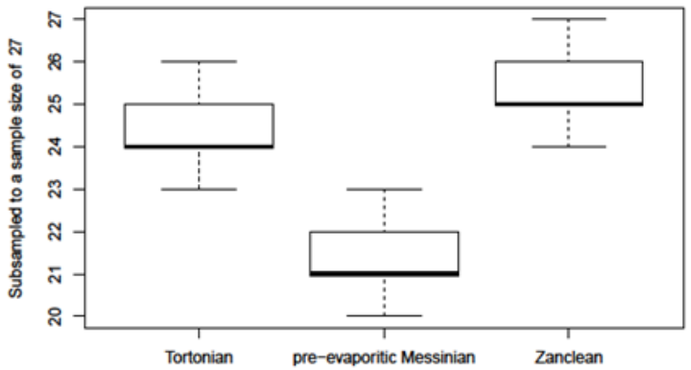
Q1: Was there a ***drop in diversity*** in the pre-evaporitic Messinian?

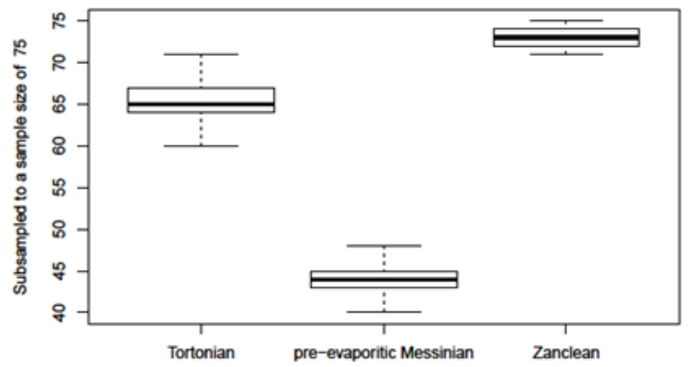


Temporal change in **species richness**

Eastern Mediterranean



Po Plain – Northern Adriatic



YES

Drop in fish diversity during the pre-evaporitic Messinian, which more than fully recovered in the Zanclean.
This is visible in the entire basin as a whole and the individual sub-basins, although we did not have enough data points for this analysis in the western Mediterranean.

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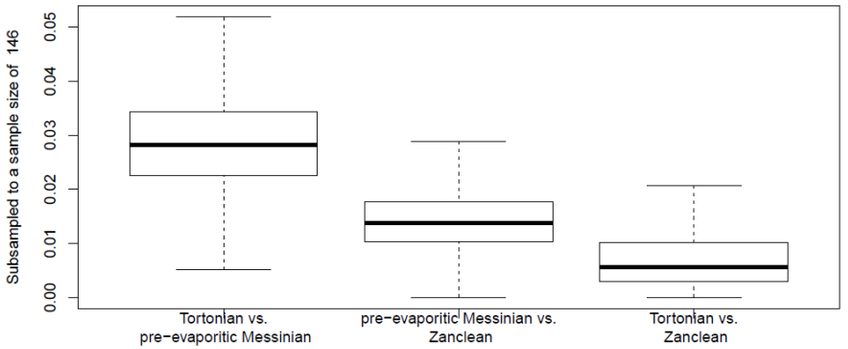
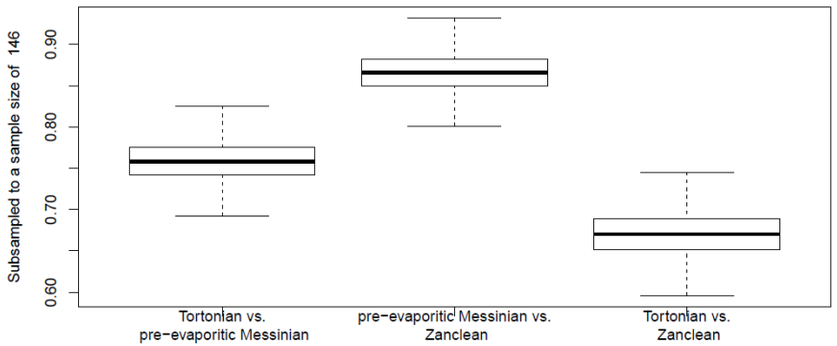
Q2: Was there a ***taxonomic change*** in the composition of the marine fauna?

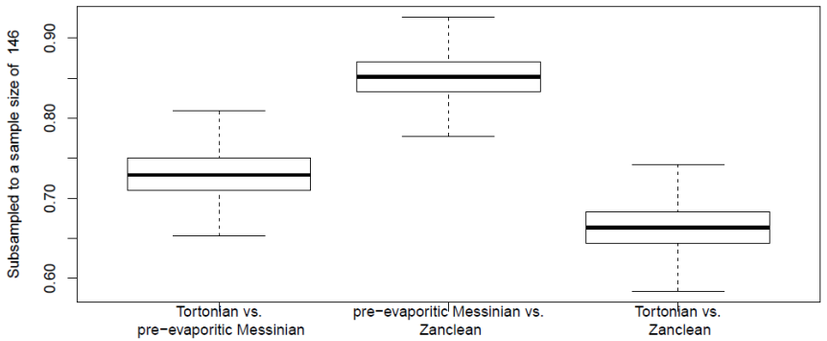
Dissimilarity due to species loss



Total dissimilarity



Dissimilarity due to species turnover

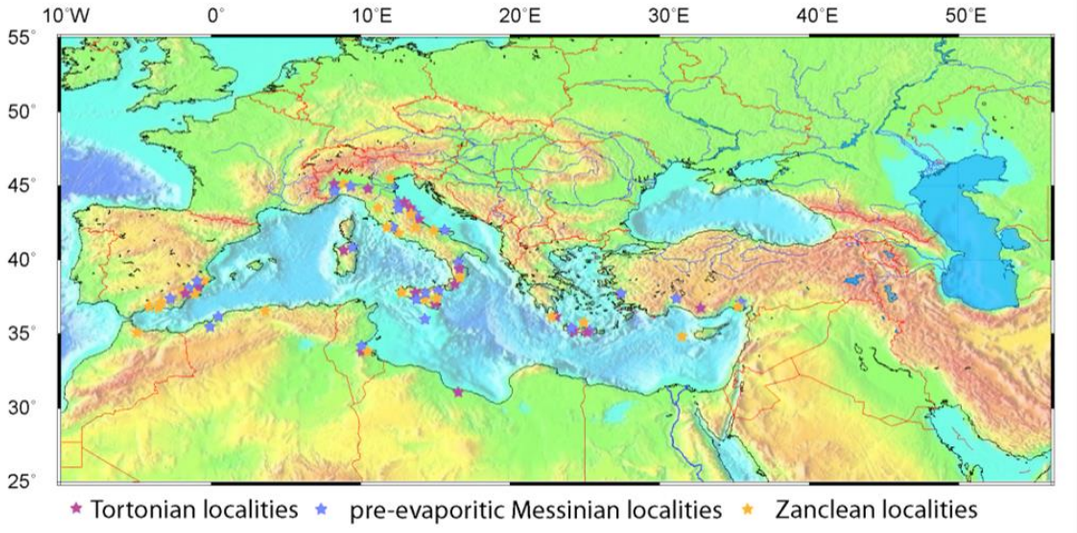


Dissimilarity of the **fish** assemblages over time for the whole basin

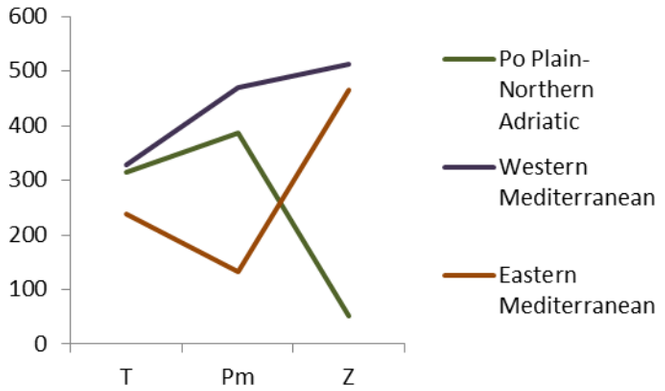
YES

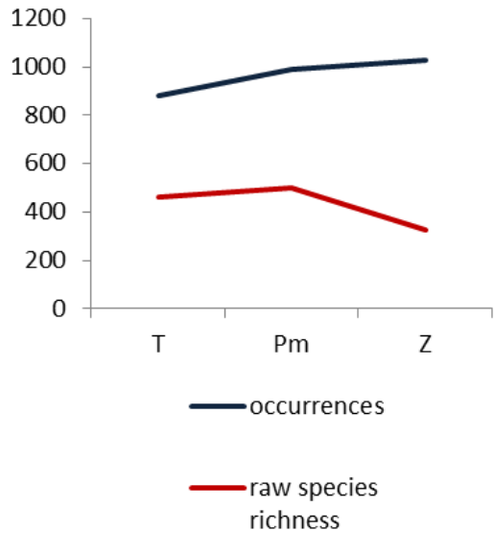
The fish fauna of the pre-evaporitic Messinian is quite different from that of the Zanclean due to replacement of species by new ones after the Messinian Salinity Crisis.
The dissimilarity between the Tortonian and Messinian, and the Tortonian and the Zanclean, is smaller. In both cases, species replacement contributes to this dissimilarity significantly more than species loss. This is observed in the western and the eastern Mediterranean. The situation is different in the Po Plain – Northern Adriatic, where the Tortonian, pre-evaporitic Messinian, and Zanclean are quite dissimilar. Again however, this is explained mostly by species replacement.

Ostracods



Number of species occurrences in the Tortonian (T), pre-evaporitic Messinian (Pm), and Zanclean (Z)





Number of occurrences and number of species recorded in each time slice

- Ostracods are benthic, thus recording mostly conditions on the sea floor.
- Here, we include both littoral and deep species for all intervals.
- The Tortonian and Messinian included many endemic ostracod species, which disappeared in the Zanclean. Although the Zanclean re-colonization with species from the Atlantic was rapid, diversity did not reach the same levels, and new endemics may have developed with a slow rate.
- As in the case of fishes, we also note here a bias in favor of northern Mediterranean sites.

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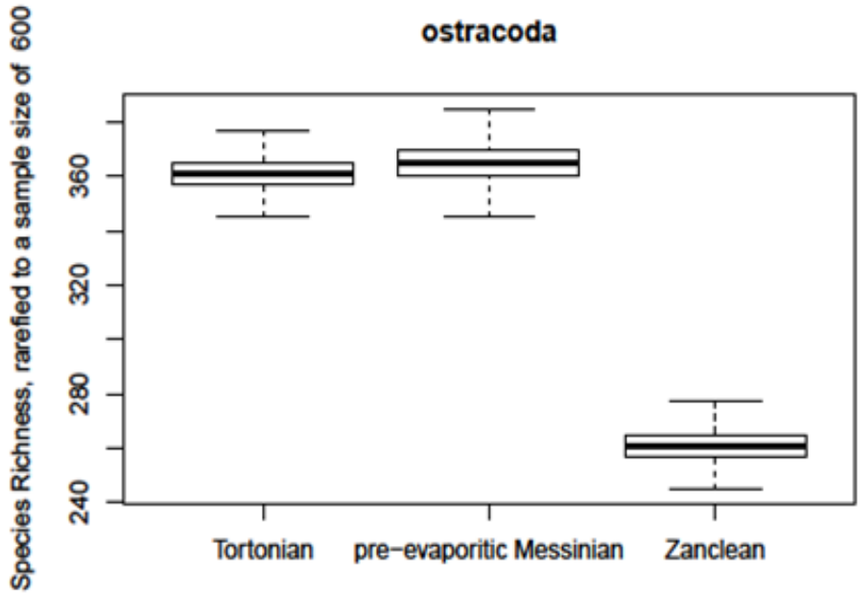
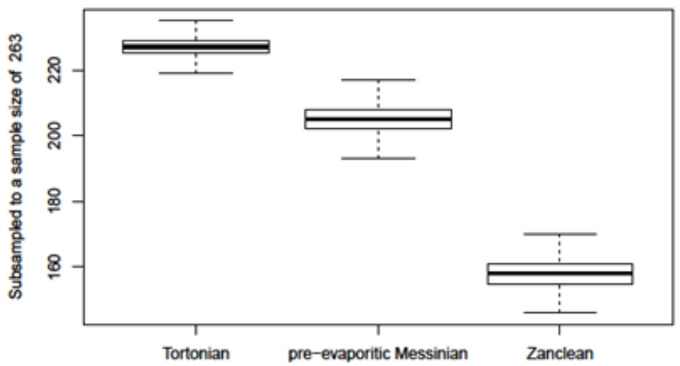
Q1: Was there a ***drop in diversity*** in the pre-evaporitic Messinian?

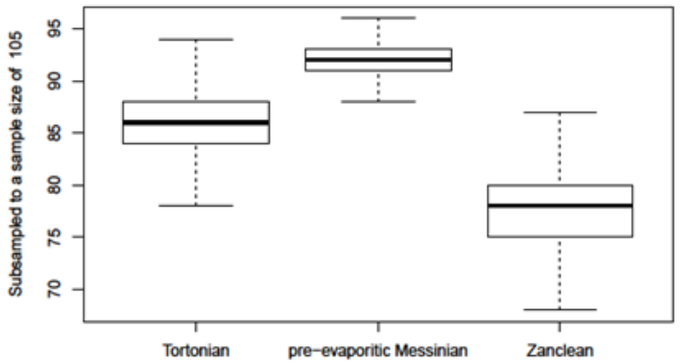


Temporal change in **species richness**

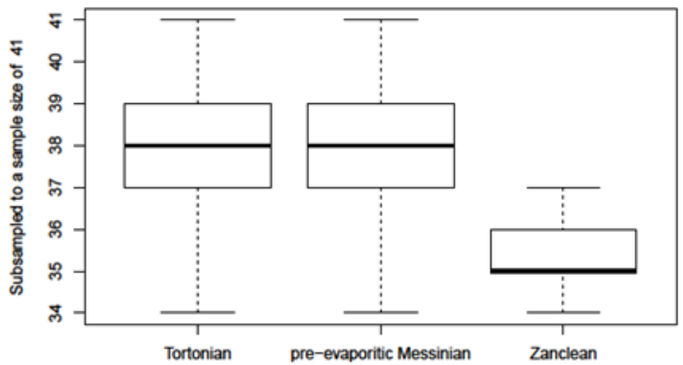
Western Mediterranean



Eastern Mediterranean



Po Plain – Northern Adriatic



NO

Drop in ostracod diversity during the Zanclean, despite the fact that we have the most data for this interval, and this is observed in all three regions. However, there is an increase in the diversity in the eastern Mediterranean during the pre-evaporitic Messinian. Could this be associated with an influx of Paratethyan taxa?

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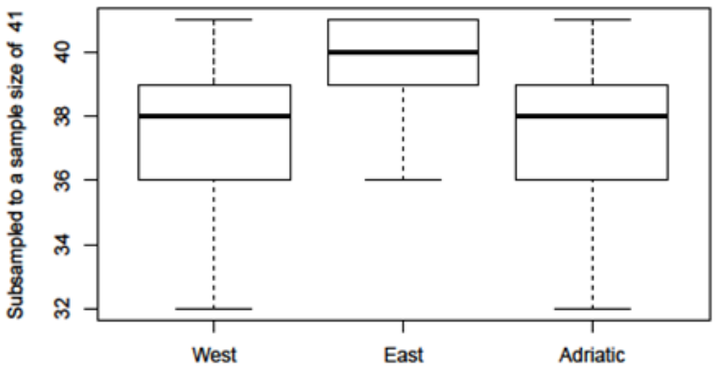
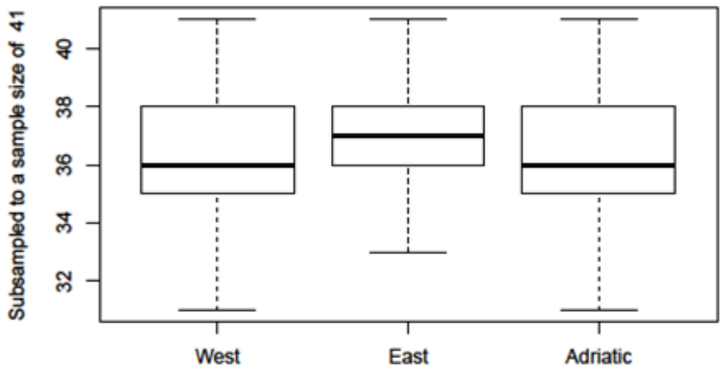
Q3: Was the present-day ***west-to-east decreasing gradient*** in species richness established before or after the Messinian?

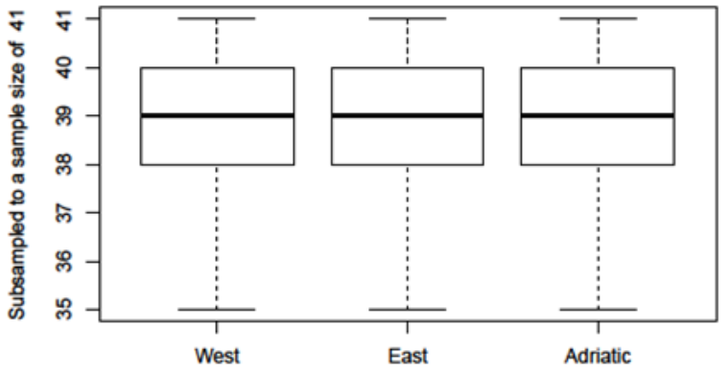
Tortonian



Zanclean



Pre-evaporitic Messinian



Spatial changes in **species richness** for ostracods

NEITHER

The eastern Mediterranean had a richer ostracod fauna than the western sub-basin and the Po Plain during the Tortonian, but that changes already in the pre-evaporitic Messinian.

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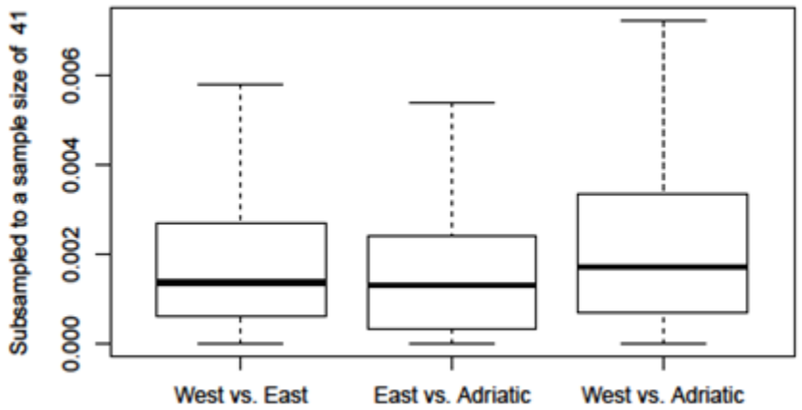
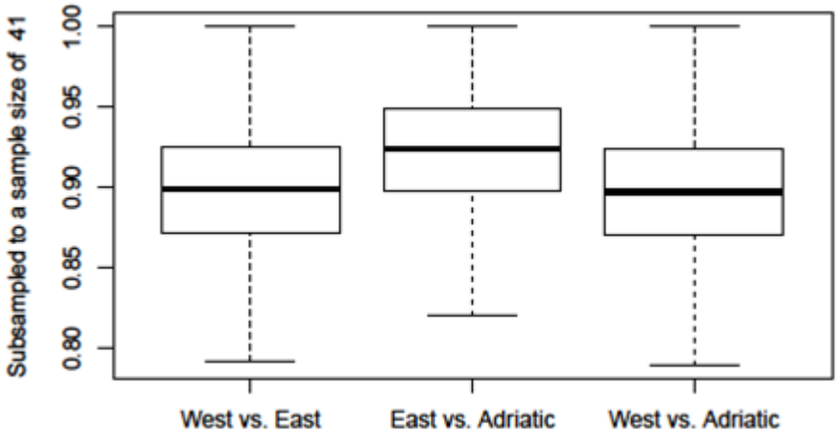
Q2: Was there a ***taxonomic change*** in the composition of the marine fauna?

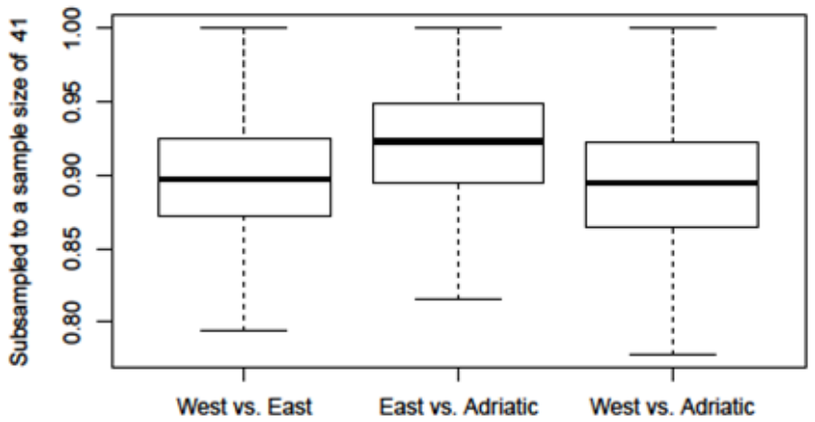
Dissimilarity due to species loss



Total dissimilarity



Dissimilarity due to species replacement



Dissimilarity of the **ostracod** assemblages in the three regions
(only Messinian is shown here as example)

YES

High dissimilarity in the ostracod faunas of the three regions is found through time, and this is due to species replacement rather than species loss. The degree of dissimilarity is reduced slightly through time.

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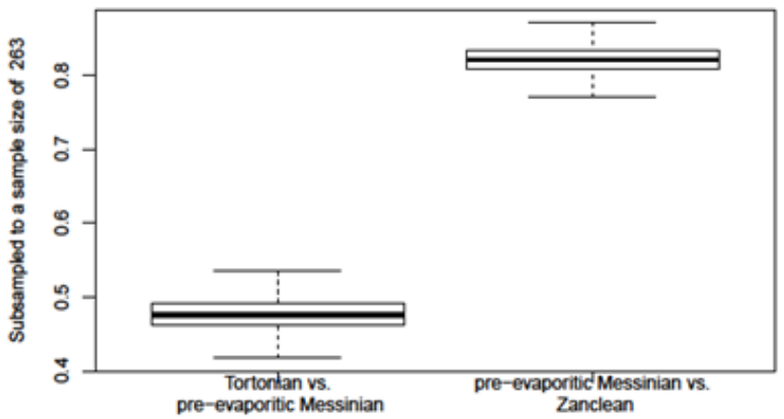
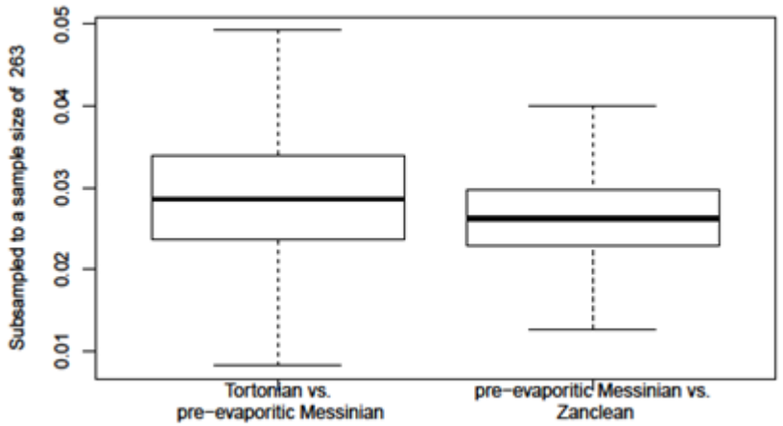
HYPOTHESES
METHODS

Q2: Was there a ***taxonomic change*** in the composition of the marine fauna?

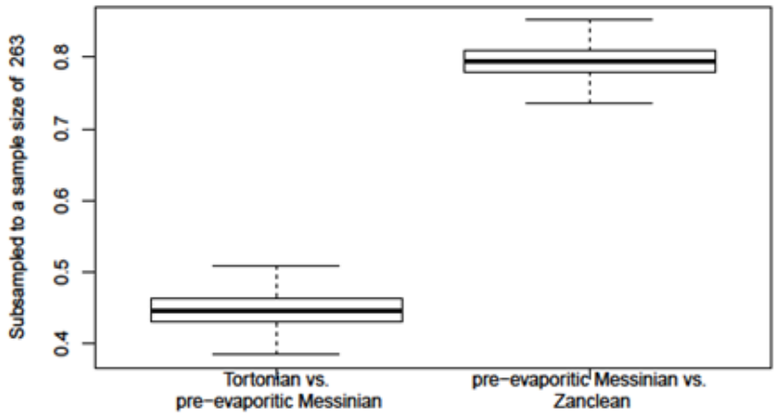
Total dissimilarity



Dissimilarity due to species loss



Dissimilarity due to species turnover



Dissimilarity of the **ostracod** assemblages over time in the western Mediterranean

YES

In the western Mediterranean, the ostracod assemblages of the Tortonian and the pre-evaporitic Messinian are quite different from that of the Zanclean and this difference is mostly due to species turnover rather than species loss.
The same is observed for the eastern Mediterranean. In the Po Plain – Northern Adriatic, the dissimilarity with the Zanclean fauna is smaller.

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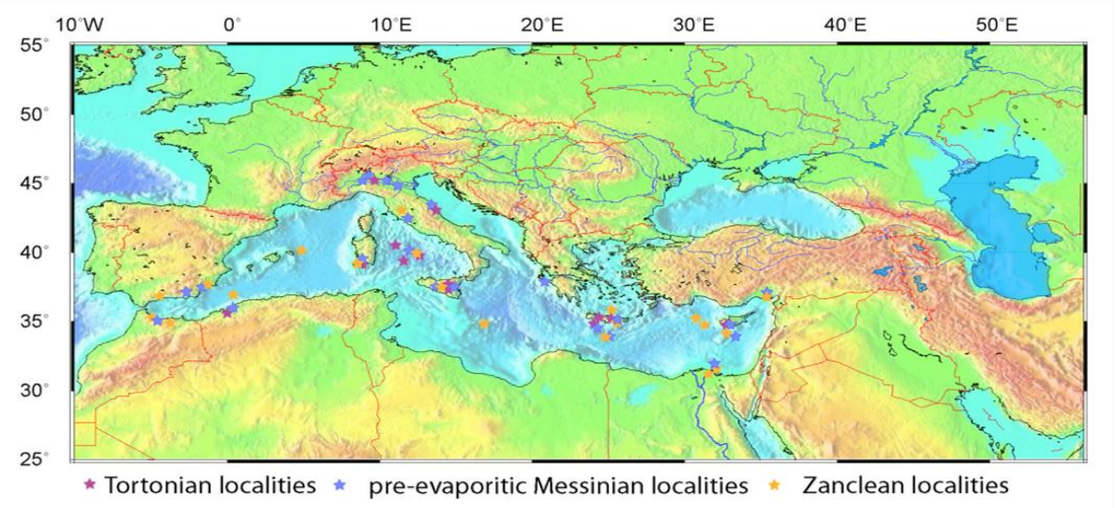
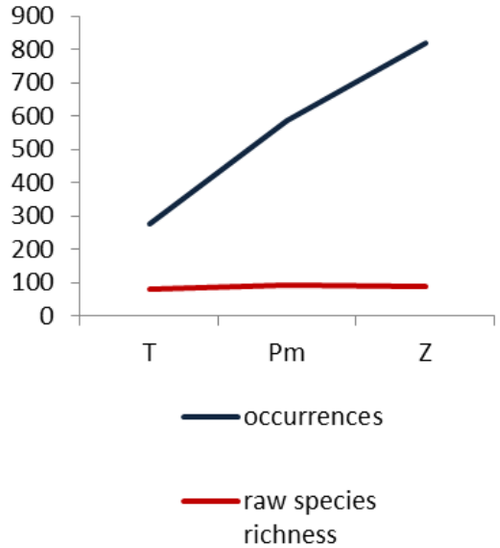
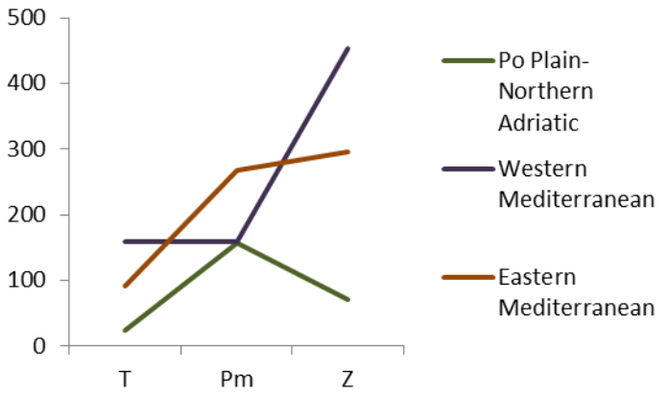
Calcareous nannoplankton





Number of occurrences and number of species recorded in each time slice

Number of species occurrences in the Tortonian (T), pre-evaporitic Messinian (Pm), and Zanclean (Z)



The spatial distribution of the recorded occurrences is much better than those of the fish and ostracods

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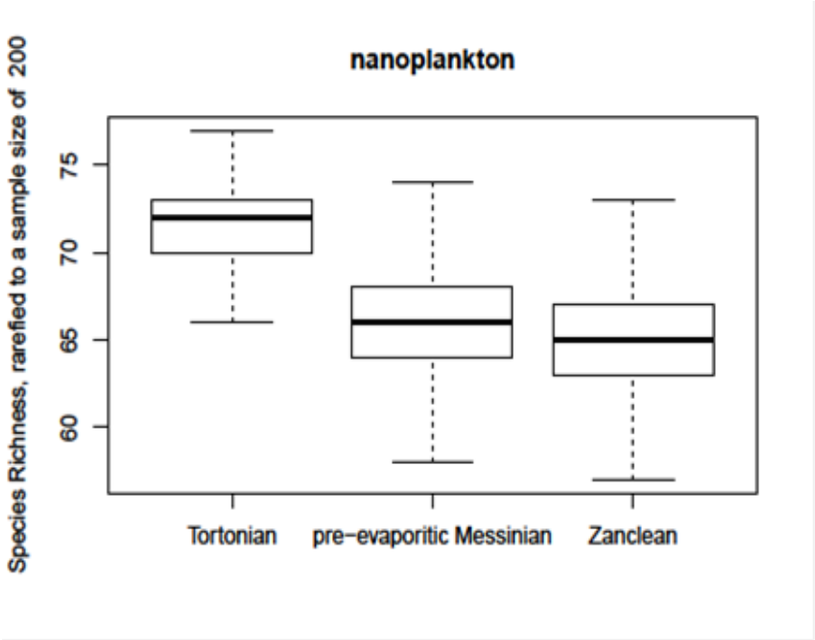
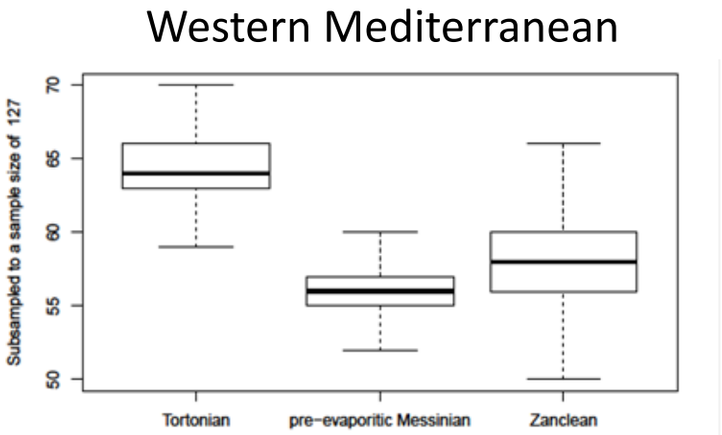
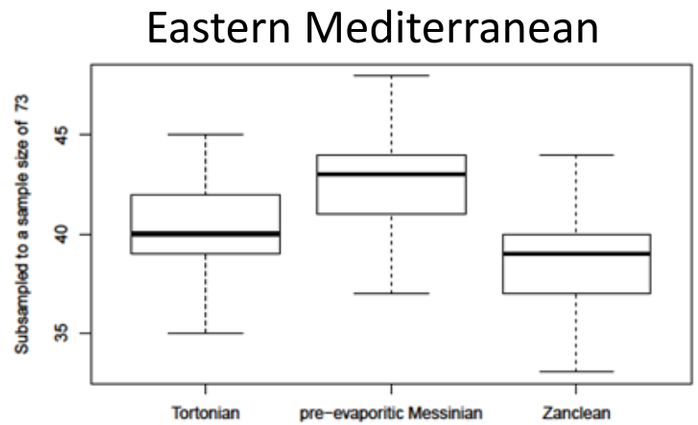
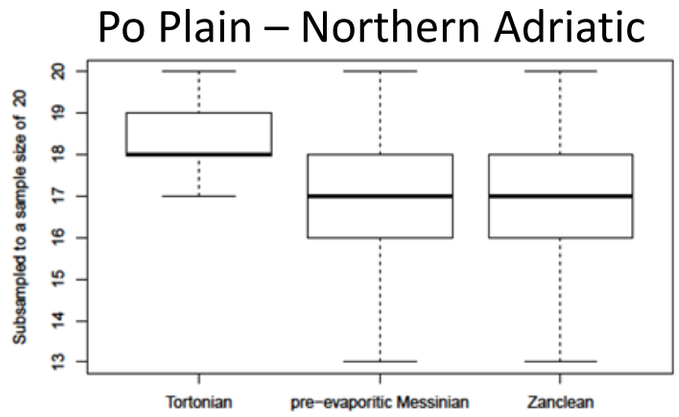
Q1: Was there a ***drop in diversity*** in the pre-evaporitic Messinian?



Temporal change in **species richness**







YES, but not everywhere

Species richness drops by ~8% from the Tortonian to the Messinian, but only a little more going into the Zanclean. This is observed in the western Mediterranean and the Northern Adriatic region, but not in the eastern Mediterranean, where we observe increase in the number of species in the Messinian and a drop in the Zanclean.

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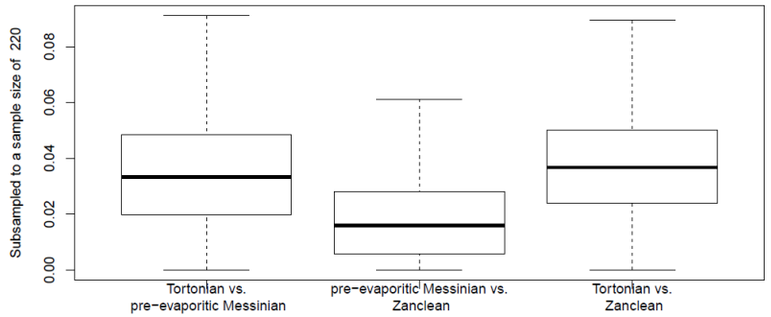
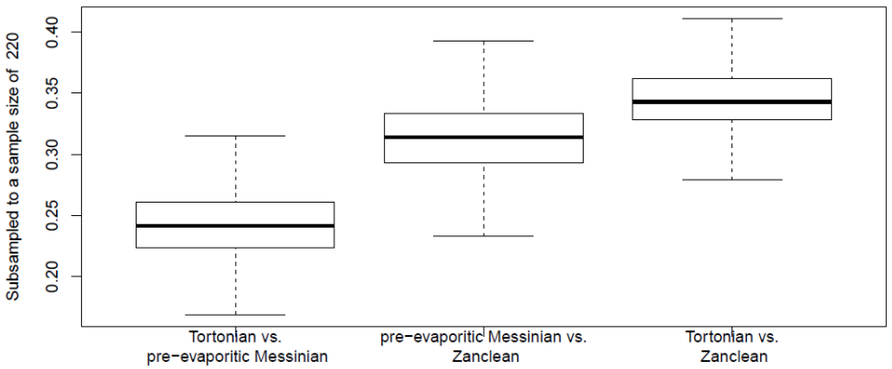
Q2: Was there a ***taxonomic change*** in the composition of the marine fauna?

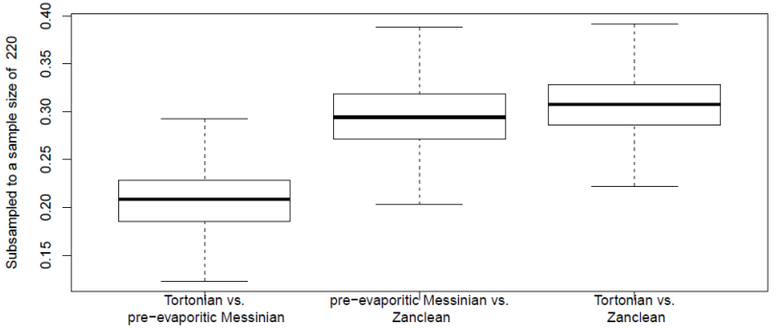
Dissimilarity due to species loss



Total dissimilarity



Dissimilarity due to species turnover



Overall **dissimilarity** of the **calcareous nannoplankton**

YES

Overall, the Tortonian and pre-evaporitic Messinian calcareous nannoplankton faunas are moderately different from the Zanclean one, and this is mostly due to species replacement. This is observed across the basin.

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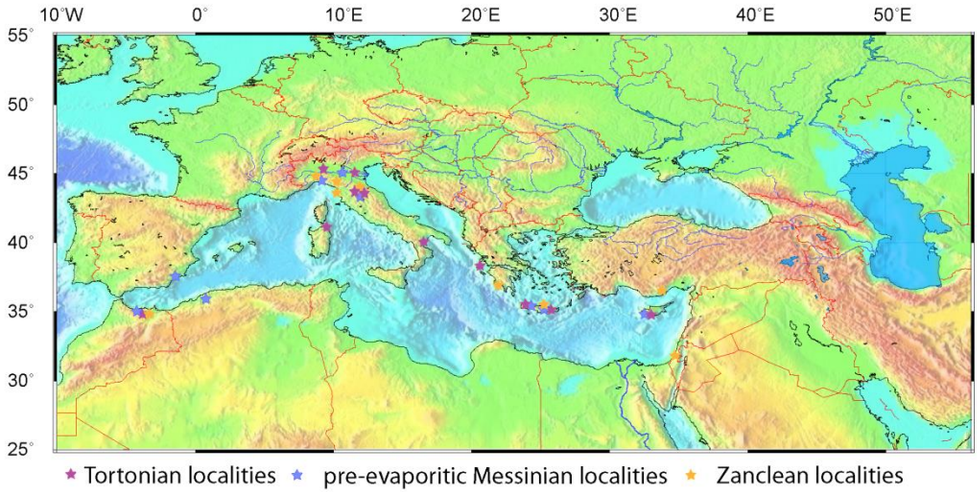
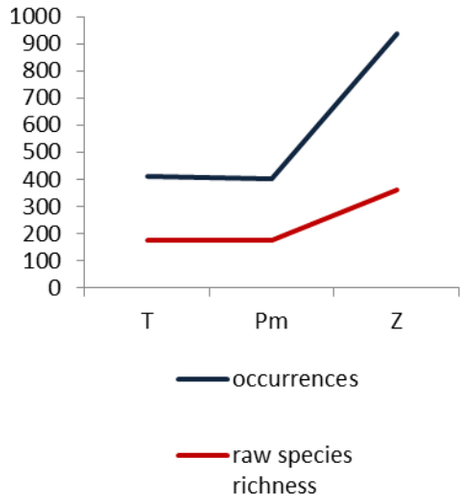
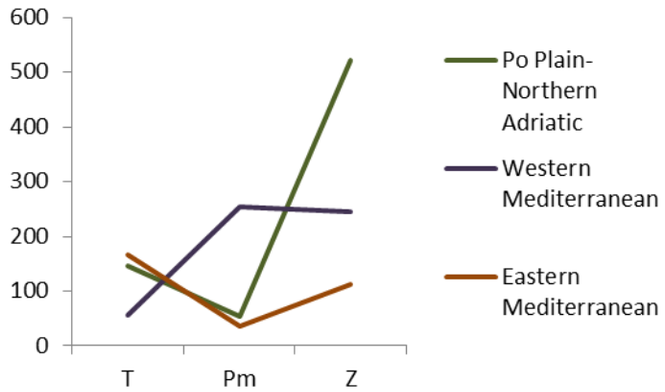
Bivalves





Number of species occurrences in the Tortonian (T), pre-evaporitic Messinian (Pm), and Zanclean (Z)



Number of occurrences and number of species recorded in each time slice

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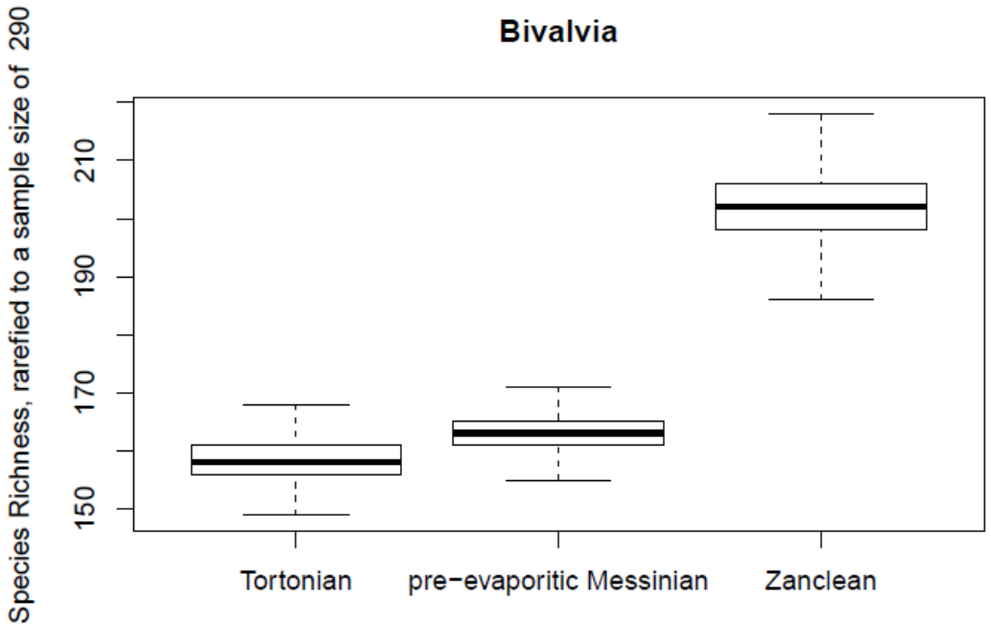
Q1: Was there a ***drop in diversity*** in the pre-evaporitic Messinian?



Temporal change in **species richness**

NO

In contrast, we observe an increase in the total number of species in the Zanclean, which is probably due to the large sampling bias toward this interval.

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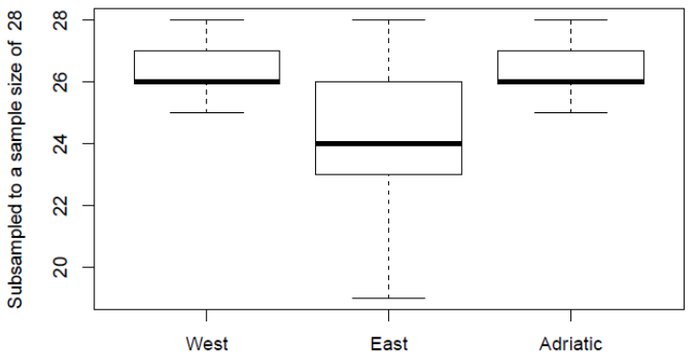
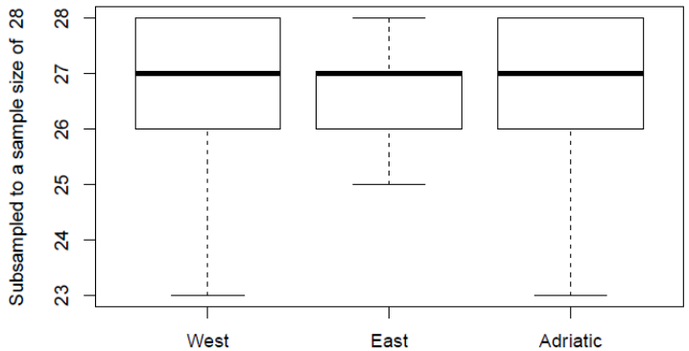
Q3: Was the present-day ***west-to-east decreasing gradient*** in species richness established before or after the Messinian?

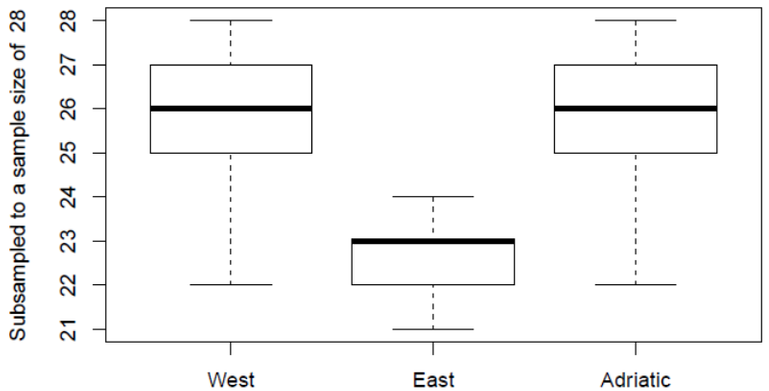
Tortonian



Zanclean



Pre-evaporitic Messinian



Spatial changes in **species richness** for bivalves

NEITHER

The eastern Mediterranean appears to have had a poorer bivalve fauna before the Messinian Salinity Crisis than the western Mediterranean and the Po Plain – Northern Adriatic region.

However, we must note that the sampling effort in the eastern Mediterranean for the pre-evaporitic Messinian is the lowest.

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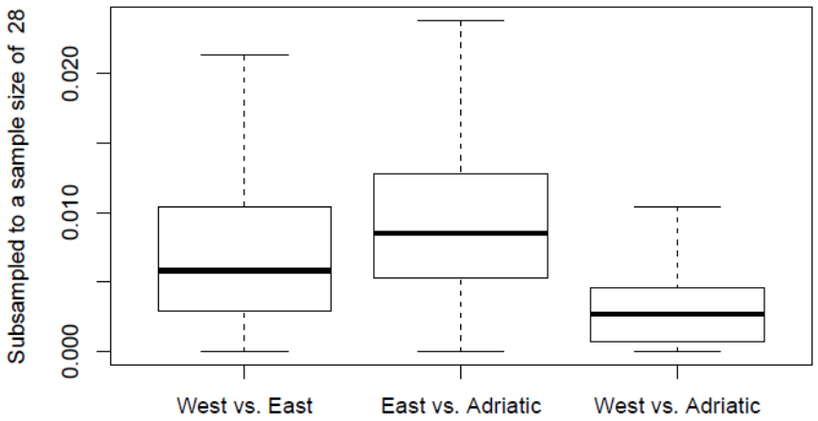
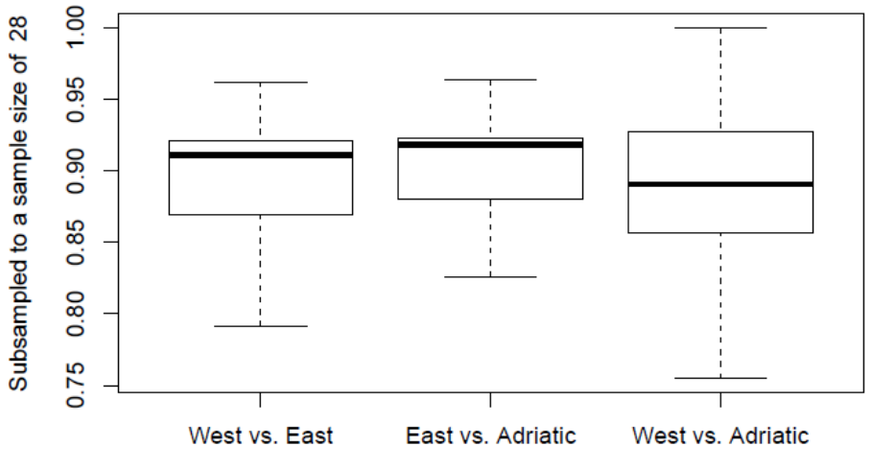
Q2: Was there a ***taxonomic change*** in the composition of the marine fauna?

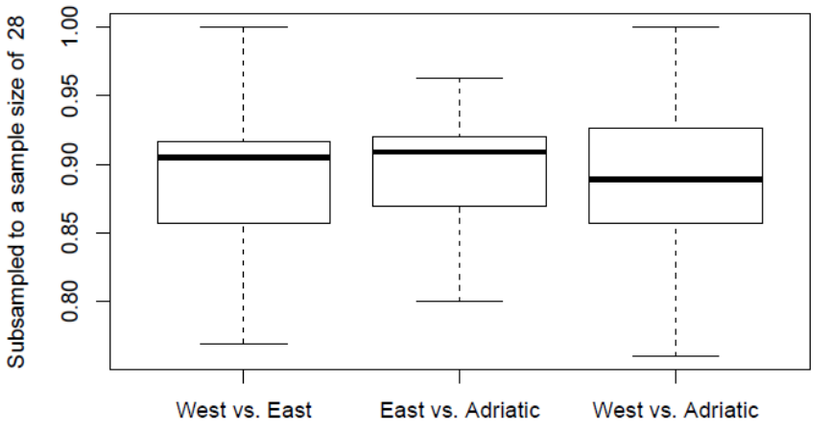
Dissimilarity due to species loss



Total dissimilarity



Dissimilarity due to species replacement



Dissimilarity of the **bivalve** assemblages in the three regions
(only Messinian is shown here as example)

YES

The three regions have very distinct bivalve faunas in all intervals.

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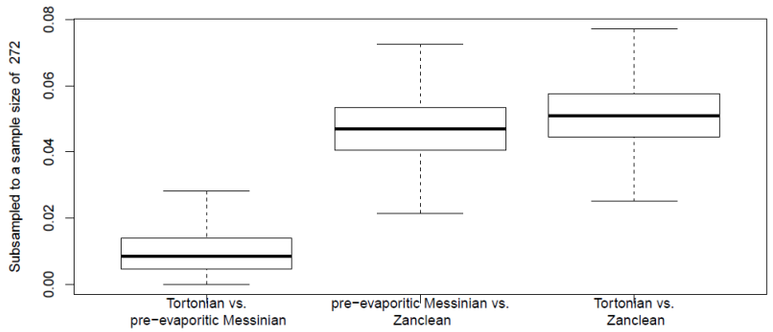
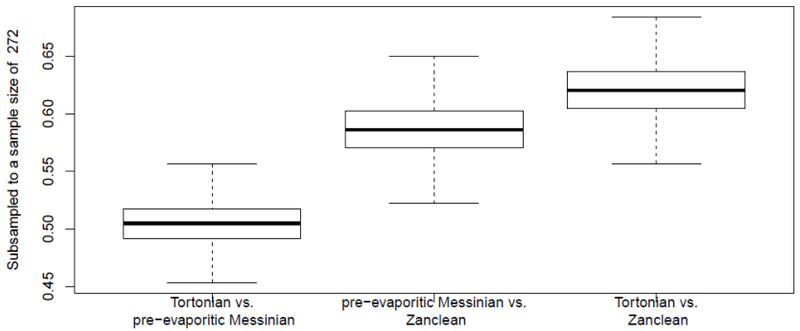
Q2: Was there a ***taxonomic change*** in the composition of the marine fauna?

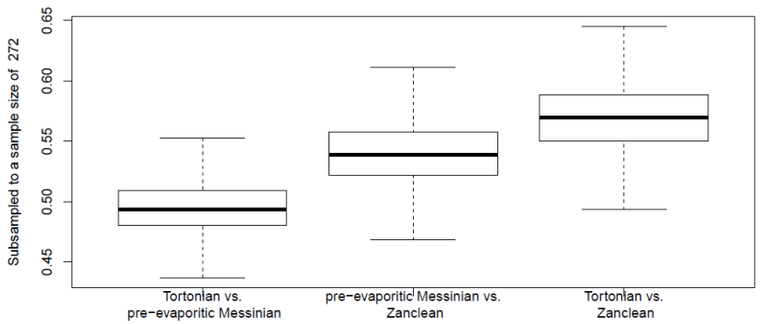
Dissimilarity due to species loss



Total dissimilarity



Dissimilarity due to species turnover



Dissimilarity of the **bivalve** assemblages over time in the whole Mediterranean

YES

The Tortonian and the pre-evaporitic Messinian bivalve faunas are very dissimilar from the Zanclean one, and this difference is caused mostly by species replacement.

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Conclusions

- Each taxonomic group shows **different patterns of diversity** change
- **Pre-evaporitic Messinian richness drop is not observed in all groups** (**Q1**)
- There are important **spatial gaps** in the fossil record
- We detect a **clear taxonomic change** in the composition of the marine fauna (**Q2**)
- The **main mechanism of diversity change** throughout the Tortonian-Zanclean is **species replacement**, rather than species loss
- Present results **do not suggest any connection** between the west-to-east decreasing gradient in species richness and the Messinian Salinity Crisis (**Q3**)

- The marine fauna, as depicted by these four groups studied so far, is quite different before and after the Messinian Salinity Crisis. Although the diversity is approximately the same, the composition of the faunas are distinct.
- In addition, the three regions have different, but equally rich faunas within each time interval.

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