Multiple phyla, one time resolution?
Time averaging in benthic foraminifera, mollusk, echinoid, crustacean and otolith fossil assemblages

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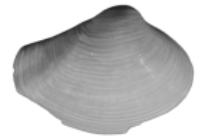


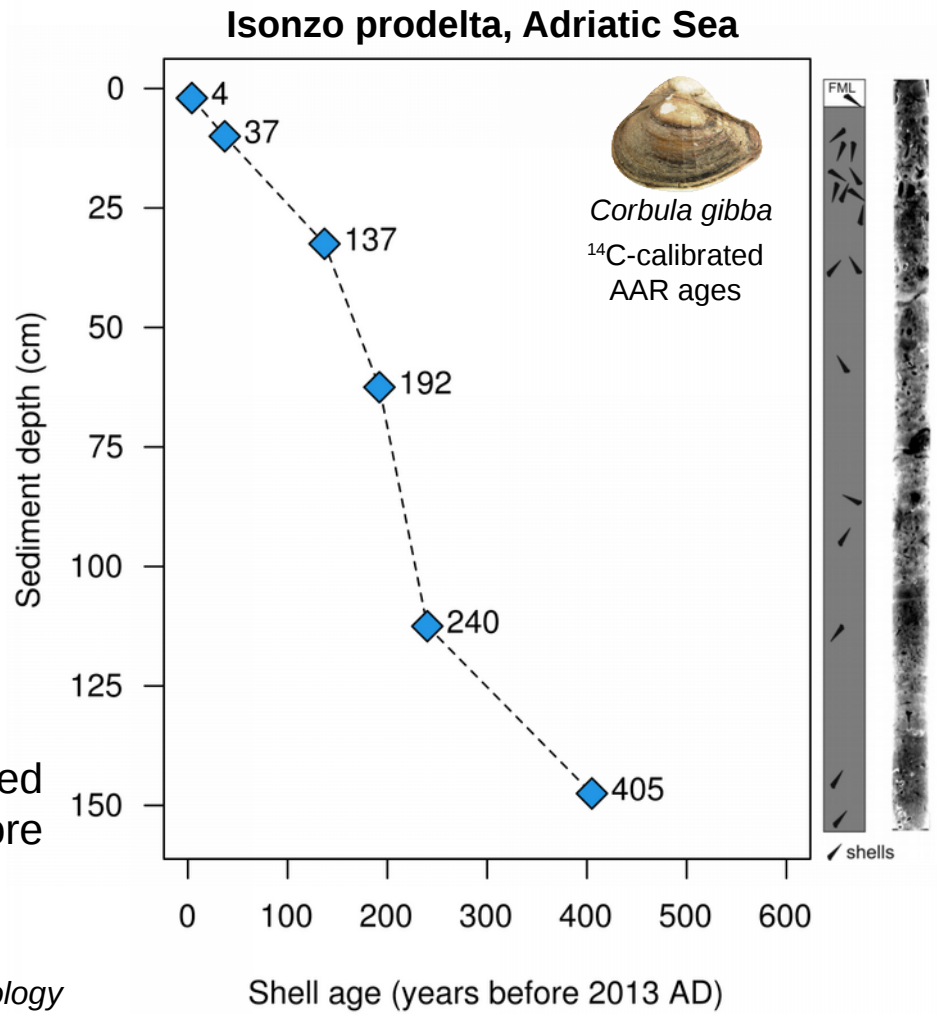


Time averaging: the fundamental property of fossil assemblages

Fossil assemblages are frequently affected by extensive time averaging
→ mixing of remains of organisms separated by decades, centuries or millennia in a single sedimentary layer

Time averaging limits the temporal resolution of geochemical and geochronological records based on biomineralized skeletal remains

6 shells dated in the entire core



data from Tomašových et al. 2018 *Paleobiology*

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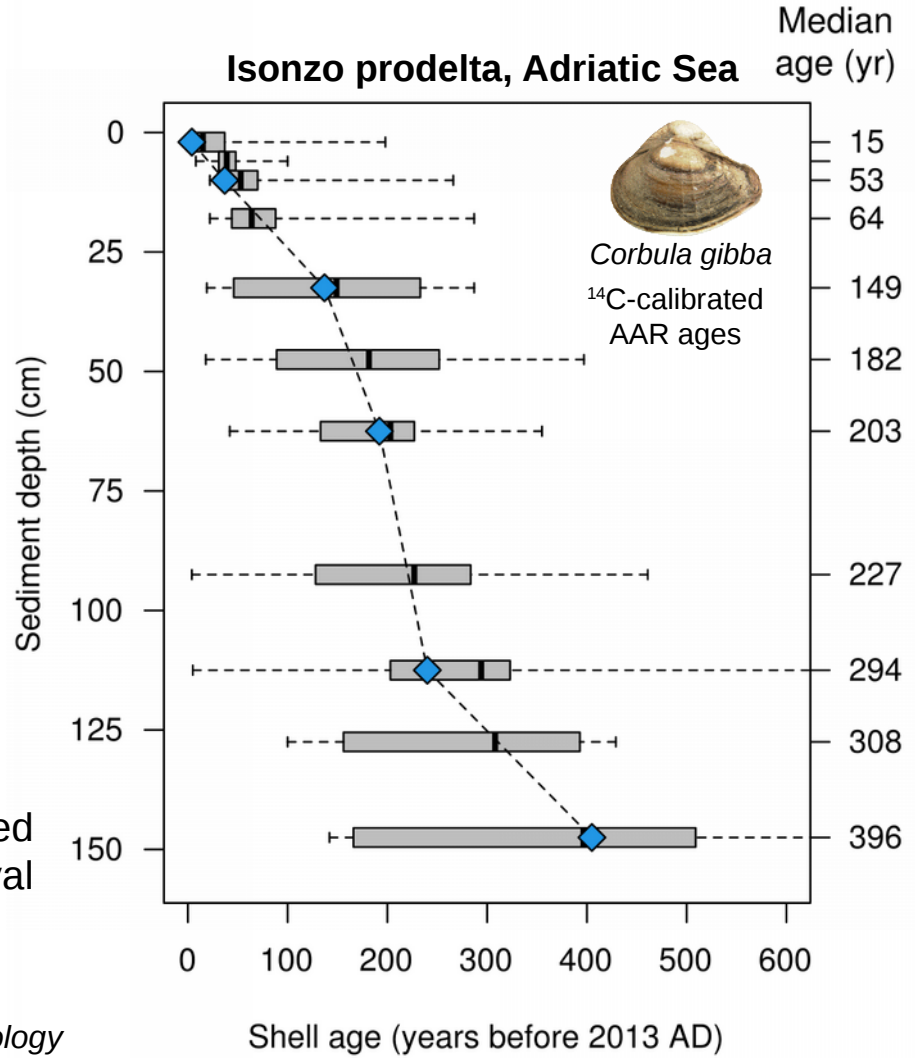
~30 shells dated per 5-cm core interval

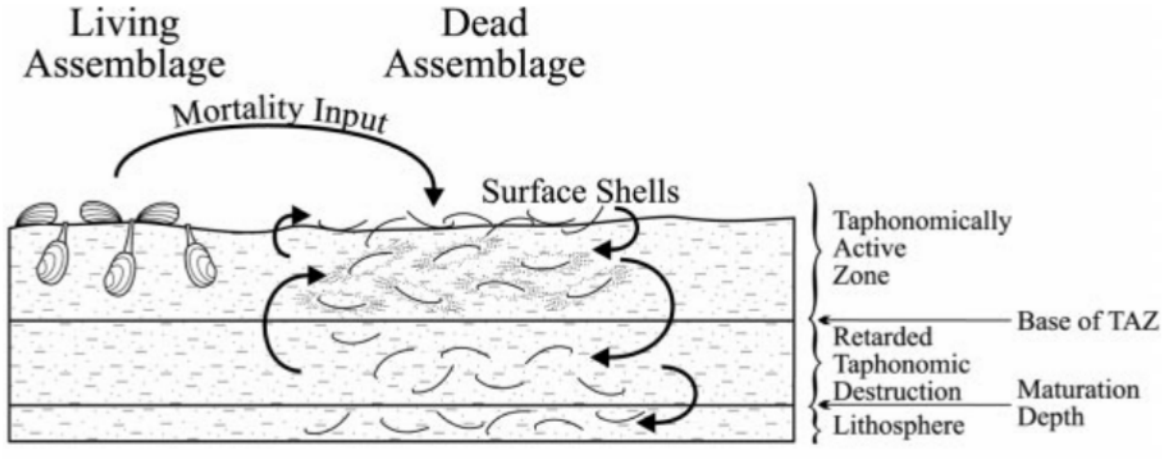


data from Tomašových et al. 2018 *Paleobiology*

Time averaging: the fundamental property of fossil assemblages

What is controlling the variation in time averaging across taxa and environments?

- skeletal production rates
- skeletal disintegration rates
- sedimentation rates
- rate and depth of sediment mixing



Olszewski 1999 *Paleobiology*

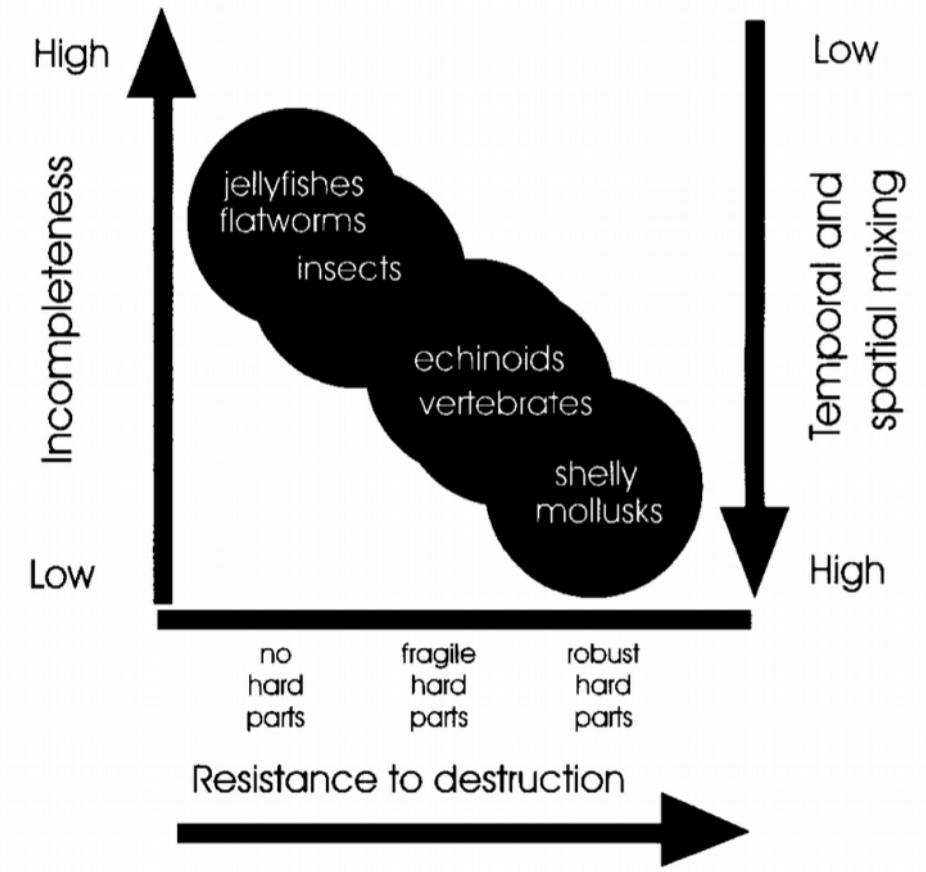
Taxonomic variation in time averaging

Variation in skeletal durability across higher taxa may be the primary factor controlling the temporal resolution of fossil assemblages

More robust and larger remains should survive prolonged mixing near the sediment surface → higher time averaging

How general in this pattern?

- many higher taxa lack direct estimates of time averaging
- processes that lead to burial and early diagenetic stabilization can allow fragile remains to escape rapid disintegration near the sediment-water interface



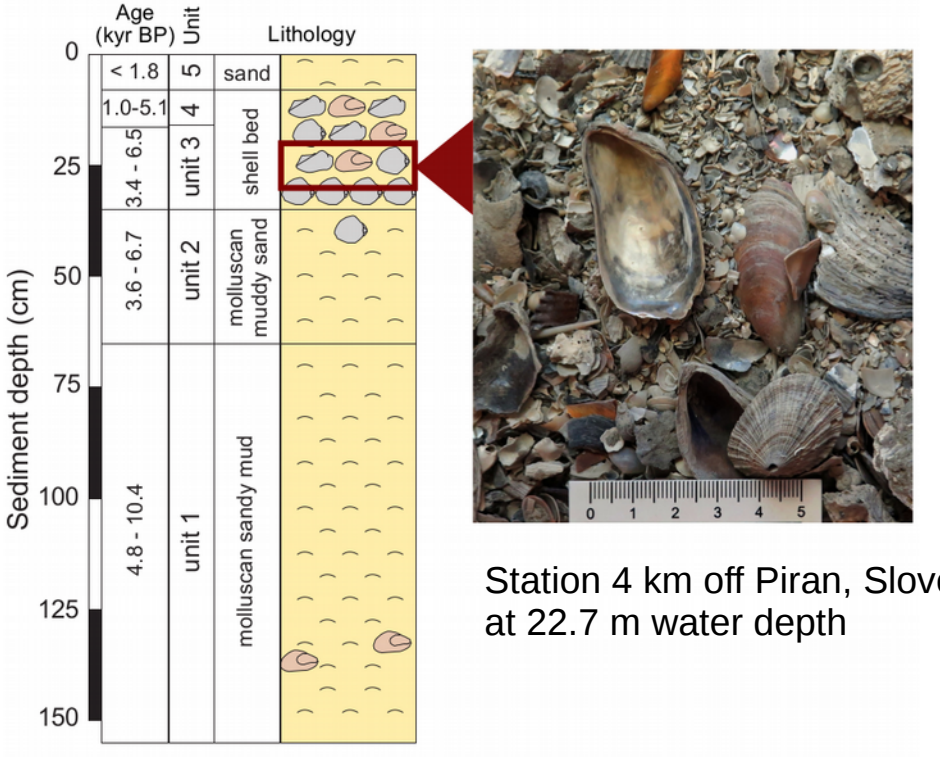
Kowalewski 1997 *Lethaia*

Case study: time averaging in five phyla of carbonate producers

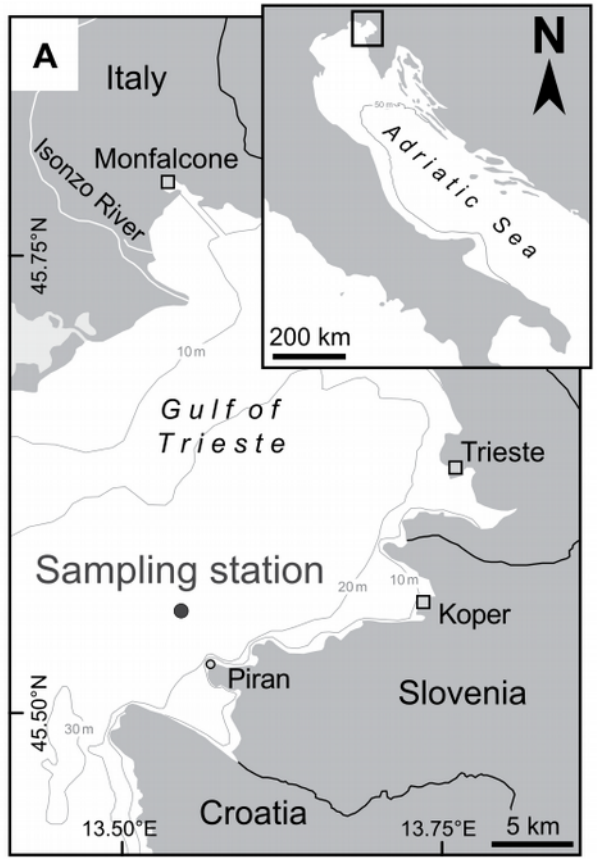
Sediment core from the NE Adriatic shelf (low sedimentation rate: ~0.15 mm/yr)

Remains of mollusks, foraminifera, echinoderms, crustacean, and fish otoliths sampled from 10-cm subsurface shell bed interval

Age-dated with ^{14}C-calibrated amino acid racemization (bivalves) and carbonate-target AMS ^{14}C (all other taxa)



Station 4 km off Piran, Slovenia at 22.7 m water depth



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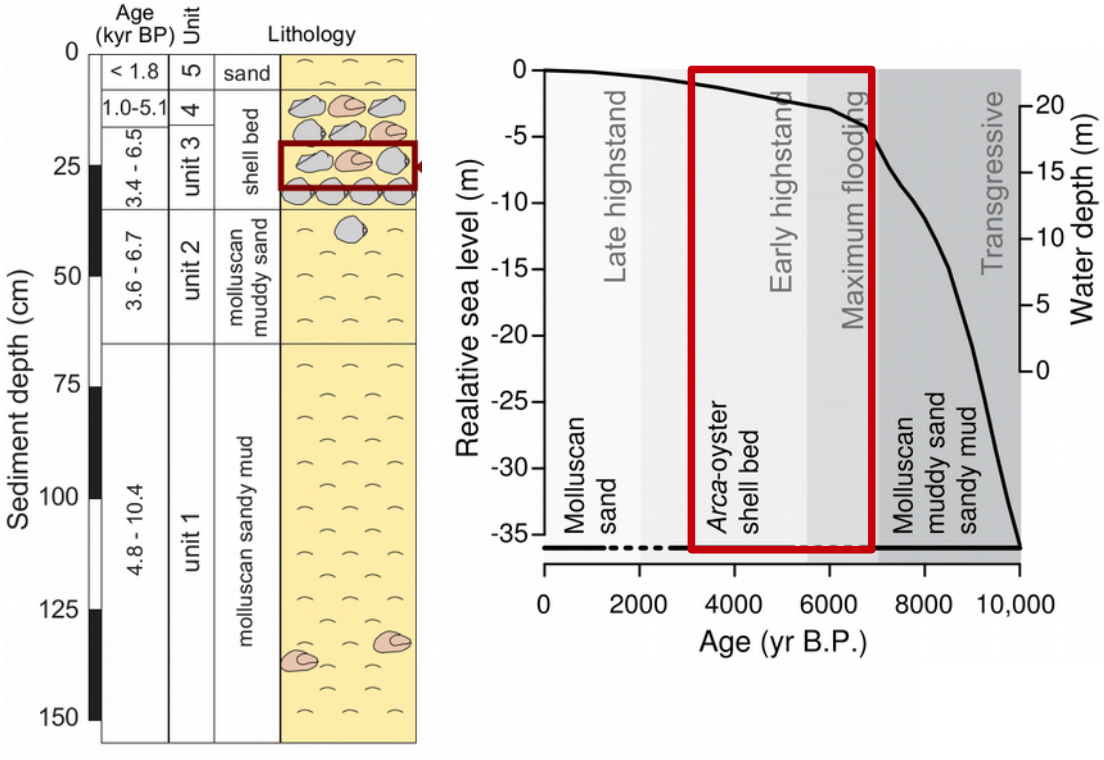
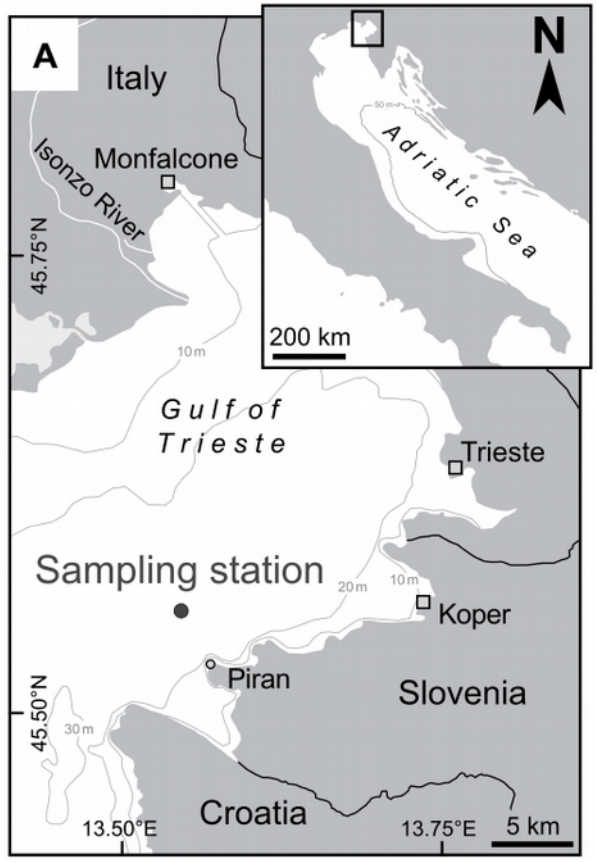
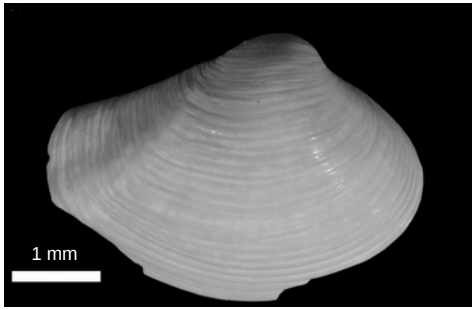




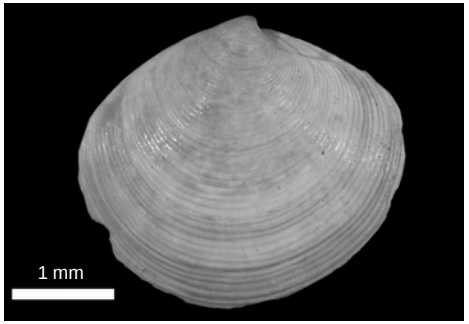
Target taxa: different size, skeletal architecture and mineralogy

Bivalves
aragonitic shells

Corbula gibba
(Corbulidea)

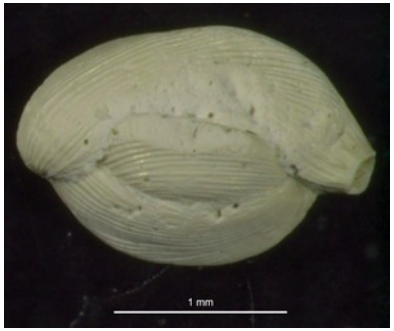


Gouldia minima
(Veneridae)



Foraminifera
high- and low-Mg calcitic tests

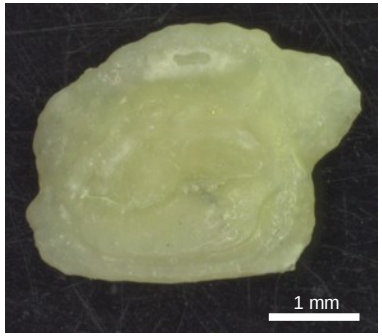
Adelosina intricata
(Miliolida, porcelaneous)

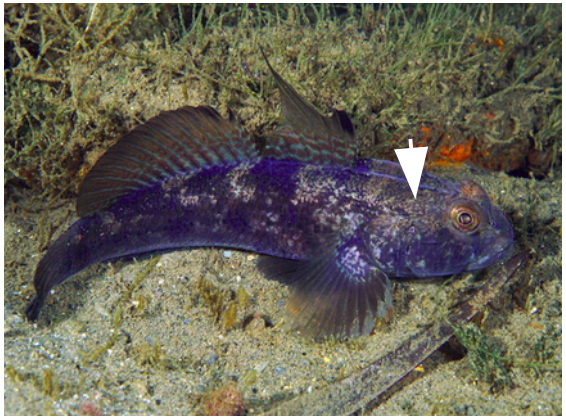


Elphidium crispum
(Rotaliida, hyaline)

Teleost fish
aragonitic otoliths

Gobius cobitis
(Gobiidae)





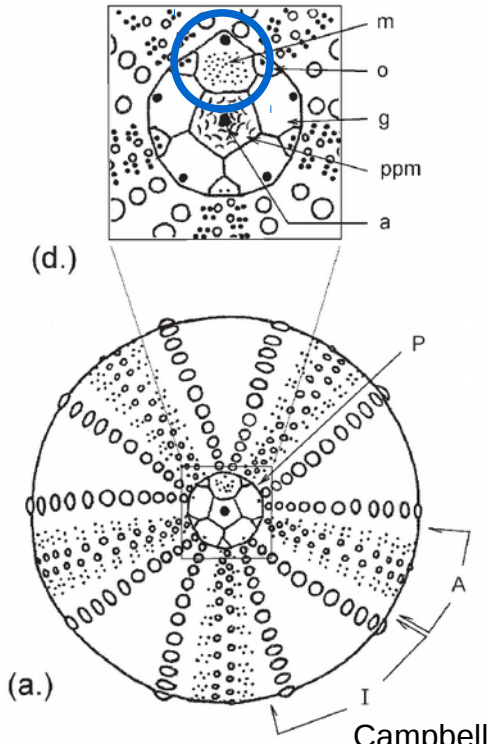
Target taxa: different size, skeletal architecture and mineralogy

Echinoids
high-Mg calcitic tests and madreporite plates

Echinocyamus pusillus
(irregular clypeasteroid)

Psammechinus and *Paracentrotus*
(regular camarodonts)

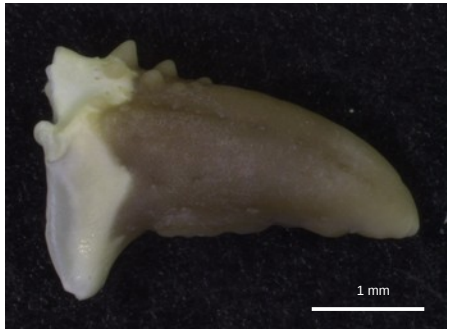
Madeporite
(unique plate in echinoid test)



Campbell 2008

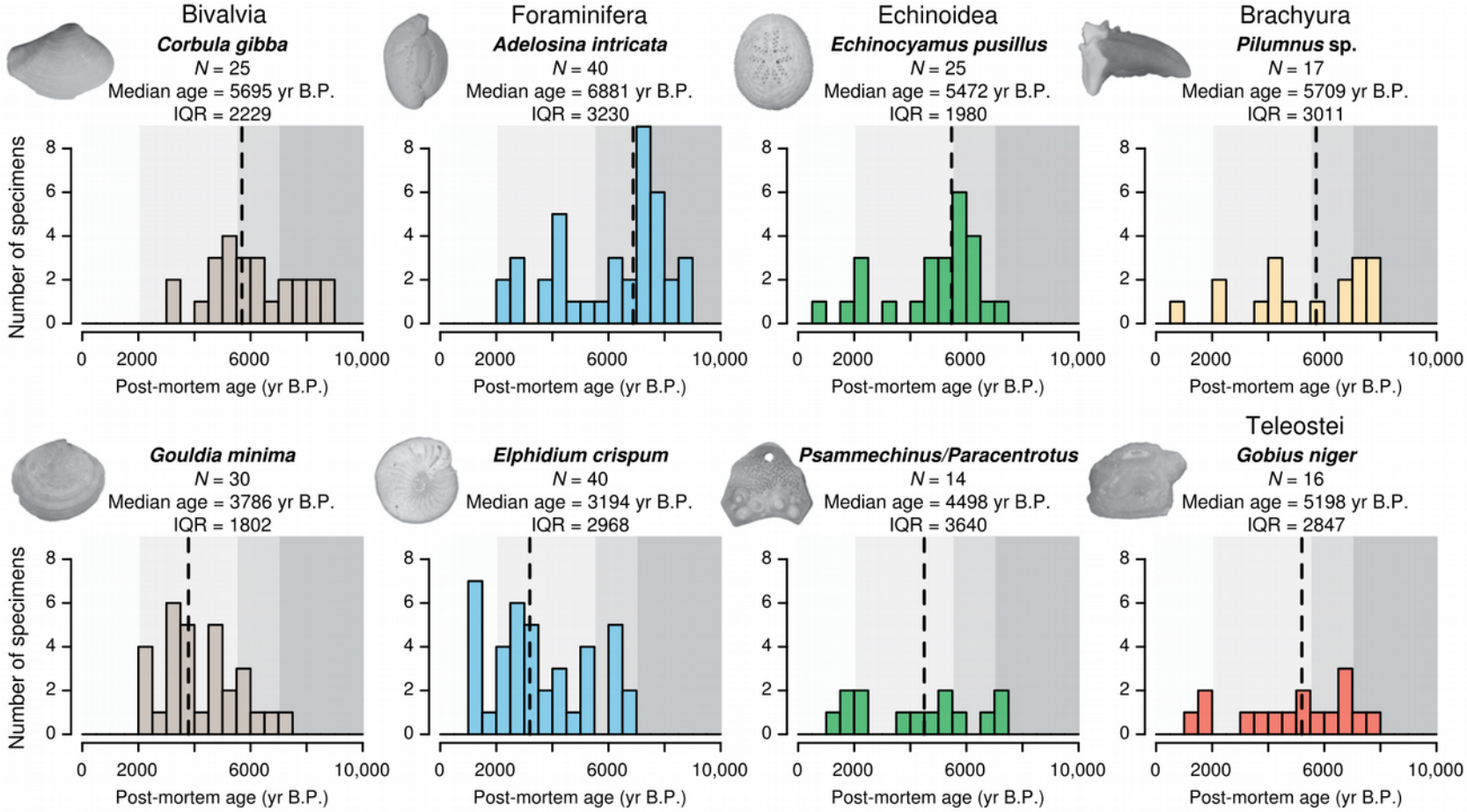
Brachyuran crustacean
low-Mg calcitic chelae

Pilumnus sp.
(Pilumnidae)



Results: multiple phyla, one time resolution

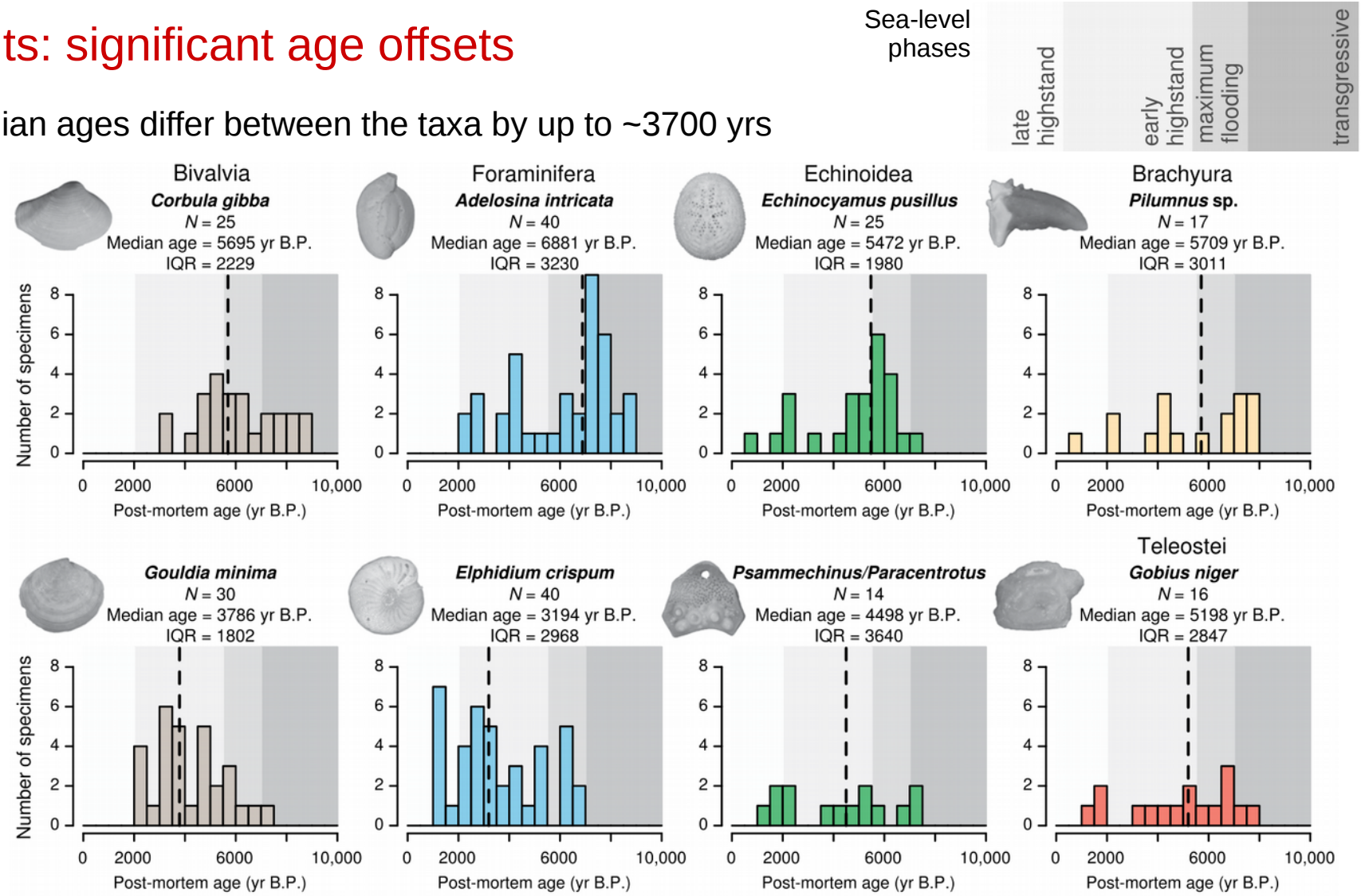
Similar extent of time averaging in all taxa: ~1800 to ~3600 yrs (interquartile age ranges)



Nawrot et al. 2022 *Geology*

Results: significant age offsets

Median ages differ between the taxa by up to ~3700 yrs



Nawrot et al. 2022 *Geology*

Summary: similar temporal resolution but different average age

Within-taxon time averaging (IQR)

min: 1800 yrs → bivalve shells

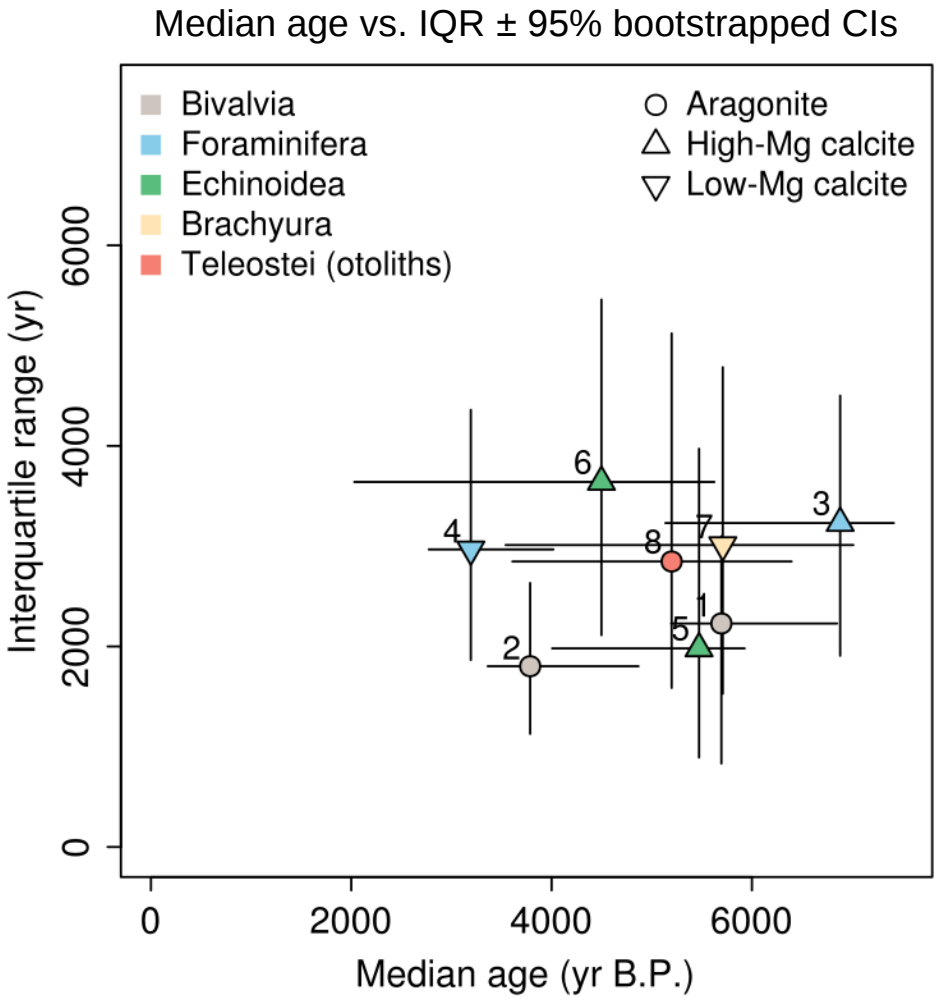
max: 3640 yrs → regular echinoid plates

Age offset (difference between median ages)

min: 14 yrs → between the crab and bivalve

max: 3700 yrs → between the two forams

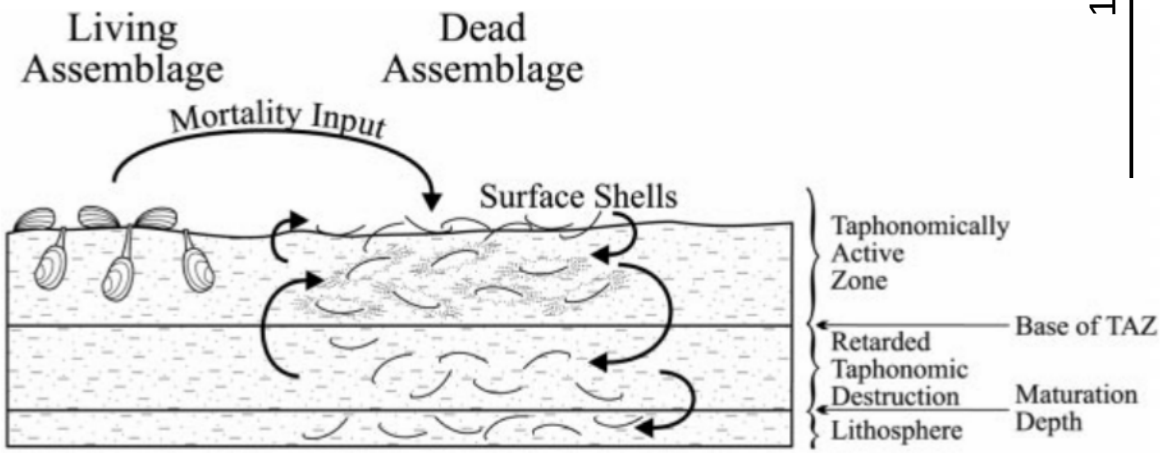
No relationship with size of the remains
or skeletal mineralogy



Controlling factors: sequestration

Sequestration decouples time averaging from the effects of skeletal durability:

- burial or early diagenetic processes in the subsurface protects shells from rapid destruction in the taphonomic active zone
- older shells are occasionally exhumed and mixed with younger cohorts by deep bioturbation



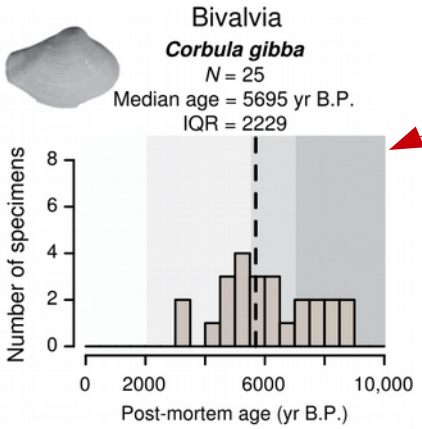
Olszewski 1999 *Paleobiology*

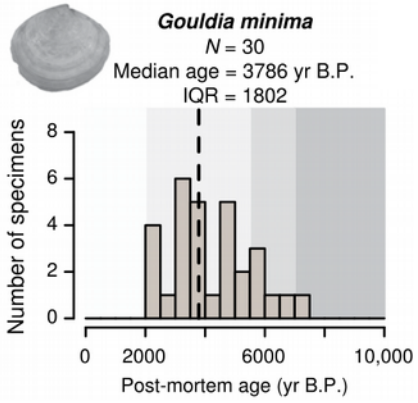
Resin cast of a shrimp burrow from the N Adriatic Sea

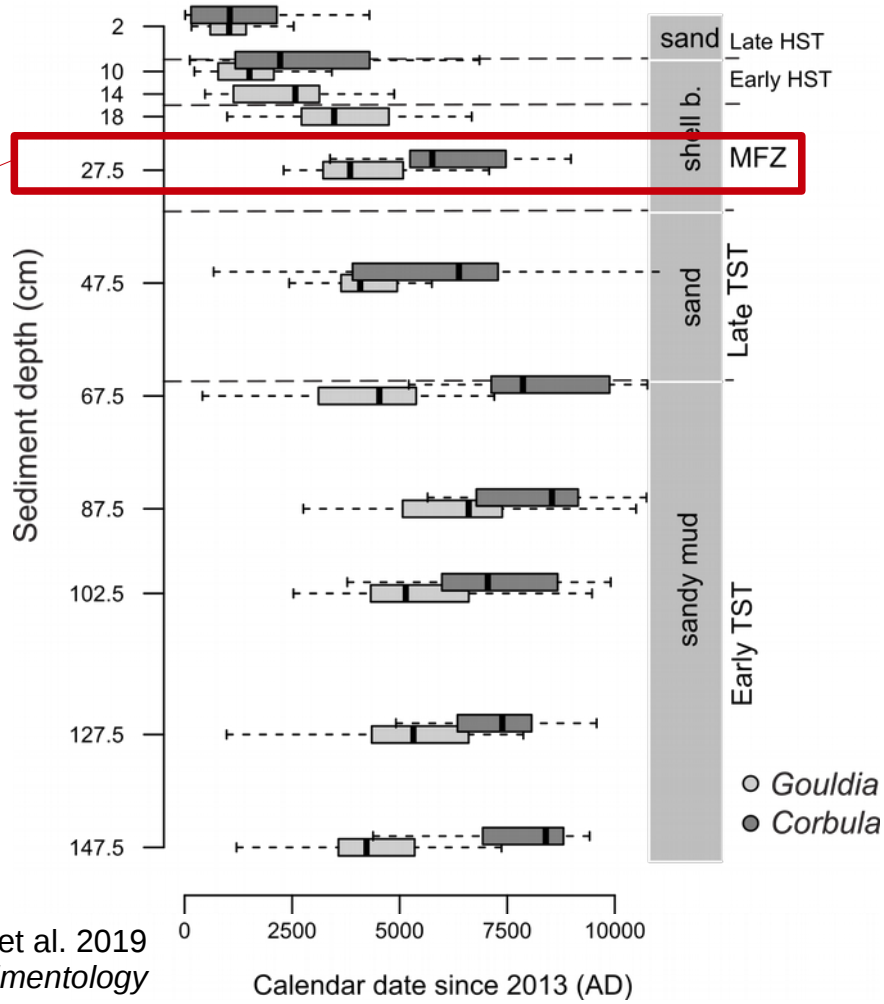
Pervesler & Dworschak 1985 *Senckenbergiana marit.*

Controlling factors: variability in skeletal production

Large age offsets between the two bivalve species are present throughout the studied core
→ effect of diachronous shifts in abundance



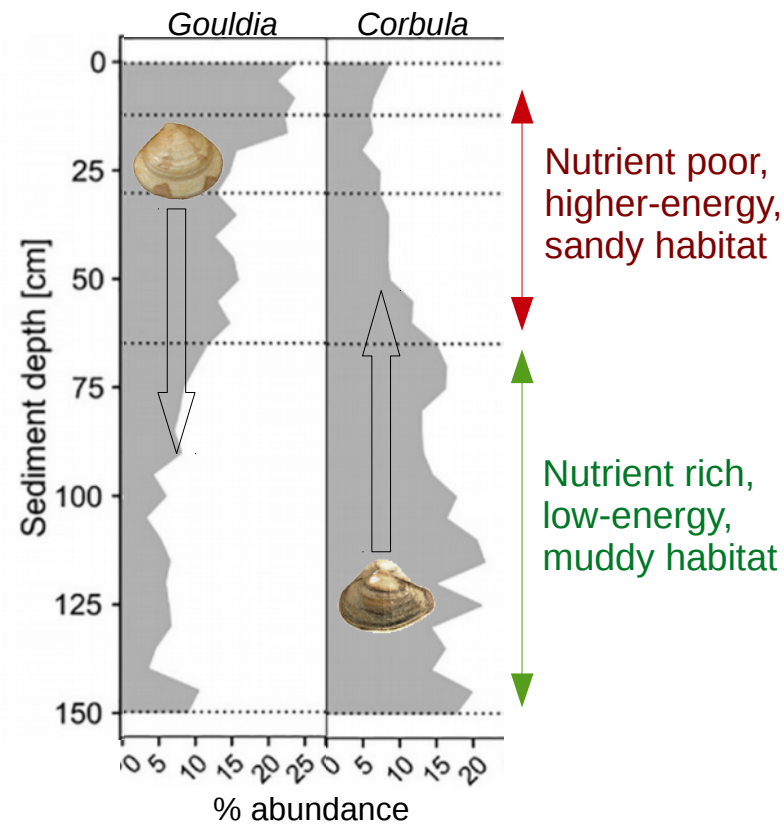


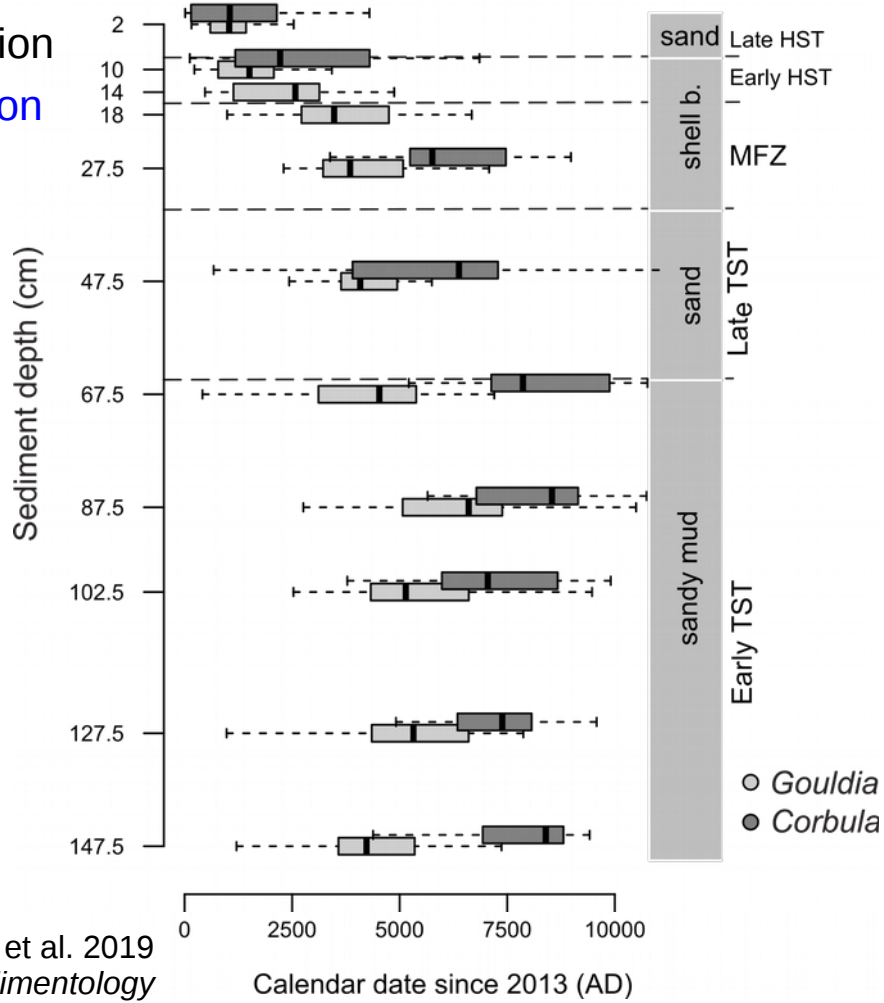


Tomašových et al. 2019
Sedimentology

Controlling factors: variability in skeletal production

- peaks of abundance (and thus shell production) occurred at different times during the transgression
- shells of different ages mixed by deep bioturbation



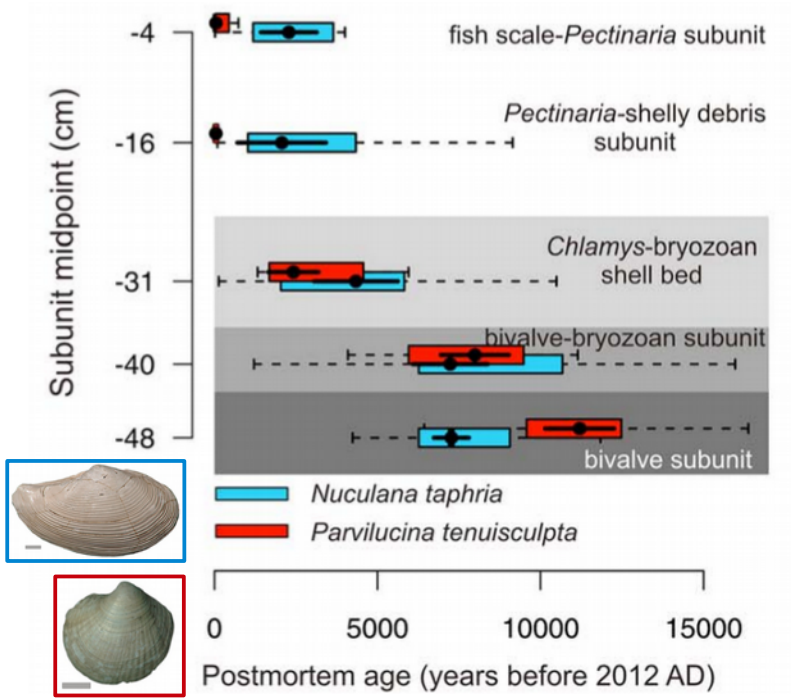


Tomašových et al. 2019
Sedimentology

Adriatic shelf in not unique

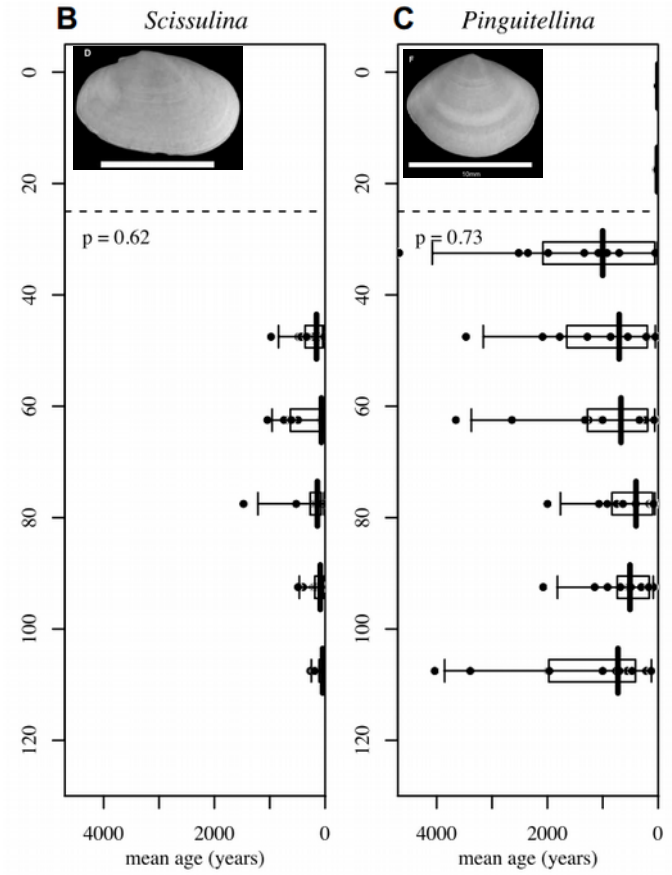
Age differences between co-occurring taxa are commonly observed in Holocene assemblages on continental shelves

Southern California
(siliciclastic shelf, 50 m water depth)



Tomašových et al. 2019 *Paleoceanogr Paleoclimatol*

Great Barrier Reef
(lagoon, 7.5 m water depth)



Kosnik et al. 2013 *Quat Geochronol*

Conclusions

Bad news

Just like macrofossils, microfossil assemblages can be time-averaged over centuries to millennia in shallow-water environments

Significant age offsets between co-occurring species can:

- complicate paleoecological and paleoenvironmental inferences
- make age models and geochemical proxy records sensitive to taxon choice

In other words, high-resolution age models based on dating of a single taxon may not be directly applicable to other members of the fossil assemblage or to geochemical proxy records based on their biomineralized hardparts

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Good news

Fossil records of taxa with fundamentally different skeletal architecture and durability can have comparable temporal resolution

Limitations imposed by time averaging can be circumvented by direct age dating of large numbers of specimens

→ now possible thanks to recent advances in radiocarbon methods