The History of Sea Level Rise in Delaware Bay:
SLR has Little Impact on the Morphology of *Limulus* or its Functional Spawning Habitat

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There are no records of fossil horseshoe crabs prior to the Cambrian, although there were candidates (*Sidneyia* -> *Molaria*).
"In the fossil record, the basic xiphosurid horseshoe crab body plan occurs in the Late Ordovician Period, about 445 million years ago" Lunataspis (D. M. RUDKIN)
The question is: Can horseshoe crabs continue to survive as beaches erode due to Sea Level Rise?

Animals like Harry Horseshoe Crab lived on earth millions of years ago!

The horseshoe crab swimming in the water of J.N. “Ding” Darling National Wildlife Refuge is a familiar sight to many visitors.
My all-time hero Alfred Wegener (1880-1930) proposed the concept of Continental Drift, but science did not believe this until the early 1960’s.
Early in the Mesozoic the lithographic limestone of the Solenhofen yielded fossils of horseshoe crabs that resembled modern species.

This is a lithographic print of a modern horseshoe crab. Fossil horseshoe crabs were originally discovered in this type of limestone.
Although examples of fossil horseshoe crabs occurred in the Mesozoic, the most remarkable find by Blazej Blazejowski of *Limulus darwini* is the beginning of an important enduring story.
The genus *Limulus* must have already evolved in an earlier Jurassic sea – by the mid- to late-Jurassic, it was preserved as a fossil that is estimated to be 148 my. During the Cretaceous, we speculate that *Limulus* began to drift east with the North American Plate.
By the end of the Cretaceous, dinosaurs disappeared most likely due to heat, not a brief “nuclear winter” caused by an asteroid. However, *Limulus* survived and is still found in the Yucatan.
During the Cenozoic, very large North American mammals evolved. But, about 2my ago repetitive glaciers began. By the end of the Last Great Ice Age, many of the large mammals were gone.

BUT NOT *Limulus polyphemus*!
In the 1970’s and 1980’s, *Limulus polyphemus* was extremely common during the spawning season, particularly along deep sandy beaches in Delaware Bay.
Huge mats of *Limulus* eggs once covered many of the open bay beaches of Delaware Bay.
By the late 1980’s, we began to see evidence of rising sea level and beach erosion along the NJ shore of Delaware Bay, exposing peat beds that have been buried for thousands of years.
The road to Thompsons Beach had to be closed!
The fact is, Sea Level Rise has been going on for a very long time. The town of South Cape May was lost due to SLR in the early 1900’s.
Life was tough then for both people and horseshoe crabs.
Beaches that once were characterized by deep sand and wide, with many spawning horseshoe crabs, were eroding by the mid-1990’s thus exposing ancient peat banks.
By the end of the 20th century, people began to notice a change in the level of high tide. Shorebirds and horseshoe crabs experienced reduced numbers. As we know, commercial fishing pressure was increasing as well – but that is another story that we don’t have time to discuss today.
Clearly, the beaches of Delaware Bay were being impacted by Sea Level Rise.
To be more specific, in New Jersey the rate of ocean rise has recently been shown to be 4 millimeters per year!

1. The last time this rate occurred was about 6,000 years ago, when the glaciers began melting big time (start of the Holocene).

2. The rate today can be partitioned into 3 factors:
   - A. Climate change (whatever the cause) accounts for at least 2 mm of ocean rise per year.
   - B. Another 1 mm is due to land subsidence.
   - C. About another 1 mm is due to withdraw of fresh water from aquifers.
With sea level rise, natural beaches slowly moved inland

An overwash beach is forming inland of the natural beach.

Sufficient buffer is needed to protect houses from an advancing beach.
Houses at the south end of Reeds Beach “moved” increasingly into the intertidal zone, especially after Hurricane Sandy.
“Armoring” the shoreline prevents the natural beach migration cycle, and destroys HSC spawning habitat.
Google map of Delaware Bay, NJ coastline from Cape May to Fortescue (2015)
We have studied several Delaware Bay beaches that have changed since 1933, using aerial photography and “ground truth” to see how horseshoe crab beaches have responded to SLR.

Loveland RE and Botton ML (2015), Sea level rise in Delaware Bay: adaptations of spawning horseshoe crabs (*Limulus polyphemus*) to the glacial past, and the rapidly changing shoreline of the bay. In: Carmichael et al. (eds.), in press.
JETTY at REEDS BEACH and BIDWELLS CREEK

After the jetty was extended to protect navigation, the movement of sand was reduced, thus exposing peat beds to the north of the creek.

Delaware Bay
Beach north of Bidwells Ditch: A case of sand starvation
EAST POINT at MAURICE RIVER COVE
The dark line represents the “queens” line used to establish riparian rights; this line is fixed in space, so the ‘relative’ movement of the shoreline represents real setback over time.
EAST POINT COVE ca. 2001

- Some development of an overwash beach, but largely peat bank.
The overwash beach at East Point Cove is an example of emerging marginal habitat for spawning horseshoe crabs.

View of overwash beach area looking out to the bay.

View of the overwash beach where horseshoe crabs actually laid eggs at high tide.
After considerable setback over 60 years, the “pocket” beach at East Point continues to be prime habitat for spawning *Limulus*. However, little is done to protect this beach, even though it is on state land.
The restored Moores Beach of summer 2014 already shows changes due to long-shore currents and storms.

Beach widened with addition of inland sand, some movement into creek.

Note loss of surface sand, with more peat bank emerging.

SUMMER 2014

SPRING 2015
Sampling eggs on open beaches, tidal creeks, and sand bars
Kimbles Beach: Open bay beach is eroding and habitat is becoming less attractive for spawning
Dense spawning on the banks of a tidal creek at Kimbles Beach
Many crabs preferred adjacent sandbars, rather than the open beach, for spawning.
So, while mankind struggles to adapt to SLR in a changing world....
Horseshoe crabs will move into “marginal habitats” as open bay beaches erode and sand becomes scarce.
A Longer View of the Importance of Marginal Habitats

Delaware Bay 2015

Delaware Bay 16,000-18,000 Years BP

Knebel et al. (1988)
Habitats such as tidal creeks and sand bars may be important refugia for horseshoe crab populations when sandy beaches are limited in size.
Summary and Conclusions

• Geological changes since the Jurassic, including SLR, have not led to dramatic changes in the morphology of Limulus (compare fossil L. darwini with extant L. polyphemus).

• SLR itself does not threaten horseshoe crabs; they’ll track the location of sandy substrate wherever it is located. Rather, it is the ‘armoring’ of the shoreline, preventing the natural movements of sand, that we must be concerned with.
Summary and Conclusions

• Strategies to preserve horseshoe crab spawning habitat must account for SLR.

• Authorities should look for cost-effective alternatives to ecologically destructive practices such as shoreline armoring.
Thank you!

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