PATHWAYS TO THE MARINE REALM IN SERPENTES

William Gearty
@willgearty
<table>
<thead>
<tr>
<th>Time (Ma)</th>
</tr>
</thead>
<tbody>
<tr>
<td>350</td>
</tr>
<tr>
<td>300</td>
</tr>
<tr>
<td>250</td>
</tr>
<tr>
<td>200</td>
</tr>
<tr>
<td>150</td>
</tr>
<tr>
<td>100</td>
</tr>
<tr>
<td>50</td>
</tr>
<tr>
<td>0</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Paleozoic</th>
<th>Mesozoic</th>
<th>Cenozoic</th>
</tr>
</thead>
<tbody>
<tr>
<td>D</td>
<td>C</td>
<td>P</td>
</tr>
<tr>
<td></td>
<td>Tr</td>
<td>J</td>
</tr>
<tr>
<td></td>
<td>K</td>
<td>Pg</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Ng Q</td>
</tr>
</tbody>
</table>

Modified from Kelley and Pyenson 2015, Science
Modified from Kelley and Pyenson 2015, Science
Modified from Tennant et al 2016, *Nature Communications*

Peters and Heim 2010, *Paleobiology*
- Lots of oxygen
- Very low salinity
- No buoyancy
- Low heat loss
- Low viscosity

- Less oxygen
- Very high salinity
- High buoyancy
- High heat loss
- High viscosity
PERMANENT LIFE IN THE OCEAN IS HARD*

*WHEN YOU’VE ADAPTED TO LIVING ON LAND
PERMANENT LIFE IN THE OCEAN IS HARD*
*WHEN YOU’VE ADAPTED TO LIVING ON LAND

FOOD ACQUISITION
SALT BALANCE
DEHYDRATION
LOCOMOTION
THERMOREGULATION
REPRODUCTION
MAMMALS GET MUCH BIGGER

Modified from Gearty et al. 2018, PNAS
CROCS GET MUCH BIGGER TOO

Gearty and Payne, in review, Evolution
PREVIOUS WORK

- Phylogeny
  - Timescaled with ape::chronos() with fossil calibrations
- Body mass (g)
- Reproductive mode (eggs vs. live birth)
- Reproductive mode (eggs vs. live birth)
- Average temperature
- Average elevation
HABITAT DATA COLLECTION

BIOME

TIERING

wikipedia.org

Marques, Eterovic, and Sazima 2012
## HABITAT DATA COLLECTION

<table>
<thead>
<tr>
<th>BIOME</th>
<th>TIERING</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marine</td>
<td>Arboreal</td>
</tr>
<tr>
<td>Brackish</td>
<td>Scansorial (“semi-arboreal” or “climber”)</td>
</tr>
<tr>
<td>Freshwater</td>
<td>Surficial (“terrestrial”)</td>
</tr>
<tr>
<td>Semi-aquatic</td>
<td>Semi-fossorial (occasional diggers)</td>
</tr>
<tr>
<td>Forest</td>
<td>Fossorial (“digger”)</td>
</tr>
<tr>
<td>Grassland</td>
<td>Aquatic</td>
</tr>
<tr>
<td>Desert</td>
<td></td>
</tr>
<tr>
<td>Tundra/montane</td>
<td></td>
</tr>
</tbody>
</table>
**BIOME**
- Marine
- Brackish
- Freshwater
- Semi-aquatic
- Forest
- Grassland
- Desert
- Tundra/montane

**TIERING**
- Arboreal
- Scansorial ("semi-arboreal" or "climber")
- Surficial ("terrestrial")
- Semi-fossorial (occasional diggers)
- Fossorial ("digger")
- Aquatic
BODY SIZE BY BIOME
WAIT, HOW?
WHICH ADAPTATIONS/CONDITIONS PRECEDED THE MARINE INVASIONS? (PERHAPS ENABLING THEM)
FIRST, RECONSTRUCT WHEN THE MARINE INVASIONS OCCURRED
THEN, RECONSTRUCT OTHER TRAITS AND ENVIRONMENTAL VARIABLES
Probability of Having Trait/Condition

Probability of Being Marine

Marine Invasion

Adaptation
JOINT RECONSTRUCTIONS

Equation:

\[ \text{Probability of Having Trait/Condition} \]

Marine Invasion

Probability of Being Marine

After Invasion

During Invasion

Before Invasion

Adaptation

Probability of Having Trait/Condition
JOINT RECONSTRUCTIONS

Adaptation
JOINT RECONSTRUCTIONS

Probability of Having Trait/Condition

Probability of Being Marine

Before Invasion

During Invasion

After Invasion

Adaptation

Exaptation/Ecological Filtering
JOINT RECONSTRUCTIONS

Adaptation

Exaptation/Ecological Filtering

Nonaptation (or adaptation for something else)
Snakes would need to be near the ocean in order to invade it.
TESTING THE METHOD: ELEVATION
TESTING THE METHOD: ELEVATION

Method seems to work

Before Invasions
TEMPERATURE

Before Invasions

Ecological filtering?
BODY MASS

Adaptation to extend dive capacity?

During Invasions
FRESHWATER OCCUPANCY

Avoid Freshwater

No ecological selectivity for freshwater adaptation

During Invasions

Before Invasions

After Invasions
VIVIPARITY

One Exception

Ecological filtering?

Before Invasions
CONCLUSIONS

- While aquatic snakes are significantly larger than their terrestrial counterparts, it doesn’t match the extent in mammals or crocs.
- Viviparity appears to have evolved before these lineages invaded the ocean, likely as an adaptation for some other reason.
- This facilitated marine invasions of snakes from many different environments, but only if those environments were in tropical regions at low elevation.
ACKNOWLEDGMENTS

Elsie Carrillo
Christianne Orsmby
Jonathan Payne
Payne Paleobiology Lab
Lyons Paleoecology Lab
QUESTIONS?
REPRODUCTIVE MODE BY BIOME

Marques, Eterovic, and Sazima 2012
In Forests
Until Fully Marine

Couple Exceptions

In Grasslands
Until Fully Marine

Couple Exceptions
Aquatic Tier
Semifossorial Tier
Surficial Tier
Scansorial Tier

Arboreal Tier