Are there common patterns of ontogenetic shell shape changes between aquatic and terrestrial emydid turtles?

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ABSTRACT

Turtles of all species have a higher risk of mortality during the juvenile stage due to their smaller, less ossified, and therefore weaker shells. Thus juvenile turtles must utilize other strategies such as concealment or escape in order to avoid predation. In line with these demands, previous research has hinted that juvenile aquatic turtles start off with shell shapes more consistent with increased hydrodynamic efficiency, and only develop shell shapes more consistent with strength as they get bigger and their shells ossify. However, these ideas have never been tested on a large set of species. We collected data from 8 species from the family Emydidae, including both terrestrial and aquatic species. 3D landmark data from the shells of individuals and the relationship between shell shape and size within and between species was analyzed. We predicted that juvenile turtle shell shapes in aquatic species will be more streamlined than in adults, while those of terrestrial species will not be more streamlined. The relationship between size and shape, species and shape, and their interactions were all significant, indicating significant correlations between the size and species of a juvenile turtle and its shape. In general, juvenile turtles start off with round and flat shells and as they grow their shells become more ovate and domed. These shape changes are consistent with decreased hydrodynamic efficiency. By understanding juvenile turtle shell structure and function, conservation efforts for juvenile turtles can be developed to protect turtles in their most vulnerable stage.

MATERIALS & METHODS

- Specimens of: *Chrysemys picta* (*n*=52), *Clemmys guttata* (*n*=29), *Deirochelys reticularia* (*n*=30), *Glyptemys insculpta* (*n*=22), *Graptemys geographica* (*n*=25), *Pseudemys concinna* (*n*=35), *Trachemys scripta* (*n*=36), & *Terrapene carolina* (*n*=22) were obtained from the Carnegie Museum of Natural History
- Dorsal, ventral, and left and right lateral views of each specimen were photographed.
- Each view was digitized (Figure 1) and the landmark coordinates from all four of these views were assembled into a single three-dimensional set of landmark coordinates.
- All specimens were aligned using a generalized Procrustes fit.
- Principle components analysis was conducted to visualize the distribution of specimens in multivariate shape space.
- Procrustes ANOVA was used to determine how shell shapes changed with growth, and whether aquatic and terrestrial species differed in their allometric trajectories.

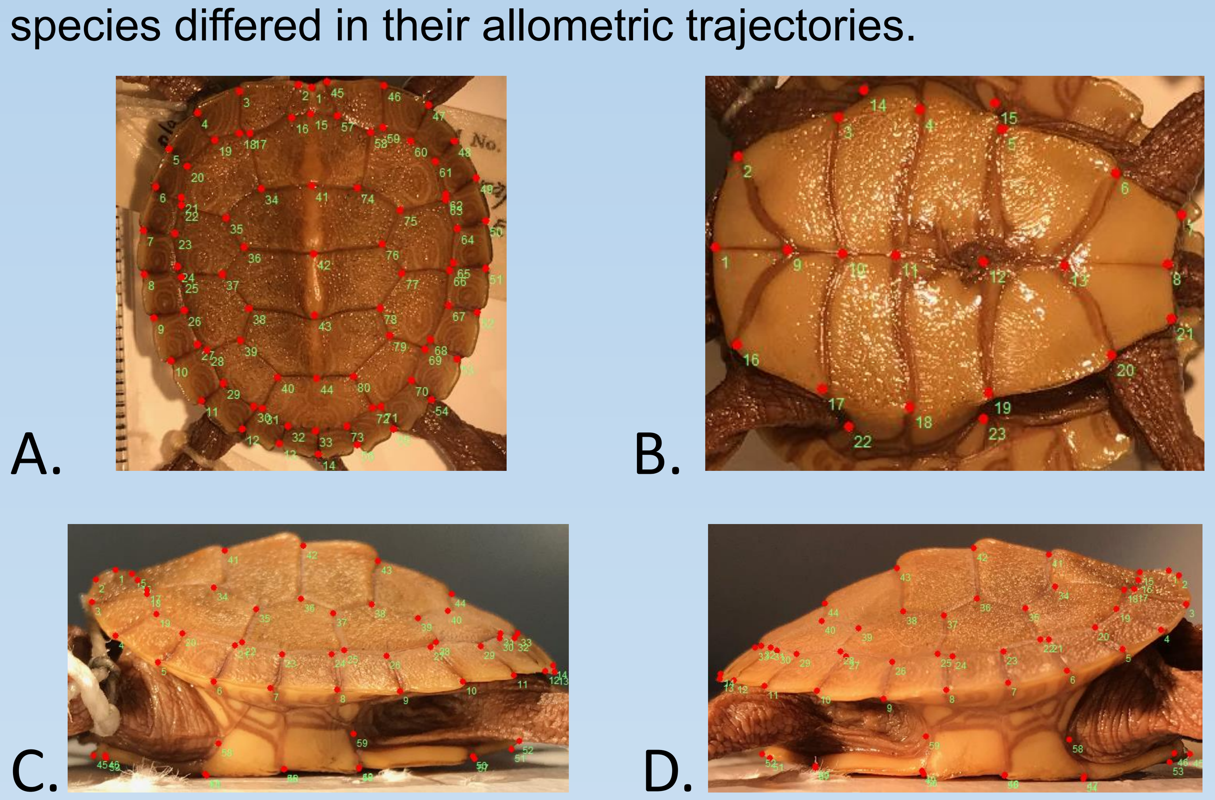

Figure 1 – Positions of all landmarks on a juvenile map turtle (*Graptemys geographica*) in A) Dorsal, B) Ventral, C) Left lateral, and D) Right later views

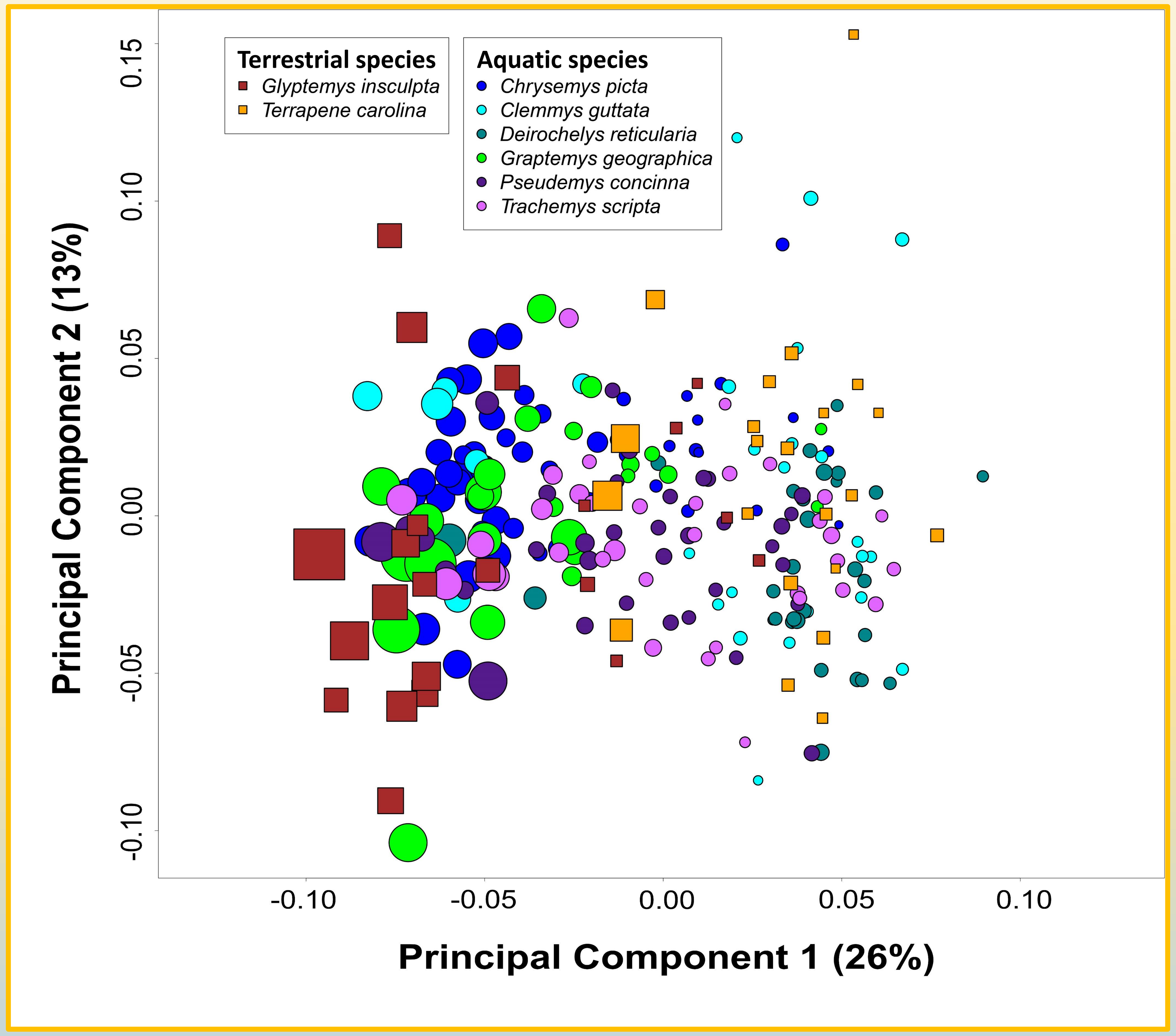

Figure 2 – Individual PC1 and PC2 scores. The size of each point is proportional to the size of the turtle.

Table 1 – Results from a Procrustes ANOVA on shell shape with size, habitat, and their interaction as factors

	Df	SS	MS	R^2	F	Z	*P*
Size (shell length)	1	0.487	0.487	0.177	58.159	8.715	<0.001
Habitat	1	0.123	0.123	0.045	14.680	6.697	<0.001
Size x Habitat	1	0.070	0.070	0.025	8.273	5.604	<0.001
Residuals	247	2.068	0.008	0.753			
Total	250	2.747					

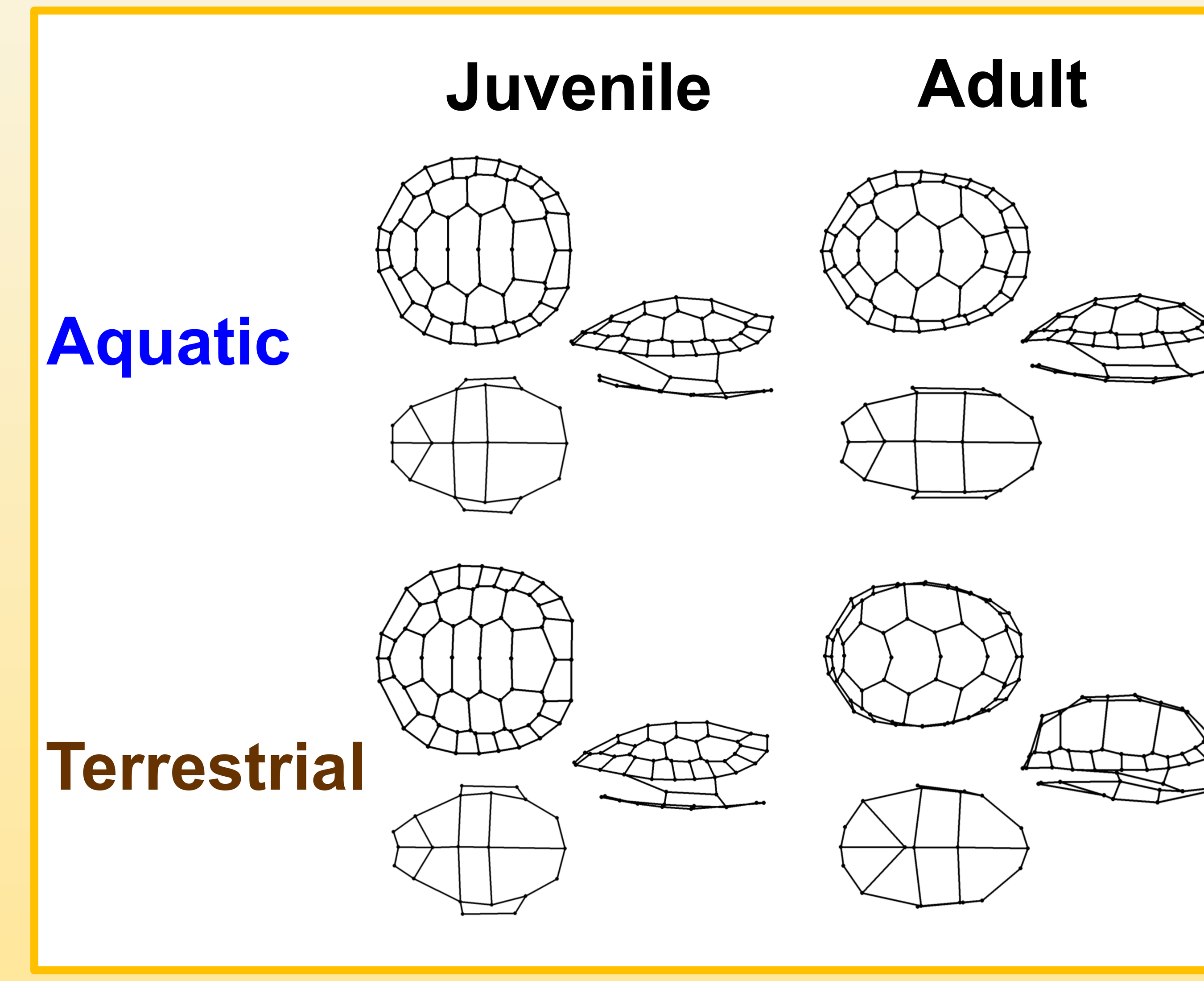

Figure 3 - Shell shapes characteristic of juvenile and adult aquatic and terrestrial turtles in lateral, dorsal, and ventral views

DISCUSSION

- There is a significant relationship between size and shape in emydid turtle shells: smaller turtles have more circular carapaces, flatter carapaces, wider vertebral scutes, and more space between the carapace and the plastron .
- All of these differences are consistent with decreased hydrodynamic efficiency among larger turtles; thus, our hypothesis is supported.
- The growth patterns of aquatic and terrestrial species are significantly different. However, the proportion of variation explained by this pattern is very small.
- Aquatic and terrestrial species show very similar shapes as juveniles, but diverge as they grow older. Thus surprisingly the terrestrial pattern is also associated with decreased hydrodynamic efficiency with growth. This is surprising, since terrestrial emydids are terrestrial from hatching.
- This surprising pattern could reflect the fact that ancestral turtles were aquatic and, as turtles moved onto land, they kept this same growth pattern.
- It could also mean that all turtles have to maintain a certain shell shape in order to fit into eggs, with this pattern fortuitously providing aquatic species greater hydrodynamic efficiency as when they are small.
- Finally, this could mean that terrestrial turtles haven't had enough time, evolutionarily, to change this growth pattern, as early developmental patterns are generally harder to change than later ones.

ACKNOWLEDGMENTS

We thank Stevie Kennedy-Gold and Jennifer Sheridan of the Carnegie Museum of Natural History for access to specimens. This work was supported by NSF grant IOS-1257142.