Supporting Information S2 for

Cranial ecomorphology of turtles and neck retraction as a possible trigger of ecological diversification

This file includes:

- Supplementary Methods
- Supplementary Results
  - Figures S1 to S32
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- Other Supplementary Data
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Other supplementary data for this manuscript include:

- Supporting Information S1
- Annotated R scripts and associated files
Supplementary Methods

Landmarks description

In the following landmark list, landmarks are numbered and associated with a short title (in **bold**) that represents our working nomenclature for landmarks used in the Avizo files, in which we landmarked the data. These short-titles sometimes include abbreviations that do not appropriately describe the landmarks, as the landmark definitions evolved during this process whereas initial names of landmark objects were kept as there is no straight forward way to rename landmark object names across different files. However, as each landmark is associated with a short description (**underlined**) and a “Remarks” section, landmark definitions should be clear irrespective of their titles. Most landmarks used herein are type I landmarks, for which homology is supported by a unique topological arrangement of the bones that define the respective landmark. However, in some instances we also use type II landmarks, for which evidence for the homology only comes from geometric arguments, whereas the bony composition of the landmarked region may vary between turtles. Type II landmarks were necessary in order to bound open semilandmark series, which are used to capture specific geometric properties of the skulls that are generally considered useful when comparing skull geometries. For instance, LM1 is a type II landmark, because it defined the anterior end of the skull roof above the external nares, irrespective of whether this point is formed by the nasal, or by the prefrontal (if nasals are lost). This landmark further bounds SL5 anteriorly, which extends across the skull roof and captures variation in skull length, and shape of the skull roof. For geometric comparisons of skull length of skull roof flexure, it is irrelevant if the anteriormost point of the compared entity is formed by the nasal or prefrontal, and thus the usage of type II landmarks is justified for our study.

**Landmarks**

1. **Skull-anteriormost**: anteriormost median junction between the bones that form the dorsal margin of the external nares

   **Remarks**: This landmark usually is between the prefrontals or nasals, depending on which of these bones form the anterior margin of the skull dorsal to the nares.

2. **FR-anteriormost**: anteriormost contact between the frontals

   **Remarks**: This landmark is placed on the quadruple-junction of right and left frontals with anteriorly adjacent bones (prefrontals or nasals).

3. **PA-anteriormost**: anteriormost contact between the parietals

   **Remarks**: This landmark is placed on the quadruple-junction of right and left parietals with anteriorly adjacent bones, which are usually the frontals.

4. **PA-posteriormost-roof**: posteriormost contact between the parietals on the skull roof

   **Remarks**: This landmark is usually placed on a triple junction between the parietals and supraoccipital. Whenever the supraoccipital is completely covered by the parietals, the landmark is in the posterior skull roof margin.

5. **SO-posteriormost**: posteriormost point of the supraoccipital

   **Remarks**: This landmark is mostly placed at the posterior end of the supraoccipital crest. However, in *Hydromedusa*, a dorsal extension of the exoccipitals (see landmarks 26/27 below)
restricts the supraoccipital to be present only in the skull roof, so that the landmark is not the posterioriormost point of the skull along the skull midline.

6. Left-FR-orbit: anterioriormost point of the lateral process of the left frontal which extends towards the orbit rim

*Remarks* (this applies for landmarks 6 and 7): Turtles show variation regarding whether the frontal extends laterally into the orbital margin or not. When the frontal extends into the orbit, the landmark is placed in the orbital margin between the frontal and the anteriorly adjacent bone, usually the prefrontal. This condition is present, the landmark is placed in the anterior suture of the frontal that contacts the orbital margin. When the lateral frontal process is retracted from contributing to the orbit, the homologous point is the frontal-prefrontal-postorbital triple junction somewhat medially to the orbit. When the latter condition is present, landmarks 6 and 7 are placed in the same spot as landmarks 67 and 70 (see below).

7. Right-FR-orbit: anterioriormost point of the lateral process of the right frontal which extends towards the orbit rim

*Remarks*: See remarks of landmark 6.

8. Left-MX-orbit: anterioriormost contact of the left maxilla in the orbit rim

*Remarks*: This landmark is usually positioned on the interception of the maxilla-prefrontal suture with the orbital margin.

9. Right-MX-orbit: anterioriormost contact of the right maxilla in the orbit rim

*Remarks*: See remarks for landmark 8.

10. Left-FR-PA-posterolateral: lateralmost contact between the left frontal and the left parietal

*Remarks*: In most turtles, this landmark is positioned in the triple junction between frontal, parietal, and postorbital, but the post

11. Right-FR-PA-posterolateral: lateralmost contact between the right frontal and the right parietal

*Remarks*: See remarks for landmark 10.

12. Left-SQ-posteriormost: posterioriormost point of the left squamosal

*Remarks*: In most turtles, the posterior part of a squamosal either forms a pointed tip or a curved, vertical ridge. In the latter case, this landmark is placed along the ridge in the posteriormost possible position.

13. Right-SQ-posteriormost: posterioriormost point of the right squamosal

*Remarks*: See remarks for landmark 12.

14. Left-QU-SQ-Temporal-margin: contact between left squamosal and adjacent bone within margin of the temporal emargination

*Remarks*: The squamosal always forms the most posterolaterally positioned element in all turtle skulls, and thus always forms the posterior part of the temporal emargination. This landmark is placed in the margin of the temporal emargination, at the contact of the squamosal with the anteriorly (or laterally) adjacent bone. Depending on the extent of the temporal emargination,
this contact can be with the parietal (e.g. when the emargination is weak as in chelonioids), but more often is with the quadrate and/or quadratojugal at the anterior end of the squamosal.

15. **Right- QU-SQ-Temporal-margin**: contact between right squamosal and adjacent bone within margin of the temporal emargination

*Remarks*: See remarks for landmark 14.

16. **Left-PO-orbit**: anteriormost contact of the left postorbital in the orbit rim

*Remarks*: This landmark always is positioned within the orbital margin, and between the postorbital and frontal or prefrontal, depending on if the frontal contributes to the orbit or is retracted from the orbital margin. In the former case, landmarks 16 and 17 coincide with landmarks 67 and 70 (see below).

17. **Right-PO-orbit**: anteriormost contact of the right postorbital in the orbit rim

*Remarks*: See remarks for landmark 16.

18. **Left-PA-SO-PR**: left contact between parietal-supraoccipital-prootic

*Remarks*: This landmark is positioned on the dorsal surface of the otic capsule. *Dermochelys* presents a unique condition in which its descending parietal process is not ossified. Because of this, it lacks the triple contact between the parietal, supraoccipital and prootic bones. However, the supraoccipital and prootic are still in contact in *Dermochelys*, and this landmark is placed at the anteriormost point where these bones contact each other. Therefore, despite of the unusual ossification of such taxon, the landmark still follows the same homology criterion.

19. **Right-PA-SO-PR**: right contact between parietal-supraoccipital-prootic

*Remarks*: See remarks for landmark 18.

20. **Left-SO-PR-OP**: left contact between supraoccipital-prootic-opisthotic

*Remarks*: This is positioned on the dorsal surface of the otic capsule. In cyclanorbine trionychids (e.g. *Cylcanorbis, Cycloderma* and *Lissemys*) and *Chelonoidis carbonaria*, the parietal has an unusually long posterior extension that reaches over the supraoccipital, prootic and opisthotic bones, hereby concealing the triple contact between these bones. However, as this contact is actually just concealed by a thin sheet of the parietal, we digitally removed the parietal extension and placed the landmark for these turtles. For these taxa, landmarks 20 and 21 coincide with the positions of landmarks 18 and 19. This landmark combination thus acknowledges both the extreme posterior extent of the parietal, but also the homology with other turtles in the general presence of a triple junction between prootic-opisthotic-supraoccipital in the otic capsule.

21. **Right-SO-PR-OP**: right contact between supraoccipital-prootic-opisthotic

*Remarks*: See remarks for landmark 20.

22. **Left-QU-PR**: left posteriormost junction between the prootic and the quadrate on the surface of the otic chamber

*Remarks*: The prootic and quadrate mediolaterally abut one another in the otic capsule of all turtles. Posteriorly, these bones usually form a triple junction with the opisthotic, but the latter can be substituted for different bones. Thus, this landmark is defined only in terms of the
prootic and quadrato, and usually lies in the central portion of the otic capsule, on its dorsal surface.

23. **Right-QU-PR**: right posteriormost junction between the prootic and the quadrato on the surface of the otic chamber

Remarks: See remarks for landmark 22.

24. **Left-SO-EX-OP**: left junction between supraoccipital-exoccipital-opisthotic

Remarks: This landmark is positioned in the posterior aspect of the dorsal surface of the otic capsule.

25. **Right-SO-EX-OP**: right junction between supraoccipital-exoccipital-opisthotic

Remarks: See remarks for landmark 24.

26. **Left-EX-Foramen-magnum**: most posterodorsal point of the left exoccipital in the margin of the foramen magnum

Remarks: This landmark is usually positioned in the exoccipital-supraoccipital suture along the margin of the foramen magnum. However, in most chelid turtles, the exoccipitals each possess a dorsal process that, when present, contact one other in the skull midline, excluding the supraoccipital from contributing to the foramen magnum. When this condition occurs, landmarks 26 and 27 are placed in the same spot.

27. **Right-EX-Foramen-magnum**: most posterodorsal point of the right exoccipital in the margin of the foramen magnum

Remarks: See remarks for landmark 26.

28. **PM-anterodorsal**: Point of contact between the right and left premaxillae in the ventral margin of the external nares

Remarks: This landmark is an unpaired, median landmark and can usually be identified by the dorsal end of the interpremaxillary suture. When the premaxillae are fused, this landmark is placed in a median position in the ventral margin of the external naris.

29. **PM-Labial-ridge**: Point of contact between the right and left premaxillae in the labial ridge of the triturating surface

Remarks: This landmark is an unpaired, median landmark and can usually be identified by the ventral end of the interpremaxillary suture. When the premaxillae are fused, this landmark is placed in a median position in the labial margin of the skull.

30. **Anteromedian-Triturating-surf**: median point of contact between the medial margins of the right and left triturating surface

Remarks: This landmark specifies the anteromedial termination of each triturating surface, and primarily is to capture variation in the depth of the triturating surface. We thus defined this landmark as the median point between the triturating surfaces. It always lies at the border of triturating surfaces and the internal narial openings. In turtles with clearly distinguished right and left triturating surfaces (i.e., in absence of a secondary palate), the landmark is usually positioned at the posterior end of the interpremaxillary contact on the palate, which often coincides with the premaxilla-premaxilla-vomer triple junction. However, in turtles with
extensive secondary palates, such as chelonioids, the landmark lies on the vomer, and in the posterior margin of the secondary palate. As the secondary palate basically represents an extension of palatal bones and a merging of the triturating surface, we believe that this landmark is topologically homologous despite the fact that it will lie on different bones across different turtle clades.

31. **Left-MX-lateroventral:** posterior end of left maxillar labial ridge

*Remarks:* In all turtles, the maxilla forms most of the anterolateral margin of the skull, including the labial ridge onto which the keratinous rhamphotheca articulates. Posteriorly, the labial ridge either ends by articulation of the maxilla with posteriorly adjacent bones, usually the jugal, or by an upturned maxillar margin that defines the beginning of the cheek emargination. This landmark is placed in this position.

32. **Right-MX-lateroventral:** posterior end of right maxillar labial ridge

*Remarks:* See remarks for landmark 31.

33. **Left-Triturating-surf-posterior:** most posteromedial point of the left triturating surface

*Remarks:* This point is usually positioned on the maxilla, and defined the posterior end of the lingual margin of the triturating surface.

34. **Right-Triturating-surf-posterior:** most posteromedial point of the right triturating surface

*Remarks:* See remarks for landmark 33.

35. **Left-QU-posteroventral:** anteroventral point of maximum curvature of the lateral wall of the left quadrate

*Remarks:* This landmark defines the posterior end of the cheek emargination, which ends in the lateroventral margin of the skull formed by the quadrate just anterior to the level of the quadrate articular processes.

36. **Right-QU-posteroventral:** anteroventral point of maximum curvature of the lateral wall of the right quadrate

*Remarks:* See remarks for landmark 35.

37. **BS-anteriormost-ventral:** anteriormost point of the basisphenoid on the ventral surface of the skull

*Remarks:* This unpaired landmark is positioned in the skull midline. Depending on the anterior structure of the palate, the landmark lies in the triple junction between basisphenoid and right and left pterygoids, or in the basisphenoid-vomer suture.

38. **BS-anteriormost-dorsal:** anteriormost point of the basisphenoid on the dorsal surface of the basicranium (tip of the rostrum basisphenoidale)

*Remarks:* This unpaired, medial landmark is positioned on the internal of the skull.

39. **Left-BS-clinoid:** tip of the left clinoid process.

*Remarks:* This landmark is positioned on the internal of the skull.

40. **Right-BS-clinoid:** tip of the right clinoid process
Remarks: See remarks for landmark 39.

41.Left-MX-PAL-anterior: most anteromedial junction between the left maxilla and the left palatine on the palate

Remarks: The palatine of turtle usually extends with anterolateral processes toward the maxilla, and contacts this bone along the lingual margin of the triturating surface. In species with extended secondary palates, this landmark is the triple junction between maxilla-palatine-vomer.

42.Right-MX-PAL-anterior: most anteromedial junction between the right maxilla and the right palatine on the palate

Remarks: See remarks for landmark 41.

43.Left-BO-BS-lateralmost: lateralmost point of contact between the basisphenoid and basioccipital on the left side

Remarks: In all turtles, the basisphenoid and basioccipital form a transverse suture in the ventral skull surface. This landmark is positioned in the lateral end of this contact, which forms a triple junction with laterally adjacent bones that can vary between clades, but usually are either the quadrate, prootic or pterygoid.

44.Right-BO-BS-lateralmost: lateralmost point of contact between the basisphenoid and basioccipital on the right side

Remarks: See remarks for landmark 43.

45.BO-BS-medial: median point between the basisphenoid and the basioccipital on the ventral surface of the skull

Remarks: This unpaired landmark is in a median position on the suture between basisphenoid and basioccipital.

46.Left-FPCCI: position of the left foramen posterius canalis carotici interni

Remarks: This landmark marks the ventral margin of the foramen posterius canalis carotici interni, through which the internal carotid artery enters the cranium.

47.Right-FPCCI: position of the right foramen posterius canalis carotici interni

Remarks: See remarks for landmark 46.

48.Left-basitubera: posteriormost tip on the left basituber

Remarks: The tubercula basioccipitale are formed by various combinations of bones in turtles, but usually the basioccipital is prominently involved. In all turtles, the processes can be identified easily, and the posteriormost point of the structure is landmarked, which is often formed as a pointed tip.

49.Right-basitubera: posteriormost tip on the right basituber

Remarks: See remarks for landmark 48.

50.Occipital-cond-posterior: posteriormost point on the occipital condyle

Remarks: This landmark is positioned centrally on the posterior surface of the occipital condyle, usually in the triple junction of both exoccipitals with the basioccipital.
51. **Left-Cavum_tympani_posterodorsal**: most posterodorsal point on the margin of the left cavum tympani

*Remarks*: To define a semilandmark curve around the cavum tympani, we defined a start and end landmark in the posterodorsal and posteroventral corners of the cavum tympani, respectively. The posterodorsal starting point is usually relatively easy to identify as a small lateral tip on the squamosum or quadrate, just above the posteroventral notch that often opens into the cavum tympani for the Eustachian tube and/or stapes. The posteroventral end point lies on the quadrate. In turtles in which the cavum tympani is ‘closed’, start and end landmarks fall on the same position. The position in these cases is mostly indicated by a suture of the quadrate with itself, which can be traced medially into the cavum tympani and toward the incisura columella auris, which is completely surrounded by the quadrate in such turtles.

52. **Left-Cavum_tympani_posteroventral**: most posteroventral point on the margin of the left cavum tympani

*Remarks*: See remarks for landmark 51.

53. **Right-Cavum_tympani_posterodorsal**: most posterodorsal point on the margin of the right cavum tympani

*Remarks*: See remarks for landmark 51.

54. **Right-Cavum_tympani_posteroventral**: most posteroventral point on the margin of the right cavum tympani

*Remarks*: See remarks for landmark 51.

55. **Left-PR-QU-PT**: left junction between the prootic, quadrate and pterygoid (or parietal) in the otic capsule region

*Remarks*: In all turtles, the anterior portion of the otic capsule if formed between the prootic medially and the quadrate laterally. These bones form an anteroposteriorly extending suture. Anteriorly, the suture slopes ventrally from the floor of the supratemporal fossa into the posterior wall of the subtemporal fossa. In this area, on the anterior surface of the otic capsule, the prootic-quadrate suture meets with the anteroventrally adjacent bone, which usually is the pterygoid. This landmark is placed on this triple junction.

56. **Right-PR-QU-PT**: right junction between the prootic, quadrate and pterygoid (or parietal) in the otic capsule region

*Remarks*: See remarks for landmark 55.

57. **Left-JU-PO-posterior-contact**: the most posterior contact between the left jugal and the left postorbital

*Remarks*: This landmark is found on the lateral side of the skull. The postorbital-jugal suture extends anteroposteriorly, and in its posterior end, it either forms a triple junction with the quadratojugal, but may instead merge into the margin of the upper temporal emargination.

58. **Right-JU-PO-posterior-contact**: the most posterior contact between the right jugal and the right postorbital

*Remarks*: See remarks for landmark 57.
59. **Left-PAL-posteromedian:** the most posteromedian contact of the left palatine in the ventral surface of the skull

*Remarks:* The palatines of turtles form part of the anterior region of the palate, but there is significant variation to their form and contacts to surrounding bones: the palatines may contact one another in the skull midline, or they are separated from one another by either the vomer, pterygoids, or basisphenoid. This landmark captures the posteriormost contact of the palatine with the bones that lie in the skull midline. When the right and left palatines have a midline contact, right and left landmarks for this point fall on the same position.

60. **Right-PAL-posteromedian:** the most posteromedian contact of the right palatine in the ventral surface of the skull

*Remarks:* See remarks of landmark 59.

61. **Left-PT-base-ventral-proc:** anteriormost contact of the ventral process of the left parietal with the ventrally adjacent bone

*Remarks:* The descending process of the parietal forms the anterior margin of the ossified braincase in turtles. Ventrally, the process contacts the palate, usually the crista pterygoidei of the pterygoid, but in some turtles the palatine. We place the landmark at the ventral end of the anterior margin of the descending process of the parietal, irrespective of which bone it contacts ventrally. This landmark captures variation pertaining to the extent of the secondary lateral braincase wall.

62. **Right-PT-base-ventral-proc:** anteriormost contact of the ventral process of the right parietal with the ventrally adjacent bone

*Remarks:* See remarks for landmark 61.

63. **Left-PA-SO-posterolateral:** most posterolateral contact between the left parietal and the supraoccipital on the skull roof

*Remarks:* In all turtles, the parietals have a midline contact in the skull roof, but contact the supraoccipital posteriorly. Depending on whether parts of the supraoccipital are integrated into the skull roof or whether most of the bone is overlain by the parietals, right and left landmarks are separated from the skull midline, or fall on the same point (together with landmark 4), respectively. This landmark serves as the medial bound for the temporal emargination.

64. **Right-PA-SO-posterolateral:** most posterolateral contact between the right parietal and the supraoccipital on the skull roof

*Remarks:* See remarks for landmark 63.

65. **Left-OP-posteriormost:** posteriormost point of the left opisthotic

*Remarks:* The paroccipital process of the opisthotic braces against the posterior part of the otic capsule in turtles, and ends laterally near the posterior squamosal process, and may even extend beyond that level posteriorly and thus form the posteriormost point of the skull. We place this landmark at the posteriormost tip of the paroccipital process.

66. **Right-OP-posteriormost:** posteriormost point of the right opisthotic

*Remarks:* See remarks for landmark 65.
67. **Left-FR-orbit-posterior:** posteriormost point of the lateral process of the left frontal which extends towards the orbit rim

*Remarks:* Turtles show variation regarding whether the frontal extends laterally into the orbital margin or not. When the frontal extends into the orbit, the landmark is placed in the orbital margin between the frontal and the posteriorly adjacent bone, which is the postorbital. In this case, landmarks 67 and 70 are in the identical spot as landmarks 16 and 17, which define the anteriormost point of the postorbital in the orbital margin. When the lateral frontal process is retracted from contributing to the orbit, the homologous point is the frontal-prefrontal-postorbital triple junction somewhat medially to the orbit. When the latter condition is present, landmarks 67 and 70 are placed in the same spot as landmarks 6 and 7 (see above).

68. **Left-MX-orbit-posterior:** posteriormost contact of the left maxilla in the orbit rim

*Remarks:* In all turtles, the maxilla forms parts of the ventral margin of the orbit. Posteriorly, it forms a contact with the posteriorly adjacent bone, usually the jugal, with which it forms a suture that crosses the orbital margin. This landmark is placed in this position, irrespective of whether the posterior bone is the jugal or postorbital.

69. **Left-PO-orbit-posterior:** ventralmost contact of the left postorbital in the orbit rim

*Remarks:* In all turtles, the postorbital forms parts of the posterior margin of the orbit. The postorbital has a ventral process that extends along the orbital margin until it reaches the ventrally adjacent bone, which is usually the jugal, but may be the maxilla when the jugal is retracted from contributing to the orbit. The landmark is placed in the suture with the ventrally adjacent bone within the orbital margin. When the postorbital directly contact the maxilla in the orbital margin, this landmark coincides with landmark 68.

70. **Right-FR-orbit-posterior:** posteriormost point of the lateral process of the right frontal which extends towards the orbit rim

*Remarks:* See remarks for landmark 67.

71. **Right-MX-orbit-posterior:** posteriormost contact of the right maxilla in the orbit rim

*Remarks:* See remarks for landmark 68.

72. **Right-PO-orbit-posterior:** ventralmost contact of the right postorbital in the orbit rim

*Remarks:* See remarks for landmark 69.

73. **Left-PAL-anteromedian:** the most anteromedian contact of the left palatine in the primary palate

*Remarks:* In all turtles, the palatine forms parts of the anterior palate, but significant variation exists in the form and relative position of this bone. The right and left palatines may form a midline contact, in which case this landmark is placed at the anterior end of this contact, and in which case right and left landmarks fall in the same position. However, in many turtles the palatines are separated from one another by either the vomer, pterygoids, or basisphenoid. In this case, right and left landmarks are in distinct positions to either side of the skull midline, and at the anterior end of the palate with the medially adjacent bone. In turtles with a secondary palate, the palate has two ‘levels’ that forms dorsoventrally separate plates. The ventral one is integrated into the secondary palate, whereas the dorsal one forms the roof of the internal narial passage. Both plates usually contact the vomer medially, and thus candidate positions for this
landmark exist both on the primary palate (dorsal plate) and secondary palate (ventral plate).
We place this landmark on the primary palate, as this surface is homologous to the part of the palate in taxa without secondary palates, which in turn are interpreted to be neomorphic structures in turtles that possess them.

74. **Right-PAL-anteromedian**: the most anteromedian contact of the left palatine in the primary palate

*Remarks*: See remarks for landmark 73.

75. **Dorsal_foramen_magnum**: the most dorsal point of the foramen magnum on the midline

*Remarks*: The foramen magnum in turtles usually form a dorsoventrally high oval, with a narrow concave dorsal margin that is usually formed by the supraoccipital, but may be formed by the exoccipitals instead. This landmark is placed in the midline dorsal margin of the foramen magnum.

76. **Ventral_foramen_magnum**: the most ventral point of the foramen magnum on the midline

*Remarks*: The foramen magnum in turtles usually form a dorsoventrally high oval, with a broad concave ventral margin that is usually formed by the basioccipital, but may be formed by the exoccipitals instead. This landmark is placed in the midline ventral margin of the foramen magnum.

**Series of sliding semilandmarks**

SL1. **Left-Internal-nares**: open curve of semilandmarks in clockwise direction from landmark 1 to landmark 28 that follows the left margin of the external nares

SL2. **Right-Internal-nares**: open curve of semilandmarks in anticlockwise direction from landmark 1 to landmark 28 that follows the right margin of the external nares

SL3. **Left-Orbit**: closed loop of semilandmarks starting in the suture the maxilla forms with the anteriorly adjacent bone (usually prefrontal) and extending around the left orbit in clockwise direction

SL4. **Right-Orbit**: closed loop of semilandmarks starting in the suture the maxilla forms with the anteriorly adjacent bone (usually prefrontal) and extending the left orbit in anticlockwise direction

SL5. **Skull-midline**: open curve of semilandmarks from landmark 1 to landmark 4 that follows the skull midline

SL6. **Left-Temporal_emargination_new**: open curve of semilandmarks from landmark 63 to landmark 14 that follows the left temporal emargination

SL7. **Right-Temporal_emargination_new**: open curve of semilandmarks from landmark 64 to landmark 15 that follows the right temporal emargination

SL8. **Left-Cheek-emargination**: open curve of semilandmarks from landmark 31 to 35 that follows the left cheek emargination
SL9. Right-Cheek-emargination: open curve of semilandmarks from landmark 32 to 36 that follows the right cheek emargination

SL10. Left-Labial-ridge: open curve of semilandmarks from landmark 31 to landmark 29 that follows the left labial ridge

SL11. Right-Labial-ridge: open curve of semilandmarks from landmark 32 to landmark 29 that follows the right labial ridge

SL12. Left-Triturating-surf: open curve of semilandmarks from landmark 33 to landmark 30 that follows the medial margin of the left triturating surface

SL13. Right-Triturating-surf: open curve of semilandmarks from landmark 34 to landmark 30 that follows the medial margin of the right triturating surface

SL14. Left-Cavum-tympani-loop: open curve of semilandmarks from landmark 52 to landmark 51 that follows the outline of the left cavum tympani in clockwise direction

SL15. Right-Cavum-tympani-loop: open curve of semilandmarks from landmark 53 to landmark 54 that follows the outline of the left cavum tympani in anticlockwise direction

SL16. Left-Mandibular-cond: a closed loop of semilandmarks going in clockwise direction around the left articulation facet of the condylus mandibularis, starting at the level of the contact between the condylus and the pterygoid

SL17. Right-Mandibular-cond: a closed loop of semilandmarks going in anticlockwise direction around the right articulation facet of the condylus mandibularis, starting at the level of the contact between the condylus and the pterygoid

SL18. BS-sella-turcica: open curve of semilandmarks from landmark 39 to landmark 40 that follows the outline of the dorsum sellae

Remarks: The landmark title says ‘sella turcica’ but we are actually landmarking the dorsum sellae between the clinoid processes.

SL19. Left-PR-QU-suture: open curve of semilandmarks from landmark 22 to landmark 55 that follows the left prootic-quadrate suture

Remarks: This suture is landmarked because it captures variation of the form of the anterior portion of the otic capsule (and thus, in cryptodires, variation pertaining to the otic trochlea). In *Rhinoclemmys pulcherrima*, the parietal extends so far laterally, that it overlay the prootic completely in this region. Consequentially, the prootic is not expressed in the otic capsule. However, as the parietal does not overlap the quadrate, the quadrate-parietal suture of *R. pulcherrima* traces the suture of quadrate with the prootic directly underneath the dorsally exposed skull surface. Thus, in *R. pulcherrima*, we landmarked the quadrate-parietal suture.

SL20. Right-PR-QU-suture: open curve of semilandmarks from landmark 23 to landmark 56 that follows the left prootic-quadrate suture

Remarks: See remarks for SL19.

SL21. BS-length: open curve of semilandmarks from landmark 37 to landmark 45 that follows the basisphenoid length
**SL22.Left_half_foramen_magnum:** a series of semilandmarks on the left side foramen magnum rim extending from landmark 75 to landmark 76

**SL23.Right_half_foramen_magnum:** a series of semilandmarks on the right side foramen magnum rim extending from landmark 75 to landmark 76

### Surface semilandmarks

In addition to landmarks and sliding semilandmarks, we placed surface semilandmarks to capture more densely potential rugosities on the triturating surfaces of the palate, and the depth of the mandibular condyles. We followed the suggestions in Bardua et al. (2019) and used as a template the specimen of which the shape was closest to the estimated mean shape of aligned 3D Procrustes coordinates. To identify such specimen, we used the “findMeanSpec” function of the R package “geomorph” 3.2.1 (Adams et al. 2020). These surface semilandmarks were placed as follows:

**Surface_palate_left:** surface semilandmarks placed labio-lingually(?) on the left side triturating surface of the palate, starting close to landmark 31 until reaching the midline contact between the premaxillae

*Remarks:* the triturating surfaces are the primary food-grinding structure of most turtles. Besides describing its outline with our landmark/sliding semilandmark concept (more specifically landmarks 29-34 and sliding semilandmarks 10-13), we found it important to include variation present on the surface itself, because many turtles bear one or multiple serrated rows of accessory ridges on the maxillae/palatines (Pritchard 1979). Therefore, these surface semilandmarks were placed on the left half of the triturating surface to capture these potential additional structures.

**Surface_palate_right:** surface semilandmarks placed labio-lingually(?) on the left side triturating surface of the palate, starting close to landmark 31 until reaching the midline contact between the premaxillae

*Remarks:* see remarks for ‘Surface_palate_left’.

**Surface_condyle_left:** surface semilandmarks placed anteroposteriorly on the left mandibular condyle surface, starting on the lateralmost edge of the structure and following it medially

**Surface_condyle_right:** surface semilandmarks placed anteroposteriorly on the right mandibular condyle surface, starting on the lateralmost edge of the structure and following it medially

These new points were then imported back to R environment in which we combined the new surface semilandmark coordinates with previous ones (landmarks and sliding semilandmarks). The combined set of landmarks were used to create an ‘atlas’ object using the “createAtlas” function of the package “Morpho” 2.8 (Schlager 2017). This atlas is used to define which are the landmarks that will be projected on the remaining specimens of our sample in an automated process. This last step was performed with the “placePatch” function of “Morpho” 2.8.
**Description of binary ecological traits**

To account for the multiple components of feeding aspects present in turtles’ diets, we developed a multivariate scheme classification containing the main resources described in turtles’ natural history surveys (see “Extra SI References” for list of bibliography). For each item we attributed “0” (absent) or “1” (present). Besides food items, we also scored absence/presence for: the use of suction feeding, feeding in the water and/or on land, marine habits, being fully-flippered (as a proxy for a fully aquatic open swimming lifestyle), capacity of neck retraction, and sideways neck retraction. This follows similar previous approaches for mammalian and avian ecology (e.g. Taylor & Thomas 2014; Wilman et al. 2014; Benson et al. 2017; Campuzano 2018) in recognising that multiple factors can influence skull shape in turtles.

The traits match those present in Supporting Information S1 table, and correspond to the presence/absence of:

**Seeds_fruits:** fruits, including also the consumption of seeds and nuts;

**Flowers:** flowers;

**Stems:** plant stems, including also plant roots;

**Terrestrial_leaves:** leaves from terrestrial plants (e.g. bushes, grasses, riparian vegetation);

**Aquatic_leaves:** aquatic macrophytes, sedges, aquatic angiosperms, and algae;

**Fungi:** mushrooms;

**Vertebrates:** mainly fishes and tadpoles, including also sporadic consumption of larger vertebrates (e.g. waterbirds, other turtles);

**Jellyfish:** jellyfish, but also free-living tunicates, for the similarity with medusae lifestyle;

**Aquatic_insects:** insects that rely on water for completing their life cycles (e.g. dragonflies, mayflies, dipteran chironomids), including also their larvae;

**Terrestrial_arthropods:** insects that mainly live on land (e.g. beetles, grasshoppers), arachnids, millipedes;

**Worms:** mostly oligochaetes, but can also include similar tubular-shaped animals (e.g. marine worms);

**Mollusks:** snails, clams, mussels;

**Crustaceans:** prawns, shrimps, crabs;

**Mostly_vegetable_matter:** this variable was included to help distinguishing between sporadic and regular feeding on plants by turtles, according to authors’ assessment on the regularity of the presence of vegetable matter in an animal’s diet through a given period of time. In the ecomorphological hypotheses (see below), this trait was used as proxy for “herbivory”;

**Mostly_animal_matter:** this variable was included to help distinguishing between sporadic and regular feeding on animals by turtles, according to authors’ assessment on the regularity of the presence of animal matter in an animal’s diet through a given period of time. In the ecomorphological hypotheses (see below), this trait was used as proxy for “carnivory”;
**Mostly_hard_food:** this variable was included to help distinguish between sporadic (e.g. Kimmel 1980; Jones & Seminoff 2013) and regular (e.g. Bels et al. 1998; Richards-Dimitrie et al. 2013) feeding on hard food (durophagy) by turtles. This follows authors’ assessment on the regularity of the presence of e.g. hard-shelled invertebrates in an animal’s diet through a given period of time. In the ecomorphological hypotheses (see below), this trait was used as proxy for “durophagy”.

**Feed_on_water:** scored ‘present’ for those turtles capable of feeding underwater;

**Feed_on_land:** scored ‘present’ for those turtles capable of feeding on land; turtles that can capture food on land but need to drag it underwater to eat (e.g. Natchev et al. 2008) were scored as ‘absent’ (see Natchev et al. 2015 for further discussion on the subject);

**Suction_feeding:** apart from turtles that actively hunt their preys (see main text), we also scored presence for turtles that exhibit neustophagia (e.g. Belkin & Gans 1968; Rhodin et al. 1981), since the jaw opening and pharyngeal expansion mechanisms of this feeding strategy parallel those of turtles described as ‘suction-feeders’;

**Marine:** scored ‘present’ for turtles that live in marine habitats;

**Open_swimmer:** scored ‘present’ for turtles that exhibit fully-flippered limbs as a proxy for a specialised highly aquatic lifestyle;

**Neck_retraction:** scored ‘present’ for turtles capable of retracting their necks;

Our multivariate scheme also includes two continuous traits: “food evasiveness” and “food hardness” indices. Based on the approach by Vanhooydonck et al. (2007), for each of the first 13 food items from the list above (i.e. from “Seeds_fruits” to “Crustaceans”) we attributed different weights depending on whether it represented a sedentary/soft (weight = 0), intermediate (0.5) or evasive/hard (1) item. The absence/presence (i.e. 0/1) of each item was then multiplied by their respective weight, and then divided by the sum of the absence/presence of such items.
Ecomorphological hypotheses – skull shape

Our D-PGLS models were built to allow that multiple factors can influence shape aspects of the turtle skull. We first tested each predictor individually alongside ‘allometry’ (see below), and then built more complex models including those predictors found to be statistically significant. To run D-PGLS analyses, we used the “procD.pgl” function of the R package “geomorph” (Adams et al. 2020), running 1000 iterations, and setting the sums of squares as hierarchical (argument “SS.type = II”). The phylogenetic tree used for these analyses is derived from the topology of Pereira et al. (2017), which accounts for nearly all extant species of turtles and is based on molecular data. From this topology, we pruned and retained only those taxa present in our analyses (Figure S6).

Using species-specific data, our regression analyses were used to test hypotheses of relationships between skull shape and the following main independent binary and continuous variables:

‘Size’: log₁₀-transformed centroid size, output from the alignment of 3D landmark coordinates (GPA). This tests the hypothesis that shape changes in turtle skulls result from modification in size, i.e. allometry (e.g. Pfaller et al. 2010). Yet, after accounting for the individual effect of size (i.e. shape ~ size), this predictor was always subsequently included as a covariate in more complex models; [continuous]; Note that this continuous variable was also used in pGLS regressions testing for the importance of different effects on turtle skull size variation (see below and Main Text);

‘Suction’: presence of suction-feeding. This behaviour implies in modifications in the feeding apparatus that accommodate wider gapes and more powerful intraoral negative pressures (Van Damme & Aerts 1997; Lemell et al. 2002). This variable tests the hypothesis that shape changes in turtle skulls result from adaptation to using this food-capturing strategy; [binary];

‘Durophagy’ : presence of durophagy, identifying turtles that feed mostly on hard food (e.g. shelled invertebrates). Because triturating this sort of food requires a larger area of the jaw surfaces to crush it prior to ingestion (Claude et al. 2004), as well as more developed muscles involved in biting, this tests the hypothesis that skull changes in turtles are explained by the acquisition of a durophagous diet; [binary];

‘Herbivory’ : presence of herbivory, identifying turtles that feed mostly on plant material (e.g. fruits, leaves, algae). Herbivory in extant reptiles is relatively rare, with changes in body size and teeth morphology recorded for lizards (Zimmerman & Tracy 1989) and physiological adaptations in the digestive system recorded for some turtles (Bjorndal 1979; 1987). Additionally, many herbivorous chelonians exhibit finely serrated ridges in the palate (Pritchard 1979; Davenport et al. 1992), usually paralleling the inner border of the triturating surface. This predictor tests the hypothesis that skull shape changes in turtles result from the acquisition of a more herbivorous lifestyle; [binary];

‘Carnivory’: this identifies turtles that feed mostly on other animals. This tests the hypothesis that changes in turtle skull shape are associated with faunivory/scavenging, and is based on a previous assumption that ‘in predatory and scavenging species the jaw surfaces may be exceedingly sharp’ (Pritchard 1979, p. 35); [binary];

‘Aquatic feeding’: indicates the capacity to feed underwater. This tests the hypothesis that the capacity to feed in water is correlated with skull shape changes, in tandem with the different
functional requirements for feeding in this medium (Lemell et al. 2019). This was shown to be the case for Testudinoidea i.e. tortoises, terrapins, Old World pond turtles (Claude et al. 2004). However, this is still to be tested for Testudines as a whole; [binary];

‘Terrestrial feeding’: indicates the capacity of feeding on land. Previous studies have shown that terrestrialisation in turtles involved drastic changes in their Bauplan, including morphological changes in limb (Joyce & Gauthier 2004), shell (Claude et al. 2003; Benson et al. 2011), and feeding apparatus (Bramble & Wake 1985; Winokur 1988; Richter et al. 2007; Natchev et al. 2015). This predictor tests the hypothesis that skull morphology in turtles can be explained by their role as terrestrial feeders; [binary];

‘Marine’: this predictor tests the hypothesis that aspects in turtle skull shape change in association with the presence of a marine lifestyle, based on previous assumptions of potential osteological cranial correlates to the presence of salt glands or modifications possibly correlating to underwater hearing (e.g. Hirayama 1998; Ferreira et al. 2015; Evers & Benson 2019); [binary];

‘Opal swimming’: this variable was included to test the hypothesis that highly aquatic fully-flippered turtles adapted to swimming non-stop in large or moving water bodies (e.g. oceans) evolved distinct cranial shapes from other turtles; [binary];

‘Neck retraction’: capacity of neck retraction. Previous studies (Werneburg 2015; Ferreira et al. 2020) revealed associations between the architecture of the posterior region of the skull and neck motion. Therefore, besides ecological factors related to diet and habitat, we included this predictor to test the hypothesis that changes in the overall skull shape of turtles (not only the posterior part) correlate with their capacity of retracting the neck; [binary];

‘Hardness index’: considering that turtles eat a wide range of food items that vary in their hardness (from soft aquatic plants to hard-shelled invertebrates; Bonin et al. 2006), this predictor tests the hypothesis that food hardness correlates to turtle cranial shape, as it has been demonstrated for some lizards, for instance (Vanhooydonck et al. 2007); [continuous];

‘Evasiveness index’: similar to the above, turtles eat a wide range of food items that vary in their evasiveness capacity (from sedentary plants to fish and elusive invertebrates; Bonin et al. 2006). Therefore, this predictor tests the hypothesis that food evasiveness correlates to turtle cranial shape, as it has also been demonstrated for some lizards (e.g. Vanhooydonck et al. 2007); [continuous];

Ecomorphological hypotheses – skull size

Similarly, our pGLS models were account for the hypothesis that multiple factors may influence turtle skull size variation. We first tested each predictor individually, and then built more complex models including those predictors found to be statistically significant. To run pGLS analyses, we used the “gls” function of the R package “nlme” (Pinheiro et al. 2020), and correlation structures from the “ape” package (Paradis & Schliep 2019), estimating Pagel’s $\lambda$ during the model fitting process. Models were then compared using AICc with the “aictab” function of the “AICcmodavg” package (Mazerolle 2020). The phylogenetic tree used and the explanatory variables included are the same as those from the D-PGLS analyses (see above). The only additional variable included here is “carapace size”, retrieved from TTWG (2021). This was included to account for allometric effects of turtle skull size (e.g. Herrel et al. 2002).
Predictions for fossils

Our phylogenetic flexible discriminant analyses (pFDA) were conducted both on extant and extinct turtle taxa, and separately on all binary predictors of the best D-PGLS model (“partial landmark dataset”, Table S5). pFDA on living turtle species were conducted as a “training step”, to verify how accurately our analyses could discriminate between turtles that presented or not a given trait. Although we had already accounted for phylogenetic covariance when retrieving regression scores, it is important to stress that the D-PGLS regression scores, as well as its residuals, are provided in the “original, phylogenetically dependent space” (Revell 2009, p. 3259). We can verify this since residuals calculation using the “phyl.resid” function (detailed in Revell 2009) yield the exact same values as residuals from a “procD.pglS” test (Adams 2014). This means that downstream analyses (e.g. discriminant analysis) should still employ methods that take phylogeny into account (e.g. pFDA; Motani & Schmitz 2011) when treating data.

In our pFDA, we randomly sampled an equal number of extant turtles from each category, so the prior probability of being classified to a given class would always be the same (see Motani & Schmitz 2011 for further discussion on the implications assuming “equal” or “empirical” prior probabilities). In each round of pFDA, considering \( j \) as the number of extant species, we obtained the posterior probability of a trait (\( PP_{\text{trait}} \)) for the \( j \)-th taxon along with the extinct taxa as if it was a fossil with unknown ecology too. This allowed us to assess how accurately our pFDA could classify extant turtles. In the end, we set an arbitrary \( PP_{\text{trait}} \) value of \( \geq 0.66 \) (e.g. Chapelle et al. 2020) to represent “likely presence” of a given trait, \( \leq 0.33 \) to represent “likely absence”, and a value in between 0.33 and 0.66 to represent “uncertainty”.

The phylogenetic trees used for these pFDA comprise composite topologies based on two different hypotheses: one from Evers et al. (2019) and the other from Sterli et al. (2018). As mentioned in the main text, relationships within extant groups follow Pereira et al. (2017), whereas the relationships between extant and extinct clades follow either the consensus tree of Evers et al. (2019) or the MkA model tree of Sterli et al. (2018; see Figure S6). Unlike the phylogeny used in the ecomorphological hypothesis tests (see above), these were calibrated using Bayesian inference (using a fossilised birth-death model), and actually represent “sub-trees” pruned from a larger topology (to be published), including only turtle taxa sampled in our analyses. Files of these pruned topologies are available at GitHub (https://github.com/G-Hermanson/Turtle-cranial-ecomorphology).

Finally, to predict the “food evasiveness index” for extinct taxa we conducted phylogenetic generalised least squares regressions (pGLS) to assess what combination of regression scores from the best D-PGLS model (“partial landmark dataset”) best explained this index for extant turtles (Supplementary Table 4). To do that, we ran pGLS using the “phylostep” function of the R package “phylolm” (Ho & Ane 2014), which compares the improvement of AIC values (i.e. obtaining lower values) from dropping and adding variables (regression scores) until no further improvement is possible (Chambers & Hastie 1992). This model was then used to calculate indices for fossil turtles using the “predict” function from R “stats” (R Core Team 2020).
Supplementary Results and Discussion

Potential correlation between certain explanatory variables

Our hypothesis tests were formulated to assess the independent effects of individual variables against skull shape and size variation (Tables S1-S4), most of the correlations having been previously suggested in the literature. For that purpose, apart from continuous variables, our binarisation of main ecological and functional explanatory traits had ultimately the goal to address questions of the sorts of: “Do turtles that use/are capable of [trait] have different cranial shapes/sizes than those that do not use/are incapable of [it]?”.

Our rationale differs from typical ecomorphology studies that, most of the time, only analyse multi-level categorical traits such as diet or habitat preference. Our models allow for the observed variation to be explained not only by one, but by multiple simultaneously important factors, which is usually the case for biological structures. However, the inclusion of some explanatory variables in the same model may imply certain statistical dependency between them at first glance, but this should not preclude one from inspecting the relative biological importance of each item. More specifically, we highlight here the inclusion of selected pairs of potentially correlated explanatory variables: “aquatic feeding” and “suction”, “durophagy” and “food hardness index”, and “suction” and “food evasiveness index”. This is noticeable, for instance, when inspecting the decrease in their individual explanatory power (R-squared) when included together in a same model, which is expected since these variables share information (Figure S27-S32). However, as we show with our shape deformation plots (Figures S8-S22), each one of these traits correlate with changes in different aspects of turtles skull shape.

In the first case, all turtles scored “presence” for “suction” are also scored that way for “aquatic feeding”, since it refers to a mechanism only physically possible under water (Bramble & Wake 1985; Lauder 1985; Lemell et al. 2019). However, because “suction” is an exclusively aquatic feeding mode, it does not make biological sense to analyse it without also taking into consideration the effects of feeding in the water. Only by evaluating what are the individual effects of each of these traits we can then understand what are the main changes in the skull shape of a turtle adapted to feeding in the water that correlate with the evolution of this feeding mechanism (e.g., Figures S8 and S10-S11).

In the second case, turtles scored 1 for “durophagy” are among those with the highest “hardness index” values (Figures S28 and S31), since their diets include mostly hard food. However, our sample also includes turtles with high hardness indices that are not considered durophagous (Figures S28 and S31), but rather generalists with a mixed diet that may include hard food items (e.g. Kinosternon baurii, Platysternon megacephalum), which is important to highlight. It shows that, despite potentially correlated (e.g., it is probable that the higher a turtle hardness index, the greater is the probability of being a durophagous), the use of these variables represents two different hypotheses. Regarding “durophagy”, it asks: “Do durophagous turtles have different head shapes/sizes than non-durophagous species?”, which considers a specific type of dietary item to be important and the others to be unimportant. On the other hand, the use of the “hardness” variable asks: “Does the shape/size of a turtle skull correlate with the proportion of hard food items in their diets?”, which proposes that the proportion of such items is the main control of morphology, and that morphological changes scale linearly with that.

Finally, as with the previous pairs of variables, “suction” and “evasiveness” also have partially redundant effects, although these traits overlap much more among each other (Figures
S29 and S32). Similar to the previous case, they represent different hypotheses: (1) “Do suction-feeding turtles have different head shapes/sizes than those species that are not?” and (2) “Does the shape/size of a turtle skull correlate with the proportion of evasive food items in their diets?” These ask whether (1) a specific feeding mode or (2) the proportion of a type of food item in their diets are the main controls of skull shape changes. Our sample includes turtles that, despite equally scored 1 for the use of suction-feeding, employ such mechanism towards preys of very different degrees of evasiveness. It spans species with very low (e.g., *Dermochelys coriacea* feeding on jellyfishes), medium-range (e.g., *Phrynops geoffroanus* feeding on aquatic plants, fish and insects), and very high indices (e.g., *Chelodina oblonga* feeding on fish and small insects). Likewise, our sample of non-suction feeders also include turtles that feed on relatively agile preys, highlighting that the evolution of this feeding mechanism does not necessarily correlate with the preference for such type of food.

**Classification accuracy of extant turtle ecological and functional traits**

The misclassification rate in our pFDA tests varied from 7% (“suction”) to 28% (“neck retraction”) based on either topology (Tables S9 and S10). Overall, the misclassified taxa were the same in both cases. In pFDA results for the presence of “suction”, 93% of extant turtles were correctly classified. Turtles scored “presence” for this trait but misclassified (i.e. PP<sub>suction</sub> < 0.66) include *Chrysemys picta*, *Dermochelys coriacea* and *Podocnemis unifilis*. These actually correspond to taxa that employ either a suction-like feeding mechanism called “neustophagia” (i.e. *C. picta* and *P. unifilis*; Rhodin et al. 1981) or have a skull shape that largely deviates from the expected for the effects of suction-feeding (Figures S11 and S19), although reported to be a suction-feeder (i.e. *D. coriacea*; Bels et al. 1998). On the other hand, turtles scored “absence” for this trait but misclassified include *Chelydra serpentina* and *Podocnemis expansa*. With respect to the former, experimental studies demonstrated the negligible effect that suction has during *C. serpentina* feeding behaviour (Lauder & Prendergast 1992), whereas in the latter, field observations did not report similar suction mechanism for *P. expansa* as it did for *P. unifilis* (Rhodin et al. 1981).

The pFDA results for the presence of “durophagy” had an accuracy of 88% correctly classified turtles. Durophages misclassified as “absent” for this trait include *Lepidochelys olivacea* (PP<sub>durophagy</sub>: 0.58) and *Cycloderma frenatum* (0.33). The misidentification of *C. frenatum* is not unexpected given its cranial shape more akin to that of other trionychids (more elongate and dorsoventrally flattened; Gaffney 1979), although authors have described a durophagous habit for this species (e.g. Mitchell 1959; Broadley & Sachsse 2011). However, *L. olivacea* misclassified as a durophage comes as a surprise, considering its great resemblance to the predicted shape of “durophagy” (Figure S12 and S20) that include very mediolaterally expanded triturating surfaces. Conversely, non-durophagous turtles misclassified as such were *Batagur baska*, *Morenia ocellata*, *Chelonia mydas*, *Natator depressus*, *Macrochelys temminckii*, *Claudius angustatus* and *Kinosternon baurii*. It is important to highlight that many of these species exhibit a very broad palate, sometimes a fully-developed secondary palate also (e.g. *B. baska*, *M. ocellata*, *C. mydas*, *N. depressus*; Gaffney 1979), similar to strict durophages. However, this mediolateral expansion may be regarded instead as a capacity a turtle has to crush harder food, which is true for some of the abovementioned turtles (e.g. Pritchard 1979; Moll 1980; Legler & Vogt 2013) or even reflect shared ancestry, from which closely related species likely inherited similar palatal architecture (e.g. Hirayama 1994; Sasaki et al. 2006).
Lastly, regarding the “neck retraction” trait, 78% of extant turtles were accurately classified. Among taxa incapable of neck retraction, only Peltoccephalus dumerilianus was misclassified. This also comes as a counterintuitive result considering the macrocephalic structure of *P. dumerilianus* skull, in addition to its correspondence to the predicted shape concerning the absence of neck retraction (Figures S13 and S21). In contrast, 17 extant turtles were wrongly predicted “absence” for this trait using the topology of Sterli et al. (2018): *Cuora flavomarginata, Heosemys grandis, Notochelys platynota, Malayemys subtrijuga, Orlitia borneensis, Geoclemys hamiltonii, Batagur baska, Aldabrachelys gigantea, Gopherus polyphemus, Dermatemys mawii, Staurotypus salvini, Claudia angustatus, Sternotherus minor, Sternotherus odoratus, Kinosternon subrubrum, and Kinosternon baurii*; and 19 using the topology from Evers et al. (2019), namely the 17 abovementioned taxa in addition to *Siebenrockiella crassicollis* and *Enys orbicularis*.

It is worth mentioning that indeed some of these turtles do have higher-domed skulls (e.g. *Cuora flavomarginata* or *Aldabrachelys gigantea*) and relatively large heads (e.g. kinosternids), or some degree of resemblance with the predicted head shape deformations regarding the “neck retraction” variable (Figures S13 and S21). However, the greatest degree of misclassification for this trait suggests different reasons that might be influencing it: (i) issues with the algorithm, that is unable to fully distinguish between turtles that can and cannot withdraw their heads based on the input data (i.e. regression scores); (ii) our arbitrary threshold (0.66) to detect absence/presence, which ultimately would change the proportion of misclassifications if modified; or (iii) aspects external to skull architecture that may also correlate to neck retraction, such as cervical anatomy, neck adjacent musculature, or the carapace anterior space (Gaffney 1975; Pritchard 1979; Ferreira & Werneburg 2019).

Nevertheless, because “neck retraction” misidentifications mostly represent neck retracting turtles being classified as lacking it, this provides us confidence in assigning the presence of this trait to the extinct turtles analysed here.
Figure S1. Landmark concept including type I and II landmarks and series of sliding semilandmarks. Numbers correspond to definitions in the text. Drawing based on the pleurodire Pelomedusa subrufa SMF 70504 (African helmeted turtle).
**Figure S2.** Landmark concepts of (A) “full landmark dataset” and (B) “partial landmark dataset” illustrated on 3D renderings of the Mediterranean pond turtle (*Mauremys leprosa* NHMUK unnumbered) and yellow-headed temple turtle (*Hieremys annandalii* FMNH 260389), respectively. These specimens correspond to those with the closest landmark coordinates to the mean shape of turtle skulls after initial Generalised Procrustes Analyses.
Figure S3. PC1 and PC2 axes of shape variation using the “full landmark dataset” (N = 71), coloured by major clades of extant turtles. (A) Chelidae: 1- Chelodina oblonga; 2- Chelus fimbriatus; 3- Elseya denata; 4- Hydromedusa tectifera; 5- Phrynops geoffroanus; 6- Phrynops hilarii. (B) Chelonioida: 1- Caretta caretta; 2- Chelonia mydas; 3- Dermochelys coriacea; 4- Eretmochelys imbricata; 5- Lepidochelys olivacea; 6- Lepidochelys kempii; 7- Natator depressus. (C) Chelydridae: 1- Chelydra serpentina; 2- Claudius angustatus; 3- Dermatemys mawii; 4- Kinosternon baurii; 5- Kinosternon subrubrum; 6- Macrochelys temminckii; 7- Staurotypus salvini; 8- Sternotherus minor; 9- Sternotherus odoratus. (D) Emysternia: 1- Chrysemys picta; 2- Clemmys guttata; 3- Deirochelys reticularia; 4- Emydidae blandingii; 5- Emys orbicularis; 6- Glyptemys insculpta; 7- Glyptemys muhlenbergii; 8- Graptemys geographica; 9- Malaclemys terrapin; 10- Platysternon megacephalum; 11- Pseudemys concinna; 12- Terrapene coahuila; 13- Terrapene ornata; 14- Trachemys scripta. (E) Geoemydidae: 1- Batagur baska; 2- Cuora amboinensis; 3- Cuora flavomarginata; 4- Heosemys grandis; 5- Malayemys subtrijuga; 6- Mauremys leprosa; 7- Melanochelys trijuga; 8- Morenia ocellata; 9- Notochelys platyrrhynchos; 10- Orlitia borneensis; 11- Pangshura tecta; 12- Rhinoclemmys melanosterna; 13- Rhinoclemmys pulcherrima; 14- Siebenrockiella crassicollis. (F) Pelomedusoides: 1- Pelomedusa subrufa; 2- Peltocephalus dumerilii; 3- Plemmys sinuatus; 4- Podocnemis expansa; 5- Podocnemis unifilis. (G) Testudinidae: 1- Aldabrachelys gigantea; 2- Chelonia gigantea; 3- Chelodina carolina; 4- Gopherus agassizii; 5- Gopherus flavomarginatus; 6- Gopherus polyphemus; 7- Malacochersus tornieri; 8- Testudo marginata. (H) Trionychia: 1- Amyda cartilaginea; 2- Apalone mutica; 3- Apalone spinifera; 4- Carettochelys insculpta; 5- Chitra indica; 6- Cyclorhynchus senegalensis; 7- Cycloderma frenatum; 8- Pelodiscus sinensis.
Figure S4. PC1 and PC2 axes of shape variation using the “partial extant landmark dataset” ($N = 76$), coloured by major clades of extant turtles. (A) Chelidae: 1- Chelodina oblonga; 2- Chelus fimbriatus; 3- Elseyia denata; 4- Hydromedusa tectifera; 5- Phrynops geoffroanus; 6- Phrynops hilarii. (B) Chelonioidae: 1- Caretta caretta; 2- Chelonia mydas; 3- Dermochelys coriacea; 4- Eretmochelys imbricata; 5- Lepidochelys olivacea; 6- Lepidochelys kempi; 7- Natator depressus. (C) Chelydridae: 1- Chelydra serpentina; 2- Claudius angustatus; 3- Dermatemys mawii; 4- Kinosternon baeri; 5- Kinosternon subrubrum; 6- Macrochelys temminckii; 7- Staurotypus salvini; 8- Sternotherus minor; 9- Sternotherus odoratus. (D) Emydidae: 1- Chrysemys picta; 2- Clemmys guttata; 3- Deirochelys reticularia; 4- Emydoidea blandingii; 5- Emys orbicularis; 6- Glyptemys insculpta; 7- Glyptemys muhlenbergii; 8- Graptemys geographica; 9- Malaclemys terrapin; 10- Platysternon megacephalum; 11- Pseudemys concinna; 12- Terrapene coahuila; 13- Terrapene ornata; 14- Trachemys scripta. (E) Geoemydidae: 1- Batagur baska; 2- Cuora amboinensis; 3- Cuora flavomarginata; 4- Cyclcopemys dentata; 5- Geoclemys hamiltonii; 6- Heosemys grandis; 7- Hieremys annandali; 8- Malayemys subtrijuga; 9- Mauremys leprosa; 10- Melanochelys trijuga; 11- Morenia ocellata; 12- Notochelys platynota; 13- Ortilia borneensis; 14- Pangshura tecta; 15- Rhinoclemmys melanosterna; 16- Rhinoclemmys pulcherrima; 17- Siebenrockiella crassicollis. (F) Pelomedusoides: 1- Pelomedusa subrufa; 2- Peltocephalus dumerilans; 3- Pelusios sinuatus; 4- Podocnemis expansa; 5- Podocnemis unifilis. (G) Testudinidae: 1- Aldabrachelys gigantea; 2- Chelonioidis carbonaria; 3- Chelonoidis nigra; 4- Gopherus agassizii; 5- Gopherus
flavomarginatus; 6- Gopherus polyphemus; 7- Malacochersus tornieri; 8- Testudo marginata. (H) Trionychia: 1- Amyda cartilaginea; 2- Apalone mutica; 3- Apalone spinifera; 4- Carettochelys insculpta; 5- Chitra indica; 6- Cyclanorbis senegalensis; 7- Cycloderma frenatum; 8- Lissemys punctata; 9- Pelodiscus sinensis; 10- Trionyx tringuis.
Figure S5. PC1 and PC2 axes of shape variation using the “combined landmark dataset” (N = 93), coloured by major clades of extant turtles as well as “stem turtles”. (A) Chelidae: 1- Chelodina oblonga; 2- Chelus fimbriatus; 3- Elseyia denata; 4- Hydromedusa tectifera; 5- Phrynops geoffroanus; 6- Phrynops hilarii. (B) Cheloniidae: 1- Argillochelys antiqua; 2- Caretta caretta; 3- Chelonia mydas; 4- Dermochelys coriacea; 5- Desmatochelys fowii; 6- Eochelone brabantica; 7- Eretmochelys imbricata; 8- Lepidochelys olivacea; 9- Lepidochelys kempi; 10- Natator depressus; 11- Pappigerus camperi; 12- Rhinochelys pulchriceps. (C) Chelydridae: 1- Chelydra serpentina; 2- Claudia angustatus; 3- Dermatemys mawii; 4- Kinosternon baurii; 5- Kinosternon subrubrum; 6- Macrochelys temminckii; 7- Staurotypus salvini; 8- Sternotherus minor; 9- Sternotherus odoratus. (D) Emydidae: 1- Chrysemys picta; 2- Clemmys guttata; 3- Deirochelys reticularia; 4- Emydidea blandingii; 5- Emys orbicularis; 6- Glyptemys insculpta; 7- Glyptemys muhlenbergii; 8- Graptemys geographica; 9- Malaclemys terrapin; 10- Platysternon megacephalum; 11- Pseudemys concinna; 12- Terrapene coahuila; 13- Terrapene ornata; 14- Trachemys scripta. (E) Geoemydidae: 1- Batagur baska; 2- Cuora amboinensis; 3- Cuora flavomarginata; 4- Cyclemys dentata; 5- Geoclemys hamiltonii; 6- Hoesemys grandis; 7- Hieremys annandali; 8- Malayemys subtrijuga; 9- Mauremys leprosa; 10- Melanochelys trijuga; 11- Morenia ocellata; 12- Notochelys platynota; 13- Orlitia borneensis; 14- Pangshura tecta; 15- Rhinoclemmys melanochelys; 16- Rhinoclemmys pulcherrima; 17- Siebenrockiella crassicollis. (F) Pelomedusoides: 1- Araiochelys hirayamai; 2- Bairdemyx hartsteini; 3- Galianemys emringeri; 4- Labrostocheles galkini; 5- Lapparentemys
vilavilensis; 6- Sahonachelys mailakavava; 7- Pelomedusa subrufa; 8- Peltocephalus dumerilianus; 9- Pelusios sinuatus; 10- Phosphatochelys tedfordi; 11- Podocnemis expansa; 12- Podocnemis unifilis; 13- Ummulisani rutgersensis. (G) Testudinidae: 1- Aldabrachelys gigantea; 2- Chelonoidis carbonaria; 3- Chelonoidis nigra; 4- Gopherus agassizii; 5- Gopherus flavomarginatus; 6- Gopherus polyphemus; 7- Malacochersus tornieri; 8- Testudo marginata. (H) Trionychia: 1- Amyda cartilaginea; 2- Apalone mutica; 3- Apalone spinifera; 4- Carettochelys insculpta; 5- Chitra indica; 6- Cyclanorbis senegalensis; 7- Cycloderma frenatum; 8- Lissemys punctata; 9- Pelodiscus sinensis; 10- Trionyx tringuis. (I) “stem turtles”: 1- Annemys sp.; 2- Eubaena cephalica; 3- Jurassichelon oleronensis; 4- Sandownia harrisi.
Figure S6. Phylogenetic tree of Pereira et al. (2017) pruned to match tips in our sample. On the left, tips included in the “full landmark dataset” analyses ($N = 71$); on the right, tips included in the “partial extant landmark dataset” analyses ($N = 76$).
Figure S7. Different phylogenetic frameworks used in phylogenetic flexible discriminant analyses. On the left, calibrated composite topology comprising extant and fossil taxa based on the consensus tree of Evers et al. (2019). On the right, composite calibrated topology based on the MKA model tree of Sterli et al. (2018). Numbers after tip labels simply denote the order they are listed in the tree.
- skull size (allometry)
- feeds in water
- suction-feeding
- durophagy
- neck retraction
- food hardness
- food evasiveness

Figure S8. Shape deformations of size-related, ecological and functional predictors of the turtle skull from the best D-PGLS model using the “full landmark dataset”. Landmark configurations describe the effects (from the top to the bottom row) of allometry, absence/presence of aquatic feeding, absence/presence of suction, absence/presence of durophagy, absence/presence of neck retraction, food hardness index, and food evasiveness index. Left, middle and right columns illustrate lateral right, dorsal and ventral views, respectively.
Figure S9. Shape deformation related to effect of “allometry” using the “full landmark dataset” (N = 71). Plots show (A) only the half right side (in right lateral view), (B) only “more dorsal” landmarks (in dorsal view) and (C) only “more ventral” landmarks (in ventral view) for clearer visualisation purposes. Redder points indicate larger Euclidean distance between the predicted shapes with minimum skull size value (i.e., 1st quartile of skull size variation) and with maximum skull size value (i.e., 3rd quartile). Vectors indicate the direction of change from the minimum to the maximum value predicted shape.

Figure S10. Shape deformation related to effect of “aquatic feeding” using the “full landmark dataset” (N = 71). Plots show (A) only the half right side (in right lateral view), (B) only “more dorsal” landmarks (in dorsal view) and (C) only “more ventral” landmarks (in ventral view) for clearer visualisation purposes. Redder points indicate larger Euclidean distance between the predicted shapes with minimum “aquatic feeding” value (i.e., 0, denoting “absence”) and with maximum “aquatic feeding” value (i.e., 1, denoting “presence”). Vectors indicate the direction of change from the minimum to the maximum value predicted shape.
Figure S11. Shape deformation related to effect of “suction” using the “full landmark dataset” (N = 71). Plots show (A) only the half right side (in right lateral view), (B) only “more dorsal” landmarks (in dorsal view) and (C) only “more ventral” landmarks (in ventral view) for clearer visualisation purposes. Redder points indicate larger Euclidean distance between the predicted shapes with minimum “suction” value (i.e., 0, denoting “absence”) and with maximum “suction” value (i.e., 1, denoting “presence”). Vectors indicate the direction of change from the minimum to the maximum value predicted shape.

Figure S12. Shape deformation related to effect of “durophagy” using the “full landmark dataset” (N = 71). Plots show (A) only the half right side (in right lateral view), (B) only “more dorsal” landmarks (in dorsal view) and (C) only “more ventral” landmarks (in ventral view) for clearer visualisation purposes. Redder points indicate larger Euclidean distance between the predicted shapes with minimum “durophagy” value (i.e., 0, denoting “absence”) and with maximum “durophagy” value (i.e., 1, denoting “presence”). Vectors indicate the direction of change from the minimum to the maximum value predicted shape.
**Figure S13.** Shape deformation related to effect of “neck retraction” using the “full landmark dataset” (N = 71). Plots show (A) only the half right side (in right lateral view), (B) only “more dorsal” landmarks (in dorsal view) and (C) only “more ventral” landmarks (in ventral view) for clearer visualisation purposes. Redder points indicate larger Euclidean distance between the predicted shapes with maximum “neck retraction” value (i.e., 1, denoting “presence”) and with minimum “neck retraction” value (i.e., 0, denoting “absence”). Vectors indicate the direction of change from the maximum to the minimum value predicted shape.

**Figure S14.** Shape deformation related to effect of “food hardness index” using the “full landmark dataset” (N = 71). Plots show (A) only the half right side (in right lateral view), (B) only “more dorsal” landmarks (in dorsal view) and (C) only “more ventral” landmarks (in ventral view) for clearer visualisation purposes. Redder points indicate larger Euclidean distance between the predicted shapes with minimum “food hardness index” value (i.e., 1st quartile of hardness index variation) and with maximum “food hardness index” value (i.e., 3rd quartile). Vectors indicate the direction of change from the minimum to the maximum value predicted shape.
Figure S15. Shape deformation related to effect of “food evasiveness index” using the “full landmark dataset” (N = 71). Plots show (A) only the half right side (in right lateral view), (B) only “more dorsal” landmarks (in dorsal view) and (C) only “more ventral” landmarks (in ventral view) for clearer visualisation purposes. Redder points indicate larger Euclidean distance between the predicted shapes with minimum “food evasiveness index” value (i.e., 1st quartile of evasiveness index variation) and with maximum “food evasiveness index” value (i.e., 3rd quartile). Vectors indicate the direction of change from the minimum to the maximum value predicted shape.

Figure S16. Shape deformation related to effect of “neck ratio” using the smaller “full landmark dataset” (N = 60). Plots show (A) only the half right side (in right lateral view), (B) only “more dorsal” landmarks (in dorsal view) and (C) only “more ventral” landmarks (in ventral view) for clearer visualisation purposes. Redder points indicate larger Euclidean distance between the predicted shapes with minimum “neck ratio” value (i.e., 1st quartile of relative neck length variation) and with maximum “neck ratio” value (i.e., 3rd quartile). Vectors indicate the direction of change from the minimum to the maximum value predicted shape.
Figure S17. Shape deformations of size-related, ecological and functional predictors of the turtle skull from the best D-PGLS model using the “partial extant landmark dataset”. Landmark configurations describe the effects (from the top to the bottom row) of allometry, absence/presence of suction, absence/presence of durophagy, and food evasiveness index. Left, middle and right columns illustrate lateral right, dorsal and ventral views, respectively.

Figure S18. Shape deformation related to effect of “allometry” using the “partial landmark dataset” (N = 76). Plots show (A) only the half right side (in right lateral view), (B) only “more dorsal” landmarks (in dorsal view) and (C) only “more ventral” landmarks (in ventral view) for clearer visualisation purposes. Redder points indicate larger Euclidean distance between the
predicted shapes with minimum skull size value (i.e., 1st quartile of skull size variation) and with maximum skull size value (i.e., 3rd quartile). Vectors indicate the direction of change from the minimum to the maximum value predicted shape.

**Figure S19.** Shape deformation related to effect of “suction” using the “partial landmark dataset” (N = 76). Plots show (A) only the half right side (in right lateral view), (B) only “more dorsal” landmarks (in dorsal view) and (C) only “more ventral” landmarks (in ventral view) for clearer visualisation purposes. Redder points indicate larger Euclidean distance between the predicted shapes with minimum “suction” value (i.e., 0, denoting “absence”) and with maximum “suction” value (i.e., 1, denoting “presence”). Vectors indicate the direction of change from the minimum to the maximum value predicted shape.

**Figure S20.** Shape deformation related to effect of “durophagy” using the “partial landmark dataset” (N = 76). Plots show (A) only the half right side (in right lateral view), (B) only “more dorsal” landmarks (in dorsal view) and (C) only “more ventral” landmarks (in ventral view) for clearer visualisation purposes. Redder points indicate larger Euclidean distance between the predicted shapes with minimum “durophagy” value (i.e., 0, denoting “absence”) and with maximum “durophagy” value (i.e., 1, denoting “presence”). Vectors indicate the direction of change from the minimum to the maximum value predicted shape.
**Figure S21.** Shape deformation related to effect of “neck retraction” using the “partial landmark dataset” (N = 76). Plots show (A) only the half right side (in right lateral view), (B) only “more dorsal” landmarks (in dorsal view) and (C) only “more ventral” landmarks (in ventral view) for clearer visualisation purposes. Redder points indicate larger Euclidean distance between the predicted shapes with maximum “neck retraction” value (i.e., 1, denoting “presence”) and with minimum “neck retraction” value (i.e., 0, denoting “absence”). Vectors indicate the direction of change from the maximum to the minimum value predicted shape.

**Figure S22.** Shape deformation related to effect of “food evasiveness index” using the “partial landmark dataset” (N = 76). Plots show (A) only the half right side (in right lateral view), (B) only “more dorsal” landmarks (in dorsal view) and (C) only “more ventral” landmarks (in ventral view) for clearer visualisation purposes. Redder points indicate larger Euclidean distance between the predicted shapes with minimum “suction” value (i.e., 0, denoting absence of evasive prey in the diet) and with maximum “suction” value (i.e., 1, denoting presence of only evasive prey in the diet). Vectors indicate the direction of change from the minimum to the maximum value predicted shape.
Figure S23. Size relationships and emargination aspects of turtle skulls. (A) pGLS regression (as in Figure 2 in the main text), with labelled points. (B) phylogenetic 2B-PLS between shape of turtle skull emarginations (as in Figure 2 in the main text), with labelled points. Numbers correspond to: 1- *Rhinoclemmys pulcherrima*; 2- *Rhinoclemmys melanosterna*; 3- *Melanochelys trijuga*; 4- *Mauremys leprosa*; 5- *Cuora flavomarginata*; 6- *Cuora amboinensis*; 7- *Heosemys grandis*; 8- *Notochelys platynota*; 9- *Malayemys subtrijuga*; 10- *Orlitia borneensis*; 11- *Pangshura tecta*; 12- *Bataagur baska*; 13- *Morenia ocellata*; 14- *Siebenrockiella crassicollis*; 15- *Malacochersus tornieri*; 16- *Testudo marginata*; 17- *Chelonoidis nigra*; 18- *Chelonoidis carbonaria*; 19- *Aldabrachelys gigantea*; 20- *Gopherus flavomarginatus*; 21- *Gopherus polyphemus*; 22- *Gopherus agassizii*; 23- *Platysternon megacephalum*; 24- *Glyptemys insculpta*; 25- *Glyptemys muhlenbergii*; 26- *Emys orbicularis*; 27- *Emydoidea blandingii*; 28- *Terrapene ornata*; 29- *Terrapene coahuila*; 30- *Clemmys guttata*; 31- *Deirochelys reticularia*; 32- *Trachemys scripta*; 33- *Graptemys geographica*; 34- *Malaclemys terrapin*; 35- *Chrysemys picta*; 36- *Pseudemys concinna*; 37- *Dermochelys coriacea*; 38- *Caretta caretta*; 39- *Lepidochelys olivacea*; 40- *Lepidochelys kempi*; 41- *Eretmochelys imbricata*; 42- *Chelonia mydas*; 43- *Natator depressus*; 44- *Macrochelys temminckii*; 45- *Chelydra serpentina*; 46- * Dermatemys mawii*; 47- *Staurotypus salvini*; 48- *Claudius angustatus*; 49- *Sternotherus minor*; 50- *Sternotherus odoratus*; 51- *Kinosternon subrubrum*; 52- *Kinosternon baurii*; 53- *Carettochelys insculpta*; 54- *Chitra indica*; 55- *Apalone mutica*; 56- *Apalone spinifera*; 57- *Amphibolichnus aspergillum*; 58- *Pelodiscus sinensis*; 59- *Cycloderma frenatum*; 60- *Cyclanorbis senegalensis*; 61- *Pelomedusa subrufa*; 62- *Pelusios sinuatus*; 63- *Peltochelys dumerilius*; 64- *Podocnemis expansa*; 65- *Podocnemis unifilis*; 66- *Elseya dentata*; 67- *Chelodina oblonga*; 68- *Hydromedusa tectifera*; 69- *Chelus fimbriatus*; 70- *Phrynops hilarii*; 71- *Phrynops geoffroanus*. 
Figure S24. Relationships of skull shape and predicted vs. observed ecology in turtles. (A–D) Multivariate morphospaces of the regression scores for selected variables taken from the best D-PGLS models using the “full landmark dataset” (see main text). Numbers correspond to: 1- Rhinoclemmys pulcherrima; 2- Rhinoclemmys melanosterna; 3- Melanochelys trijuga; 4- Mauremys leprosa; 5- Cuora flavomarginata; 6- Cuora amboinensis; 7- Heosemys grandis; 8- Notochelys platynota; 9- Malayemys subtrijuga; 10- Orlitia borneensis; 11- Pangshura tecta; 12- Batagur baska; 13- Morenia ocellata; 14- Siebenrockiella crassicollis; 15- Malacocephalus tornieri; 16- Testudo marginata; 17- Chelonoidis nigra; 18- Chelonoidis carbonaria; 19- Aldabrachelys gigantea; 20- Gopherus flavomarginatus; 21- Gopherus polyphemus; 22- Gopherus agassizii; 23- Platysternon megacephalum; 24- Glyptemys insculpta; 25- Glyptemys muhlenbergii; 26- Emys orbicularis; 27- Emydidae blandingii; 28- Terrapene ornata; 29- Terrapene coahuila; 30- Clemmys guttata; 31- Deirochelys reticularia; 32- Trachemys scripta; 33- Graptemys geographica; 34- Malaclemys terrapin; 35- Chrysemys picta; 36- Pseudemys concinna; 37- Dermochelys coriacea; 38- Caretta caretta; 39- Lepidochelys olivacea; 40- Lepidochelys kempi; 41- Eretmochelys imbricata; 42- Chelonia mydas; 43- Natator depressus; 44- Macrochelys temminckii; 45- Chelydra serpentina; 46- Dermatemys mawii; 47- Staurotypus salvinii; 48- Cladius angustatus; 49- Sternotherus minor; 50- Sternotherus odoratus; 51- Kinosternon subrubrum; 52- Kinosternon baurii; 53- Caretochelys insculpta; 54- Chitra indica; 55- Apalone mutica; 56- Apalone spinifera; 57- Amyda cartilaginea; 58- Pelodiscus sinensis; 59- Cycloderma frenatum; 60- Cyclanorbis senegalensis; 61- Pelomedusa subrufa; 62- Pelusios sinuatus; 63- Peltoccephalus dumerilianus; 64- Podocnemis expansa; 65- Podocnemis unifilis; 66- Elseya dentata; 67- Chelodina oblonga; 68- Hydromedusa tectifera; 69- Chelus fimbriatus; 70- Phrynops hilarii; 71- Phrynops geoffroanus.
Figure S25. Multivariate regression scores of (A) suction, (B) durophagy, (C) evasiveness, and (D) neck retraction traits derived from the best D-PGLS model using the “partial extant landmark dataset” \((N = 76)\) plotted against respective posterior probabilities of exhibiting it (for “suction”, “durophagy” and “neck retraction”) and against their evasiveness indices. Numbers correspond to: 1- Eubaena cephalica; 2- Annemys sp.; 3- Sandownia harrisi; 4- Jurassichelon oleronensis; 5- Hydromedusa tectifera; 6- Chelus fimbriatus; 7- Phrynops hilarii; 8- Phrynops geoffroanus; 9- Chelodina oblonga; 10- Elseya dentata; 11- Pelomedusa subrufa; 12- Pelusios sinuatus; 13- Sahonachelys mailakavava; 14- Galianemys emringeri; 15- Araiochelys hirayamai; 16- Labrostochelys galkini; 17- Phosphatochelys tedfordi; 18- Ummulisani ratgersensis; 19- Lapparentemys vilavilensis; 20- Podocnemis unifilis; 21- Podocnemis expansa; 22- Pelocephalus dumerilianus; 23- Bairdmys hartsteini; 24- Carettochelys insculpta; 25- Lissemys punctata; 26- Cyclanorbis senegalensis; 27- Cycloderma frenatum; 28- Trionyx triunguis; 29- Chitra indica; 30- Apalone spinifera; 31- Apalone mutica; 32- Pelodiscus sinensis; 33- Amyda cartilaginea; 34- Rhinoclemmys pulchriceps; 35- Desmatochelys lowii; 36- Dermochelys coriacea; 37- Chelonia mydas; 38- Natator depressus; 39- Eretmochelys imbricata; 40- Caretta caretta; 41- Lepidochelys kempii; 42- Lepidochelys olivacea; 43- Eochelone brabantica; 44- Puppigerus camperi; 45- Argillochelys antiqua; 46- Chelydra serpentina; 47- Macrochelys temminckii; 48- Dermatemys mawii; 49- Claudius angustatus; 50- Staurotypus salvini; 51- Sternotherus minor; 52- Sternotherus odoratus; 53- Kinosternon baurii; 54- Kinosternon subrubrum; 55- Platysternon megacephalum; 56- Glyptemys insculpta; 57- Glyptemys muhlenbergii; 58- Emydidae blandingii; 59- Emys orbicularis; 60- Clemmys guttata; 61- Terrapene coahuila; 62- Terrapene ornata; 63- Deirochelys reticularia; 64- Chrysemys picta; 65- Pseudemys concinna; 66- Trachemys scripta; 67- Malaclemys terrapin; 68- Graptemys geographica; 69- Rhinoclemmys pulcherrima; 70- Rhinoclemmys melanosterna; 71- Siebenrockiella crassicollis; 72- Malayemys subtrijuga; 73- Orlitia borneensis; 74- Morenia
ocellata; 75- Geoclemys hamiltonii; 76- Pangshura tecta; 77- Batagur baska; 78- Melanochelys trijuga; 79- Cyclemys dentata; 80- Notochelys platynota; 81- Hieremys annandali; 82- Heosemys grandis; 83- Mauremys leprosa; 84- Cuora amboinensis; 85- Cuora flavomarginata; 86- Gopherus polyphemus; 87- Gopherus agassizii; 88- Gopherus flavomarginatus; 89- Malacochersus tornieri; 90- Testudo marginata; 91- Aldabrachelys gigantea; 92- Chelonia carbonaria; 93- Chelonia nigra.
Figure S26. Correlation between the posterior probabilities (PP) of fossils to present ecological and functional traits, based on the two different topologies, calculated using pFDA. The dashed red lines indicate threshold of 0.66 indicative of “likely presence” (e.g. Chapelle et al. 2020), and “cor” represents Pearson’s coefficient of correlation. Numbers correspond to the following taxa: 1, *Annemys* sp.; 2, *Araiochelys hirayamai*; 3, *Argillochelys antiqua*; 4, *Bairdemys hartsteini*; 5, *Desmatochelys lowii*; 6, *Eochelone brabantica*; 7, *Eubaena cephalica*; 8, *Galianemys emringeri*; 9, *Jurassichelon oleronensis*; 10, *Labrostochelys galkini*; 11, *Lapparentemys vilavilensis*; 12, *Sahonachelys mailakavava*; 13, *Phosphatochelys tedfordi*; 14, *Puppigerus camperi*; 15, *Rhinochelys pulchriceps*; 16, *Sandownia harrisi*; 17, *Ummulisani rutgersensis*.

Figure S27. Variation of shape (x-axis) explained by pairs of potentially correlated variables in each procD.pglsl model (y-axis) using the “full landmark dataset” (N = 71). (A) R² of the “aquatic feeding” variable in each model, when included without (grey) and with (purple) the “suction” variable. (B) R² of the “suction” variable in each model, when included without (grey) and with (purple) the “aquatic feeding” variable. No bar indicates that the variable was not included in the model. Arrows indicate the best model discussed in the Main Text.
Figure S28. Variation of shape (x-axis) explained by pairs of potentially correlated variables in each procD.pglS model (y-axis) using the “full landmark dataset” (N = 71). (A) R² of the “durophagy” variable in each model, when included without (grey) and with (purple) the “food hardness” variable. (B) R² of the “food hardness” variable in each model, when included without (grey) and with (purple) the “durophagy” variable. No bar indicates that the variable was not included in the model. Arrows indicate the best model discussed in the Main Text. (C) Distribution of the “food hardness index” variable among extant turtles, plotted against the absence (white) or presence (black) of “durophagy”. Numbers correspond to: 1- *Rhinoclemmys pulcherrima*; 2- *Rhinoclemmys melanosterna*; 3- *Melanochelys trijuga*; 4- *Mauremys leprosa*; 5- *Cuora flavomarginata*; 6- *Cuora amboinensis*; 7- *Heosemys grandis*; 8- *Notochelys platynota*; 9- *Malayemys subtrijuga*; 10- *Orlitia borneensis*; 11- *Pangshura tecta*; 12- *Batagur baska*; 13- *Morenia ocellata*; 14- *Siebenrockiella crassicollis*; 15- *Malacochersus torquatus*; 16- *Testudo marginata*; 17- *Chelonia mydas*; 18- *Lepidochelys kempii*; 19- *Malaclemys terrapin*; 20- *Gopherus flavomarginatus*; 21- *Gopherus polyphemus*; 22- *Gopherus agassizii*; 23- *Platysternon megacephalum*; 24- *Glyptemys insculpta*; 25- *Glyptemys muhlenbergii*; 26- *Emys orbicularis*; 27- *Emydoidea blandingii*; 28- *Terrapene ornata*; 29- *Terrapene coahuila*; 30- *Clemmys guttata*; 31- *Deirochelys reticularia*; 32- *Trachemys scripta*; 33- *Graptemys geographica*; 34- *Chrysemys picta*; 35- *Pseudemys concinna*; 36- *Dermochelys coriacea*; 37- *Caretta caretta*; 38- *Eretmochelys imbricata*; 39- *Chelonoidis nigra*; 40- *Lepidochelys olivacea*; 41- *Chelonia mydas*; 42- *Natator depressus*; 44-...
Macrochelys temminckii; 45- Chelydra serpentina; 46- Dermatemys mawii; 47- Staurotypus salvinii; 48- Claudius angustatus; 49- Sternotherus minor; 50- Sternotherus odoratus; 51- Kinosternon subrubrum; 52- Kinosternon baurii; 53- Carettochelys insculpta; 54- Chitra indica; 55- Apalone mutica; 56- Apalone spinifera; 57- Amyda cartilaginea; 58- Pelodiscus sinensis; 59- Cycloderma frenatum; 60- Cyclanorbis senegalensis; 61- Pelomedusa subrufa; 62- Pelusios sinuatus; 63- Peltochelys dumeriliana; 64- Podocnemis expansa; 65- Podocnemis unifilis; 66- Elseya dentata; 67- Chelodina oblonga; 68- Hydromedusa tectifera; 69- Chelus fimbriatus; 70- Phrynops hilarii; 71- Phrynops geoffroanus.

Figure S29. Variation of shape (x-axis) explained by pairs of potentially correlated variables in each procD.pgl model (y-axis) using the “full landmark dataset” (N = 71). (A) $R^2$ of the “suction” variable in each model, when included without (grey) and with (purple) the “food evasiveness” variable. (B) $R^2$ of the “food evasiveness” variable in each model, when included without (grey) and with (purple) the “suction” variable. No bar indicates that the variable was not included in the model. Arrows indicate the best model discussed in the Main Text. (C) Distribution of the “food evasiveness index” variable among extant turtles, plotted against the absence (white) or presence (black) of “suction”. Numbers correspond to: 1- Rhinoclemmys pulcherrima; 2- Rhinoclemmys melanosterna; 3- Melanochelys trijuga; 4- Mauremys leprosa.
5- Cuora flavomarginata; 6- Cuora amboinensis; 7- Heosemys grandis; 8- Notochelys platynota; 9- Malayemys subtrijuga; 10- Orlitia borneensis; 11- Pangshura tecta; 12- Batagur baska; 13- Morenia ocellata; 14- Siebenrockiella crassicollis; 15- Malacochersus tornieri; 16- Testudo marginata; 17- Chelonoidis nigra; 18- Chelonoidis carbonaria; 19- Aldabrachelys gigantea; 20- Gopherus flavomarginatus; 21- Gopherus polyphemus; 22- Gopherus agassizii; 23- Platysternon megacephalum; 24- Glyptemys insculpta; 25- Glyptemys muhlenbergii; 26- Emys orbicularis; 27- Emydoidea blandingii; 28- Terrapene ornata; 29- Terrapene coahuila; 30- Clemmys guttata; 31- Deirochelys reticularia; 32- Trachemys scripta; 33- Graptemys geographica; 34- Malaclemys terrapin; 35- Chrysemys picta; 36- Pseudemys concinna; 37- Dermochelys coriacea; 38- Caretta caretta; 39- Lepidochelys olivacea; 40- Lepidochelys kempii; 41- Eretmochelys imbricata; 42- Chelonia mydas; 43- Natator depressus; 44- Macrochelys temminckii; 45- Chelydra serpentina; 46- Dermatemys mawii; 47- Staurotypus salvinii; 48- Clausdius angustatus; 49- Sternotherus minor; 50- Sternotherus odoratus; 51- Kinosternon subrubrum; 52- Kinosternon baurii; 53- Carettochelys insculpta; 54- Chitra indica; 55- Apalone mutica; 56- Apalone spinifera; 57- Amyda cartilaginea; 58- Pelodiscus sinensis; 59- Cycloderma frenatum; 60- Cyclanorbis senegalensis; 61- Pelomedusa subrufa; 62- Pelusios sinuatus; 63- Peltodermus dumerilianus; 64- Podocnemis expansa; 65- Podocnemis unifilis; 66- Elseya dentata; 67- Chelodina oblonga; 68- Hydromedusa tectifera; 69- Chelus fimbriatus; 70- Phrynops hilarii; 71- Phrynops geoffroanus.

Figure S30. Variation of shape (x-axis) explained by pairs of potentially correlated variables in each procD.pgl model (y-axis) using the “partial landmark dataset” (N = 76). (A) R² of the “aquatic feeding” variable in each model, when included without (grey) and with (purple) the “suction” variable. (B) R² of the “suction” variable in each model, when included without (grey) and with (purple) the “aquatic feeding” variable. No bar indicates that the variable was not included in the model. Arrows indicate the best model discussed in the Main Text.
Figure S31. Variation of shape (x-axis) explained by pairs of potentially correlated variables in each procD.pglS model (y-axis) using the “partial landmark dataset” (N = 76). (A) R² of the “durophagy” variable in each model, when included without (grey) and with (purple) the “food hardness” variable. (B) R² of the “food hardness” variable in each model, when included without (grey) and with (purple) the “durophagy” variable. No bar indicates that the variable was not included in the model. Arrows indicate the best model discussed in the Main Text. (C) Distribution of the “food hardness index” variable among extant turtles, plotted against the absence (white) or presence (black) of “durophagy”. Numbers correspond to: 1- *Rhinoclemmys pulcherrima*, 2- *Rhinoclemmys melanosterna*, 3- *Melanochelys trijuga*, 4- *Mauremys leprosa*, 5- *Cuora flavomarginata*, 6- *Cuora amboinensis*, 7- *Cyclemys dentata*, 8- *Hieremys annandalii*, 9- *Heosemys grandis*, 10- *Notochelys platynota*, 11- *Malayemys subtrijuga*, 12- *Orlitia borneensis*, 13- *Geoclemys hamiltonii*, 14- *Pangshura tecta*, 15- *Batagur baska*, 16- *Morenia ocellata*, 17- *Siebenrockiella crassicollis*, 18- *Malacochersus tornieri*, 19- *Testudo marginata*, 20- *Chelonoidis nigra*, 21- *Chelonoidis carbonaria*, 22- *Aladabrachelys gigantea*, 23- *Gopherus flavomarginatus*, 24- *Gopherus polyphemus*, 25- *Gopherus agassizii*, 26- *Platysternon megacephalum*, 27- *Glyptemys insculpta*, 28- *Glyptemys muhlenbergii*, 29- *Emys orbicularis*, 30- *Emydoidea blandingii*, 31- *Terrapene ornata*, 32- *Terrapene coahuila*, 33- *Clemmys guttata*, 34- *Deirochelys reticularia*, 35- *Trachemys scripta*, 36- *Graptemys geographica*, 37- *Malaclemys terrapin*, 38- *Chrysemys picta*, 39- *Pseudemys concinna*, 40- *Dermochelys*
Figure S32. Variation of shape (x-axis) explained by pairs of potentially correlated variables in each procD.pgl model (y-axis) using the “partial landmark dataset” (N = 76). (A) $R^2$ of the “suction” variable in each model, when included without (grey) and with (purple) the “food evasiveness” variable. (B) $R^2$ of the “food evasiveness” variable in each model, when included without (grey) and with (purple) the “suction” variable. No bar indicates that the variable was not included in the model. Arrows indicate the best model discussed in the Main Text. (C) Distribution of the “food evasiveness index” variable among extant turtles, plotted against the
absence (white) or presence (black) of “suction”. Numbers correspond to: 1- *Rhinoclemmys pulcherrima*, 2- *Rhinoclemmys melanosterna*, 3- *Melanochelys trijuga*, 4- *Mauremys leprosa*, 5- *Cuora flavomarginata*, 6- *Cuora amboinensis*, 7- *Cyclemys dentata*, 8- *Hieremys annandallii*, 9- *Heosemys grandis*, 10- *Notochelys platynota*, 11- *Malayemys subtrijuga*, 12- *Orlitia borneensis*, 13- *Geoclemys hamiltonii*, 14- *Pangshura baska*, 15- *Morenia ocellata*, 17- *Siebenrockiella crassicollis*, 18- *Malacochersus tornieri*, 19- *Testudo marginata*, 20- *Chelonoidis nigra*, 21- *Chelonoidis carbonaria*, 22- *Aldabrachelys gigantea*, 23- *Gopherus flavomarginatus*, 24- *Gopherus polyphemus*, 25- *Gopherus agassizii*, 26- *Platysternon megacephalum*, 27- *Glyptemys insculpta*, 28- *Glyptemys muhlenbergii*, 29- *Emys orbicularis*, 30- *Emydoidea blandingii*, 31- *Terrapene ornata*, 32- *Terrapene coahuila*, 33- *Clemmys guttata*, 34- *Deirochelys reticularia*, 35- *Trachemys scripta*, 36- *Graptemys geographica*, 37- *Malaclemys terrapin*, 38- *Chrysemys picta*, 39- *Pseudemys concinna*, 40- *Dermochelys coriacea*, 41- *Caretta caretta*, 42- *Lepidochelys olivacea*, 43- *Lepidochelys kempii*, 44- *Eretmochelys imbricata*, 45- *Chelonia mydas*, 46- *Natator depressus*, 47- *Macrochelys temminckii*, 48- *Chelydra serpentina*, 49- *Dermatemys mawii*, 50- *Staurotypus salvini*, 51- *Claudius angustatus*, 52- *Sternotherus minor*, 53- *Sternotherus odoratus*, 54- *Kinosternon subrubrum*, 55- *Kinosternon baurii*, 56- *Carettochelys insculpta*, 57- *Trionyx triunguis*, 58- *Chitra indica*, 59- *Apalone mutica*, 60- *Apalone spinifera*, 61- *Amyda cartilaginea*, 62- *Pelodiscus sinensis*, 63- *Cycloderma frenatum*, 64- *Cyclanorbis senegalensis*, 65- *Lissemys punctata*, 66- *Pelomedusa subrufa*, 67- *Pelusios sinuatus*, 68- *Peletocephalus dumerilianus*, 69- *Podocnemis expansa*, 70- *Podocnemis unifilis*, 71- *Elseya dentata*, 72- *Chelodina oblonga*, 73- *Hydromedusa tectifera*, 74- *Chelus fimbriatus*, 75- *Phrynops hilarii*, 76- *Phrynops geoffroanus*. 
### Tables S1 to S11

**Table S1.** Relative neck length data, extended from previous dataset of Joyce et al. (2021).

Abbreviations: CAS, California Academy of Sciences, San Francisco, USA; INPA, Instituto Nacional de Pesquisas da Amazônia, Belém, Brazil; LIRP, Laboratório de Ictiologia de Ribeirão Preto, Ribeirão Preto, Brazil; MVZ, Museum of Vertebrate Zoology, Berkeley, USA; NMNS, Natural Museum of Natural Science, Taichung City, Taiwan; UF, University of Florida, Florida Museum of Natural History, Gainesville, USA; UMMZ, University of Michigan Museum of Zoolog, Ann Arbor, USA. See Joyce et al. (2021) for the other collection acronyms.

| Taxon                          | Specimen       | Neck length [mm] | Carapace length [mm] | Ratio | Source                        |
|-------------------------------|----------------|------------------|----------------------|-------|-------------------------------|
| Aldabrachelys gigantea        | NA             | NA               | NA                   | NA    | NA                            |
| Amyda cartilaginea            | USNM 22522     | 319.5            | 319                  | 1     | Joyce et al. 2021             |
| Apalone matica                | USNM 313562    | 126.7            | 141                  | 0.9   | Joyce et al. 2021             |
| Apalone spinifera             | YPM R 190893   | 226.4            | 251                  | 0.9   | Joyce et al. 2021             |
| Batagur baska                 | USNM 226381    | 229              | 580                  | 0.39  | Joyce et al. 2021             |
| Caretta caretta               | AMNH 129869    | 189.7            | 585.3                | 0.32  | Joyce et al. 2021             |
| Caretochelys insculpta        | CRI 14         | 193.1            | 487                  | 0.4   | Joyce et al. 2021             |
| Chelodina oblonga             | CRI 4632       | 202.8            | 263                  | 0.77  | Joyce et al. 2021             |
| Chelonia mydas                | AMNH 5912      | 237              | 694                  | 0.34  | Joyce et al. 2021             |
| Chelonoidis carbonaria        | UF H52533      | 119.5            | 230.4                | 0.519 | Morphosource                  |
| Chelonia nigra                | MNHN 1883-230  | 468              | 1300                 | 0.36  | Vlachos&Rabi 2018; specimen photos |
| Chelus fimbriatus             | AMNH 70638     | 258.4            | 441                  | 0.59  | Joyce et al. 2021             |
| Chelydra serpentina           | UFR VP1        | 244              | 650                  | 0.38  | Joyce et al. 2021             |
| Chitra indica                 | UMMZ 227967    | 98.8623          | 100.2791             | 0.986 | Morphosource                  |
| Chrysemys picta               | AMNH 75250     | 65.6             | 143                  | 0.46  | Joyce et al. 2021             |
| Claudius angustatus           | MVZ Herps 164771 | 68.9742       | 88.89                | 0.776 | Morphosource                  |
| Clemmys guttata               | USNM 220858    | 48.9             | 107                  | 0.46  | Joyce et al. 2021             |
| Cuora amboinensis             | USNM 241427    | 61.3             | 120                  | 0.51  | Joyce et al. 2021             |
| Cuora flavomarginata          | MVZ Herps 23932 | 104.6254       | 187.0974             | 0.559 | Morphosource                  |
| Cyclanorbis senegalensis      | NA             | NA               | NA                   | NA    | NA                            |
| Cyclemys dentata              | CAS Herps 248369 | 89.2747       | 190.8185             | 0.468 | Morphosource                  |
| Cycloderma frenatum           | AMNH 110180    | 354.2            | 377                  | 0.94  | Joyce et al. 2021             |
| Deirochelys reticularia       | USNM 80965     | 166.2            | 216                  | 0.77  | Joyce et al. 2021             |
| Dermatemys mawii              | SMF 59462      | 160.7            | 351                  | 0.46  | Joyce et al. 2021             |
| Dermochelys coriacea          | NMNS 003619-003772 | 310           | 1521                 | 0.203 | Chang et al. 2003             |
| Elseya dentata                | QM J59280      | 64.9             | 244                  | 0.27  | Joyce et al. 2021             |
| EmYPDoeida_blandingii         | USNM 220869    | 135              | 215                  | 0.63  | Joyce et al. 2021             |
| Emys orbicularis              | MNHN Pal unnumbered | 88.6           | 152                  | 0.58  | Joyce et al. 2021             |
| Eretmochelys imbricata        | NA             | NA               | NA                   | NA    | NA                            |
| Geoclemys hamiltonii          | CRI 487        | 134.2            | 262                  | 0.51  | Joyce et al. 2021             |
| Glyptemys insculpta           | YPM VZ5947     | 72.7559          | 136.088              | 0.535 | Morphosource                  |
| Glyptemys mahunbergii         | NA             | NA               | NA                   | NA    | NA                            |
| Species                  | Catalogue Numbers | Longitude | Latitude | Accuracy | Source |
|-------------------------|-------------------|-----------|----------|----------|--------|
| Gopherus agassizii      | USNM 222094       | 129.3     | 275      | 0.47     | Joyce et al. 2021 |
| Gopherus flavomarginatus| USNM 51357        | 166.1     | 389      | 0.43     | Joyce et al. 2021 |
| Gopherus polyphemus     | AMNH 73053        | 104.5     | 273      | 0.38     | Specimen photos |
| Graptemys geographica   | FMNH 22080        | 83        | 199      | 0.42     | Joyce et al. 2021 |
| Heosemys grandis        | UMMZ 227766       | 40.8362   | 89.9306  | 0.454    | Morphosource |
| Hieremys annandali      | UCMVZ 241498      | 240       | 114.7    | 0.48     | Joyce et al. 2021 |
| Hydromedusa tectifera   | AMNH 133629       | 102.5     | 157      | 0.65     | Joyce et al. 2021 |
| Kinosternon baurii      | USNM 167527       | 56.8      | 99.5     | 0.57     | Joyce et al. 2021 |
| Kinosternon subrubrum   | MVZ Herps 137439  | 55.2982   | 78.7032  | 0.703    | Morphosource |
| Lepidochelys kempii     | NA                | NA        | NA       | NA       | NA     |
| Lepidochelys olivacea   | QM J85545         | 162.5     | 476      | 0.34     | Joyce et al. 2021 |
| Lissemys punctata       | NHMUK 172.2066; USNM 293490; CRI 2819; AMNH 108907 | 131.27 | 174.12 | 0.75 | Joyce et al. 2021 |
| Macrochelys temminckii  | CRI 6880          | 261       | 488      | 0.53     | Joyce et al. 2021 |
| Malaclemys terrapin     | NA                | NA        | NA       | NA       | NA     |
| Malacochersus tornieri  | USNM 72539        | 56.6      | 145      | 0.39     | Joyce et al. 2021 |
| Malayemys subtrijuga    | NHMUK 1903.4.13.1 | 73.937    | 140.278  | 0.527    | Morphosource |
| Mauremys leprosa        | MVZ Herps 237439  | 85.6486   | 172.2602 | 0.497    | Morphosource |
| Melanochelys trijuga    | YPM VZ014519      | 40.6291   | 83.5291  | 0.486    | Morphosource |
| Morenia ocellata        | NHMUK 91.11.26.1-5| 75.7585   | 185.7099 | 0.408    | Morphosource |
| Natator depressus       | QM J14463         | 231.3     | 794      | 0.29     | Joyce et al. 2021 |
| Notochelys platynota    | NA                | NA        | NA       | NA       | NA     |
| Orilia borneensis       | NA                | NA        | NA       | NA       | NA     |
| Pangshura tecta         | UF H81010         | 42.8562   | 80.55    | 0.532    | Morphosource |
| Pelodiscus sinensis     | USNM 539335       | 90.3      | 109      | 0.83     | Joyce et al. 2021 |
| Pelomedusa subrufa      | AMNH 131262       | 69.6      | 143      | 0.49     | Joyce et al. 2021 |
| Peltocephalus dumerilianus | INPA-H 12940   | 140.9     | 388      | 0.36     | Specimen photos |
| Pelusios sinuatus       | UMZC R18170       | 53.0563   | 113.6439 | 0.467    | Morphosource |
| Phrynops geoffroanus    | AMNH 79048        | 174.4     | 372      | 0.47     | Joyce et al. 2021 |
| Phrynops hilarii        | NA                | NA        | NA       | NA       | NA     |
| Platysternon megacephalus | NCSM 76497    | 49.71     | 106      | 0.47     | Joyce et al. 2021 |
| Podocnemis expansa      | LIRP unnumbered   | 261       | 684      | 0.38     | Specimen photos |
| Podocnemis unifilis     | USNM 313861; USNM 222470; CRI 7527; AMNH 6823 | 153     | 463.75   | 0.318    | Joyce et al. 2021 |
| Pseudemys concinna      | NA                | NA        | NA       | NA       | NA     |
| Rhinoclemmys melanosterna | MVZ Herps 79099 | 84.9585   | 178.9594 | 0.475    | Morphosource |
| Rhinoclemmys pulcherrima | MVZ Herps 79099 | 84.9585   | 178.9594 | 0.475    | Morphosource |
| Siebenrockiella crassicollis | YPM VZ014452 | 47.7359   | 97.5836  | 0.489    | Morphosource |
| Species                  | Museum Accession | X      | Y      | X/Y   | Source            |
|-------------------------|------------------|--------|--------|-------|------------------|
| *Staurotypus salvinii*  | UF H33255        | 133.0374 | 257.1466 | 0.517 | Morphosource     |
| *Sternotherus minor*     | USBM 167534      | 59.1   | 90     | 0.66  | Joyce et al. 2021|
| *Sternotherus odoratus*  | AMNH 69040       | 66.1   | 109    | 0.627 | Joyce et al. 2021|
| *Terrapene coahuila*    | OUMNH 8795       | 60.84  | 115.1  | 0.530 | Joyce et al. 2021|
| **Terrapene ornata**    | MVZ Herps 250709 | 71.2382 | 130.0525 | 0.548 | Morphosource     |
| *Testudo marginata*     | MVZ Herps 247484 | 96.8553 | 239.1132 | 0.405 | Morphosource     |
| *Trachemys scripta*     | UF H49423        | 102.3495 | 206.6832 | 0.495 | Morphosource     |
| *Trionyx triunguis*     | UF H65522        | 89.5447 | 91.2998 | 0.981 | Morphosource     |
Table S2. Full results of phylogenetic regressions (pGLS) of turtle skull size against size-related, ecological and functional traits as explanatory variables. AICc-best model shown on top. Abbreviations: Coef., estimated coefficient; SE, standard error; t-value, t statistics value; P-value, P statistics value, in which numbers in **bold** denote significance at an α < 0.05 level; P-value (FDR), P statistics value corrected using “false discovery rate (FDR)” method; AAICc, scores of Akaike Information Criterion for small samples; AICc, relative difference to AICc score of best model; AICc w, relative importance of the model; R², coefficient of determination of the model, calculated as in Ives (2019); λ, phylogenetic signal (Pagel’s lambda) of residuals estimated as part of the model-fitting process. N = 71 in all analyses.

| Model | λ  | R²  | AICc | ΔAICc | AAICc | Variable          | Coef.   | SE     | t-value | P-value   | P-value (FDR) |
|-------|----|-----|------|-------|-------|-------------------|---------|--------|---------|-----------|---------------|
| skull size ~ carapace size + neck retraction | 0.132 | 0.806 | -103.307 | 0 | 0.354 | (Intercept)      | 0.409   | 0.165  | 2.483   | 0.015     | 0.015         |
| skull size ~ carapace size + neck retraction + open swimming | 0.137 | 0.81 | -101.911 | 1.396 | 0.176 | (Intercept)      | 0.416   | 0.165  | 2.518   | 0.014     | 0.018         |
| skull size ~ carapace size + marine + open swimming + neck retraction | 0.103 | 0.813 | -101.31 | 1.997 | 0.131 | (Intercept)      | 0.431   | 0.163  | 2.64    | 0.01      | 0.017        |
| skull size ~ carapace size + neck retraction + hardness | 0.153 | 0.807 | -101.026 | 2.281 | 0.113 | (Intercept)      | 0.434   | 0.177  | 2.444   | 0.017     | 0.022        |
| skull size ~ carapace size + neck retraction + durophagous | 0.129 | 0.806 | -100.93 | 2.377 | 0.108 | (Intercept)      | 0.405   | 0.173  | 2.379   | 0.02      | 0.026        |
| skull size ~ carapace size + neck retraction + marine | 0.132 | 0.806 | -100.918 | 2.389 | 0.107 | (Intercept)      | 0.409   | 0.166  | 2.463   | 0.015     | 0.021        |
| skull size ~ carapace size + marine | 0.163 | 0.779 | -93.531 | 9.776 | 0.003 | (Intercept)      | 0.173   | 0.158  | 1.091   | 0.278     | 0.278        |
| skull size ~ carapace size | 0.491 | 0.773 | -89.615 | 13.692 | 0      | (Intercept)      | 0.185   | 0.054  | 3.417   | 0.001     | 0.007        |
| skull size ~ neck retraction | 0.825 | 0.599 | -43.968 | 59.339 | 0      | (Intercept)      | 2.087   | 0.121  | 17.192  | 0.000     | 0.000        |
| skull size ~ open swimming | 0.819 | 0.596 | -42.364 | 60.943 | 0      | (Intercept)      | 1.735   | 0.094  | 18.33   | 0.000     | 0.000        |
| skull size ~ marine | 0.832 | 0.593 | -41.936 | 61.371 | 0 | (Intercept) | 1.768 | 0.095 | 18.532 | 0.000 | 0.000 |
| skull size ~ herbivory | 0.907 | 0.581 | -35.336 | 67.971 | 0 | (Intercept) | 1.777 | 0.112 | 15.861 | 0.000 | 0.000 |
| skull size ~ suction | 0.92 | 0.572 | -34.248 | 69.059 | 0 | (Intercept) | 1.755 | 0.118 | 14.864 | 0.000 | 0.000 |
| skull size ~ hardness | 0.921 | 0.574 | -32.836 | 70.471 | 0 | (Intercept) | 1.836 | 0.124 | 14.744 | 0.000 | 0.000 |
| skull size ~ durophagous | 0.917 | 0.578 | -32.831 | 70.476 | 0 | (Intercept) | 1.8 | 0.115 | 15.611 | 0.000 | 0.000 |
| skull size ~ terrestrial feeding | 0.915 | 0.578 | -32.679 | 70.628 | 0 | (Intercept) | 1.799 | 0.115 | 15.632 | 0.000 | 0.000 |
| skull size ~ evasiveness | 0.911 | 0.577 | -32.678 | 70.629 | 0 | (Intercept) | 1.828 | 0.121 | 15.072 | 0.000 | 0.000 |
| skull size ~ aquatic feeding | 0.914 | 0.577 | -32.125 | 71.182 | 0 | (Intercept) | 1.818 | 0.145 | 12.506 | 0.000 | 0.000 |
| skull size ~ carnivory | 0.916 | 0.577 | -32.069 | 71.238 | 0 | (Intercept) | 1.798 | 0.118 | 15.147 | 0.000 | 0.000 |
Table S3. Full results of phylogenetic regressions (pGLS) of turtle skull size against size-related, ecological, and functional traits, including relative neck length (“neck ratio”) as an additional explanatory variable. Abbreviations: Coef., estimated coefficient; SE, standard error; \( t\)-value, \( t\) statistics value; P-value, P statistics value, in which numbers in bold denote significance at an \( \alpha < 0.05 \) level; P-value (FDR), P statistics value corrected using “false discovery rate (FDR)” method; AIC, scores of Akaike Information Criterion; \( \Delta \text{AIC} \), relative difference to AIC score of best model; \( R^2 \), coefficient of determination of the model, calculated as in Ives (2019); \( \lambda \), phylogenetic signal (Pagel’s lambda) of residuals estimated as part of the model-fitting process. \( N = 60 \) in all analyses.

| Model                          | \( \lambda \) | \( R^2 \) | AIC   | \( \Delta \text{AIC} \) | Variable                   | Coef.  | SE       | \( t\)-value | P-value | P-value (FDR) |
|-------------------------------|---------------|----------|-------|-------------------------|-----------------------------|--------|----------|--------------|---------|---------------|
| skull size ~ carapace size    | 0.856         | 0.814    | -82.418 | 15.998                  | (Intercept)                 | 0.138  | 0.191    | 0.720        | 0.475   | 0.475         |
|                               |               |          |        |                         | carapace size               | 0.614  | 0.067    | 9.192        | 0.000   | 0.000         |
| skull size ~ aquatic feeding  | 0.631         | -32.35   | 66.066 |                         | (Intercept)                 | 1.764  | 0.146    | 12.052       | 0.000   | 0.000         |
|                               |               |          |        |                         | aquatic feeding             | 0.036  | 0.080    | 0.447        | 0.657   | 0.657         |
| skull size ~ terrestrial feeding | 0.62         | -32.234  | 66.182 |                         | (Intercept)                 | 1.800  | 0.124    | 14.483       | 0.000   | 0.000         |
|                               |               |          |        |                         | terrestrial feeding         | -0.018 | 0.061    | -0.294       | 0.770   | 0.770         |
| skull size ~ suction          | 0.611         | -35.151  | 63.265 |                         | (Intercept)                 | 1.755  | 0.124    | 14.165       | 0.000   | 0.000         |
|                               |               |          |        |                         | suction                     | 0.103  | 0.060    | 1.726        | 0.090   | 0.090         |
| skull size ~ durophagous       | 0.622         | -32.684  | 65.732 |                         | (Intercept)                 | 1.803  | 0.124    | 14.552       | 0.000   | 0.000         |
|                               |               |          |        |                         | durophagous                 | -0.038 | 0.052    | -0.724       | 0.472   | 0.472         |
| skull size ~ herbivory         | 0.618         | -32.946  | 65.47  |                         | (Intercept)                 | 1.788  | 0.124    | 14.410       | 0.000   | 0.000         |
|                               |               |          |        |                         | herbivory                  | 0.056  | 0.063    | 0.883        | 0.381   | 0.381         |
| skull size ~ carnivory         | 0.618         | -32.678  | 65.738 |                         | (Intercept)                 | 1.817  | 0.126    | 14.389       | 0.000   | 0.000         |
|                               |               |          |        |                         | carnivory                  | -0.034 | 0.047    | -0.720       | 0.474   | 0.474         |
| skull size ~ marine            | 0.91          | 0.64     | -43.325 | 55.091                  | (Intercept)                 | 1.769  | 0.097    | 18.232       | 0.000   | 0.000         |
|                               |               |          |        |                         | marine                      | 0.572  | 0.152    | 3.761        | 0.090   | 0.090         |
| skull size ~ neck retraction   | 0.939         | 0.65     | -44.867 | 53.549                  | (Intercept)                 | 2.084  | 0.124    | 16.754       | 0.000   | 0.000         |
|                               |               |          |        |                         | neck retraction             | -0.335 | 0.086    | -3.875       | 0.000   | 0.000         |
| skull size ~ open swimming     | 0.906         | 0.64     | -43.335 | 55.081                  | (Intercept)                 | 1.730  | 0.098    | 17.704       | 0.000   | 0.000         |
|                               |               |          |        |                         | open swimming               | 0.486  | 0.129    | 3.782        | 0.000   | 0.000         |
| skull size ~ hardness          | 0.618         | -32.301  | 66.115 |                         | (Intercept)                 | 1.817  | 0.133    | 13.687       | 0.000   | 0.000         |
|                               |               |          |        |                         | hardness                   | -0.033 | 0.085    | -0.389       | 0.698   | 0.698         |
| skull size ~ evasiveness       | 0.62          | -32.146  | 66.27  |                         | (Intercept)                 | 1.801  | 0.131    | 13.793       | 0.000   | 0.000         |
|                               |               |          |        |                         | evasiveness                 | -0.003 | 0.076    | -0.043       | 0.966   | 0.966         |
| skull size ~ neck ratio        | 0.989         | 0.619    | -32.608 | 65.808                  | (Intercept)                 | 1.876  | 0.161    | 11.639       | 0.000   | 0.000         |
|                               |               |          |        |                         | neck ratio                 | -0.141 | 0.194    | -0.726       | 0.471   | 0.471         |
| skull size ~ carapace size + marine | 0.148     | 0.806    | -86.209 | 12.207                  | (Intercept)                 | 0.207  | 0.164    | 1.265        | 0.211   | 0.211         |
|                               |               |          |        |                         | carapace size               | 0.578  | 0.062    | 9.307        | 0.000   | 0.000         |
|                               |               |          |        |                         | marine                      | 0.241  | 0.068    | 3.524        | 0.001   | 0.001         |
| skull size ~ carapace size + open swimming | 0        | 0.809    | -88.516 | 9.9                     | (Intercept)                 | 0.169  | 0.144    | 1.174        | 0.245   | 0.245         |
|                               |               |          |        |                         | carapace size               | 0.586  | 0.057    | 10.325       | 0.000   | 0.000         |
|                               |               |          |        |                         | open swimming               | 0.233  | 0.056    | 4.164        | 0.000   | 0.000         |
| skull size ~ carapace size + neck retraction | 0        | 0.835    | -97.27  | 1.146                   | (Intercept)                 | 0.409  | 0.153    | 2.669        | 0.010   | 0.010         |
|                               |               |          |        |                         | carapace size               | 0.581  | 0.051    | 11.472       | 0.000   | 0.000         |
|                               |               |          |        |                         | neck retraction             | -0.238 | 0.044    | -5.387       | 0.000   | 0.000         |

### Abbreviations
- Coef.: estimated coefficient
- SE: standard error
- \( t\)-value: \( t\) statistics value
- P-value: P statistics value
- \( \Delta \text{AIC} \): relative difference to AIC score of best model
- \( R^2 \): coefficient of determination of the model
- FDR: false discovery rate
| Model                                           | carapace size | neck ratio | skull size | marine | open swimming | neck retraction | durophagous | hardness | marine | open swimming | neck retraction | marine | open swimming | neck retraction | durophagous | hardness | marine | open swimming | neck retraction | marine | open swimming | neck retraction | durophagous | hardness | marine | open swimming | neck retraction |
|------------------------------------------------|---------------|------------|------------|--------|---------------|----------------|-------------|-----------|--------|---------------|----------------|--------|---------------|----------------|-------------|-----------|--------|---------------|----------------|--------|---------------|----------------|-------------|-----------|--------|---------------|----------------|
| skull size ~ carapace size + neck ratio       | 0.616         | 0.070      | 8.839      |        |               |                |             |           |        |               |                 |        |               |                |             |           |        |               |                 |        |               |                |             |           |        |               |                 |
| skull size ~ carapace size + marine + open swimming + neck retraction | 0.085         | 0.846      | -98.416    | 0      |               | -0.188         | 0.112       |           |        |               |                 |        |               |                |             |           |        |               |                 |        |               |                |             |           |        |               |                 |
| skull size ~ carapace size + neck retraction + open swimming + marine | 0.098         | 0.838      | -95.741    | 2.675  |               | -0.209         | 0.059       |           |        |               |                 |        |               |                |             |           |        |               |                 |        |               |                |             |           |        |               |                 |
| skull size ~ carapace size + neck retraction + hardness | 0.082         | 0.811      | -84.49     | 13.926 |               | 0.057          | 0.245       |           |        |               |                 |        |               |                |             |           |        |               |                 |        |               |                |             |           |        |               |                 |
| skull size ~ carapace size + marine + neck ratio | 0.117         | 0.802      | -84.49     | 13.926 |               | 0.045          | 0.245       |           |        |               |                 |        |               |                |             |           |        |               |                 |        |               |                |             |           |        |               |                 |
Table S4. Full results of D-PGLS analyses using the “full landmark dataset” testing different models of ecomorphological associations of turtle skull shape. In all analyses, \(N = 71\). Abbreviations: \(Df\), degrees of freedom; \(SS\), sum of square; \(MS\), mean sum of square; \(R^2\), coefficient of determination of the predictor; \(F\), \(F\)-statistic value; \(Z\), \(Z\)-test statistics; \(P\)-value, \(P\) statistics value, in which numbers in **bold** denote significance at an \(\alpha < 0.05\) level; \(P\)-value (FDR), \(P\) statistics value corrected using “false discovery rate (FDR)” method; \(R^2\) model, coefficient of determination of the whole model (i.e. sum of \(R^2\)'s of individual predictors).

| Model                                         | \(R^2\) model | Variable                        | \(R^2\) | \(F\)  | \(Z\)   | \(P\)-value | \(P\)-value (FDR) |
|-----------------------------------------------|----------------|--------------------------------|---------|--------|---------|-------------|-------------------|
| shape ~ skull size                            | 0.0562         | skull size                      | 0.0562  | 4.1053 | 4.2948  | 0.001       | 0.001             |
| shape ~ skull size + aquatic feeding          | 0.0807         | skull size, aquatic feeding      | 0.0562  | 4.1537 | 4.2741  | 0.001       | 0.002             |
| shape ~ skull size + terrestrial feeding      | 0.0734         | skull size, terrestrial feeding  | 0.0566  | 4.15   | 4.2602  | 0.001       | 0.002             |
| shape ~ skull size + suction                  | 0.1069         | skull size, suction              | 0.0567  | 4.311  | 4.4853  | 0.001       | 0.001             |
| shape ~ skull size + durophagy                | 0.1039         | skull size, durophagy            | 0.0557  | 4.2253 | 4.4853  | 0.001       | 0.001             |
| shape ~ skull size + herbivory                | 0.0896         | skull size, herbivory            | 0.0582  | 4.34   | 4.5232  | 0.001       | 0.002             |
| shape ~ skull size + carnivory                | 0.0805         | skull size, carnivory            | 0.0562  | 4.1552 | 4.401   | 0.001       | 0.002             |
| shape ~ skull size + open swimming            | 0.0746         | skull size, open swimming        | 0.0533  | 3.9253 | 4.2003  | 0.001       | 0.002             |
| shape ~ skull size + neck_retraction          | 0.1008         | skull size, neck_retraction      | 0.0484  | 3.6933 | 3.934   | 0.001       | 0.001             |
| shape ~ skull size + hardness                 | 0.1007         | skull size, hardness             | 0.0561  | 4.2427 | 4.4491  | 0.001       | 0.001             |
| shape ~ skull size + evasiveness              | 0.1148         | skull size, evasiveness          | 0.0564  | 4.3296 | 4.5829  | 0.001       | 0.001             |
| shape ~ skull size + suction + durophagy + herbivory + carnivory + neck retraction + hardness + evasiveness | 0.2203 | skull size, suction, durophagy, herbivory, carnivory, neck retraction, hardness, evasiveness | 0.0456  | 3.9518 | 4.2758  | 0.001       | 0.004             |
| shape ~ skull size + suction + durophagy + neck retraction + hardness + evasiveness | 0.1996 | skull size, suction, durophagy, neck retraction, hardness, evasiveness | 0.0445  | 3.8226 | 4.2256  | 0.001       | 0.002             |
| shape ~ skull size + aquatic feeding + suction + durophagy + neck retraction + hardness + evasiveness | 0.2177 | skull size, aquatic feeding, suction, durophagy, neck retraction, hardness, evasiveness | 0.0445  | 3.8684 | 4.2069  | 0.001       | 0.003             |

Abbreviations: \(Df\), degrees of freedom; \(SS\), sum of square; \(MS\), mean sum of square; \(R^2\), coefficient of determination of the predictor; \(F\), \(F\)-statistic value; \(Z\), \(Z\)-test statistics; \(P\)-value, \(P\) statistics value, in which numbers in **bold** denote significance at an \(\alpha < 0.05\) level; \(P\)-value (FDR), \(P\) statistics value corrected using “false discovery rate (FDR)” method; \(R^2\) model, coefficient of determination of the whole model (i.e. sum of \(R^2\)'s of individual predictors).
|                          | durophagy | neck retraction | hardness | evasiveness |
|--------------------------|-----------|-----------------|----------|-------------|
| shape ~ skull size + aquatic feeding + suction + durophagy + open swimming + neck retraction + hardness + evasiveness | 0.0294    | 0.0481          | 0.02     | 0.0298      |
|                          | 2.556     | 4.1855          | 1.7405   | 2.5969      |
|                          | 3.0534    | 4.4295          | 1.9571   | 3.2433      |
|                          | 0.003     | 0.001           | 0.032    | 0.002       |
|                          | 0.005     | 0.003           | 0.037    | 0.004       |
| skull size               | 0.046     | 0.0207          | 0.0255   | 0.0312      |
|                          | 4.0307    | 1.8092          | 2.2294   | 2.7307      |
|                          | 4.3404    | 1.8526          | 2.5234   | 3.2251      |
|                          | 0.001     | 0.04            | 0.011    | 0.002       |
| 0.002                   | 0.044     | 0.017           | 0.004    | 0.002       |
| aquatic feeding          | 0.0162    | 0.0424          | 0.02     | 0.0293      |
|                          | 1.4166    | 3.7142          | 1.7485   | 2.5699      |
|                          | 1.2909    | 4.0028          | 1.9685   | 3.1912      |
|                          | 0.107     | 0.001           | 0.032    | 0.001       |
|                          | 0.106     | 0.002           | 0.042    | 0.002       |
Table S5. Full results of D-PGLS analyses using the “partial extant landmark dataset” testing different models of ecomorphological associations of turtle skull shape. In all analyses, $N = 76$. Abbreviations: $Df$, degrees of freedom; $SS$, sum of square; $MS$, mean sum of square; $R^2$, coefficient of determination of the predictor; $F$, $F$-statistic value; $Z$, $Z$-test statistics; $P$, $P$-value, $P$ statistics value, in which numbers in **bold** denote significance at an $\alpha < 0.05$ level; $P$-value (FDR), $P$ statistics value corrected using “false discovery rate (FDR)” method; $R^2$ model, coefficient of determination of the whole model (i.e. sum of $R^2$s of individual predictors).

| Model                                      | $R^2$ model | Variable                  | $R^2$ | $F$    | $Z$     | P-value   | $P$-value (FDR) |
|--------------------------------------------|-------------|---------------------------|-------|--------|---------|-----------|-----------------|
| shape ~ skull size                         | 0.038       | skull size                | 0.038 | 2.887  | 2.76    | **0.004** | **0.004**       |
| shape ~ skull size + aquatic feeding       | 0.061       | skull size                | 0.038 | 2.931  | 2.834   | **0.004** | **0.008**       |
|                                            |             | aquatic feeding           | 0.024 | 1.842  | 1.531   | 0.067     | 0.068           |
| shape ~ skull size + terrestrial feeding   | 0.054       | skull size                | 0.035 | 2.744  | 2.671   | **0.005** | **0.01**        |
|                                            |             | terrestrial feeding       | 0.018 | 1.403  | 1.079   | 0.153     | 0.15            |
| shape ~ skull size + suction               | 0.096       | skull size                | 0.04  | 3.254  | 3.076   | **0.002** | **0.002**       |
|                                            |             | suction                   | 0.055 | 4.463  | 3.718   | **0.001** | **0.002**       |
| shape ~ skull size + durophagy             | 0.09        | skull size                | 0.041 | 3.254  | 3.144   | **0.002** | **0.002**       |
|                                            |             | durophagy                 | 0.049 | 3.958  | 3.509   | **0.001** | **0.002**       |
| shape ~ skull size + herbivory             | 0.084       | skull size                | 0.038 | 3.048  | 2.871   | **0.001** | **0.001**       |
|                                            |             | herbivory                 | 0.045 | 3.612  | 3.249   | **0.001** | **0.001**       |
| shape ~ skull size + carnivory             | 0.067       | skull size                | 0.038 | 2.957  | 2.877   | **0.005** | 0.01            |
|                                            |             | carnivory                 | 0.029 | 2.243  | 2.109   | **0.021** | **0.023**       |
| shape ~ skull size + open swimming         | 0.061       | skull size                | 0.044 | 3.391  | 3.141   | **0.003** | **0.006**       |
|                                            |             | open swimming             | 0.017 | 1.296  | 0.825   | 0.217     | 0.217           |
| shape ~ skull size + neck retraction       | 0.079       | skull size                | 0.041 | 3.246  | 3.035   | **0.001** | **0.002**       |
|                                            |             | neck retraction           | 0.038 | 3.016  | 2.573   | **0.005** | **0.005**       |
| shape ~ skull size + hardness              | 0.088       | skull size                | 0.04  | 3.219  | 3.022   | **0.002** | **0.002**       |
|                                            |             | hardness                  | 0.047 | 3.776  | 3.269   | **0.001** | **0.002**       |
| shape ~ skull size + evasiveness           | 0.109       | skull size                | 0.038 | 3.125  | 2.974   | **0.001** | **0.001**       |
|                                            |             | evasiveness               | 0.071 | 5.771  | 4.309   | **0.001** | **0.001**       |
| shape ~ skull size + suction + durophagy + herbivory + carnivory + neck retraction + hardness + evasiveness | 0.196 | skull size | 0.04 | 3.663 | 3.407 | **0.001** | **0.008** |
|                                            |             | suction                   | 0.021 | 1.904 | 1.797 | **0.035** | 0.052 |
|                                            |             | durophagy                 | 0.026 | 2.371 | 2.408 | **0.008** | **0.016** |
|                                            |             | herbivory                 | 0.019 | 1.701 | 1.591 | 0.056     | 0.073           |
|                                            |             | carnivory                 | 0.013 | 1.225 | 0.659 | 0.264     | 0.0269          |
|                                            |             | neck retraction           | 0.033 | 2.988 | 2.781 | **0.003** | **0.01**       |
|                                            |             | hardness                  | 0.017 | 1.555 | 1.304 | 0.091     | 0.11            |
|                                            |             | evasiveness               | 0.027 | 2.484 | 2.498 | **0.004** | **0.01**       |
| shape ~ skull size + suction + durophagy + neck retraction + evasiveness | 0.184 | skull size | 0.043 | 3.869 | 3.544 | **0.001** | **0.002** |
|                                            |             | suction                   | 0.021 | 1.886 | 1.752 | **0.036** | **0.033** |
|                                            |             | durophagy                 | 0.044 | 3.907 | 3.709 | **0.001** | **0.002** |
|                                            |             | neck retraction           | 0.036 | 3.214 | 2.918 | **0.004** | **0.005** |
|                                            |             | evasiveness               | 0.041 | 3.631 | 3.452 | **0.002** | **0.003** |
| shape ~ skull size + suction + neck retraction + hardness + evasiveness | 0.17  | skull size | 0.044 | 3.837 | 3.575 | **0.001** | **0.005** |
|                                            |             | suction                   | 0.025 | 2.229 | 2.153 | **0.013** | **0.013** |
|                                            |             | neck retraction           | 0.032 | 2.838 | 2.582 | **0.006** | **0.007** |
|                                            |             | hardness                  | 0.031 | 2.754 | 2.691 | **0.005** | **0.007** |
|                                            |             | evasiveness               | 0.037 | 3.287 | 3.132 | **0.002** | **0.005** |
|                          | skull size | suction | durophagy | neck retraction | evasiveness | aquatic feeding |
|--------------------------|------------|---------|-----------|-----------------|-------------|-----------------|
| shape ~ skull size + suction + durophagy + neck retraction + evasiveness + aquatic feeding | 0.043 | 3.891 | 3.602 | 0.001 | 0.002 |
|                          | suction | 0.021 | 1.881 | 1.753 | 0.034 | 0.042 |
|                          | durophagy | 0.044 | 4.012 | 3.793 | 0.001 | 0.002 |
|                          | neck retraction | 0.036 | 3.242 | 2.909 | 0.004 | 0.006 |
|                          | evasiveness | 0.036 | 3.269 | 3.158 | 0.001 | 0.002 |
|                          | aquatic feeding | 0.017 | 1.563 | 1.231 | 0.12 | 0.125 |
| shape ~ skull size + suction + durophagy + neck retraction + evasiveness + open swimming | 0.048 | 4.3 | 3.834 | 0.001 | 0.003 |
|                          | suction | 0.021 | 1.901 | 1.785 | 0.036 | 0.042 |
|                          | durophagy | 0.046 | 4.165 | 3.902 | 0.001 | 0.003 |
|                          | neck retraction | 0.037 | 3.34 | 2.888 | 0.003 | 0.004 |
|                          | evasiveness | 0.039 | 3.565 | 3.438 | 0.002 | 0.004 |
|                          | open swimming | 0.018 | 1.621 | 1.363 | 0.088 | 0.086 |
Table S6. Full results of D-PGLS analyses using the smaller “full landmark dataset” testing different models of ecomorphological associations of turtle skull shape. These include the “neck ratio” trait as an additional explanatory variable. In all analyses, N = 60. Abbreviations: Df, degrees of freedom; SS, sum of square; MS, mean sum of square; R², coefficient of determination of the predictor; F, F-statistic value; Z, Z-test statistics; P-value, P statistics value, in which numbers in bold denote significance at an α < 0.05 level; P-value (FDR), P statistics value corrected using “false discovery rate (FDR)” method; R² model, coefficient of determination of the whole model (i.e. sum of R²’s of individual predictors).

| Model | R² model | Variable | R² | F  | Z   | P-value | P-value (FDR) |
|-------|----------|----------|----|----|-----|---------|---------------|
| shape ~ skull size | 0.056 | skull size | 0.056 | 3.419 | 3.583 | 0.001 | 0.001 |
| shape ~ skull size + aquatic feeding | 0.084 | skull size | 0.055 | 3.423 | 3.515 | **0.001** | **0.002** |
| | | aquatic feeding | 0.029 | 1.786 | 1.565 | 0.072 | 0.072 |
| shape ~ skull size + terrestrial feeding | 0.076 | skull size | 0.056 | 3.427 | 3.582 | **0.001** | **0.002** |
| | | terrestrial feeding | 0.02 | 1.259 | 0.812 | 0.221 | 0.221 |
| shape ~ skull size + suction | 0.112 | skull size | 0.055 | 3.528 | 3.844 | **0.001** | **0.001** |
| | | suction | 0.058 | 3.698 | 4.047 | **0.001** | **0.001** |
| shape ~ skull size + durophagous | 0.109 | skull size | 0.057 | 3.633 | 3.853 | **0.001** | **0.001** |
| | | durophagous | 0.052 | 3.301 | 3.265 | **0.001** | **0.001** |
| shape ~ skull size + herbivory | 0.08 | skull size | 0.056 | 3.493 | 3.58 | **0.001** | **0.002** |
| | | herbivory | 0.023 | 1.43 | 1.161 | 0.125 | 0.125 |
| shape ~ skull size + carnivory | 0.09 | skull size | 0.056 | 3.517 | 3.493 | **0.001** | **0.002** |
| | | carnivory | 0.033 | 2.086 | 2.368 | 0.01 | 0.01 |
| shape ~ skull size + open swimming | 0.077 | skull size | 0.051 | 3.147 | 3.376 | **0.001** | **0.002** |
| | | open swimming | 0.027 | 1.664 | 1.515 | 0.064 | 0.064 |
| shape ~ skull size + neck retraction | 0.1 | skull size | 0.039 | 2.538 | 2.924 | **0.003** | **0.003** |
| | | neck retraction | 0.06 | 3.879 | 3.644 | 0.001 | 0.002 |
| shape ~ skull size + hardness | 0.098 | skull size | 0.057 | 3.581 | 3.478 | **0.001** | **0.002** |
| | | hardness | 0.041 | 2.593 | 2.783 | **0.004** | **0.004** |
| shape ~ skull size + evasiveness | 0.111 | skull size | 0.056 | 3.574 | 3.457 | **0.001** | **0.001** |
| | | evasiveness | 0.055 | 3.55 | 4.215 | **0.001** | **0.001** |
| shape ~ skull size + neck ratio | 0.099 | skull size | 0.054 | 3.437 | 3.584 | **0.001** | **0.001** |
| | | neck ratio | 0.045 | 2.858 | 3.215 | **0.001** | **0.001** |
| shape ~ skull size + suction + durophagous + herbivory + carnivory + neck retraction + hardness + evasiveness + neck ratio | 0.239 | skull size | 0.029 | 2.146 | 2.459 | **0.008** | **0.024** |
| | | suction | 0.027 | 2.021 | 2.13 | **0.014** | **0.025** |
| | | durophagous | 0.03 | 2.219 | 2.283 | **0.014** | **0.025** |
| | | herbivory | 0.016 | 1.222 | 0.771 | 0.218 | 0.245 |
| | | carnivory | 0.01 | 0.724 | -0.9 | 0.819 | 0.819 |
| | | neck retraction | 0.049 | 3.645 | 3.568 | **0.001** | **0.009** |
| | | hardness | 0.024 | 1.767 | 1.87 | **0.036** | **0.046** |
| | | evasiveness | 0.024 | 1.806 | 1.993 | **0.026** | **0.039** |
| | | neck ratio | 0.029 | 2.165 | 2.631 | **0.003** | **0.013** |
| shape ~ skull size + suction + durophagous + neck retraction + hardness + evasiveness + neck ratio | 0.229 | skull size | 0.034 | 2.499 | 2.788 | **0.004** | **0.009** |
| | | suction | 0.028 | 2.052 | 2.194 | **0.015** | **0.017** |
| | | durophagous | 0.032 | 2.354 | 2.511 | **0.007** | **0.012** |
| | | neck retraction | 0.054 | 4.04 | 3.881 | **0.001** | **0.007** |
| | | hardness | 0.023 | 1.74 | 1.835 | **0.037** | **0.037** |
| shape ~ skull size + aquatic feeding + suction + durophagous + neck retraction + hardness + evasiveness + neck ratio |
|---|---|---|---|---|---|---|
| skull size | aquatic feeding | suction | durophagous | neck retraction | hardness | evasiveness | neck ratio |
| 0.033 | 0.024 | 0.026 | 0.032 | 0.054 | 0.023 | 0.024 | 0.029 |
| 2.506 | 1.829 | 1.965 | 2.415 | 4.11 | 1.713 | 1.846 | 2.197 |
| 2.801 | 1.855 | 2.039 | 2.517 | 3.866 | 1.767 | 2.072 | 2.714 |
| 0.004 | 0.029 | 0.023 | 0.007 | 0.001 | 0.037 | 0.015 | 0.004 |
| 0.01 | 0.033 | 0.03 | 0.014 | 0.008 | 0.037 | 0.024 | 0.01 |

| shape ~ skull size + aquatic feeding + suction + durophagous + open swimming + neck retraction + hardness + evasiveness + neck ratio |
|---|---|---|---|---|---|---|---|
| skull size | aquatic feeding | suction | durophagous | open swimming | neck retraction | hardness | evasiveness | neck ratio |
| 0.037 | 0.024 | 0.026 | 0.034 | 0.017 | 0.05 | 0.023 | 0.025 | 0.024 |
| 2.825 | 1.816 | 2.006 | 2.567 | 1.317 | 3.827 | 1.744 | 1.901 | 1.816 |
| 3.059 | 1.859 | 2.101 | 2.731 | 0.958 | 3.545 | 1.807 | 2.139 | 2.089 |
| 0.004 | 0.03 | 0.02 | 0.006 | 0.168 | 0.001 | 0.037 | 0.014 | 0.018 |
| 0.018 | 0.038 | 0.03 | 0.018 | 0.168 | 0.009 | 0.041 | 0.03 | 0.03 |
Table S7. Full results of D-PGLS analyses using the smaller “partial landmark dataset” testing different models of ecomorphological associations of turtle skull shape. These include the “neck ratio” trait as an additional explanatory variable. In all analyses, N = 65. Abbreviations: Df, degrees of freedom; SS, sum of square; MS, mean sum of square; $R^2$, coefficient of determination of the predictor; $F$, F-statistic value; Z, Z-test statistics; P-value, P statistics value, in which numbers in bold denote significance at an $\alpha < 0.05$ level; P-value (FDR), P statistics value corrected using “false discovery rate (FDR)” method; $R^2$ model, coefficient of determination of the whole model (i.e. sum of R²s of individual predictors).

| Model | $R^2$ model | Variable | $R^2$ | F   | Z   | P-value | P-value (FDR) |
|-------|-------------|----------|-------|-----|-----|---------|---------------|
| shape ~ skull size | 0.027 | skull size | 0.027 | 1.737 | 1.445 | 0.078 | 0.078 |
| shape ~ skull size + aquatic feeding | 0.054 | skull size | 0.026 | 1.716 | 1.435 | 0.077 | 0.077 |
| shape ~ skull size + terrestrial feeding | 0.048 | skull size | 0.026 | 1.709 | 1.419 | 0.073 | 0.144 |
| shape ~ skull size + suction | 0.09 | skull size | 0.03 | 2.024 | 1.844 | 0.033 | 0.033 |
| shape ~ skull size + durophagous | 0.083 | skull size | 0.03 | 2.047 | 1.862 | 0.033 | 0.033 |
| shape ~ skull size + herbivory | 0.059 | skull size | 0.028 | 1.831 | 1.569 | 0.062 | 0.062 |
| shape ~ skull size + carnivory | 0.067 | skull size | 0.03 | 1.979 | 1.792 | 0.033 | 0.033 |
| shape ~ skull size + open swimming | 0.063 | skull size | 0.038 | 2.49 | 2.229 | 0.016 | 0.032 |
| shape ~ skull size + neck retraction | 0.069 | skull size | 0.037 | 2.646 | 2.553 | 0.009 | 0.018 |
| shape ~ skull size + hardness | 0.066 | skull size | 0.028 | 1.873 | 1.676 | 0.047 | 0.047 |
| shape ~ skull size + evasiveness | 0.089 | skull size | 0.028 | 1.873 | 1.658 | 0.046 | 0.046 |
| shape ~ skull size + neck ratio | 0.068 | skull size | 0.028 | 1.861 | 1.603 | 0.057 | 0.057 |
| shape ~ skull size + suction + durophagous + herbivory + carnivory + neck retraction + hardness + evasiveness + neck ratio | 0.191 | skull size | 0.024 | 1.811 | 1.637 | 0.053 | 0.115 |
| shape ~ skull size + suction + durophagous + neck retraction + hardness + evasiveness + neck ratio | 0.195 | skull size | 0.028 | 2.125 | 2.024 | 0.02 | 0.035 |
|          | skull size | suction | durophagous | neck retraction | evasioness | neck ratio |
|----------|------------|---------|-------------|----------------|------------|------------|
| shape ~ | 0.24       | 0.024   | 0.043       | 0.001          | 0.024      | 0.113      |
| skull size | 2.058     | 1.956   | 2.022       | 2.009           | 1.898      | 0.915      |
| suction  | 0.027     | 0.024   | 0.049       | 0.037           | 0.032      | 0.017      |
| durophagous | 3.649     | 3.391   | 3.791       | 2.832           | 2.447      | 1.308      |
| neck retraction | 2.774   | 2.704   | 2.774       | 2.613           | 2.362      | 1.101      |
| evasioness | 0.043     | 0.043   | 0.043       | 0.035           | 0.028      | 0.114      |
| neck ratio | 1.46      | 1.189   | 3.235       | 3.215           | 2.101      | 0.016      |

**shape ~ skull size + suction + durophagous + neck retraction + evasioness**

|          | skull size | suction | durophagous | neck retraction | evasioness | neck ratio |
|----------|------------|---------|-------------|----------------|------------|------------|
| shape ~ | 0.022      | 0.022   | 0.047       | 0.008          | 0.022      | 0.178      |
| skull size | 2.113     | 2.022   | 1.797       | 1.308           | 2.009      | 1.898      |
| suction  | 0.028     | 0.024   | 0.05        | 0.017           | 0.039      | 0.035      |
| durophagous | 3.791     | 3.539   | 2.832       | 2.447           | 2.374      | 1.308      |
| neck retraction | 2.774   | 2.704   | 2.774       | 2.613           | 2.362      | 1.101      |
| evasioness | 0.032     | 0.032   | 0.032       | 0.035           | 0.028      | 0.114      |
| neck ratio | 1.308     | 1.189   | 3.235       | 3.215           | 2.101      | 0.016      |

**shape ~ skull size + suction + durophagous + neck retraction + neck ratio**

|          | skull size | suction | durophagous | neck retraction | neck ratio |
|----------|------------|---------|-------------|----------------|------------|
| shape ~ | 0.033      | 0.033   | 0.001       | 0.002          | 0.016      |
| skull size | 2.009     | 1.898   | 2.009       | 1.987           | 1.898      |
| suction  | 0.027     | 0.039   | 0.047       | 0.035           | 0.028      |
| durophagous | 3.498     | 3.336   | 2.874       | 2.613           | 2.062      |
| neck retraction | 2.797   | 2.797   | 2.797       | 2.595           | 2.101      |
| neck ratio | 0.028     | 0.016   | 0.016       | 0.016           | 0.114      |
Table S8. Phylogenetic regression model \((N = 76)\) used to predict the “evasiveness index” for fossil turtles. Abbreviations: \(\lambda\), phylogenetic signal (Pagel’s lambda) of residuals estimated as part of the model-fitting process; \(R^2\), coefficient of determination of the model; \(SE\), standard error of coefficient values; \(t\)-value, \(t\)-test statistics; \(p\)-value, significance at an \(\alpha < 0.05\) level; \(AICc\), scores of Akaike Information Criterion for small samples.

| Model                                      | \(\lambda\) | \(R^2\) | AICc | Variable          | Coefficient | SE   | t-value | p-value |
|--------------------------------------------|--------------|---------|------|-------------------|-------------|------|---------|---------|
| evasiveness ~ skull size + durophagy + neck retraction | 0.88         | 0.41    | -8.04| (Intercept)       | 0.40        | 0.13 | 3.03    | < 0.01  |
|                                            |              |         |      | skull size        | -322.88     | 44.94| -7.18   | < 0.001 |
|                                            |              |         |      | durophagy         | 270.56      | 36.49| 7.41    | < 0.001 |
|                                            |              |         |      | neck retraction   | 214.16      | 38.88| 5.5     | < 0.001 |
**Table S9.** Posterior probabilities calculated for extant turtle taxa using pFDA based on the topology of Evers et al. (2019). Numbers in **bold** indicate species misclassified as “absent”, whereas asterisks (*) after numbers indicate species misclassified as “present” for a given trait.

| Taxon                          | Suction | Durophagous | Neck_retraction |
|--------------------------------|---------|-------------|-----------------|
| Rhinoclemmys pulcherrima        | 0.47    | 0.01        | 0.79            |
| Rhinoclemmys melanosterna       | 0.24    | 0.05        | 0.73            |
| Melanochelys trijuga            | 0.51    | 0           | 0.89            |
| Mauremys leprosa                | 0.36    | 0.07        | 0.85            |
| Cuora flavomarginata            | 0.47    | 0.16        | 0.62*           |
| Cuora amboinensis               | 0.4     | 0.01        | 0.82            |
| Cyclemys dentata                | 0.3     | 0.03        | 0.88            |
| Hieremys annandali              | 0.27    | 0.12        | 0.7             |
| Heosemys grandis                | 0.34    | 0.02        | 0.56*           |
| Notochelys platynota            | 0.24    | 0.11        | 0.37*           |
| Malayemys subtrijuga            | 0.12    | 1           | 0.54*           |
| Orlitia borneensis              | 0.2     | 0.26        | 0.53*           |
| Geoclemys hamiltonii            | 0.06    | 0.77        | 0.26*           |
| Pangshura tecta                 | 0.3     | 0.18        | 0.79            |
| Batagur baska                   | 0.16    | 0.89*       | 0.5*            |
| Morenia ocellata                | 0.14    | 0.72*       | 0.67            |
| Siebenrockiella crassicollis    | 0.31    | 0.01        | 0.66*           |
| Malacochersus tornieri          | 0.36    | 0.02        | 0.73            |
| Testudo marginata               | 0.32    | 0.03        | 0.72            |
| Chelonoidis nigrum              | 0.37    | 0.01        | 0.86            |
| Chelonoidis carbonaria          | 0.05    | 0.12        | 0.74            |
| Aldabrachelys gigantea          | 0.27    | 0           | 0.59*           |
| Gopherus flavomarginatus        | 0.39    | 0.02        | 0.89            |
| Gopherus polyphemus             | 0.15    | 0.02        | 0.53*           |
| Gopherus agassizii              | 0.34    | 0.02        | 0.89            |
| Platysternon megacephalum       | 0.12    | 0.64        | 0.12            |
| Glyptemys insculpta             | 0.24    | 0.52        | 0.66*           |
| Glyptemys muhlenbergii          | 0.19    | 0.08        | 0.86            |
| Emys orbicularis                | 0.13    | 0.11        | 0.65*           |
| Emydoidea blandingii            | 0.77    | 0.09        | 0.94            |
| Terrapene ornata                | 0.13    | 0.17        | 0.78            |
| Terrapene coahuila              | 0.14    | 0.22        | 0.64*           |
| Clemmys guttata                 | 0.1     | 0.07        | 0.76            |
| Deirochelys reticularia         | 0.91    | 0.03        | 0.97            |
| Trachemys scripta               | 0.33    | 0.06        | 0.74            |
| Graptemys geographica           | 0.24    | 0.83        | 0.8             |
| Malaclemys terrapin             | 0.34    | 0.76        | 0.84            |
| Chrysemys picta                 | **0.53**| 0.04        | 0.9             |
| Pseudemys concinna              | 0.27    | 0.1         | 0.89            |
| Dermochelys coriacea            | **0.01**| 0.01        | 0.64            |
| Caretta caretta                 | 0.01    | 0.97        | 0.02            |
| Lepidochelys olivacea           | 0.02    | **0.59**    | 0.14            |
| Lepidochelys kempii             | 0.01    | 0.84        | 0.3             |
| Species                          | Value1 | Value2 | Value3 |
|---------------------------------|--------|--------|--------|
| Eretmochelys imbricata          | 0.01   | 0.99   | 0.44   |
| Chelonia mydas                  | 0.05   | 0.82*  | 0.56   |
| Natator depressus               | 0.04   | 0.76*  | 0.46   |
| Macrochelys temminckii          | 0.15   | 0.96*  | 0.03   |
| Chelydra serpentina             | 0.93*  | 0.03   | 0.91   |
| Dermatemys mawii                | 0.17   | 0.22   | 0.6*   |
| Staurotypus salvini             | 0.15   | 0.89   | 0.4*   |
| Claudius angustus               | 0.19   | 0.71*  | 0.32*  |
| Sternotherus minor              | 0.03   | 0.98   | 0.3*   |
| Sternotherus odoratus           | 0.09   | 0.58   | 0.34*  |
| Kinosternon subrubrum           | 0.04   | 0.9    | 0.52*  |
| Kinosternon baurii              | 0.05   | 0.85*  | 0.4*   |
| Carettochelys insculpta         | 0.28   | 0.17   | 0.78   |
| Trionyx triunguis               | 0.78   | 0.04   | 0.93   |
| Chitra indica                   | 0.96   | 0.6    | 0.95   |
| Apalone mutica                  | 0.87   | 0.06   | 0.98   |
| Apalone spinifera               | 0.77   | 0.19   | 0.98   |
| Amyda cartilaginea              | 0.83   | 0.11   | 0.96   |
| Pelodiscus sinensis             | 0.89   | 0.12   | 0.99   |
| Cycloderma frenatum             | 0.92   | 0.32   | 0.91   |
| Cyclanorbis senegalensis        | 0.97   | 0.15   | 0.98   |
| Lissemys punctata               | 0.92   | 0.26   | 0.98   |
| Pelomedusa subrufa              | 0.53   | 0.01   | 0.86   |
| Pelusios sinatus                | 0.6    | 0.02   | 0.89   |
| Peltococephalus dumerilianus    | 0.27   | 0.46   | 0.74   |
| Podocnemis expansa              | 0.67*  | 0.22   | 0.85   |
| Podocnemis unifilis             | 0.58   | 0.15   | 0.93   |
| Elseya dentata                  | 0.28   | 0.09   | 0.81   |
| Chelodina oblonga               | 0.84   | 0.04   | 0.97   |
| Hydromedusa tectifera           | 0.96   | 0.01   | 0.99   |
| Chelus fimbriatus               | 0.99   | 0.01   | 0.91   |
| Phrynops hilarii                | 0.79   | 0.01   | 0.92   |
| Phrynops geofroanus             | 0.68   | 0.01   | 0.9    |
| Taxon                        | suction | durophagy | neck retraction |
|-----------------------------|---------|-----------|-----------------|
| Rhinoclemmys pulcherrima    | 0.39    | 0.01      | 0.84            |
| Rhinoclemmys melanosterna   | 0.19    | 0.04      | 0.77            |
| Melanochelys trijuga        | 0.41    | 0         | 0.92            |
| Mauremys leprosa            | 0.27    | 0.06      | 0.88            |
| Cuora flavomarginata        | 0.12    | 0.15      | 0.65*           |
| Cuora amboinensis           | 0.31    | 0.01      | 0.85            |
| Cyclemys dentata            | 0.22    | 0.02      | 0.9             |
| Hieremys annandalii         | 0.17    | 0.11      | 0.73            |
| Heosemys grandis            | 0.25    | 0.01      | 0.61*           |
| Notochelys platynota        | 0.17    | 0.1       | 0.38*           |
| Malayemys subtrijuga        | 0.08    | 1         | 0.55*           |
| Orlitia borneensis          | 0.13    | 0.25      | 0.57*           |
| Geoclemys hamiltonii        | 0.03    | 0.78      | 0.24*           |
| Pangshura tecta             | 0.21    | 0.18      | 0.81            |
| Batagur baska               | 0.09    | 0.9*      | 0.5*            |
| Morenia ocellata            | 0.08    | 0.72*     | 0.66            |
| Siebenrockiella crassicolor | 0.22    | 0.01      | 0.7             |
| Malacochersus tornieri      | 0.26    | 0.02      | 0.75            |
| Testudo marginata           | 0.22    | 0.02      | 0.75            |
| Chelonoidis nigra           | 0.26    | 0.01      | 0.88            |
| Chelonoidis carbonaria      | 0.03    | 0.11      | 0.76            |
| Aldabrachelys gigantea      | 0.16    | 0         | 0.6*            |
| Gopherus flavomarginatus    | 0.25    | 0.02      | 0.91            |
| Gopherus polyphemus         | 0.1     | 0.02      | 0.55*           |
| Gopherus agassizii          | 0.23    | 0.02      | 0.91            |
| Platysternon megacephalum   | 0.09    | 0.64      | 0.11            |
| Glyptemys insculpta         | 0.18    | 0.52      | 0.69            |
| Glyptemys muhlenbergii      | 0.14    | 0.07      | 0.88            |
| Emyrs orbicularis           | 0.1     | 0.1       | 0.68            |
| Emydoidea blandingii        | 0.74    | 0.08      | 0.96            |
| Terrapene ornata            | 0.1     | 0.16      | 0.8             |
| Terrapene coahuila          | 0.11    | 0.21      | 0.67            |
| Clemmys guttata             | 0.07    | 0.06      | 0.79            |
| Deirochelys reticularia     | 0.91    | 0.03      | 0.98            |
| Trachemys scripta           | 0.28    | 0.05      | 0.77            |
| Graptemys geographica       | 0.21    | 0.84      | 0.8             |
| Malaclemys terrapin         | 0.29    | 0.77      | 0.86            |
| Chrysemys picta             | 0.44    | 0.04      | 0.93            |
| Pseudemys concinna          | 0.2     | 0.1       | 0.91            |
| Dermochelys coriacea        | 0.01    | 0.01      | 0.66            |
| Caretta caretta             | 0       | 0.97      | 0.01            |
| Lepidochelys olivacea       | 0.01    | 0.6       | 0.1             |
| Lepidochelys kempii         | 0.01    | 0.85      | 0.23            |
| Species                      | R | S  | I  |   |
|------------------------------|---|----|----|---|
| Eretmochelys imbricata       | 0 | 0.99 | 0.38 |   |
| Chelonia mydas               | 0.02 | 0.82* | 0.5 |   |
| Natator depressus            | 0.02 | 0.76* | 0.42 |   |
| Macrochelys temminckii       | 0.14 | 0.96* | 0.02 |   |
| Chelydra serpentina          | 0.93* | 0.03 | 0.93 |   |
| Dermatemyx mawii             | 0.11 | 0.21 | 0.57* |   |
| Staurotypus salvinii         | 0.09 | 0.89 | 0.39* |   |
| Claudius angustatus          | 0.15 | 0.71* | 0.3* |   |
| Sternotherus minor           | 0.02 | 0.98 | 0.26* |   |
| Sternotherus odoratus        | 0.06 | 0.59 | 0.3* |   |
| Kinosternon subrubrum        | 0.03 | 0.91 | 0.48* |   |
| Kinosternon baurii           | 0.03 | 0.86* | 0.35* |   |
| Carettochelys insculpta      | 0.24 | 0.16 | 0.8 |   |
| Trionyx triunguis            | 0.87 | 0.04 | 0.94 |   |
| Chitra indica                | 0.98 | 0.6 | 0.97 |   |
| Apalone mutica               | 0.93 | 0.05 | 0.98 |   |
| Apalone spinifera            | 0.84 | 0.18 | 0.98 |   |
| Amyda cartilaginea           | 0.9 | 0.11 | 0.97 |   |
| Pelodiscus sinensis          | 0.94 | 0.04 | 0.99 |   |
| Cycloderma frenatum          | 0.96 | 0.32 | 0.92 |   |
| Cyclanorbis senegalensis     | 0.98 | 0.15 | 0.99 |   |
| Lissemys punctata            | 0.95 | 0.25 | 0.98 |   |
| Pelomedausa subrufa          | 0.57 | 0.01 | 0.89 |   |
| Pelusios sinuatus            | 0.64 | 0.02 | 0.92 |   |
| Peltocephalus dumerilianus   | 0.28 | 0.46 | 0.79 |   |
| Podocnemis expansa           | 0.72* | 0.21 | 0.88 |   |
| Podocnemis unifilis          | 0.62 | 0.14 | 0.95 |   |
| Elseya dentata               | 0.32 | 0.08 | 0.84 |   |
| Chelodina oblonga            | 0.89 | 0.04 | 0.98 |   |
| Hydromedusa tectifera        | 0.98 | 0.01 | 1 |   |
| Chelus fimbriatus            | 0.99 | 0.01 | 0.94 |   |
| Phrynops hilarii             | 0.83 | 0 | 0.95 |   |
| Phrynops geoffroanus         | 0.74 | 0.01 | 0.93 |   |
Table S11. Predicted posterior probabilities (PP\text{trait}) of fossils to have ecological/functional traits present in the best D-PGLS model using the “partial extant landmark dataset”. PPs were calculated using pFDA with two different phylogenetic hypotheses: Evers et al. (2019) and Sterli et al. (2018). “Evasiveness” denotes the “food evasiveness index” of extinct turtles predicted with pGLS (see main text and Supplementary Table 4 above).

| Taxon                        | Evers et al. (2019) | Sterli et al. (2018) | Evers et al. (2019) | Sterli et al. (2018) |
|-----------------------------|---------------------|----------------------|---------------------|----------------------|
|                             | suction  | durophy  | neck retraction | suction | durophy | neck retraction | evasiveness |
| Annemys sp.                 | 0.91     | 0.01     | 0.98            | 0.92     | 0.01     | 0.98            | 0.73        |
| Araiochelys hirayamai       | 0.48     | 0.05     | 0.85            | 0.51     | 0.05     | 0.88            | 0.46        |
| Argillochelys antiqua       | 0        | 0.98     | 0.23            | 0        | 0.98     | 0.17            | 0.03        |
| Bairdemys hartsteini        | 0.19     | 0.42     | 0.61            | 0.19     | 0.42     | 0.6             | 0.16        |
| Desmatochelys lowii         | 0.08     | 0.37     | 0.61            | 0.02     | 0.37     | 0.55            | 0.0         |
| Eochelone brabantica        | 0.21     | 0.8      | 0.67            | 0.11     | 0.81     | 0.65            | 0.38        |
| Eubena cephalica            | 0.07     | 0.86     | 0.58            | 0.07     | 0.87     | 0.59            | 0.5         |
| Galianemys emringeri        | 0.61     | 0.1      | 0.65            | 0.67     | 0.1      | 0.68            | 0.36        |
| Jurassichelon oleronensis   | 0.22     | 0        | 0.97            | 0.24     | 0        | 0.97            | 0.66        |
| Labrostochelys galkini      | 0.92     | 0        | 0.99            | 0.93     | 0        | 0.99            | 0.73        |
| Lapparentemys vilavilensis | 0.75     | 0.15     | 0.89            | 0.8      | 0.15     | 0.91            | 0.53        |
| Sahonachelys mailakavava    | 0.98     | 0        | 0.96            | 0.98     | 0        | 0.98            | 0.84        |
| Phosphatochelys tedfordi    | 0.07     | 0.02     | 0.14            | 0.07     | 0.01     | 0.15            | 0.1         |
| Puppigerus camperi          | 0        | 0.99     | 0.39            | 0        | 0.99     | 0.32            | 0.02        |
| Rhinocolyphus pulchriceps   | 0        | 0.92     | 0.64            | 0        | 0.92     | 0.53            | 0.23        |
| Sandownia harrisi           | 0.95     | 0.17     | 1               | 0.96     | 0.16     | 1               | 0.41        |
| Ummulisani rutgersensis     | 0.15     | 0        | 0.49            | 0.14     | 0        | 0.52            | 0.17        |
Other Supplementary Data

**Supporting Information S1.** Spreadsheet including specimen data, size-related, ecological and functional explanatory variables used for analyses.

**Scripts and associated files.** GitHub repository including (i) 3D landmark coordinates information for each specimen used; (ii) Phylogenetic trees in Newick format required for analyses; and (iii) R scripts used to load landmark data, perform geometric morphometric analyses, hypothesis tests, predictions for fossils and graphical visualisation of results. Available at ([https://github.com/G-Hermanson/Turtle-cranial-ecomorphology](https://github.com/G-Hermanson/Turtle-cranial-ecomorphology)).
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