ELECTRONIC APPENDIX

This is the Electronic Appendix to the article

Revised systematics of Palaeozoic 'horseshoe crabs' and the myth of monophyletic Xiphosura

by

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Comprising the morphological character list and character matrix used in the phylogenetic analysis and the full strict consensus tree with branch support

Character list

1. *Cephalization in adult: 1+0 (0); 1+3 (1); 1+5 (2).* In *Fuxianhuia* the head consists solely of the deuterocerebral (antennula) appendage. Most of the non-chelicerate euarthropods in the analysis possess a head incorporating the antennula plus three postantennular appendages. The euchelicerate prosoma consists of the antennula (chelicera) plus five postantennular appendages. Pycnogonids, despite possessing six postantennular appendages that are likely homologous to the appendages in the euchelicerate prosoma, only have three postantennular appendages incorporated into the head region.

2. *Anterior projection from carapace: absent (0); present (1).* The synziphosurines *Legrandella*, *Cyamocephalus* and *Pseudoniscus* all have the prosomal carapace developed into an anterior angular projection, as does *Leanchoilia*. This character is inapplicable for pycnogonids, which do not possess an enlarged dorsal carapace.

3. *Segmentation in cephalon fully expressed: absent (0); present (1).* Pycnogonids, without an enlarged dorsal carapace, retain the dorsal expression of their cephalic segmentation. This character is inapplicable for *Fuxianhuia*, which only incorporates a single segment into the head.

4. *Sagittal crease or keel of tergites of encephalized segments: absent (0); crest or crease (1); keel (2). Fuxianhuia* displays a median crease in its head tergite, as does the carapace of the scorpion *Palaeophonus*. The xiphosurids *Euproops*, *Paleolimulus* and *Limulus* all have the head shield developed into a median keel.

5. *Ancillary eyes: present (0); absent (1).* Ancillary eyes are simple, median eyes found on a number of arthropods. In chelicerates they are termed the ocelli and are incorporated dorsally into the carapace. Simple ancillary eyes are also found in *Fuxianhuia* and *Alalcomenaeus*, where they are positioned between the deuterocerebral appendages. Ancillary eyes absent from *Sidneyia* and *Olenoides*

6. *Ancillary eyes incorporated dorsally into head shield: absent (0); present (1).* The ancillary eyes are incorporated into the dorsal head shield in all chelicerates, where they form the ocelli. This character is inapplicable for taxa without ancillary eyes (character 5).

7. *Unpaired median node: absent (0); between hypostome and doublure (1).* An unpaired median node located ventrally on the cephalic region between the hypostome and doublure is present in *Leanchoilia* and *Alalcomenaeus* as well as *Limulus* and *Paleolimulus* and is absent in the extant arachnids. This character is unknown for the majority of other taxa. In *Limulus* this node bears light-sensitive sense organs.

8. *Lateral eyes: anteroventral (0); dorsal (1); absent (2).* Lateral compound eyes are known from the majority of arthropods in the analysis, although they are absent in pycnogonids, *Galeodes* and potentially *Offacolus* while they are reduced to individual lenses in scorpions and *Mastigoproctus*. In euchelicerates and *Olenoides* the lateral eyes are positioned dorsally on the carapace, while in megacheirans, xenopods and *Fuxianhuia* they are located anteroventrally on stalks.

9. *Visual surface of lateral eyes part of dorsal cuticle of head shield: absent (0); present (1).* The visual surface of the lateral eyes is part of the dorsal cuticle in

chelicerates and trilobites, however in some taxa like *Xandarella* the eyes are incorporated in carapace slits and remain distinct from the carapace cuticle.

10. Eye shaded dorsally by palpebral lobe forming ophthalmic ridge: absent (0); present (1). An ophthalmic ridge is found in most synziphosurines and xiphosurids as well as a number of chasmataspidids including *Octoberaspis*. This character is inapplicable for taxa without dorsal lateral eyes (character 8).

11. Well-developed m-shaped ophthalmic ridge: absent (0); present (1). In xiphosurids the ophthalmic ridges merge anteriorly with the median ridge, forming a double arch shape. This morphology is also seen in *Willwerathia*. This character is inapplicable for taxa without an ophthalmic ridge (character 10).

12. Extraophthalmic ridges: absent (0); present (1). Extraophthalmic ridges are located on the outer regions of the carapace in *Limuloides* and *Bunodes*. This character is inapplicable for pycnogonids.

13. Interophthalmic ridges: absent (0); present (1). Interophthalmic ridges are located on the inner regions of the carapace and are present in *Euproops*, *Weinbergina*, *Venustulus*, *Camanchia* and *Legrandella*. This character is inapplicable for pycnogonids.

14. Marginal rim: absent (0); independent of doublure (1); congruent with doublure (2). A marginal rim congruent with the doublure is seen in *Olenoides*. Euchelicerates possess a marginal rim independent of the doublure, with the exception of *Offacolus*, *Weinbergina*, *Venustulus* and *Camanchia*, which lack a marginal rim.

15. Extensive (>10% of width of head shield) doublure in headshield: absent (0); present (1). An extensive doublure in the head is absent in xenopods and arachnids. This character is inapplicable for pycnogonids.

16. Transverse suture on cephalic doublure: absent (0); present (1). A transverse suture on the cephalic doublure is present in stylonurine eurypterids. This character is inapplicable for taxa without a doublure (character 15).

17. Connective sutures on cephalic doublure: paired (0); single median (1); absent (2). Paired connective sutures on the doublure are present in *Fuxianhuia*, *Olenoides*, *Alalcomenaeus* and *Stoermeropterus*. Connective sutures are absent in xiphosurids and synziphosurines where known. This character is inapplicable for taxa without a doublure (character 15).

18. Cardiac lobe: absent (0); present (1). A cardiac lobe is present on the carapace in most euchelicerates, with the exception of arachnids and *Offacolus*.

19. Cardiac lobe extends anteriorly beyond posterior half of carapace: absent (0); present (1). The cardiac lobe extends onto the anterior half of the carapace in *Willwerathia*, *Kasibelinurus* and xiphosurids. This character is inapplicable for taxa without a cardiac lobe (character 18).

20. Well-developed H-shaped cardiac lobe: absent (0); present (1). A H-shaped cardiac lobe is present in bunodids, pseudoniscids and *Kasibelinurus*. This character is inapplicable for taxa without a cardiac lobe (character 18).

21. Carapace width: wider than long (0); longer than wide or equal (1). The carapace is longer than wide or of equal width in *Offacolus*, *Pasternakevia*, pseudoniscids, eurypterids, *Octoberaspis* and arachnids. This character is inapplicable for pycnogonids.

22. Vaulted carapace absent (0); present (1). A vaulted carapace is present in synziphosurines and xiphosurids. This character is inapplicable for pycnogonids.

23. *Vaulted tergopleura of the head completely covering appendages dorsally and laterally: absent (0); present (1).* A carapace with the tergopleura completely covering the cephalic appendages dorsally and laterally is present in xiphosurids. This character is inapplicable for pycnogonids.

24. *Carapace genal spines: absent (0); present (1); reduced cornua (2).* Genal spines are absent in eurypterids and arachnids. The genal spines of *Weinbergina*, *Camanchia*, *Venustulus* and *Bembicosoma* are reduced to blunt cornua. This character is inapplicable for pycnogonids.

25. *Posterior margin of carapace: flat (0); convex (1).* The posterior margin of the carapace is convex in *Cyamocephalus* and *Pseudoniscus*. This character is inapplicable for pycnogonids.

26. *Configuration of fully ventral prehypostomal plate ('rostral plate'): section of doublure (0); complete fusion with doublure (1).* In sampled eurypterids the prehypostomal plate has completely fused with the doublure, with the exception of *Stoermeropterus*. This character is inapplicable for pycnogonids and arachnids, which lack a prehypostomal plate.

27. *Proboscis: absent (0); present (1).* A proboscis is present in pycnogonids.

28. *Presence of a hypostome as sclerotized plate: present (0); absent (1).* The hypostome is present as a sclerotized plate in all taxa except pycnogonids and arachnids.

29. *Composition of prehypostomal sclerite ('rostral plate'): with dorsal portion (0); only ventral ('rostral plate') (1); absent (2).* The prehypostomal sclerite is visible dorsally in *Fuxianhuia* and is completely absent in pycnogonids and arachnids.

30. Number of segments incorporated into sternum: postantennular segments 2–3 (0); postantennular segments 2–4 (1). Limulus incorporates the sternites of postantennular segments 2–4 into the sternum, while other extant chelicerates along with *Eurypterus* incorporate only segments 2–3. This character is inapplicable for *Galeodes*, which lacks a sternum.

31. Total expressed segment count: 28 (0); 15 (1); 17 (2); 16 (3); 13 (4); 10 (5); 12 (6); 19 (7). Eurypterids, chasmataspidids, scorpions and *Mastigoproctus* express seventeen segments. Synziphosurines and xiphosurids, where known, express seventeen, as does *Galeodes*, *Yohoia* and *Olenoides*.

32. Morphology of tergite of sixth postantennular segment: fully expressed (0); anteroposteriorly reduced (1). The tergite of the sixth postantennular segment is at least partially anteroposteriorly reduced in all euchelicerate taxa.

33. Reduced tergite of sixth postantennular segment: retained in reduced form or microtergite (0); complete loss (1). The tergite of somite VII is retained in various stages of reduction in most chelicerates but is completely lost in limulids. This character is inapplicable for taxa without a reduced sixth postantennular tergite (character 32).

34. Form of reduced tergite of sixth postantennular segment: dorsal tergite (0); subsumed under carapace (1). The tergite of somite VII is retained as a dorsal tergite in chasmataspidids and synziphosurines but appears to be subsumed under the carapace in eurypterids. This character is inapplicable for taxa without reduced sixth postantennular tergite (character 32) or that have completely lost the tergite (character 33).

35. Morphology of sternite of sixth postantennular segment: fully expressed (0); narrowing towards centre (1); medially divided (2). The sternite of somite VII is fully expressed in most taxa. In stylonurine eurypterids it is narrowing towards its centre, becoming medially divided in eurypterine eurypterids.

36. Morphology of tergite of seventh postantennular segment: undifferentiated (0); partially reduced (1); macrotergite (2); axially reduced, lateral portions forming free lobes (3). The tergite of somite VIII is partially reduced in eurypterids, *Octoberaspis* and arachnids. In *Limuloides*, *Bunodes*, *Bembicosoma* and *Pasternakevia* it is expanded into a microtergite, which in limulids it is axially reduced with the lateral portions forming the free lobes of the thoracetron.

37. Trilobation of trunk: present (0); absent (1). Trilobation of the trunk is present in all taxa except pycnogonids.

38. Ventral plate underlying tergites: absent (0); present (1). Chasmataspidids have a ventral plate underlying the tergites of the buckler. This character is inapplicable for pycnogonids.

39. Morphological division of trunk: undifferentiated (0); limbless abdomen of segments with ankylosed tergites and sternites retaining tergopleurae (1); reduced abdomen (2). Fuxianhuia has a limbless abdomen of ankylosed segments, as does *Yohoia*, *Sidneyia*, euchelicerates and the pycnogonid *Palaeoisopus*. The remaining pycnogonids have a reduced abdomen.

40. Anterior trunk segments fused into thoracetron: absent (0); segments VIII-XIV (1); segments VII-X (2). Xiphosurids have a thoracetron consisting primarily of trunk segments VIII–XIV while chasmataspidids possess a buckler made up of the first four segments.

41. Pleural groove in anterior tergopleurae: absent (0); present (1). Pasternakevia, *Limuloides*, *Bunodes* and *Kasibelinurus* all have a pleural groove in their anterior tergopleurae. This character is inapplicable for pycnogonids, eurypterine eurypterids, xiphosurids and arachnids where the anterior tergopleurae are either fused or lost.

42. Tergopleurae of anterior tergites: tergopleurae expressed (0); tergopleurae reduced (1). The anterior tergopleurae are reduced in eurypterids and arachnids. This character is inapplicable for pycnogonids.

43. Form of tergopleurae on anterior tergites: angular (pointed termination) (0); quadrate (flat termination) (1). Venustulus and *Camanchia* both have quadrate anterior tergopleurae. This character is inapplicable for pycnogonids and any taxa where the anterior tergopleurae have been reduced (character 42).

44. Caudal abdomen defined by marked taper (undergoes a sudden constriction and then does not narrow further until the telson): absent (0); present (1). A constricted abdomen is present in *Fuxianhuia*, *Rhenopterus* and scorpions. This character is inapplicable for taxa without a limbless abdomen composed of ankylosed segments (character 39).

45. Number of segments in constricted abdomen: 3 (0); 5 (1); 6 (2); 3+10 (3); 1 (4); 2 (5); 9 (6). This character is independent of the number of limbless segments in the abdomen, instead marking the point of dorsal differentiation. Synziphosurines, *Lunataspis*, *Yohoia* and *Mastigoproctus* all have a constricted abdomen of three visible segments (although these segments are fused in *Lunataspis*). *Pasternakevia* and *Kasibelinurus* show only two segments, while in the remaining xiphosurids the abdominal segments have fused into one. Scorpions and most eurypterids have the last five segments constricted. Chasmataspidids exhibit constriction of the last nine segments. This character is inapplicable for taxa without a limbless abdomen composed of ankylosed segments (character 39).

46. Moveable lateral spines associated with opisthosomal segments IX-XIII (postantennular segments 8-15): absent (0); present (1). Moveable lateral spines are present in limulids and the eurypterid *Stoermeropterus*.

47. Somites XV-XVII (postantennular segments 14-16) fused: absent (0); present (1). The segments of somites XV-XVII are fused in xiphosurids.

48. Tergopleurae on posterior tergites other than pretelson: tergopleurae present (0); tergopleurae reduced (1); tergopleurae absent (2). The tergopleurae of the posterior tergites are reduced in *Fuxianhuia*, *Yohoia*, *Sidneyia*, *Chasmataspis*, most eurypterids and the synziphosurines *Legrandella*, *Limuloides*, *Bembicosoma* and *Kasibelinurus.* In *Octoberaspis*, arachnids, *Eurypterus*, *Bunodes*, *Camanchia*, *Venustulus* and the xiphosurids the tergopleurae are absent. This character is inapplicable for pycnogonids.

49. Posterior tergopleurae crescentic, with those of pretelson engulfing the proximal portion of the telson: absent (0); present (1). The posterior tergopleurae are crescentic in *Leanchoilia* and *Alalcomenaeus* as well as *Pasternakevia*, *Pseudoniscus* and *Cyamocephalus*. This character is inapplicable for pycnogonids and any taxa where the posterior tergopleurae are absent (character 48).

50. Main articulating device: anterior axial recess for arthrodial membrane (0); no obvious articulating device (1); articulating ridge and/or shelf functioning with next anterior segment (2); articulating half-ring and furrow (3). Most taxa possess an articulating ridge, however *Olenoides* has true half-rings, *Fuxianhuia* possesses an axial recess, and pycnogonids, *Mastigoproctus* and *Galeodes* show no obvious articulating device.

51. Articulating ridge adaxially projecting as a pseudo-half-ring: absent (0); present (1). The articulating ridge is adaxially projected into a pseudo-half-ring in xiphosurids and *Willwerathia*. This character is inapplicable for any taxa without an articulating ridge (character 50).

52. Articulation of tergopleurae: overlap (0); edge-to-edge (1); gape (2). The tergopleurae of most chelicerates gape laterally, with the exception of *Weinbergina*, *Camanchia*, *Venustulus* and *Offacolus* where they overlap as in most other arthropods. The character is inapplicable for pycnogonids and arachnids where the tergopleurae are reduced.

53. Articulating flanges on tergopleural region: absent (0); present (1). Articulating flanges are present in xiphosurids.

54. Extensive doublure in trunk tergites: absent (0); present (1). Extensive doublure in the trunk tergites is present in *Olenoides*, xiphosurids and chasmataspidids. This character is inapplicable for pycnogonids.

55. Trunk width: narrowing from first segment (0); constant for first few segments (1). Among most synziphosurines and xiphosurids the trunk begins narrowing immediately from the first segment, however in bunodids and pseudoniscids the trunk width remains constant for a number of segments before narrowing, as it does in chasmataspidids, eurypterids and arachnids.

56. Width of axis compared to cardiac lobe: wider, in line with ophthalmic ridges (0); same width as cardiac lobe (1); effaced (2). The axis is effaced in *Willwerathia*, eurypterids and chasmataspidids, and in line with the cardiac lobe in xiphosurids, bunodids and pseudoniscids. In all other taxa the axis corresponds to the position of the ophthalmic ridges. This character is inapplicable for taxa without a cardiac lobe (character 18).

57. *Enlarged axial nodes: present (0); absent (1).* Distinctive, enlarged axial nodes are found on the tergites of most synziphosurines and xiphosurids, as well as *Offacolus*. This nodes are lost in eurypterids, chasmataspidids and arachnids, and are also absent from bunodids and pseudoniscids, with the exception of *Limuloides*. This character is inapplicable for pycnogonids.

58. *Subaxial nodes: absent (0); present (1).* Subaxial nodes are present in *Weinbergina*, *Legrandella*, *Willwerathia*, *Lunataspis* and *Limuloides*. This character is inapplicable for pycnogonids.

59. *Somites XII-XIII fused: absent (0); present (1).* Somites XII–XIII are fused into a diplotergite in *Pseudoniscus* and *Cyamocephalus*. These tergites are also fused as part of the *Offacolus* pygidium and the xiphosurid thoracetron. This character is inapplicable for pycnogonids.

60. *Somites XIII-XIV fused: absent (0); present (1).* Somites XII–XIII are fused into a diplotergite in *Bunodes* and *Limuloides*. These tergites are also fused as part of the *Offacolus* pygidium and the xiphosurid thoracetron. This character is inapplicable for pycnogonids.

61. *Gape in tergopleurae increasing posteriorly: absent (0); present (1).* The lateral gape in the tergopleurae increases posteriorly in pseudoniscids and eurypterids. This

character is inapplicable for taxa that to not exhibit a lateral tergopleural gape (character 52).

62. Antennular articles elongated and as robust than podomeres of anterior endopods: absent (0); present (1). The individual antennular articles of *Yohoia*, *Offacolus*, *Weinbergina* and pycnogonids are elongated. This character is inapplicable for *Pycnogonum* which has reduced chelifores in its adult instar.

63. Number of aspiniferous segments in spiniferous short (6 or less segments) antennula: 1 (0); 2 (1). In megacheirans, pycnogonids and *Offacolus* there are two aspiniferous segments in the antennula. Larval instars of *Pycnogonum*, which retain the chelifores, also show this condition.. This character is inapplicable for taxa without a short antennula.

64. Antennular peduncle: simple (0); bipartite (1). The antennular peduncle is bipartite in megacheirans and pycnogonids. All other taxa possess a simple peduncle. This character is inapplicable for *Pycnogonum* which has reduced chelifores in its adult instar.

65. Number of articles forming fingers on antennula: four (0); three (1); two (2). *Yohoia* has four fingers, *Leanchoilia* and *Alalcomenaeus* three, and all included chelicerates two. This is inapplicable for taxa which do not have the spines on the antennula modified into fingers.

66. Arrangement of spines on antennula: absent (0); biserial (1); mediodistally extended into fingers (2). Megacheirans and chelicerates have an armature of mediodistally extended fingers.

67. Number of antennular articles: 7–20 (0); ≤6 (1); >20 (2). Megacheirans and chelicerates have six or less antennular articles, *Olenoides* and the xenopods have more than twenty.

68. Filiform antennula: absent (0); present (1). A filiform antennula is present in *Olenoides*, *Emeraldella* and *Sidneyia*.

69. Exopod on second post-antennular limb: simple flap-like (0); bilobate flap-like (1); multiarticulate pediform (2); reduced (3). The exopod of somite III is a simple flap in megacheirans, pediform in *Offacolus*, a bilobate flap in *Olenoides*, and reduced in the other euchelicerates. This character is inapplicable for pycnogonids, which have completely reduced all their exopods.

70. Endopod of postantennular limbs 1–4: chela absent (0); chelate (1); subchelate (2). The endopods of pycnogonids are subchelate, while in xiphosurids and *Offacolus* they are chelate.

71. Exopod on postantennular appendages 3–4: present (0); lacking (1). Exopods are lacking in all euchelicerates except *Offacolus*. This character is inapplicable for pycnogonids, which have completely reduced all their exopods.

72. Terminal podomere of endopod: conical podomere (0); spinose podomere (1). The terminal endopod podomere is conical in *Fuxianhuia* and pycnogonids and spinose in all other taxa.

73. Terminal podomere of fifth postantennular limb: prong-like or blunt (0); chelate (1); part of pusher (2); subchelate (3). The terminal podomore of the endopod of somite VI is subchelate in pycnogonids, chelate in *Offacolus* and *Chasmataspis*, part of a pusher in *Limulus* and *Paleolimulus*, and prong-like or blunt in all other taxa.

74. Exopod of fifth postantennular limb: as in postantennular limbs 3–n (0); flabellum (1); absent (2). The exopod of somite VI is absent in most chelicerates where known, but forms the flabellum in *Offacolus*, xiphosurids and possibly *Chasmataspis*. This character is inapplicable for pycnogonids, which have completely reduced all their exopods.

75. Basipod of fifth postantennular limb expanded into dorsal 'ear': absent (0); present (1). The basipod (or coxa in traditional chelicerate terminology) of the sixth appendage in eurypterine eurypterids in dorsally expanded into an 'ear'. This may represent the remnants of the exopod. This character is inapplicable in *Fuxianhuia* as the dorsal region of the proximal podomere is disconnected from the exopod.

76. Modified spine (podomere 7a) at the distal part of the 'basitarsus' of fifth postantennular limb: absent (0); present (1). A podomere 7a is found only in eurypterine eurypterids.

77. Form of sixth postantennular limb: pediform (0); reduced, masticatory function (1); flap-like (2). The sixth postantennular limb is pediform in the majority of arthropods, including *Weinbergina*. In *Offacolus* it is large and flap-like, while in xiphosurids and the other euchelicerates it is reduced.

78. Fusion of sixth postantennular limbs: absent (0); present (1). In eurypterids and chasmataspidids the sixth postantennular limbs are fused to form the metastoma.

79. Limb-bearing segments enclosed by fully sclerotized rings: absent (0); fusion product of tergites, sternites, limb-bases (1). In pycnogonids all limb-bearing segments are fully enclosed within sclerotized rings, while other arthropods retain a separate tergite and sternite.

80. Body-limb joint: short, sclerotized, pivot-jointed rings (0); lightly sclerotized rings or half-rings in arthrodial membrane ['corm'] (1); arthrodial membrane only (2). The body-limb joint for *Fuxianhuia* and *Palaeoisopus* consists of sclerotized pivot-jointed rings, while in the megacheirans, *Olenoides* and *Emeraldella* the joint consists of a series of lightly sclerotized half-rings in arthrodial memberane. In the remaining taxa the joint consists of arthrodial membrane only when known.

81. Basipod with elongate lateroproximal extension: absent (0); present (1). The basipod is extended dorsally into an elongate lateroproximal process in *Sidneyia*, *Limulus* and *Paleolimulus*. This character is inapplicable in *Fuxianhuia* as the dorsal region of the proximal podomere is disconnected from the exopod.

82. Endites on basipod: absent (0); single, medially drawn out endite (1); multiple endites [four to five] (2). Pycnogonids, *Emeraldella* and *Fuxianhuia* lack any endites on the proximal podomere. *Olenoides*, *Sidneyia* and the euchelicerates possess a single, medially drawn out endite; the remaining arthropods bear multiple endites.

83. Endites on basipod of first postantennular limb: absent (0); present (1). The euchelicerates have an enditic basipod for limb II, in contrast to the other arthropods in the analysis. This character is inapplicable for taxa that do not possess any basipod endites (character 82).

84. Insertion of endopod on basipod: distally (0); laterally (1). The endopods of the majority of taxa insert distally on the basipod; the exceptions are eurypterids, chasmataspidids and arachnids, the prosomal limbs of which insert laterally. This character is inapplicable in *Fuxianhuia* as the dorsal region of the proximal podomere is disconnected from the exopod so there is no way to resolve the orientation of the limb insertion.

85. Moveable endite (epicoxa) dorsally on gnathal edge of basipod of prosomal appendages: absent (0); present (1). An epicoxa is present in *Eurypterus* and *Limulus* and absent in all other taxa where known. This character is inapplicable in *Fuxianhuia*.

86. Maximum number of endopod podomeres: nine (0); eight (1); seven (2); six (3). Endopod podomere count does not include the basipod but does include the terminal spine. Megacheirans possess ten endopod podomeres, eurypterids eight. Arachnids, chasmataspidids and *Weinbergina* share seven podomeres with the xenopods and *Olenoides*. The xiphosurids only possess six podomeres. The podomere count in pycnogonids is uncertain as it is not clear how many podomores have fused with the body segments. This character is inapplicable in *Fuxianhuia* as it is unclear whether the basipod would be homologous to the first proximal podomere or whether the exopod and endopods fuse behind this to form a new distinct unit; without knowing this it is impossible to be sure that homologous podomeres are being included in the count.

87. First podomere with gnathal edge: absent (0); present (1). The first podomere bears a gnathal edge in *Olenoides*, the xenopods and *Limulus*. This character is inapplicable in *Fuxianhuia* as it is unclear whether the basipod would be homologous to the first proximal podomere or whether the exopod and endopods fuse behind this to form a new distinct unit; without knowing this it is impossible to be sure that homologous podomeres are being included in the count.

88. Armature on distal margin of podomeres other than distal spines: absent (0); fringe of bristles (1); denticles (2). Megacheirans have a fringe of bristles around the distal margin of their podomeres, while eurypterids bear denticles in this position.

89. Presence of mediodistal spines on podomeres: absent (0); present (1). Mediodistal spines are present on the podomeres of most taxa, but are absent in *Fuxianhuia*, *Pycnogonum*, *Euproops*, *Limulus*, *Mastigoproctus* and *Galeodes*.

90. Reduction of mediodistal spines on podomeres: not reduced (0); reduced on postantennular limbs 4 and 5 (1); reduced on postantennular limbs 3, 4, and 5 (2). *Eurypterus* and *Parastylonurus* have the mediodistal spines on limbs V and VI reduced, while *Stoermeropterus* and *Rhenopterus* show reduction on limbs IV, V and VI. All other arthropods show no reduction. This character is inapplicable for taxa lacking mediodistal spines (character 89).

91. Presence of laterodistal spines on podomeres: absent (0); present (1). Laterodistal spines are present in *Sidneyia*, *Olenoides* and the pycnogonids.

92. Laterodistal spines on podomeres: present on all podomeres (0); on non-enditic or two penultimate podomeres only (1). Laterodistal spines are present only on non-enditic podomeres in *Olenoides* and *Sidneyia*. This character is inapplicable for taxa lacking laterodistal spines (character 91).

93. Morphology of distal spines on podomeres: socketed (seta type) (0); projections of podomeres (1). The distal spines are socketed in most taxa but projections of the podomeres in *Pycnogonum*, *Stoermeropterus* and *Rhenopterus*. This character is inapplicable for taxa lacking either laterodistal or mediodistal spines (characters 89 and 91).

94. Spines or endites on median edges of podomeres other than the first: absent (0); present (1). Spines or endites on the succeeding podomeres are present in *Emeraldella*, *Sidneyia*, *Olenoides*, *Haliestes* and *Palaeoisopus*.

95. Gradual change of stance of endopods from splayed anteriorly to dangling posteriorly: absent, all limbs dangling (0); rotation in proximal podomeres (1); rotation in basipod insertion (2); absent, all limbs splayed (3). There is no differentiation in megacheirans or chelicerates, which are coded based on their opisthosomal appendages. *Emeraldella* shows rotation in the proximal podomeres, while in *Olenoides* it is the basipod insertion that rotates.

96. Reduction of count of podomere in first postantennular limb: absent (0); present (1). Emeraldella, *Pycnogonum*, *Haliestes*, xiphosurids, eurypterids and arachnids all show a reduction in podomere count of appendage II. This character is inapplicable for *Fuxianhuia*.

97. Podomere count in endopod of first postantennular limb compared to max count in limbs: n-1 (0); n-2 (1); n-n (2); n-3–4 (3). The limb in *Haliestes* is reduced by two podomeres as is the limb in eurypterids, while the limb in *Pycnogonum* is completely lost. Xiphosurids and scorpions lose a single podomere; *Galeodes* and *Mastigoproctus* each lose three or four podomeres. This character is inapplicable for taxa that show no reduction in podomere count (character 96).

98. Exopods: present (0); absent (1). Exopods are present in all taxa except pycnogonids. Euchelicerates retain exopods in their opisthosomal limbs, and are thus coded as being present.

99. Exopod armature other than lamellae: none (0); setae or spines (1). Only arachnids possess no armature on their exopods. This character in inapplicable for taxa without exopods (character 98).

100. Exopod of first postantennular limb: simple flap-like (0); multiarticulate, pediform (1); reduced (2). The exopod of somite II is a simple flap in *Alalcomenaeus*, pediform in *Offacolus*, and reduced in the other euchelicerates and *Leanchoilia*. This character is inapplicable for pycnogonids, which have completely reduced all their exopods.

101. Podomere count in endopod of second postantennular limb reduced compared to max count in limbs: not reduced (0); reduced (1). The second postantennular limb is reduced in limulids, eurypterids, *Galeodes* and *Mastigoproctus*. This character is inapplicable for *Fuxianhuia*.

102. Second postantennular appendage modified into ovigers: absent (0); present (1). Ovigers are found only in pycnogonids.

103. Trunk limb medial fusion: separate (0); medially fused (1). The trunk limbs are medially fused in chasmataspidids, eurypterids and arachnids. This character is inapplicable for pycnogonids.

104. Eighth postantennular limb fused with limb of genital segment (7th postantennular limb): absent (0); present (1). The limbs of somites VIII and IX are fused in eurypterids. This character is inapplicable for pycnogonids.

105. Endopods or limb axis of seventh to thirteenth postantennular limbs: present on all segments (0); present on seventh only (1); absent on all segments (2). Endopods are generally present on all trunk limb segments. Exceptions are chasmataspidids and eurypterids, where only the limb of somite VIII is present, and arachnids where all limbs are reduced. This character is inapplicable for pycnogonids.

106. Endopods or limb axis of seventh postantennular limbs fused medially into genital appendage: separate (0); fused (1). The endopods of somite VIII are fused into a genital appendage in chasmataspidids and eurypterids. This character is inapplicable for taxa where the endopod is reduced (character 105).

107. Gross morphology of exopods of postcephalic appendages: simple flap-like (0); bilobate flap-like (1). The exopods of *Olenoides* and *Emeraldella* are bilobate. This character is inapplicable for pycnogonids.

108. Lamellar blades on exopod: absent (0); present (1). Lamellar blades are present on the exopods of *Sidneyia*, *Emeraldella* and *Olenoides*. This character is inapplicable for pycnogonids.

109. Structure of caudal appendages: uniramous paddle (0); filiform cerci (1); absent (2). The caudal appendages are absent from most taxa, but in *Olenoides* they form filiform cerci and are uniramous paddles in *Fuxianhuia*, *Sidneyia* and *Emeraldella*.

110. Form of telson: plate-like (0); styliform keeled (with triangular cross-section) (1); flagelliform (2); expanded with venom sack (3); styliform tubular (with circular or oval/flat cross-section) (4); reduced (5). The telson is plate-like in *Fuxianhuia*, megacheirans , *Sidneyia* and *Olenoides*. It is expanded with a venom sack in scorpions, and styliform with a flat cross-section in *Emeraldella*. The remaining chelicerates possess a styliform telson with a triangular cross section with the exception of *Mastigoproctus*, which has a flagelliform telson and *Haliestes*, *Pycnogonum* and *Galeodes*, which have a reduced telson.

111. Telson fused with terminal segment (pretelson): absent (0); present (1). The telson is fused to the pretelson in *Olenoides* and *Palaeoisopus*. This character is inapplicable for taxa in which the telson is reduced (character 110).

112. Telson with joints along its length: absent (0); present (1). Emeraldella possesses a jointed telson that retains its styliform shape and therefore is not flagelliform. *Offacolus* also has at least one joint along its telson. This character is inapplicable for taxa in which the telson is reduced (character 110).

113. Cuticular terrace lines: absent (0); present (1). Cuticular terrace lines are present in *Stoermeropterus*, *Eurypterus* and *Olenoides*, however their absence in other taxa may be preservational.

114. Tuberculate ornamentation: absent (0); present (1). Bembicosoma and *Bunodes* possess a distinct ornament of dense, peg-like tubercles that are unlike the pustulation seen in other taxa.

Character matrix

Taxon		10		20		30		40		50		60
		70		80		90		100		110		
Fuxianhuia protensa	00-10	0?00-	-0001	000--	00000	0000?	00--?	00010	00013	00100	-0001	-1000
	-0-0-	000?0	?0??-	?0000	-0---	--00-	0--0?	--0??	-0000	00000	0000	
Leanchoilia illecebrosa	1100?	?100-	-0001	0?0--	00000	??0??	10--?	00000	000--	00012	000?1	-1000
	00111	21000	0100?	00001	02?00	00110	0-?00	??012	?0000	000?0	00?0	
Alalcomenaeus cambricus	10000	0100-	-0001	000--	00000	0001?	10--?	00000	000--	00?1?	?0001	-1000
	00111	21000	0100?	00001	02?00	00110	0-000	??010	00000	00020	0000	
Yohoia tenuis	1000?	??00-	-00?0	--0--	00000	?????	20--?	00010	00000	00102	02001	-1000
	-1110	21000	0100?	?0?0?	???0?	???10	0-0?0	??01?	?0000	00020	00?0	
Emeraldella brocki	?0001	-??0-	-0000	--0--	00000	?001?	30--?	00000	000--	00002	00001	-1000
	00-0-	121?0	01000	00001	00000	21010	0-011	1?01?	?0000	01104	01?0	
Sidneyia inexpectans	?0001	-000-	-0000	--0--	00000	?0???	40--?	00010	00000	00102	00001	-1000
	-0-0-	121?0	?1000	00002	11?00	21010	11013	??01?	??000	00100	00?0	
Olenoides serratus	10001	-0111	00021	000--	00010	0001?	20--0	00000	000--	00003	-1111	-1000
	00-0-	02110	01000	00001	01000	21010	11012	0-01?	00000	01110	1010	
Pycnogonum litorale	1-100	1020-	---0-	--0--	-----	-1120	50--0	01-20	---0-	00--1	--0--	-----
	--0-1	210-2	-03-0	00012	?00?0	?000-	10103	121--	01---	----5	--00	
Haliestes dasos	1-10?	??20-	---0-	--0--	-----	-112?	50--0	01-20	---0-	00--1	--0--	-----
	-1112	210-2	-03-0	0001?	?0??0	?0???	10013	101--	01---	----5	--?0	
Palaeoisopus problematicus	1-100	1?20-	---0-	--0--	-----	-112?	60--0	01-10	---01	00--1	--0--	-----
	-1112	210-2	-03-0	00011	?00?0	?0010	10013	0-1--	?1---	---21	10?0	

Offacolus kingi	2002?	??20-	-000?	??0-0	10010	?0?1?	11??0	00010	0000?	0-00?	?0??0	-0011
	01102	21021	01110	0200?	?????	?????	????0	??0?1	?000?	0002?	01?0	
Weinbergina opitzi	2000?	????1	00101	0?100	01020	???1?	21???	00010	00000	00002	000?0	00100
	01?02	21?30	110??	0000?	0110?	2??10	????0	0-012	00?0?	00021	00?0	
Camanchia grovensis	2000?	?????	?0101	02100	01020	???1?	?????	00010	00100	002-2	00000	01000
	-000?	?????	?????	?1?0?	?????	?????	?????	?????	?????	?????	0??0	
Venustulus waukeshaensis	20000	1???1	00101	0??00	01020	???1?	?????	00010	00100	002-2	00?00	01000
	-000?	???3?	1????	01?0?	?????	?????	????0	????2	???0?	????1	00?0	
Willwerathia laticeps	?0000	1???1	1001?	??110	0??10	???1?	?100?	00010	00000	00002	12000	20100
	0????	?????	?????	???0?	?????	?????	?????	?????	?????	????1	0000	
Legrandella lombardi	?1000	1?111	00111	0?100	01?20	?0???	2100?	00010	00000	00102	02000	00100
	0????	?????	?????	?????	?????	?????	?????	?????	?????	???21	00?0	
Bembicosoma pomphicus	?000?	?????	?001?	??101	01?20	?????	?100?	20?10	00000	0010?	020?1	01000
	0????	?????	?????	?????	?????	?????	?????	?????	?????	????1	00?1	
Bunodes lunula	?000?	1????	?100?	??101	01?10	?????	?100?	20?10	10000	002-2	020?1	01001
	-????	?????	?????	?????	?????	?????	?????	?????	?????	????1	00?1	
Limuloides limuloides	?0000	1???1	0101?	??101	01?10	?????	21???	20010	10000	00102	020?1	00101
	0????	?????	?????	?????	?????	?????	?????	?????	?????	????1	00?0	
Pasternakevia podolica	?000?	?????	?001?	??101	11?10	?????	?100?	20010	10005	0?012	020?1	01000
	0????	?????	?????	?????	?????	?????	?????	?????	?????	????1	00?0	
Cyamocephalus loganensis	?1000	??111	000??	??101	11?11	?????	?1???	00010	00000	00012	020?1	01010
	1????	?????	?????	?????	?????	?????	?????	?????	?????	????1	00?0	
Pseudoniscus roosevelti	?100?	????1	0001?	??101	11?11	?????	?1???	00010	00000	0001?	020?1	11010
	1????	?????	?????	?????	?????	?????	?????	?????	?????	????1	00?0	

Kasibelinurus amicorum	?000?	??111	0001?	??111	01?10	?????	?1???	00010	10005	00102	020?0	10000
	0????	?????	?????	?????	?????	?????	?????	?????	?????	????1	00?0	
Euproops anthrax	20020	1?111	10111	0?110	01110	?0?1?	21???	00011	-00-4	01002	12?10	10011
	-0?0?	??031	11?1?	0??0?	?????	???0-	0--0?	????2	?0???	???21	0000	
Lunataspis aurora	?0000	1?111	?001?	??110	01110	???1?	?1???	00?11	-0000	012-2	121?0	10111
	-????	?????	?????	???0?	?????	?????	?????	?????	?????	????1	00?0	
Limulus polyphemus	20020	11111	10011	02110	01110	10011	211-0	30011	-00-4	112-2	12110	10011
	-0002	21031	11211	01002	11101	3100-	0--00	10012	10000	00021	0000	
Paleolimulus signatus	2002?	?1111	10111	02110	01110	?0?11	211-0	30011	-00-4	112-2	12110	10011
	-0?0?	??031	11211	0100?	1????	3????	????0	100?2	10?0?	00021	0000	
Stoermeropterus conicus	2000?	??110	-0011	00100	10000	0001?	71??2	10010	-1-01	10102	02001	21000
	10?02	21030	11021	11102	0111?	10?12	0-100	110?2	10111	10021	0010	
Eurypterus	20000	1?110	-0011	01100	10000	10010	71012	10010	-1-01	002-2	0-0-1	21000
tetragonophthalmus	-0002	21030	11021	11102	01111	10211	0-000	11012	10111	10021	0010	
Rhenopterus diensti	20000	1?110	-0011	11100	10000	1001?	71??1	10010	01-12	00102	02001	21000
	10?02	21030	11020	01102	0111?	10?12	0-100	110?2	10111	10021	0000	
Parastylonurus ornatus	2000?	??110	-0011	11?00	10000	1001?	71??1	10010	01-01	00102	02001	21000
	10?02	21030	11020	0110?	0111?	10211	0-000	1?0?2	?0111	10021	00?0	
Chasmataspis laurencii	?0000	1?11?	?00??	??100	00?10	?????	7100?	?0112	00006	00102	?-0?1	?1000
	1????	?????	??111	0??0?	01?1?	2000-	0--0?	??0??	?????	???2?	00?1	
Octoberaspis ushakovi	20000	1?111	000?1	0?100	10010	?????	71000	10112	00006	002-2	0-011	21000
	-????	????0	?10??	1110?	?????	??00-	0--00	??0??	?0101	10?21	0001	
Centruroides vittatus	20000	10110	-0010	--0--	10000	-0120	71010	10010	-1-11	002-2	0-0-1	-1000
	-0002	21030	11020	01102	0001?	20010	0-000	10002	00102	-0023	0000	

Palaeophonus nuncius	20010	1?110	-00?0	--0--	10000	?0???	7???0	10?10	-1-11	002-2	0-0-1	-1000
	-0?02	21?30	110??	01?0?	?????	2?010	0-000	100?2	00102	-0023	0000	
Mastigoproctus giganteus	20000	10110	-0010	--0--	10000	-0120	7???0	10010	-1-00	002-1	0-0-1	-1000
	-0002	21030	11020	01102	0001?	2000-	0--00	13002	10102	-0022	0100	
Galeodes armeniacus	[1,2]0000	1020-	-0010	--0--	10000	-012-	2???0	10010	-1-0?	002-1	0-0-1	-1000
	-0002	21030	11020	0??02	0001?	2000-	0--00	13??2	10??2	-??25	--00	

Supplementary figure 1:
Strict consensus of 12 most parsimonious trees. CI = 0.580, RI = 0.768, RC = 0.445. Numbers beneath the nodes are Bremer support values. Jacknife values (33% deletion, 1000 repetitions) are shown above the nodes with Bootstrap values (50% deletion, 1000 repetitions) shown in parentheses.