Supplemental Material

CBE—Life Sciences Education

Schramm *et al.*

Item	Skill level	Item Discrimination	Item Difficulty	Item Outfit	Item Infit
A1	1	.332	0.083	0.990	0.988
A2	1	.142	-0.583	1.158	1.094
A3	2	.318	-1.325	0.833	0.912
A4	2	.274	-0.363	1.041	1.013
A5	3	.342	-0.321	0.964	0.980
A6	3	.164	0.477	1.131	1.093
A7	1	.263	-0.337	1.021	1.028
A9	4	.319	0.796	1.027	0.989
A10	2	.225	-0.166	1.075	1.056
A11	2	.455	-1.555	0.749	0.874
A12	3	.371	-0.543	0.926	0.965
A13	3	.378	-0.402	0.941	0.960
A14	4	.278	1.287	1.052	0.989
B1	1	.236	1.222	1.053	1.027
B2	1	.299	0.262	1.003	0.998
B3	2	.408	-0.999	0.864	0.919
B4	2	.148	0.168	1.153	1.112
B5	3	.297	-0.532	0.999	1.016
B6	4	.257	1.217	1.038	1.017
B7	3	.234	1.487	1.078	1.009
B8	1	.355	1.577	0.914	0.951
B9	1	.095	-0.174	1.193	1.159
B10	2	.392	-0.765	0.907	0.928
B11	2	.432	-1.382	0.824	0.897
B12	3	.408	-0.726	0.885	0.932
B14	4	.253	0.817	1.062	1.013
M		.295	-0.030	0.995	0.997
SD		.094	0.908	0.111	0.068
Min		.095	-1.555	0.749	0.874
Max		.432	1.577	1.193	1.159

Color coding: red = unscientific argumentation and wrong answer chosen
orange = correct argumentation and wrong answer chosen
yellow = unscientific argumentation and correct answer chosen
green = correct argumentation and correct answer chosen

Interview A-H	Identifying structures (A1 / B2)	Handling apomorphies (A10 / B3)	Determining monophyletic groups (A12 / B12)	Identifying relationships (A6 / B7)	Comparing trees (A9 / B6)
A	Internal nodes represent mutations mutation	Track apomorphies from terminal nodes backwards	Identify monophyletic groups by arguing with MRCA and naming all descendants	Number of internal nodes between groups is counted to determine relationship	Rationale is based on MRCA, rotation of nodes is stated as having no influence
B	Different internal nodes are attributed with different meaning	Apomorphy on the last bifurcation event (eusociality in termites) is attributed to both sister groups	No rationale given	Order of terminal nodes represents relationship	Rationale only based on comparison of apomorphies
C	Internal nodes are identified as MRCA	Track apomorphies from terminal nodes backwards	Identify monophyletic groups by arguing with MRCA and naming all descendants	MRCA is basis for response	Rationale is based on MRCA, rotation of nodes is stated as having no influence
D	Internal nodes are identified as MRCA	Track apomorphies from root to terminal nodes	Identify monophyletic groups by arguing with MRCA and naming all descendants	Number of internal nodes between groups is counted to determine relationship	Rationale only based on comparison of apomorphies
E	Internal nodes are identified as MRCA	Track apomorphies from terminal nodes backwards	Proximity of terminal nodes is used as basis for argumentation	MRCA is basis for response	Rationale is based on MRCA, rotation of nodes is stated as having no influence

F	Internal nodes are identified as MRCA	Track apomorphies from root to terminal nodes	Identify monophyletic groups by arguing with MRCA and naming all descendants	Number of internal nodes between groups is counted to determine relationship	Rationale based on apomorphies and various learners' conceptions
G	Internal nodes are identified as MRCA	Track apomorphies from terminal nodes backwards	Identify monophyletic groups by arguing with MRCA and naming all descendants	MRCA is basis for response	Correct rationale using nested hierarchy, stating that order of terminal nodes does not bear any meaning. Different learners' conceptions are called upon but refused
H	Answer is given 'at first glance'. MRCA is explicitly excluded	Track apomorphies from root to terminal nodes	Identify monophyletic groups by arguing with MRCA and naming all descendants	Number of internal nodes between groups is counted to determine relationship	Rationale is based on comparison of sister taxa

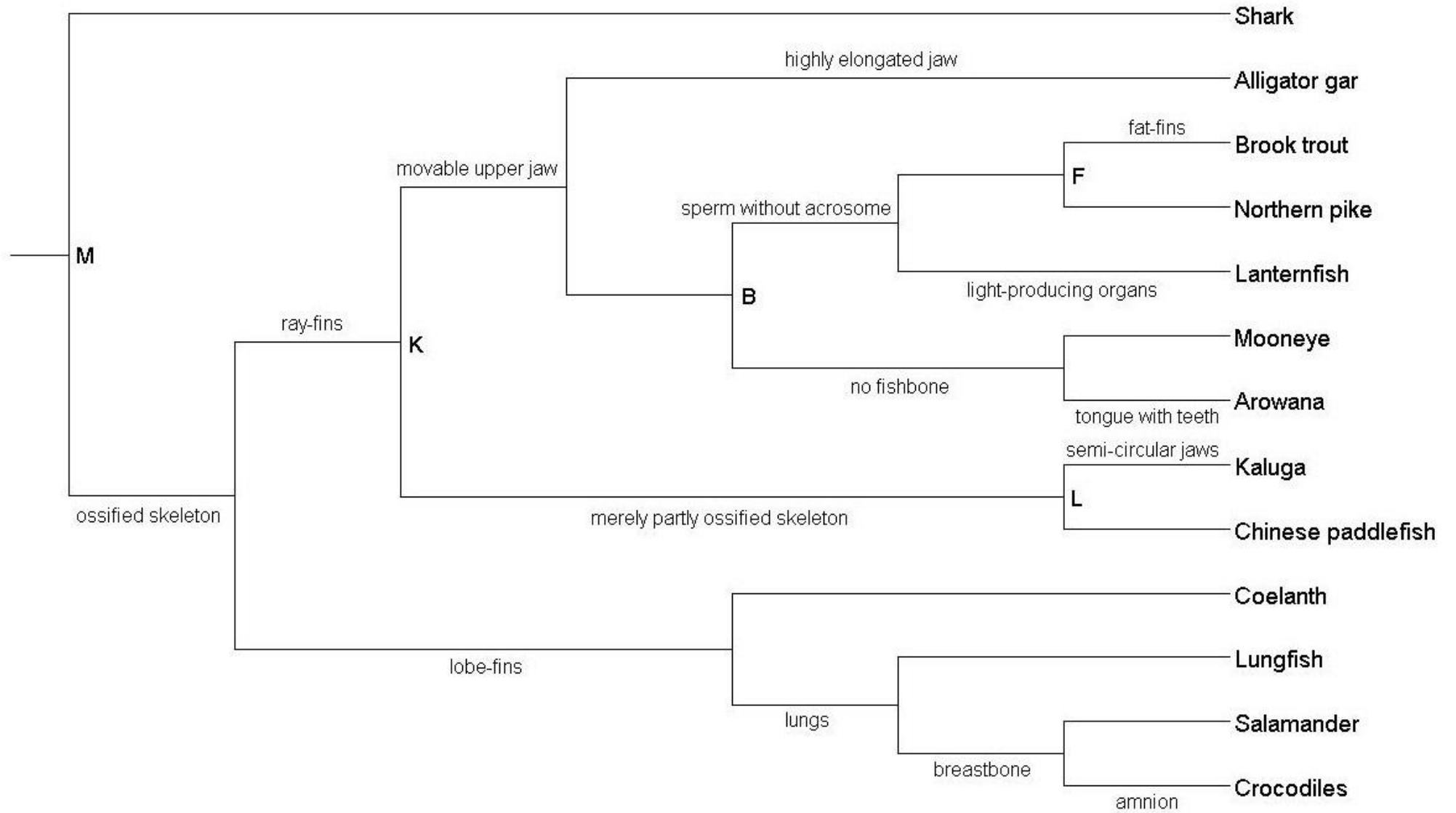# Modeling and Measuring Tree-Reading Skills in (Under-) Graduate Students

Schramm, Jose & Schmiemann 2021

Supplement Material 2

Synthetic Tree-Reading model testing instrument.

Correct answers are printed in bold.

Material A 'Fish'

Shark

highly elongated jaw — Alligator gar

fat-fins — Brook trout

F

movable upper jaw

sperm without acrosome — Northern pike

M

B

light-producing organs — Lanternfish

ray-fins

K

Mooneye

no fishbone

Arowana

tongue with teeth

semi-circular jaws — Kaluga

L

ossified skeleton

merely partly ossified skeleton — Chinese paddlefish

Coelanth

lobe-fins

Lungfish

lungs

Salamander

breastbone

amnion — Crocodiles

Fish

Please answer the following questions **concerning the evolutionary tree of fish (Material A).**

A1: What does the node L represent? (see Material A: Fish).

☐ The node represents the conjunction of the development lines of Kaluga and Chinese paddlefish.

☐ The node represents a change in the environment of Kaluga and Chinese paddlefish.

☐ **The node represents the most recent common ancestor of Kaluga and Chinese paddlefish.**

☐ The node represents the extinction of a species and the survival of Kaluga and Chinese paddlefish.

☐ The node represents the occurrence of a mutation, leading to a split into Kaluga and Chinese paddlefish.

A2: Tick the correct interpretation of the given evolutionary (see Material A: Fish).

☐ **Brook trout and Northern pike are equally developed sister species.**

☐ Brook trout is further developed than Northern pike and Lanternfish.

☐ Lanternfish is an older species than Northern pike and Brook trout.

☐ Northern pike is an intermediate form between Brook trout and Lanternfish.

☐ Brook trout and Northern pike developed from Lanternfish

A3: Assuming that all evolutionary changes are marked in the tree, which of the following traits does a Lung fish show (see Material A: Fish)?

☐ Lungs	breastbone	no amnion	lobe-fins
☐ No breastbone	no amnion	lobe-fins	not ossified skeleton
☐ No breastbone	amnion	lobe-fins	no light-producing organs
☐ Lungs	ray-fins	no fat-fins	ossified skeleton
☐ **Lungs**	**no breastbone**	**no amnion**	**ossified skeleton**

A4: Tick the group showing the following traits: Ray-fins, movable upper jaw, no light-producing organs, tongue without teeth (see Material A: Fish).

☐ Northern pike and Mooneye

☐ Brook trout, Northern pike, and Mooneye

☐ Chinese paddlefish, Northern pike, and Mooneye

☐ Brook trout, Northern pike, Alligator gar, and Arowana

☐ **Brook trout, Northern trout, Alligator gar, and Mooneye**

A5: Which of the following groups forms a clade / monophyletic group with Brook trout and Mooneye (see Material A: Fish). *(A clade / monophyletic group contains all descendants of a species, as well as this species itself, but no other species.)*

- ☐ **Northern pike, Arowana, and Lanternfish**
- ☐ Alligator gar, Northern pike, and Lanternfish
- ☐ Northern pike and Lanternfish
- ☐ Northern pike, Alligator gar, and Arowana
- ☐ Arowana and Northern pike

A6: Which of the following groups is most closely related to the Alligator gar (see Material A: Fish)?

- ☐ Kaluga and Chinese paddlefish
- ☐ Shark
- ☐ Brook trout and Shark
- ☐ Arowana, Kaluga, and Lanternfish
- ☐ **Brook trout and Mooneye**

A7: Which of the following is a sequence from the oldest to the youngest group (see Material A: Fish)?
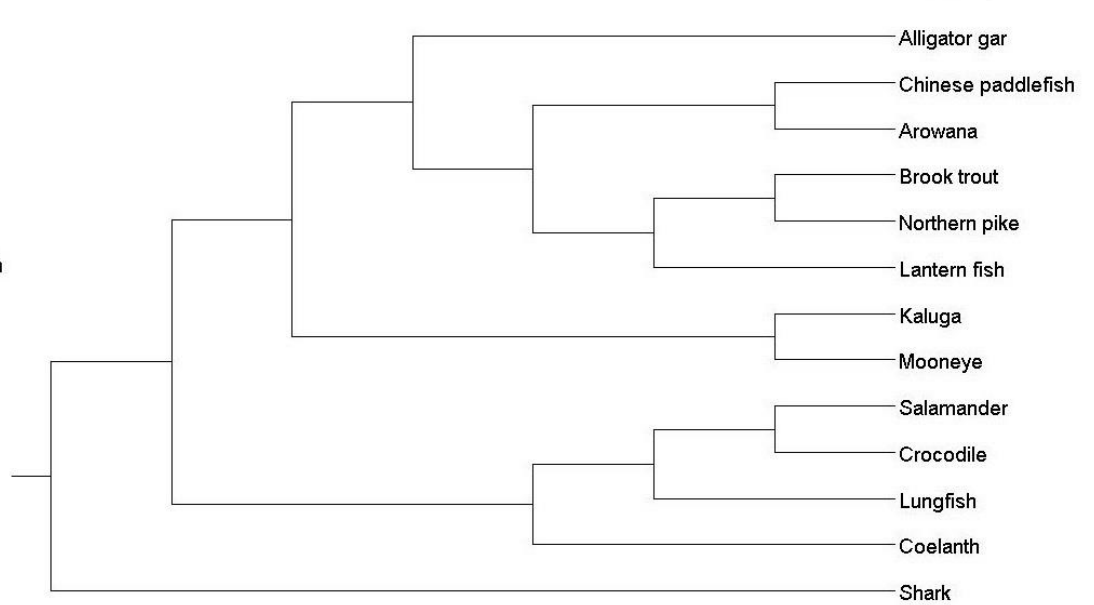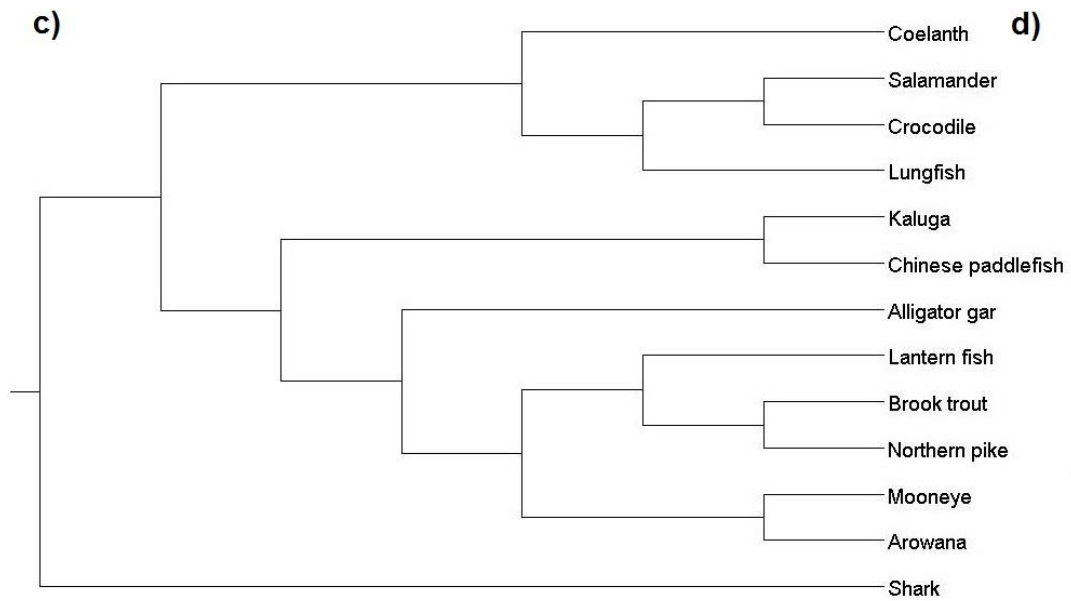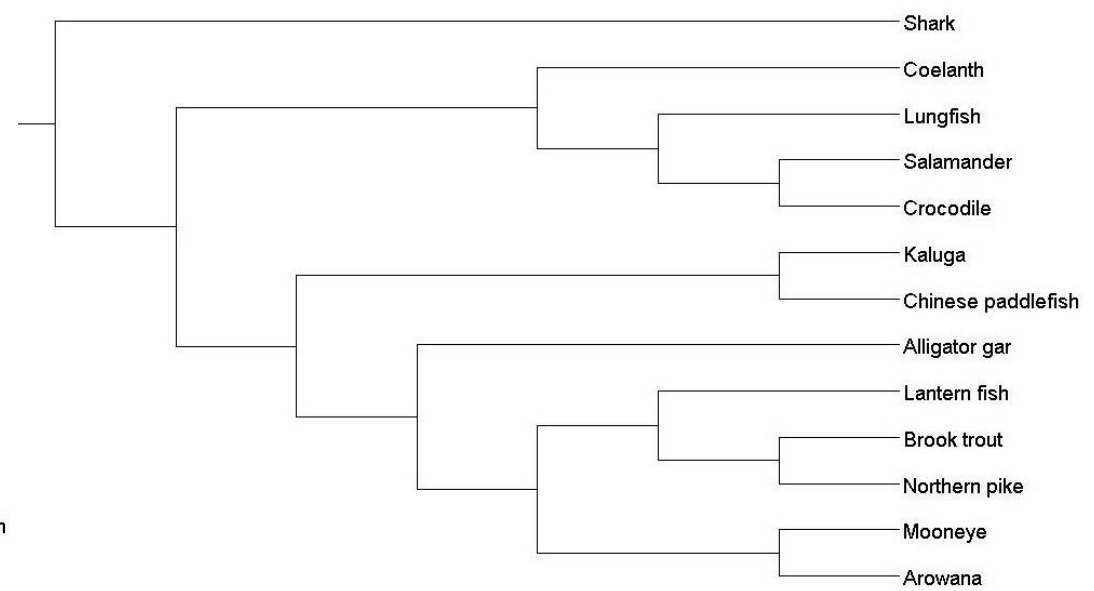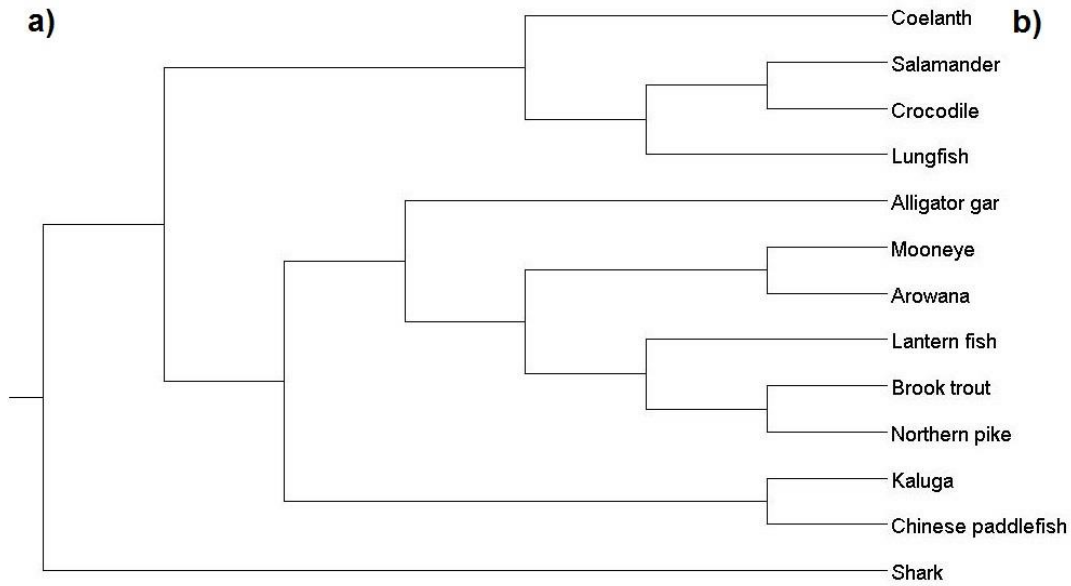
- ☐ Group K, Group B, Group L, Kaluga
- ☐ Shark, Brook trout, Chinese paddlefish, Crocodile
- ☐ Shark, Group M, Group K, Alligator gar
- ☐ **Group M, Group K, Group B, Mooneye**
- ☐ None of the other answers is correct.

A8: Which of the following groups is the closest relative to the group M (see Material A: Fish)?

- ☐ Kaluga and Chinese paddlefish
- ☐ Brook trout and Northern pike
- ☐ Coelanth
- ☐ Group K
- ☐ **All given species are equally closely related to group M.**

A9: Which of the evolutionary trees on the following page does not show the same relationships as the other three?

- ☐ Tree a)
- ☐ Tree b)
- ☐ Tree c)
- ☐ **Tree d)**
- ☐ All four trees show the same relationship.

a)

- Coelanth
- Salamander
- Crocodile
- Lungfish
- Alligator gar
- Mooneye
- Arowana
- Lantern fish
- Brook trout
- Northern pike
- Kaluga
- Chinese paddlefish
- Shark

b)

- Shark
- Coelanth
- Lungfish
- Salamander
- Crocodile
- Kaluga
- Chinese paddlefish
- Alligator gar
- Lantern fish
- Brook trout
- Northern pike
- Mooneye
- Arowana

c)

- Coelanth
- Salamander
- Crocodile
- Lungfish
- Kaluga
- Chinese paddlefish
- Alligator gar
- Lantern fish
- Brook trout
- Northern pike
- Mooneye
- Arowana
- Shark

d)

- Alligator gar
- Chinese paddlefish
- Arowana
- Brook trout
- Northern pike
- Lantern fish
- Kaluga
- Mooneye
- Salamander
- Crocodile
- Lungfish
- Coelanth
- Shark

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A10: Assuming that all evolutionary changes are marked in the tree, which of the following traits does a Mooneye show (see Material A: Fish)?

☐ Toothless tongue	no fishbone	movable upper jaw	no sperm
☐ Tongue with teeth	no fishbone	ossified skeleton	ray-fins
☐ **Toothless tongue**	**no fishbone**	**ossified skeleton**	**sperm with acrosome**
☐ Tongue with teeth	no fishbone	movable upper jaw	ray-fins
☐ Toothless tongue	no fishbone	no lobe-fins	fat-fins

A11: Which traits do Mooneye and Brook trout show (see Material A: Fish).

☐ Ray-fin	light-producing organs	no lungs	movable upper jaw
☐ **Ossified skeleton**	**no light producing organs**	**no amnion**	**movable upper jaw**
☐ Toothless tongue	movable upper jaw	ray-fins	light-producing organs
☐ Ossified skeleton	no breastbone	no amnion	immobile upper jaw
☐ Ossified skeleton	fishbone	ray-fins	not elongated jaw

A12: Which of the following groups forms a clade / monophyletic group (see Material A: Fish). *(A clade / monophyletic group contains all descendants of a species, as well as this species itself, but no other species.)*
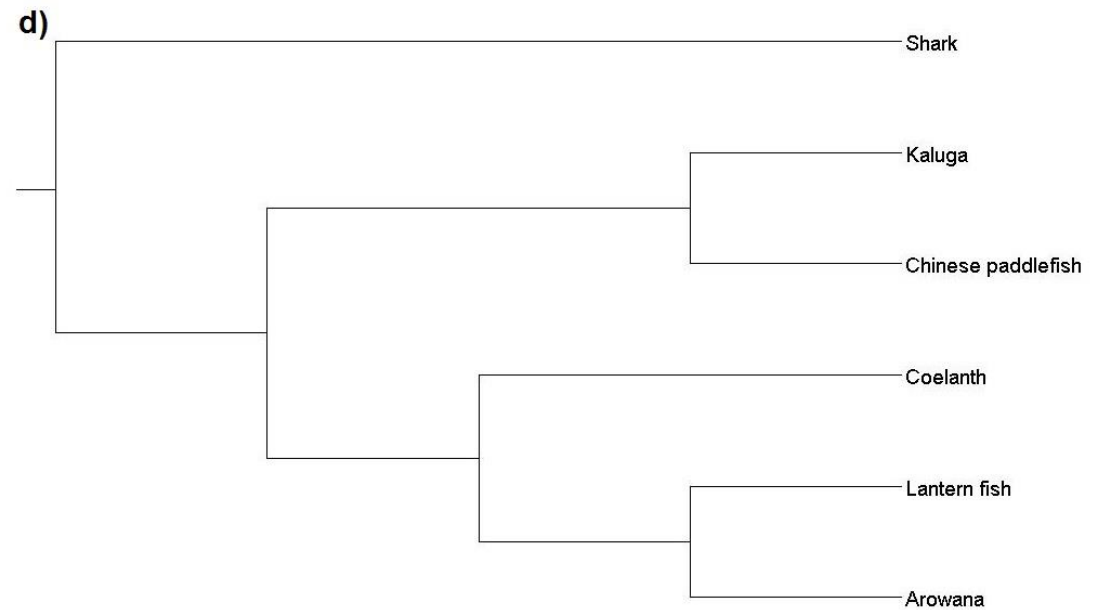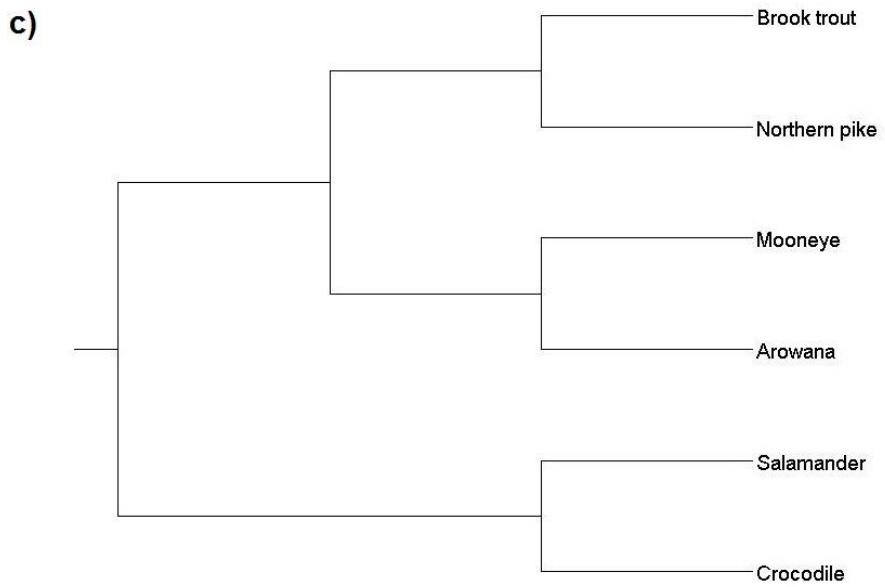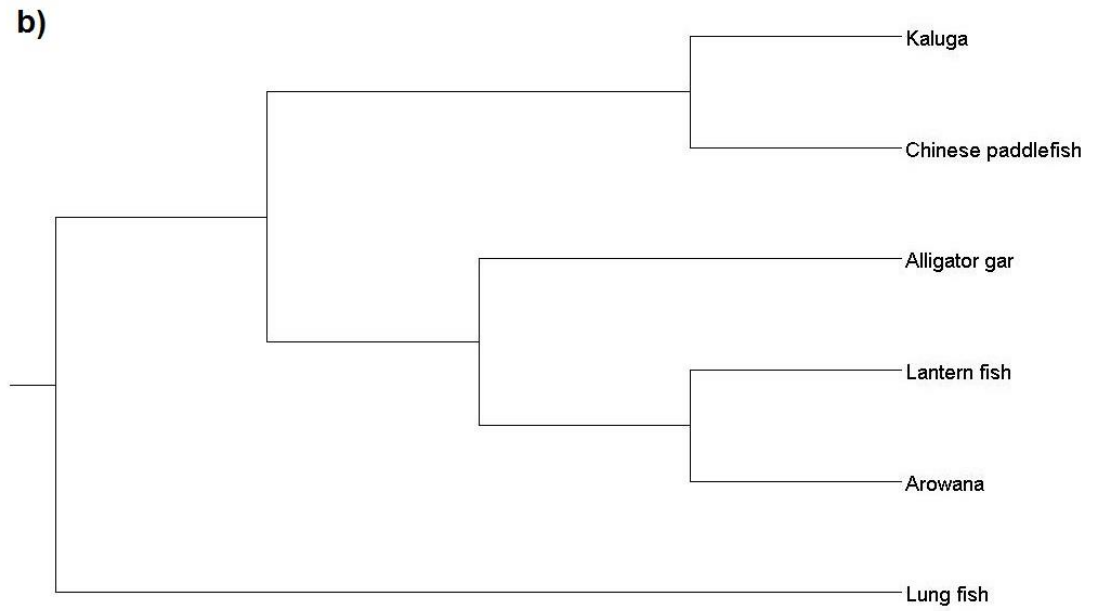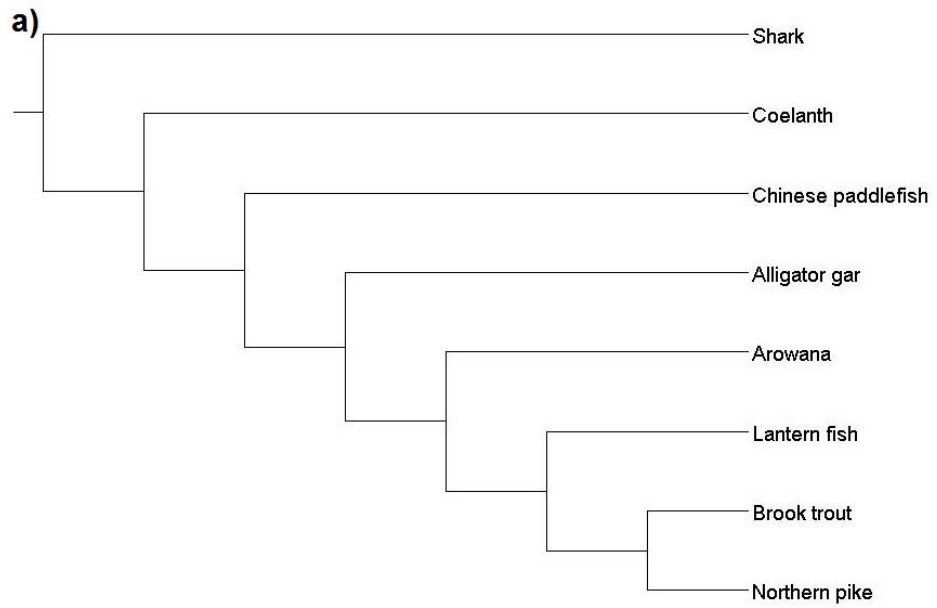
- ☐ Alligator gar, Brook trout, Northern pike, and Lanternfish
- ☐ Northern pike and Lanternfish
- ☐ **Mooneye and Arowana**
- ☐ Coelanth, Lung fish, and Salamander
- ☐ Lanternfish, Arowana, Brook trout, and Mooneye

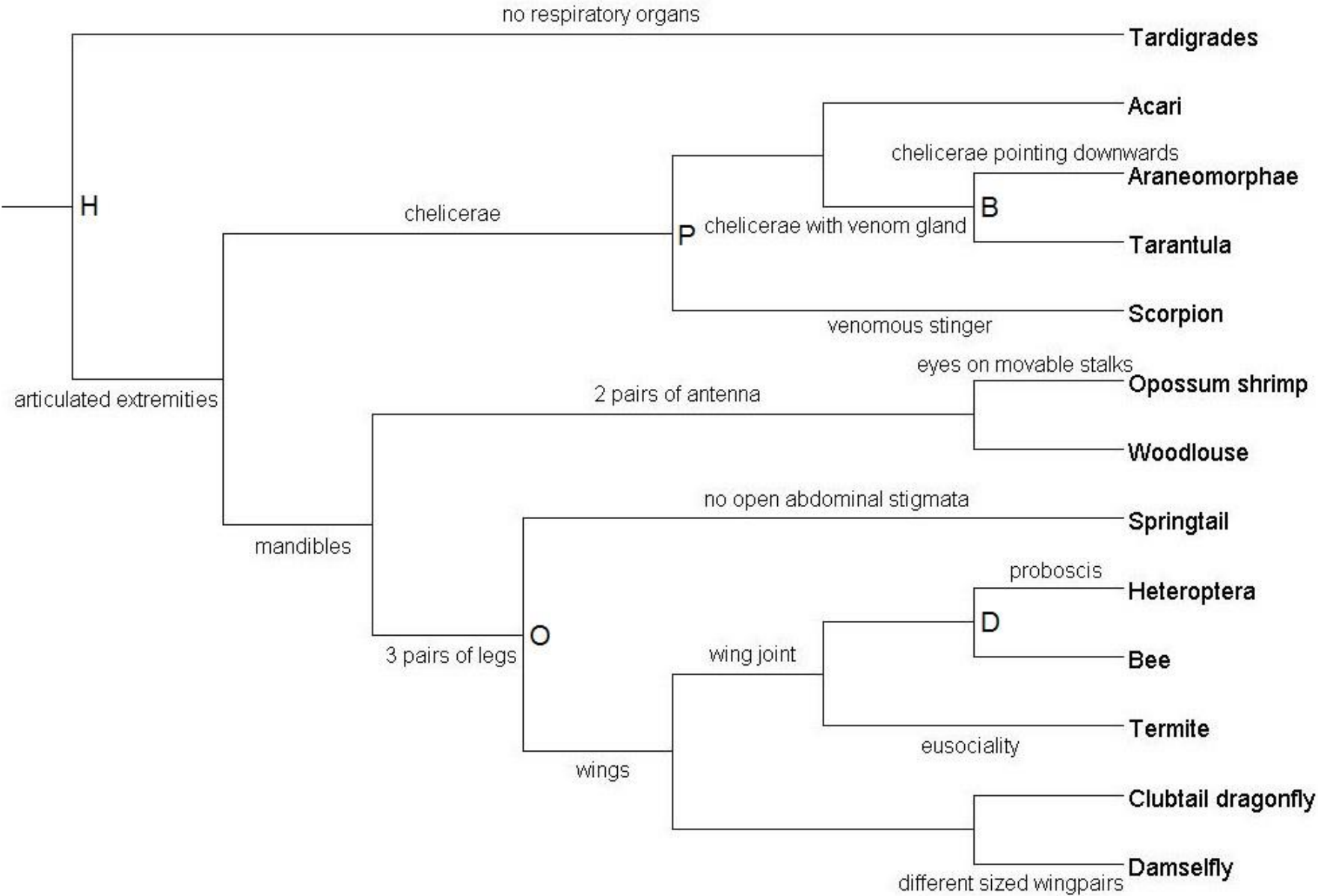**A13: Which of the following statements is in line with the given tree (see Material A: Fish)?**

- ☐ Arowana are more closely related to Kaluga than to Brook trout.
- ☐ **Arowana are more closely related to Brook trout than to Kaluga**
- ☐ The last common Ancestor of Brook trout and Arowana is also an ancestor of Kaluga
- ☐ Arowana are equally close related to Brook trout and Kaluga.
- ☐ None of the other statements is correct.

A14: Which of the trees on the next page shows different relationships as the tree given in Material A (Fish)?

- ☐ Tree a)
- ☐ Tree b)
- ☐ Tree c)
- ☐ **Tree d)**
- ☐ All trees show the same relationships.

Material B 'Arthropods'

no respiratory organs — **Tardigrades**

H

chelicerae

Acari

chelicerae pointing downwards — **Araneomorphae**

P — chelicerae with venom gland

B

Tarantula

venomous stinger — **Scorpion**

articulated extremities

eyes on movable stalks — **Opossum shrimp**

2 pairs of antenna

Woodlouse

mandibles

no open abdominal stigmata — **Springtail**

O

proboscis — **Heteroptera**

wing joint

D

Bee

3 pairs of legs

eusociality — **Termite**

wings

Clubtail dragonfly

different sized wingpairs — **Damselfly**

Arthropods

Please answer the following questions **concerning the evolutionary tree of Arthropods (Material B).**

B1: Which of the following statements about the given tree is correct (see Material B: Arthropods)?

☐ **The diagram shows, how species are related to each other via their shared ancestors.**

☐ The diagram shows, how closely organisms resemble (e.g. look like) each other.

☐ The diagram shows, which species evolved first, second, third, etc.

☐ The diagram shows, which species have changed the most over time.

☐ The diagram shows, which evolutionary developments led to splitting into different species.

B2: What do the nodes H, O, P, B and D represent (see Material B: Arthropods).

☐ They represent where two lineages come together.

☐ They represent the occurrence of mutation, leading to splitting into two groups

☐ **They represent the last common ancestor of groups.**

☐ They represent the extinction of a species.

☐ The represent the point where natural selection has occurred.

B3: Assuming that all evolutionary changes are marked in the tree, which of the following traits do Heteroptera show (see Material B: Arthropods)?

☐ Mandibles	2 pairs of antennae	wing joint	respiratory organs
☐ **Proboscis**	**no chelicerae**	**respiratory organs**	**3 leg pairs**
☐ 3 leg pairs	no wings	proboscis	mandibles
☐ Mandibles	wing joint	proboscis	unjointed legs
☐ Proboscis	wings	eusociality	mandibles

B4: Which group shows the following traits: jointed legs, mandibles, respiratory organs, no wing joint and no 2 pair of antennae (see Material B: Arthropods)?

☐ Dragonfly, Heteroptera, Bee, Termite, and Damselfly

☐ Dragonfly and Damselfly

☐ Springtail, Heteroptera, Bee, and Termite

☐ Springtail, Bee, and Damselfly

☐ **Springtail, Damselfly, and Dragonfly**

B5: Which of the following groups forms a clade / monophyletic group with Bees and Dragonfly (see Material B: Arthropods). *(A clade / monophyletic group contains all descendants of a species, as well as this species itself, but no other species.)*

- ☐ Heteroptera and Termite
- ☐ Springtails, Heteroptera, and Termite
- ☐ **Termite, Heteroptera, and Damselfly**
- ☐ Damselfly and Heteroptera
- ☐ Termite and Springtails

B6: Which of the evolutionary trees on the following page does not show the same relationships as the other three?

- ☐ **Tree a)**
- ☐ Tree b)
- ☐ Tree c)
- ☐ Tree d)
- ☐ All four trees show the same relationship.
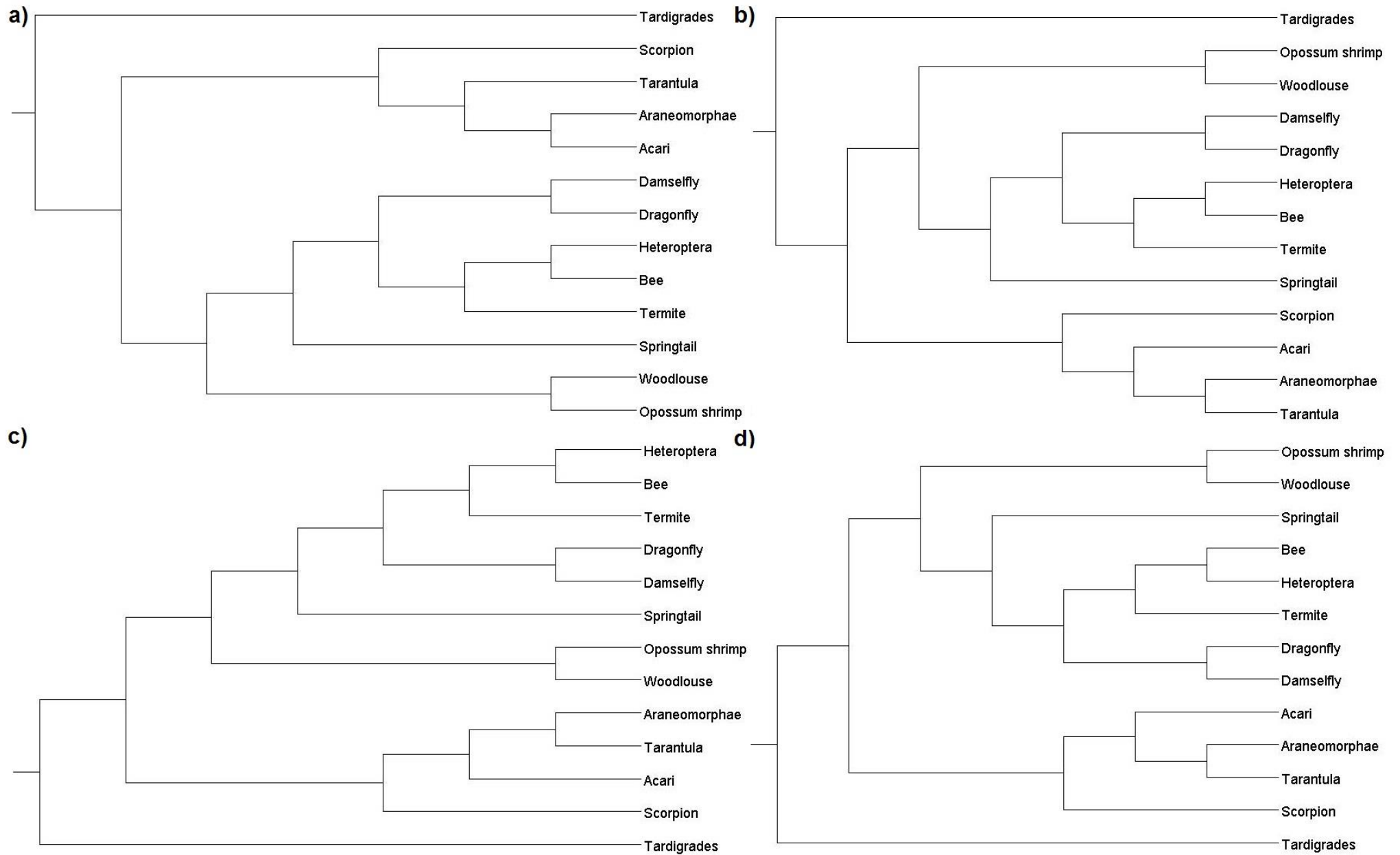
B7: Which of the following groups is the closest relative to Opossum shrimp (see Material B: Arthropods)?

☐ Group H

☐ Scorpion and Woodlouse

☐ Tarantula, Araneomorphae, and Scorpion

☐ Group H, Group P, and Group O

☐ **Dragonfly and Damselfly**

B8: Which of the following is a sequence from the oldest to the youngest group (see Material B: Arthropods)?

☐ **Group H, Woodlouse**

☐ Tardigrade, Group H, Group O, Termite

☐ Acari, Group P, Group B

☐ Group H, Group P, Group D

☐ None of the other answers is correct.

B9: Which of the following groups is the closest relative to the Group at node O (see Material B: Arthropods)?

☐ Woodlouse, Bee, Termite, and Damselfly

☐ Group H and Group D

☐ Group H

☐ **Springtail, Termite, and Dragonfly**

☐ All groups are equally close related to group O.

B10: Assuming that all evolutionary changes are marked in the tree, which of the following traits does a Scorpion show (see Material B: Arthropods)?

☐ Articulated extremities   venomous stinger
  3 leg pairs   chelicerae

☐ respiratory organs   chelicerae
  no mandibles   unjointed extremities

☐ No 3 leg pairs   no wing joint
  Proboscis   venomous stinger

☐ **jointed extremities   no 3 leg pairs**
  no wings   chelicerae without venom glands

☐ jointed extremities   venomous stinger
  no wings   chelicerae pointing downwards

B11: Which traits do Bees and Termites show (see Material B: Arthropods).

☐ mandibles	wings	eusociality	3 leg pairs
☐ not 2 pairs of antennae	mandibles	3 leg pairs	unjointed extremities
☐ articulated extremities	chelicerae	wings	abdominal stigmata
☐ **articulated extremities**	**wing joint**	**no chelicerae**	**respiratory organs**
☐ mandibles	3 leg pairs	proboscis	articulated extremities

B12: Which of the following groups forms a clade / monophyletic group (see Material B: Arthropods)? *(A clade / monophyletic group contains all descendants of a species, as well as this species itself, but no other species.)*

- ☐ Araneomorphae, Scorpion, and Tarantula
- ☐ **Opossum shrimp and Woodlouse**
- ☐ Scorpion, Opossum shrimp, and Woodlouse
- ☐ Heteroptera, Bee, Termite, and Springtail
- ☐ Termite, Dragonfly, and Damselfly

B13: Which of the following groups is the closest relative to Acari (see Material B: Arthropods)?

- ☐ Opossum shrimp, Woodlouse, and Springtail
- ☐ Dragonfly and Damselfly
- ☐ **Heteroptera, Bee, and Termite**
- ☐ Woodlouse, Heteroptera, and Dragonfly
- ☐ All stated groups are equally closely related to Acari.

A14: Which of the trees on the next page shows different relationships as the tree given in Material B (Arthropods)?

- ☐ Tree a)
- ☐ Tree b)
- ☐ **Tree c)**
- ☐ Tree d)
- ☐ All trees show the same relationships.

a)
- Damselfly
- Dragonfly
- Termite
- Springtail
- Woodlouse
- Acari

b)
- Tardigrades
- Heteroptera
- Bee
- Termite
- Dragonfly
- Damselfly

c)
- Tardigrades
- Opossum shrimp
- Scorpion
- Heteroptera
- Acari
- Tarantula

d)
- Tardigrades
- Termite
- Bee
- Dragonfly
- Woodlouse
- Acari
- Tarantula

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