Support Metrics

Phylogenetic trees are just …

Phylogenetic trees are just … hypotheses!

It is important to know how much we can be **confident** in our findings…

Teese are the metrics we are going to explore:

- nonparametric & parametric bootstrap (**BPs**)
- Tranfer Bootstrap Expectation (**TBE**)
- parametric & nonparametric jackknife
- SH-like approximate Likelihood Ratio Test (**SHaLRT**)
- genes & sites Concordance Factors (**gCFs** & **sCFs**)
- Posterior Probabilities (**PP**)
- Quartet Support (**QS**) … will see that in **lesson 13**!

non-parametric bootstrapping

Is a general statistical method for estimating the parameters of an unknown probability distribution by resampling from a sample that was drawn from this distribution.

Transferred to phylogenetics by **Felsenstein** in this paper from 1985.

This is the process step-by-step:

- start with an alignment of length **n**
- generate a bootstrapped alignment:
  - randomly sample **n** columns with replacement
  - arrange the new columns into a bootstrapped alignment of length **n**
- build a tree from the bootstrapped alignment with the same method as for the original alignment
- repeat the process many times and store all resulting bootstrap trees
- the **bootstrap proportion (BPs)** is the percentage of trees containing a given bipartition

It reflects the consistence with the sequence data support that branch.

BPs are typically shown on the "*best tree*" or the majority-rule consensus of bootstrap trees.

```
species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
```

```
species 1
species 2
species 3
species 4
species 5
species 6
species 7
```

```
species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
                         *
```

```
species 1   G
species 2   G
species 3   G
species 4   G
species 5   G
species 6   G
species 7   G
```

```
species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
                                *
```

```
species 1   GA
species 2   GT
species 3   GC
species 4   GT
species 5   GA
species 6   GC
species 7   GT
```

```
species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
                                 *
```

```
species 1   GAA
species 2   GTA
species 3   GCA
species 4   GTA
species 5   GAA
species 6   GCA
species 7   GTA
```

```
species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
                                        *
```

```
species 1   GAAC
species 2   GTAC
species 3   GCAC
species 4   GTAC
species 5   GAAG
species 6   GCAG
species 7   GTAC
```

```
species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
                                *
```

```
species 1   GAACA
species 2   GTACT
species 3   GCACC
species 4   GTACT
species 5   GAAGA
species 6   GCAGC
species 7   GTACT
```

```
species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
                                                                                          *
```

```
species 1   GAACAA
species 2   GTACTA
species 3   GCACCC
species 4   GTACTA
species 5   GAAGAC
species 6   GCAGCA
species 7   GTACTA
```

```
species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
                                                                                          *
```

```
species 1   GAACAAT
species 2   GTACTAT
species 3   GCACCCT
species 4   GTACTAT
species 5   GAAGACT
species 6   GCAGCAG
species 7   GTACTAG
```

```
species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
                                        *
```

```
species 1   GAACAATG
species 2   GTACTATG
species 3   GCACCCTG
species 4   GTACTATG
species 5   GAAGACTG
species 6   GCAGCAGG
species 7   GTACTAGG
```

```
species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
                                                                          *
```

```
species 1   GAACAATGGT
species 2   GTACTATGTT
species 3   GCACCCTGTT
species 4   GTACTATGGT
species 5   GAAGACTGTG
species 6   GCAGCAGGCT
species 7   GTACTAGGTT
```

```
species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
                                *
```

```
species 1   GAACAATGGTA
species 2   GTACTATGTTT
species 3   GCACCCTGTTC
species 4   GTACTATGGTT
species 5   GAAGACTGTGA
species 6   GCAGCAGGCTC
species 7   GTACTAGGTTT
```

```
species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
```

```
species 1   GAACAATGGTA…                                                    …AGTAAA
species 2   GTACTATGTTT…                                                    …TGTTAT
species 3   GCACCCTGTTC…                                                    …CGTCAC
species 4   GTACTATGGTT…                                                    …TGTTAT
species 5   GAAGACTGTGA…                                                    …AGTAAA
species 6   GCAGCAGGCTC…                                                    …CGGCAC
species 7   GTACTAGGTTT…                                                    …TGGTAT
```

Sampling with replacement!

Is the same information present in this bootstrapped alignment?

node	branch is present?	branch is present?	branch is present?	BPs
1	Y	Y	Y	100%
2	Y	N	N	33%
3	Y	Y	Y	100%
4	N	N	N	0%
5	N	Y	Y	66%
..	…	…	…	…
last	Y	Y	Y	100%

parametric bootstrapping

A **model-based approach** to estimate support using simulated data.

This is the process step-by-step:

- estimate from the original alignment **X**:
  - model of substitution
  - a phylogenetic tree **T**
- use the model and tree T to simulate replicate alignments $\mathbf{X}_i$
- phylogenetic trees $\mathbf{T}_i$ are inferred for each of the alignments $\mathbf{X}_i$
- branch support values are derived - as in non-parametric bootstrapping - by computing the percentage with which a certain branch occurs in the set of generated trees $\mathbf{T}_i$

⚠️ Important:

- parametric bootstrap values **depend heavily on the model** estimated from the original data
- if the model is misspecified, support values may be biased or misleading

original alignment

↓

estimate model and tree

↓

simulation of alignments

↓

simulated alignment

↓

bootstrapped tree

↓

simulated alignment

↓

bootstrapped tree

↓

simulated alignment

↓

bootstrapped tree

↓

node	branch is present?	branch is present?	branch is present?	BPs
1	Y	Y	Y	100%
2	Y	N	N	33%
3	Y	Y	Y	100%
4	N	N	N	0%
5	N	Y	Y	66%
..	…	…	…	…
last	Y	Y	Y	100%

transfer bootstrap expectation (TBE)

The bootstrap is used extensively 🤩 but scaling to thousands of tips introduces new challenges 🤯. Felsenstein BPs yield **low support on deep branches** and is **not robust to taxon sampling** noise.

This is due to its **binary scoring** system: a branch is either **present** or **absent** in a replicate tree.

Lemoine et al. 2018 introduced TBE which uses a **transfer index based on gradual distances** of a branch in the replicate tree to the reference branch, capturing partial support in bootstap trees.

In detail:

- for a reference clade **R**, split the tips into two complementary groups.
- for each bipartition **B** in the bootstrap tree, compute the transfer distance: that is the minimum number of tips that need to be moved from one side to the other so that **B** matches **R**
- select the branch with the smallest transfer distance - i.e. the best-matching clade
- compute the transfer index from this match: $\text{Transfer Index} = 1 - \frac{\text{Transfer Distance}}{\min(|R|, |\neg R|)}$
- averaging the transfer indices across all replicates gives the TBE value for the clade **R**

jacknife

A resampling method related to BPs but uses **deletion rather than resampling** with replacement.

This is the process step-by-step:

- generate a jacknifed alignment from the starting alignment
  - randomly delete a fixed proportion of alignment columns
  - typically, 50% of sites are removed per replicate as im Felsenstein 1985
  - equivalent to drawing n/2 sites without replacement from an alignment of length n
- build a tree from the jacknifed alignment with the same method as for the original alignment
- repeat the process many times and store all resulting jacknife trees
- the **jacknife** is the percentage of trees containing a given bipartition.

It reflects the consistence with the sequence data support that branch.

Jacknife is typically shown on the "*best tree*" or the majority-rule consensus of bootstrap trees.

… an parametric version of the jacknife is also possible, but not shown!

```
species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
```

```
species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   AGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
```

```
species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
                                *
```

```
species 1   AGAATCTGCAATTGCTCA CTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCT CCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCC CCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   AGGAAATGCAGTTGCTCT CCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCA CCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCC CCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCT CCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
```

```
species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
                                                                                *
```

```
species 1   AGAATCTGCAATTGCTCA CTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTT CTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCT CCGATCTGTCTGATGATCTATCTGAGTCTGGATCTT CTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCC CCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTT CTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   AGGAAATGCAGTTGCTCT CCGATCTGTCTGATGATCTATCTGAGTCTGGATCTT CTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCA CCGATCTGTGTGATGATCTATCTGAGTCTGGATCGT CTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCC CCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTT CTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCT CCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTT CTCTTTTGCTCGCTCAAACCGGGCTCAG
```

```
species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
                                                                  *
```

```
species 1   AGAATCTGCAATTGCTCA CTGATCTGTCTGATGATCTGTCTGAGTCTGG TCTT CTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCT CCGATCTGTCTGATGATCTATCTGAGTCTGG TCTT CTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCC CCGATCTGTCTGATGATGTGTCTGCGTCTGG TCTT CTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   AGGAAATGCAGTTGCTCT CCGATCTGTCTGATGATCTATCTGAGTCTGG TCTT CTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCA CCGATCTGTGTGATGATCTATCTGAGTCTGG TCGT CTCTTCTGCTGGCTCAACCCTGACCCCG
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species 7   AGGATCTGCAGTTGCTCT CCGATCTGTCTGATGATCTGTCTGAGTCTGG TCTT CTCTTTTGCTCGCTCAAACCGGGCTCAG
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species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
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species 1   AGAATCTGCAATTGCTCA CTGATCTGTC GATGATCTGTCTGAGTCTGG TCTT CTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCT CCGATCTGTC GATGATCTATCTGAGTCTGG TCTT CTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCC CCGATCTGTC GATGATGTGTCTGCGTCTGG TCTT CTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   AGGAAATGCAGTTGCTCT CCGATCTGTC GATGATCTATCTGAGTCTGG TCTT CTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCA CCGATCTGTG GATGATCTATCTGAGTCTGG TCGT CTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCC CCGATCTGTG GATGATCTGTCTGAGTCTGG TCTT CTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCT CCGATCTGTC GATGATCTGTCTGAGTCTGG TCTT CTCTTTTGCTCGCTCAAACCGGGCTCAG
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species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
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species 1   AGAATCTGCAATTGCTCA CTGATCTGTC  ATGATCTGTCTGAGTCTGG TCTT CTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCT CCGATCTGTC  ATGATCTATCTGAGTCTGG TCTT CTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCC CCGATCTGTC  ATGATGTGTCTGCGTCTGG TCTT CTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   AGGAAATGCAGTTGCTCT CCGATCTGTC  ATGATCTATCTGAGTCTGG TCTT CTGTTTTGCTCGCTCAAACCTGGCTCAG
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species 6   AGGAAATGCAGCCGCTCC CCGATCTGTG  ATGATCTGTCTGAGTCTGG TCTT CTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCT CCGATCTGTC  ATGATCTGTCTGAGTCTGG TCTT CTCTTTTGCTCGCTCAAACCGGGCTCAG
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species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
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species 1   AGAATCTGCAATTGCTCA CTGATCTGTC  ATGATCTGTCTGAG CTGG TCTT CTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCT CCGATCTGTC  ATGATCTATCTGAG CTGG TCTT CTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCC CCGATCTGTC  ATGATGTGTCTGCG CTGG TCTT CTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   AGGAAATGCAGTTGCTCT CCGATCTGTC  ATGATCTATCTGAG CTGG TCTT CTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCA CCGATCTGTG  ATGATCTATCTGAG CTGG TCGT CTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCC CCGATCTGTG  ATGATCTGTCTGAG CTGG TCTT CTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCT CCGATCTGTC  ATGATCTGTCTGAG CTGG TCTT CTCTTTTGCTCGCTCAAACCGGGCTCAG
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species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
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species 1   AGAATCTGCAATTGCTCA CTGATCTGTC  ATGATCTGTCTGAG CTGG TCTT CTCTTTTGCTCGCTCAAAGC GGCTCAG
species 2   AGGATCTAAAGTTGCTCT CCGATCTGTC  ATGATCTATCTGAG CTGG TCTT CTAATTTGCTCGCTCAAAGC GGCTCAG
species 3   AGGATCTGCAGCCGCTCC CCGATCTGTC  ATGATGTGTCTGCG CTGG TCTT CTCTTCTGCTGGCTCAACCC GGCCCAG
species 4   AGGAAATGCAGTTGCTCT CCGATCTGTC  ATGATCTATCTGAG CTGG TCTT CTGTTTTGCTCGCTCAAACC GGCTCAG
species 5   AGGATCTGCAGTTGCTCA CCGATCTGTG  ATGATCTATCTGAG CTGG TCGT CTCTTCTGCTGGCTCAACCC GACCCCG
species 6   AGGAAATGCAGCCGCTCC CCGATCTGTG  ATGATCTGTCTGAG CTGG TCTT CTGTTCTGCTCGCTCAAACC GACTCAG
species 7   AGGATCTGCAGTTGCTCT CCGATCTGTC  ATGATCTGTCTGAG CTGG TCTT CTCTTTTGCTCGCTCAAACC GGCTCAG
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species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
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species 1   AGAATCTGCAATTGCTC  CTGATCTGTC  ATGATCTGTCTGAG CTGG TCTT CTCTTTTGCTCGCTCAAAGC GGCTCAG
species 2   AGGATCTAAAGTTGCTC  CCGATCTGTC  ATGATCTATCTGAG CTGG TCTT CTAATTTGCTCGCTCAAAGC GGCTCAG
species 3   AGGATCTGCAGCCGCTC  CCGATCTGTC  ATGATGTGTCTGCG CTGG TCTT CTCTTCTGCTGGCTCAACCC GGCCCAG
species 4   AGGAAATGCAGTTGCTC  CCGATCTGTC  ATGATCTATCTGAG CTGG TCTT CTGTTTTGCTCGCTCAAACC GGCTCAG
species 5   AGGATCTGCAGTTGCTC  CCGATCTGTG  ATGATCTATCTGAG CTGG TCGT CTCTTCTGCTGGCTCAACCC GACCCCG
species 6   AGGAAATGCAGCCGCTC  CCGATCTGTG  ATGATCTGTCTGAG CTGG TCTT CTGTTCTGCTCGCTCAAACC GACTCAG
species 7   AGGATCTGCAGTTGCTC  CCGATCTGTC  ATGATCTGTCTGAG CTGG TCTT CTCTTTTGCTCGCTCAAACC GGCTCAG
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species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
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species 1   AGAATCTGCAATTGCTC  CTGATCTGTC  ATGATCTGTCTGAG CTGG TCTT CTCTTTTGCTCGC CAAAGC GGCTCAG
species 2   AGGATCTAAAGTTGCTC  CCGATCTGTC  ATGATCTATCTGAG CTGG TCTT CTAATTTGCTCGC CAAAGC GGCTCAG
species 3   AGGATCTGCAGCCGCTC  CCGATCTGTC  ATGATGTGTCTGCG CTGG TCTT CTCTTCTGCTGGC CAACCC GGCCCAG
species 4   AGGAAATGCAGTTGCTC  CCGATCTGTC  ATGATCTATCTGAG CTGG TCTT CTGTTTTGCTCGC CAAACC GGCTCAG
species 5   AGGATCTGCAGTTGCTC  CCGATCTGTG  ATGATCTATCTGAG CTGG TCGT CTCTTCTGCTGGC CAACCC GACCCCG
species 6   AGGAAATGCAGCCGCTC  CCGATCTGTG  ATGATCTGTCTGAG CTGG TCTT CTGTTCTGCTCGC CAAACC GACTCAG
species 7   AGGATCTGCAGTTGCTC  CCGATCTGTC  ATGATCTGTCTGAG CTGG TCTT CTCTTTTGCTCGC CAAACC GGCTCAG
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species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
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species 1   AGAATCTGCAATTGCTC  CTGATCTGTC  ATGATCTGTCTG G CTGG TCTT CTCTTTTGCTCGC CAAAGC GGCTCAG
species 2   AGGATCTAAAGTTGCTC  CCGATCTGTC  ATGATCTATCTG G CTGG TCTT CTAATTTGCTCGC CAAAGC GGCTCAG
species 3   AGGATCTGCAGCCGCTC  CCGATCTGTC  ATGATGTGTCTG G CTGG TCTT CTCTTCTGCTGGC CAACCC GGCCCAG
species 4   AGGAAATGCAGTTGCTC  CCGATCTGTC  ATGATCTATCTG G CTGG TCTT CTGTTTTGCTCGC CAAACC GGCTCAG
species 5   AGGATCTGCAGTTGCTC  CCGATCTGTG  ATGATCTATCTG G CTGG TCGT CTCTTCTGCTGGC CAACCC GACCCCG
species 6   AGGAAATGCAGCCGCTC  CCGATCTGTG  ATGATCTGTCTG G CTGG TCTT CTGTTCTGCTCGC CAAACC GACTCAG
species 7   AGGATCTGCAGTTGCTC  CCGATCTGTC  ATGATCTGTCTG G CTGG TCTT CTCTTTTGCTCGC CAAACC GGCTCAG
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species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
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species 1   AGA   TGCA   G TC  CTGATCTGT   ATGATCT TCTG G CTGG TCTT C  TT   CT GC CAA  C G C CAG
species 2   AGG   TAAA   G TC  CCGATCTGT   ATGATCT TCTG G CTGG TCTT C  AT   CT GC CAA  C G C CAG
species 3   AGG   TGCA   G TC  CCGATCTGT   ATGATGT TCTG G CTGG TCTT C  TT   CT GC CAA  C G C CAG
species 4   AGG   TGCA   G TC  CCGATCTGT   ATGATCT TCTG G CTGG TCTT C  TT   CT GC CAA  C G C CAG
species 5   AGG   TGCA   G TC  CCGATCTGT   ATGATCT TCTG G CTGG TCGT C  TT   CT GC CAA  C G C CCG
species 6   AGG   TGCA   G TC  CCGATCTGT   ATGATCT TCTG G CTGG TCTT C  TT   CT GC CAA  C G C CAG
species 7   AGG   TGCA   G TC  CCGATCTGT   ATGATCT TCTG G CTGG TCTT C  TT   CT GC CAA  C G C CAG
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species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
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species 1   AGATGCAGTCCTGATCTGTATGATCTTCTGGCTGGTCTTCTTCTGCCAACGCCAG
species 2   AGGTAAAGTCCCGATCTGTATGATCTTCTGGCTGGTCTTCATCTGCCAACGCCAG
species 3   AGGTGCAGTCCCGATCTGTATGATGTTCTGGCTGGTCTTCTTCTGCCAACGCCAG
species 4   AGGTGCAGTCCCGATCTGTATGATCTTCTGGCTGGTCTTCTTCTGCCAACGCCAG
species 5   AGGTGCAGTCCCGATCTGTATGATCTTCTGGCTGGTCGTCTTCTGCCAACGCCCG
species 6   AGGTGCAGTCCCGATCTGTATGATCTTCTGGCTGGTCTTCTTCTGCCAACGCCAG
species 7   AGGTGCAGTCCCGATCTGTATGATCTTCTGGCTGGTCTTCTTCTGCCAACGCCAG
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species 1   AGAATCTGCAATTGCTCAGCTGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAAGCTGGCTCAG
species 2   AGGATCTAAAGTTGCTCTTCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTAATTTGCTCGCTCAAAGCTGGCTCAG
species 3   AGGATCTGCAGCCGCTCCTCCGATCTGTCTGATGATGTGTCTGCGTCTGGCTCTTGCTCTTCTGCTGGCTCAACCCTGGCCCAG
species 4   cGGAAATGCAGTTGCTCTGCCGATCTGTCTGATGATCTATCTGAGTCTGGATCTTGCTGTTTTGCTCGCTCAAACCTGGCTCAG
species 5   AGGATCTGCAGTTGCTCATCCGATCTGTGTGATGATCTATCTGAGTCTGGATCGTGCTCTTCTGCTGGCTCAACCCTGACCCCG
species 6   AGGAAATGCAGCCGCTCCCCCGATCTGTGTGATGATCTGTCTGAGTCTGGATCTTGCTGTTCTGCTCGCTCAAACCGGACTCAG
species 7   AGGATCTGCAGTTGCTCTTCCGATCTGTCTGATGATCTGTCTGAGTCTGGATCTTGCTCTTTTGCTCGCTCAAACCGGGCTCAG
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species 1   AGATGCAGTCCTGATCTGTATGATCTTCTGGCTGGTCTTCTTCTGCCAACGCCAG
species 2   AGGTAAAGTCCCGATCTGTATGATCTTCTGGCTGGTCTTCATCTGCCAACGCCAG
species 3   AGGTGCAGTCCCGATCTGTATGATGTTCTGGCTGGTCTTCTTCTGCCAACGCCAG
species 4   AGGTGCAGTCCCGATCTGTATGATCTTCTGGCTGGTCTTCTTCTGCCAACGCCAG
species 5   AGGTGCAGTCCCGATCTGTATGATCTTCTGGCTGGTCGTCTTCTGCCAACGCCCG
species 6   AGGTGCAGTCCCGATCTGTATGATCTTCTGGCTGGTCTTCTTCTGCCAACGCCAG
species 7   AGGTGCAGTCCCGATCTGTATGATCTTCTGGCTGGTCTTCTTCTGCCAACGCCAG
```

Sampling without replacement!

Is the same information present in the jacknifed alignment?

node	branch is present?	branch is present?	branch is present?	JF
1	Y	Y	Y	100%
2	Y	N	N	33%
3	Y	Y	Y	100%
4	N	N	N	0%
5	N	Y	Y	66%
..	…	…	…	…
last	Y	Y	Y	100%

approximate Likelihood Ratio Test (aLRT)

aLRT is a fast, branch-specific metric, related to the **conventional Likelihood Ratio Test (LRT)**.

The standard LRT uses the test statistics $2(L_1 - L_0)$:

L_1 - **alternative hypothesis**: is the log-likelihood of the current tree
L_0 - **null hypothesis**: is the log-likelihood of the same tree, but with the branch of interest collapsed

aLRT approximation: L_2 is the second best NNI configuration around the branch of interest

Why use L_2 in aLRT?

- **much faster** than evaluating a collapsed model or full likelihood surface
  L_2 is computed by optimising only over the branch of interest and the four adjacent branches
  other parameters are fixed at their optimal values corresponding to the best ML tree

- allows efficient estimation of **branch-specific support**, especially in large trees
  focuses on local rearrangements around a branch - just 4 adjacent branches!

⚠️ Local rearrangements approach may miss topologies distant to current one but with higher lnL!

Posterior Probabilities (PPs)

Bayesian Inference is associated to **Posterior Probabilities** - also called clade credibility values.

- frequency that a bipartition appears in sampled trees ate the stationary phase of MCMC chain
- ranges from 0 to 1 - a PP of 0.95 means that the clade appeared in 95% of sampled trees

⚠️ important:

- PPs tend to be higher than non-parametric BPs
- sensitive to model choice and priors

Concordance Factors (CFs)

Quantify how many gene trees or sites support each branch in a reference tree.

2 types of CFs

• gene Concordance Factor **(gCF)**:
proportion of **gene trees** that contain a specific branch (or split).

• site Concordance Factor **(sCF)**:
proportion of **informative sites** in the alignment that support the branch.

Interpreting CFs values:

High (e.g., >70%) Strong signal and high agreement across loci/sites
Moderate (40–70%) Moderate support; possible discordance
Low (<40%) Weak support or substantial gene tree conflict

⚠️ Different support **metrics** have different **pitfalls**:

- parametric supports assume the evolutionary model is the correct one.
- standard metrics - PPs or BPs - can support conflicting topologies.
- …

🙃 Good practices:

- different support metrics must be compared
- observe consistent outcomes from different approaches

FINISH