

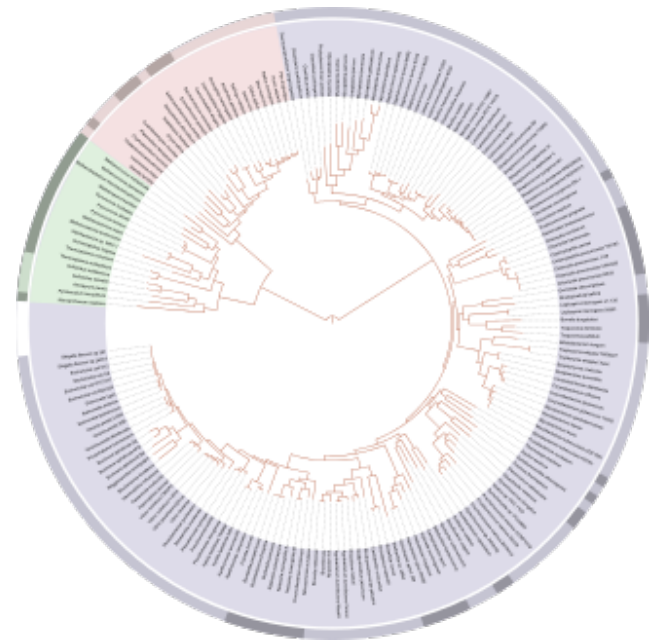
# Current Views on Insect Relationships

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# Why is phylogenetics important?

- Tree of Life is essential for the field of comparative biology and for determining evolutionary relationships between all species on Earth
- Insects make up a large portion of the Tree with over 1 million described species
- A greater understanding of the insect phylogeny is especially important if the ultimate goal is to construct a more accurate and complete picture of the Tree



# The rapidly changing landscape of insect phylogenies

(2016)  
The field of insect phylogenetics is constantly changing due to new innovations:

Genomics

Phenomics and morphology

New techniques for analyzing older museum specimens + field specimens

Software programs and algorithms for interpreting large amounts of data

Obtaining massive quantities of genetic and phenotypic data is no longer the issue, the focus now is on how to store/interpret all of this data



# Genomics

Inexpensive to sequence entire genomes

In 2001, the cost to sequence a genome was about 100 million; now less than \$1000

Cutting sequencing costs further by utilizing:

Transcriptome sequencing

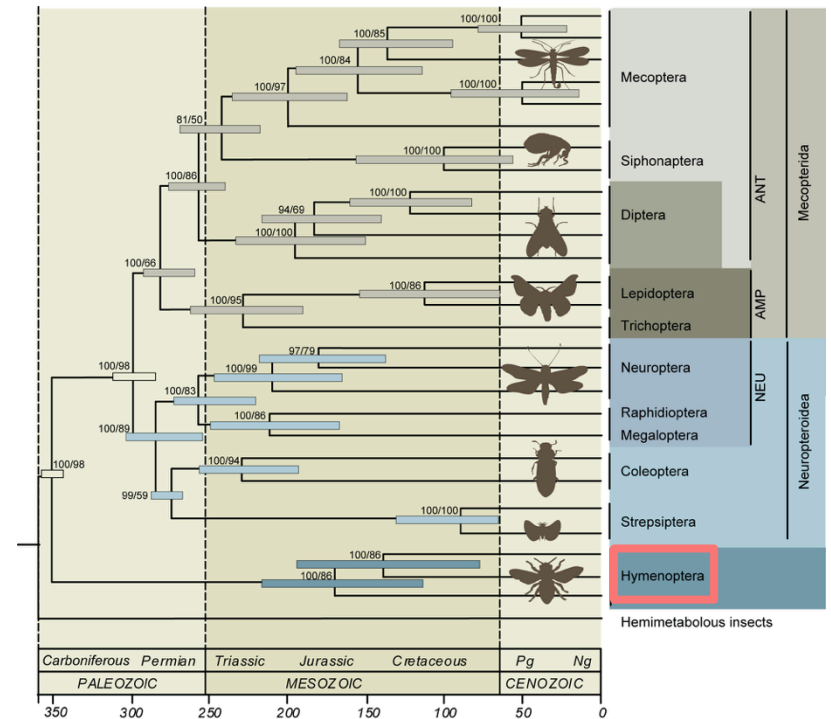
Hybrid capture sequencing

Genotype-by-sequencing (GBS)

Restriction-site associated DNA sequencing

These methods provide data that can be compared with data from phylogenetically distant taxa

(RADSeq)  
phylogenetically distant taxa



Wiegmann et al.

# Phenomics

Revitalizing the use of morphological and structural data even in the age of molecular phylogenies

New methodologies like MicroCT and confocal microscopy provide 3D reconstructions of structure



Wipfler  
et al.

# Field and museum specimens

New tools and technology for collecting specimens

Large amounts of data can be gathered in the field with portable, hand-held sequencing devices

Next-gen sequencing methods can also be used to extract DNA from dried specimens in collections



# Software for interpreting data

Important to develop efficient systems that can organize previously unorganized or poorly tracked data

Repositories for data include  
TaxonWorks, GenBank,  
MorphoBank, TreeBase,  
OpenTree

All of these programs promote collaboration and openness of data sharing



This initial **tree of life** will **not be static**; instead, we will **develop tools for scientists** to update and revise the tree as **new data** come in.



*A Database of Phylogenetic Knowledge*

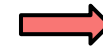
# Will insects enter the “Phylocognisant Age”?

- “Phylocognisant Age” = where scientists know the majority of a phylogenetic tree, from the ancestral nodes to the species at the tips
- Do you think a “phylocognisant age” of insects will ever be possible?
  - It will take significantly longer, but if the focus remains on:
    - Evaluation of existing resources that will contribute to progress rather than hinder it
    - Effective synthesis of old methods with new innovations
- It may be possible! In fact ...



# Phylogenomics resolves the timing and pattern of insect evolution (2014)

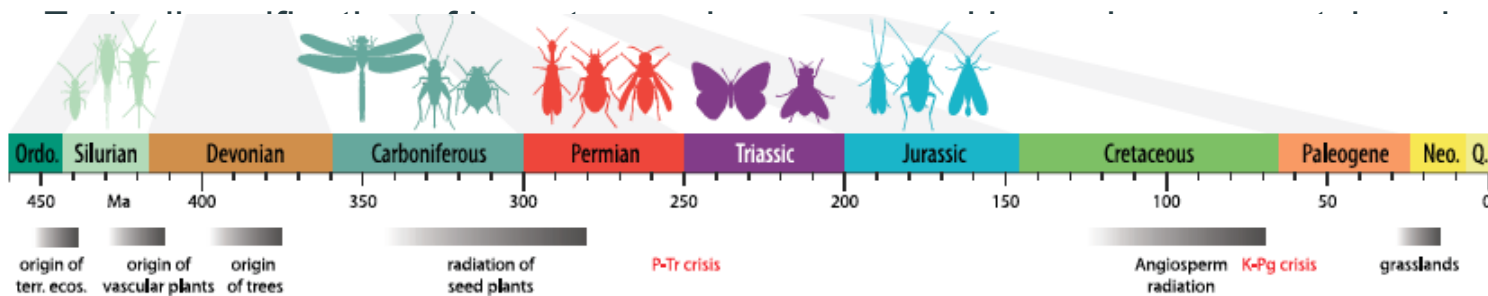
Oldest known fossil that dates back 400 million years ago (Collembola)



When did insects originate?

Oldest known fossil insects from Early Devonian (~412 mya)

Molecular data suggest that insects originated in the Early Ordovician



nents

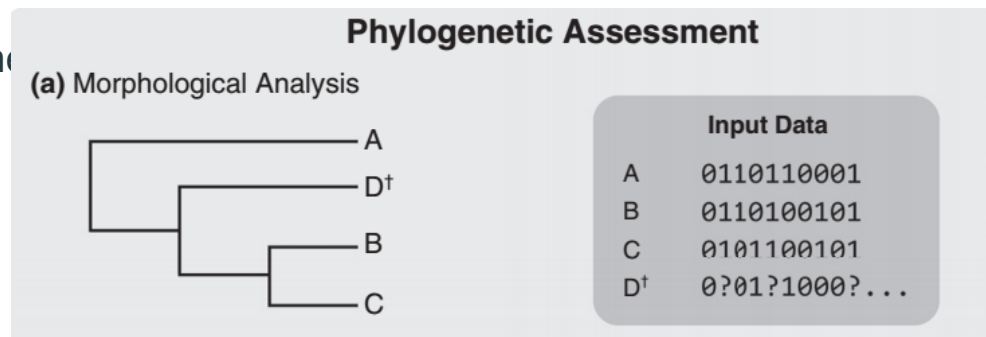
# Fossils (Ware, 2016)

Majority of insect species have already gone extinct so fossils are the only way we can learn about the morphology, biogeography, and temporal history of extant lineages

Estimates rely on fossil calibrations to estimate node ages (divergence times)

Fossils were incorporated into a phylogenetic treatment of insects based on morphological synapomorphies (unique, derived, and indicate relationships)

First phylogen



# Methods

Complex algorithmic approach

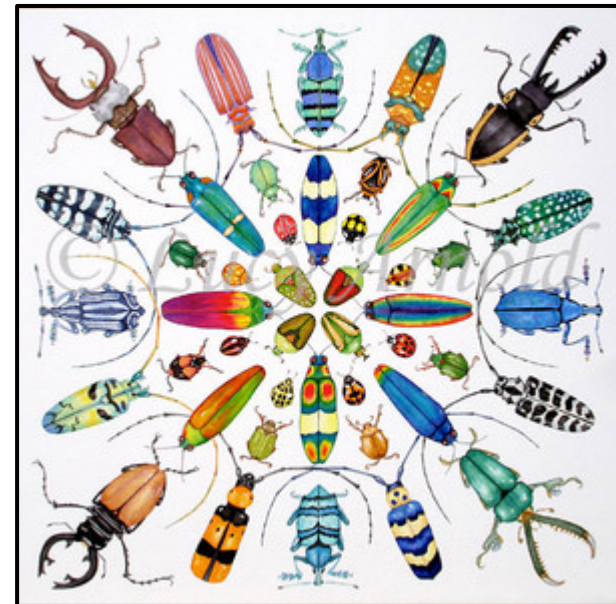
Phylogenomic analyses of transcriptome  
and genome sequence data

Transcriptome = messenger RNA

All protein-coding sequences  
**What potential problem might there  
be with only using protein-coding  
sequences?**

Selection

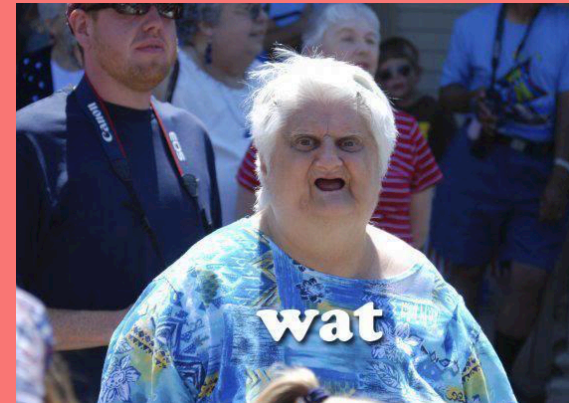
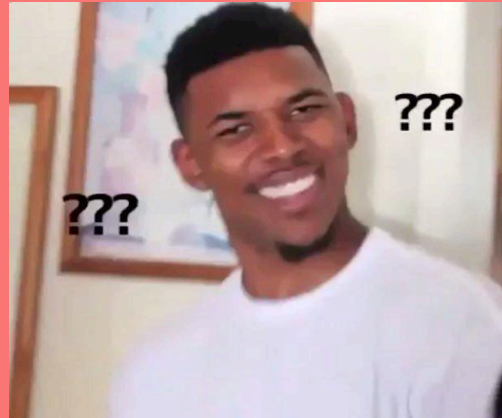
Evolve differently

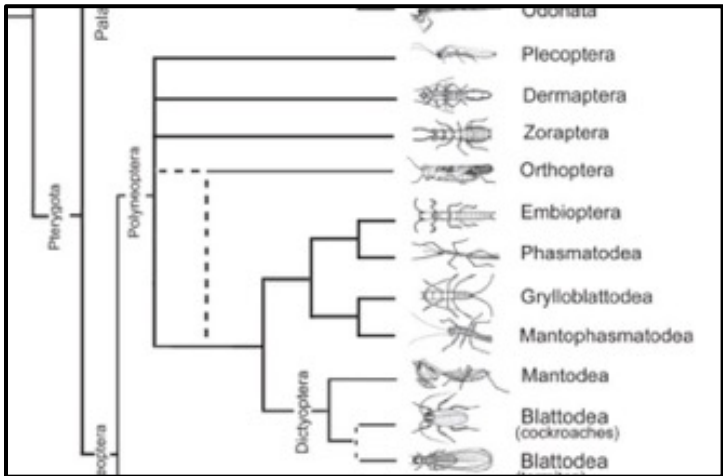




# Try not to get too mixed up with these taxa:

- Polyneoptera
- Palaeoptera
- Neoptera
- Paraneoptera





# Polyneoptera

Earwigs, Crickets, Stick insects,  
Mantids, Cockroaches,  
Termites



# Palaeoptera

Dragonflies, Mayflies

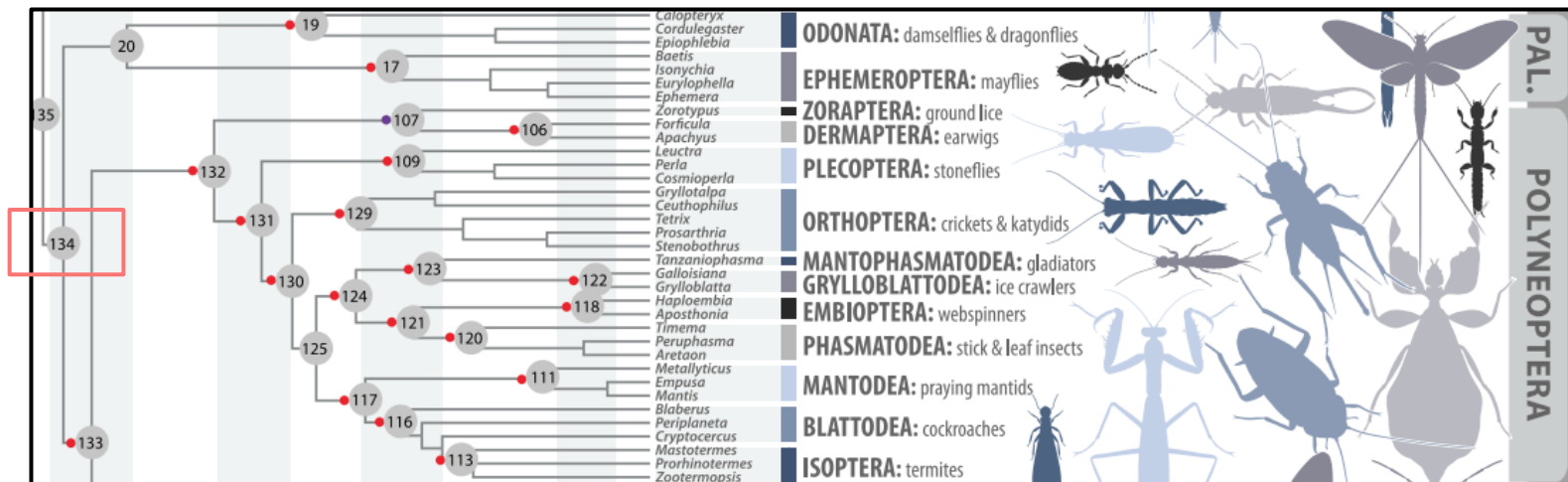
# Neoptera

ALL other winged insects

Misof et al. found that they are sister taxa, however, node support is low



Skepticism due to the morphological feature of having the ability (Palaeoptera) or inability (Neoptera) to fold the wings over the abdomen

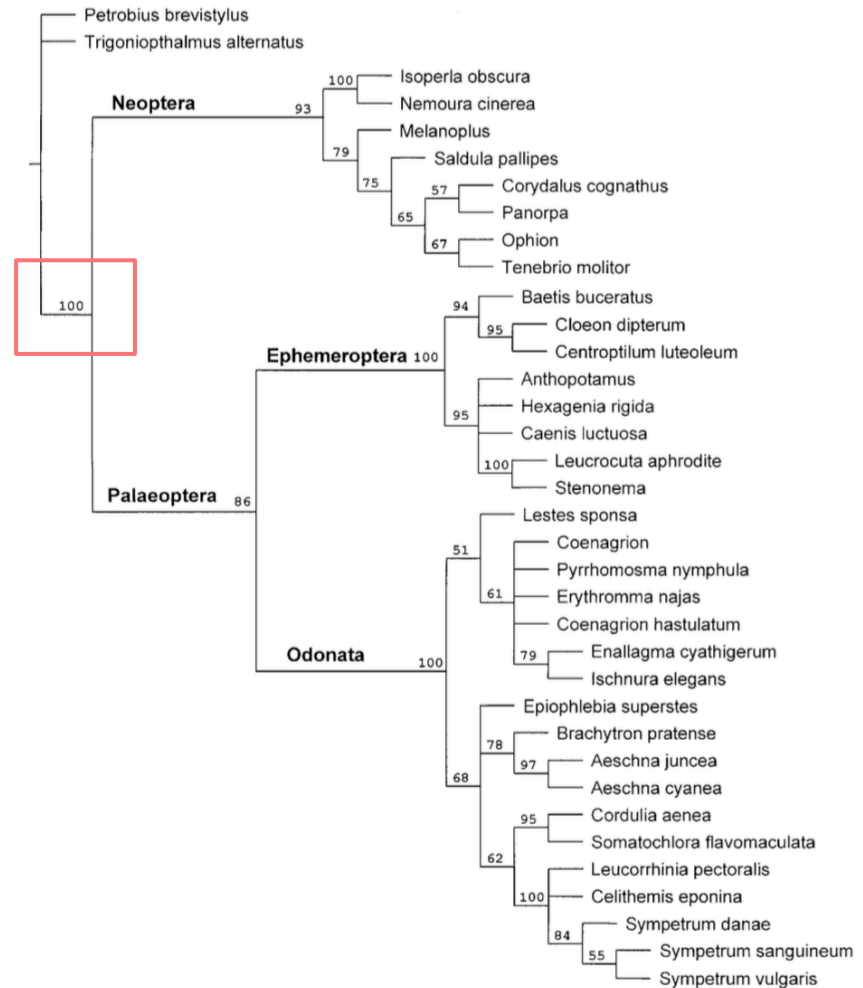


# Hovmoller, 2002

Study focused on the relationships surrounding Palaeoptera

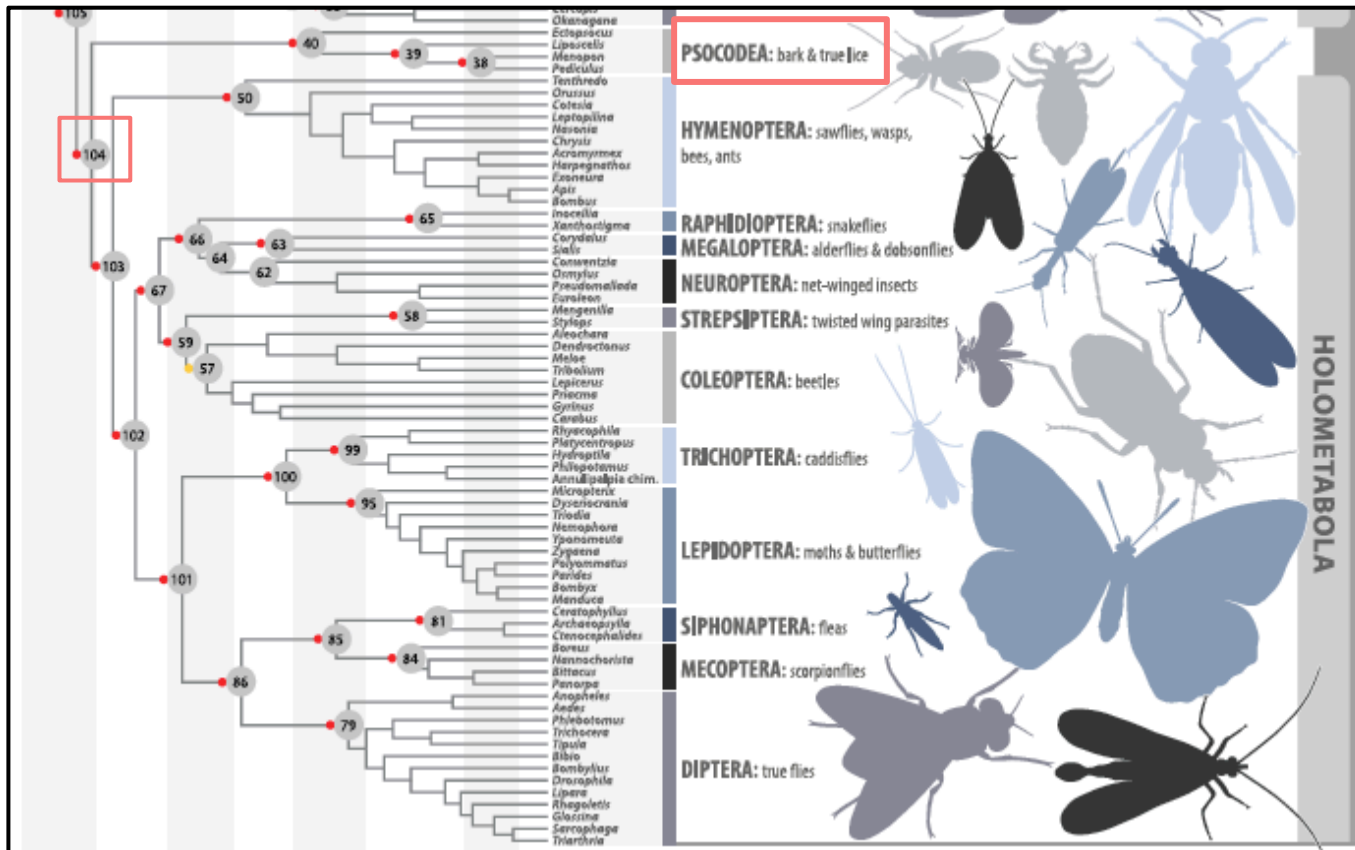
Supported by a 100% jackknife value

Used to estimate bias and standard error of a statistic

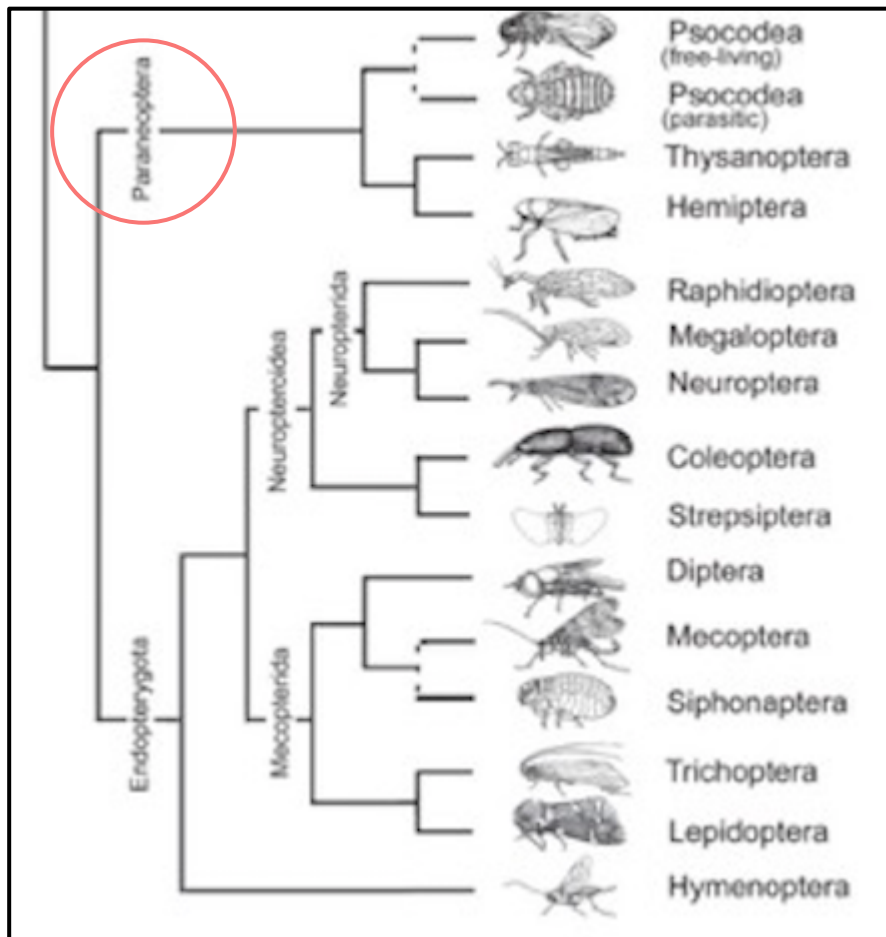


# Psocodea

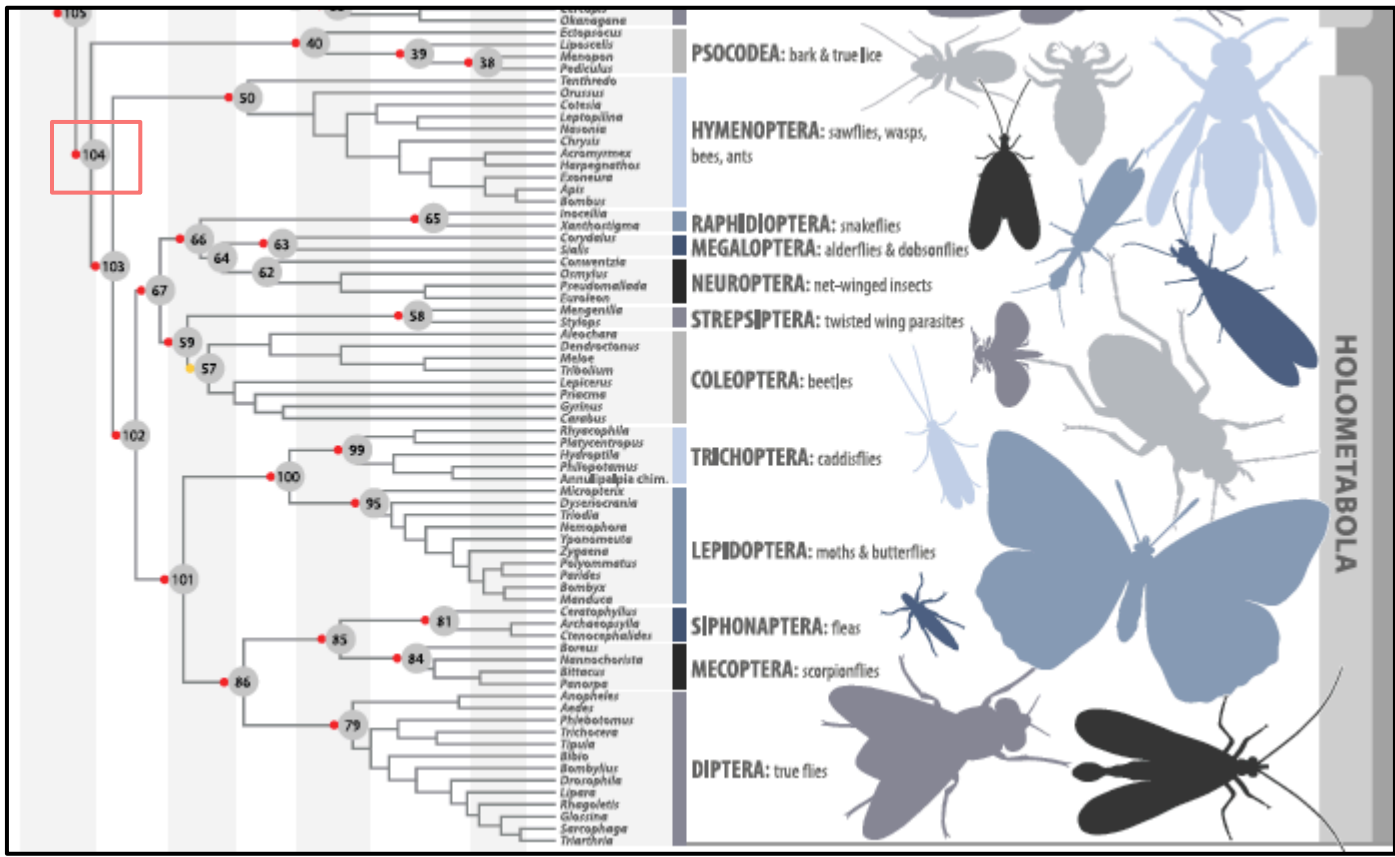
## Bark lice, True lice



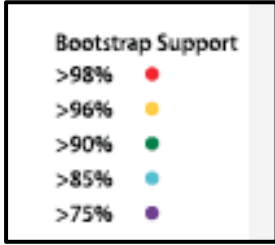
- Psocodea are a lineage that has exhibited inconsistent results in terms of placement/divergence in the insect tree
- This study suggests that Psocodea are sister to Holometabola
- Many disagree with these results



- Phylogeny from the book (2014)
- Most other studies illustrate a similar phylogeny containing a monophyletic clade called **Paraneoptera**, which includes Psocodea, Thysanoptera, and Hemiptera
- Psocodea are **not** sister taxa to Holometabola (Endopterygota) in this phylogeny



- Based on Misof et al.'s data, they are >98% confident that this node is correct
- “This result did not receive support in all statistical tests and ... should be further investigated in future studies that embrace additional types of characters.”

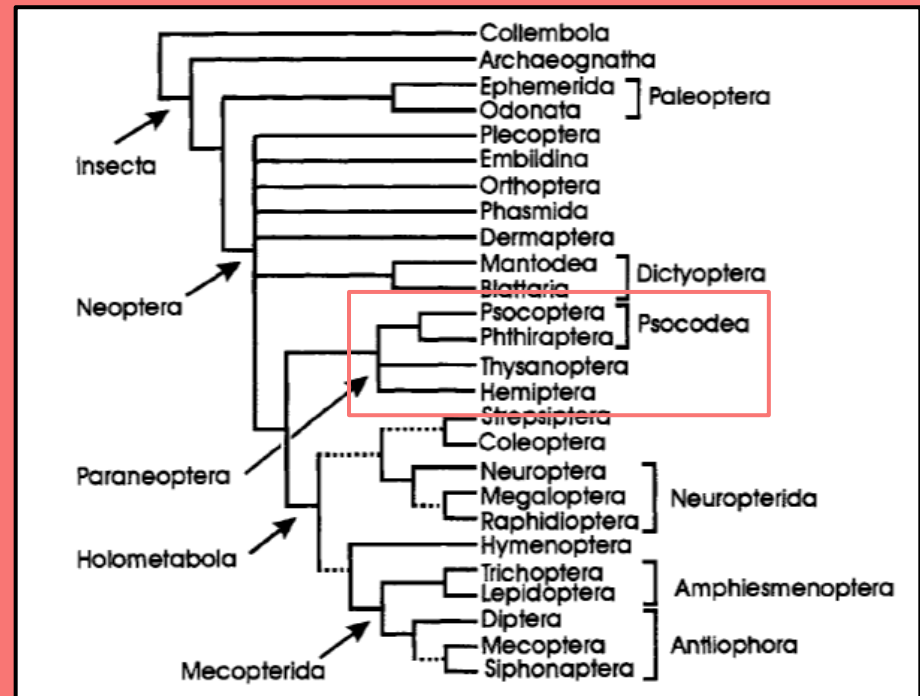


# Now, let's look at older phylogenies ...



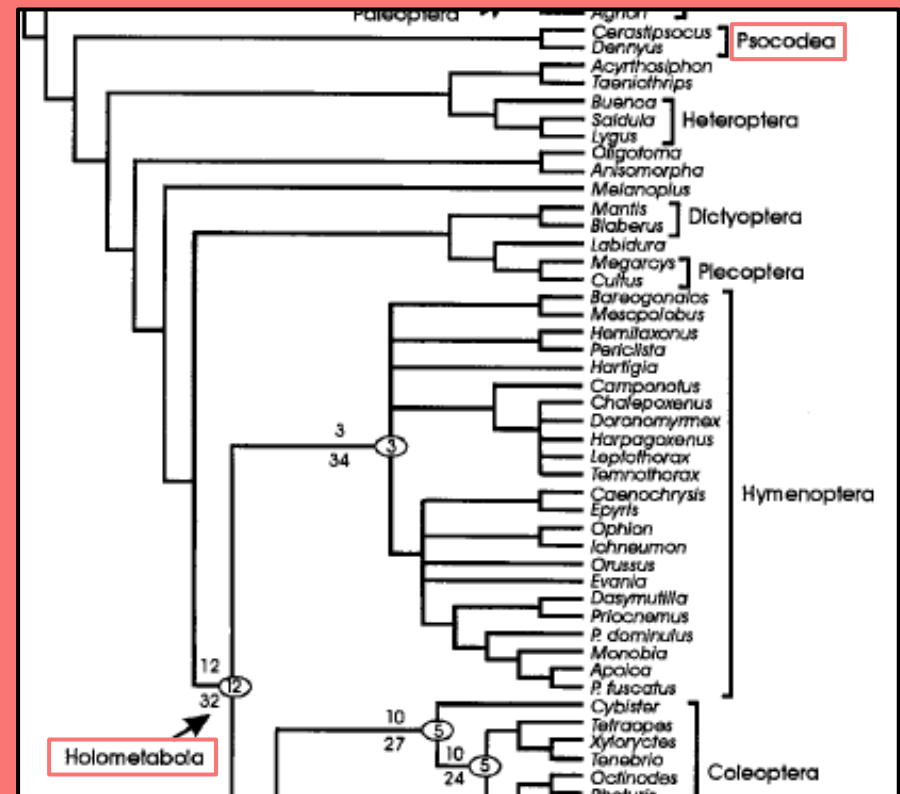
# Kristensen, 1991

- Phylogeny solely based on **morphologies**
- Psocodea sister taxa to Thysanoptera and Hemiptera
  - Monophyletic group
  - Paraneoptera

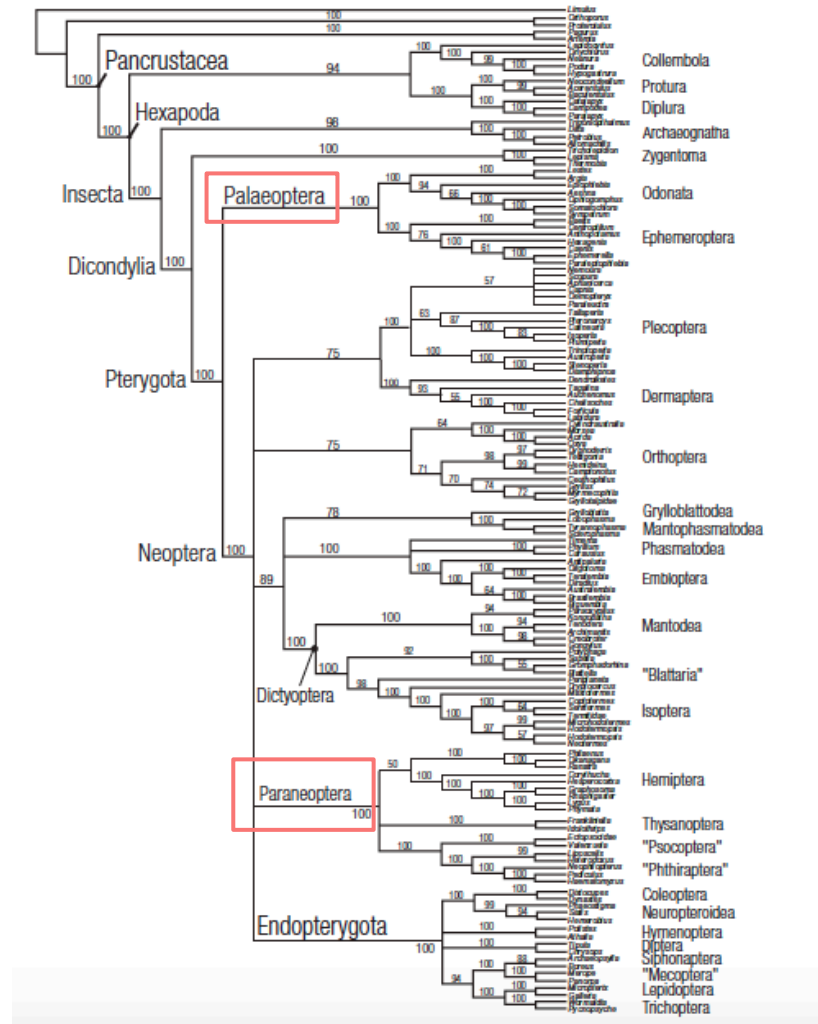


# Whiting, 1997

- Molecular phylogeny of insects
- Psocodea are placed closer to the root of the tree and are **not** grouped with Hemiptera and Thysanoptera



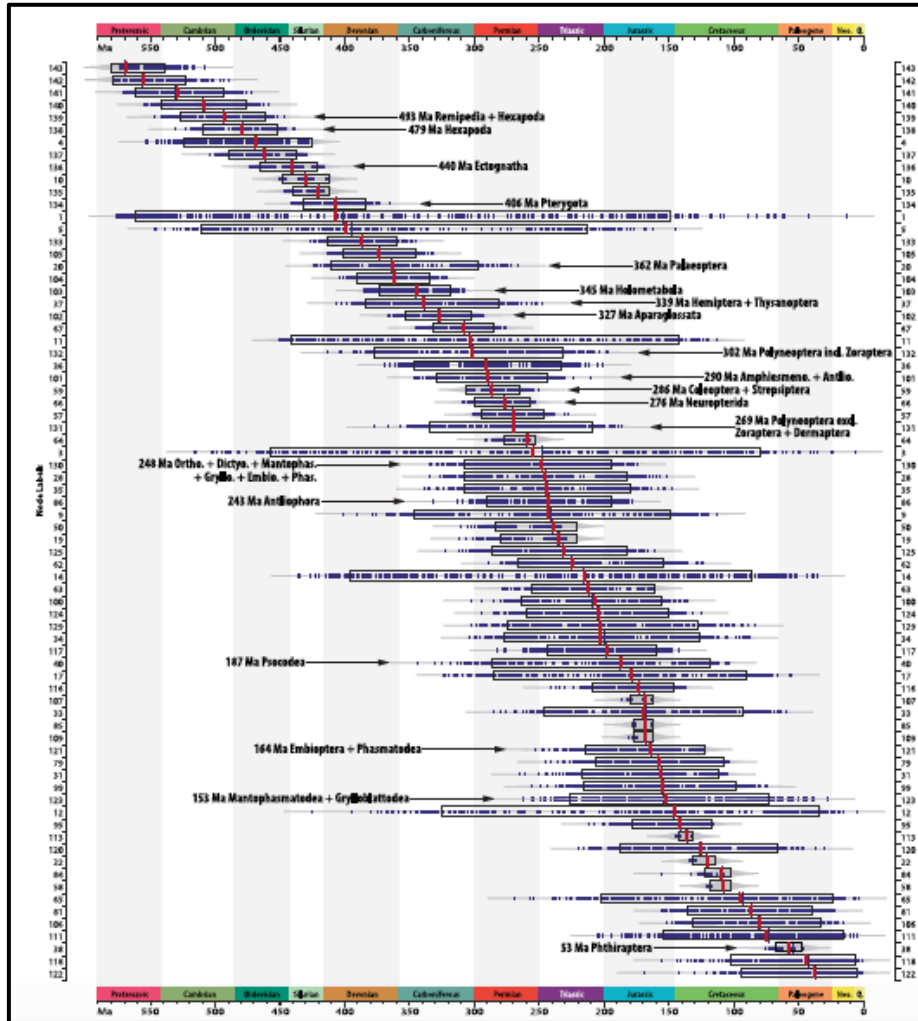
# Kjer, 2006





**Since phylogenies are strictly hypotheses, at what point is a tree that was made up from extensive research considered to be relatively definitive, if ever? In other words, is there a time when research will stop being performed on certain insect taxa because the previous research is accepted?**

- Can never be positive about the insect tree of life, but it can be 'accepted'
- The relationships between many of the taxa are fairly consistent among studies, so these may be accepted by the scientific community due to the large amount of evidence
- There are, however, the few lineages that are more difficult to place
  - Fossils
  - More difficult to obtain evidence
  - Studies have shown inconsistent results



- Each node age estimate refers to the estimated **common origin** of included species

# Big Picture: How else can we use phylogenies?

In response to past climate shifts, the distribution and abundance of a variety of species changed

Cold-dwelling butterflies of the genus *Oeneis* diversified into new habitats during the Pleistocene

A result of adaptive or non-adaptive speciation?

Is it possible to predict species' responses to the current climate change crisis using knowledge of certain traits and phylogenetic relatedness?



**Table 1 Studies examining the ability of phylogeny and traits to predict distribution and phenological shifts<sup>a</sup>**

Taxa	Number of species (N)	Location	Time period	Phylogeny	↑Earlier season	↑Growth rate	↑Dispersal	↑Ecological generalization	↑Body or range size	↑Elevation or latitude	↓Trophic level	R <sup>2</sup>	Reference
<b>Distribution</b>													
Plants	171	Western Europe	1905–2005			+		-					Lenoir et al. 2008
Plants (alpine)	133	Switzerland	1885–2004	1		o	o	o	o	-		0.18	Angert et al. 2011
Butterflies	51	United Kingdom	1970–1999				o	o		o			Hill et al. 2002
Butterflies	48	Finland	1992–2004	3	+	o+	+	x-o	+				Pöyry et al. 2009
Odonata	24	United Kingdom	1960–1995	1		o	o	+	o	o		0.24	Angert et al. 2011
Birds	254	North America	1775–2004	1		o	o	o	o-	o		0.07	Angert et al. 2011
Birds (passerine)	254	North America	1775–2004	1		o	o	+	o	o		0.07	Angert et al. 2011
Birds	55	Peru	1969–2010					o				0.03	Forero-Medina et al. 2011
Fish	90	North Sea	1977–2001			+			-			0.24 <sup>b</sup>	Perry et al. 2005
Fish	28	North Sea	1980–2004							+			Dulvy et al. 2008
Mammals	28	Western North America	1914–2008	1		o		o	o	o-		0.33	Angert et al. 2011
<b>Phenology</b>													
Plants	557	United Kingdom	1954–2000		+	+	-					0.19 <sup>b</sup>	Fitter & Fitter 2002
Plants	478	Eastern United States	1851–2007	5								NA	Willis et al. 2008
Plants	323	United Kingdom	1954–2000	5								NA	Davis et al. 2010
Butterflies/moths	566	Europe	1964–2008	4	+	+		+				0.47 <sup>b</sup>	Altermatt 2010
Butterflies	51	United Kingdom	1976–2010	1	+	o	o	-	-	o		0.52	Diamond et al. 2011
Butterflies	17	Northwest Mediterranean	1988–2002	4	o	o	o	x					Stefanescu et al. 2003
Odonata	37	Netherlands	1995–2004	2								NA	Dingemanse & Kalkman 2008
Odonata	25	United Kingdom	1960–2004	3	+							0.31 <sup>b</sup>	Hassall et al. 2007
Birds	307	Global	1995–2006			o							Gienapp et al. 2007
Birds	184	Europe	1960–2006	5			-					0.18	Rubolini et al. 2007
Birds	117	Eastern Hungary	1969–2007	1		o+	-	o+				0.11 <sup>b</sup>	Vegvari et al. 2010
Birds	103	Eastern United States	1903–1993				-	x				NA	Butler 2003
Birds	100	Europe	1970–2000	1								NA	Davis et al. 2010
Birds	56	Northern Germany	1977–2006	3		o	-	o	o			0.11 <sup>b</sup>	Rubolini et al. 2010
Birds	34	Scandinavia	1980–2004				+						Jonzén et al. 2006
Birds	18	United States	2000–2010				-					0.63	Hurlbert & Liang 2012
Birds	9	Northern Europe	1976–1997	3								0.64	Spottiswoode et al. 2006
Multiple	726	United Kingdom	1976–2005			o		o			+	0.06 <sup>b</sup>	Thackeray et al. 2010
<b>Total +</b>					5	6	2	4	1	1	1		
<b>Total o</b>					1	12	7	9	6	6	0		
<b>Total -</b>					0	0	6	3	3	2	0		

Buckley et al.

- **Darker blue** equates to better predictive ability
- **Light blue** equates to poor predictive ability

# Big Picture: How else can we use phylogenies?

What kinds of characteristics might be *better* predictors of species' responses to climate change?

**Higher individual and population growth rates** enable more rapid evolutionary responses to environmental change

**Higher elevation or more poleward species** may be more responsive to changes because they may be adapted to colder temperatures or may be more habitat restricted

- **Lower trophic levels** may respond more readily to change because they are less constrained by prey availability
- Traits and climate change responses tend to be **phylogenetically conserved**, so further studies will enhance our ability to forecast the ecological consequences of climate change

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**Thank you!**

