J. Appl. Zool. Res. (2020) **31**(1): 1-15
ISSN 0970-9304

EVOLUTION OF MODERN INSECT CLASSIFICATION: A COMPREHENSIVE ACCOUNT

RAHUL KUMAR[1], SHASHANK, P.R.[1] NARESH, M. MESHRAM[1], ANOOJ, S. S.[1] AND KOLLA SREEDEVI[2]*

1= Division of Entomology, ICAR- Indian Agricultural Research Institute, Pusa Campus, New Delhi-110 012, India

2= Division of Germplasm Collection and Characterization, ICAR-National Bureau of Agricultural Insect Resources, Hebbal, Bellary Road, Bengaluru – 560 024, India

*Email ID: spathour@gmail.com (corresponding author)

Received: 18 December, 2019 **Accepted: 31 March, 2020**

ABSTRACT: Insects are the most numerous and diverse group of animals in the entire animal kingdom. Insect classification has evolved in different phases over a considerable period of time. There are four different phases or eras, *viz*., the Pre-Linnean Era, the Linnean Era, the Darwinian Era, and the Hennigian Era and other developments. Among all eras the Hennigian Era marks a revolutionary shift in classification of insects with introduction of Phylogenetic Systematics that strictly considers monophyly of different taxa to decide their respective positions within the tree of classification. Modern classification of insects is based on knowledge gained from multiple sources like Anatomy, Paleontology, Molecular Biology, and Embryology leading to a more natural and reliable classification scheme. Modern classification of insects also reflects their phylogeny. With new findings and advent of new technologies there is always a scope of change in the existing framework of insect classification in future.

KEY WORDS: Classification, Insecta, Monophyly, Phylogeny, Systematics

INTRODUCTION

Being the most evolutionary successful animals on the planet Earth and the most diverse ones, insects were never easy to classify. Insect classification has evolved through hundreds of years. With advent of new technologies, use of molecular tools and discovery of new fossil records, insect classification has been revised from time to time. The evolution of modern classification of insects is often studied under four subheadings as given by ENGEL and KRISTENSEN (2013). These subheadings demarcate different stages of progress in insect classification that is based on the timeline of a set of changes and progression, hence are called **eras**. These stages are: the Pre-Linnean Era, the Linnean Era, the Darwinian Era, and the Hennigian Era and other developments (ENGEL and KRISTENSEN, 2013). With transition of one era into another, the misconceptions of previous one were discarded and crude ideas were more refined with more number of evidences, trying to make the classification system as natural as possible minimizing all sorts of artificialities. A list of important literary contributions from past on insect classification is provided in Table-1 in chronological order.

The Pre-Linnean Era

The most primitive evidence on insect classification comes from the writings of Aristotle (384-322 BC), who, in his book *Historia Animalium*, grouped all flying insects with other flying animals like bats and birds which reflects huge artificiality in his classification (WEISS, 1929). Insects were often perceived to arise spontaneously (a conception, often dubbed as "*the theory of spontaneous generation*", which was later disproved by various workers).

Table-1: Important books on insect classification in past and their authors (based on ENGEL and KRISTENSEN, 2013)

Author	**Book Title**
Aristotle (384-322 BC)	*Historia Animalium*
St. Isidore of Seville (ca. 560-636 BC)	*Etymologiae*
Ulissw Aldrovandi of Bologna (1522-1603)	*De Animalibus Insectin Libri VII*
Thomas Mouffet (1553-1604)	*Insectorumsive Minimorum Animalium Theatrum*
John Ray (1627-1705)	*Historia Insectorum*
Maria SibyllaMerian (1647-1717)	*Metamorphosis Insectorum Surinamensium*
August Johann Rösel von Rosenhof (1705-1759)	*Insecten-Belustigung*
Carl Linnaeus (1707-1778)	*Systema Naturae, Fauna Svecica*
Johan Christian Fabricius (1745-1808)	*Philosophia Entomologica, Systema Entomologiae, Genera Insectorum*
Pierre Andrè Latreille (1762-1833)	*Précis des Caractères Génériques des Insectes*
William Sharp MacLeay (1792-1865)	*Horae Entomologicae (Essays on the Annulose Animals)*
William Kirby (1759-1850) and William Spence (1783-1850)	*An Introduction to Entomology*
Karl Hermann Konrad Burmeister (1807–1892)	*De Insectorum Systemate Naturali, Handbuch der Entomologie*
John Obadiah Westwood (1805–1893)	*An Introduction to the Modern Classification of Insects*
Ernst Heinrich Philipp August Haeckel (1834–1919)	*Generelle Morphologie*
Alpheus Spring Packard (1839–1905)	*Guide to the Study of Insects*
Anton Handlirsch (1865–1935)	*Die Fossilen Insekten*
Frank M. Carpenter (1902–1994)	*Brues & Melander's Classification of Insects (2nd ed.), Treatise on Invertebrate Paleontology*
August D. Imms (1881–1949)	*General Textbook of Entomology*
Emil Hans Willi Hennig (1913–1976)	*Grundzügeeiner Theorie der phylogenetischen Systematik, Die Stammesgeschichte der Insekten*

Saint Isidore of Seville (ca. 560-636 BC), in his book Etymologie, recognized two separate groups, De verminibus and De minutisvolatibus (though both these groups were of insects, these were not included formally under a common insect group) (Barney *et al*., 2006) (Fig. 1).

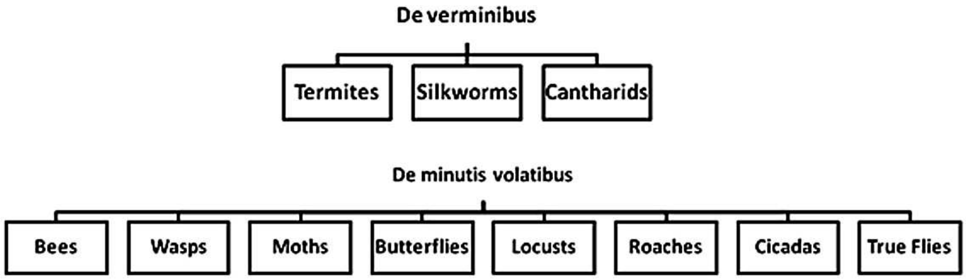

Fig. 1: Two distinct and mutually unrelated groups of "Insects" proposed by Saint Isidore of Seville

Invention of microscope and printing press during 15th century (GUENTHER, 2002) paved way for remarkable revisions of the insect classification. Marcello Malphighi (1628-1694) and Antoine van Leeuwenhoek (1632-1723) studied anatomy of insects using microscope. Inspired by Malphighi study on silkworm, Jan Swammerdam (1637–1680) became pioneer in microscopic study of insect anatomy (SMITH, MITTLER and SMITH, 1973) and has put forward a revolutionary classification of insects in 1669 based on their modes of development, which is in use still today. Ulisse Aldrovandi (1522-1605) of Bologna is credited to write the first specialized text exclusively on the study of insects (OGILVIE, 2008). Aldrovandi in 1602 distinguished insects based on their habitat mainly land and water (terrestrial and aquatic) and attempted classification of insects based on wing and leg morphology. Thomas Mouffet (1553-1604) attempted to classify insects based on their habits in his book *Insectorum sive Minimorum Animalium Thetrum* (KRISTENSEN, 1999). An influential work of this era on classification of insects based on their morphology, biology, ecology and anatomy was produced by John Ray (1627-1705) in his book *Historia Insectorum* (RAVEN, 1942). Maria Sibylla Merian (1647-1717), Furchault de Reaumur (1683-1756) and Rösel von Rosenhof (1705-1759) extensively studied the life histories of insects and along with John Ray, they influenced the research work of Linnaeus (ENGEL and KRISTENSEN, 2013).

The Linnean Era

As the name reflects, this era includes the period when Carl Linnaeus (1707-1778) put forth a systematic classification of insects in 10th edition of his book *Systema Naturae* wherein the bionomial nomenclature as the convention of naming the organisms was popularized. He classified insects on the basis of presence or absence and the number of wings present in adult insect. He recognised three "alae" under class Insecta, namely Aptera with no wings, Diptera with 2 wings, Superior alae with 4 wings and Omnes with 4 wings (LINNAEUS, 1758) (Fig. 2). Johan Christian Fabricius (1745-1808) classified insects on the basis of mouth parts and he regarded it as a more natural character than number of wings (Fig. 3). He published his system of classification in his books *Systema Entomologiae* and *Genera Insectorum* (SMITH *et al*., 1973). Baron Charles De Geer (1720-1778) tried to unite systems of Linnaeus and Fabricius and proposed a new order Dermaptera. Guillaume Antoine Olivier (1756-1814) recognised another new order Orthoptera (earlier included under Neuroptera) (SMITH *et al.,* 1973; ENGEL and KRISTENSEN, 2013).

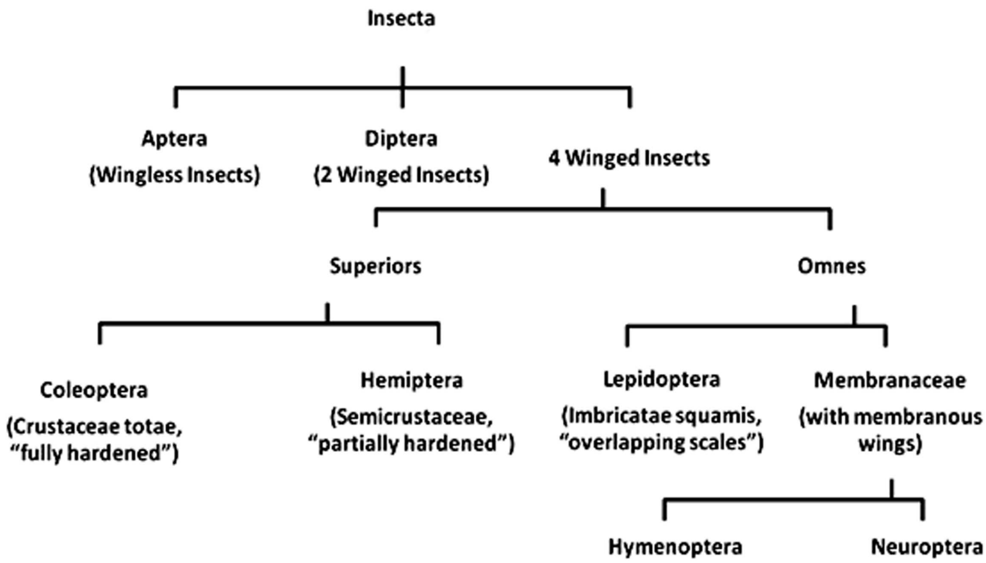

Fig. 2 Classification of insects proposed by Linnaeus

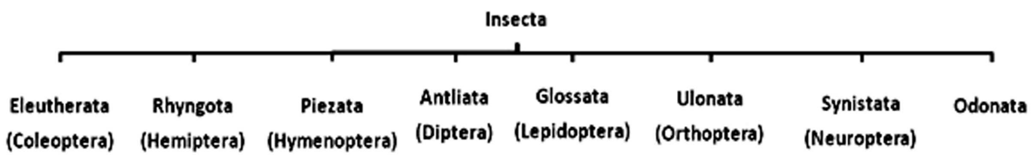

Fig. 3 Classification of insects proposed by Fabricius

Glovami Antonio Scopoli (1723-1788) stated that classification should be based on whole structure of the insects. Utilising multiple traits, PIERRE ANDRÈ LATREILLE (1762-1833) proposed the classification of insects that is considered first truly natural classification of insects (Fig. 4) (SMITH *et al*., 1973). His contemporaries, Etienne Geoffroy Saint-Hilaire (1772-1844), Jean Baptiste Lamarck (1744-1829) and Georges Cuvier (1769-1832) are credited of studying comparative anatomy, homology, and evolution of different animal groups including insects' thereby influencing biology as a whole on a wider level (APPEL, 1987; RACINE, 2013). William Sharp MacLeay's (1792-1869) quninarian system and Edward Newman's septenary system of classification were based on the philosophy of Lamarck but were quiet weird in the sense that these always involved grouping and subgrouping of insects into 5 and 7 taxa (order, families, etc.), respectively (ENGEL and KRISTENSEN, 2013). William Kirby (1759-1850) proposed two new orders i.e. order Strepsiptera and order Trichoptera and along with William Spence (1783-1850), he wrote a book "An Introduction to Entomology". **William Kirby** is considered as the **Father of Entomology** (CLARK, 2009). Karl Hermann Konrad Burmeister (1807-1892) classified insects mainly on the basis of different kinds of metamorphosis and to some extent he also considered other characters like wings and mouthparts (SMITH *et al.*, 1973; ENGEL and KRISTENSEN, 2013) (Fig. 5).

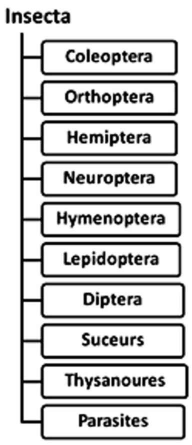

Fig. 4: Latreille's Classification of insects

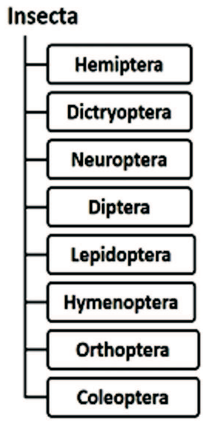

Fig. 5: Burmeister's Classification of insects

Westwood (1805-1893) of Oxford University proposed a classification of "Hexapod metamorphotic insects" based mainly on the type of mouth parts. He recognised various series orders and few osculant orders which act as connecting links between two series orders (Fig. 6). Instead of various drawbacks like considering Thysanoptera to be osculant order between order Orthoptera and Neuroptera, by describing consistent patterns of characters and pointing connecting links (WESTWOOD, 1839; WESTWOOD, 1840).

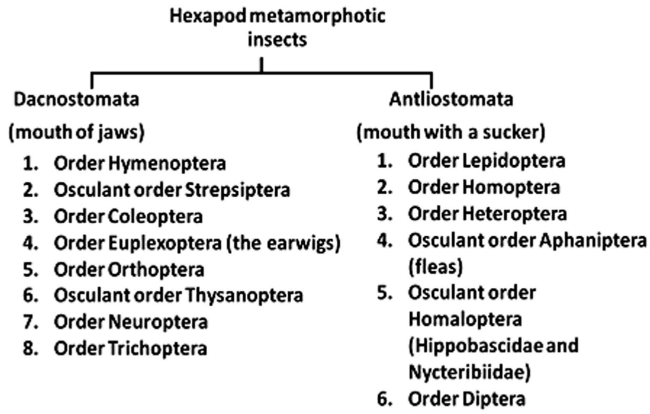

Fig. 6: Westwood's Classification of "Hexapod Metamorphotic Insects"

The Darwinian Era

In this era, studies on the classification of insects achieved new horizons as these were initiated to study under the light of evolution after Charles Darwin (1809-1882) proposed his revolutionary "Theory of Natural Selection" of organic evolution in his book "On the Origin of Species by Means of Natural Selection, or the Preservation of Favoured Races in the Struggle for Life" (FREEMAN, 1977). To establish "natural" relationships among taxa, entomologists started considering new and more characters while classifying insects. James Dwight Dana (1813-1895) put stress upon the degree of cephalization (DANA, 1864), Gustav Schich (1833-1899) and Franstišek Klap lek (1863-1919) emphasized on the structure of the thorax and mode of locomotion, John Bernhardt Smith (1858-1912) focused on mouth parts and thoracic characters, Benjamin Cooke (1816-1833) emphasized on nature of the pupa, Carlo Emery and Vein Graber (1844-1892) considered development and embryology more important for classifying the insects (WILSON and DONER, 1937).

Ernst Heinrich Philipp August Haeckel (1834-1919) for the first time proposed an explicit phylogeny of the insect orders (termed articulata) in his book Generelle Morphologie (WILLMANN, 2003). Paul Mayer (1848-1923) attempted to reconstruct an ancestral insect Protentomon and suggested parallel evolution of wingless hexapods and winged hexapods. Alpheus Hyatt (1838-1902) and Jennie M. Arms (1852-1937) are credited for constructing an explicit evolutionary tree of insects and they considered Ephemeroptera as a distinct order. Friedrich, M. Brauer (1832-1904) was the first to classify insects based on Darwinism (BRAUER, 1869; BRAUER, 1885) (Fig. 7).

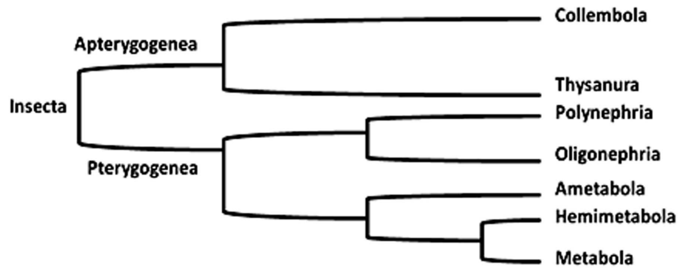

Fig. 7: Brauer's Classification of insects depicted in the form of a tree

In his classification, Brauer put all primarily wingless taxa under Apterygogenea and all secondarily wingless taxa and winged forms under Pterygogenea. He along with Labbock suggested independent evolution of Apterygogenea and Pterygogenea. He recognised 16 orders. Earlier he put termites, bark lice and true lice under Corrodentia and also accepted Erichson's grouping of mayflies, dragonflies, damselflies, stoneflies and Comstock's grouping of corrodentia under Pseudoneuroptera. But later he recognised the artificiality of these groups and classified them as distinct orders, Isoptera, Ephemeroptera (then called as Ephemerida), Odonata, Plecoptera, Mallaphaga and Corrodentia (equivalent to Psocoptera). He also suggested a new order Panorpatae (now known as Mecoptera or Mecaptera) for scorpionflies same time with Packard, and Hyatt and Arms. Alpheus Spring Packard (1839-1905) proposed an evolutionary classification in which hierarchy was generated by creating superorders, orders and suborders. He recognized Eurynchota (modern Paraneoptera) under superorder Phyloptera. He also recognized Orthoptera, Dermaptera, Neuroptera (for Trichoptera and Planipennia) and Pseudoneuroptera (for Odonata, Ephemeroptera and Platyptera) as orders (SMITH *et al.*, 1973; ENGEL and KRISTENSEN, 2013).

The classification system of insects in this era showed a progressive shift in pattern over previous systems as it involved evolution of systems based on diverse characters, analogy-homology distinction and dealing with problems concerned with assigning weightage to conflicting characters, etc. This era witnessed the rise of the field of Palaeoentomology. Scientists started exploring palaeontological evidences to understand interrelationships of insects. These studied influenced the classification of insects too. Samuel, H. Scudder (1837-1911) published one of the first catalogues of the fossil insects of the world (SCUDDER, 1891). Friederich Goldenberg (1798-1881) & Charles Brongniart (1859-1899) proposed groups such as Palaeodictyoptera, Megasecoptera and Protodonata for fossil insects and regarded them as primordial prodenitors of living insect orders (CARPENTER, 1992).

Anton Handirsch (1865-1935) recognized that it is not necessary that all fossil lineages must leave modern counterparts rather some become extinct without leaving any successor. He proposed few extinct orders too. Handlirsch wrote one of the most comprehensive accounts of fossil insects in the form of three volume monolith named *Die FossilenInsekten* integrating Palaeontology and Neoentomology. He proposed evolutionary history of insects based on palaeontological evidence. His accounts also suffered few drawbacks like he wrote that pterygotes arose from a trilobite ancestor which was found to be incorrect (GRIMALDI, 2001).

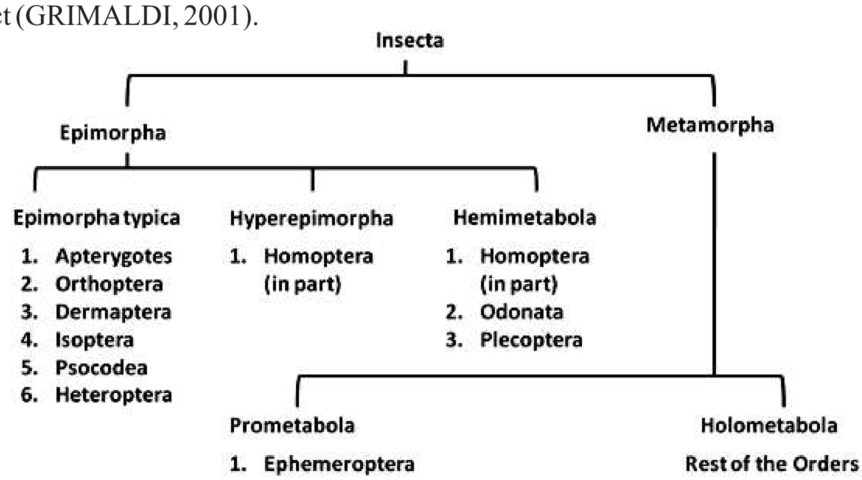

Fig. 8: Classification of insects proposed by Richard Heymons

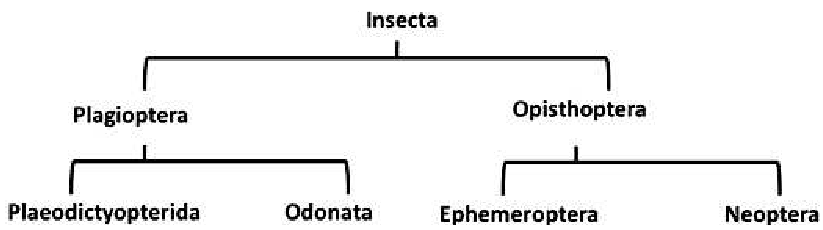

Fig. 9: Division of insects according to Lemche

Crampton (1881-1951) studied Grylloblatta and recognised new taxa called Notoptera. Carl, J. B. Börner (1880-1953) recognised the differences between Zygentoma (silverfish) and Archaeognatha (bristletails), and suggested their separation into different groups. He suggested silverfish to be allied to Pterygota (that was later recognised by Willi Hennig who placed silverfish and pterygotes under a common clade). He also suggested closeness among Odonata and Neoptera based on his studies on mouth parts and proposed a higher group named Metapterygota to include them. He supported anatomical evidences consisting of more number of characters than fragmentary palaeontological evidences based on few characters (SMITH *et al.*, 1973; ENGEL and KRISTENSEN, 2013). Similarly Heymons (1867-1943) focused more on development of insects, elucidating many finer aspects of insect development. Based on his studies he proposed a classification of insects as depicted in Fig. 8 (HEYMONS, 1909).

Four new extant higher-rank taxa were described in the beginning of 20th century that played a pivotal role in studying insect phylogeny. These are Protura, Zoraptera, Grylloblattodea and nammochoristid scorpion flies. Based on the fundamental structure of insect wings, Martynov proposed division of winged insects (Pterygota) into Palaeoptera and Neoptera (ENGEL and KRISTENSEN, 2013). Most entomologists supported common origin of pterygotes but Lemche suggested a diphyletic origin of winged insects dividing insects into two broad groups, Plagioptera and Opisthoptera, and their further sub-divisions as shown in Fig. 9 (MATSUDA, 1981).

The Hennigian Era and subsequent developments

This era marks the breakthrough in studies pertaining to the classification of insects. The basic framework of classification of insects got established in this era. David Sharp (1840-1922) divided winged insects into Exopterygota and Endopterygota on the basis of external or internal development of wings that was adopted by August D. Imm (1881-1949) too in his influential book *"General Textbook of Entomology"* (RICHARDS and DAVIES, 1957; RICHARDS and DAVIES, 1977). Non-endopterygote insects were never grouped together in past. Crampton objected this classification citing it's non-agreement with the concepts of phylogeny (Crampton, 1938). Hermann Rober Weber (1899-1956) supported non-monophyly of endopterygote insects as earlier suggested by Handlirsch. He was of the opinion that different endopterygotes were independently derived from nonendopterygote ancestors (ENGEL and KRISTENSEN, 2013).

As the name of this era suggests, this period marks the occurrence of Hennigian Revolution (or Cladistic Revolution) that led to the development of the field of Phylogenetic Systematics. Phylogenetic Systematics deals with organising (more precisely systematising) organisms solely on the basis of synapomorphy into taxa where each taxon includes organisms that are strctly monophyletic in nature. This very concept of Phylogenetic Systematics was materialised by Emil Hans Willi Hennig's (1913–1976) in his book *Grundzügeeiner Theorie der phylogenetischen Systematik* (ENGEL and KRISTENSEN, 2013). He discarded taxa Apterygota except Thysanura, where the latter included the non-monophyletic taxa Archaeognatha and Zygentoma. He proposed names for putative monophyletic taxa that included Zygentoma and Pterygota as "Dicondyla" and that included Psocoptera, Mallophaga and Anoplura as "Psocodea". He included monophyletic Odonata along with Neoptera within Boner's Metapterygota. He accepted monophyly of Parametabola (Paraneoptera), Saltatoria (Orthoptera) and the clade containing Mantodea along with Blattodea and Isoptera.

Monophyly of Paurometabola (Polyneoptera) was not accepted. The monophyly of Coleoptera, Hymenoptera, Neuropteria and Mecopteria was accepted within endopterygotes but Strepsiptera and Siphonaptera were suggested to be unassociated with other endopterygotes. Parametabolans and Endopterygotes were included under monophyletic Eumetabola. He revised and expanded the account of insect phylogeny in his book *'Die*

Stammesgeschichte der Insekten". In this book he proposed more resolved and natural order-level phylogeny of insects. He recognized monophyletic nature of Ellipura, Palaeoptera, and Paurometabola (this includes Polyneoptera minus Plecoptera). He proposed relationship among different taxa within monophyletic Paurometabola as represented in Fig. 10 (HENNIG, 1969; 1981).

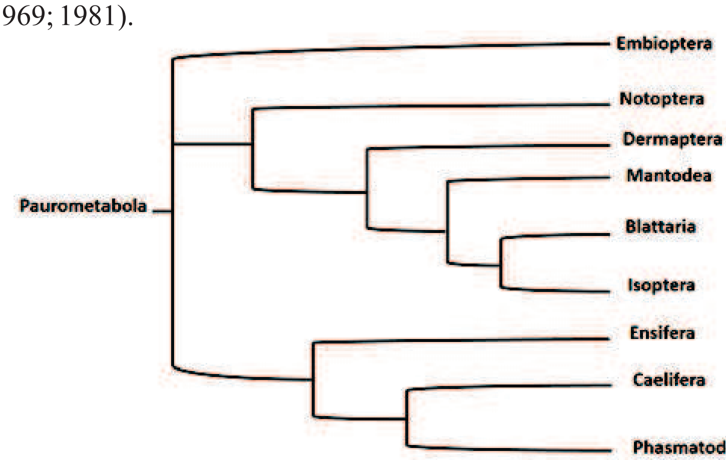

Fig. 10: Tree showing relationship among different Taxa under Monophyletic Clade Paurometabola as proposed by Hennig (branch length not up to scale)

Howard, E. Hinton (1913-1977) provided important information regarding insect phylogeny in a review published in third volume of Annual Review of Entomology. He mentioned about the polyphyletic nature of Myriapoda and Hexapoda, closeness of Symphyla, Entotrophi (Diplura) and Insecta, recognition of Collembola to be a distinct class with respect to the Insecta, recognition of Protura as a distinct class from the Insecta, demarcation of strong differences between Ephemeroptera and other pterygotes; specially; Odonata, removal of the Dictyoptera from the order Orthoptera, recognition of close relationship of Isoptera and Zoraptera with the Dictyoptera; and recognition of close relationship among clades Megaloptera plus Neuroptera and Coleoptera plus Strepsiptera. His findings suffered from few drawbacks too. Zorapteran affinities are obscure and not yet fully resolved but he recognized close relationship of Zoraptera with Isoptera and Dictyoptera. He proposed separate order for micropterigid moths (order Zeugloptera) and boreidmecopterans (order Neomecoptera) that was incompatible with logic of Phylogenetic-Systematics (SMITH et al., 1973; ENGEL and KRISTENSEN, 2013).

Initiated by Weber and latter carried forward by Gerhard Mickoleit in more extensive manner, a trend of clarifying phylogenetic issues using anatomical data was a remarkable approach for modern classification. Using same approach Mickoleit confirmed the monophyly of Mecopterida and the clade consisiting of Diptera plus Mecoptera on the basis of his studies on the pterothorax; the monophyletic status of Neuropterida, the monophyly of clade consisting of Raphidioptera, Megaloptera and Neuroptera/Planipennia and sister group relationship between Neuropterida and Coleoptera on the basis of his studies on endopterygote ovipositors and their derivatives. Rähle suggested sister group relationship between the Embiodea and Phasmatodea that was later confirmed using molecular analyses (ENGEL and KRISTENSEN, 2013). Kristensen cited some drawbacks in Hennig's work like ambiguity of some clades and their contradictory nature, and insufficient number of evidences or literature cited in favour of many of his findings. In this regard, Hennig ambiguously placed Strepsiptera under Endopterygota that was questioned by Kristensen. Also the unresolved status of assemblage/clade containing Plecoptera plus Paurometabola was brought into picture (KRISTENSEN, 1975).

Later, H. Bruce Boudreux provided a much resolved hexapod tree consisting of both insects and non-insect hexapods. He suggested sister group relationships between Ephemeroptera and Neoptera, between Plecoptera and Embioptera, between Gryllablattodea and clade comprising of Zoraptera and assemblage of Isoptera and Blattodea-Mantodea pair within. Among Holometabolans, he suggested sister group relationship between Neuropterida and Mecopteroida (BOUDREUX, 1979).

In the same era, insect Palaeontology achieved new heights. Works of Aleksander Grigorevich Sharav (1922-1973) and Boris Borisovich Rohdendorf (1904-1977) helped Hennig to establish time of origin of the recognized high-rank clades (GRIMALDI and ENGEL, 2005). KUKALOVÁ-PECK (2008) worked extensively on morphology of fossil insects and studied origin of extant insect taxa based on paleontological evidences. She established monophyly of Palaeoptera, included monophyletic clade Orthoneoptera (consisting of Plecoptera, Embioptera, and Orthoptera) within neoptera, established monophyly of Blatoneoptera (consisting of Dermaptera, Gryllablattodea and Dictyoptera), and recognized sister group relationship among Orthoneoptera, Blatoneoptera and clade consisting of Paraneoptera plus Endopterygota (KUKALOVA-PECK and BRAUCKMANN, 1992 and KUKALOVA-PECK, 2008).

Table-2: List of some important fossil insect taxa (based on GRIMALDI, 2001)

S. No.	Order	Fossil Taxa	Site of Discovery	Period
1.	COLLEMBOLA	*Rhyniellapraecursor*	Scotland	Devonian
2.	COLLEMBOLA	*Permobrya mirabilis*	South Africa	Permian
3.	ARCHAEOGNATHA	*Monura (Dasyleptus)*	Europe	Carboniferous
4.	ARCHAEOGNATHA	*Triassomachilis*	Europe	Triassic
5.	Lepidothrichidae*	*Lepidotrix*	Baltic	Eocene amber
6.	EPHEMEROPTERA	*Lithoneura*	Illinois	Carboniferous
7.	EPHEMEROPTERA	*Protereisma*	Kansas, Oklahoma	Permian
8.	Palaeodictyopteroidea**	*Thuringopteryx*	Germany	Triassic
9.	MANTODEA	*Jersimantis*	New Jersey	Cretaceous amber
10.	ISOPTERA	*Meiatermes*	Spain	Cretaceous
11.	ISOPTERA	*Valditermes*	England	Cretaceous
12.	ISOPTERA	*Cretatermes carpenteri*	Canada	Cretaceous
13.	ISOPTERA	*Carinatermes*	New Jersey	Cretaceous amber
14.	EMBIOPTERA	*Burmitembia*	Burma	Cretaceous amber

*Extinct family. **Extinct super order.

Contemporary discoveries of fossil deposits like Cretaceous Lagerstätte and insect bearing amber deposits led to surge in number of newly described fossil insect species that contributed much to establish more precise and accurate phylogenetic relationships among extant taxa with respect to their ancestral counterparts (GRIMALDI and ENGEL, 2005).

Table-2 shows list of some of the important insect fossils described from these fossil deposits (GRIMALDI, 2001).

Modern Classification of Insects

Modern classification of insects is more natural and accurate than previous classifications. It is based on multiple evidences like Palaeontology, Embryology, Anatomy as well as Molecular Biology. Such an approach based on multiple sources that takes advantage of complementarily among disciplines to characterize, classify and name taxa is known as Integrative Taxonomy (SCHLICK-STEINER *et al*., 2010). With invention of Electron Microscopy and advanced Molecular Biology tools, it has become easier to establish more accurate phylogenetic relationships among various high rank taxa. DNA sequence data are widely used now-a-days to establish relationships among low rank taxa as well, e.g., identification of species, genus, varieties as well as solving family level conflicts by comparing sequence from different specimens. This approach is called Comparative Genomics (MILLER *et al.*, 2004).

To gain wider and more accurate insights, modern entomologists use sequence data from both Genomic DNA as well as Mitochondrial DNA. Using Mitochondrial DNA sequence has some specific advantages as it is maternal in origin, simple in structural design as it doesn't contain introns and have lost recombination ability, making it a reliable tool to trace point of divergence and extant of accumulation of genetic changes in an organism over time (DESALLE, 2017). For instance, mitochondrial Cyochrome Oxidase-I gene is being used universally to generate DNA Barcode of different species among invertebrates (FOLMER *et al*., 1994). DNA Barcodes are molecular signatures based on specific DNA sequences that are unique for each individual species. Also, the availability of *in silico* tools and publically accessible data bases containing DNA sequences over internet has revolutionized the area of molecular analyses to establish more reliable phylogenetic relationships among taxa (as well as individual organisms) (WILSON *et al*., 2017).

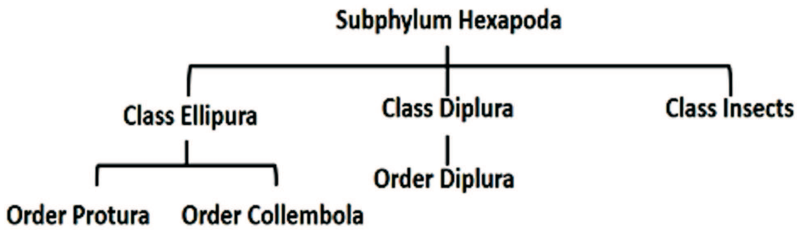

Fig. 11: Outline of the modern classification of Subphylum Hexapoda

In modern classification, non-insect hexapods have been assigned two classes, Ellipura and Diplura, and all true insects have been grouped together under class Insecta. Class Ellipura is further divided into two orders, Protura (coneheads) and Collembola (springtails). Class Diplura consists of only one order Diplura (two-pronged bristletails) (ANDERSON, 2001). Class Insecta is an assemblage of a large number orders assigned under different subclasses and comprises of the largest number of species in animal kingdom. The outline of modern classification of class Insecta up to the rank of orders has been tabulated below (Table-3). This classification has been taken from BARNARD (2011) which as 28 Orders.

This classification has also been accepted and followed by Royal Entomological Society. Many modern zoologists and entomologists like RUPPERT, FOX and BARNES (2004); BRUSCA and BRUSCA (2003); ANDERSON (2001) follow or have proposed somewhat similar classification of insects with minor modifications.This classification takes into account the monophyly of each taxa to avoid coming together of non-monophyletic taxa and to allow closely related taxa to be grouped together. In this regard, monophyletic order Dictyoptera includes three suborders Blattodea, Mantodea and Isoptera that were demoted from the rank of independent orders, the reason that led these suborders to get their names mentioned in Table-3 as well. Name of many orders have kept as it is to avoid confusion and to allow easy comparison with respect to older classifications. For many such reasons, present classification of insects also represents phylogeny of insect taxa. This classification is simple, easy-to-follow yet accurate in comparison to earlier classifications of insects.

Table-3: Modern Classification of Class Insecta (BARNARD, 2011)

Class INSECTA

- Subclass Apterygota
  - Order Archaeognatha or Microcoryphia (Bristletails)
  - Order Zygentoma (Silverfish and firebrats)
- Subclass Palaeoptera
  - Order Ephemeroptera (Mayflies or upwing flies)
  - Order Odonata (Dragonflies and Damselflies)
- Subclass Polyneoptera
  - Order Dermaptera (Earwigs)
  - Order Dictyoptera (Cockroaches, termites and mantids)
    - Suborder Blattodea, Blattaria, or Blattoptera (Cockroaches)
    - Suborder Mantodea (Mantids)
    - Suborder Isoptera (Termites)
  - Order Embioptera (Webspinners)
  - Order Grylloblattaria (Rock crawlers)
  - Order Mantophasmatodea (Heelwalkers)
  - Order Orthoptera (Grasshoppers, crickets and bush-crickets)
  - Order Phasmida (Stick insects)
  - Order Plecoptera (Stoneflies)
  - Order Zoraptera (Zorapterans)
- Subclass Paraneoptera
  - Order Hemiptera (True bugs)
  - Order Phthiraptera (Sucking and biting lice)
  - Order Psocoptera (Booklice and barklice)
  - Order Thysanoptera (Thrips)
- Subclass Endopterygota
  - Order Coleoptera (Beetles)
  - Order Diptera (True flies)
  - Order Hymenoptera (Ants, bees and wasps)
  - Order Lepidoptera (Butterflies and moths)
  - Order Mecoptera (Scorpionflies)
  - Order Megaloptera (Alderflies)
  - Order Neuroptera (Lacewings)
  - Order Raphidioptera (Snakeflies)
  - Order Siphonaptera (Fleas)
  - Order Strepsiptera (Stylops)
  - Order Trichoptera (Caddisflies or sedge flies)

Another recent classification of insects as compiled by Gary Parsons (PARSONS, 2015) has elevated the orders Protura, Collembola and Diplura to the status of class and has included 27 orders under class Insecta. Following Willi Hennig's classification, Thysanura has been referred as order Zygentoma. The orders Grylloblattodea and Mantophasmatodea have been included under order Notoptera and Isoptera into Blattodea in the recent classification.

CONCLUSION: The classification of insects which we follow today is the result of numerous years of hard work by myriad number of keen researchers. Modern classification of insects is based on evidences derived from multiple sources. This makes this classification more reliable and accurate. This doesn't imply that this area of study has achieved a static phase. Insect classification is still evolving. It is a dynamic area that is still under the process of continuous refinement. With accumulation of more evidences, there is always a possibility of new additions, arrangements and subtractions of taxa from existing classification scheme

REFERENCES

ANDERSON, D. T. 2001. Invertebrate Zoology, 2nd edn. *Oxford University Press, Victoria,* pp 1-476.

APPEL, T. A. 1987. *The Cuvier-Geoffroy Debate: French Biology in the Decades Before Darwin. Oxford Univ. Press, Oxford, U.K.,* pp 1-334.

BARNARD, P. C. 2011. The Royal Entomological Society Book of British Insects. *Wiley-Blackwell.* pp 1-396.

BARNEY, S. A., LEWIS, W. J., BEACH, J. A. and BERGHOF, O. 2006. The *Etymologies of Isidore of Seville. Cambridge Univ. Press, Cambridge, U.K.,* pp 1-488.

BOUDREAUX, H. B. 1979. Arthropod Phylogeny with Special Reference to Insects. *Wiley, New York.* pp 1-320.

BRAUER, F. 1869. *Betrachtungenuber die Verwandlung der Insektenim Sinne der Descendenz-Theorie. Verhandl. k.-k. Zool. Bot. Ges.,* **19**: 299–318.

BRAUER, F. 1885. *Systematische-ZoologischeStudien. Sitzungsber. kais. Akad. Wissen., Math.-Naturwissen. Klass., Abt. 1, Mineral. Bot. Zool. Anat. Geol. Palaontol.*, **91**: 237–414.

BRUSCA, R. C. and BRUSCA, G. J. 2003. Invertebrates. Sinauer Associates, *Sunderland, Massachusetts.* pp 1-922.

CARPENTER, F. M. 1992. Superclass Hexapoda. *In Treatise on Invertebrate Paleontology, Part R, Arthropoda 4, Vols. 3–4, ed. Kaesler, R.L. Geol. Soc. Am. Univ. Kans, Lawrence,* pp 1-655.

CLARK, J. F. M. 2009. Bugs and the Victorians. *Yale University Press*. pp 1-322.

CRAMPTON, G. C. 1938. The Interrelationships and Lines of Descent of Living Insects. *Psyche,* **45**: 165–181.

DANA, J. D. 1864. The classification of animals based on the principle of cephalization. No. II. Classification of Insects. *Am. J. Sci. Ser. 2.* **37**: 10–33.

DESALLE, R., SCHIERWATER, B. and HADRYS, H. 2017. MtDNA: The Small Workhorse of Evolutionary Studies. *Frontiers in Bioscience, Landmark.* **22**: 873-887.

ENGEL, M. S. and KRISTENSEN, N. P. 2013. A history of entomological classification. *Annual Review of Entomology,* **58**: 585-607.

FOLMER, O., BLACK, M., HOEH, W., LUTZ, R., and VRIJENHOEK, R. 1994. DNA Primers for Amplification of Mitochondrial Cytochrome C Oxidase Subunit I from Diverse Metazoan Invertebrates. *Molecular Marine Biol. & Biotech.* **3**(5): 294-299.

FREEMAN, R. B. 1977. The Works of Charles Darwin: *An Annotated Bibliographical Handlist. 2nd edn. Folkstone, Dawson,* pp 1-235.

GRIMALDI, D. 2001. Insect Evolutionary History from Handlirsch to Hennig, and Beyond. *J. Paleont*., **75**(6): 1152–1160.

GRIMALDI, D. and ENGEL, M. S. 2005. Evolution of the Insects. *Cambridge Univ. Press, Cambridge, U.K.,* pp 1-760.

GUENTHER, A. H. 2002. International Trends in Applied Optics. *SPIE Press, Bellingham, WA.,* pp 1-697

HENNIG, W. 1969. *Die Stammesgeschichte der Insekten*. *Kramer, Frankfurt*, pp 1-436.

HENNIG, W. 1981. Insect Phylogeny. *Wiley, New York*, pp 1-514.

HEYMONS, R. 1909. *Die verschiedenen Formen der Insecten-metamorphose und ihreBedeutungim Vergleichzur Metamorphose anderer Arthropoden. Ergeb. Fortschr. Zool*., **1**: 137–188.

KRISTENSEN, N. P. 1975. The Phylogeny of Hexapod "Orders". A Critical Review of Recent Accounts. *Z. Zool. Syst. Evol.* **13**: 1–44.

KRISTENSEN, N. P. 1999. Lepidoptera, Moths and Butterflies: Evolution, Systematics and Biogeography. *Handbuch der Zoologie: Eine Naturgeschichte der Stämme des Tierreiches. Arthropoda: Insecta. Walter de Gruyter, Berlin,* **4**(35): 1-5

KUKALOVA-PECK, J. 2008. Phylogeny of higher taxa in Insecta: finding synapomorphies in the extant fauna and separating them from homoplasies, *Evol. Biol.* 35: 4–51.

KUKALOVA-PECK, J. and BRAUCKMANN, C. 1992. Most Paleozoic Protorthoptera are Ancestral Hemipteroids: Major Wing Braces as Clues to a New Phylogeny of Neoptera (Insecta). *Canadian J. Zool.,* **70**: 2452–2473.

LINNAEUS, C. 1758. *Systema Naturae per Regna TriaNatura, Secundum Classes, Ordines, Genera, Species, cum Characteribus, Differentiis Synonymis, Locis*. *Laurentii Salvii, Stockholm. 10th ed., Rev.* pp 1-1384.

MATSUDA, R. 1981. The origin of insect wings (Arthropoda :Insecta). *International Journal of Insect Morphology and Embryology*. **10**(5, 6): 387-398.

MILLER, W., MAKOVA, K. D., NEKRUTENKO, A. and HARDISON, R. C. 2004. Comparative Genomics. *Annual Review of Genomics and Human Genetics*. **5**: 15-56.

OGILVIE, B. W. 2008. Nature's Bible: Insects in Seventeenth-Century European Art and Science, *Tidsskrift for kulturforskning,* **7**(3): 5-21.

PARSONS, G. L. 2015. Recent Classification of Orders of Insects. *Presented at seminar to Entomology Department on 12th October 2015 at Michigan State University*.

PARSONS, G. L., CASSIS, G., MOLDENKE, A. R., LATTIN, J. D., ANDERSON, N. H., MILLER, J. C., HAMMOND, P., and SCHOWALTER, T. D. 1991. Invertebrates of the H. J. Andrews Experimental Forest, Western Cascade Range, Oregon. V: An annotated list of insects and other arthropods, *U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station*. pp 1-168.

RACINE, V. 2013. Essay: The Cuvier-Geoffroy Debate. *Embryo Project Encyclopedia. http://embryo.asu.edu/pages/essay-cuvier-geoffroy-debate*.

RAVEN, C. E. 1942. New Light on John Ray. *Proc. Linnean Society London*. **154** (1): 3-10

RICHARDS, O. W and DAVIES, R.G. 1957. Imms' A General Textbook of Entomology: Including the Anatomy, Physiology, Development and Classification of Insects (9th edn.), *Methuen, London*. pp 1-886.

RICHARDS, O. *W and DAVIES, R.G.* 1977. Imms' General Textbook of Entomology: vol. 2: Classification and Biology (10th edn.). *Chapman & Hall, London.* pp 421-1354.

RUPPERT, E. E., FOX, R. S., and BARNES, R. D. 2004. Invertebrate zoology: A functional evolutionary approach. *Thomson-Brooks/Cole: Belmont, C.A*., pp 1-963.

SCHLICK-STEINER, B. C., STEINER, F.M., SEIFERT, B., STAUFFER, C., CHRISTIAN, E. and

CROZIER, R.H. (2010). Integrative Taxonomy: A Multisource Approach to Exploring Biodiversity. *Annual Review of Entomology.* **55**(1): 421–438.

SCUDDER, S. H. 1891. Index to the known fossil insects of the world including myriapods and arachnids. *Bull. U.S. Geol. Surv.* **71**: 1–744.

SMITH, R. F., MITTLER, T. E. and SMITH, C.N. 1973. History of Entomology. *Annual Reviews, Inc., Palo Alto, C.A.,* pp 1-517.

WEISS, H. B. 1929. The Entomology of Aristotle. *J. New York Entomol. Soc.,* **37**(2): 101-109.

WESTWOOD, J. O. 1839. Volume 1. An Introduction to the Modern Classification of Insects; Founded on the Natural Habits and Corresponding Organisation of Different Families. *Longman, Orme, Brown, Green and Longmans, London,* pp 1-462.

WESTWOOD, J. O. 1840. Volume 2. An Introduction to the Modern Classification of Insects; Founded on the Natural Habits and Corresponding Organization of Different Families. *Longman, Orme, Brown, Green and Longmans, London,* pp 1-587.

WILLMANN, R. 2003. From Haeckel to Hennig: the early development of phylogenetics in German speaking Europe, *Cladistics.* **19**: 449–79.

WILSON, H. F. and DONER, M. H. 1937. The Historical Development of Insect Classification. *Swift, St. Louis, M.O.*, pp 1-133.

WILSON, J. J., SING, K. W., FLOYD, R. M., and HEBERT, P. D.N. 2017. Chapter 17- DNA Barcodes and Insect Biodiversity. *In the Insect Biodiversity: Science and Society. (eds. Foottit, R.G., & Adler, P.H.). Oxford Univ. Press, Oxford, U.K.*, pp575-592.