

CONTENTS

Sl. No.	Chapter	Page No.
1	General Introduction	1
	1.1 General introduction to insects	1
	1.2 Order: Odonata	2
	1.3 History of Odonatology	2
	1.4 Odonate diversity	3
	1.5 Behaviour	5
	1.5.1 Migration	6
	1.6 Feeding	7
	1.7 Odonate biology	7
	1.7.1 Morphology of odonates	7
	1.7.2 Lifecycle	8
	1.7.3 Reproduction	9
	1.8 Economic importance	10
	1.9 Conservation	11
	1.10 Significance of the study	12
	1.11 Objectives of the proposed work	14
2	Morphology and Molecular Characterisation	15
	2.1 Introduction	15
	2.1.1 Taxonomy	15
	2.1.2 Molecular Taxonomy and DNA Barcoding	16
	2.1.3 Molecular Markers	18
	2.2 Review of literature	22
	2.3 Materials and Methods	34
	2.3.1 Study area	34
	2.3.2 Collection, Identification and Preservation	34
	2.3.3 Photographic documentation	34
	2.3.4 Molecular characterisation	34
	2.3.4.1 Sample preparation	35
	2.3.4.2 Isolation of genomic DNA	35
	2.3.4.3 Determination of Quality of DNA	36
	2.3.4.4 Amplification of COI gene	36
	2.3.4.5 Amplification of 18S rRNA gene	37
	2.3.4.6 Agarose Gel electrophoresis	39
	2.3.4.7 Sequencing	39
	2.3.4.8 Sequence analysis	39
	2.4 Results	41
	2.4.1 Systematic account of Order Odonata	44
	2.4.2 Detailed systematic account of Order Odonata	48

	2.4.3 Photographic documentation of observed odonates	94
	2.4.4 Molecular characterisation of selected families of odonates	94
	2.4.5 Novel records of the present work	103
	2.5 Discussion	105
3	Taxonomic Key	108
4	Phylogenetic analysis	120
	4.1 Introduction	120
	4.1.1 Construction of phylogenetic tree	121
	4.2 Review of literature	124
	4.3 Materials and Methods	134
	4.3.1 Retrieval of supplementary sequences	134
	4.3.2 Construction of phylogenetic tree	134
	4.3.3 Calculation of genetic divergence	135
	4.3.4 Estimation of nucleotide composition	135
	4.4 Results	136
	4.4.1 Phylogeny of the suborder Zygoptera	137
	4.4.2 Phylogeny of the suborder Anisoptera	139
	4.4.3 Phylogeny of selected families	140
	4.4.4 Phylogeny of selected genera	197
	4.5 Discussion	304
5	Conclusion	320
6	Recommendations	322
7	References	323
8	Publications	

LIST OF TABLES

Table No.	Title
2.3.1	Details of primers used for the amplification of COI gene
2.3.2	PCR mix for the amplification of COI gene
2.3.3	PCR conditions optimized for amplification of COI gene
2.3.4	Details of primers used for the amplification of 18S rRNA gene
2.3.5	PCR mix for the amplification of 18S rRNA gene
2.3.6	PCR conditions optimized for amplification of 18S rRNA gene
2.4.1	Details of study locations
2.4.2	Details of molecular characterization
2.4.3	Translation products of the obtained COI gene sequences
2.4.4	Novel GenBank records of the present work
4.4.1	Estimates of genetic divergence between COI gene sequences of family Lestidae and out group.
4.4.2	Nucleotide base composition of COI gene sequences of family Lestidae and out group
4.4.3	Estimates of genetic divergence between 18S rRNA gene sequences of family Lestidae and out group
4.4.4	Nucleotide base composition of 18S rRNA gene sequences of family Lestidae and out group
4.4.5	Estimates of genetic divergence between COI gene sequences of family Platystictidae and out group
4.4.6	Nucleotide base composition of COI gene sequences of family Platystictidae and out group
4.4.7	Estimates of genetic divergence values of 18S rRNA gene sequences of family Platystictidae and out group
4.4.8	Nucleotide base composition of 18S rRNA gene sequences of family Platystictidae and out group
4.4.9	Estimates of genetic divergence among the COI gene sequences of family Calopterygidae and out group
4.4.10	Nucleotide base composition of COI gene sequences of family Calopterygidae and out group

- 4.4.11 Estimates of genetic divergence values of 18S rRNA gene sequences of family Calopterygidae and out group
- 4.4.12 Nucleotide base composition of 18S rRNA gene sequences of family Calopterygidae and out group
- 4.4.13 Estimates of genetic divergence of the COI gene sequences of family Chlorocyphidae and out group
- 4.4.14 Nucleotide base composition of COI gene sequences of family Chlorocyphidae and out group
- 4.4.15 Estimates of genetic divergence values of 18S rRNA gene sequences of family Chlorocyphidae and out group
- 4.4.16 Nucleotide base composition of 18S rRNA gene sequences of family Chlorocyphidae and out group
- 4.4.17 Estimates of genetic divergence of the COI gene sequences of family Euphaeidae and out group
- 4.4.18 Nucleotide base composition of COI gene sequences of family Euphaeidae and out group
- 4.4.19 Estimates of genetic divergence values of 18S rRNA gene sequences of family Euphaeidae and out group
- 4.4.20 Nucleotide base composition of 18S rRNA gene sequences of family Euphaeidae and out group
- 4.4.21 Estimates of genetic divergence of the COI gene sequences of family Platycnemididae and out group
- 4.4.22 Nucleotide base composition of COI gene sequences of family Platycnemididae and out group
- 4.4.23 Estimates of genetic divergence values of 18S rRNA gene sequences of family Platycnemididae and out group
- 4.4.24 Nucleotide base composition of 18S rRNA gene sequences of family Platycnemididae and out group
- 4.4.25 Estimates of genetic divergence of the COI gene sequences of family Coenagrionidae and out group
- 4.4.26 Nucleotide base composition of COI gene sequences of family Coenagrionidae and out group
- 4.4.27 Estimates of genetic divergence values of 18S rRNA gene sequences of family Coenagrionidae and out group

- 4.4.28 Nucleotide base composition of 18S rRNA gene sequences of family Coenagrionidae and out group
- 4.4.29 Estimates of genetic divergence of the COI gene sequences of family Aeshnidae and out group
- 4.4.30 Nucleotide base composition of COI gene sequences of family Aeshnidae and out group
- 4.4.31 Estimates of genetic divergence values of 18S rRNA gene sequences of family Aeshnidae and out group
- 4.4.32 Nucleotide base composition of 18S rRNA gene sequences of family Aeshnidae and out group
- 4.4.33 Estimates of genetic divergence of the COI gene sequences of family Gomphidae and out group
- 4.4.34 Nucleotide base composition of COI gene sequences of family Gomphidae and out group
- 4.4.35 Estimates of genetic divergence values of 18S rRNA gene sequences of family Gomphidae and out group
- 4.4.36 Nucleotide base composition of 18S rRNA gene sequences of family Gomphidae and out group
- 4.4.37 Estimates of genetic divergence of the COI gene sequences of family Libellulidae and out group
- 4.4.38 Nucleotide base composition of COI gene sequences of family Libellulidae and out group
- 4.4.39 Estimates of genetic divergence values of 18S rRNA gene sequences of family Libellulidae and out group
- 4.4.40 Nucleotide base composition of 18S rRNA gene sequences of family Libellulidae and out group
- 4.4.41 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Lestes*
- 4.4.42 Estimates of genetic divergence of the COI gene sequences of genus *Lestes* and out group
- 4.4.43 Nucleotide base composition of COI gene sequences of genus *Lestes* and out group
- 4.4.44 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Protosticta*

- 4.4.45 Estimates of genetic divergence of the COI gene sequences of genus *Protosticta* and out group
- 4.4.46 Nucleotide base composition of COI gene sequences of genus *Protosticta* and out group
- 4.4.47 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Neurobasis*
- 4.4.48 Estimates of genetic divergence of the COI gene sequences of genus *Neurobasis* and out group
- 4.4.49 Nucleotide base composition of COI gene sequences of genus *Neurobasis* and out group
- 4.4.50 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Heliocypha*
- 4.4.51 Estimates of genetic divergence of the COI gene sequences of genus *Heliocypha* and out group
- 4.4.52 Nucleotide base composition of COI gene sequences of genus *Heliocypha* and out group
- 4.4.53 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Libellago*
- 4.4.54 Estimates of genetic divergence of the COI gene sequences of genus *Libellago* and out group
- 4.4.55 Nucleotide base composition of COI gene sequences of genus *Libellago* and out group
- 4.4.56 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Dysphaea*
- 4.4.57 Estimates of genetic divergence of the COI gene sequences of genus *Dysphaea* and out group
- 4.4.58 Nucleotide base composition of COI gene sequences of genus *Dysphaea* and out group
- 4.4.59 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Copera*
- 4.4.60 Estimates of genetic divergence of the COI gene sequences of genus *Copera* and out group
- 4.4.61 Nucleotide base composition of COI gene sequences of genus *Copera* and out group

- 4.4.62 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Prodasineura*
- 4.4.63 Estimates of genetic divergence of the COI gene sequences of genus *Prodasineura* and out group
- 4.4.64 Nucleotide base composition of COI gene sequences of genus *Prodasineura* and out group
- 4.4.65 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Aciagrion*
- 4.4.66 Estimates of genetic divergence of the COI gene sequences of genus *Aciagrion* and out group
- 4.4.67 Nucleotide base composition of COI gene sequences of genus *Aciagrion* and out group
- 4.4.68 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Agriocnemis*
- 4.4.69 Estimates of genetic divergence of the COI gene sequences of genus *Agriocnemis* and out group
- 4.4.70 Nucleotide base composition of COI gene sequences of genus *Agriocnemis* and out group
- 4.4.71 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Archibasis*
- 4.4.72 Estimates of genetic divergence of the COI gene sequences of genus *Archibasis* and out group
- 4.4.73 Nucleotide base composition of COI gene sequences of genus *Archibasis* and out group
- 4.4.74 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Ceriagrion*
- 4.4.75 Estimates of genetic divergence of the COI gene sequences of genus *Ceriagrion* and out group
- 4.4.76 Nucleotide base composition of COI gene sequences of genus *Ceriagrion* and out group
- 4.4.77 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Ischnura*
- 4.4.78 Estimates of genetic divergence of the COI gene sequences of genus *Ischnura* and out group

- 4.4.79 Nucleotide base composition of COI gene sequences of genus *Ischnura* and out group
- 4.4.80 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Paracercion*
- 4.4.81 Estimates of genetic divergence of the COI gene sequences of genus *Paracercion* and out group
- 4.4.82 Nucleotide base composition of COI gene sequences of genus *Paracercion* and out group
- 4.4.83 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Pseudagrion*
- 4.4.84 Estimates of genetic divergence of the COI gene sequences of genus *Pseudagrion* and out group
- 4.4.85 Nucleotide base composition of COI gene sequences of genus *Pseudagrion* and out group
- 4.4.86 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Gynacantha*
- 4.4.87 Estimates of genetic divergence of the COI gene sequences of genus *Gynacantha* and out group
- 4.4.88 Nucleotide base composition of COI gene sequences of genus *Gynacantha* and out group
- 4.4.89 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Ictinogomphus*
- 4.4.90 Estimates of genetic divergence of the COI gene sequences of genus *Ictinogomphus* and out group
- 4.4.91 Nucleotide base composition of COI gene sequences of genus *Ictinogomphus* and out group
- 4.4.92 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Diplacodes*
- 4.4.93 Estimates of genetic divergence of the COI gene sequences of genus *Diplacodes* and out group
- 4.4.94 Nucleotide base composition of COI gene sequences of genus *Diplacodes* and out group
- 4.4.95 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Hydrobasileus*

- 4.4.96 Estimates of genetic divergence of the COI gene sequences of genus *Hydrobasileus* and out group
- 4.4.97 Nucleotide base composition of COI gene sequences of genus *Hydrobasileus* and out group
- 4.4.98 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Orthetrum*
- 4.4.99 Estimates of genetic divergence of the COI gene sequences of genus *Orthetrum* and out group
- 4.4.100 Nucleotide base composition of COI gene sequences of genus *Orthetrum* and out group
- 4.4.101 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Palpopleura*
- 4.4.102 Estimates of genetic divergence of the COI gene sequences of genus *Palpopleura* and out group
- 4.4.103 Nucleotide base composition of COI gene sequences of genus *Palpopleura* and out group
- 4.4.104 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Rhodothemis*
- 4.4.105 Estimates of genetic divergence of the COI gene sequences of genus *Rhodothemis* and out group
- 4.4.106 Nucleotide base composition of COI gene sequences of genus *Rhodothemis* and out group
- 4.4.107 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Tetrathemis*
- 4.4.108 Estimates of genetic divergence of the COI gene sequences of genus *Tetrathemis* and out group
- 4.4.109 Nucleotide base composition of COI gene sequences of genus *Tetrathemis* and out group
- 4.4.110 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Tholymis*
- 4.4.111 Estimates of genetic divergence of the COI gene sequences of genus *Tholymis* and out group
- 4.4.112 Nucleotide base composition of COI gene sequences of genus *Tholymis* and out group

- 4.4.113 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Tramea*
- 4.4.114 Estimates of genetic divergence of the COI gene sequences of genus *Tramea* and out group
- 4.4.115 Nucleotide base composition of COI gene sequences of genus *Tramea* and out group
- 4.4.116 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Urothemis*
- 4.4.117 Estimates of genetic divergence of the COI gene sequences of genus *Urothemis* and out group
- 4.4.118 Nucleotide base composition of COI gene sequences of genus *Urothemis* and out group
- 4.4.119 Details of the COI gene sequences selected for the phylogenetic analysis of genus *Zyxomma*
- 4.4.120 Estimates of genetic divergence of the COI gene sequences of genus *Zyxomma* and out group
- 4.4.121 Nucleotide base composition of COI gene sequences of genus *Zyxomma* and out group
- 4.4.122 Calculated intraspecific divergence values of selected species
- 4.4.123 Interspecific divergence within genera

LIST OF FIGURES

Figure No.	Title
4.4.1	Inferred phylogenetic tree based on COI gene sequences of suborder Zygoptera
4.4.2	Inferred phylogenetic tree based on 18S rRNA gene sequences of suborder Zygoptera
4.4.3	Inferred phylogenetic tree based on COI gene sequences of suborder Anisoptera
4.4.4	Inferred phylogenetic tree based on 18S rRNA gene sequences of suborder Anisoptera
4.4.5	Inferred phylogenetic tree based on COI gene sequences of family Lestidae, rooted by out group
4.4.6	Inferred phylogenetic tree based on 18S rRNA gene sequences of family Lestidae, rooted by out group
4.4.7	Inferred phylogenetic tree based on COI gene sequences of family Platystictidae, rooted by out group
4.4.8	Inferred phylogenetic tree based on 18S rRNA gene sequences of family Platystictidae, rooted by out group
4.4.9	Inferred phylogenetic tree based on COI gene sequences of family Calopterygidae, rooted by out group
4.4.10	Inferred phylogenetic tree based on 18S rRNA gene sequences of family Calopterygidae, rooted by out group
4.4.11	Inferred phylogenetic tree based on COI gene sequences of family Chlorocyphidae, rooted by out group
4.4.12	Inferred phylogenetic tree based on 18S rRNA gene sequences of family Chlorocyphidae, rooted by out group
4.4.13	Inferred phylogenetic tree based on COI gene sequences of family Euphaeidae, rooted by out group
4.4.14	Inferred phylogenetic tree based on 18S rRNA gene sequences of family Euphaeidae, rooted by out group
4.4.15	Inferred phylogenetic tree based on COI gene sequences of family Platynemididae, rooted by out group

- 4.4.16 Inferred phylogenetic tree based on 18S rRNA gene sequences of family Platycnemididae, rooted by out group
- 4.4.17 Inferred phylogenetic tree based on COI gene sequences of family Coenagrionidae, rooted by out group
- 4.4.18 Inferred phylogenetic tree based on 18S rRNA gene sequences of family Coenagrionidae, rooted by out group
- 4.4.19 Inferred phylogenetic tree based on COI gene sequences of family Aeshnidae, rooted by out group
- 4.4.20 Inferred phylogenetic tree based on 18S rRNA gene sequences of family Aeshnidae, rooted by out group
- 4.4.21 Inferred phylogenetic tree based on COI gene sequences of family Gomphidae, rooted by out group
- 4.4.22 Inferred phylogenetic tree based on 18S rRNA gene sequences of family Gomphidae, rooted by out group
- 4.4.23 Inferred phylogenetic tree based on COI gene sequences of family Libellulidae, rooted by out group
- 4.4.24 Inferred phylogenetic tree based on 18S rRNA gene sequences of family Libellulidae, rooted by out group
- 4.4.25 Inferred phylogenetic tree of the genus *Lestes*, rooted by outgroup
- 4.4.26 Inferred phylogenetic tree of the genus *Protosticta*, rooted by outgroup
- 4.4.27 Inferred phylogenetic tree of the genus *Neurobasis*, rooted by outgroup
- 4.4.28 Inferred phylogenetic tree of the genus *Heliocypha*, rooted by outgroup
- 4.4.29 Inferred phylogenetic tree of the genus *Libellago*, rooted by outgroup
- 4.4.30 Inferred phylogenetic tree of the genus *Dysphaea*, rooted by outgroup
- 4.4.31 Inferred phylogenetic tree of the genus *Copera*, rooted by outgroup
- 4.4.32 Inferred phylogenetic tree of the genus *Prodasineura*, rooted by outgroup
- 4.4.33 Inferred phylogenetic tree of the genus *Aciagrion*, rooted by outgroup
- 4.4.34 Inferred phylogenetic tree of the genus *Agriocnemis*, rooted by outgroup

- 4.4.35 Inferred phylogenetic tree of the genus *Archibasis*, rooted by outgroup
- 4.4.36 Inferred phylogenetic tree of the genus *Ceriagrion*, rooted by outgroup
- 4.4.37 Inferred phylogenetic tree of the genus *Ischnura*, rooted by outgroup
- 4.4.38 Inferred phylogenetic tree of the genus *Paracercion*, rooted by outgroup
- 4.4.39 Inferred phylogenetic tree of the genus *Pseudagrion*, rooted by outgroup
- 4.4.40 Inferred phylogenetic tree of the genus *Gynacantha*, rooted by outgroup
- 4.4.41 Inferred phylogenetic tree of the genus *Ictinogomphus*, rooted by outgroup
- 4.4.42 Inferred phylogenetic tree of the genus *Diplacodes*, rooted by outgroup
- 4.4.43 Inferred phylogenetic tree of the genus *Hydrobasileus*, rooted by outgroup
- 4.4.44 Inferred phylogenetic tree of the genus *Orthetrum*, rooted by outgroup
- 4.4.45 Inferred phylogenetic tree of the genus *Palpopleura*, rooted by outgroup
- 4.4.46 Inferred phylogenetic tree of the genus *Rhodothemis*, rooted by outgroup
- 4.4.47 Inferred phylogenetic tree of the genus *Tetrathemis*, rooted by outgroup
- 4.4.48 Inferred phylogenetic tree of the genus *Tholymis*, rooted by outgroup
- 4.4.49 Inferred phylogenetic tree of the genus *Tramea*, rooted by outgroup
- 4.4.50 Inferred phylogenetic tree of the genus *Urothemis*, rooted by outgroup
- 4.4.51 Inferred phylogenetic tree of the genus *Zyxomma*, rooted by outgroup

LIST OF PLATES

Plate No.	Title
PLATE 1	Map of Kerala showing the districts selected for the study
PLATE 2	Study locations
PLATE 3	Odonates observed during the study
PLATE 4	Odonates observed during the study (cont.)
PLATE 5	Odonates observed during the study (cont.)
PLATE 6	Odonates observed during the study (cont.)
PLATE 7	Odonates observed during the study (cont.)
PLATE 8	Odonates observed during the study (cont.)
PLATE 9	Odonates observed during the study (cont.)
PLATE 10	Odonates observed during the study (cont.)
PLATE 11	Odonates observed during the study (cont.)
PLATE 12	Wing venation of dragonfly