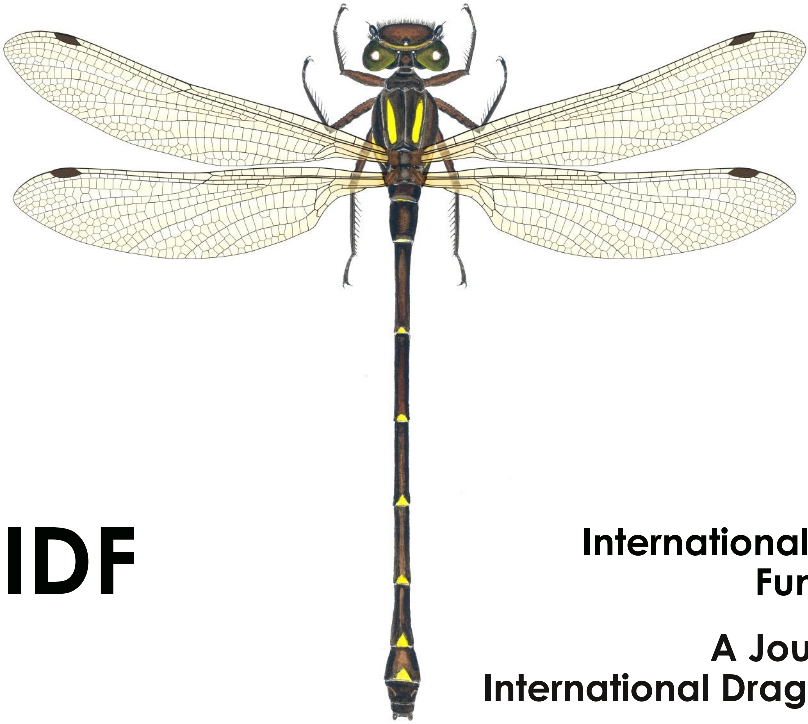

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Composition of the dragonfly fauna at different altitudes in Bhutan based on larval samples

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Abstract

In 2020 thirty sites with running water and ten sites with standing water were sampled for both adult and larval odonates in both the pre-monsoon and the post-monsoon period. This sampling was performed along an altitudinal gradient from 500-3000 m in Punakha and Wangduephodrang provinces of Bhutan. The results of the running water sites showed that there are clear differences between the overall abundance, species diversity and species associations at different altitudes. Furthermore, a clear difference was observed in the number of larvae collected in running water in the post-monsoon (404 specimens) and the pre-monsoon (654 specimens) periods, with five species being clearly more abundant in the pre-monsoon and one species being more abundant in the post-monsoon period.

Key words: Bhutan, monsoon, elevation, distribution, Himalaya.

Introduction

Bhutan is a small country in the eastern Himalaya region of south Asia renowned for its diverse and well-preserved biodiversity. It lies at the transition zone between the Oriental and the Palearctic region. At present 123 species of dragonflies and damselflies are known from Bhutan and it is likely that further field work will show that at least 150 species occur in the country (Gyeltshen et al., 2017; Gyeltshen, Kalkman & Orr, 2017; Gurung et al., 2021). Only a few species of Odonata are found above 3000 m a.s.l. (Gyeltshen, Kalkman and Orr, 2017). Knowledge of Odonata in Bhutan has greatly increased in the past decade due to the cooperation of the National Biodiversity Centre, Serbithang with the Dutch Naturalis Biodiversity Center resulting in the start of the Bhutan Invertebrate Biodiversity Project in 2014 (Gyeltshen & Kalkman, 2017). Odonata was among the five focal groups identified for this study, with the result being various papers published in the last couple of years (Kalkman & Gyeltshen, 2016; Gyeltshen & Kalkman, 2017; Gyeltshen, et al., 2017; Gyeltshen, 2020; Gurung, et al., 2021). Despite this increase in knowledge little is known of the altitudinal distribution of dragonfly communities in the eastern Himalayan region. An overview of elevational range of species occurring in Nepal, largely based on information on adults was published by Vick (1989). The only paper with a focus on dragonflies in which the larval communities were studied along an altitudinal gradient in this part of the Himalayan range is Mahato & Edds (1993). They used data on larvae collected at 40 sites at the Gandaki river in central Nepal, collected between 50 and 1189 m a.s.l. with one site at 2560 m a.s.l. In 2020 the first author performed field work on aquatic habitats in Bhutan to assess odonate biodiversity in terms of breeding habitats. Emphasis was put on collecting data of species of running water over a large altitudinal gradient. The results are presented here.

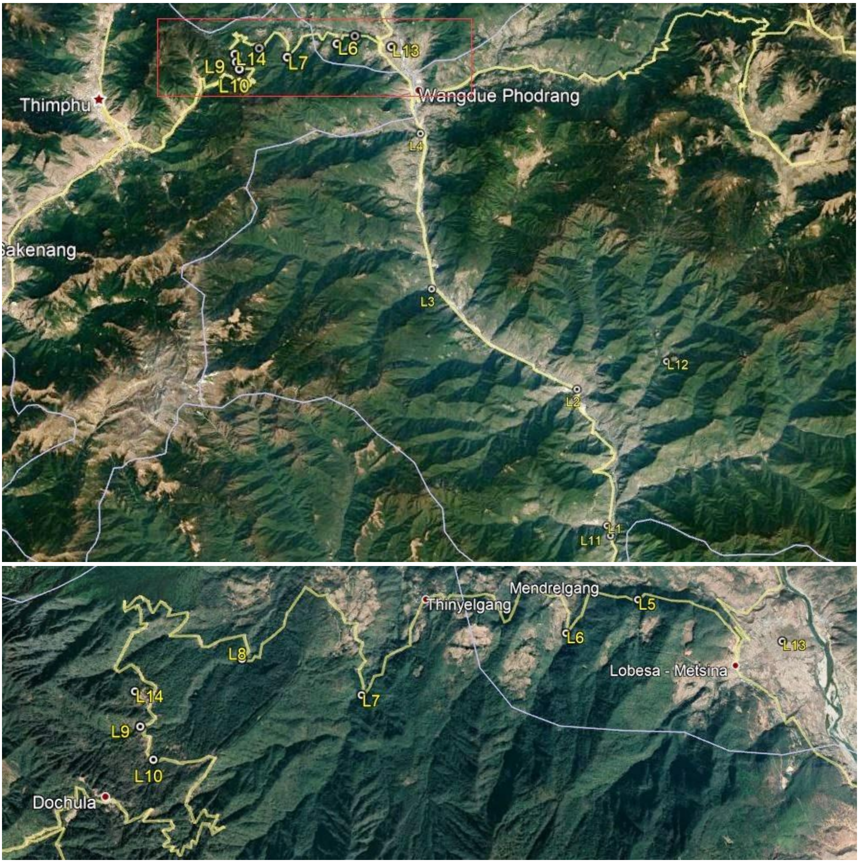

Figure 1a, b. Maps of Punakha and Wangduephodrang provinces in Bhutan showing the location of the 14 sampling localities.

Material and methods

In 2020 the dragonfly fauna of a total of 40 sites at 14 different localities (L1-L14 in figure 1) was studied in the Punakha and Wangduephodrang provinces of Bhutan. Thirty of these were running water sites and 10 were standing water. The thirty running water sites were divided over 10 different streams with clusters of three sites on every stream. These three sites (lower, middle and upper sites) were each 100m long and separated from each other by an intervening stretch of 100m, so in total forming a stretch of 500 m. The ten standing water sites were divided over four different localities with sites 32-35 belonging to different sections of Adha lake and sites 37-40 to different sections of a natural lake at Lamperi. The sites sampled along the shore at standing water were 50 m long. Each of these sites were visited during the pre-monsoon period (15.iv.2020 to 15.vi.2020) and during the post-monsoon period (1.x.2020 to 31.xi.2020). Adult dragonflies were photographed and/or collected but as no field work was conducted during

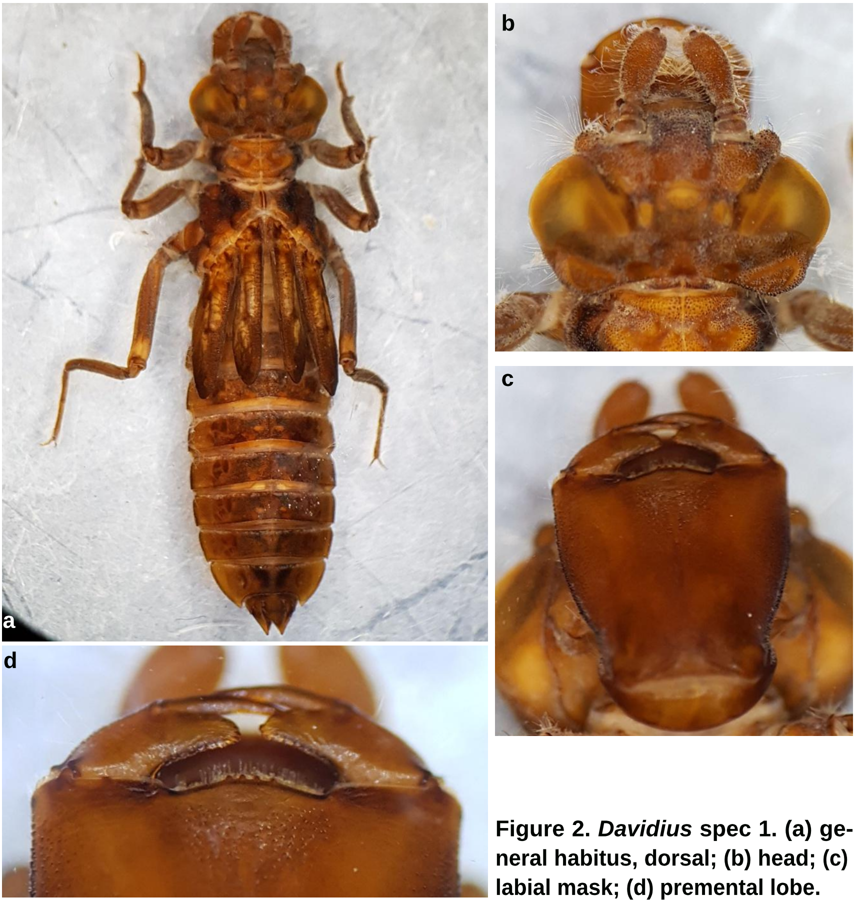

Figure 2. *Davidius* spec 1. (a) general habitus, dorsal; (b) head; (c) labial mask; (d) premental lobe.

summer due to Covid restrictions the list of adult dragonflies recorded is incomplete. Sampling visits lasted two hours per site—as many larvae as possible were collected and the sampling was done at every 10 m at each site of a 100 m (running water) or 50 m (standing water) site. All larvae were collected and put in vials with 70% alcohol. Both the collected adults and larvae are stored in the collection of College of Natural Resources, Punakha and the National Biodiversity Centre, Serbithang (Bhutan).

Except to the key to the families by Nesemann et al. (2011) no general key to the species or genera for the larva found in the Himalayan region is available, hence for identification we consulted numerous papers (see Kalkman et al., 2020 for an overview of larval description from the South Asia). Four species of Gomphidae were found commonly but two could not be identified beyond genus level, and in one case not even to genus. In order to facilitate future identification of these records to species level we provide short descriptions of each, detailing the characters we used to separate them.

Davidius spec 1 (Fig 2). Several species of *Davidius* occur in the region and it is at present not possible to identify their larvae to species level. Characterization: Third antennal segment oval shaped and about twice as long as broad, flattened and bent inwards. Head between base of antennae and eyes with a prominent knob like protrusion. Apical margin of prementum, gently convex with four conspicuous black teeth; labial palps bluntly rounded. Burrowing hooks (blunt) present on fore and middle tibae. No dorsal spines or knobs on dorsum of abdomen, segment 7 (very small) and segments 8-9 with short lateral hooks. Anal pyramid about as long as wide. Wing sheaths parallel.

Davidius spec 2 (Fig 3). Several species of *Davidius* occur in the region and it is at present not possible to identify their larvae to species level. Characterization: Third antennal segment, flat, oval shaped and broader than long, covering front of head. Head between base of antennae and eyes with a prominent knob like protrusion. Apical margin of prementum strongly convex, with about 14 conspicuous black teeth; labial palps bluntly rounded. Burrowing hooks (sharply pointed) present on fore and middle tibae. No dorsal spines or knobs on dorsum of abdomen, lateral spines absent. Anal pyramid about as long as wide. Wing sheaths parallel.

Perissogomphus stevensi (Fig 4). The larva of this genus is still undescribed and the identification is based on preliminary DNA results. Characterization: Third antennal segment long, almost straight, slightly flattened. Apical margin of prementum convex, with >30 small black teeth; labial palps bluntly rounded. Blunt dorsal knobs present on segment 2-9, short lateral spines present on segment 7-9; large burrowing hooks present on fore and middle tibiae. Anal pyramid longer than wide. Wing sheaths diverging.

Gomphidae genus indet. (Fig 5). Based on its diverging wing sheaths and distribution, this is most likely *Scalmogomphus* or *Lamelligomphus*. Characterization: Third antennal segment long, bent inwards gradually expanding reaching its broadest point at two-thirds of the segment, its ventral point flattened. Apical margin of prementum weakly convex, with about 16 small black teeth; labial palps bluntly rounded. Blunt dorsal knobs present on segment 2-9, short lateral spines present on segment 9; small burrowing hooks on fore and middle tibiae small. Anal pyramid longer than wide. Wing sheaths diverging.

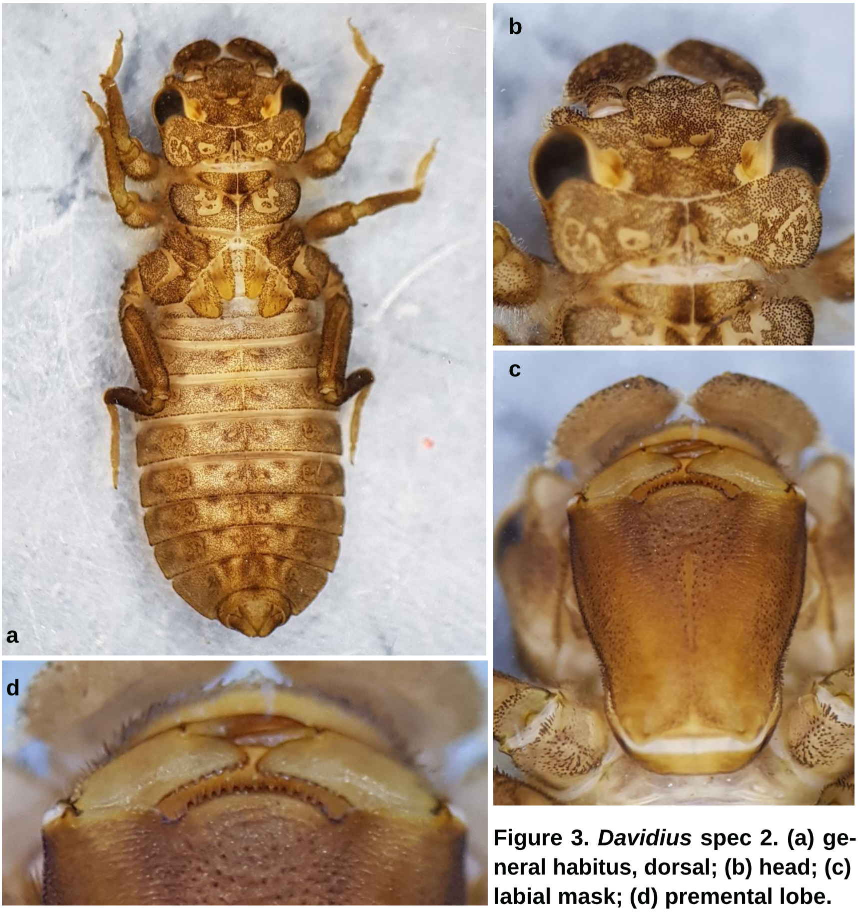

Figure 3. ***Davidius*** **spec 2. (a) general habitus, dorsal; (b) head; (c) labial mask; (d) premental lobe.**

List of localities (L) and sites

(L1, site 1) (Fig. 6) Wangduephodrang District, Taksha; lower reach of the stream beside gravel and sand deposit (27.171084°N, 90.064520°E, 509 m a.s.l.) 16.iv.2020, 23.xi.2020. **(L1, site 2)** Wangduephodrang District, Taksha; middle reach of the stream beside human settlement with dumped waste (27.171346°N, 90.060634°E, 536 m a.s.l.) 17.iv.2020, 24.xi.2020. **(L1, site 3)** Wangduephodrang District, Taksha; upper reach with large rocks stacked on the bank (27.171565°N, 90.056923°E, 564 m a.s.l.) 20.iv.2020, 26.xi.2020.

(L2, site 4) Wangduephodrang District, Kamichu; lower reach with algal growth, dust covering the leaves and some plastic and paper litter (27.270752°N, 90.037214°E, 640 m a.s.l.) 19.iv.2020, 17.xi.2020. **(L2, site 5)** Wangduephodrang District, Kamichu; middle

Figure 4. ***Perissogomphus stevensi*** **(a) general habitus, dorsal; (b) head; (c) labial mask; (d) premental lobe.**

reach with algal growth; earth excavated beside the bank and dust covering leaves (27.269575°N, 90.035763°E, 641 m a.s.l.) 21.iv.2020, 20.xi.2020. **(L2, site 6)** Wangduephodrang District, Kamichhu; upper reach with algal growth (27.268347°N, 90.034366°E, 641 m a.s.l.) 21.iv.2020, 21.xi.2020.

(L3, site 7) Wangduephodrang District, Rurichhu; lower reach of the stream with flow controlled from the reservoir dam and some plastic and paper litter (27.342048°N, 89.915077°E, 931 m a.s.l.) 18.v.2020, 9.ix.2020. **(L3, site 8)** Wangduephodrang District, Rurichhu;

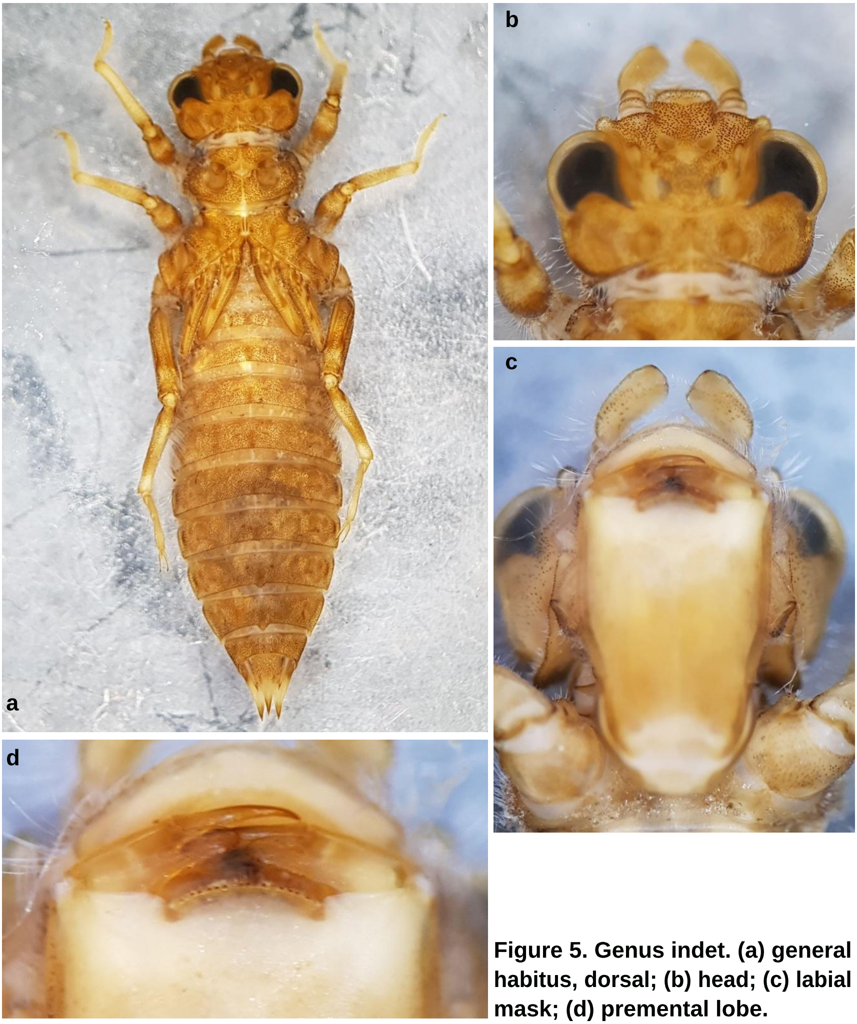

Figure 5. Genus indet. (a) general habitus, dorsal; (b) head; (c) labial mask; (d) premental lobe.

middle reach of the stream with flow controlled from the reservoir dam; some plastic and paper litter and animal dung present (27.341171°N, 89.913172°E, 989 m a.s.l.) 19.v.2020, 12.xi.2020. **(L3, site 9)** Wangduephodrang District, Rurichhu; upper reach of the stream with flow controlled from the reservoir dam and some plastic and paper litter (27.340457°N, 89.911867°E, 1071 m a.s.l.) 19.v.2020, 12.xi.2020.

(L4, site 10) (Fig. 7) Wangduephodrang District, Hesothanka; lower reach of the stream with rapid current; some plastic and paper litter and settlements within 50 m (27.456273°N, 89.902611°E, 1231 m a.s.l.) 26.v.2020, 8.xi.2020. **(L4, site 11)** Wang-

Figure 6. Habitat at site 1 showing the impact of road construction. Larvae of *Perissogomphus stevensi*, *Gomphidae* spec and *Macromia moore*i were collected here.

Figure 7. Habitat at site 4. At this site the natural bank site vegetation was largely destroyed and some plastic and paper litter were found in the water. Here larvae of *Bayadera* spec, *Perissogomphus stevensi* and *Macromia moorei* were collected.

duephodrang District, Hesothanka; middle reach of the stream with some plastic and paper litter (27.456030°N, 89.900604°E, 1240 m a.s.l.) 27.v.2020, 9.xi.2020. **(L4, site 12)** Wangduephodrang District, Hesothanka; upper reach of the stream (27.456098°N, 89.899032°E, 1261 m a.s.l.) 1.v.2020, 13.xi.2020.

(L5, site 13) Punakha District, Mendelgang; lower reach with water diverted resulting in irregular flow; overgrowth bush and plastic and paper litter (27.526618°N, 89.846681°E, 1613 m a.s.l.) 28.v.2020, 23.x.2020. **(L5, site 14)** Punakha District, Mendelgang; middle reach with dry bed (27.525007°N, 89.847273°E, 1646 m a.s.l.) 30.v.2020, 23.x.2020. **(L5, site 15)** Punakha District, Mendelgang; upper reach with dry bed (27.523096°N, 89.846717°E, 1712 m a.s.l.) 30.v.2020, 23.x.2020.

(L6, site 16) Punakha District, Mendelgang; lower reach with fallen tree along the brook and some plastic and paper litter (27.520715°N, 89.832620°E, 1588 m a.s.l.) 17.v.2020, 26.x.2020. **(L6, site 17)** Punakha District, Mendelgang; middle reach of the brook with animal trampling and dry land within 50m (27.518010°N, 89.831685°E, 1632 m a.s.l.) 21.v.2020, 28.x.2020. **(L6, site 18)** Punakha District, Mendelgang; upper reach of the brook with grass mat and overgrowing vegetation (27.516542°N, 89.830285°E, 1661 m a.s.l.) 21.v.2020, 28.x.2020.

(L7, site 19) Punakha District, Thinleygang; lower reach with stony brook; some plastic and paper litter (27.508373°N, 89.792520°E, 1934 m a.s.l.) 9.v.2020, 16.x.2020. **(L7, site 20)** Punakha District, Thinleygang; middle reach with fast running brook and water channelled into a large pipe (27.507038°N, 89.790558°E, 1986 m a.s.l.) 14.v.2020, 20.x.2020. **(L7, site 21)** Punakha District, Thinleygang; upper reach with fast running brook, some pipelines and concrete water tank (27.505191°N, 89.789944°E, 2068 m a.s.l.) 15.v.2020, 20.x.2020.

(L8, site 22) Punakha District, Menchuna; lower reach with fast running brook with over growth of *Aconogonum molle* and some plastic and paper litter (27.513843°N, 89.769893°E, 2250 m a.s.l.) 24.v.2020, 16.x.2020. **(L8, site 23)** Punakha District, Menchuna; middle reach with fast running brook and some plastic and paper litter (27.512609°N, 89.768034°E, 2266 m a.s.l.) 27.v.2020, 18.x.2020. **(L8, site 24)** Punakha District, Menchuna; upper reach with stony brook (27.512833°N, 89.765819°E, 2290 m a.s.l.) 27.v.2020, 18.x.2020.

(L9, site 25) Punakha District, Lamperi; lower reach with stony brook; plastic and paper litter and over growth of *Aconogonum molle* (27.502119°N, 89.752943°E, 2683 m a.s.l.) 29.v.2020, 7.x.2020. **(L9, site 26)** Punakha District, Lamperi; middle reach of the stony brook (27.500993°N, 89.751264°E, 2810 m a.s.l.) 30.v.2020, 9.x.2020. **(L9, site 27)** Punakha District, Lamperi; upper reach of the stony brook (27.499951°N, 89.749565°E, 2890 m a.s.l.) 30.v.2020, 9.x.2020.

(L10, site 28) (Fig. 8) Punakha District, Lamperi; lower reach of the stony brook with much plastic and paper litter (27.496874°N, 89.755801°E, 2736 m a.s.l.) 2.vi.2020, 7.x.2020. **(L10, site 29)** Punakha District, Lamperi; middle reach of a stony brook (27.494850°N, 89.755140°E, 2787 m a.s.l.) 5.vi.2020, 8.x.2020. **(L10, site 30)** Punakha District; upper reach of a stony brook (27.494844°N, 89.754633°E, 2958 m a.s.l.) 5.vi.2020, 8.x.2020.

(L11, site 31) Wangduephodrang District, Taksha; stagnant water beside the road with abundance of macrophytes, *Nasturtium officinale* (27.163886°N, 90.067485°E, 476 m a.s.l.) 25.iv.2020, 28.xi.2020.

(L12, site 32) (Fig. 9) Wangduephodrang District, Adha; along north shoreline of natural lake (27.293414°N, 90.108940°E, 1254 m a.s.l.) 6.v.2020, 2.xi.2020. **(L12, site 33)** Wangduephodrang District, Adha; along west shoreline of natural lake (27.292216°N,

Figure 8. Habitat at site 10. Here larvae of *Anisopleura* spec, *Bayadera* spec, *Davidius* spec1, Gomphidae spec, *Perissogomphus stevensi* and *Macromia moorei* were collected.

Figure 9. Habitat at site 12. Here larvae of *Bayadera* spec, *Anotogaster/Neallogaster*, *Chlorogomphus* spec, *Davidius* spec1, Gomphidae spec, *Perissogomphus stevensi*, *Macromia moorei* were collected.

90.109160°E, 1236 m a.s.l.) 6.v.2020, 2.xi.2020. **(L12, site 34)** Wangduephodrang District, Adha; along south shoreline of natural lake (27.291748°N, 90.110073°E, 1217 m a.s.l.) 6.v.2020, 2.xi.2020. **(L12, site 35)** Wangduephodrang District, Adha; along east shoreline of natural lake (27.292823°N, 90.110026°E, 1260 m a.s.l.) 6.v.2020, 2.xi.2020.

(L13, site 36) Punakha District, Lobesa; artificial pool in orchard (27.520144°N, 89.876707°E, 1275 m a.s.l.) 10.vi.2020, 6.xi.2020.

(L14, site 37) Punakha District, Lamperi, along south shoreline of natural pond (27.507220°N, 89.752080°E, 2696 m a.s.l.) 7.vi.2020, 3.x.2020. **(L14, site 38)** Punakha District, Lamperi; along east shoreline of natural pond (27.507759°N, 89.752080°E, 2699 m a.s.l.) 7.vi.2020, 3.x.2020. **(L14, site 39)** Punakha District, Lamperi; along north shoreline of natural pond (27.507793°N, 89.751561°E, 2699 m a.s.l.) 7.vi.2020, 4.x.2020. (**L14, site 40**) Punakha District, Lamperi; along west shoreline of natural pond (27.507390°N, 89.751493°E, 2705 m a.s.l.) 7.vi.2020, 4.x.2020.

Results

A total of 95 specimens representing 29 species of dragonflies and damselflies were recorded as adults. In total 1210 larvae were collected belonging to 22 different species. Of these only seven can be assigned to a named species. One gomphid could not be assigned to genus.

List of species collected

The taxonomy follows that of (Kalkman et al., 2020).

Synlestidae

1. *Megalestes* sp.

(19) 3 larvae (9.v.2020) **(21)** 2 larvae (15.v.2020) **(21)** 3 larvae (20.x.2020).

Lestidae

2. *Indolestes cyaneus* (Selys, 1862)

(37) 3♂1♀ adults (7.vi.2020) **(38)** 1♂1♀ adults (7.vi.2020) **(38)** 1♂ adult (4.x.2020) **(39)** 1♂ adult (4.x.2020).

Calopterygidae

3. *Neurobasis chinensis* (Linnaeus, 1758)

(9) 1 larva (19.v.2020).

Chlorocyphidae

4. *Aristocypha* sp.

(9) 1♀ adult (19.v.2020).

5. *Paracypha unimaculata* (Selys, 1853)

(9) 1♂ adult (19.v.2020).

Euphaeidae

6. *Anisopleura lestoides* (Selys, 1853)

(2) 1♂ adult (17.iv.2020).

7. *Anisopleura* sp.

(7) 1 larva (18.v.2020) **(10)** 1 larva (26.v.2020) **(16)** 31 larvae (17.v.2020) **(17)** 25 larvae (21.v.2020) **(17)** 18 larvae (28.x.2020) **(18)** 2 larvae (21.v.2020) **(18)** 12 larvae (28.x.2020) **(31)** 1♂ adult (25.iv.2020) 1♀ teneral (17.iv.2020).

8. *Bayadera indica* (Selys, 1853)

(6) 1♂ adult (21.iv.2020) **(6)** 1♀ adult (21.iv.2020) **(9)** 1♂ adult (19.v.2020).

9. *Bayadera* sp.

(2) 1 larva (17.iv.2020) **(3)** 3 larvae (20.iv.2020) **(4)** 2 larvae (19.iv.2020) **(5)** 2 larvae (21.iv.2020) **(5)** 2 larvae (20.xi.2020) **(6)** 5 larvae (21.iv.2020) **(10)** 6 larvae (26.v.2020) **(11)** 10 larvae (27.v.2020) **(11)** 2 larvae (9.xi.2020) **(12)** 11 larvae (1.v.2020).

Platycnemidae

10. *Calicnemia eximia* (Selys, 1863)

(31) 1♂ adult (25.iv.2020)

Coenagrionidae

11. *Ceriagrion fallax* (Ris, 1914)

(31) 2♂ adult (25.vi.2020) **(37)** 1♀ adult (7.vi.2020) **(39)** 1♀ adult (7.vi.2020) **(40)** 1♂ adult (2.xi.2020).

12. Coenagrionidae sp.

(31) 13 larvae (25.iv.2020) **(31)** 32 larvae (28.xi.2020) **(36)** 1 larva (6.xi.2020) **(38)** 1♀ adult (4.x.2020) **(39)** 1♀ adult (4.x.2020).

13. *Ischnura rubilio* (Selys, 1876)

(36) 1♂ adult (6.xi.2020) **(40)** 2♂ adults (4.x.2020).

Epiophlebiidae

14. *Epiophlebia laidlawi* (Tillyard, 1921)

(19) 4 larvae (9.v.2020) **(20)** 1 larva (14.v.2020) **(21)** 1 larva (20.x.2020) **(22)** 1 larva (16.x.2020) **(23)** 1 larva (27.v.2020) **(23)** 1 larva (18.x.2020) **(24)** 3 larvae (27.v.2020) **(24)** 4 larvae (18.x.2020) **(25)** 3 larvae (29.v.2020) **(25)** 1 larva (7.x.2020) **(26)** 1 larva (30.v.2020) **(28)** 2 larvae (7.x.2020) (29) 1 larva (8.x.2020).

Aeshnidae

15. *Anax indicus* (Lieftinck, 1942)

(36) 1♂ (10.vi.2020).

16. *Anax nigrolineatus* (Fraser, 1935)

(32) 1♂ adult (6.v.2020) **(34)** 1♂ (2.xi.2020).

17. *Anax* sp.

(36) 9 larvae (6.ix.2020) **(38)** 1 larva (3.x.2020).

18. *Cephalaeschna* sp.

(18) 3♂ adult (28.x.2020) **(19)** 3 larvae (16.x.2020) **(20)** 3 larvae (20.x.2020) **(21**) 2 larvae (20.x.2020) **(22)** 1 larva (16.x.2020) **(23)** 2 larvae (18.x.2020) **(26)** 1 larva (30.v.2020) **(27)** 1 larva (9.x.2020).

19. *Cephalaeschna triadica* (Lieftinck, 1977) (identification based on superstition)

(16) 1 larva (17.v.2020) **(17)** 1 larva (28.x.2020).

20. *Polycanthagyna erythromelas* (McLachlan, 1896)

(31) 1 larva (25.iv.2020).

Gomphidae

21. cf. *Davidius* sp.

(29) 1♀ adult (5.vi.2020).

22. *Davidius* sp.1.

(7) 5 larvae (9.xi.2020) **(8)** 9 larvae (12.xi.2020) **(9)** 3 larvae (12.xi.2020) **(10)** 1 larva (8.xi.2020) **(12)** 1 larva (1.v.2020) **(12)** 3 larvae (13.xi.2020) **(19)** 3 larvae (9.v.2020) **(19)** 33 larvae (16.x.2020) **(20)** 13 larvae (14.v.2020) **(20)** 15 larvae (20.x.2020) **(21)** 11 larvae (15.v.2020) **(21)** 9 larvae (20.x.2020) **(22)** 2 larvae (24.v.2020) **(23)** 1 larva (27.v.2020) **(23)** 5 larvae (18.x.2020) **(24)** 8 larvae (27.v.2020) **(24)** 3 larvae (18.x.2020) **(25)** 14 larvae (29.v.2020) **(25)** 5 larvae (7.x.2020) **(26)** 11 larvae (30.v.2020) **(26)** 3 larvae (9.x.2020) **(27)** 1 larva (30.v.2020) **(27)** 1 larva (9.x.2020) **(28)** 7 larvae (2.vi.2020) **(28)** 12 larvae (7.x.2020) (29) 6 larvae (5.vi.2020) (29) 1 larva (8.x.2020) (30) 3 larvae (5.vi.2020) (30) 4 larvae (8.x.2020).

23. *Davidius* sp.2.

(17) 1 larva (28.x.2020) **(18)** 3 larvae (28.x.2020).

24. *Perissogomphus stevensi* (Laidlaw, 1922)

(1) 10 larvae (16.iv.2020) **(1)** 14 larvae (23.xi.2020) **(2)** 5 larvae (17.iv.2020) **(2)** 11 larvae (24.xi.2020) **(3)** 3 larvae (20.iv.2020) **(3)** 18 larvae (26.xi.2020) **(4)** 17 larvae (19.iv.2020) **(4)** 22 larvae (17.xi.2020) **(5)** 12 larvae (21.iv.2020) **(5)** 21 larva (20.xi.2020) **(6)** 14 larvae (21.iv.2020) **(6)** 11 larvae (21.xi.2020) **(7)** 13 larvae (18.v.2020) **(7)** 7 larvae (9.xi.2020) **(8)** 7 larvae (19.v.2020) **(8)** 3 larvae (12.xi.2020) **(9)** 14 larvae (19.v.2020) **(9)** 1 larva (12.xi.2020) **(10)** 10 larvae (26.v.2020) **(10)** 19 larvae (8.xi.2020) **(11)** 2 larvae (27.v.2020) **(11)** 7 larvae (9.xi.2020) **(12)** 12 larvae (1.v.2020) **(12)** 23 larvae (13.xi.2020) **(16)** 3 larvae (26.x.2020) **(17)** 4 larvae (21.v.2020) **(17)** 4 larvae (28.x.2020) **(18)** 25 larvae (21.v.2020) **(18)** 3 larvae (28.x.2020) **(19)** 3 larvae (9.v.2020) **(19)** 12 larvae (16.x.2020) **(20)** 17 larvae (14.v.2020) **(20)** 13 larvae (20.x.2020) **(21)** 6 larvae (15.v.2020) **(21)** 7 larvae (20.x.2020) **(22)** 1 larva (16.x.2020) **(36)** 1 larva (6.xi.2020).

25. Gomphidae genus indet

(1) 35 larvae (16.iv.2020) **(2)** 19 larvae (17.iv.2020) **(3)** 31 larva (20.iv.2020) **(5)** 1 larva (21.iv.2020) **(7)** 24 larvae (18.v.2020) **(8)** 5 larvae (19.v.2020) **(9)** 3 larvae (19.v.2020) **(10)** 15 larvae (26.v.2020) **(10)** 1 larva (8.xi.2020) **(11)** 15 larvae (27.v.2020) **(11)** 1 larva (9.xi.2020) **(12)** 14 larvae (1.v.2020) **(16)** 9 larvae (17.v.2020) **(16)** 1 larva (26.x.2020) **(17)** 6 larvae (21.v.2020) **(18)** 15 larvae (21.v.2020) **(26)** 1 larva (9.x.2020).

Chlorogomphidae

26. *Chlorogomphus* sp.

(9) 1 larva (19.v.2020) **(12)** 1 larva (13.xi.2020) **(16)** 6 larvae (17.v.2020) **(16)** 3 larvae (26.x.2020) **(17)** 3 larvae (21.v.2020) **(18)** 8 larvae (28.x.2020).

Cordulegastridae

27. *Anotogaster/Neallogaster* sp.

(8) 1 larva (12.xi.2020) **(12)** 1 larva (1.v.2020) **(12)** 1 larva (13.xi.2020) **(16)** 4 larvae (17.v.2020) **(17)** 5 larvae (21.v.2020) **(17)** 2 larvae (28.x.2020) **(18)** 2 larvae (21.v.2020) **(18)** 1 larva (28.x.2020) **(19)** 1 larva (9.v.2020) **(22)** 1 larva (24.v.2020) **(24)** 1 larva (27.v.2020) **(26)** 1 larva (30.v.2020).

Macromiidae

28. *Macromia moorei* (Selys, 1874)

(1) 5 larvae (16.iv.2020) **(1)** 3 larvae (23.xi.2020) **(4)** 5 larvae (19.iv.2020) **(5)** 14 larvae (21.iv.2020) **(6)** 15 larvae (21.iv.2020) **(7)** 10 larvae (18.v.2020) **(7)** 1 larva (9.xi.2020) **(8)** 5 larvae (19.v.2020) **(10)** 4 larvae (26.v.2020) **(11)** 2 larvae (27.v.2020) **(12)** 1 larva (1.v.2020) **(17)** 1 larva (28.x.2020).

Libellulidae

29. *Brachythemis contaminata* (Fabricius, 1793)

(39) 1♀ (7.vi.2020).

30. *Crocothemis* sp.

(5) 1♂ adult (21.iv.2020) **(31)** 1♂ adult (28.xi.2020) **(32)** 1♂ adult (2.xi.2020) **(32)** 1♂ adult teneral (2.xi.2020) **(34)** 1♂ teneral (2.xi.2020).

31. *Diplacodes trivialis* (Rambur, 1842)

(32) 1♂ adult (2.xi.2020).

32. *Orthetrum glaucum* (Brauer, 1865)

(1) 1♂ adult (16.iv.2020) **(7)** 1♂ adult (9.xi.2020) **(8)** 1♂ adult (12.xi.2020) **(12)** 1♂ adult (13.xi.2020) **(31)** 1♂ adult (28.xi.2020) **(39)** 2♂♂ adult (4.x.2020).

33. *Orthetrum pruinosum neglectum* (Burmeister, 1839)

(9) 1♂ adult (12.xi.2020)

34. *Orthetrum sabina* (Drury, 1773)

(37) 2♂♂ adult (2.xi.2020) **(34)** 1♂ (2.xi.2020).

35. *Orthetrum* sp.

(1) 1♀ adult (16.iv.2020) **(2)** 1♀ adult (24.xi.2020) **(2)** 1♀ adult (17.iv.2020) **(10)** 1♀ adult (26.iv.2020) **(12)** 1♀ adult (13.xi.2020) **(31)** 46 larvae (25.iv.2020) **(31)** 17 larvae (28.xi.2020) **(36)** 1 larva (6.xi.2020).

36. Orthetrum triangulare (Selys, 1878)

(1) 2♂♂ adults (16.iv.2020) **(2)** 1♂ adult (17.iv.2020) **(4)** 1♂ adult (19.iv.2020) **(5)** 1♂ adult (21.iv.2020) **(8)** 2♂♂ adults (19.v.2020) **(9)** 2♂♂ adults (12.xi.2020) **(13)** 1♂ adult (28.iv.2020) **(31)** 1♂ adult (28.xi.2020) **(31)** 1♂ adult (25.iv.2020) **(32)** 1♂ adult (2.xi.2020) **(32)** 3♂♂ adults (4.v.2020) **(34)** 1♂ adult (2.xi.2020) **(35)** 1♂ adult (4.v.2020).

37. *Palpopleura sexmaculata* (Selys, 1878)

(32) 1♂ adult (2.xi.2020).

38. *Pantala flavescens* (Fabricius, 1798)

(5) 1♂ adult (21.iv.2020) **(10)** 1♂ adult (24.iv.2020).

39. *Sympetrum fonscolombii* (Selys, 1840)

(1) 1♂ adult (16.iv.2020) **(36)** 14 larvae (10.vi.2020) **(36)** 1 larva (6.xi.2020) **(37)** 1♂ adult (4.x.2020) **(38)** 5 larvae (3.x.2020) **(39)** 1♂ adult (4.x.2020) **(40)** 1♂ adult (4.x.2020).

40. *Sympetrum hypomelas* (Selys, 1884)

(36) 1♂ adult (6.xi.2020) **(37)** 1♂, 1♀ adults (4.x.2020) **(40)** 1♂ adult (4.x.2020).

41. *Sympetrum* sp.

(37) 1 larva (3.x.2020).

42. *Tramea virginea* (Rambur, 1842)

(36) 1♂ adult (6.xi.2020).

43. *Tramea* sp.

(36) 4 larvae (6.xi.2020).

44. *Trithemis aurora* (Burmeister, 1839)

(12) 1♂ adult (13.xi.2020) **(31)** 1♂ adult (28.xi.2020) **(39)** 1♂ adult (7.vi.2020) **(32)** 2♂♂ adult (4.v.2020).

45. *Trithemis festiva* (Rambur, 1842)

(5) 1♂ adult (21.iv.2020).

46. *Zyxomma* sp.

(37) 3 larvae (3.x.2020).

Discussion

Most of the specimens collected as adults are common and wide spread species and most of them are species breeding at standing water. As no fieldwork could be conducted from mid-June to the end of September due to Covid the list of species observed as adult is incomplete and gives little information on the composition of the fauna.

The larvae found at the 10 standing water sites are all of common and widespread species. Exception to this is the discovery of three larvae of *Zyxomma* at site 33. This genus is new to Bhutan although its presence was expected as it is common in India. Surprisingly however is the elevation (1236 m), at which the larvae were found. It may be that these larvae are the offspring of a dispersing female ovipositing there in spring 2020 as a population with larva surviving the winter at this elevation seems unlikely. Corbet (1962) refers to a personal communication by Lieftinck stating that *Zyxomma petiolatum* has a larval development of about 180 days, indicating that a time line in which oviposition took place early spring and nearly full-grown larvae are found in late autumn is possible.

The most interesting data are those of the larva collected at running waters. The larvae found at running waters all belong to taxa with relatively small ranges, most of them largely confined to the Himalayan region with *Neurobasis chinensis* being the only wide-ranging species. Figure 10 gives a visual summary of the larval composition of the 27 sites where larvae were collected (sites 13-15 were dry during sampling and no larvae were collected). The first thing it shows is that each of the three sites belonging to one sampling stretch at a stream (L1-L10) in most cases strongly resembles each other. The number of larvae collected at each site range from 3 to 71. The average number of larva and the average number of species found at each site vary between elevation with an average of 49 larvae found in the range between 0-1000 m; 56 larvae found in the range between 1000-2000 m and 16 larvae found in the range between 2000-3000 m. Probably it is mainly the colder temperatures resulting in a lower number of larvae at higher altitudes.

The figure also shows that not only the number of larvae and number of species change with altitude but also the composition of the fauna changes. The three commonest species are three species of Gomphidae: *Perissogomphus stevensi* (375 specimens), Gomphidae genus indet spec (196 specimens) and *Davidius* spec1 (193 specimens). All the 196 larvae of Gomphidae genus indet spec are found between 509-1661 m and all the 375 larvae of *Perissogomphus stevensi* are found between 509-2250 m. In contrast all the 193 larvae of *Davidius* spec1 are found between 931-2958 m with 160 of these found above 1934 m. *Epiophlebia laidlawi* is one of the three species of the suborder Epiophlebiidae. In the last decade a series of papers appeared which showed that larvae are common in large parts of Bhutan (e.g. Brockhaus & Hartmann, 2009; Nidup et al. 2020). We found it at ten localities between 1934 and 2778 m a.s.l. Surprisingly not a single observation of its adult is known from Bhutan although one record from 9 May 2017 pertains to specimen died within its larval skin during emerging (Observation.org). Davies (1992) encountered adults of *E. laidlawi* away from water at two mountaintops in Darjeeling, one of which was dense bamboo forest at 11.000 ft (3.350 m). Based on this it seems likely that adults *E. laidlawi* move away from their breeding habitat and can be found slightly higher up but records of this from Bhutan are still wanting.

Figure 10. Composition of the larval community of odonates in running water at different altitudes. The x-axis shows the altitude and the total number of larvae caught at the locality in brackets.

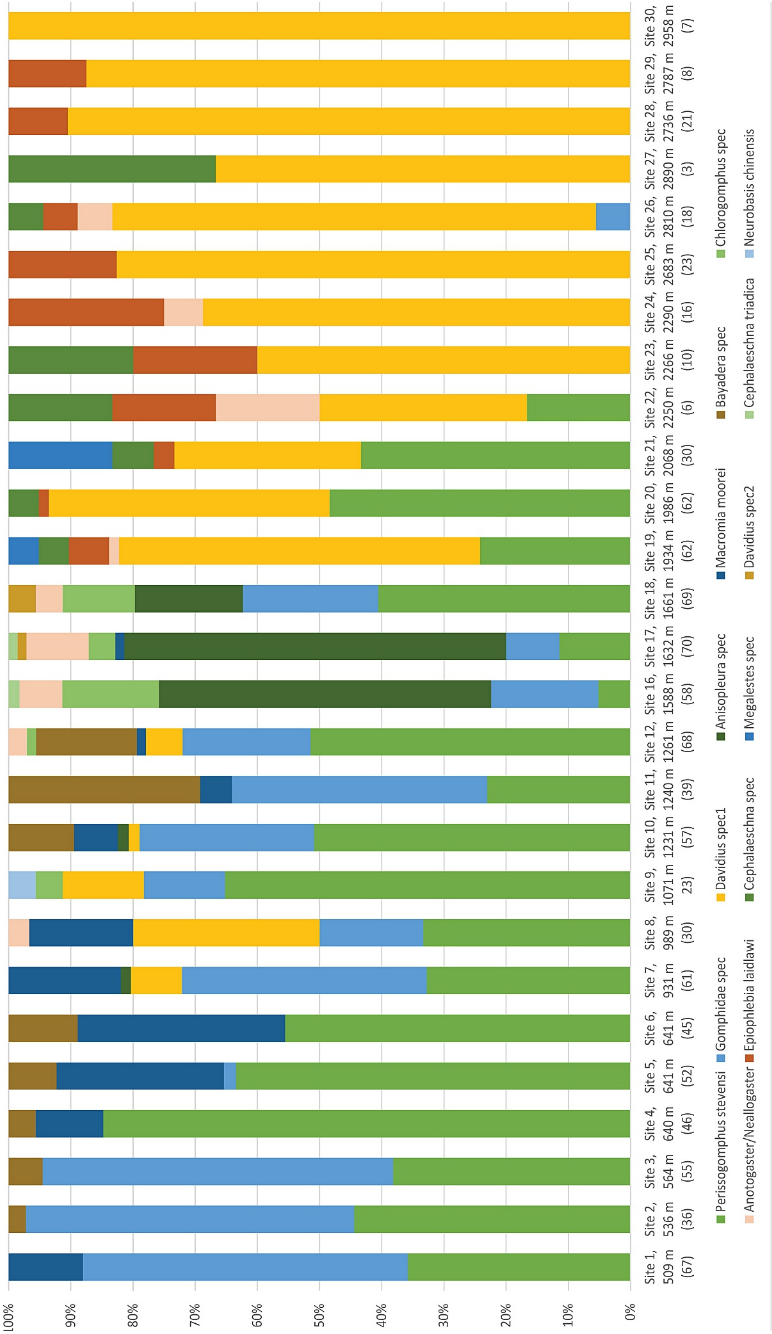
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Site 1, 509 m (67)
Site 2, 536 m (36)
Site 3, 564 m (55)
Site 4, 640 m (46)
Site 5, 641 m (52)
Site 6, 641 m (45)
Site 7, 931 m (61)
Site 8, 989 m (30)
Site 9, 1071 m 23)
Site 10, 1231 m (57)
Site 11, 1240 m (39)
Site 12, 1261 m (68)
Site 16, 1588 m (58)
Site 17, 1632 m (70)
Site 18, 1661 m (69)
Site 19, 1934 m (62)
Site 20, 1986 m (62)
Site 21, 2068 m (30)
Site 22, 2250 m (6)
Site 23, 2266 m (10)
Site 24, 2290 m (16)
Site 25, 2683 m (23)
Site 26, 2810 m (18)
Site 27, 2890 m (3)
Site 28, 2736 m (21)
Site 29, 2787 m (8)
Site 30, 2958 m (7)
Perissogomphus stevensi
Gomphidae spec
Davidius spec1
Anisopleura spec
Macromia moorei
Bayadera spec
Chlorogomphus spec
Anotogaster/Neallogaster
Epiophlebia laidlawi
Cephalaeschna spec
Megalestes spec
Davidius spec2
Cephalaeschna triadica
Neurobasis chinensis

Table 1 shows the number of larvae collected at the sites with running water in the pre- and post-monsoon period. Of the 1058 larva a total of 654 (61.9%) were collected in the pre-monsoon period and 404 (38.1%) in the post-monsoon period. This difference

Table 1. Number of larvae collected in the pre-monsoon and in the post-monsoon period. Species with more than 10 larvae collected and over 60% of the collected larvae confined to one of the periods are shown in green.

Family	Species	Larvae pre-monsoon	Larvae post-monsoon	Premon-soon %	Postmon-soon %
Synlestidae	*Megalestes* spec	5	3	62,5	37,5
Calopterygidae	*Neurobasis chinensis*	1	0	100	0
Euphaeidae	*Anisopleura* spec	60	30	66,7	33,3
Euphaeidae	*Bayadera* spec	40	4	90,9	9,1
Epiophlebidae	*Epiophlebia laidlawi*	13	11	54,2	45,8
Aeshnidae	*Cephalaeschna* spec	1	12	7,7	92,3
Aeshnidae	*Cephalaeschna triadica*	1	1	50	50
Cordulegastridae	*Anotogaster/Neallogaster* spec	16	5	76,2	23,8
Chlorogomphidae	*Chlorogomphus* spec	10	12	45,4	64,6
Gomphidae	*Davidius* spec1	81	112	42	58
Gomphidae	*Davidius* spec2	0	4	0	100
Gomphidae	Gomphidae spec	192	4	98	2
Gomphidae	*Perissogomphus stevensi*	173	201	46,4	53,6
Macromiidae	*Macromia moorei*	61	5	92,4	7,6
TOTAL		**654**	**404**	**61,9**	**38,1**

can either be due to a lower number of larvae in the water in the post-monsoon period or can be caused by the higher water flow making it more difficult to find larvae. In six species of which at least 10 larvae were collected 60% or more of the larvae were collected in either the pre-monsoon period (*Anisopleura* spec, *Bayadera* spec, *Anotogaster/Neallogaster* spec, Gomphidae spec, *Macromia moorei*) or the post-monsoon period (*Cephalaeschna* spec). Some of the differences between the two periods are very pronounced but interpretation is not straightforward. For instance, 61 of the 66 larvae of *Macromia* were caught in the pre-monsoon period but these were of different sizes suggesting that the species spends several years in the water before emerging which would suggest that the low abundance of larvae in autumn is caused by the larvae being more difficult to catch due to a higher water table. The relatively high number of larvae of *Bayadera* and *Anisopleura* could be caused by these species emerging in May to July resulting in the larger sized classes being less common in autumn. The only species being more common as larva in autumn is *Cephalaeschna* (12 of 13 larvae caught in the post-monsoon period). This is slightly surprising as the species of *Cephalaeschna* are all autumn species. Due to this one would expect that a part of the larvae already had emerged at the time the sampling was conducted resulting in a lower number of larvae in the post-monsoon period instead of the observed higher number. A possible explanation is that the larvae of *Cephalaeschna* are still small in spring and are easily missed but this explanation only holds when the larvae of this genus spend only one year in the water as larvae, which seems unlikely for a species of Aeshnidae living in cold, running water.

Conclusion

The results show clearly that the number of larvae and number of species differs strongly between different elevations, and that the number of larvae and species rapidly decreases above 2000 m. None of the species of running water is common throughout the whole range from 500 to 3000 m although some have an altitudinal range stretching across 1500 m. Sampling in the pre- or the post-monsoon clearly has influence on the number of larvae found with at least six of the 14 taxa showing clear differences between sampling period, five of them being most common in the pre-monsoon. This shows that when monitoring habitats based on larval dragonflies it is important to compare data collected at similar periods of the year. It is interesting to compare the results with those of the Mahato & Edds (1993) who collected larvae at 40 sites at the Gandaki river in central Nepal slightly over 600 km to the west of our research area. Their sites were between 50 and 1189 m a.s.l. with one site at 2560 m a.s.l. Relatively many of their sites were from the lowland, with 14 of their 40 sites lower than our lowest (509 m a.s.l.) site. Although no habitat descriptions are given the species they encountered suggest that these lower sites had a relatively slow current, maybe even with largely stagnant sections, resulting in the presence of species of Coenagrionidae and Libellulidae normally associated with standing water (*Pseudagrion rubriceps* Selys, 1876, *Brachythemis contaminata, Crocothemis servilia*, or waters with a moderate current (*Trithemis festiva, Orthetrum taeniolatum* (Schneider, 1845), *O. pruinosum*). However, like in our study the bulk of the specimens consist of *Macromia moorei* (103 specimens) and four species of Gomphidae (713 specimens). Two of these species of Gomphidae were not found by us: *Burmagomphus* spec. and *Paragomphus lineatus* (Selys, 1850) (respectively 14 and 32 specimens) the latter probably simply because it occurs at more sluggish habitats in lower areas which were not sampled by us. By far the commonest species Mahato & Edds (1993) encountered were *Davidius* spec (480 specimens) and *Anisogomphus occipitalis* (Selys, 1854) (187 specimens). The later was not found by us although our Gomphidae spec might be this species. Also, in our study *Davidius* was among the most common taxa encountered, sharply contrasting with the small numbers of observations of adults available for this genus. Remarkably Mahato & Edds (1993) did not record *Perissogomphus stevensi* which was with 375 specimens in our study the most common species. This seems to be a difference caused by geographical distance.

In 2021 a river system 60 km to the east of our study sites will be sampled for odonate larvae over an even slightly wider altitudinal range. This will make it possible to compare the results of two river systems with relatively little impact of geographic distance. These data will give a good indication if the differences observed by us between post- and pre-monsoon are an annual pattern and not merely based on the specific circumstances of 2020. It will also give some insight in the extent in which the different river systems found have a comparable faunal composition.

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The distribution, phenology and altitudinal range of dragonflies and damselflies in Bhutan

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Abstract

Dragonflies and damselflies are attractive and relatively well studied insects that can serve to monitor the conservation status of freshwater habitats. Their effective use as conservation tools necessitates some basic requirements. It should be possible to identify adults and preferably also larvae with relative ease, and basic data on distribution and habitat preferences needs to be available. Freshwater habitats in Bhutan are relatively well preserved but are nonetheless threatened by both climate change and the construction of hydroelectric installations. Biological monitoring of freshwater biodiversity in Bhutan is therefore urgently needed and should include data on dragonflies and damselflies. In order to establish a framework for effective monitoring we constructed a database of all published records and use these to present information on the distribution, the altitudinal range and phenology of all species thus far recorded from Bhutan.

Key words: freshwater; conservation; Himalayan region; biogeography.

Introduction

Compared with the Himalayan regions of India and Nepal the freshwater habitats of Bhutan are relatively well preserved. This is the result of the relatively low population density of Bhutan combined with the attention for environment in Bhutan's' constitution which for instance stipulates that at any time at least 60 percent of the country should be under forest cover. But this does not mean that freshwater habitats are completely unthreatened. The construction of roads and hydro-electric installations is impacting the larger rivers and on a more local scale the smaller tributaries of these rivers (Allen et al. 2010). The worst threat in the long run is likely to be climate change which already resulted in glaciers retracting and snow cover declining at higher altitudes and more intensive monsoon rains at lower altitudes. At present it is still difficult to predict how this will impact freshwater ecosystems and biodiversity (Wangmo & Rai 2017). In order to understand the changes in freshwater biodiversity a monitoring scheme is highly desirable. However, monitoring all freshwater invertebrates is time consuming and expensive. Also, many freshwater invertebrates occurring in the Himalayan region are still undescribed meaning that they cannot be identified to species level. A relative cheap and time efficient alternative would be using standardised counts of adult dragonflies. This could be done by combining the efforts of professionals and volunteers and could be carried out equally in cities, agricultural areas and nature reserves. In order for dragonflies and damselflies to be used to measure change in freshwater biodiversity two criteria have to be met: (1) there must be field guides allowing the identification of species, (2) a basic scheme for the interpretation of the results needs to be available. For Bhutan a field guide to the common species of dragonflies and damselflies was recently published (Gyeltshen et al. 2017c). This guide is however still insufficient to identify all species but work is underway for a more detailed field guide to be published in the next few years.

The second criteria can be addressed by making use of existing monitoring methodologies such as the Dragonfly Biotic Index (DBI) (Samways & Simaika, 2016) or the Dragonfly Association Index (Chovanec et al. 2014). The former puts more emphasis on the distribution of species and their global threat status while the latter uses the composition of the Odonata fauna to measure habitat intactness. While the latter is probably better from a management point of view the former is easier to apply in areas where the exact indicator value of species is partly or even largely unknown. In order to work towards a better overview of the indicating value of odonates occurring in Bhutan this paper provides basic information on the distribution, the elevational preference and the phenology of all Bhutanese species. It is hoped that this data will contribute to development of a freshwater monitoring scheme on the basis of dragonflies and damselflies for the eastern Himalayan region.

Material and methods

The data on distribution, altitudinal range and phenology presented in this paper is compiled from all published records of dragonflies and damselflies from Bhutan. This includes a total of 22 papers: Brockhaus & Hartmann 2009; Conniff & Sasamoto 2019; Dorji, 2014 2015; Dorji & Nidup 2020; Fraser 1936; Gurung et al. 2021; Gyeltshen 2017, 2020; Gyeltshen & Kalkman 2017; Gyeltshen et al. 2017a, b; Kalkman & Gyeltshen 2016; Lieftinck 1977; Mitra 2002, 2006, 2008, 2013; Mitra & Thinley 2006; Mitra et al. 2012, 2014 and Nidup et al. 2020. All records from these publications were compiled into a database. When not stated in the publication the coordinates were determined using Google Earth. For some of the older records the level of detail given on the locality is poor and in these cases the coordinate was determined as best as possible. In the database constructed by us we have noted the species name as given in the original reference and included a separate field with our own interpretation partly based on re-identifications or nomenclatural changes. The taxonomy used is that of Kalkman et al. (2020). The database has two fields for the date, with the second one only used to indicate a period of observation, for example when the original paper only indicates ‘site visited from 15 June to 2 August’.

We used the database to summarise information creating maps showing the distribution and making a checklist indicating the altitudinal range and phenology. For the maps all records were used for which coordinates were available and for which we were certain of the identification. The maps of species were made using the outline of country Bhutan in

QGIS Desktop 3.16.2. For the altitudinal range we simply used the lowest observation and the highest observation of either an adult or a larva. The phenology is based on the records of adults only with only records which could be attributed to a single month being used.

A record of *Orthetrum internum* by Mitra et al. (2012) is from 247 m elevation, far lower than any of the other records of this species from Bhutan and the elevation is therefore indicated with a question mark in Table 1.

Results

The database is based on slightly over 1200 records (presence of a species on a given day at a locality) of a total 123 species (on average about eight records per species). Almost 98% percent of these records have a coordinate, over 90% percent have a date referring to a single month and 92% percent have information on the elevation.

Figure 1 shows all the localities where records were collected and figure 2 (see appendix) shows the distribution map for each species. Table 1 contains a checklist of the species known from Bhutan with information on the months in which adults were observed and the altitudinal range in which species were observed (the later based on adults & larva). For the altitudinal range the lowest and highest record was used and it was assumed that the species was also present in the areas in between.

Figure 3 shows the number of species observed for each altitudinal section of 500 m. Figure 4 shows the number of species observed as adult for each of the twelve months of the year.

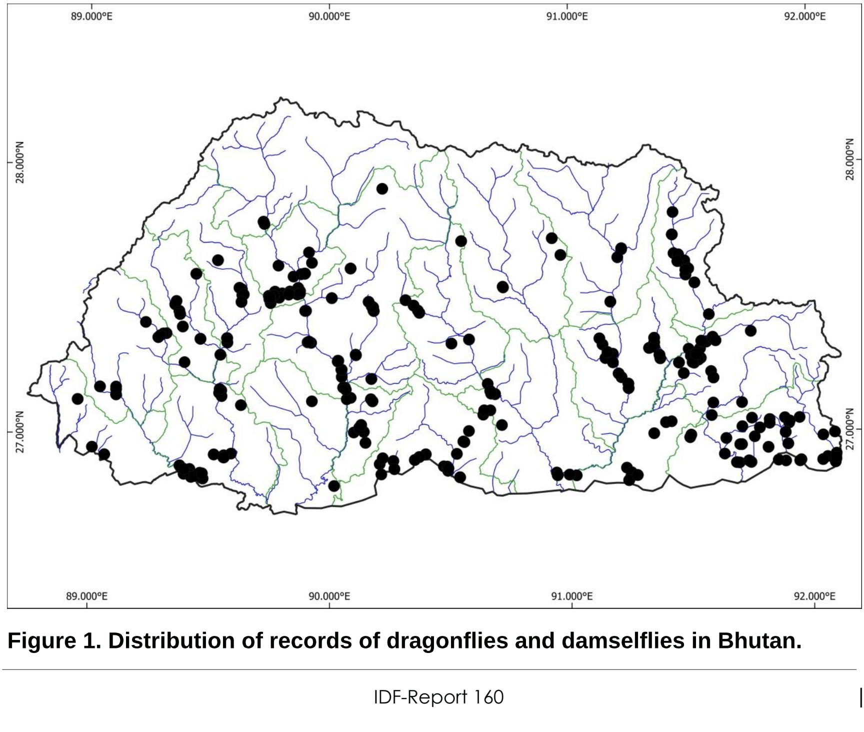

Figure 1. Distribution of records of dragonflies and damselflies in Bhutan.

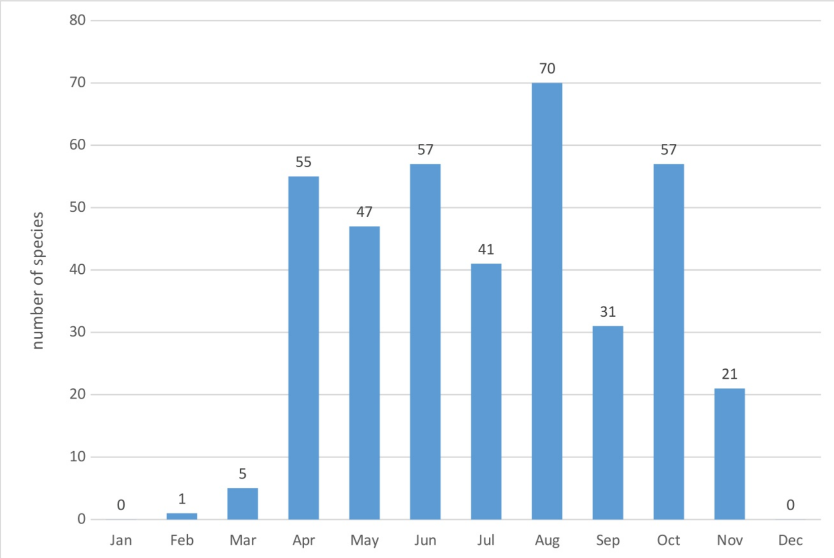

Figure 3. The number of species observed as adults during each of the twelve months of the year.

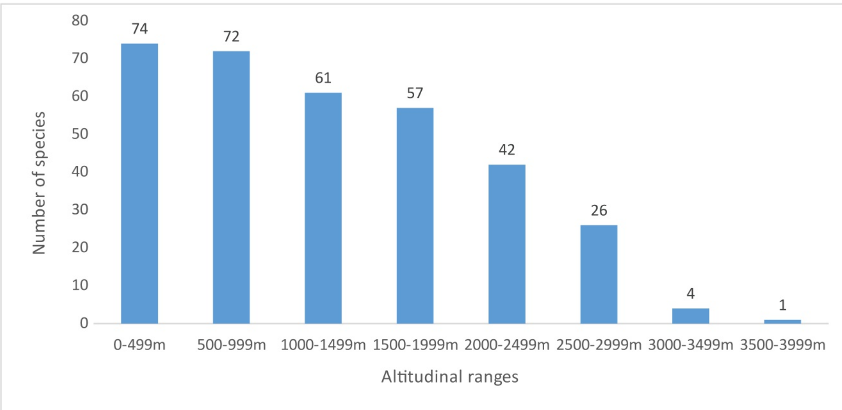

Figure 4. The number of species observed either as adult or larva for different altitudinal ranges.

Table 1. Checklist of the dragonflies and damselflies in Bhutan. For each species the altitudinal range and the presence of adults in each month is given. (1) The upper limit of occurrence of *C. servillia* is unclear as it is likely that many of the reports of this species from higher altitudes in fact pertain to *C. erythraea*.

		Alt (low)	Alt (high)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Order Odonata	**Fabricius, 1793**														
Suborder Zygoptera	**Selys, 1854**														
Superfamily Lestoidea	**Calvert, 1901**														
Family: Synlestidae	**Tillyard, 1917**														
Megalestes gyalsey	Gyeltshen, Kalkman & Orr 2017	2450	2450										x		
Megalestes major	Selys, 1862	741	2562						x		x	x	x	x	
Megalestes micans	Needham, 1930	1165	1827					x					x		
Family: Lestidae	**Calvert, 1907**														
Indolestes cyaneus	(Selys, 1862)	950	3274				x	x	x	x	x		x	x	
Lestes dorothea	Fraser, 1924	1927	1927						x				x		
Lestes concinnus	Hagen in Selys, 1862	253	253					x							
Lestes praemorsus decipiens	Kirby, 1893	270	2195				x	x	x		x				
Superfamily: Platystictoidea	**Kennedy, 1920**														
Family: Platystictidae	**Kennedy, 1920**														
Drepanosticta carmichaeli	(Laidlaw, 1915)	337	508					x	x						
Protosticta himalaica	Laidlaw, 1917	255	1844												
Superfamily Calopterygoidea	**Selys, 1850**														
Family: Calopterygidae	**Selys, 1850**														
Caliphaea confusa	Hagen in Selys, 1859	1150	1965				x	x	x		x	x			
Neurobasis chinensis	(Linnaeus, 1758)	149	1233				x	x	x	x	x	x	x		
Vestalis gracilis	(Rambur, 1842)	265	360				x	x			x				
Family: Chlorocyphidae	**Cowley, 1937**														
Aristocypha cuneata	(Selys, 1853)	125	1493				x	x	x		x		x		
Aristocypha quadrimaculata	Selys, 1853	125	1071				x	x			x		x		
Libellago lineata	(Burmeister, 1839)	405	405										x		
Paracypha unimaculata	(Selys, 1853)	125	1870				x	x	x	x					
Family: Euphaeidae	**Yakobson & Bainchi, 1905**														
Anisopleura comes	Hagen, 1880	508	2380				x	x	x		x	x	x		
Anisopleura lestoides	Selys, 1853	536	1290				x		x				x		
Anisopleura subplatystyla	Fraser, 1927	980	2846						x	x	x		x		
Bayadera indica	(Selys, 1853)	325	1774				x	x	x	x	x				
Bayadera longicauda	Fraser, 1928	2187	2187						x						
Dysphaea gloriosa	Fraser, 1938	535	535				x								
Euphaea ochracea	Selys, 1859	326	399				x	x			x				
Family: Philogangidae	**Kennedy, 1920**														
Philoganga montana	(Hagen in Selys, 1859)	399	720				x	x							
Superfamily Coenagrionidea	**Kirby, 1890**														
Family: Platycnemididae	**Yakobson & Bainchi, 1905**														
Calicnemia eximia	(Selys, 1863)	247	2900				x	x	x	x	x	x	x	x	

		Alt (low)	Alt (high)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Calicnemia miniata	(Selys, 1886)	399	1614				x	x	x		x				
Calicnemia mortoni	(Laidlaw, 1917)	240	2068					x	x	x	x				
Coeliccia svihleri	Asahina, 1970	247	923				x	x			x				
Copera vittata	Selys, 1863	255	750				x	x							
Family: Coenagrionidae	**Kirby, 1890**														
Aciagrion olympicum	Laidlaw, 1919	980	2425					x	x	x	x		x		
Aciagrion pallidum	Selys, 1891	498	604						x				x		
Agriocnemis clauseni	Fraser, 1922	265	821								x		x		
Agriocnemis femina	(Brauer, 1868)	253	821				x				x				
Agriocnemis lacteola	Selys, 1877	345	345				x								
Agriocnemis pygmaea	(Rambur, 1842)	240	317						x	x			x		
Amphiallagma parvum	(Selys, 1877)	253	2860				x	x			x				
Agiocnemis rubescens rubeola	Selys, 1877	253	349				x	x			x		x		
Ceriagrion azureum	(Selys, 1891)	581	581					x							
Ceriagrion coromandelianum	(Fabricius, 1798)	253	574				x	x			x		x		
Ceriagrion fallax	Ris, 1914	476	2696				x	x	x	x	x	x	x	x	
Ceriagrion rubiae	Laidlaw, 1916	253	253					x							
Coenagrion exclamationis	(Fraser, 1919)	1973	1973								x				
Huosoma tinctipenne	(McLachlan, 1894)	2620	2633								x	x			
Ischnura forcipata	Morton, 1907	1750	2000							x			x	x	
Ischnura rubilio	Selys, 1876	125	2705			x	x		x	x	x	x	x	x	
Pseudagrion rubriceps	Selys, 1876	125	1973				x			x	x		x		
Suborder Anisozygoptera	**Hanlirsch, 1906**														
Superfamily Epiophlebioidae	**Muttkowshi, 1910**														
Family: Epiophlebiidae	**Muttkowshi, 1910**														
Epiophlebia laidlawi	Tillyard, 1921	1568	2922												
Suborder Anisoptera	**Selys, 1854**														
Superfamily Platystictoidea	**Leach, 1815**														
Family: Aeshnidae	**Leach, 1815**														
Aeshna shennong	Zhang & Cai, 2014	2850	2850								x				
Aeshna petalura	Martin, 1906	2042	2695						x		x		x		
Anaciaeschna martini	(Selys, 1897)	1775	1775						x						
Anaciaeschna jaspidea	(Burmeister, 1839)	296	296				x								
Anax ephippiger	(Burmeister, 1839)	240	500								x				
Anax guttatus	(Burmeister, 1839)	1435	1435								x				
Anax indicus	Lieftinck, 1942	270	2696				x	x	x		x	x		x	
Anax nigrofasciatus nigrolineatus	Fraser, 1935	508	2695				x	x	x		x		x		
Cephalaeschna triadica	Lieftinck, 1977	2195	2300						x				x		
Gynacantha khasiaca	McLachlan, 1896	320	320										x		
Gynacantha incisura	Fraser, 1935	1290	1290										x		

		Alt (low)	Alt (high)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Gynacantha subinterrupta	Rambur, 1842	250	250								x				
Gynacanthaeschna sikkima	(Karsch, 1891)	1165	1992										x		
Periaeschna magdalena	Martin, 1909	720	1507				x					x			
Polycanthagyna erythromelas	(McLachlan, 1896)	632	1794					x				x	x		
Superfamily Gomphoidea	**Rambur, 1842**														
Family: Gomphidae	**Rambur, 1842**														
Anisogomphus bivittatus	Selys, 1854	868	1233									x			
Anisogomphus occipitalis	(Selys, 1854)	460	1708				x	x	x	x					
Asiagomphus odoneli	(Fraser, 1922)	320	320								x				
Davidius baronii	Lieftinck, 1977	931	1900				x	x	x						
Davidius delineatus	Fraser, 1926	848	2187					x	x						
Lamelligomphus biforceps	(Selys, 1878)	900	950										x	x	
Lamelligomphus risi	(Fraser, 1922)	320	545								x		x		
Nychogomphus duaricus	(Fraser, 1924)	399	399					x							
Scalmogomphus bistrigatus	(Hagen in Selys, 1854)	460	1870						x		x				
Paragomphus lineatus	(Selys, 1850)	317	360						x		x		x		
Perissogomphus stevensi	Laidlaw, 1922	345	1917				x	x	x		x				
Stylogomphus inglisi	Fraser, 1922	720	720				x								
Superfamily Cordulegastroidea	**Hagen, 1875**														
Family: Chlorogomphidae	**Needham, 1903**														
Chlorogomphus mortoni	Fraser, 1936	390	923				x								
Chlorogomphus preciosus preciosus	(Fraser, 1924)	923	923				x								
Family: Cordulegasteridae	**Hagen, 1875**														
Anotogaster nipalensis	Selys, 1854	1234	2325					x	x		x	x	x		
Neallogaster hermionae	(Fraser, 1927)	2685	2685								x				
Neallogaster latifrons	(Selys, 1878)	2134	2134												
Family: Macromiidae	**Needham, 1903**														
Macromia moorei	Selys, 1874	545	2380				x		x		x	x	x		
Somatochlora	**Selys, 1871**														
Somatochlora daviesi	Lieftinck, 1977	2425	3480								x		x		
Family: Libellulidae	**Leach, 1815**														
Acisoma panorpoides	Rambur, 1842	349	2002					x		x	x	x	x		
Brachydiplax sobrina	(Rambur, 1842)	240	1228								x				
Brachythemis contaminata	(Fabricius, 1793)	255	2699					x	x	x			x		
Bradinopyga geminata	(Rambur, 1842)	240	400						x	x					
Camacinia gigantea	(Brauer, 1867)	581	581					x							
Cratilla lineata calverti	Förster, 1903	832	832				x								

		Alt (low)	Alt (high)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Crocothemis erythraea	(Brullé, 1832)	1435	2326								x		x		
Crocothemis servilia	(Drury, 1770)	125	2900 (1)		x	x	x	x	x	x	x	x	x	x	
Diplacodes lefebvrii	(Rambur, 1842)	226	226							x					
Diplacodes nebulosa	(Fabricius, 1793)	125	446				x			x					
Diplacodes trivialis	(Rambur, 1842)	149	3274				x	x	x	x	x	x	x	x	
Indothemis limbata	(Selys, 1891)	240	400							x					
Lyriothemis bivittata	(Rambur, 1842)	187	1085				x		x						
Neurothemis fulvia	(Drury, 1773)	250	1080				x	x		x	x	x	x		
Neurothemis intermedia	(Rambur, 1842)	240	400						x	x	x				
Orthetrum chrysis	(Selys, 1891)	240	400						x	x		x			
Orthetrum glaucum	(Brauer, 1865)	250	2699				x		x		x		x	x	
Orthetrum internum	McLachlan, 1894	247 (?)	3570			x	x	x	x	x	x				
Orthetrum luzonicum	(Brauer, 1868)	265	1756				x		x	x	x			x	
Orthetrum pruinosum neglectum	(Rambur, 1842)	265	1992				x		x	x	x	x	x	x	
Orthetrum sabina sabina	(Drury, 1770)	250	2326			x	x			x	x	x	x	x	
Orthetrum taeniolatum	(Schneider, 1845)	149	2195						x	x	x		x		
Orthetrum triangulare triangulare	(Selys, 1878)	149	2326				x	x	x	x	x	x	x	x	
Palpopleura sexmaculata	(Fabricius, 1787)	125	2300			x	x		x	x	x	x	x	x	
Pantala flavescens	(Fabricius, 1798)	149	2845				x	x	x	x	x		x		
Potamarcha congener	(Rambur, 1842)	270	270				x								
Rhyothemis variegata	(Linnaeus, 1763)	240	400						x			x			
Rhyothemis phyllis	(Sulzer, 1776)	320	320								x				
Sympetrum commixtum	Selys, 1884	800	2900							x	x	x	x	x	
Sympetrum fonscolombii	(Selys, 1840)	509	2705				x				x		x		
Sympetrum hypomelas	(Selys, 1884)	1182	2920							x	x	x	x	x	
Sympetrum speciosum	Oguma, 1915	1999	1999						x			x			
Tholymis tillarga	(Fabricius, 1798)	149	149										x		
Tramea basilaris	(Palisot de Beauvois, 1805)	240	1352						x		x		x		
Tramea limbata	(Desjardins, 1832)	1999	1999						x			x			
Tramea virginia	(Rambur, 1842)	240	1435							x	x			x	
Trithemis aurora	(Burmeister, 1839)	149	2699					x	x	x	x	x	x	x	
Trithemis festiva	(Rambur, 1842)	149	1922				x		x	x	x	x	x		
Trithemis pallidinervis	(Kirby, 1889)	125	446				x			x	x				
Urothemis signata	(Rambur, 1842)	2326	2326							x	x				
Zygonyx iris	Selys, 1869	915	915					x							
Genera incertae sedis															
Idionyx stevensi	Fraser, 1924	460	460						x						

Discussion

The available records of dragonflies and damselflies from Bhutan are not evenly distributed (Figure 1). The virtual absence of records from the north corresponds with the high altitude of this region and is due to a combination of inaccessibility and genuine absence of species above 4000 m elevation. The absence of records from parts of the southern two-thirds of the country indicates a lack of exploration and, as can be seen from Figure 1, many areas have not been explored at all. Some of these are difficult to access mountain areas where roads and villages are scarce making exploration difficult. Despite of the limited number of records available, the distribution maps are already a great help in understanding diversity patterns in this part of the Himalayan region. Examples for this are the maps of *Megalestes gyalsey, M. micans* and *M. major* which clearly show that the latter is by far the most common and widespread species of this genus. Good examples of the visualisation of the altitudinal range are the maps of *Aristocypha quadrimaculata* (low elevation; 125-1071 m), *Caliphaea confusa* (mid elevation; 1150-1965 m) and *Somatochlora daviesi* (upper elevation; 2425-3480 m). The clearest general distributional pattern is the difference between the southern lowland which is dominated by Oriental species with Palearctic species becoming more dominant in the north, above 1000 m. Figure 3 clearly shows that the diversity is highest below 1000 m, that there is a gradually decline in number of species between 1000 and 2000 m and that the number of species start to drop rapidly above 2000 m. Only four species have been recorded above 3000 m: *Indolestes cyaneus* which was found reproducing at 3274 m at Rukubji along the Wangdue Phodrang to Trongsa road, *Somatochlora daviesi, Diplacodes trivialis* and *Orthetrum internum*. Of these *Orthetrum internum* and especially *Somatochlora daviesi* seem to be restricted to high altitude. *Diplacodes trivialis* is a very wide-ranging species which is highly abundant in the lowland of the Indian Pensinsula but also reproduces at higher altitudes in the main valleys of Bhutan. There are several records above 2500 m including one of at least 10 individuals at 2695 m which seems to indicate that the species can reproduce at higher elevations although it might not be able to survive the winter. Further field work will undoubtably show more species to be present above 3000 m and probably also some will be found above 4000 m. However, the number of new species to be found at lower altitudes is expected to be far greater and their discovery would result in an even stronger difference in diversity between low and high altitudes.

In addition to the clear south-north patterns related to elevation the maps also show some east-west patterns with some species such as *Coeliccia svihleri* seemingly being restricted to the east. More data is needed to determine if these patterns are real or merely a sampling artefact. If real, then it needs to be determined if these patterns can be explained by climatic conditions or if some of the deeper river valleys form barriers to the distribution of species.

Data on the phenology of dragonflies and damselflies in the Indian Peninsula is scattered and no overviews are currently available. Despite the relatively small number of records available the data from Bhutan gives a good indication of the flight period of most species. Figure 4 gives an indication of the number of species on the wing during each month. This graph is influenced by the period of year in which field work was conducted and probably underestimates the number of species on the wing during the winter. A small number of species is found throughout the year. All of these are species breeding at standing waters and mainly occur at lower altitude. There are however some species such as *Indolestes cyaneus, Ischnura rubilio, Diplacodes trivialis* and *Orthetrum sabina* which probably also occur throughout the winter at slightly higher altitudes from 1500-2000 m in the valleys where the main towns (Paro and Thimphu) of Bhutan are located. Species from running water have not been found as adults during the winter (December-February) period. Nonetheless a surprising number of them have a long flight period stretching from early spring (March-April) to late autumn (October-November); these include *Neurobasis chinensis, Aristocypha cuneata, A. quadrimaculata, Anisopleura comes, Calicnemia eximia* and *Macromia moorei*. The most interesting are those which have a restricted flight period as these species can easily be missed when a site is visited at the wrong time of the year. The following species seem to have a flight period that is largely restricted to spring and early summer (pre monsoon): *Paracypha unimaculata, Bayadera indica, Calicnemia miniata, C. mortoni, Anisogomphus occipitalis, Davidius* sp*., Perissogomphus stevensi* and *Orthetrum internum.* Species for which the available records suggest a flight period largely restricted to late summer and autumn (post monsoon) include: *Megalestes major, Cephalaeschna* sp*., Gynacanthaeschna sikkima, Gynacantha* sp*., Lamelligomphus* sp*., Sympetrum commixtum, S. hypomelas*. Projects estimating the abundance of dragonflies and damselflies of certain habitats throughout the year will enable the flight periods of species to be determined in greater detail.

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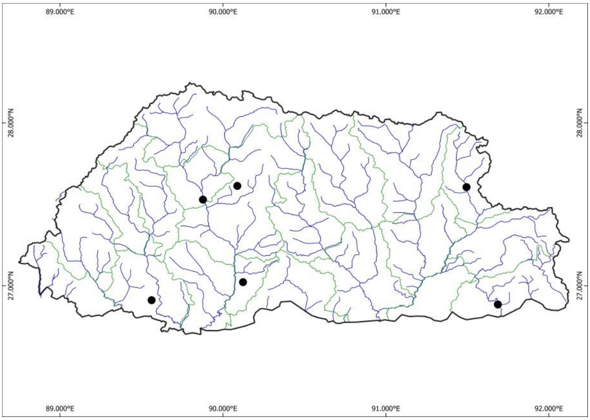
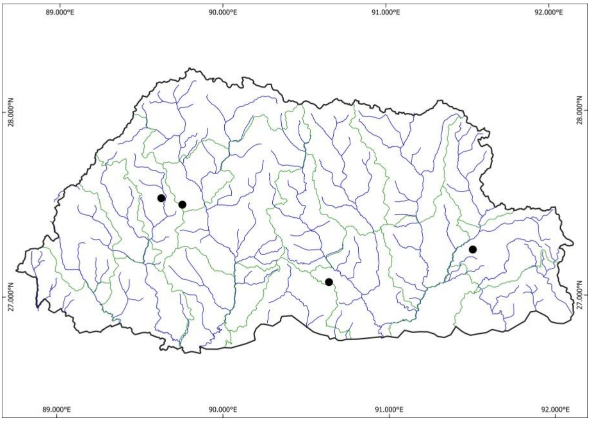
Appendix: Distribution maps 1-123

Anisoptera: 1-75

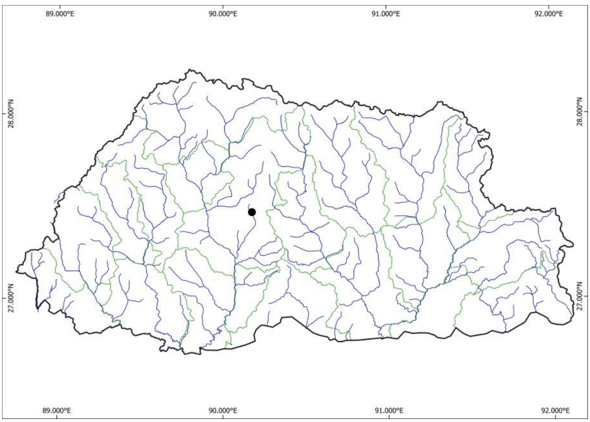
1. *Acisoma panorpoides*



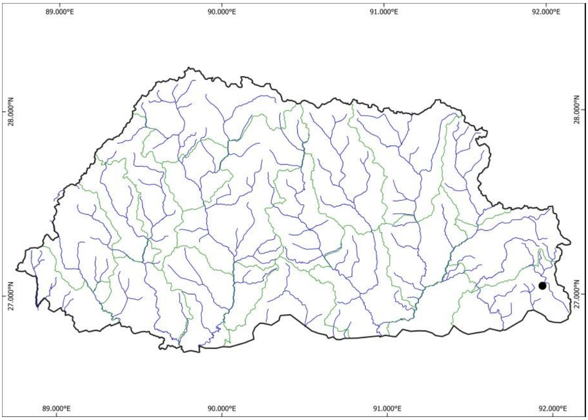
2. *Aeshna petalura*



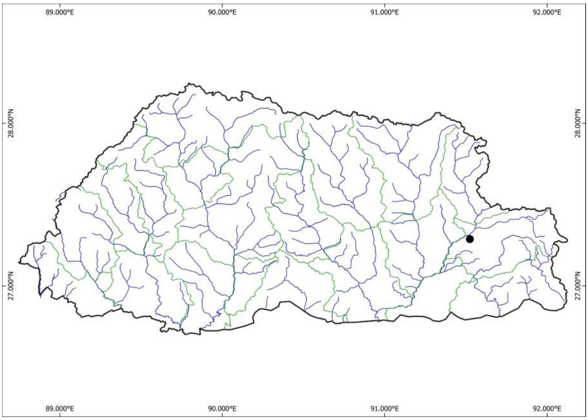
3. *Aeshna shennong*



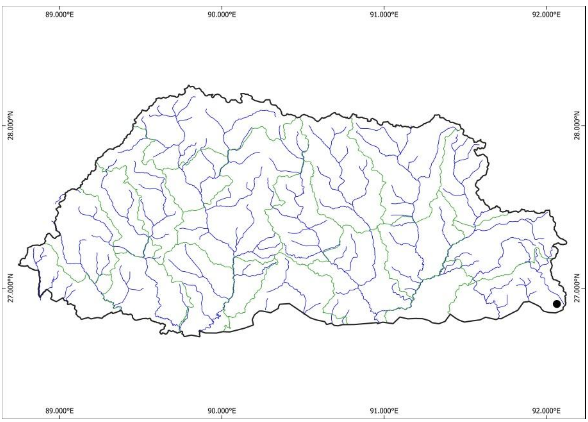
4. *Anaciaeschna jaspidea*

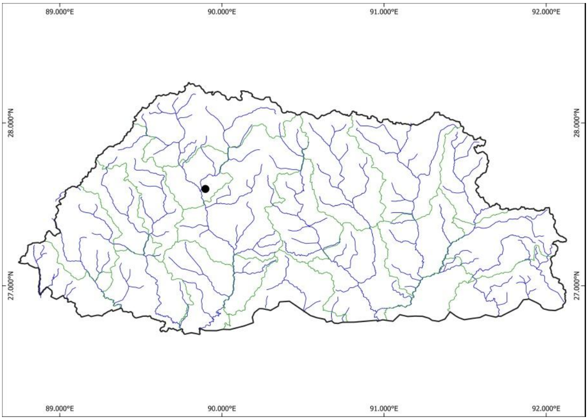


5. *Anaciaeschna martini*

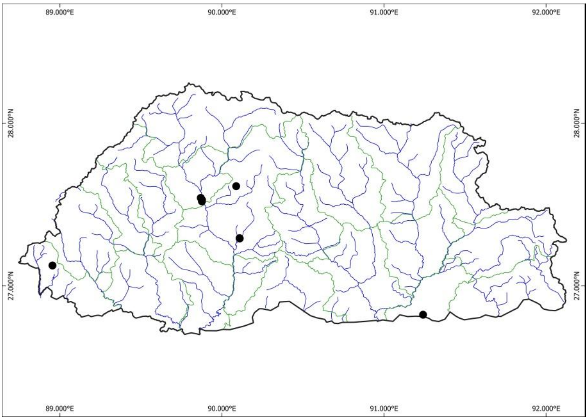


6. *Anax ephippiger*

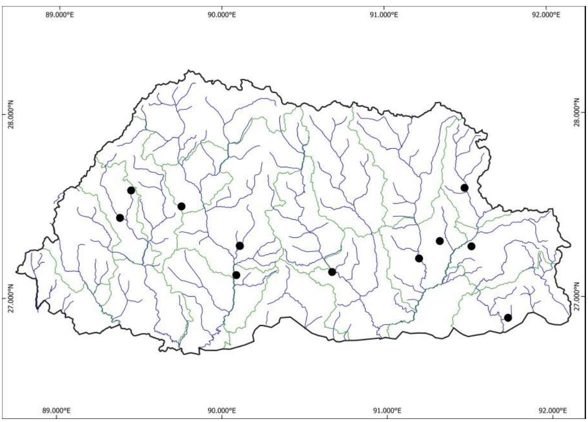




7. *Anax guttatus*

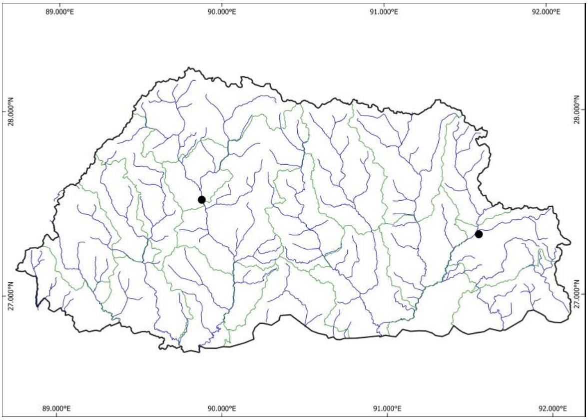


8. *Anax indicus*

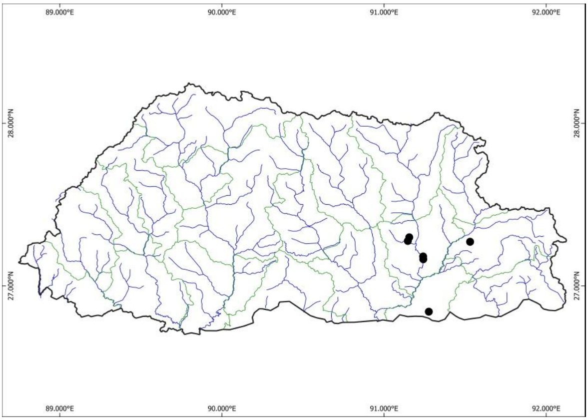


9. *Anax nigrofas-ciatus*

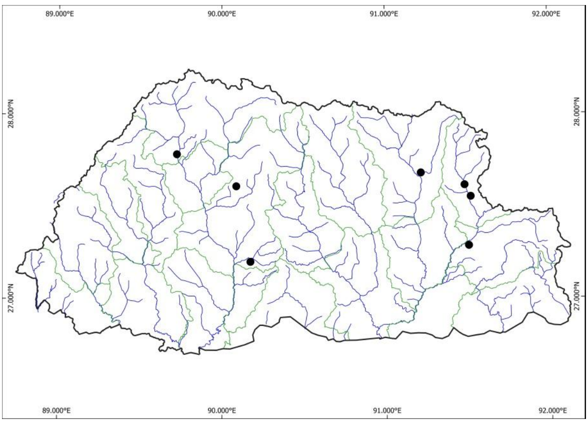
10. ***Anisogomphus bivittatus***

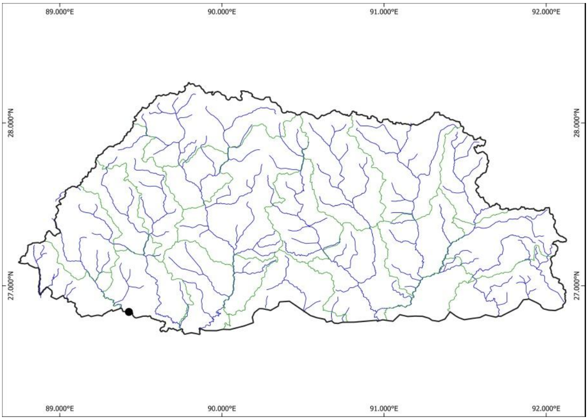


11. ***Anisogomphus occipitalis***

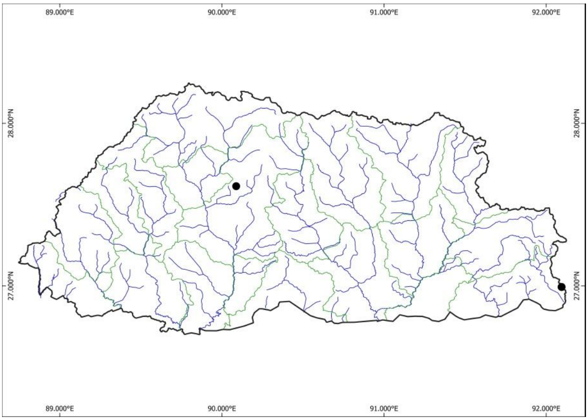


12. ***Anotogaster nipalensis***

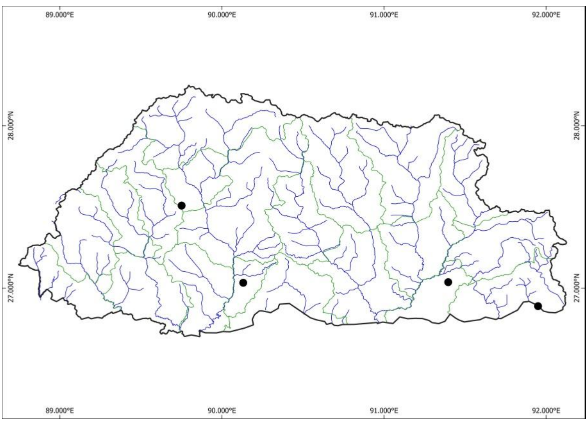




13. *Asiagomphus odoneli*

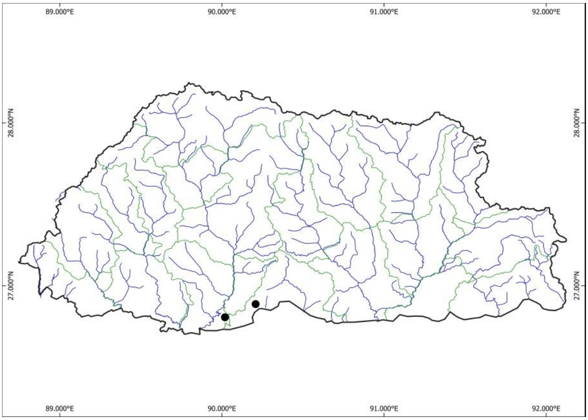


14. *Brachydiplax sobrina*

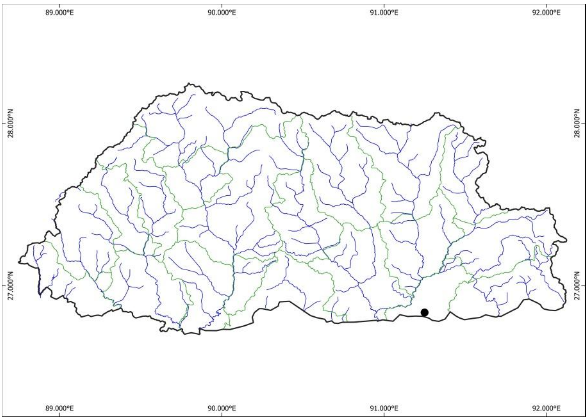


15. *Brachythemis contaminata*

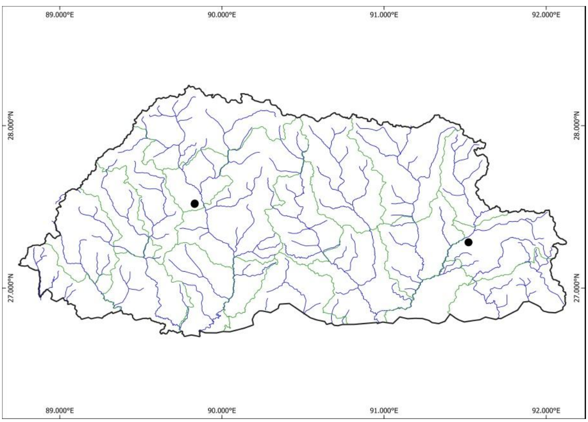
16. ***Bradinopyga geminata***

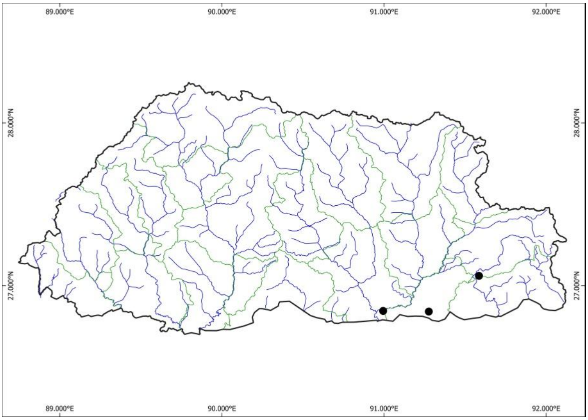


17. ***Camacinia gigantea***

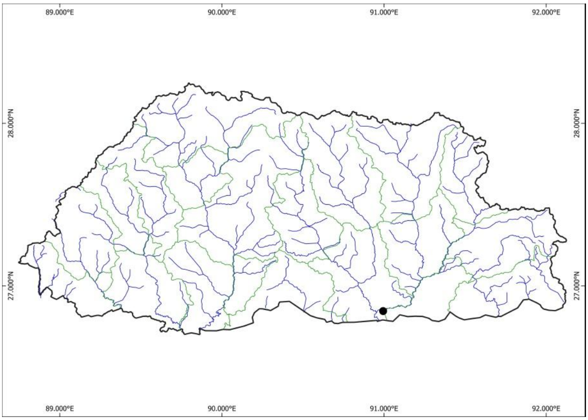


18. ***Cephalaeschna triadica***

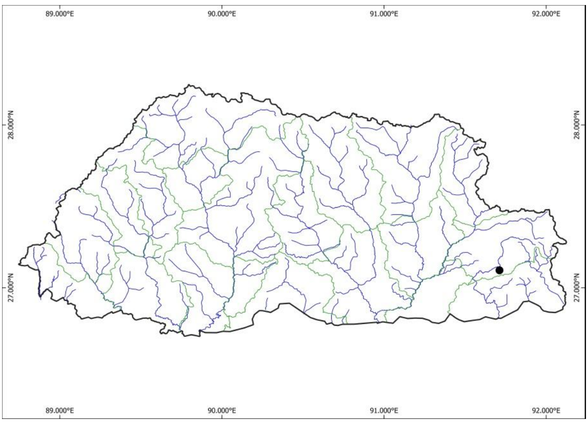




19. *Chlorogomphus mortoni*

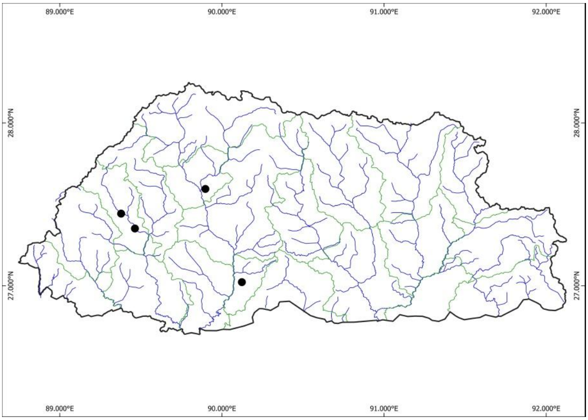


20. *Chlorogomphus preciosus*

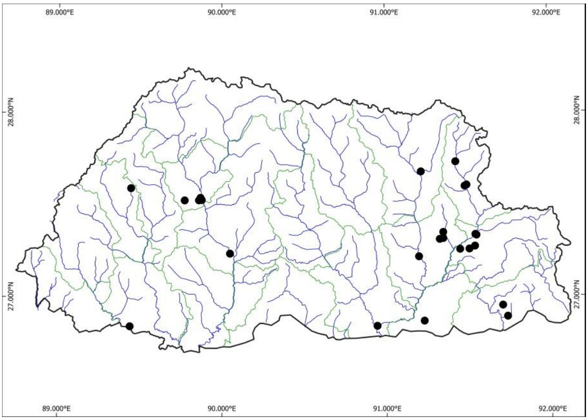


21. *Cratilla lineata*

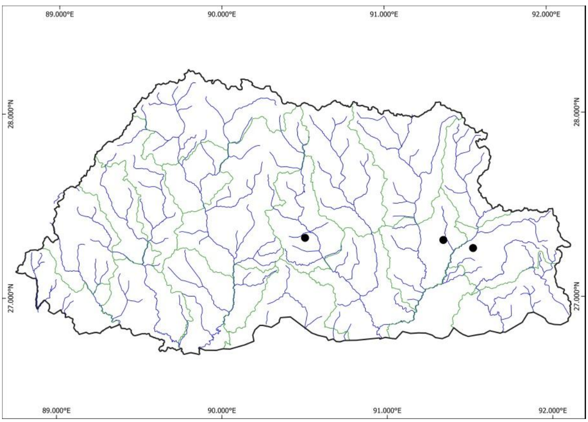
22. ***Crocothemis erythraea***



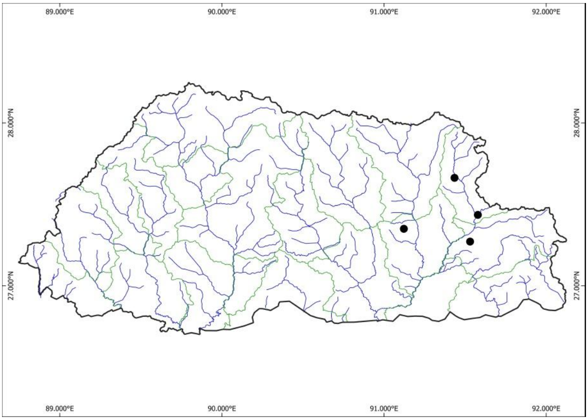
23. ***Crocothemis servilia***



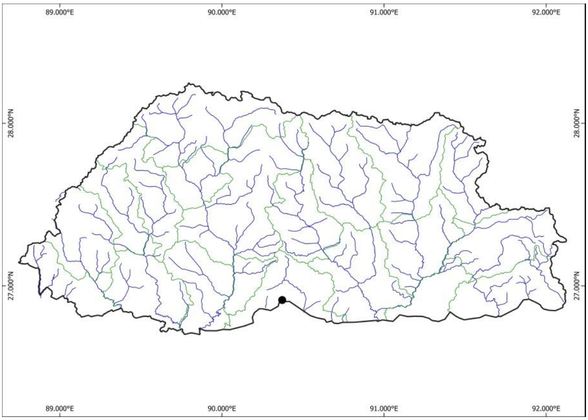
24. ***Davidius baronii***



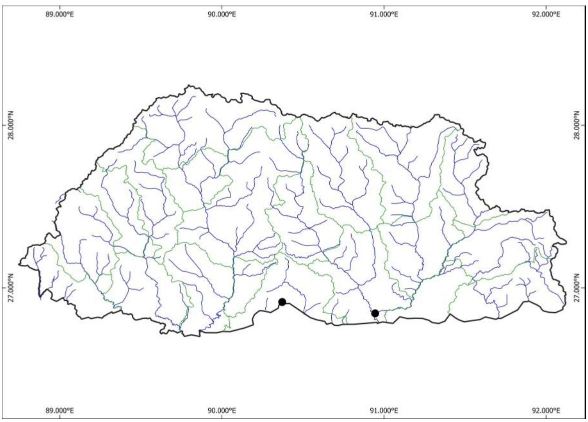
25. *Davidius delineatus*



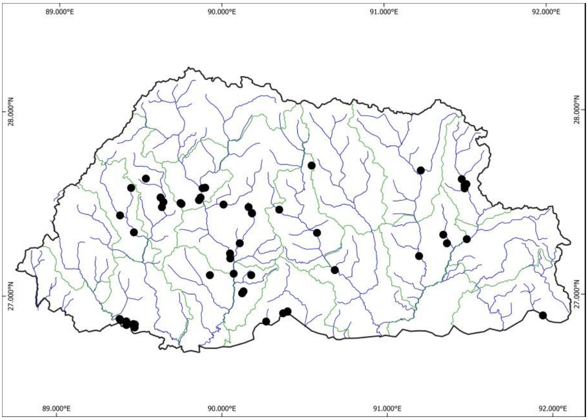
26. *Diplacodes lefebvrii*



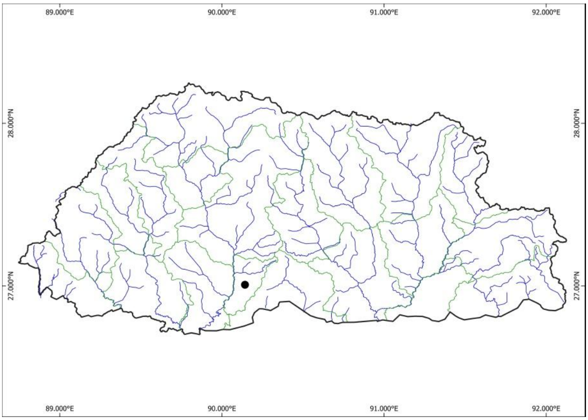
27. *Diplacodes nebulosa*



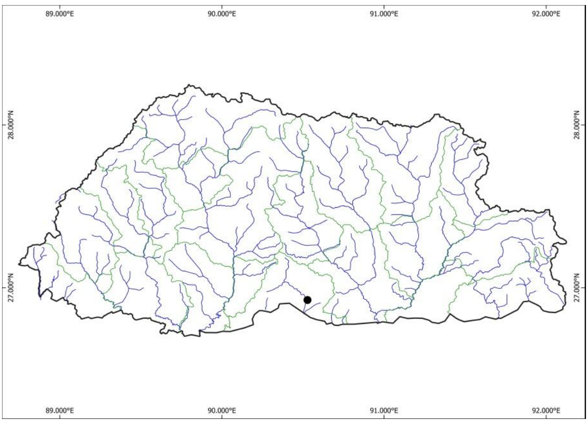
28. ***Diplacodes trivialis***

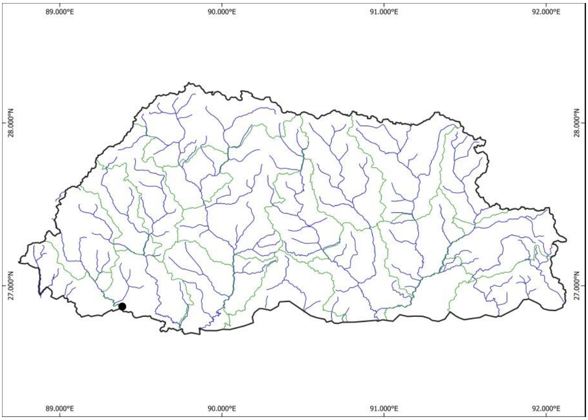


29. ***Gynacantha incisura***

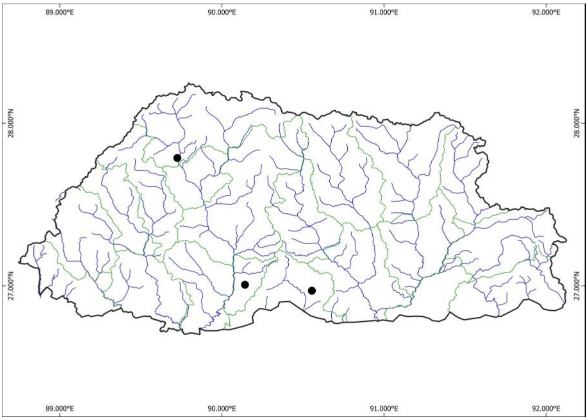


30. ***Gynacantha khasiaca***

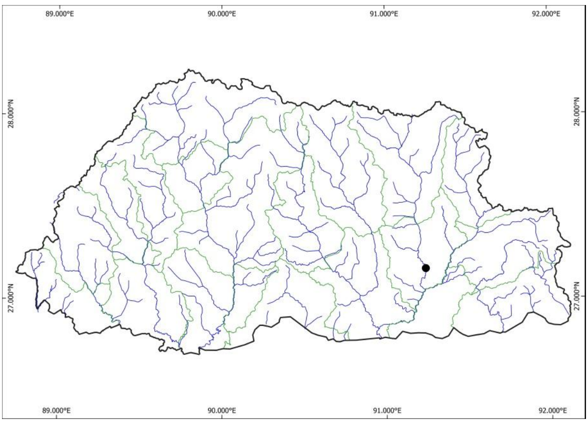




31. ***Gynacantha subinterrupta***

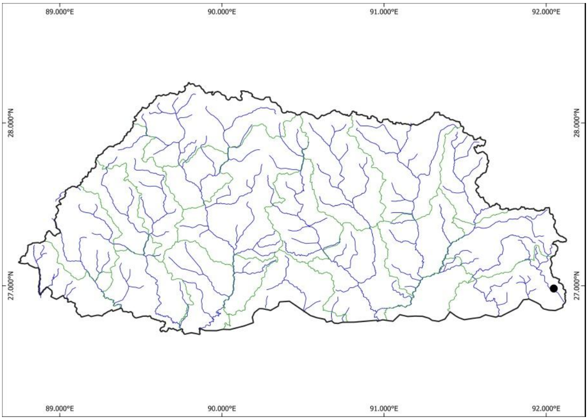


32. ***Gynacanthaeschna sikkima***

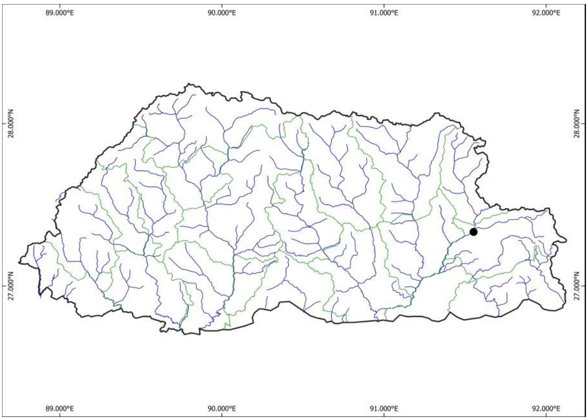


33. ***Idionyx stevensi***

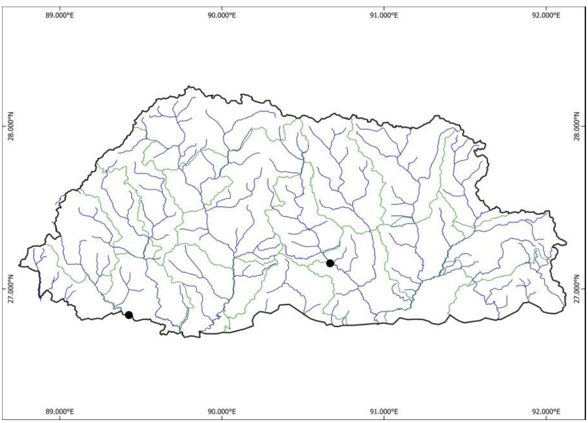
34. *Indothemis limbata*

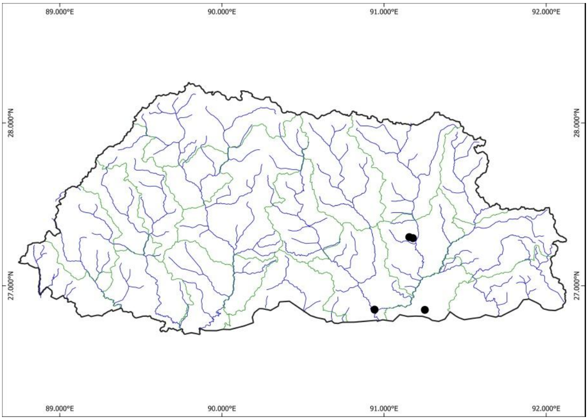


35. *Lamelligomphus biforceps*

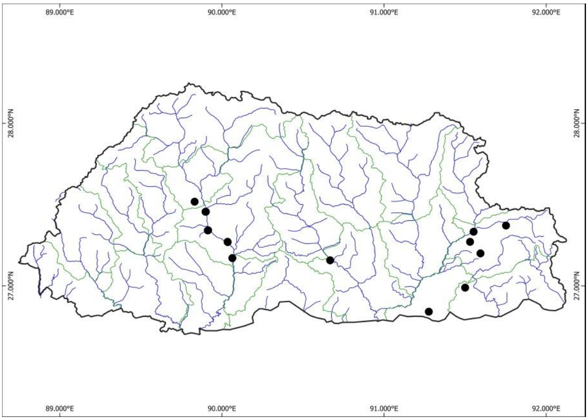


36. *Lamelligomphus risi*

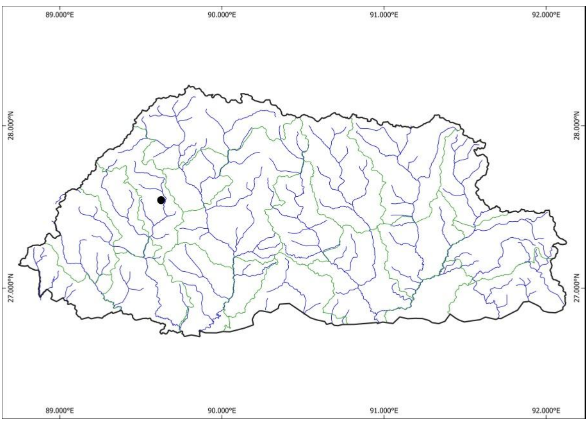




37. ***Lyriothemis bivittata***

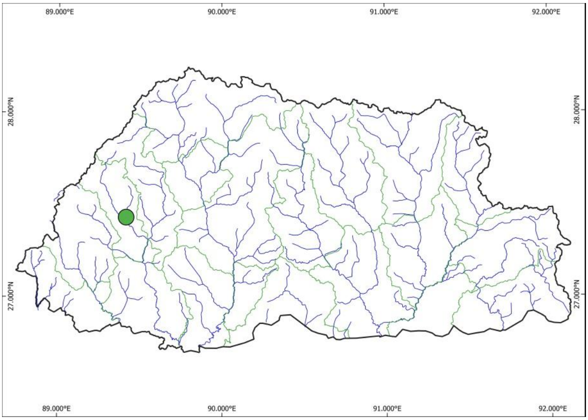


38. ***Macromia moorei***

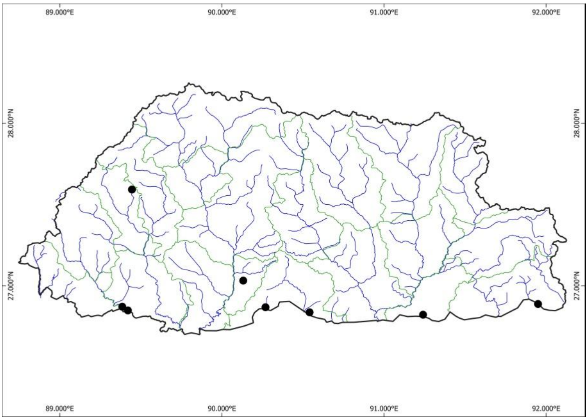


39. ***Neallogaster hermionae***

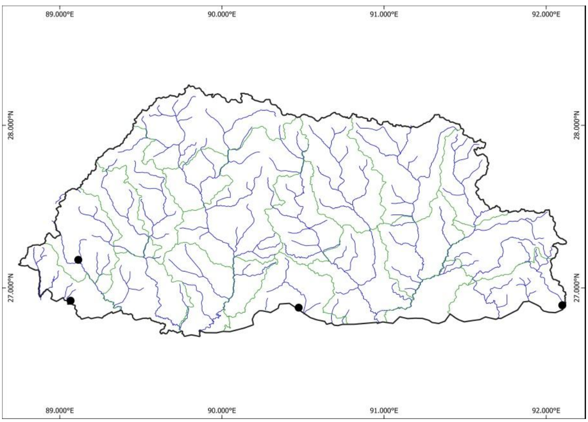
40. *Neallogaster latifrons*



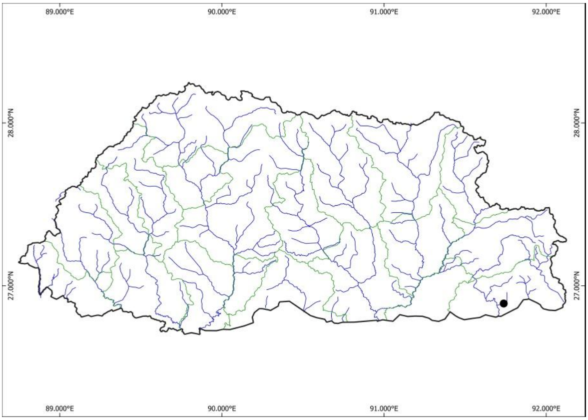
41. *Neurothemis fulvia*



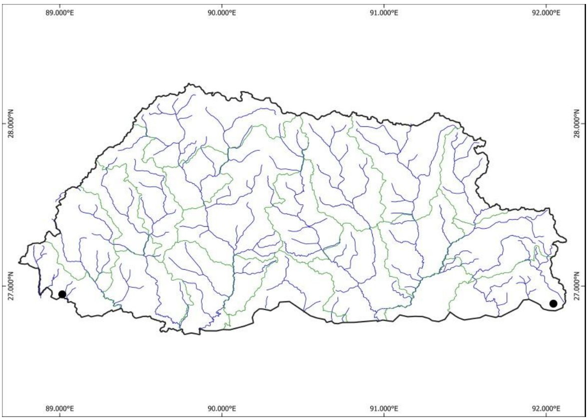
42. *Neurothemis intermedia*



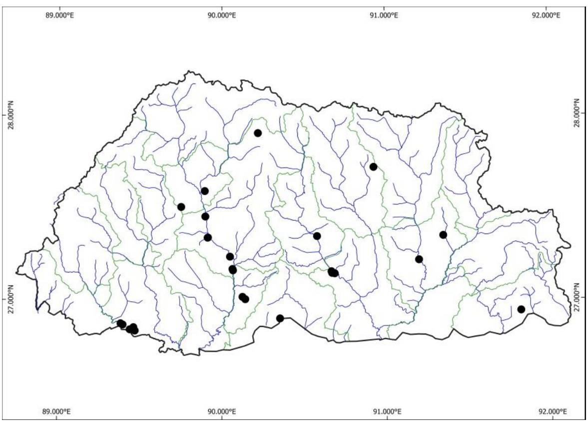
43. *Nychogomphus duaricus*



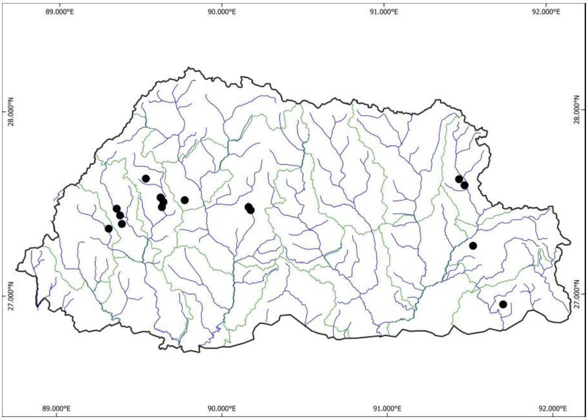
44. *Orthetrum chrysis*



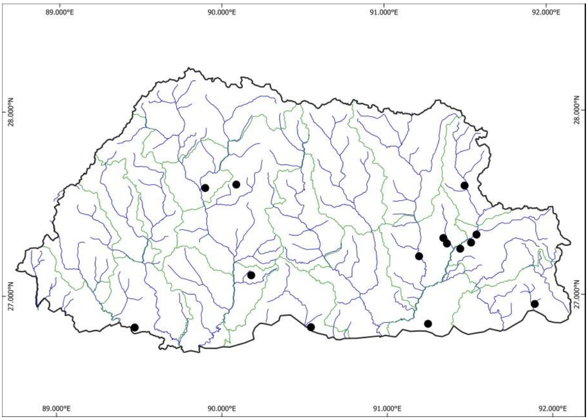
45. *Orthetrum glaucum*



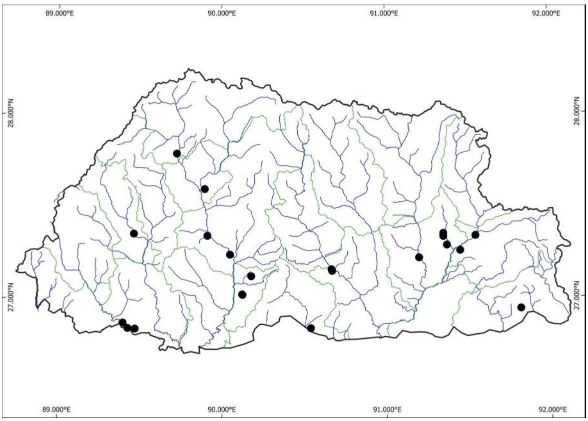
46. ***Orthetrum internum***

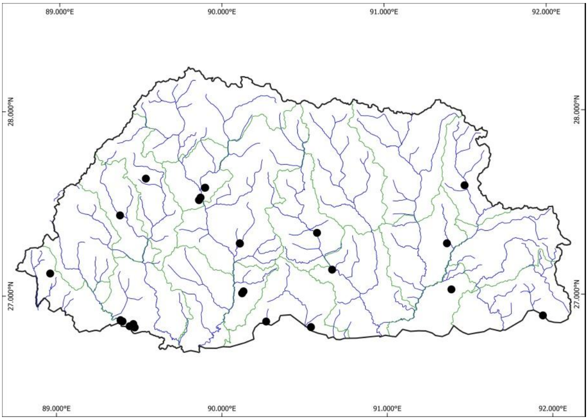


47. ***Orthetrum luzonicum***

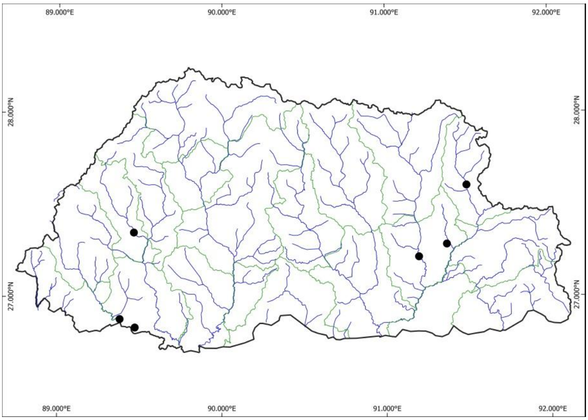


48. ***Orthetrum pruinosum***

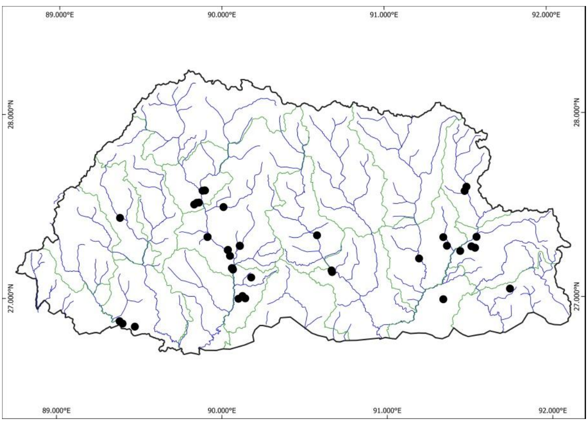




49. ***Orthetrum sabina sabina***

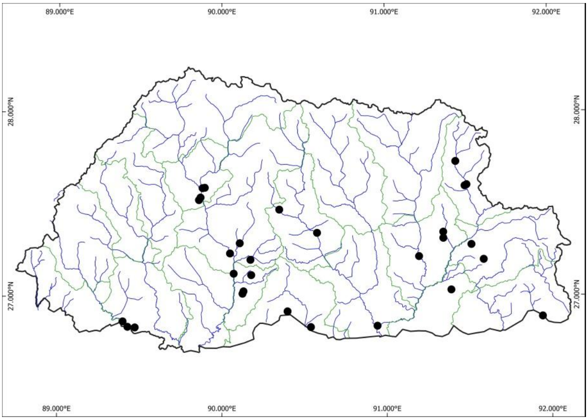


50. ***Orthetrum tae-niolatum***

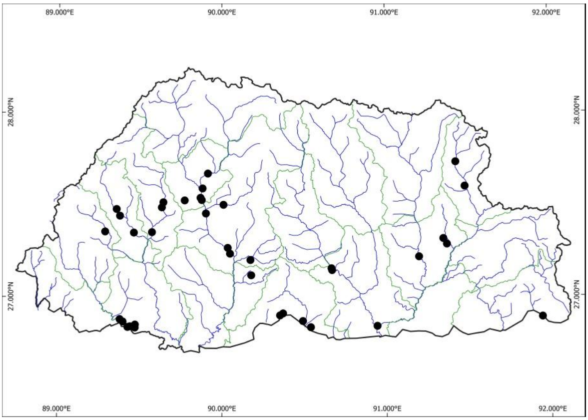


51. ***Orthetrum tri-angulare***

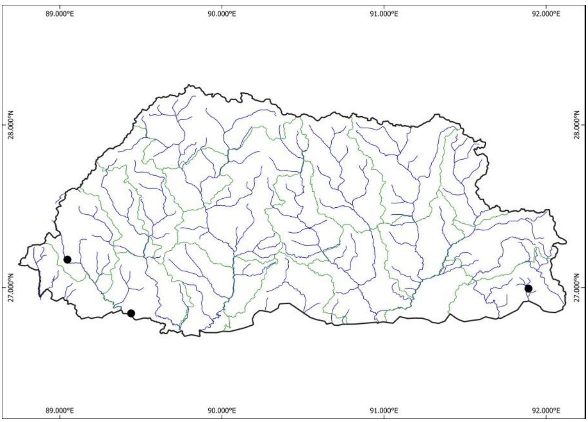
52. ***Palpopleura sex-maculata***

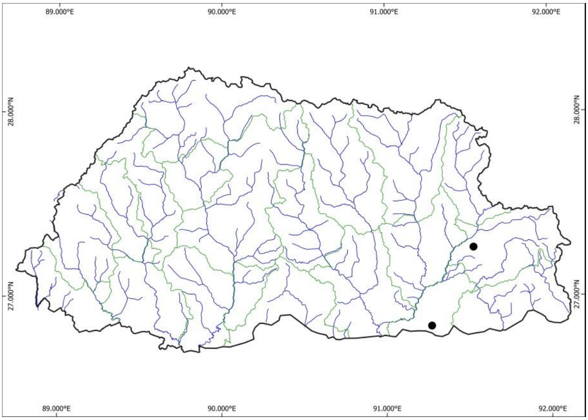


53. ***Pantala flavescens***

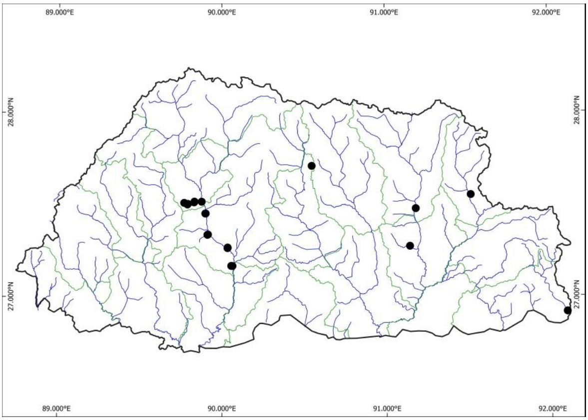


54. ***Paragomphus lineatus***

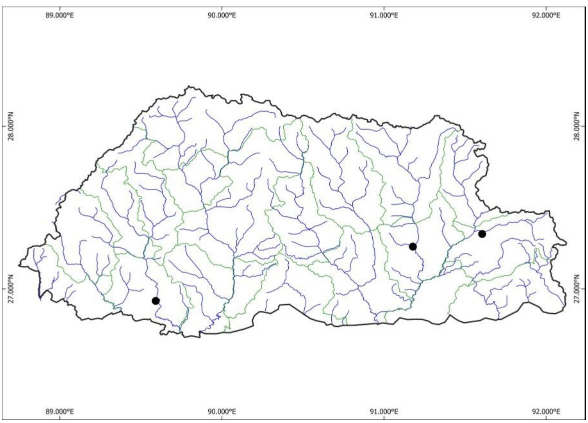




55. ***Periaeschna magdalena***

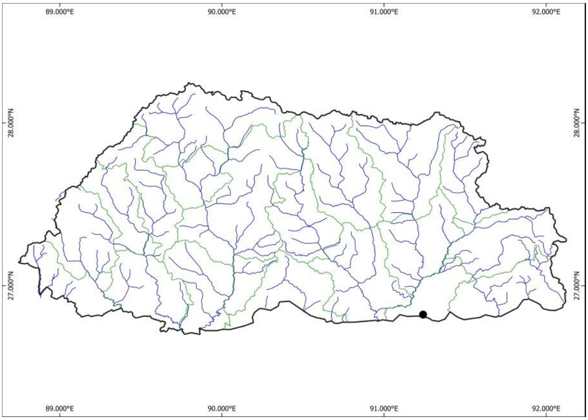


56. ***Perissogomphus stevensi***

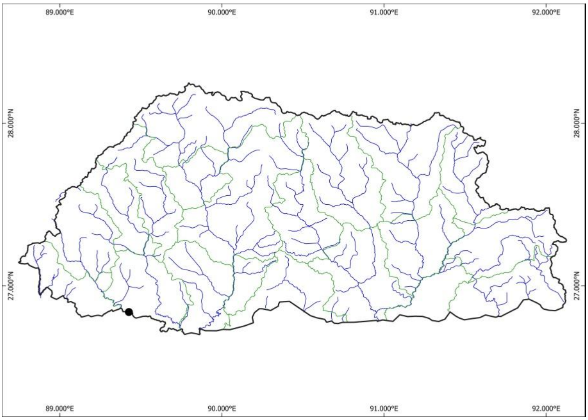


57. ***Polycanthagyna erythromelas***

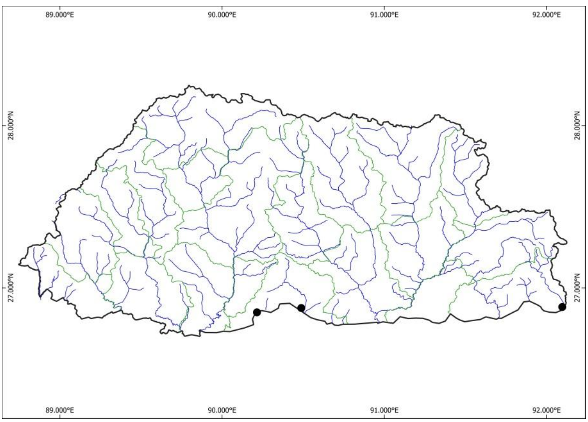
58. ***Potamarcha congener***

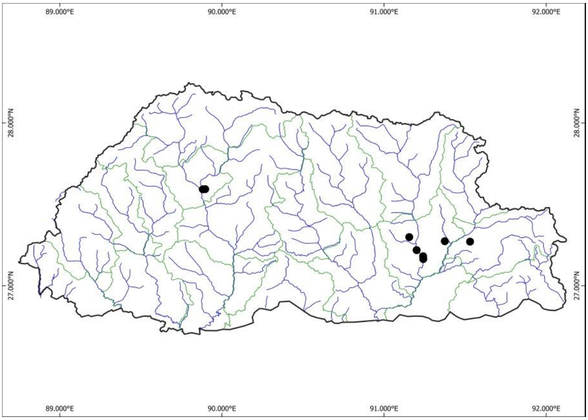


59. ***Rhyothemis phyllis***

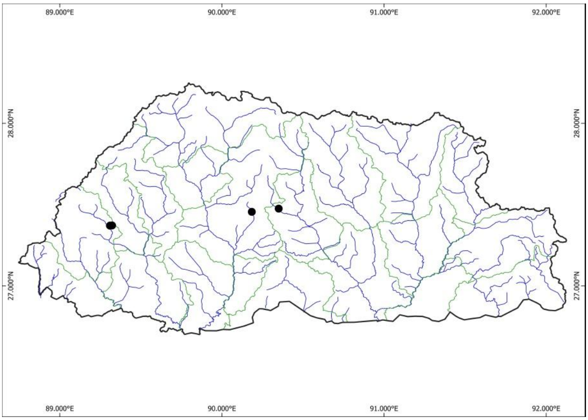


60. ***Rhyothemis variegata***

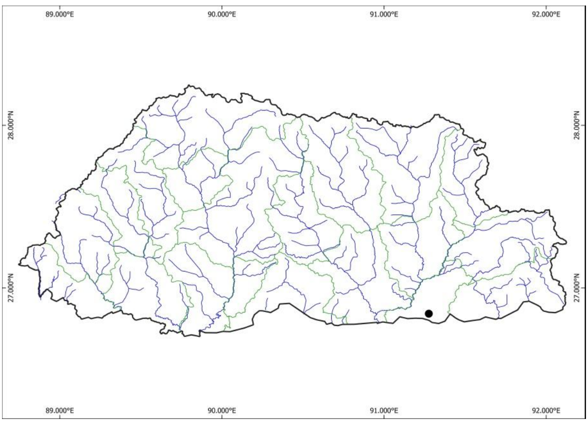




61. ***Scalmogomphus bistrigatus***

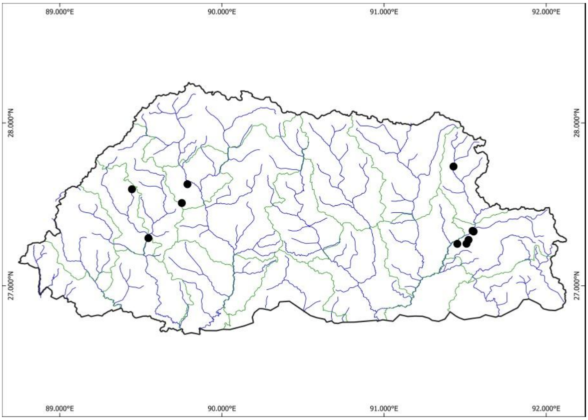


62. ***Somatochlora daviesi***

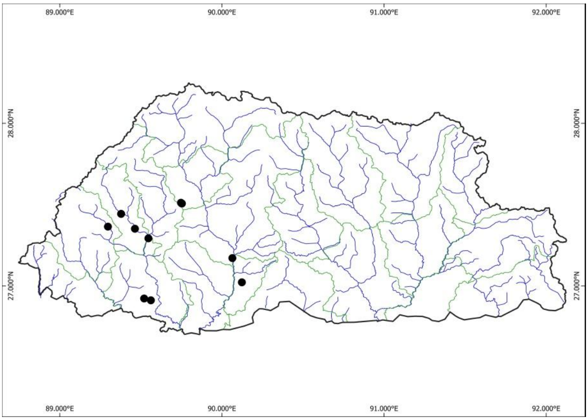


63. ***Stylogomphus inglisi***

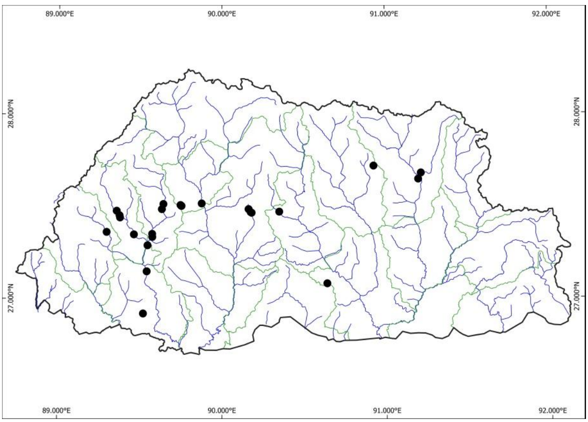
64. ***Sympetrum commixtum***

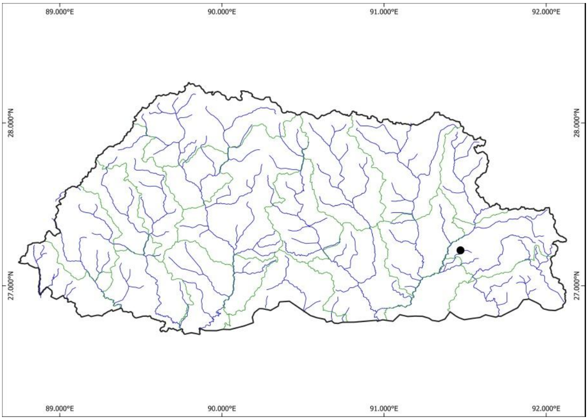


65. ***Sympetrum fonscolombii***

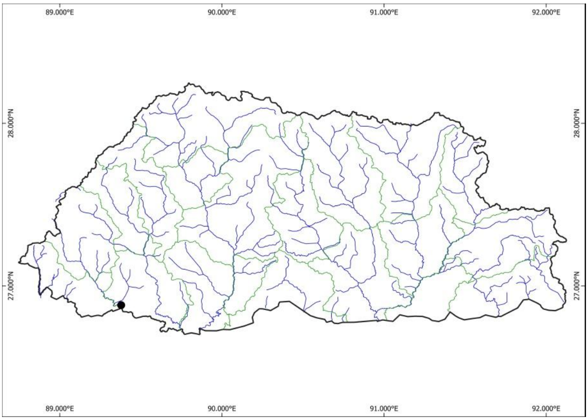


66. ***Sympetrum hypomelas***

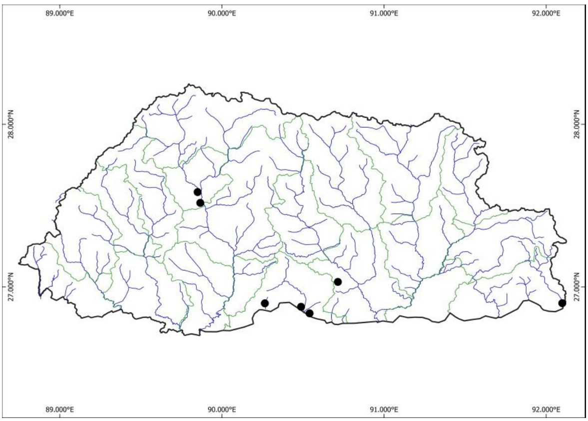




67. *Sympetrum speciosum*

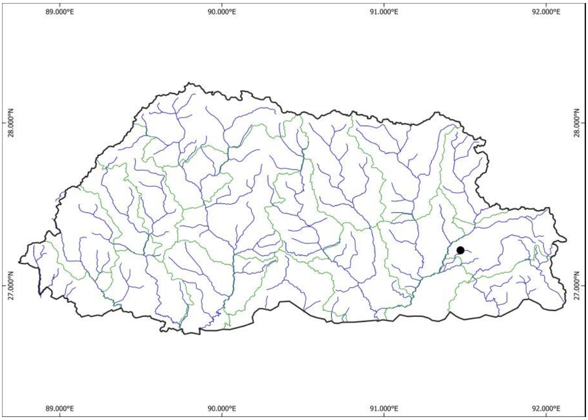


68. *Tholymis tillarga*

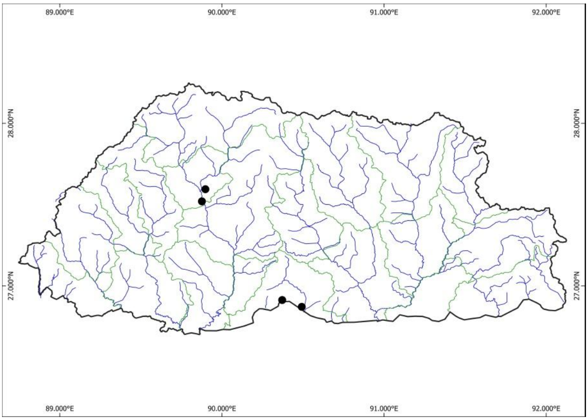


69. *Tramea basilaris*

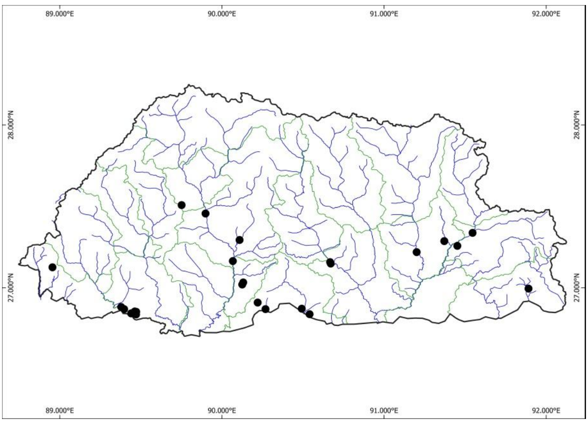
70. ***Tramea limbata***

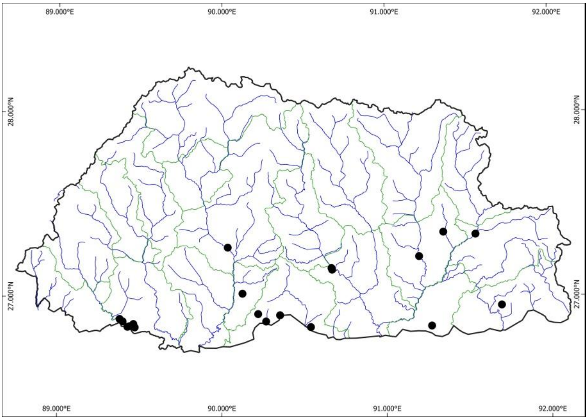


71. ***Tramea virginia***

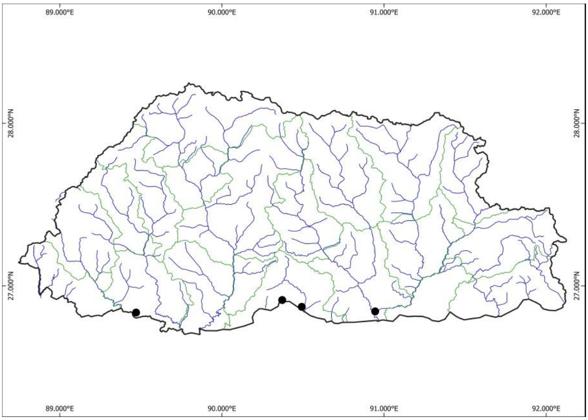


72. ***Trithemis aurora***

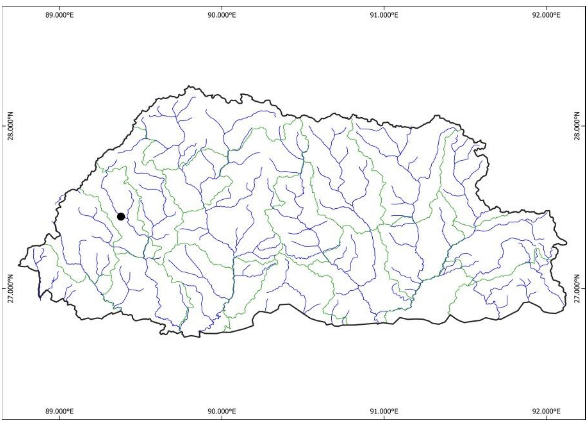




73. *Trithemis festiva*

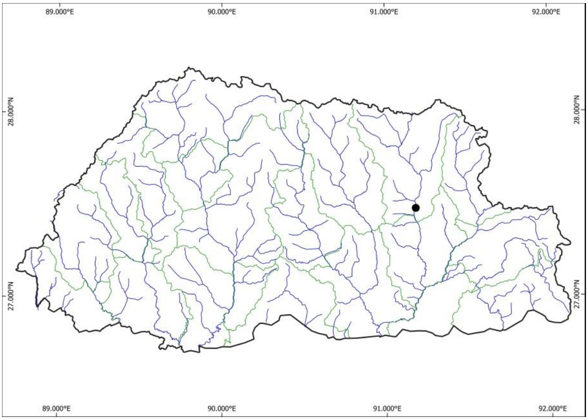


74. *Trithemis palli-dinervis*



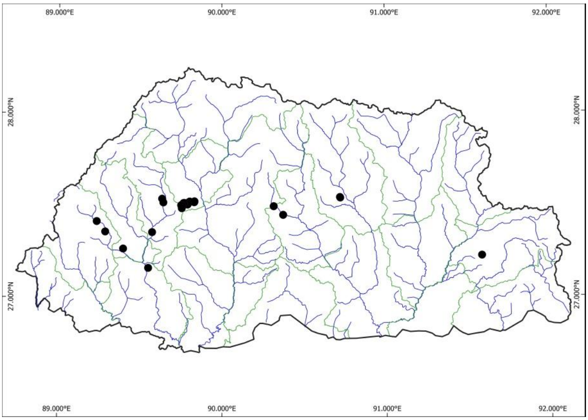
75. *Urothemis signata*

76. *Zygonyx iris*



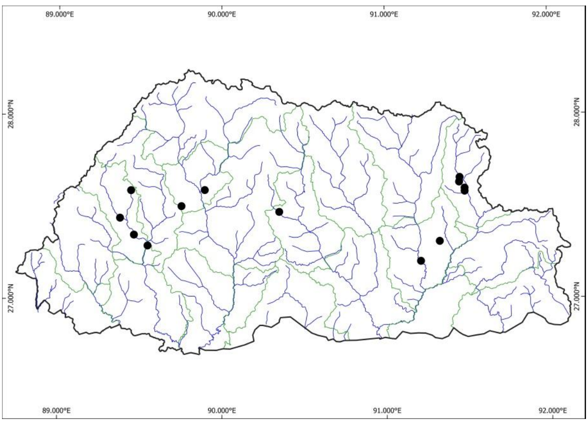
Anisozygoptera: -77

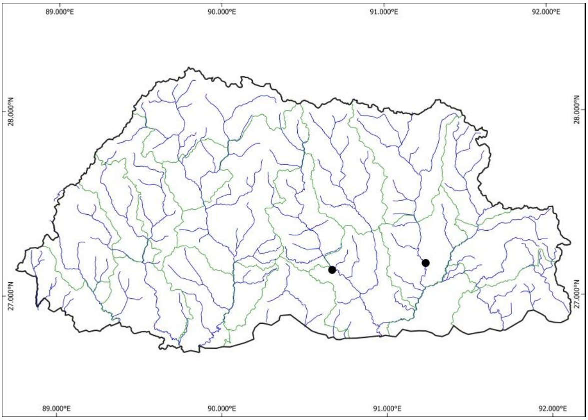
77*. Epiophlebia laidlawi*



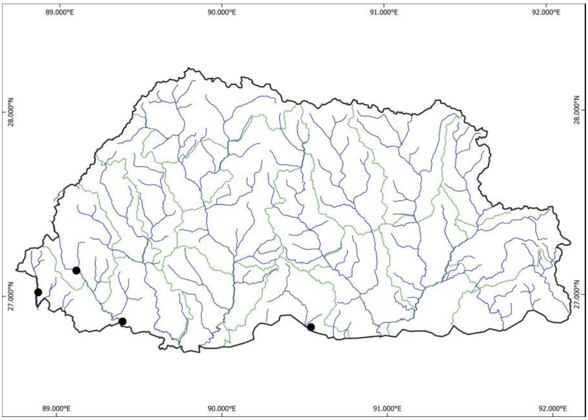
Zygoptera: 78- 123

78*. Aciagrion olympicum*

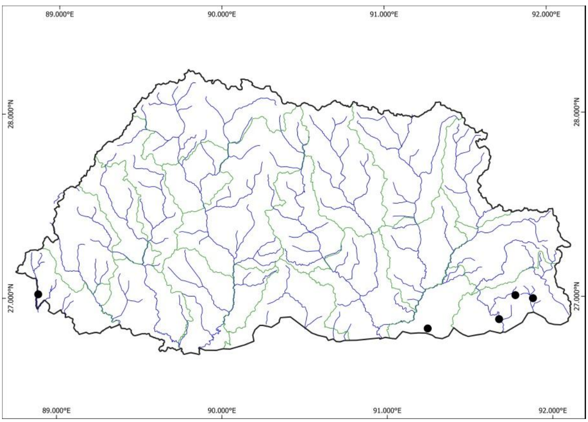




79. ***Aciagrion pallidum***

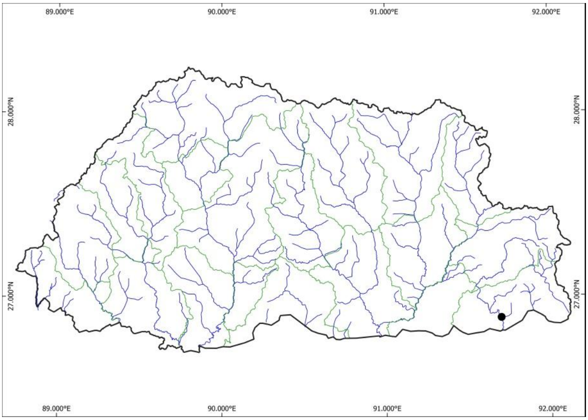


80. ***Agriocnemis clauseni***

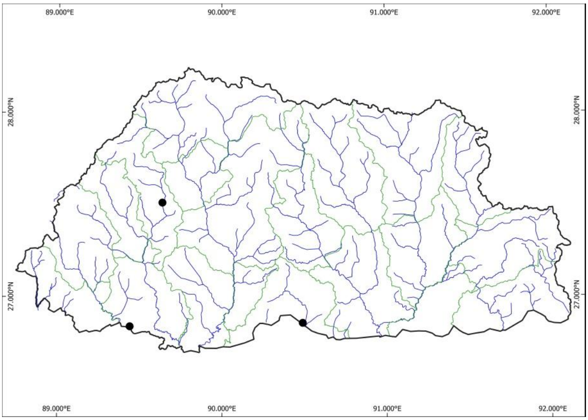


81. ***Agriocnemis femina***

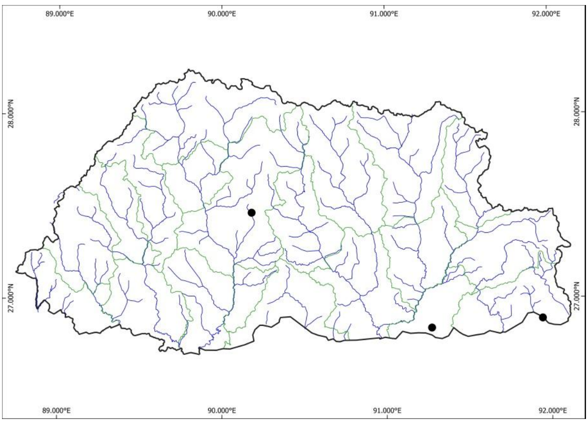
82. ***Agriocnemis lacteola***

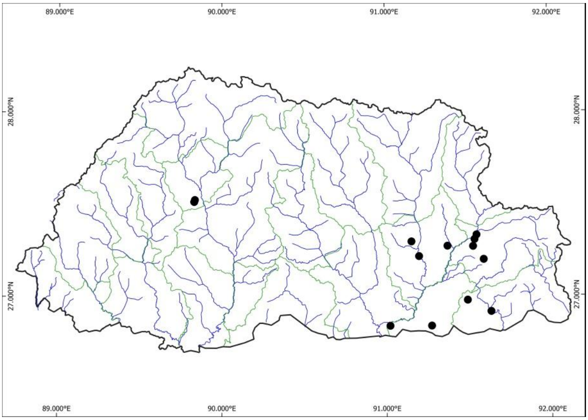


83. ***Agriocnemis pygmaea***

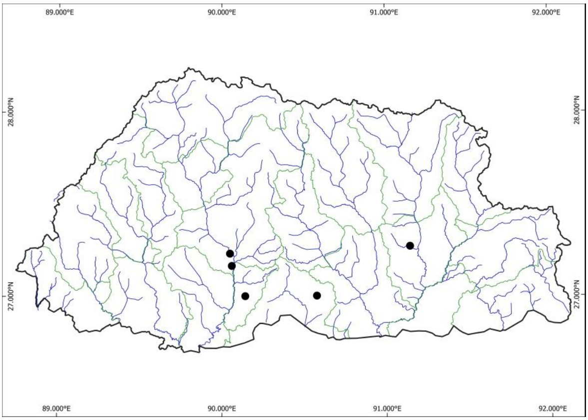


84. ***Amphiallagma parvum***

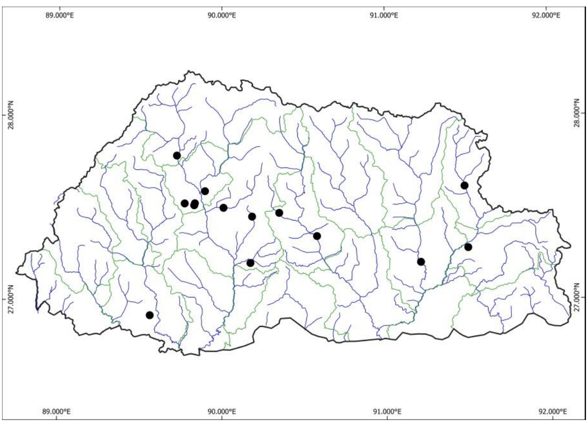




85. ***Anisopleura comes***

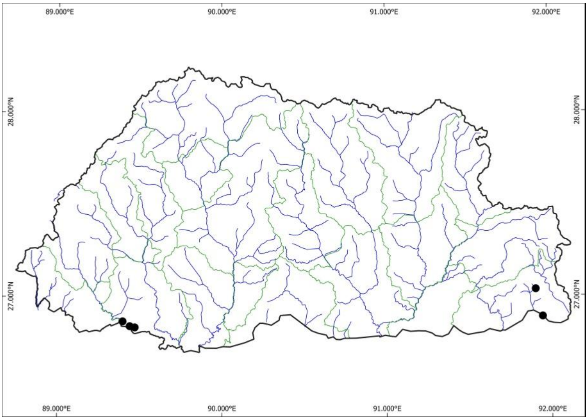


86. ***Anisopleura lestoides***

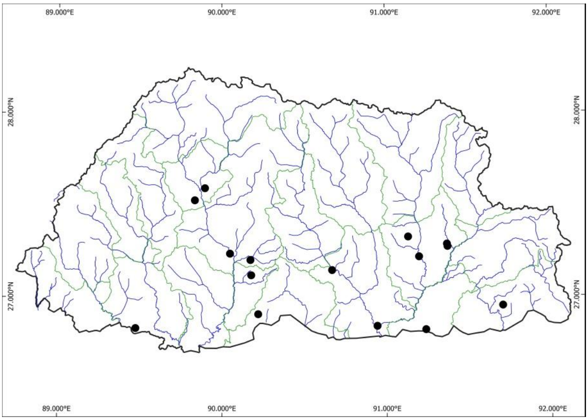


87. ***Anisopleura subplatystyla***

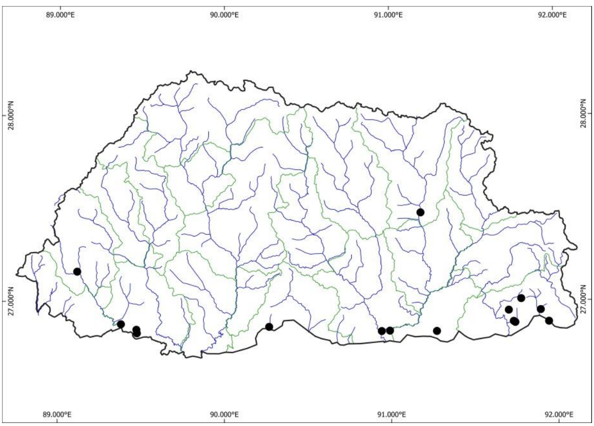
88. ***Argiocnemis rubescens***

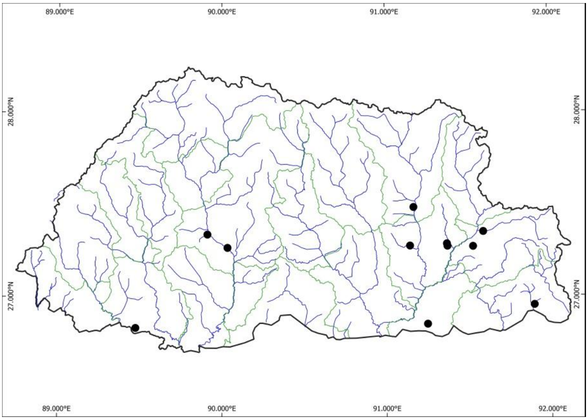


89. ***Aristocypha cuneata***

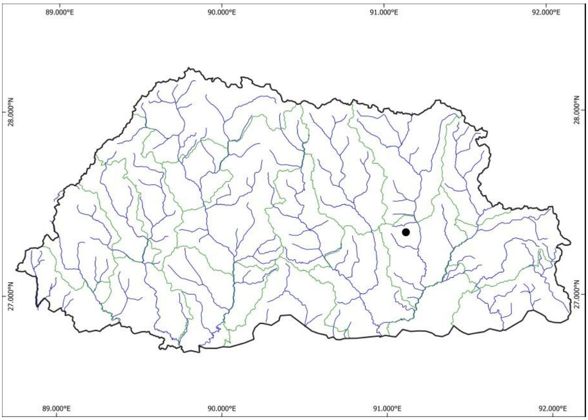


90. ***Aristocypha quadrimaculata***

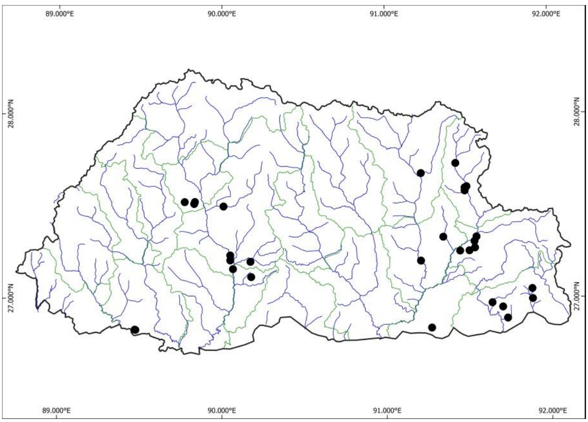




91. ***Bayadera indica***

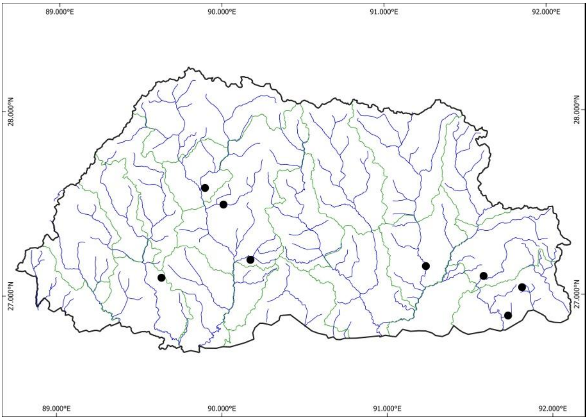


92. ***Bayadera longi-cauda***

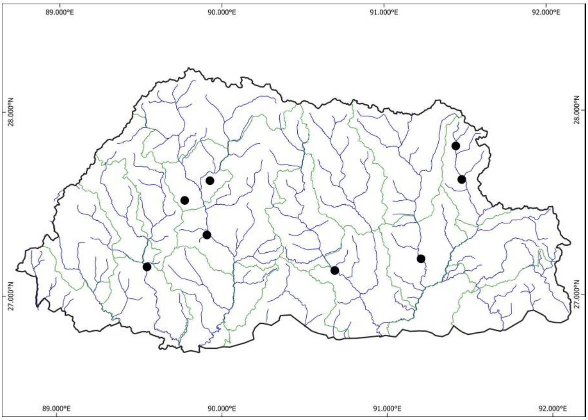


93. ***Calicnemia eximia***

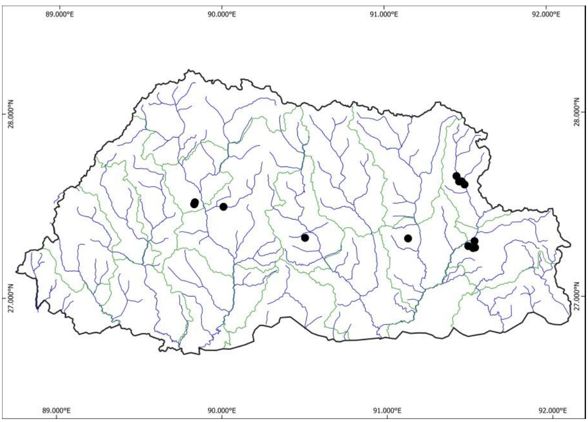
94. ***Calicnemia miniata***

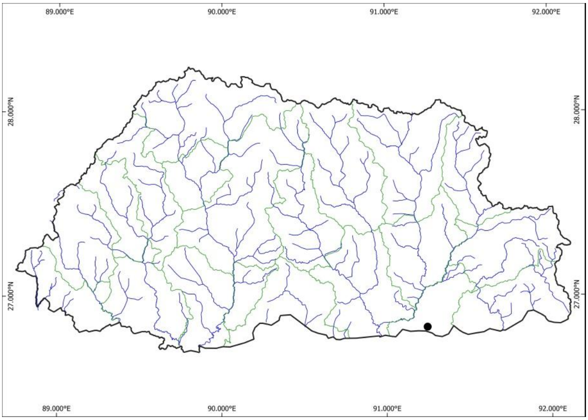


95. ***Calicnemia mortoni***

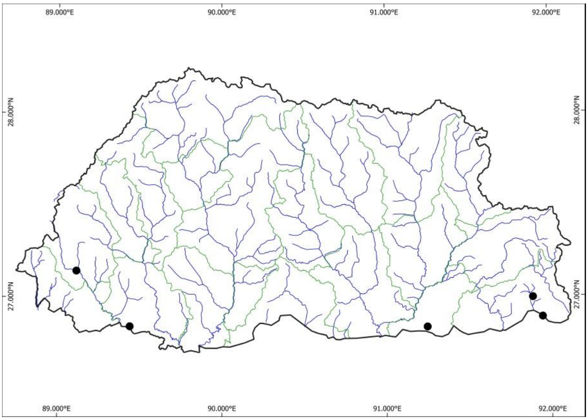


96. ***Caliphaea confusa***

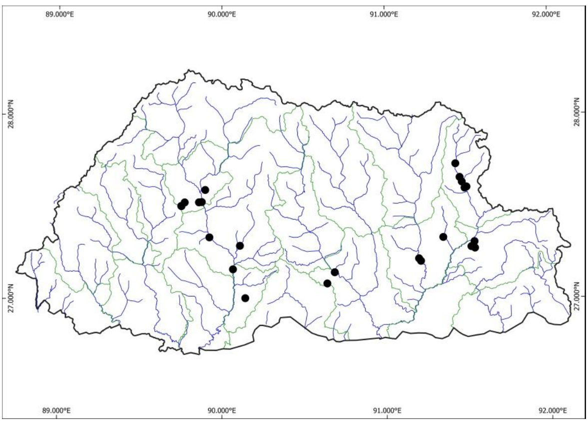




97. *Ceriagrion azureum*

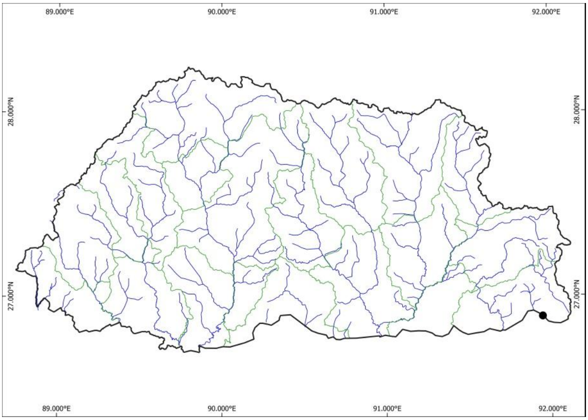


98. *Ceriagrion coromandelianum*

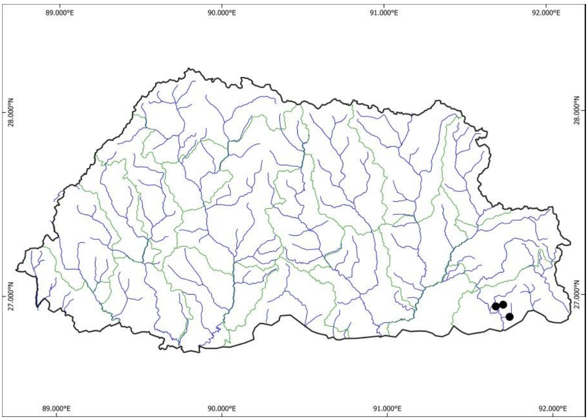


99. *Ceriagrion fallax*

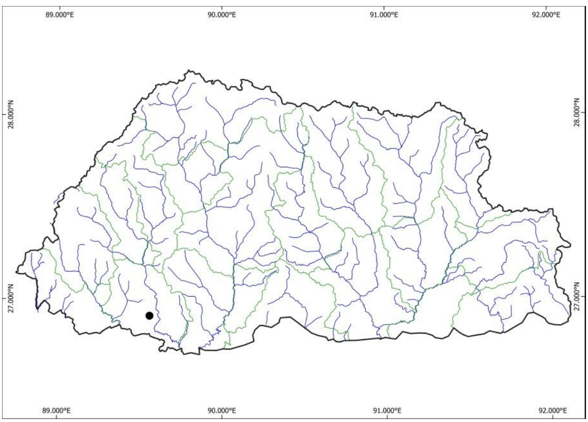
100. *Ceriagrion rubiae*

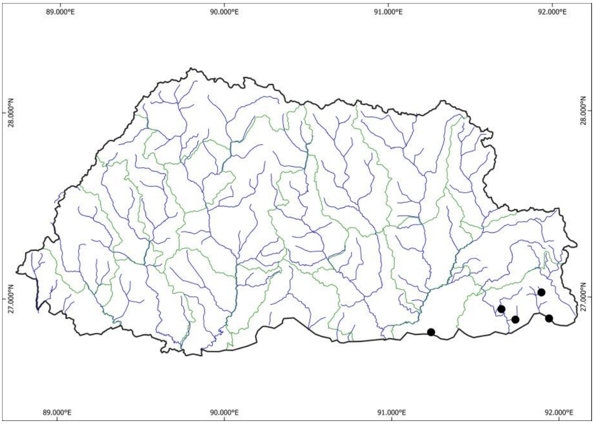


101. *Coeliccia svihleri*

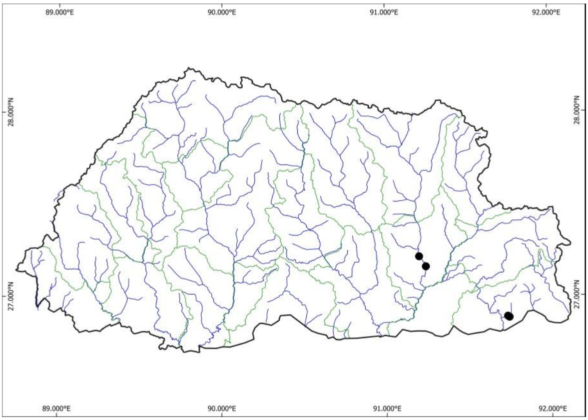


102. *Coenagrion exclamationis*

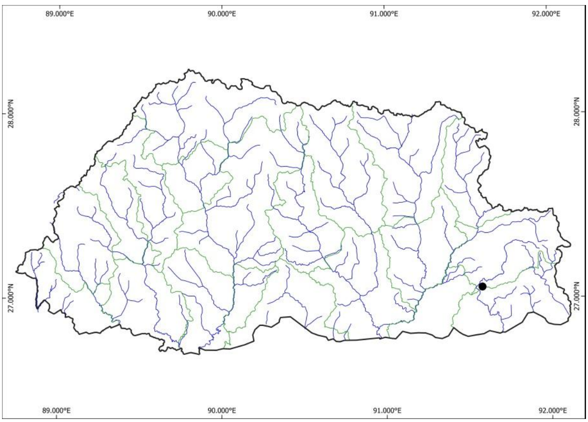




103. ***Copera vittata***

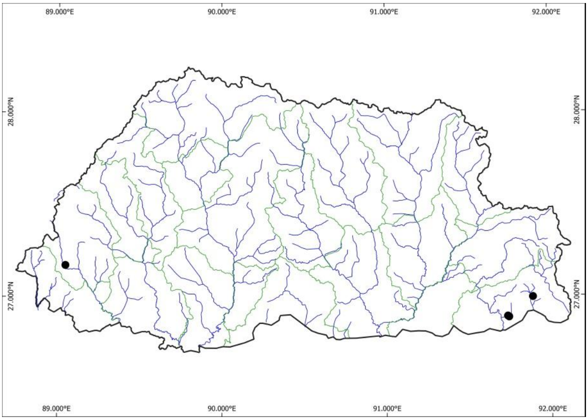


104. ***Drepanosticta carmichaeli***

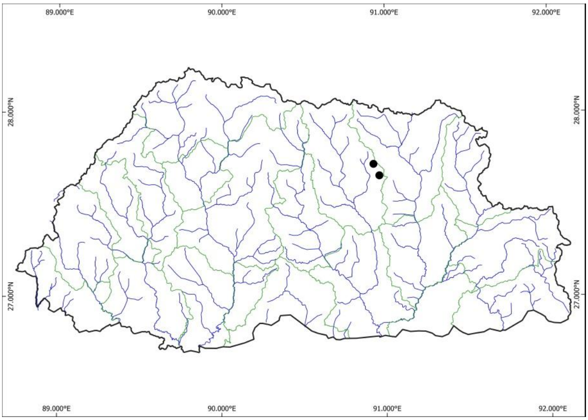


105. ***Dysphaea gloriosa***

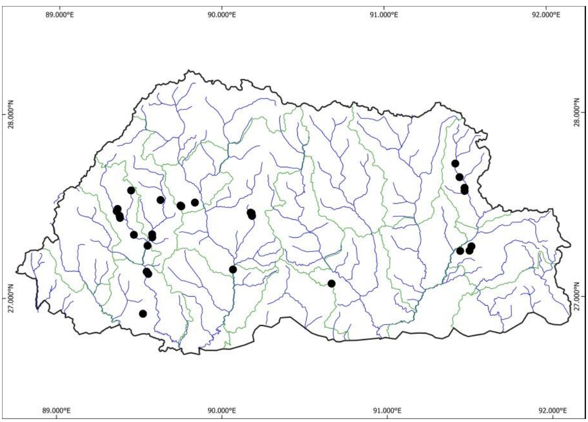
106. *Euphaea ochracea*



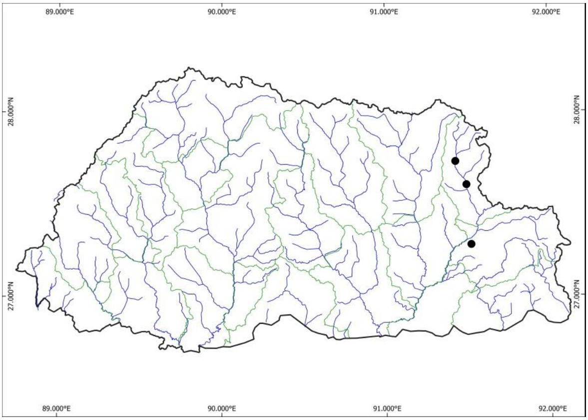
107. *Huosoma tinctipenne*



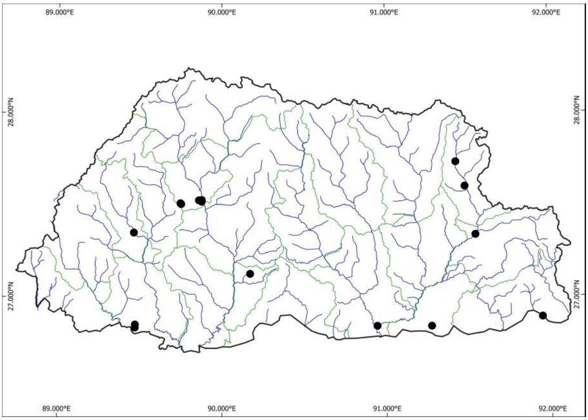
108. *Indolestes cyaneus*



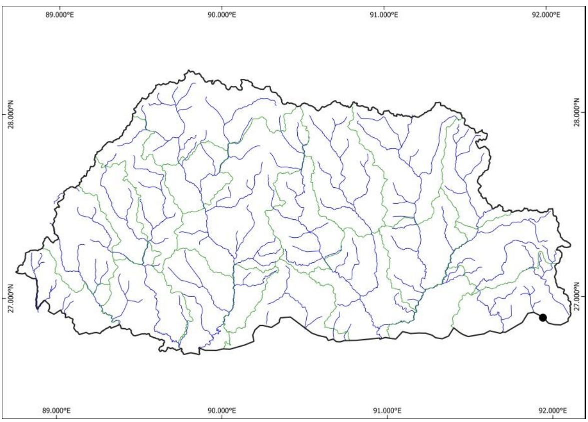
109. ***Ischnura forcipata***



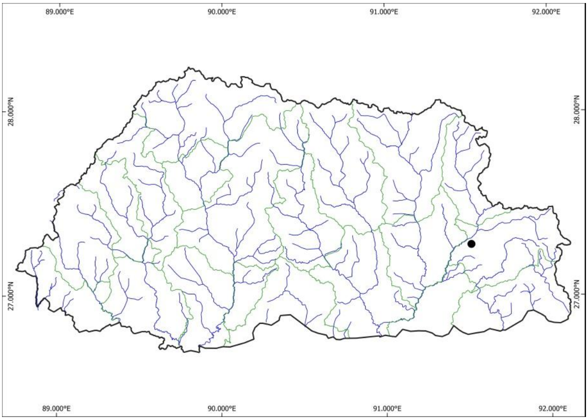
110. ***Ischnura rubilio***



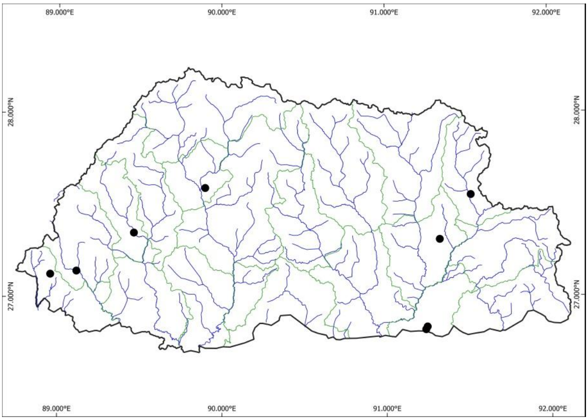
111. ***Lestes concinnus***



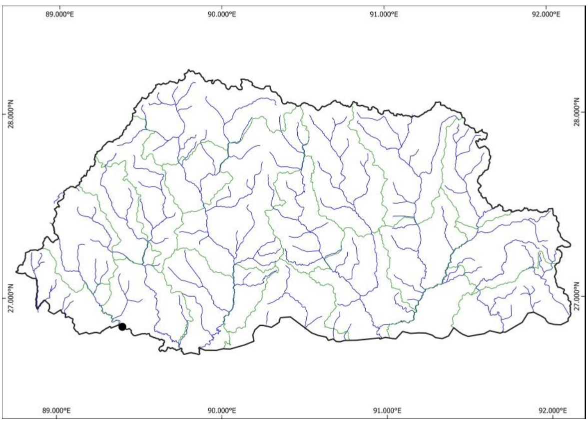
112. ***Lestes dorothea***

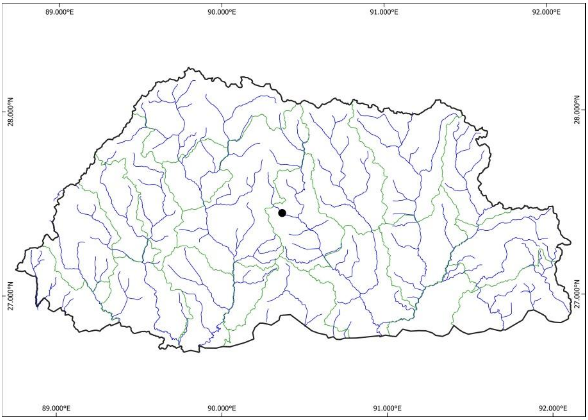


113. ***Lestes praemorsus***

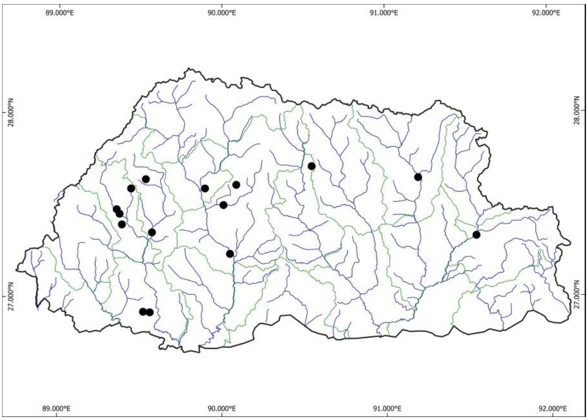


114. ***Libellago lineata***

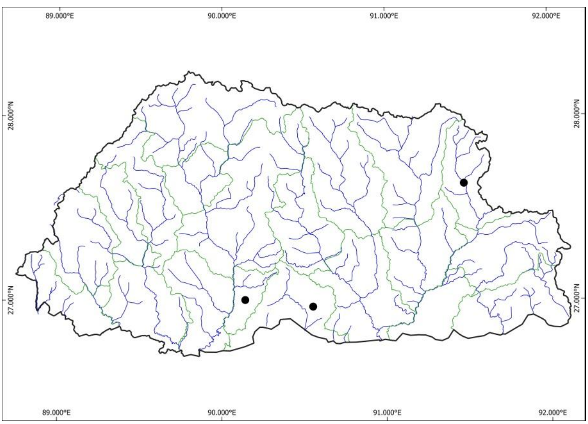




115. ***Megalestes gyalsey***

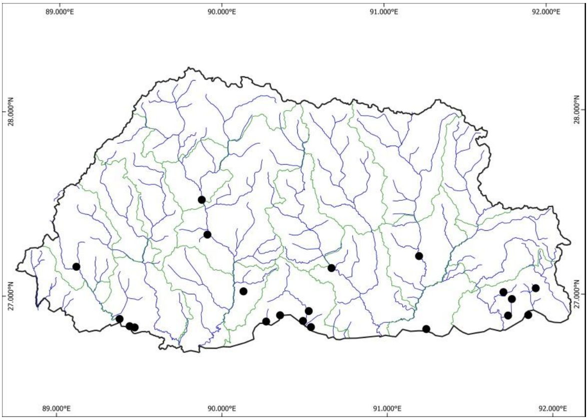


116. ***Megalestes major***

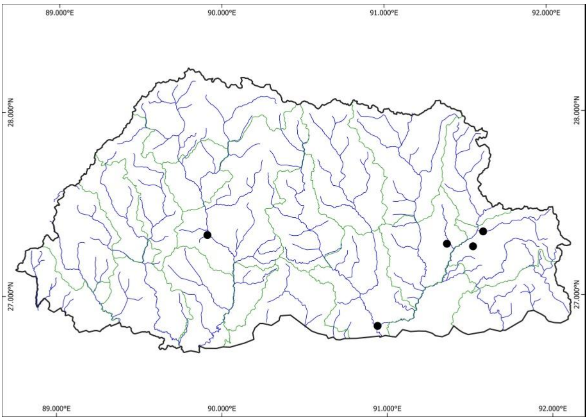


117. ***Megalestes micans***

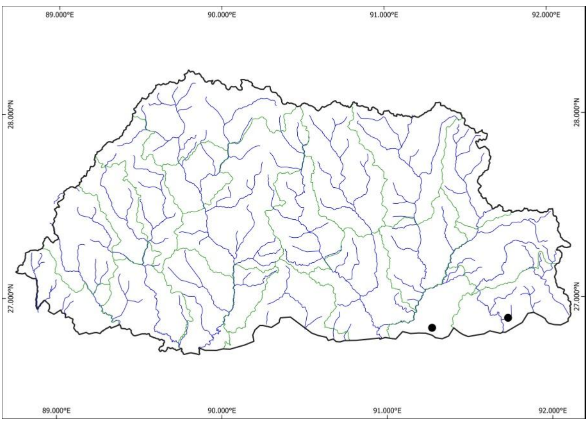
118. ***Neurobasis chinensis***

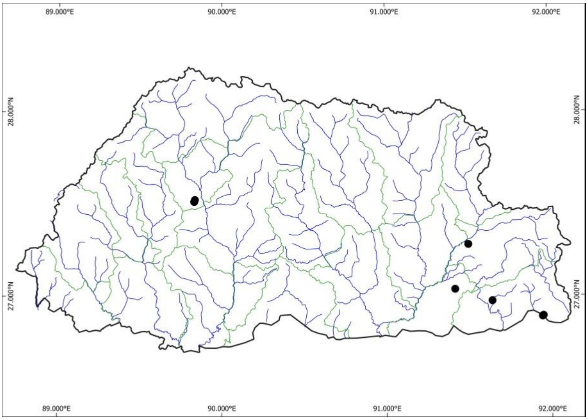


119. ***Paracypha unimaculata***

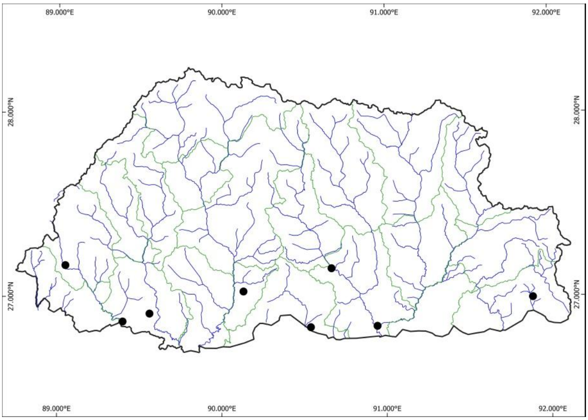


120. ***Philoganga montana***

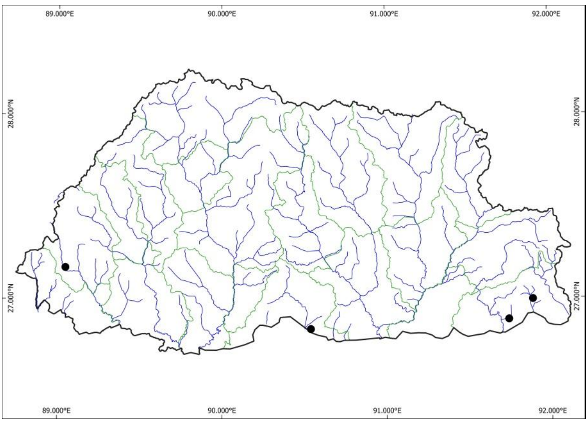




121. ***Protosticta himalaica***



122. ***Pseudagrion rubriceps***



123. ***Vestalis gracilis***

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