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# NEW RECORDS OF *EPIOPHLEBIA LAIDLAWI* TILLYARD, 1921 IN BHUTAN WITH NOTES ON ITS BIOLOGY, ECOLOGY, DISTRIBUTION, ZOOGEOGRAPHY AND THREAT STATUS (ANISOZYGOPTERA: EPIOPHLEBIIDAE)*

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*E. laidlawi* larvae were found for the first time in Bhutan, collected in 5 streams in W and central parts of the country, at altitudes 2350-2885 m a.s.l. The habitats and larval development stages are described, and a brief overview is presented on the biology, ecology and known distribution in Bhutan, India and Nepal. The sp. inhabits fast running mountain streams in Himalayan broadlef and subtropical pine forests at an altitude of 1300-2885 m a.s.l. The palaeobiogeographical history of the fossil Epiophlebiidaae and Stenophlebiidae and of the 2 extant *Epiophlebia* spp. is discussed. *E. laidlawi* is a relict sp., living in headwaters of pristine mountain forests. It is endangered because human influences, such as deforestation, provision of water power, erosion and other factors. The best protection would be ensured by the conservation of specific habitats in vast protected areas. This has at least partly been put into action in Nepal.

## INTRODUCTION

*Epiopihlebia laidlawi* Tillyard, 1921 was described controversially from a larva found in 1918, and the adult was only found 45 years later; even now much remains to be discovered about this poorly understood species, described as the "old veteran", the "old relict" (DAVIS 1992), and the "living ghost" (MAHATO, 1993).

* BECHLY (2003) understands Epiophlebiidae as part of the monophyletic group of Anisoptera. According to his systematics, the Anisozygoptera is a paraphyletic group.

While we already know a good deal of the sister species *E. superstes* in Japan regarding taxonomy (ASAHINA, 1949, 1961a, 1986), as well as biology (ASAHINA, 1954; ASAHINA & EDA 1956, 1958, 1982; RÜPPELL & HILFERT, 1993; TABARU, 1984, NARAOKA, 2006; NARAOKA & TAKAHASHI, 2007) and distribution (http://www.biodic.go.jp), we are still in the dark for the Himalayan species.

During the work of the project ASSESS-HKH, evidence of the existence of larvae of this species from Bhutan was obtained, and this now provides an opportunity for a brief discussion of the existing information on the distribution, development, habitats and biogeographic problems as well as its threat status. We are aware that there are still many more questions than answers available.

## MATERIAL AND METHODS

Specimens for this study were collected in Bhutan during the international project "Development of an Assessment System to Evaluate the Ecological Status of Rivers in the Hindu-Kush Himalayan Region" (ASSESS-HKH). This was a three-year research project, founded by the European Union (Contract-number: INCO-CT-2005_003659). The expeditions to Bhutan were carried out in November and December 2005 (post-monsoon) and April 2006 (pre-monsoon). The inner valleys and passes in western Bhutan (Himalayan broadleaf forest) as well as the southern mountains and gorges (Himalayan subtropical pine forests) were sampled. The sampling followed a multi-habitat approach for wadeable rivers and streams (MOOG, 2007). A sample usually consists of 20 "sampling units" taken from all representative habitat types at the sampling site, each with a share of at least 5 % coverage. The material is stored in the collection of the NEC (National Environment Commission) in Thimphu, Bhutan.

Using ASAHINA (1961b) *E. laidlawi* larvae were assigned to following stages of development (instars): F-1 (penultimate), F-2, and F-4. The remaining larvae that were found were identified according to the works listed in the references.

Table I
Sites for *E. laidlawi* as discovered by the ASSESS HKH

| Stream | Province/district/next village | Altitude a. s. l. | Stage of development* |
|---|---|---|---|
| Drey Chhu | Thimphu | 2700 | F-1 |
| Drey Chhu | Thimphu | 2700 | F-2 |
| Taba Chhu | Taba, Thimphu | 2400 | F-2 |
| Chanana Chhu | Haa | 2885 | F-2 |
| Nagu Chhu | Haa | 2670 | F-4 |
| Lamchela Chhu | Trongsa, Chendepji | 2350 | F-1 |
| Lamchela Chhu | Trongsa, Chendepji | 2350 | F-1 |
| Lamchela Chhu | Trongsa, Chendepji | 2350 | F-2 |
| Lamchela Chhu | Trongsa, Chendepji | 2350 | F-4 |

* According to ASAHINA (1961b)

## RECORDS OF *EPIOPHLEBIA LAIDLAWI* IN BHUTAN

The species was found in five streams which are situated in an area reaching from the West of the country to Trongsa, which is located in the centre of Bhutan (Fig. 1). Altogether nine larvae were caught (Tab. I).

- Site 1: Thimphu district, Drey Chhu at Dechenphug Monastery, 27°32'10.10"N 89°38'7.07"E, 2700m, 13-XII-2005, sample code H03TD0231*, A. Hartmann, M. Hartmann & P. Wandue leg.
- Site 2: Thimphu district, Drey Chhu, at Dechenphug Monastery, 27°32'10.10"N 89°38'7.07"E, 2700m, 16-IV-2006, sample code H03TD021, W. Graf, A. Schmidt-Kloiber, P. Dema, & K. Chhopel leg.

  The Drey Chhu is situated North of the capital Thimphu, flowing from NW to SE through the small village of Dechencholing. The sampling site at Drey Chhu is situated near to the Dechenphug Monastery, which lies on a hill above the stream. The Drey Chhu is a mountain brook of stream order 1 at the sampling site with an average stream width measured as 2.5 m (maximum 4 m) and a depth of 20 cm (max. 80 cm). The stream flows through a trough-shaped valley with dense vegetation of mainly scrub and ferns along the shorelines. The shading at zenith (mid-day) on the stream was estimated at 20%. The substrate was 30% megalithal (boulders and rocks), 50% macrolithal (coarse cobbles), and 20% mesolithal (hand-sized cobbles) covered with micro-algae (mainly diatoms). The water was clear, clean and odourless with a temperature of 3.7 °C on the first sampling date (13-XII-2005) and 10.4 °C on the second sampling date (16-IV-2006). The flow velocity was highly variable, ranging from 100 cm/s in the riffle sections to a minimum of 1 cm/s in the pools. The catchment land use of the Drey Chhu is mainly formed by na-

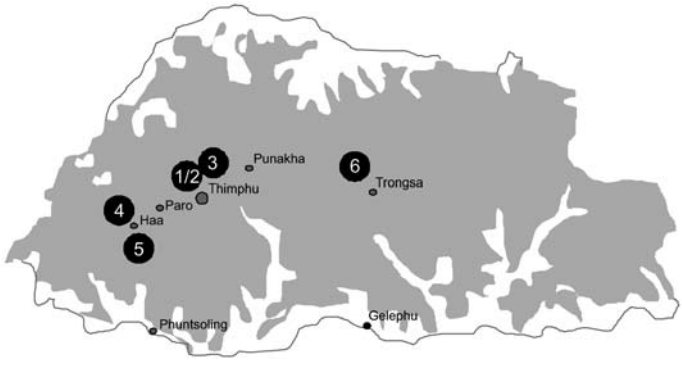


Figure 1: Sites of records of *E. laidlawi* within the project ASSESS HKH (shaded area denotes altitudes from 1000 to 3000 m a.s.l.); numbers refer to sites as described under habitat description

tive coniferous and deciduous forest. Along the banks, some disposal of waste had taken place and there was some grazing by cattle.

- Site 3: Thimphu district, Taba Chhu in Taba, 27°30‘57.71“N, 89°38‘33.71“E, 2400m, 17-IV-2006, sample code H03TT011*, W. Graf, A. Schmidt-Kloiber, P. Dema, & K. Chhopel leg.
  Taba Chhu is a small mountain brook of stream order 1 flowing through the village Taba north of Thimphu. The sampling site is situated on the road to Thimphu, next to some village houses. With an average stream width of 2.5 m (max. 3 m) and a mean depth of 15 cm (maximum 50 cm) the small brook is lined with wooded riparian vegetation of about 2 m width. The shading at zenith on the stream was estimated at 20%. The stream substrate was 50% macrolithal, 15 % megalithal, 30% mesolithal and 5% microlithal. Most of the substrate (75%) was covered by micro-algae as well as some mosses. The stream velocity ranged from a maximum of 60 cm/s to 15 cm/s. The water was clear, clean and odourless with a temperature of 17.9 °C. The catchment area of the Taba Chhu is formed by pristine coniferous forest. The pools of the stream at the sampling sites were partly used for washing and bathing by the village inhabitants; also some rubbish was noticed along the banks.
- Site 4: Haa district, Chanana Chhu, 10 km NW of Haa town, 27°24’47,5”N/89°14’10,6”E, 2885m, 07-XII-2005, sample code H03HC013*, A. Hartmann, M. Hartmann, P. Wandue & P. Dema leg.
  Chanana Chhu is situated North of the town Haa, flowing from the hilly mountains towards the Haa Chhu. Chanana Chhu is a mountain stream of stream order 2, with an average stream width of 3 m (max. 6 m) and a mean depth of 35 cm (max. 60 cm). The stream is characterized by a sequence of riffles and pools, formed by a substrate composition which was 50% macrolithal, 20% megalithal and 30% mesolithal, all covered by micro-algae (mainly diatoms). The catchment area of the stream is formed by pristine native coniferous and deciduous forest, and the vegetation along the banks consists of dense riparian vegetation. Shading at zenith at the sampling site was estimated at 80%. The water was clear, clean and odourless with a temperature of 4 °C. The flow velocity was very variable ranging from 30 cm/s to 100 cm/s with pools, riffles and numerous protruding boulders breaking the flow. No human influence was noticed at the sampling site or further upstream.
- Site 5: Haa district, Nagu Chhu, Jaba Nagu, 25 km SE of Haa town, 27°15‘53“N/89°23‘52,3“E, 2670m, 08-XII-2005, sample code H03AN013*, A. Hartmann, M. Hartmann, P. Wandue & P. Dema leg.
  The sampling site at Nagu Chhu is situated in a very pristine location beyond a mill. The stream flows over numerous cascades above the sampling site, discharging into a large pool. The presence of several logs and boulders caused a large variety of flow velocities and habitat structures. The substrate was 30% megalithal, 25% macrolithal, 30% mesolithal and 15% microlithal all covered by micro-algae (mainly diatoms) and some mosses. The stream width of this

mountain stream (stream order 1) ranged from 1 to 4 m (average width 2.5 m) with a mean depth of 40 cm. The catchment area of the stream is formed by pristine native coniferous and deciduous forest, the vegetation along the banks consists of dense riparian vegetation. Shading at zenith at the sampling site was estimated at 20%. The water was clear, clean and odourless with a temperature of 3.1 °C. The flow velocity was very variable ranging from 30 cm/s to 100 cm/s. Apart from the small mill below the sampling site, no human influence was noticed.

– Site 6: Trongsa district, Lamchela Chhu, Upstream of Chendebji village (u/s), 4 km NW of the Trongsa Highway (u/s), 27°29‘44.01“N 90°18‘59.79“E, 2270m, 23-IV-2006, sample code H03WL031*, W. Graf, A. Schmidt-Kloiber, P. Dema, & K. Chhopel leg.
The Lamchela Chuu is the easternmost site where *E. laidlawi* was discovered. Situated upstream of the village Chendebji, the mountainous stream flows through a very pristine native forest. The brook of stream order 1 at the sampling site has an average stream width measured of 3.5 m (max. 6 m) and a mean depth of 25 cm (max. 130 cm). The stream flows through a canyon-like valley with dense riparian vegetation along the shorelines. The shading at zenith on the stream was estimated at 80%. The substrate was 30% megalithal, 45% macrolithal, and 25% mesolithal, all covered by micro-algae (mainly diatoms). The water was clear, clean and odourless with a temperature of 9 °C. The stream showed a sequence of riffles, pools and waterfalls with a variable flow velocity ranging from 0 to 200 cm/s (average 50 cm/s). The catchment land use of the Lamchela Chhu is mainly formed by native coniferous and deciduous forest. No particular human influence was noticed at the sampling site, or further upstream.

## STAGES OF DEVELOPMENT OF LARVAE

In Lamchela Chhu a total of four larvae was caught. Two larvae were in the penultimate F-1 (width of head capsule 6.0 mm, wingpads up to 2nd abdominal segment), one in the F-2 stage (width of head capsule 4.1 mm, wingpads up to 1st abdominal segment) and another very small larva was in the F-4 instar (width of head capsule 2.6 mm, no wingpads developed). In the other mountain streams, only one and two F-1 or F-2 larvae respectively were found.

## OTHER ODONATA LARVAE

In Chanana Chhu a small gomphid larva was discovered (*Lamelligomphus*/*Onychogomphus*). At the other sampling sites (Drey Chhu, Taba Chhu, Lamchela Chhu and Nagu Chhu) also *Davidius* larvae were collected along with *E. laidlawi* larvae.

* Sample codes of ASSESS-HKH

## DISCUSSION

### BIOLOGY AND ECOLOGY

DEVELOPMENT OF LARVAE. – In odonate species whose larvae inhabit summer-cold streams, the larval stage usually lasts several years. For the western palaearctic *Cordulegaster* species this period takes up to seven years (STERNBERG & BUCHWALD, 2000). In *E. laidlawi,* the developmental period presumably takes about five to seven years according to ASAHINA (1982). Our samples indicate the coexistence of at least four different larval stages. However, it is uncertain whether these represent four separate cohorts (eggs laid in different years). Nevertheless, it is very likely that several cohorts are present in the samples. NESEMANN et al. (2008a) sampled 67 larvae with size ranges from 3 to 29 mm. Reports of the discovery of F-0 larvae are relatively rare. Only ASAHINA (1958) and SVIHLA (1961) found F-0 larvae in their samples, the former on March 11, 1958, and the latter on October 9, 1960. Samples taken in April (this article) or May (TANI & MIYATAKE, 1979, ASAHINA, 1982; BUTLER, 1997) have never contained F-0 larvae. It is possible that the mature larvae, like *E. superstes* (NARAOKA & TAKAHASHI, 2007), leave the water and live semi-terrestrially in April/May until they hatch.

LARVAL HABITATS. – All sites in Bhutan are small pristine mountain streams with no (or minimal) anthropogenic impacts in their headwaters, or along the banks. Accordingly the water quality of all sites is very good and the assemblages of macro-invertebrates consist of various species indicative of clean water. The precondition of an unpolluted environment and unpolluted or only slightly-polluted water for the existence of *E. laidlawi* has already been documented (ASAHINA, 1982; SVIHLA, 1984; BUTLER, 1997; SAVILLE, 1990; SHARMA & OFENBÖCK, 1996). All streams in Bhutan where *E. laidlawi* was found are characterised by a sequence of riffles and pools with substrate consisting mainly of large boulders, cobbles and pebbles. The water velocity of all sites is rather high and ranges from 15 cm/s in the pool sections to 200 cm/s in the riffle sections. As all larvae were collected as part of a multi-habitat sampling (MOOG, 2007) it is hard to say whether *E. laidlawi* was living in the rocky, rapidly flowing river sections or the still water sections. However, we observed that no *E. laidlawi* could be found in comparable streams of rapidly flowing water which lacked pools and low current zones. According to literature (SVIHLA, 1961, 1984, SAVILLE, 1990, BUTLER, 1997) *E. laidlawi* seems to be confined to fast flowing waters, but note that SHARMA & OFENBÖCK (1996) believed that the species avoided the zones of highest flow-rate within these rapid water courses.

ASSOCIATION. – *E. laidlawi* larvae co-occur with other species that are typical for the headwater of the Himalayan rivers. This especially concerns the gomphid larvae of the genus *Davidius*. The streams of the Shivapuri Mountains,

where *E. laidlawi* larvae were found (TANI & MIYATAKE, 1979; ASAHINA, 1982; SAVILLE, 1990), are also inhabited by *Caliphaea confusa* (Hagen), *Davidius abberans senchalensis* Fraser, *Neallogaster hermionae* Fraser 1927, *N. ornata* ASAHINA, 1982, *Chlorogomphus atkinsoni* (SELYS, 1878) and *Ch. selysi* Fraser, (BROCKHAUS, 2001; BROCKHAUS et al., 2007). These are stenoecious mountain stream species of the Himalaya native to elevations above 1500 m a.s.l. The niche occupancy or interspecific competition between the larvae of these species are unknown.

## DISTRIBUTION

The current knowledge on the distribution of *E. laidlawi* in the Himalayan region is described in the following.

### India

FEDERAL STATE OF WEST BENGAL. – In June 1918 Mr S. Kemp collected a dragonfly larva from a rapid flowing river near Darjeeling. This larva was recognized as unusual and described as a new species by TILLYARD (1921). The locality is situated on the southern slopes of the Himalaya at about 2100 m a.s.l. Here also ASAHINA (1958) found larvae of various developmental stages in March 1958. SVILHLA (1961, 1962) reports further discoveries of larvae in several rivers near Ghoom and Sonada. Von Rosen (pers. comm.) discovered larvae in the Jore Khola river near Ghoom in June 1973 and 1975. Finally DAVIES (1992) described the sightings of an unknown number of adults at Tiger Hill.This is located about 11 km outside Darjeeling at an altitude of ca 2250 m (VERMA, 2000).

### Nepal

EASTERN NEPAL. – In the catchment area of the Tamar river Japanese lepidopterologists caught two adults near the village of Chitre in July 1963. Those were the first known adults of *E. laidlawi* (ASAHINA, 1963).

SHIVAPURI MOUNTAINS. – These are part of the Mabharabat range and are situated North of Kathmandu Valley. TANI & MIYATAKE (1979) were the first to report *E. laidlawi* occurrence there. In early May 1979, they found two immature adults, the exuviae of one final instar larva, and five larvae of this species. In 1981, also in May, ASAHINA (1982) was able to find only larvae (in various developmental stages) in this area. MAHATO (1993) caught a female imago on the 13th of June 1987. In December 1988 an entomological expedition from Cambridge University found larvae at several sites in the stream ecosystem of Shivapuri Mountains (SAVILLE, 1990). The most recent reports date from the years 1996 and 2000 (BUTLER, 1997; BROCKHAUS et al., 2007).

CENTRAL NEPAL. – NESEMANN et al. (2008b) found *E. laidlawi* larvae in 10 forest streams near Daman and Helambu, Southwest of the Langtang National Park (Sim Khola and its tributaries, Simbhanjayang Khola and its tributaries). The highest larval abundance was found to be in the Sim Khola.

BHOTEKOSI RIVER. – At the headwater of Bhotekosi river near Phelping not far from the border with Tibet, SHARMA & OFENBÖCK (1996) collected one larva in November 1993. BUTLER (1997) found two larvae at this site in May 1997.

DUDHKOSI RIVER. – At the catchment of Dudhkosi River SHARMA & OFENBÖCK (1996) found scattered larvae in Bihla Khola, Phakding Khola and Kahrte Khola in March and April 1994.

## Bhutan

The sites in Bhutan are described here.

## Overall distribution

The distribution of *E. laidlawi* as known at the moment, reaches from the central Himalaya and its foothills in Nepal to the eastern Himalayan region in Bhutan. In the mountainous rivers and streams of the southern Himalaya at an altitude of 1300 to 2885 m above sea level this species seems to be widespread but does not occur very frequently.

Table II
Evidence of fossil species of Epiophlebiidae and Stenophlebiidae (according to NEL et al., 1993)

| Species | Period | Site of discovery / locality |
|---|---|---|
| *Mesoepiophlebia veronicae* Nel & Henrotay | Lower Jurassic, ca. 190 Myr | Luxembourg |
| *Ensphingophlebia undulata* Bode | Lower Jurassic, ca. 190 Myr | Braunschweig, Germany |
| *Stenophlebia amphitrite* (Hagen) | Upper Jurassic, ca. 155 Myr | Eichstätt, Germany |
| *Stenophlebia latreilli* (Germar) | Upper Jurassic, ca. 155 Myr | Eichstätt-Solnhofen, Germany |
| *Stenophlebia casta* (Hagen, 1862) | Upper Jurassic, ca. 155 Myr | Eichstätt-Solnhofen, Germany |
| *Stenophlebia eichstattense* Nel & Martínez-Delclòs | Upper Jurassic, ca. 155 Myr | Eichstätt-Solhofen, Blumenberg, Germany |
| *Stenophlebia karatavica* Pritykina | Upper Jurassic, ca. 155 Myr | Karatau, Kazakhstan |
| *Sinostenophlebia zhanjiakouensis* Hong | Mesozoic | Northern China |
| *Prostenophlebia jurassica* Nel & Martínez-Delclòs | Upper Jurassic, ca. 155 Myr | Eichstätt-Solnhofen, Germany |

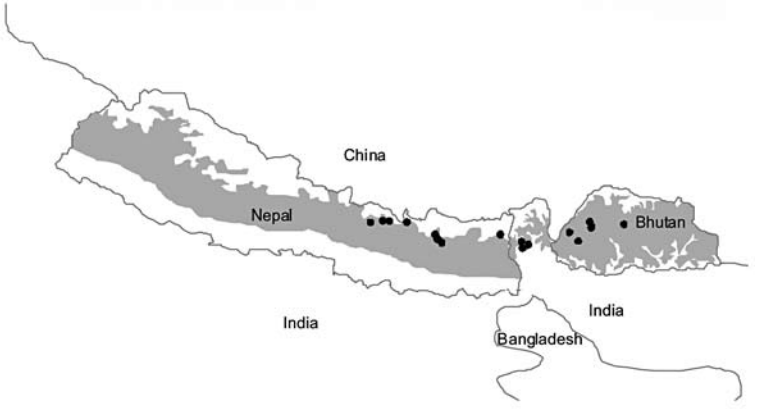


Figure 2: Records of *E. laidlawi* in the Himalayan region (shaded area denotes altitudes from 1000 to 3000 m a.s.l.)

## BIOGEOGRAPHY

Worldwide there are only two species of the suborder Anisozygoptera* known to science. Ecologically they can be compared to the species of the genus *Cordulegaster* that also inhabit the headwaters of stream ecosystems. However, while the Palaearctic distribution of the *Cordulegaster* species is restricted to the west, including northern Africa, and hence gives a biogeographically clearly understandable picture (BOUDOT, 2001), the distribution ranges of *E. laidlawi* in the Himalya and *E. superstes* on the two Japanese islands Hokkaido and Honshu are over 5000 km apart! In the following the question of why two species, systematically and ecologically so closely related, inhabit areas that are so far apart will be discussed.

During the Jurassic period the supercontinent Pangäa broke apart and Eurasia drifted northwards. The representatives of the Epiophlebiidae and Stenophlebiidae can be considered as parts of an archeo-palaearctic dragonfly fauna that developed during this period of time. It seems that they inhabitated the entire Palaearctic. While the representatives of the Stenophlebiidae became extinct, *E. superstes* survived on the Japanese islands in the eastern Palaeartic and *E. laidlawi* met with the fauna of the Indian subcontinent, which originated in Gondwanaland (HARTMANN et al., 1998). When it hit the Eurasian mainland, the former seabed of the Thethys Sea was thrust upwards and the world's highest mountain range came into being. In the extensively uplifted and much fragmented parts of the Himalayan range an intermingling of oriental and palaearctic faunal elements occurred over millions of years (MARTENS, 1979, 1987; WEIGOLD, 2005).

* See footnote appended to the title

This is also the case for the dragonfly fauna of the Himalayan countries (Nepal: VICK, 1989; Bhutan: MITRA, 2006; West-Himalaya: KUMAR & PRASAD, 1981). Therefore both *Epiophlebia* species can be considered among the last representatives of a dragonfly fauna which originated during the Jurassic on the rising continent of Eurasia.

## THREAT STATUS

In order to diagnose the threat status of *E. laidlawi*, we need more knowledge of its frequency in its distribution range, information about habitat selection by larvae as well as adults, and an understanding of the effects that human-impacted changes to the habitats make on population sizes. At present this information does not exist. It is safe to say that in its distribution range on the southern slopes of the Himalaya the species only inhabits primary habitats situated in mountainous rain forests. The populations seem to be very small, since at none of the sampling sites large numbers of larvae or adults were found. Despite relatively intensive searches (see below), only five adults (four females and one male) were collected over the first 70 years, for which the species was known to science.

Research projects on the population dynamics and biology of the species, conducted specifically in the Shivapuri Mountains in Nepal, have obtained some new information (ASAHINA, 1982; SAVILLE, 1988, 1990). One project could not even be put into action because of the riots which took place in Nepal in the 1990s

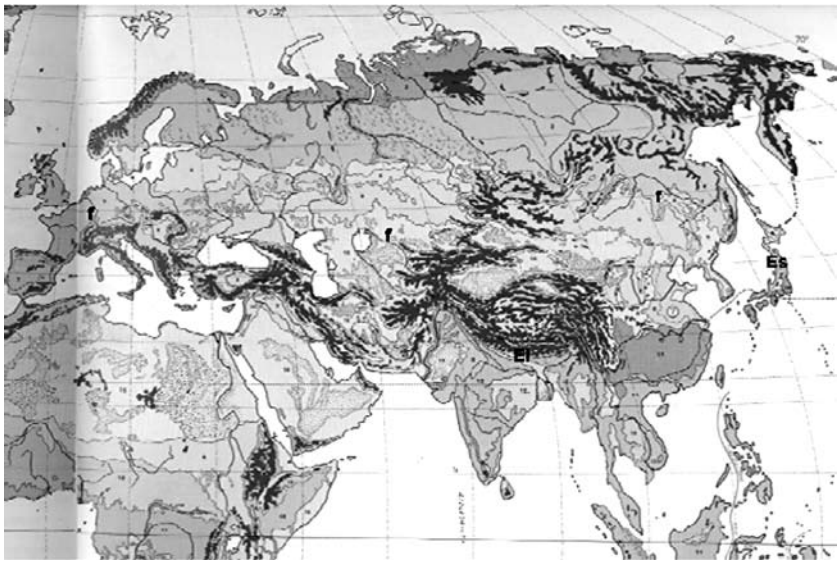


Figure 3: Areas of the recent *E. laidlawi* (El), recent *E. superstes* (Es) as well as fossil findings of Epiophlebiidae and Stenophlebiidae in the Palaearctic (f)

(TYAGI, 1991, 1992). Only from the discovery site near Darjeeling has specific information on the population dynamics and its causes been made available. In October 1960 and April 1961, SVILHA (1961, 1962) discovered many larvae in a rapidly flowing stony stream near the Siliguri-Darjeeling railway line. While he was visiting the discovery sites for a second time in 1983 the author noticed, that the stream sections, in which he had found *Epiophlebia* larvae previously, had dried out. This was caused by a heavy water abstraction from the brook. Erosion and water contamination by grazing cattle also can result in endangering the larval habitats (SVIHLA, 1984). ASAHINA (1982) described the development of the area which resulted from the building of a road, which causes more and more traffic and direct destruction of habitats, as one of the threats to the species in the Shivapuri Hills. The greatest danger is the deforestation and transformation of former mountain forests into terrace fields. So far there are no population vulnerability analyses for the Himalayan fauna, like those that exist for dragonfly faunas in other regions of Asia (INOUE, 2004; KALKMAN et al., 2004; KOSTERIN et al., 2004; ORR, 2004; WILSON, 2004).

The best protection would be the conservation of specific habitats in vast protected areas. This has at least been partly put into action in Nepal. Thus the Shivapuri Hills are protected by the law as water and wildlife conservation area, as well as parts of the Dudhkhosi fluvial system in Sagarmatha National Park. In both conservation areas, the springs and headwaters of important river catchment areas are situated. Here forest clearance is prohibited and reforestation programs stabilize the situation at the margins of those areas (CHAUDHARY, 1998).

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