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# The Stoneflies (Insecta: Plecoptera) of Israel: Past, Present, Future . . . ?

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**Abstract:** Of the more than 3900 described species worldwide, stoneflies (order Plecoptera) are represented in Israel, a semi-arid country, by as few as five species. As a group of highly sensitive aquatic insects, they are restricted to the northernmost watershed of the Sea of Galilee, where the most pristine streams in Israel are found. The Israeli stoneflies are not often collected in the field, and they have not been recorded in the literature in the last 30 years. In order to provide an up-to-date picture, I gathered the available historical records of the local fauna, as well as all verified data from the last decade, and compared the two datasets. Despite the unprecedented efforts that have recently been invested in studying freshwater macroinvertebrates in Israel, a sharp decrease in stonefly occurrence is evident. Whilst the populations of three species have dramatically declined (*Protonemura zernyi*, *Leuctra hippopus*, and *L. kopetdaghi*), the remaining two have not been collected at all in over four decades and are considered locally extinct (*Brachyptera galeata* and *Marthamea beraudi*). These findings highlight the joint impact of multiple stressors on the stream system in the Sea of Galilee Watershed—namely, stream pollution and water diversion on the local level and climate change on the global level. If the current trends continue, there is a great concern that the entire local stonefly fauna will become extinct, and many stream-dwelling taxa may follow soon after.

**Keywords:** anthropogenic impact; distribution; local extinction; museum study; Plecoptera; population decline

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## 1. Introduction

The approximately 3900 valid species of stoneflies (order Plecoptera) are well distributed across temperate regions and in mountainous landscapes but are extremely rare in semi-arid and arid regions [1–4]. Similar to many other aquatic insects, their life cycle includes an aquatic nymph stage and an aerial adult stage. The nymphs develop in freshwater bodies, in particular streams, where they employ various feeding strategies, including detritivory, herbivory, and carnivory. They obtain dissolved oxygen by absorption through their body integument and specialised gills. They require well-oxygenised waters and, therefore, can usually be found only in unpolluted, running waters with low temperatures, compared with many other freshwater invertebrates. The adults are typically winged and emerge following several moulting events. Adults, many of which are short lived and do not feed, often remain in the vicinity of aquatic habitats, where they mate and oviposit in the water [1,2].

Stoneflies are not adapted to arid and semi-arid regions, and their nymphs require pristine conditions [1], a combination that naturally dictates their distribution. In Israel, they are confined to the Sea of Galilee Watershed in the very north of the country, where human disturbance is relatively moderate and the climatic conditions are humid-mediterranean. While stoneflies are abundant in Lebanon [5], they are completely absent from other neighbouring countries, such as Jordan, highlighting that this watershed is apparently the southernmost stonefly suitable habitat in the Levant (in accordance to "Nehring Line", see [6]).

Only five species are known from Israel. Evidence for the first two species is found in sporadic reports [7–9]. Bromley [10] was the first, and so far the only one, to provide a full checklist of the local species alongside information regarding their identification, distribution, and phenology. Her publication was based on material collected primarily in the 1970s, which was partially identified by P. Zwick. Part of this material is currently housed in the entomological collection in the Steinhardt Museum of Natural History at Tel Aviv University and has been examined as part of the preparation of the current study. Additional material should be housed in the old Inland Water Ecological Service (IES) collection at the Hebrew University of Jerusalem [10] but could not be located for the purposes of this study (E. Gavish-Regev, pers. comm.). Bromley [10] determined two distinct geographical clusters of stoneflies in Israel (Figure 1)—namely, the headwaters (main tributaries) of the Jordan River (three species) and streams in the central Golan Heights (two species). Following these publications, Israeli stoneflies have rarely been mentioned in the literature [11–15] and always as part of a wider invertebrate community. The paucity of scientific and grey literature regarding Israeli stoneflies does not mean that local research has stopped. In fact, numerous sampling expeditions in the streams of northern Israel have been carried out in the last decade. These expeditions included studies for several graduate theses focusing on stream macroinvertebrates; independent research projects; growing interest and demand by local authorities, such as the Nature and Parks Authority, to assess the ecological status of streams; above all, those carried out by the Israel Center for Aquatic Ecology. Although no accurate numbers of old or recent sampling expeditions are available, it is highly probable that the sampling effort over the last few years is as great, if not greater, than in the past.

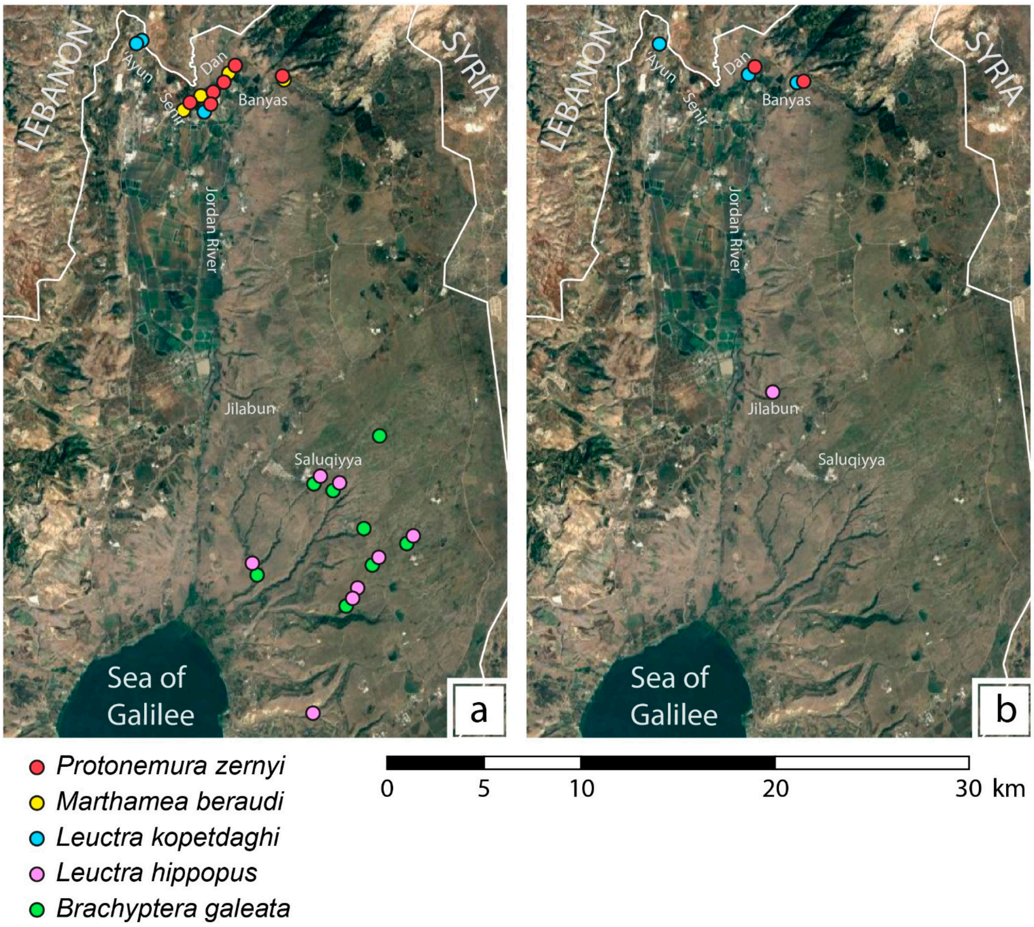


**Figure 1.** Geographical distribution of the five stonefly species in Israel. The two geographical clusters are the headwaters of the Jordan River in the north of the map and the Golan Heights in the south. All the streams mentioned in the main text are indicated by their names: (**a**) past distribution, i.e., prior to 1988 (reproduced based on [10]); (**b**) present known distribution, i.e., data points from 1989 and onwards.

As they are environmentally sensitive (most of them are narrow-ranged stenothermal species), stoneflies are usually considered to be good bioindicators of ecological changes [1,2,4]. Recently, a growing number of studies worldwide have compared old and current distribution patterns of stoneflies in order to assess small- and large-scale spatial trends (e.g., [16–18]) and, in particular, the effects of climate change. In this study, I applied a similar methodology to the Israeli fauna, by gathering the latest data on the occurrence of stoneflies in Israel, drawing an up-to-date picture of their distribution, and discussing their potential response to future environmental change.

## 2. Materials and Methods

In order to assemble a database with all of the old and the new records of Israeli stoneflies, I combined all of the available data from the literature and from museum collections. I examined all of the locatable stonefly material ever collected in Israel (48 museum entries with a total of 222 individuals). Most of this material is stored in the entomological collection of the Steinhardt Museum of Natural History at Tel Aviv University (SMNH). Additional collections I examined include those in the Israel Centre for Aquatic Ecology (ICAE) and the Museum of Zoology, Lausanne, Switzerland (MZL), which houses an important collection of aquatic insects from the Levant. As noted above, I attempted to check the collection of the Hebrew University in Jerusalem (HUJI), but 13 existing vials contain foreign material only. Other important entomological collections from the Levant (in Budapest, Prague, and Vienna) do not include Israeli stoneflies either (D. Murányi, pers. comm.). The lists below include all of the identified Israeli stoneflies that could be located. Additional, unidentified material found in the SMNH collection (ca. 15 pinned adults) was collected in the known sites in Israel between 1943 and 1984, and therefore, no information is lost by excluding them. The analysed material includes nymphs and adults (marked below as N and A, respectively). The majority of the material was determined by P. Zwick in the early 1980s. I re-examined the old material, to confirm the validity of my own identifications, using the identification key presented in [10] and then identified the more recent material (i.e., post-1980s). Material from MZL was first determined by J.-P. Reding. It is noteworthy that some collection details in the old material are missing from the original labels.

The material was collected over the years by several collectors, who, according to the details in the published literature and personal communication with the available collectors, employed various sampling techniques. Nymphs were usually collected from streams using aquatic hand nets of various mesh sizes. Adults were collected either by hand nets in the vicinity of streams or in light traps. In most cases, newer material was preserved in ethanol (at least 70%), and the old adult material was occasionally pinned. Sampling effort varied greatly over the years, with a few peaks representing the thorough fieldwork led by the IES and the Hebrew University team during the 1970s–1980s, and by scientists from Tel Aviv University in the last decade. The latter include former students of A. Gasith, and more recently, members of the ICAE, led by Y. Hershkovitz. Previously recorded localities are mostly found in nature reserves which are frequently sampled for various scientific and monitoring purposes. Despite the inconsistency in sampling effort, it is fair to assume that the presence of sustainable populations would have been identified, as current fieldwork in the northern streams of Israel is at least as intensive as it always has been. It is unlikely that a stable population, which was recorded in the past and persisted in the same sites, escaped all modern sampling efforts.

Building DNA libraries based on the barcoding segment of the mitochondrial cytochrome *c* oxidase (COI) gene is a common practice nowadays in order to keep track, identify, and compare sampled specimens. No such data are available for stoneflies of the five local species (neither from Israel nor from foreign populations). In order to bridge this gap, I extracted DNA and sequenced the 658-bp COI segment from fresh material of *P. zernyi* and of *L. kopetdaghi*. Extraction and amplification protocols are detailed in [19]. The resulting sequences (Table 1) were compared against available sequences in GenBank.

**Table 1.** New mitochondrial cytochrome *c* oxidase (COI) sequences, with closest available sequences in GenBank database (accessed on 29 November 2021).

| Species | GenBank Accession Number | Closest Available Taxon |
|---|---|---|
| *Protonemura zernyi* | OL352236 | *Protonemura meyeri* [KY262295]: 88% identity |
| *Protonemura zernyi* | OL352237 | *Protonemura meyeri* [KY262295]: 88% identity |
| *Leuctra kopetdaghi* | OL352238 | *Leuctra inermis* [HM376115]: 88% identity |

A literature survey included the few papers published on Israeli stoneflies (mainly [10]), as well as two recently completed Master's theses that include stonefly records [14,15]. Approximate locality data for Figure 1 were retrieved from collected material and from the literature. Stream names and their spelling vary in the literature and on collection labels, and they are often replaced by a landmark such as a named waterfall. The following list of common spellings should aid the non-local reader: Ayun = Ayun = Iyyon = HaTanur; Banyas = Banias = Panyas = Hermon; Senir = Hatzbani = Hazbani; Jilabun = Gilbon; Qusbiye = Qusbiya = Salukiyya = Saluqiyya.

## 3. Results

### 3.1. *Brachyptera galeata Koponen, 1949*

In the past, this species was reported to be fairly abundant, albeit confined to three small streams in the Golan Heights [10]. However, this species has not been found in any of the numerous field surveys conducted in the central Golan Heights in the past four decades, suggesting that it has disappeared from Israel. The old material was collected by D. Furth from 'Qusbiye', a ruined Syrian village in the central Golan. This locality is not characterised by any reliable water body that may explain the occurrence of this population, but the collecting probably occurred near a small bridge nearby (D. Furth, pers. comm.)—facilities in this area have considerably changed over the years. Saluqiyya Springs, found less than 2km away, used to be the most important water source around Qusbiye (see below), and probably the closest stonefly suitable habitat to the village.

Genetic information: the COI segment has never been sequenced for this species.

Available material in collections: ISRAEL: SMNH378713, 2A, Qusbiye, 31.i.1978, Furth D.G. leg. • SMNH378714, 20N, Qusbiye, 3.ii.1981, Furth D.G. leg. • SMNH378715, 51N, Qusbiye, 3.ii.1981, Furth D.G. leg.

### 3.2. *Leuctra hippopus Kempny, 1899*

This is a common stonefly, with a wide Palearctic distribution, reaching its southern limit of distribution in Israel. It was previously recorded in the 1970s from a few springs and streams in the Golan Heights [10] (Figure 1a). Two *Leuctra* nymphs were collected in the Jilabun Stream in 2015, in moderately running water upon medium and large stones with plenty of aquatic vegetation and leaf litter. Although they are too small to be identified to the species level with certainty, they are assumed to belong to *L. hippopus* based on their distribution. Despite the fact that the Jilabun Stream has never been a locality record for the species, it is fairly close to the other *L. hippopus* localities and relatively far from the *L. kopetdaghi* localities (Figure 1). It is only owing to this unusual sample that the species is not considered extinct from Israel.

Genetic information: *L. hippopus* is the only Israeli stonefly species with available genetic data in GenBank and in BOLD databases, owing to sequences obtained from its central European populations. No sequences from Israel are available, and my attempts to extract DNA from the fresh small specimens have failed.

Available material in collections: ISRAEL: SMNH378716, 13A, Saluqiyya Springs, 31.i.1978, Furth D.G. leg. • SMNH378717, 3A, Saluqiyya Springs, 31.i.1978, Furth D.G. leg. • SMNH342801, 2N, Jilabun Stream, 29.x.2015, Yanai Z. leg.

### 3.3. *Leuctra kopetdaghi* Zhiltzova, 1972

This is a common stonefly in West and Central Asia, with Israel being its southernmost limit of distribution. The species was recorded in two important tributaries of the Jordan headwaters, the Ayun and Tal Streams, in the 1970s [10]. More recently it was recorded from Ayun in 2004 and 2010 [13], and also from the Dan Stream. Nymphs were collected around the year, providing no new information on phenology. They were found in the main course of a stream in moderate current velocity with a substrate of pebbles, gravel, and leaf litter [15].

Genetic information: a single specimen from the Dan Stream was successfully sequenced for its COI barcoding segment (Table 1). An 88% similarity to the closest match on GenBank confirms that the specimen probably belongs to the genus *Leuctra* but not to any species available in GenBank, i.e., it is very likely that this is the first genetic contribution of *L. kopetdaghi*.

Available material in collections: ISRAEL: SMNH378718, 2♀A, Ayun Stream (haTanur Waterfall), 21.ii.1974, Furth D. leg. • SMNH342800, 1N, Dan Stream (Tel Dan), 10.iii.2017, Gattolliat J.-L. & Truskanov N. leg. • ICAE1160, 3N, Dan Stream (Tel Dan), 7.v.2018, Weiss A. leg. • ICAE1164, 1N, Dan Stream (Tel Dan), 19.viii.2018, Weiss A. leg. • ICAE1165, 2N, Dan Stream (Tel Dan), 19.viii.2018, Weiss A. leg. • ICAE1169, 1N, Dan Stream (Tel Dan), 4.xi.2018, Weiss A. leg.

### 3.4. *Marthamea beraudi* (Navás, 1909)

This species was detected in the material from Israel for the first time by Illies [7], mentioned as '*Lerpa beraudi*', and later placed in its current generic position by Zwick [9]. *Marthamea beraudi* is currently known from Lebanon and from Israel, in the headwaters of the Litani and the Jordan Rivers, respectively [5,9,10]. It is assumed to favour potamal habitats [9], although in Israel, it was found in the crenal/rhithral sections of the Banyas, Dan, and Senir Streams [10,11] (Figure 1a). It was recently claimed to be found in the Dan Stream [14]; however, I failed to locate the relevant samples for validation, and I suspect that they were in fact misidentified *P. zernyi* (supported by the fact that these were reported to be rare and very young specimens [15]).

The material listed by Zwick [11] should be housed in the collection of Tel Aviv University (which was integrated into the SMNH collection), although a recent check revealed that part of this collection was missing.

Genetic information: the COI segment has never been sequenced for this species.

Available material in collections: ISRAEL: SMNH374414, 1A, Banyas Stream, 4.vi.1943, Bytinski-Salz H. leg. • SMNH374415, 1A, Banyas Stream, 4.vi.1943, Bytinski-Salz H. leg. • SMNH378719, 3N, 7A, Banyas Stream, 16.v.1968 • SMNH378730, 2A, Banyas Stream, 16.v.1968 • SMNH378720, 2N, Banyas Stream, 31.i.1970 • SMNH378726, 2N, Banyas Stream, 31.i.1970 • SMNH378724, 1N, Senir Stream, 17.v.1967 • SMNH378727, 1A, Senir Stream, 16.v.1968 • SMNH378723, 2N, Senir Stream, 16.i.1970 • SMNH378725, 2N, Senir Stream, 16.i.1970 • SMNH378721, 3N, Senir Stream, 31.i.1970 • SMNH378731, 3N, Senir Stream, 31.i.1970 • SMNH374416, 1A, Senir Stream, 9.v.1972, Kugler J. leg. • SMNH378729, 1N, Senir Stream, vii.1974, Freidberg A. leg. • SMNH378728, 1N, Dan Stream (Tel Dan), 2.i.1973, Freidberg A. leg. • SMNH378722, 1N, two labels: (Banyas Stream, 17.v.1967; Senir Stream, 16.v.1968).

### 3.5. *Protonemura zernyi* Aubert, 1964

This species is only known from Lebanon, where it was described based on a single male [5,20], and from Israel. Zwick [8] reported and described the female and the nymph based on two males, one female, and one female nymph, which were collected in Tel Dan, Israel on 15.iv.1971. These specimens are housed in an unknown collection. He also determined two adults and two nymphs collected in the early 1970s, which are found in the SMNH collection. However, they must be different specimens than those reported, based on their collection details. The species was found in the Dan Stream during special excursions in 1979 and in 1982–1984 [11,12]. More recently, *P. zernyi* has been occasionally collected in the Banyas and Dan Streams (e.g., [14,15]; Weiss et al. in prep.). Although it remains rare, compared with other aquatic invertebrates, it seems to maintain its rank as the most abundant stonefly in Israel (Figure 1). It was also reported from the Ayun Stream recently [14], a first record for the species from this stream, yet the relevant sample could not be located and was excluded in this study since it cannot be verified. In recent years, *P. zernyi* nymphs were mainly collected in brooks near the mainstream course in the Tel Dan Nature Reserve, where water runs moderately, but quiet waters are available near banks and between boulders. The sites are well shaded by riparian trees and accommodate aquatic herbaceous vegetation with leaf litter. The substrate is composed of pebbles and gravel. Nymphs were most successfully collected in the spring (March–May) but were recorded in smaller numbers in August and in November.

Genetic information: the barcoding segment of the mitochondrial COI gene was sequenced for the first time for *P. zernyi*. Two sequences are available in GenBank (Table 1), and both support the claim that this is an independent species that has never been sequenced before within *Protonemura*.

Available material in collections: ISRAEL: SMNH378732, 1♀A, Senir Stream, 13.ii.1970 • SMNH378733, 2N, 1A, Dan Stream (Tel Dan), 2.i.1973, Freidberg A. leg. • MZL-GBIFCH 00981383, 2N, Dan Stream (Tel Dan), 8.v.1990, Sartori M. leg. • SMNH342803, 1N, Dan Stream (Tel Dan), 5.vi.2015, Yanai Z. & Cohen S. leg. • ICAE750, 4N, Dan Stream (Tel Dan), 14.vi.2015, Hershkovitz Y. leg. • SMNH342802, 8N, Dan Stream (Tel Dan), 5.xi.2015, Yanai Z. leg. • ICAE784, 1N, Dan Stream (Tel Dan), 10.viii.2016, Hershkovitz Y. leg. • SMNH342797, 21N, Dan Stream (Tel Dan), 10.iii.2017, Gattolliat J.-L. & Truskanov N. leg. • SMNH342798, 4N, Dan Stream (Tel Dan), 10.iii.2017, Gattolliat J.-L. & Truskanov N. leg. • SMNH342799, 2N, Dan Stream (Tel Dan), 10.iii.2017, Gattolliat J.-L. & Truskanov N. leg. • MZL-GBIFCH00981380, 7N, Dan Stream (Tel Dan), 10.iii.2017, Yanai Z. & Gattolliat J.-L. leg. • MZL-GBIFCH00981381, 1♀N, 1♂N, Dan Stream (Tel Dan), 10.iii.2017, Yanai Z. & Gattolliat J.-L. leg. • MZL-GBIFCH00981382, 20N, Dan Stream (Tel Dan), 10.iii.2017, Yanai Z. & Gattolliat J.-L. leg. • ICAE1164, 1N, Dan Stream (Tel Dan), 19.viii.2018, Weiss A. leg. • SMNH342804, 1N, Dan Stream (Tel Dan), 6.viii.2020, Yanai Z. & Hershko A. leg. • ICAE1168, 8N, Dan Stream (Tel Dan), 4.xi.2018, Weiss A. leg. • ICAE1162, 1N, Banyas Stream, 22.v.2018, Weiss A. leg. • ICAE1170, 4N, Banyas Stream, 5.xi.2018, Weiss A. leg. • ICAE reference collection, 3N, 1A, Banyas Stream, 10.xi.2021, Hershkovitz Y. & Luz D. leg. • SMNH379008, 1N, 1A, Banyas Stream, 10.xi.2021, Hershkovitz Y. & Luz D. leg.

## 4. Discussion

Examination of the historical stonefly material proved to be complicated due to a combination of insufficient details in the literature, difficulties in locating some of the material, and poor labelling of many of the old vials. The rough resolution of information given in the old literature makes it even harder to identify exact sites and characterise the nature of the habitats of the local stoneflies. In many cases, in particular, in the old labels and in the literature (e.g., [10]), a stream is only mentioned by its name, and no coordinates or detailed data regarding the exact site are given. These streams can vary greatly, from their crenal headwaters to their rhithral and, sometimes, potamal segments [21]. When necessary (e.g., in Figure 1), I tried to indicate the most probable site for stoneflies based on my own knowledge and on other collected material. For example, most of the stoneflies from the Banyas and Dan Streams were probably found in the upper segments close to the Panyas Ruins and Tel Dan, respectively. Similarly, the assumption that Saluqiyya Springs are more accurate than the old records mentioned as ‘Qusbiye’ is based on acquaintance with this site. It is, therefore, challenging to accurately assess populations and habitats retroactively and to assess past and current threats to this group. Nevertheless, it is possible to draw conclusions regarding general trends in stonefly distributions.

*Protonemura zernyi* is currently the most common stonefly in Israel, followed by *L. kopetdaghi*. Both were found in the northern geographical cluster (Figure 1), suggesting that their populations survived the environmental changes that occurred in this region over the years (see below). Both species are known today from fewer localities than in the past, suggesting slight population declines, although this cannot be ascertained without reliable long-term population monitoring. *Protonemura zernyi* persists in half of its previously known localities, perhaps owing to the fact that these are crenal stream sections, which are relatively protected and exhibit stable conditions, such as temperature (<17 °C) and chemical composition [11,12], despite a slight decline in water discharge [22,23]. *Leuctra kopetdaghi* is still common in the same water system and has recently been found in the Dan Stream as well. A probable explanation is that streamflow in all streams in the watershed has declined over the years [22,24], and perhaps, the unique conditions that were once available in smaller tributaries are now only available in the Dan Stream and in the rehabilitated Ayun Stream. The water transfer from Dan to Ayun [13,25] may also be of crucial importance for the *L. kopetdaghi* population in the latter stream. The origins of the Jordan River are protected in nature reserves and are, therefore, relatively moderately disturbed and serve as refugia for threatened crenal species. Similar to stoneflies, other orders of sensitive freshwater insects are well established there. Tel Dan supports 35% and 24% of the Israeli diversity of mayflies (Ephemeroptera) and caddisflies (Trichoptera), respectively ([12,14,15]; unpublished data), highlighting the importance of Tel Dan as a conservation hotspot at the local scale.

In central Golan Heights, *L. hippopus* has not been found in any of its historical sites, but a very rare finding from the Jilabun Stream suggests that some *Leuctra* still exist in the Israeli Golan Heights. These nymphs were impossible to identify and may represent either an expansion northward by *L. hippopus* or southward by *L. kopetdaghi*. The former seems more likely, considering the location (Figure 1b) and the ecological features of the stream, which is a typical Golan stream [21]. The question of the specific identity of this population can be resolved by future samplings, through either collection of adults or more mature nymphs, or successful COI sequencing. In any case, this single observation in the Jilabun Stream probably represents either a sink population from a Lebanese source or a fragile relict population, rather than a stable, sustainable one. Compared with other local stoneflies, *L. hippopus* is probably the most tolerant to environmental changes. It is distributed across a very wide range in the Palearctic and, unlike many other species, has exhibited an increase in populations in disturbed (channelised, polluted) sites in the Czech Republic [17].

Available material in SMNH, as well as reliable published information, suggests that *M. beraudi* was last documented and collected in Israel in 1974 [9]. Almost 50 years later, with considerable sampling efforts in its habitats, it appears that *M. beraudi* is extinct in Israel. *Marthamea beraudi* requires a set of unique conditions that can rarely be found in Israel, including low water temperature and high current velocity [12]. Recent changes in rainfall and water discharge in the Dan and adjacent streams [22–24] may have rendered them uninhabitable for *M. beraudi*.

The case of *B. galeata* is similar, with 40 years of absence from Israel. In the Golan Heights, organic pollution due to cattle activity affects most water sources. Touristic pressure has increased rapidly, including trampling and swimming in the Golan streams. Saluqiyya springs, where the most important population of *B. galeata* was sampled by D. Furth in the 1970s, has been for decades the main source for a large plant for bottled water, which altered the structural environment and significantly decreased the amount of water downstream.

The stonefly fauna in Lebanon is much richer, with many endemic species [5]. It appears that Lebanese stonefly populations are more stable than those in Israel and may be subject to weaker anthropogenic pressures in some habitats. The Israeli populations, on the other hand, are on the margin of the species distribution range and limited to a very small area which is experiencing massive climatic and anthropogenic changes. It is reasonable to expect that, at least for a few species, Lebanese populations represent a source that supports sink populations in Israel. International collaboration, with long-term sampling and genetic analyses, may shed light on these migration patterns.

Sequencing the barcoding COI segment for *P. zernyi* and *L. kopetdaghi*, had a threefold purpose in this study—namely, (a) it is the best available, genetics-based method to confirm the generic position of these species. In addition, it allowed me to confirm that these species had not yet been sequenced for their COI, i.e., to confirm that these were not synonyms or misidentifications of any other species that could be found in GenBank; (b) it is a step towards the inclusion of stoneflies in the ongoing process of building a COI library for all of the local freshwater macroinvertebrates; (c) it contributes to the global knowledge of these two species, allowing wider systematic studies. These three goals have been achieved for *P. zernyi* and *L. kopetdaghi*, and their COI sequences are now available for future comparisons and analyses (Table 1). I am hopeful that we will soon obtain sequences for the remaining three species—if not from Israeli populations, then from nearby Lebanese ones, furthering the three abovementioned aims.

Despite the fact that the Israeli stonefly fauna is rather poor, a loss of two out of five known species in just a few decades is alarming. It corresponds to recently reported trends in much faunistically richer regions, which have also had severe declines in their stonefly faunas [16–18]. Whilst in some countries (e.g., Czech Republic, USA [16–18]) there is a long tradition of monitoring freshwater invertebrates using a standard, consistent methodology, such data are not always available. Nevertheless, even in countries with more sporadic data, such as Israel, analysing long-term changes in populations and distribution patterns using publications and collection-based methods is of scientific value. It is particularly important in understanding ongoing processes and setting future conservation and research priorities.

Stoneflies are widely used as bioindicators of stream health, as they have strict environmental requirements, thus highlighting their importance for management practices. The knowledge of the concrete environmental requirements of the local stoneflies is extremely limited due to a lack of ecological, long-term research. Whilst this gap should be bridged via field surveys, laboratory experiments, and modelling techniques, it is likely that generally Israeli stoneflies are affected by similar environmental factors as other stoneflies (e.g., [17,18]). Their habitats in Israel suffer from multiple stressors, including water pumping and overtake, damming and other hydrological barriers, and increasing pressure from recreation. Smaller streams in the Golan Heights (the southern stonefly cluster, Figure 1) are usually subject to organic pollution due to cattle presence, whilst the important Dan and Banyas Streams in the northern cluster regularly receive wastewaters from commercial fishponds. Furthermore, the area is affected by climate change, with predictions of a significant decrease in rainfall and an increase in temperature in the future [23,24]. For stenothermal species such as stoneflies, this means that current habitats may become entirely unsuitable. With the continuing degradation in habitat quality in northern Israel, I expect that stonefly species will keep seeking the few refugia left, either within Israel (such as *L. kopetdaghi*) or closer to their source populations in Lebanon (probably the cases of *B. galeata*, *L. hippopus*, and *M. beraudi*). The trend seen in Israeli stoneflies, often considered quick responding bioindicators, is expected to be seen in the future in other species, especially in light of climate change, which may push the entire zoogeographical boundary ('Nehring Line' [6]) northwards. It is, therefore, of crucial importance to minimise all anthropogenic disturbances to the stream systems in northern Israel, with special attention on removing hydrological barriers and reducing agricultural pollution (e.g., cattle grazing and fishpond wastewaters). As the ability to reverse climatic processes is limited, they can still be mitigated by ensuring sufficient quantities of water from natural sources, such as springs in the streams. Finally, proper monitoring, studying, and reporting of stream biota are essential for tracking trends and identifying threats before it is too late.

## 5. Conclusions

It is reasonable to state that two stonefly species (*P. zernyi*, *L. kopetdaghi*) have maintained their populations, despite a slight decline. One species (*L. hippopus*) has severely declined but potentially maintains a local relict population in the Golan Heights. The remaining two species (*B. galeata*, *M. beraudi*) are extinct in Israel, remaining endemic to Lebanon. Accumulating evidence of local anthropogenic disturbances and global changes appear to be related to the observed decline. Plecoptera species are sensitive aquatic invertebrates that cope with a given set of anthropogenic and climatic stressors. Monitoring and understanding their response can predict the responses of other groups and serve as a warning sign for irreversible future changes.

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**Data Availability Statement:** Collecting details that were analysed in this study are given in the text. Genetic sequences are available on NCBI GenBank (www.ncbi.nlm.nih.gov/, accessed 19 January 2022). Museum specimens are available for study in accordance with the policy of the housing institutes. Additional data are available from the author upon request.

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