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**Autor:** Knipsel, Sandra / Lubini, Verena

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# Assessing the stability of stonefly (Plecoptera) biodiversity in the Swiss National Park

Sandra Knispel[1] & Verena Lubini[2]

[1] Bureau Akuatik, écologie aquatique et appliquée, route d'Essertines 3, CH-1416 Pailly; sandra.knispel@akuatik.ch
[2] Büro für Gewässerökologie, Eichhalde 14, CH-8053 Zürich

An inventory of stonefly species in the alpine Swiss National Park was conducted during 2011 and 2012 over 33 sites in various stream types, from springs and brooklets to larger rivers. 34 species were identified, representing 60% of the central eastern Alps fauna. Most species were widespread alpine species, 5 were alpine endemics and 3 species were threatened in Switzerland. Cold stenotherm and rheophilic species dominated, but eurytherm and limnophilic species appeared in streams with high habitat diversity. Historical stonefly data, collected between 1934 and 1964, enabled a long-term comparison. The stability of the stonefly fauna over more than half a century is remarkable. The low impacted stream morphology and flow regime, as well as diversity of stream types and substrate are important biodiversity drivers. In the present study one species was missing, but has always been rare in the Park. Three species are new for the Park. One species expands to higher locations and this could be related to climate changes. The present species data basis is particularly valuable for assessment of further impacts, as some changes are only perceptible at the species level.

Keywords: Plecoptera, freshwater ecology, alpine streams, biodiversity, species, protected area

## INTRODUCTION

The Swiss National Park (SNP) includes a complex hydrological network in a multitude of small catchment areas including springs, brooklets, brooks, torrents, rivers, ponds and lakes. These aquatic environments shelter a characteristic fauna including the insect order Plecoptera (Stoneflies). Aquatic insects in this region have been studied by Adolf Nadig between 1934 and 1942 (Nadig 1942), and by Jacques Aubert from 1949 to 1964 (Aubert 1965). Nadig specialized in spring fauna, whereas Aubert concentrated on the insect order Plecoptera. He collected in the SNP as well as in the neighbouring regions, and also studied the specimens collected by Nadig. The results were presented in a volume of the series dedicated to the research activities in the SNP (Aubert 1965). Stoneflies in the SNP were poorly studied during the following decades (less than 10 new records in the national database CSCF, as of October 2013). Nevertheless, macroinvertebrates were still collected during long term monitoring programs and stonefly records have recently been added to the national database. A second inventory of the stonefly species was conducted in 2011 and 2012, in order to assess today's species composition and distribution. Comparison with historical data is therefore possible and sets the basis for a long term monitoring.

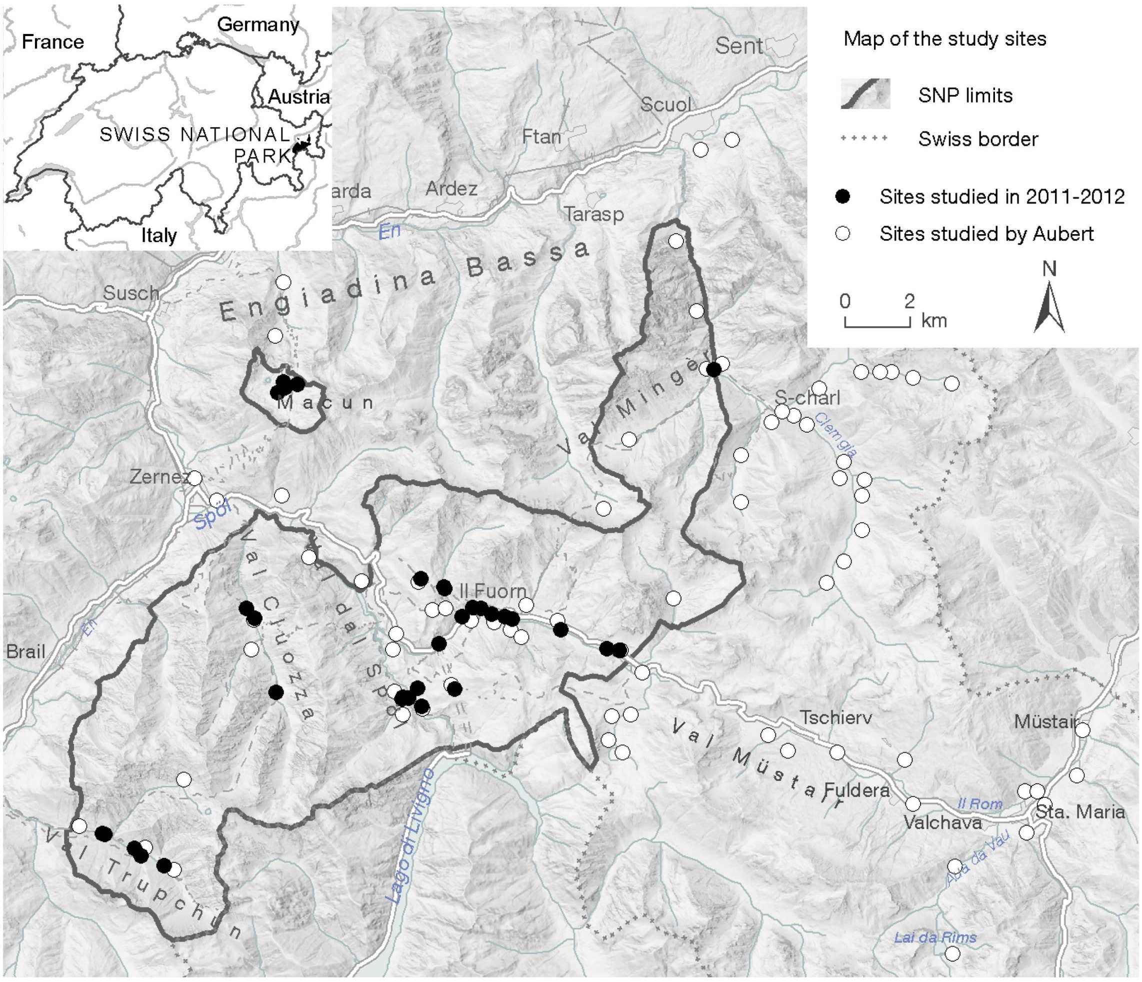



Fig. 1: Map of sites studied in 2011-2012 (○) and by Aubert (1965) (●).

## MATERIAL & METHODS

### *Study area*

The SNP is located at the very south-east corner of Switzerland in the canton of Graubünden (Fig. 1). Created in 1914, it is the oldest national park in the Alps and central Europe, classified by IUCN as a category 1 nature reserve. It covers an area of 170 km$^2$ at a mean altitude of 2320 m asl. 31 % of the SNP is covered by forest, 17 % by grassland, the rest has no vegetation cover and glaciers are absent.

### *Characteristics of the catchment area*

The hydrological network of the SNP belongs to the Inn catchment and therefore its waters drain via the Danube River into the Black Sea. Streams have a natural alpine nival runoff regime, except the River Spöl, which is regulated by the Livigno dam since 1962, and the River Clemgia, which is regulated since 1967. The Ofenpass road crosses the Park and some streams are very locally impacted (bridges). Beyond that the freshwater system is morphologically pristine. Most streams are classified as alpine, situated over 1800 m except the Spöl valley, the

River Clemgia and the lower section of the River Fuorn (beneath Il Fuorn). The maximum elevation of nearly all catchment basins is above 3000 m asl. Water temperatures rarely exceed 10 °C (Eisenhut 2013). The flow regime is very dynamic, with low flow in winter, higher and fluctuating flows during summer, which is influenced by snowmelt and heavy thunderstorms. Rivers have a wide and rocky streambed. Springs are rheocrenes, except one limnocrene, originating from a pool at Il Fuorn. Because of mostly permeable soils, ponds and lakes are the exception, and the Macun-lakes belong to the SNP since 2000.

Tab. 1: Sampling sites and sampling periods.

| Stream, location | coord. X | coord. Y | altitude (m) | 1-4.6.2011 | 5-8.9.2011 | 2-3.4 or 15.5.2012 | 15-18.6.2012 | 24-31.7.2012 | 13-16.9.2012 |
|---|---|---|---|---|---|---|---|---|---|
| Ova dal Fuorn, Il Fuorn | 811848 | 171847 | 1781 | x | x | x | | | |
| God sur Il Fuorn, brook | 811603 | 171869 | 1777 | x | x | x | | | |
| Champlönch, brook | 810000 | 172760 | 2010 | x | x | | | | x |
| Ova da Val Ftur, Val Ftur | 810717 | 172511 | 1871 | x | x | | | | |
| Ova da Stabelchod | 714425 | 171525 | 1916 | x | x | x | | | |
| Ova da Val Chavagl | 812830 | 171530 | 1857 | x | x | | | | |
| Ova dals Pluogls | 815740 | 170615 | 1940 | x | x | | | | |
| Alp La Schera, brook | 811028 | 169370 | 2087 | x | x | | | | |
| Val Ftur, brook | 810740 | 172470 | 1888 | x | x | | | | |
| Clemgia, Pradatsch | 819055 | 179221 | 1666 | x | x | | | | |
| Spring, Spöl right bank | 809885 | 169378 | 1754 | | | | x | x | x |
| Spring, Plan da l'Acqua Suot | 809416 | 169065 | 1752 | | | | x | x | x |
| Ova da l'Acqua, Plan da l'Acqua Suot | 809450 | 169115 | 1745 | | | | x | x | x |
| Spring, Spöl left bank | 809619 | 169070 | 1712 | | | | x | x | x |
| Ova da Cluozza, Chamanna | 804860 | 171536 | 1810 | | | | x | x | x |
| Spring near path, Val Cluozza | 804604 | 171842 | 1820 | | | | x | x | x |
| Spring, opposite to Val dal Fuorn | 812581 | 171598 | 1841 | | | | x | x | x |
| Spring, God dal Fuorn (GFQ1) | 812178 | 171678 | 1822 | | | | x | x | x |
| Ova da Trupchun, Alp Trupchun | 802059 | 163915 | 2024 | | | | x | x | x |
| God Trupchun, brook | 801351 | 164225 | 1991 | | | | x | x | x |
| Ova da Trupchun, Alp Purcher | 800250 | 164885 | 1868 | | | | x | x | x |
| Spring, Alp Purcher | 800156 | 164901 | 1855 | | | | x | x | x |
| Spring Dschembrina, Val Trupchun | 801157 | 164451 | 1975 | | | | x | x | x |
| Spring, Ova dals Pluogls | 816117 | 170555 | 1969 | | | | | x | x |
| Ova dal Fuorn, under O. Stabelchod | 814320 | 171195 | 1891 | | | x | | | |
| Ova dal Fuorn, Punt La Drossa | 810560 | 170755 | 1695 | | | x | | | |
| Ova da Val  Ftur, lower Val Ftur | 811271 | 171607 | 1764 | | | x | | | |
| Macun, Aua da Zeznina | 806193 | 178766 | 2594 | | | | | x | |
| Macun, N Lai Sura | 805748 | 178832 | 2631 | | | | | x | |
| Macun, Lais d'Immez | 805805 | 178661 | 2623 | | | | | x | |
| Ova da Cluozza, Plaun Sassa | 805532 | 169254 | 1935 | | | | x | | |
| Punt Periv, brook | 810023 | 168814 | 1707 | | | | x | | |
| Macun, springbrook | 805579 | 178503 | 2662 | | | | | x | |

We considered 5 types of freshwater habitats:
- mid-sized streams, flowing on large valley floors: rivers
- lateral 2nd order tributaries with variable flow over the year and steep slope (> 7%): torrents
- small 1st order streams flowing in forested or open areas (former pastures), gentle slope (< 3 %): brooks
- springs and their spring brooklets: spring brooklets
- standing water bodies: ponds and lakes

*Sites and sampling methods*

In 2011 and 2012, 23 primary sites were sampled two or three times each (Tab. 1) for three groups of aquatic insects, Ephemeroptera, Plecoptera and Trichoptera. These sites are representative of stream types and different valleys in the SNP, and had already been sampled by Aubert or Nadig (Fig. 1). Some secondary sites (Tab. 1) were sampled to look for early emerging species or using the opportunity to access and sample particular systems (e.g. Macun). Sampling methods were combined. Larvae were collected in all aquatic habitats using a kick-net and qualitative sampling by hand. Adults were collected in the riparian vegetation, using a sweep net or a beating sheet. Each site was prospected for 30 to 45 minutes depending on the stream size. Insects were preserved in 80 % ethanol and the probe was labelled with date, name of the site and coordinates (Garmin etrex). Sampling periods were chosen according to the phenology of stonefly species: April-May (remaining snow cover in 2012), June (beginning of vegetation period), end of July, September. Stoneflies were identified to species level (Lubini *et al.* 2012a), the specimens preserved and labelled as recommended (Stucki 2012) and deposited in the collections of the Musée Cantonal de Zoologie in Lausanne (Switzerland). Data are recorded in the national database (CSCF, Neuchâtel).

*Other data sources*

Stoneflies from two long term monitoring programs focusing on benthic fauna were controlled or identified: monitoring of hydropower effects in the Spöl river basin (Mürle & Ortlepp 2012), biodiversity monitoring in ponds at the Macun Lakes region (Indermühle & Oertli 2007). Data from the national database (CSCF, Neuchâtel) was provided, including historical data from Nadig (1942) and Aubert (1965) who sampled 90 stream sites in the SNP region, 40 of which were located inside the SNP limits.

*Data analyses*

The species were classified considering their ecological preferences for current and temperature using the system of Moog (1995, 2002) completed by Graf *et al.* (2009). Temperature preference was not documented for *Taeniopteryx kuehtreiberi*, and current preference was not documented for *Leuctra rosinae* and *Protonemura algovia*. For *Rhabdiopteryx harperi* and *Leuctra muranyii*, the preferences of *R. alpina* and *L. braueri*, respectively, were used because the species have ecological similarities concerning zonation and habitat.

Similarity (%) of the species composition between different streams was calculated using Jaccard-index (Jaccard 1908). Values ≥ 64 % are considered as simi-

Tab. 2: Species list: Species in **bold** are new for the SNP; — [A]: Categories as in Red Data List of Switzerland (Lubini *et al*. 2012b); — [B]: Conservation priorities as in the Swiss list of national priority species (OFEV 2011); — [C]: Responsibility as in the Swiss list of national priority species (OFEV 2011); — in grey, species not found since 1951.
Notes from 1 to 11: leg. or det. when not by the authors, and species names before nomenclature changes and corrections vs Aubert (1965); — [1]: syn. *Perlodes intricata* (Pictet 1841); — [2]: first records leg. Ortlepp 2008, syn. *Perla maxima* (Scopoli 1763); — [3]: re-identification of *Chloroperla tripunctata* (Scopoli 1763); — [4]: syn. *Chloroperla montana* (Pictet 1841); — [5]: confused with *Rhabdiopteryx alpina*; — [6]: leg. Ortlepp, det. Mürle; — [7]: re-identification of *Protonemura nimborella* Moselyi 1930; — [8]: leg. Mürle, det. Mürle; — [9]: leg. Ortlepp, det. Knispel; — [10]: re-identification of *Leuctra braueri* Kempny 1898; — [11]: leg. Aubert, det. Aubert.

| | | | Threatening category[A] | Alpine endemite (E) | National priority[B] | National responsibility[C] | Last records in the SNP |
|---|---|---|---|---|---|---|---|
| Perlodidae | *Dictyogenus alpinum* | (Pictet, 1841) | | | | | 2012 |
| | *Dictyogenus fontium* | Ris, 1896 | NT | | | | 2012 |
| | *Isoperla rivulorum* | (Pictet, 1841) | | | | | 2012 |
| | *Perlodes intricatus*[1] | (Pictet 1841) | | | | | 2013 |
| Perlidae | ***Perla grandis***[2] | Rambur 1842 | | | | | 2012 |
| Chloroperlidae | *Chloroperla susemicheli*[3] | Zwick 1967 | | | | | 2012 |
| | *Siphonoperla montana*[4] | (Pictet 1841) | NT | | | | 2012 |
| Taeniopterygidae | *Rhabdiopteryx alpina* | Kühtreiber, 1934 | NT | | 4 | 2 | 2012 |
| | ***Rhabdiopteryx harperi***[5] | Vinçon & Murányi, 2008 | VU | E | 3 | 2 | 2012 |
| | *Rhabdiopteryx neglecta* | (Albarda, 1889) | | | | | 2012 |
| | *Taeniopteryx kuehtreiberi*[6] | Aubert, 1950 | | | | | 2013 |
| Nemouridae | *Amphinemura standfussi* | (Ris, 1902) | NT | | | | 2012 |
| | *Protonemura algovia*[7] | Mendl 1968 | VU | E | 3 | 2 | 2012 |
| | *Protonemura brevistyla* | (Ris, 1902) | | | | | 2012 |
| | *Protonemura lateralis* | (Pictet, 1836) | | | | | 2012 |
| | *Protonemura nimborum* | (Ris, 1902) | | | | | 2012 |
| | *Protonemura nitida* | (Pictet, 1835) | | | | | 2012 |
| | *Nemoura cinerea* | (Retzius, 1783) | | | | | 2011 |
| | *Nemoura mortoni* | Ris, 1902 | | | | | 2012 |
| | *Nemoura obtusa* | Ris, 1902 | NT | | 4 | 2 | 2012 |
| | *Nemoura sinuata* | Ris, 1902 | NT | | 4 | 2 | 2012 |
| | *Nemoura undulata* | Ris, 1902 | CR | E | 1 | 2 | 2012 |
| | *Nemurella pictetii* | Klapalek, 1900 | | | | | 2013 |
| Capniidae | *Capnia nigra* | (Pictet, 1833) | | | | | 2012 |
| | *Capnia vidua* | Klapalek, 1904 | NT | | | | 2012 |
| Leuctridae | *Leuctra alpina* | Kühtreiber, 1934 | | | | | 2012 |
| | *Leuctra armata* | Kempny, 1899 | NT | | 4 | 2 | 2012 |
| | *Leuctra helvetica*[8] | Aubert, 1956 | EN | E | 2 | 2 | 2014 |
| | *Leuctra inermis* | Kempny, 1899 | | | | | 2012 |
| | *Leuctra major* | Brinck, 1949 | | | | | 2012 |
| | ***Leuctra moselyi***[9] | Morton, 1929 | | | | | 2012 |
| | *Leuctra muranyii*[10] | Vinçon & Graf 2011 | | E | | | 2012 |
| | *Leuctra rauscheri* | Aubert, 1957 | NT | | | | 2012 |
| | *Leuctra rosinae* | Kempny, 1900 | | | | | 2012 |
| | *Leuctra teriolensis*[11] | Kempny, 1900 | | | | | 1951 |

Tab. 3: Species composition and abundances in the SNP streams studied since 2011. Presence of adult stages (A), larval stages (L) including exuviae. — *sampled by Mürle & Orlepp (2012) during the ongoing Spöl basin monitoring; — **species sampled in a stream type where it can obviously not originate from; not taken into account in the Jaccard index and the stream type diversity.

| | *Sites* | Spöl* | Clemgia, Pradatsch | Ova dal Fuorn | Ova Cluozza | Ova Trupchum | Ova Ftur | Ova da Val Chavagl | Ova da l'Acqua, Plan da l'Acqua Suot | Ova da Stabelchod | God Trupchum, brook |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | *Freshwater habitat type (number of sites when grouped)* | *river (4)* | *river* | *river (4)* | *river (2)* | *river (2)* | *torrent (2)* | *torrent* | *torrent* | *torrent* | *torrent* |
| Perlodidae | *Dictyogenus alpinum* | | 5L | 1A 8L | 10L | 3L | 2L | 8L | 6L | 1L | 1L |
| | *Dictyogenus fontium* | | | 1A** | | | | | | | |
| | *Isoperla rivulorum* | 2L | 8A | 10L | 2L | 1L | | 1L | 1A 2L | | |
| | *Perlodes intricatus* | | | 9L | 2A 1L | | | 1L | 1L | 2L | |
| Perlidae | *Perla grandis* | | | 2L | | | | | | | |
| Chloroperlidae | *Chloroperla susemicheli* | 1A 1L | 1L | | 1L | | | | 1A 19L | | |
| | *Siphonoperla montana* | | 3L | 3L | 2A 7L | 1L | | 10L | 2L | 1L | |
| Taeniopterygidae | *Rhabdiopteryx alpina* | | | | 1A | | | | | | |
| | *Rhabdiopteryx harperi* | | | 12L | | | 6A 14L | | | 8A 13L | |
| | *Rhabdiopteryx neglecta* | | | 2A 10L | | | 8L | | | | 1A |
| | *Taeniopteryx kuehtreiberi* | 1L* | | 2L * | | | | | | | |
| Nemouridae | *Amphinemura standfussi* | | | | | | | | | | |
| | *Protonemura algovia* | | | 1L | 1L | | | | | | |
| | *Protonemura brevistyla* | | | 1A 2L | 20L | 8L | | 1L | 19L | 11L | 8L |
| | *Protonemura lateralis* | | 2L | 2L | | | | | 2L | | 1A 1L |
| | *Protonemura nimborum* | | | 15L | | | 2L | | | 1A | 2A |
| | *Protonemura nitida* | 4A | 1A 5L | 3L | | | | | | | |
| | *Nemoura cinerea* | | | | | | | | | | |
| | *Nemoura mortoni* | | 9L | 7L | 14L | | | 1L | 3L | 5L | 5L |
| | *Nemoura obtusa* | | | | | | | | | | |
| | *Nemoura sinuata* | | | | | | | | | | |
| | *Nemoura undulata* | | | | | | | | | 1L | |
| | *Nemurella pictetii* | | 1A** | | | | | | 12L | | |
| Capniidae | *Capnia nigra* | 3A 3L | 1A | | | | | | | | |
| | *Capnia vidua* | | | 14A 2L | | | | | | | |
| Leuctridae | *Leuctra alpina* | | 1A | | | | | | | | |
| | *Leuctra armata* | | | | | | | | | | |
| | *Leuctra inermis* | 101 A | 4A | 5A | 2A | | | 1A | 1A | 2L | |
| | *Leuctra helvetica* | | | 6A * | | | | | | | |
| | *Leuctra major* | 4A | | | 9A | | | | 1A | | |
| | *Leuctra moselyi* | 6A | | | | | | | | | |
| | *Leuctra muranyii* | | | 1A** | | | | | | | |
| | *Leuctra rauscheri* | 2A | 2A | 7A | | 1A | 1A | | | | |
| | *Leuctra rosinae* | 16A | 2A | 4A | 14A 15L | 2A | | 2A | 1A | 4A 1L | 1A |

lar, and values between 50 and 63% as a weak similarity (Smukalla & Friedrich 1994). Similarity was calculated for streams sampled with comparable effort (3 sampling periods). For streams sampled at different sites, a species list for the whole stream is given in Tab. 3 (e.g. Ova dal Fuorn, Ova da Val Ftur). Species in the adult stage were sometimes sampled in a stream type where they can obviously not originate from. These occurrences were pointed out in Tab. 3 and not taken into account in stream type diversity (Tab. 4) and Jaccard-index (Tab. 5).

## RESULTS

### *Biodiversity and stream type*

Today the SNP shelters 34 stonefly species (Tab. 2), which represent nearly 60 % of all 57 species listed in the "central eastern Alps" biogeographic zone (Lubini *et*

| God sur Il Fuorn, brook | Val Ftur, brook | Ova dals Pluogls | Champlönch, brook | Alp La Schera, brook | Spring near path, Val Cluozza | Spring, God dal Fuorn (GFQ1) | Spring, Alp Purcher | Spring, Plan da l'Acqua Suot | Spring, Spöl right bank | Spring, Spöl left bank | Spring Dschembrina, Val Trupchun | Spring, Ova dals Pluogls | Spring, opposite to Val dal Fuorn | Macun |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| *brook* | *brook* | *brook* | *brook* | *brook* | *spring brooklet* | *spring brooklet* | *spring brooklet* | *spring brooklet* | *spring brooklet* | *spring brooklet* | *spring brooklet* | *spring brooklet* | *spring brooklet* | *lake* |
| | | | | | | | 1L | | | 1L | | | | |
| 4L | 2L | | 1L | 1A 3L | 4A 5L | | | | | | | | 3L | |
| 12L | 1L | 1A 13L | 5L | 2L | | 1A | 10L | | | | | 12A 5L | | |
| 1A | | 3L | | | | | 2L | | | | | | 3L | |
| | | | | | | | | | | | | | | |
| | | | | | | | | 1A 4L | | | | | | |
| | | | | | | | | | | | | | 2A | |
| | | | | | | | | | | | | | | 1A** |
| | | | | | | | | | | | | | | |
| | | | | | | 1A** | | | | | | | | |
| | | | | | | | | | | | | | | |
| 1A | 4A | | 15A 3L | 2A | | 2A | | | | | | | | |
| | | | | | | | | | | | | | | |
| 1L | | 8A 9L | | | 8A 5L | | | | | | | 1A | 1L | |
| 1A 3L | 1L | 6A 6L | 3L | 1A 5L | 1L | 2A | 4A 9L | | 2L | 1A 7L | | 6A 9L | 1A 16L | |
| 1L | | | | | | | | | | | | | | 10A 11L |
| 6L | | | | | 1A | | | | | | | | | |
| | | | 2L | | | | | | | | | | | |
| 1A 7L | 4L | 3A 18L | 5L | 3A 2L | | | 1A 3L | | | | | 1L | 2L | |
| 4L | 1L | | | | | | | | | | 1A 6L | | 1L | |
| 1A | 1L | | | 2A 10L | 1A 1L | 1L | | 5L | 1A | 2A 1L | | | 8A 5L | |
| | | | | | 1A | | | | | | | | | |
| 1A | | 4L | | | | 5A 27L | 12A 19L | 9L | | | | 15A 14L | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | 4A | | | | | |
| | 1L | 3A | 14A | 60A 2L | | | | | 6A | 1A | | 2A | 1A | |
| 1A | | | | 2A | | | | 2A** | 3A** | 15A** | | | | |
| | | | | | | | | | | | | | | |
| | | | | | | | | | | | | | 2A** | |
| | | | | | | | | | | | | | | |
| 4L | 1A 8L | | 1L | 20A 4L | | 10A 22L | | | 5A 2L | 21A 9L | | | | |
| 9L | | 24A | | | | | 47A | | | | | | | |
| 1A | | 4A 4L | | 1A | 32L | | 2A | | | | 1A | | 11A | |

*al*. 2012a, Gonseth *et al*. 2001). The fauna is composed mainly of widespread and characteristic alpine species, with additional presence of five endemic alpine species. *Nemoura undulata*, found in a spring brooklet and in the Ova Stabelchod (torrent), is a species limited to the central Alps, known from the Engadin (Inn valley), as well as *Leuctra muranyii*, *Protonemura algovia* and *Rhabdiopteryx harperi*. The geographic distribution of *Protonemura algovia* covers the entire Swiss Alps and was found in the SNP in the rivers Fuorn and Cluozza. *Leuctra muranyii*, previously confused with *L. braueri*, is a crenophilic species collected in several springs and spring brooklets in the SNP. In Europe its distribution is limited to the south-eastern Alps, from Italy to the Austrian upper Inn valley (Vinçon & Graf 2011) and, in Switzerland, is limited to the SNP, to the Val Müstair, lower Engadin and Puschlav valleys. *Leuctra helvetica* is an extensive alpine and epirhithral species, originally described from the Engadin (Val Sesvenna). In Switzerland it is limited to the

Tab. 4: Species diversity in different stream types as the sum of all observations since 2011.

| | Rivers (N=5) | Spring brooklets (N=9) | Brooks (N=5) | Torrents (N=5) | Lakes (N= 2) |
|---|---|---|---|---|---|
| Total species | 25 | 20 | 18 | 17 | 1 |
| Arithmet. mean | 12 ± 5 | 6 ± 2 | 10 ± 3 | 8 ± 3 | |
| Maxima/Minima | 19/6 | 10/2 | 16/8 | 12/5 | |

Engadin (Inn valley) and the Val Colla on the southern slope of the Alps. Detailed species composition and their abundances in the streams are given in Tab. 3. One third of the species are threatened or nearly threatened in Switzerland (Lubini *et al.* 2012b). *Nemoura undulata* is critically endangered (category CR), *Leuctra helvetica* is endangered (category EN), *Protonemura algovia* and *Rhabdiopteryx harperi* vulnerable (category VU). *Nemoura undulata* has a very high national priority (OFEV 2011).

The highest species diversity is found in rivers (Tab. 4) with some characteristic species: *Capnia nigra*, *C. vidua*, *Perla grandis*, *Protonemura algovia* (Tab. 3). Few species live in torrents where waterflow is reduced after the snowmelt and which even dry out in summer, like some of the streams at Alp Trupchun. Torrents and rivers have species in common, which were not found in other stream types in larval stages: *Rhabdiopteryx harperi*, *R. neglecta* and *Siphonoperla montana*. *Chloroperla susemicheli* and *Dictyogenus alpinum* were rare in brooklets. Lakes only shelter larvae of *Nemurella pictetii*. Numerous species live in springs and brooks.

Comparing communities between stream types shows that very few streams have a similar species composition, which might be related to distinct ecological characteristics, although stream physiography might be similar. Highest similarity was shown for a small group of brooks (Tab. 5). The brook at Alp La Schera had a similar stonefly fauna to that at Champlönch and the forested brook in Val Ftur (≥ 64 % of similarity) because the species composition included strongly creno-

Tab. 5: Similarity (%) of the species composition between different rivers, torrents and brooks (Jaccard 1908), 2011-2012 observations. Values ≥ 64 % (in bold ) are considered as similar (Smukalla & Friedrich, 1994).

| | | | | rivers | | | | torrents | | | | | brooks | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Clemgia | Ova dal Fuorn | Ova Cluozza | Ova Trupchun | Ova Ftur | Ova da Val Chavagl | Ova da l'Acqua | Ova da Stabelchod | God Trupchun | God sur il Fuorn | Val Ftur | Ova dals Pluogls | Champlönch |
| rivers | Ova dal Fuorn | 45 | | | | | | | | | | | | |
| | Ova Cluozza | 41 | 41 | | | | | | | | | | | |
| | Ova Trupchun | 38 | 29 | 38 | | | | | | | | | | |
| torrents | Ova Ftur | 7 | 21 | 7 | 11 | | | | | | | | | |
| | Ova da Val Chavagl | 43 | 42 | **67** | 56 | 9 | | | | | | | | |
| | Ova da l'Acqua | 50 | 41 | **71** | 38 | 7 | **67** | | | | | | | |
| | Ov da Stabelchod | 29 | 45 | 47 | 33 | 27 | **64** | 47 | | | | | | |
| brooks | God Trupchun | 27 | 37 | 40 | 30 | 38 | 36 | 36 | 42 | | | | | |
| | God sur il Fuorn | 33 | 40 | 27 | 22 | 5 | 33 | 40 | 30 | 28 | | | | |
| | Val Ftur | 17 | 12 | 17 | 7 | 0 | 13 | 17 | 6 | 14 | 47 | | | |
| | Ova dals Pluogls | 31 | 33 | 31 | 36 | 0 | 42 | 50 | 27 | 33 | 47 | 29 | | |
| | Champlönch | 18 | 13 | 11 | 8 | 0 | 14 | 18 | 6 | 15 | 33 | **70** | 31 | |
| | Alp La Schera | 29 | 21 | 22 | 14 | 0 | 29 | 29 | 24 | 21 | 53 | **73** | 36 | **70** |

Tab. 6: Similarity (%) of the species composition between different spring brooklets (Jaccard 1908), 2011-2012 observations. Values $\geq$ 64 % (in bold) are considered as similar (Smukalla & Friedrich, 1994).

| | | spring brooklets | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| | | Val Cluozza | God dal Fuorn | Pluogls | Val dal Fuorn | Alp Purcher | Dschembrina | Spöl rhight bank | Spöl left bank |
| spring brooklets | God dal Fuorn | 18 | | | | | | | |
| | Ova dals Pluogls | 18 | 33 | | | | | | |
| | Val dal Fuorn | 45 | 14 | 33 | | | | | |
| | Alp Purcher | 15 | 30 | 40 | 29 | | | | |
| | Dschembrina | 13 | 0 | 0 | 20 | 11 | | | |
| | Spöl right bank | 20 | 38 | 22 | 25 | 8 | 0 | | |
| | Spöl left bank | 20 | 38 | 20 | 21 | 18 | 0 | **67** | |
| | Plan dal Acqua Suot | 10 | 29 | 13 | 8 | 10 | 0 | 14 | 14 |

philic species such as *Amphinemura standfussi*, *Leuctra muranyii*, *L. armata*, *N. sinuata* and *Dictyogenus fontium*, beside species with larger ecological preferences. Within the group of torrents, only Ova da Val Chavagl, Ova da l'Acqua and Ova Stabelchod had a species composition considered as similar (Tab. 5). Ova Cluozza had also a similar composition to two of these torrents. No similarity between the species composition has been demonstrated for rivers, nor for spring brooklets with the exception of two in the Val Spöl (Tab. 6).

*Ecological traits of the stonefly fauna*

Most species are considered as being stenoecious, particularly regarding temperature tolerance, and most are cold stenotherm (Fig. 2). Cold and very cold stenotherm species were found in all stream types, as for example larvae of *Perlodes intricatus* (Tab. 3). However, five species, *Nemoura cinerea*, *Protonemura nitida*, *Nemurella pictetii*, *Leuctra inermis* and *Leuctra major* are eurytherm. The larvae of these species develop in habitats with wider temperature ranges (Tab. 3), such as lower Spöl, Clemgia and Ova dal Fuorn up to Il Fuorn as well as some tributaries (*Protonemura nitida*, *Leuctra inermis*), brooks with high amount of particulate organic matter (Champlönch, *Nemoura cinerea*) or deep in the sediment pores of rivers (*Leuctra major*). *Nemurella pictetii* has been found in some springs as well as in the lakes of Macun. These species occur all over Switzerland down to low altitudes.

The high amount of rheophilic species (Fig. 2) has to be related with the prevalence of steep streams and fluctuating discharge during summer. Species with no current preference (e.g. *Amphinemura standfussi*, *Protonemura nitida*) or limnophilic species (e.g. *Nemoura cinerea*, *Nemurella pictetii*) occur mainly in lakes, spring brooklets, but also in streams with slight slopes and calm, shallow riverbanks (e.g. transition to fens/marshland).

Temperature and current preferences of occurring species were not very different between stream types (Fig. 3). Rivers and torrents have a very low amount of limnophilic or current indifferent species. Cold stenotherm species were frequent

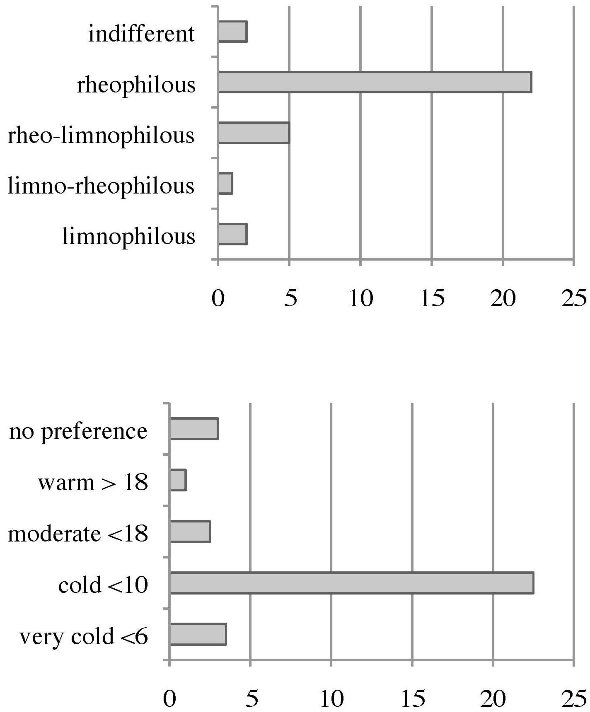


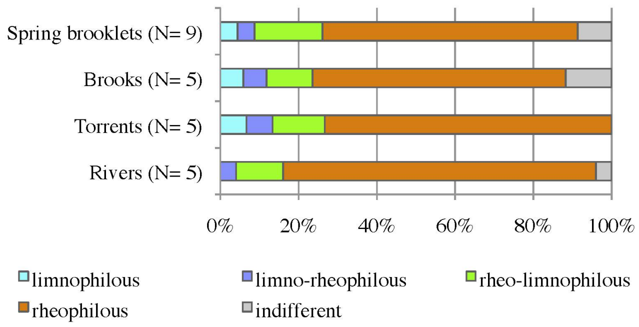

Fig. 2: Number of stonefly species in the SNP with distinct current (upper; n = 32) and temperature (lower; n = 33) preferences.

in springs and brooks, and their abundance was higher than in larger streams. The situation is opposite for warm tolerant species or temperature indifferent species.

*Temporal development of the stonefly fauna*

Aubert (1965) recorded 38 stonefly species. Four of them had been located outside the SNP in the neighbouring regions: *Amphinemura sulcicollis*, *Perla grandis* (syn. *Perla maxima*), *Leuctra mortoni*, *Leuctra moselyi*. A control of the «catalogue des espèces» in Aubert (1965) and the location of sampling sites gave evidence for two further species sampled outside of the SNP limits: *Leuctra sesvenna* and *Leuctra handlirschi*. *L. sesvenna* is mentioned in Aubert (1965) from the Aua da Sesvenna, Marangun, between 2300 and 2500 m asl. This location is situated outside the SNP, just east of Val Nüglia and Val Foraz. *L. handlirschi* is mentioned in Aubert (1965) only from the Aua da Zeznina, at Val Zeznina at 1930 m asl, located outside the SNP, just north of the Macun lakes. Aubert (1965) thus finally recorded 32 stonefly species for the SNP. Descriptions of new species have been published since then. Material of the concerned species, collected before 1965 by Nadig or Aubert (today in museum collections in Lausanne or Chur), has been revised during the Red List Project (Lubini *et al.* 2012b) or the present work and recorded in the national database. Unverified data was put aside (e.g. *Leuctra* spp. larvae, or specimens cited in publications, but not found in the corresponding museum collections). Corrections and nomenclature changes have been mentioned in Tab. 2.

The current stonefly inventory of 34 species includes two more than nearly 60 years ago. Examining changes in composition and distribution provided evidence that one species, *Leuctra teriolensis*, has not been collected in the SNP again. In fact, the only verified record before 1965 in the SNP is from the river Ova Spin at



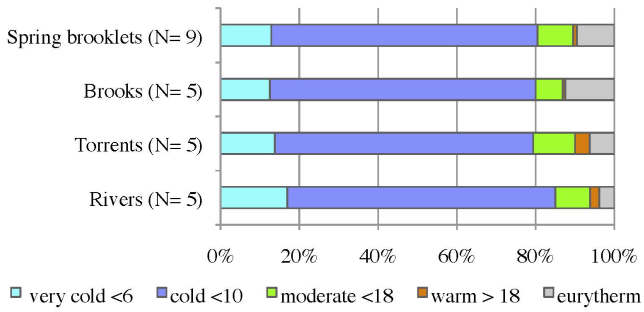




Fig. 3: Average composition of species (%) relative to their current (upper; n =32) and temperature (lower; n =33) preferences in different stream types.

Ova Spin. It means that the species was rare and could not be confirmed until now in the SNP. It was recently collected near the SNP, at Tschierv (Val Müstair) and at Susch (Inn Valley) (CSCF, Neuchâtel). The species is, however, common in the Alps. Three species collected in 2011 and 2012 were new for the SNP: *Leuctra moselyi*, *Perla grandis* and *Rhabdiopteryx harperi*. *R. harperi* was recently taken out from the *R. alpina*-species complex and described as new by Vinçon & Murányi (2009). Due to the lack of adult male specimens in Aubert's material, its presence in the SNP before 1965 cannot be confirmed or invalidated. Concerning *Perla grandis* and *Leuctra moselyi*, both species are widespread in Switzerland, mainly in streams below 1400 m as shown from *P. grandis* larvae records (Fig. 4). Both species were collected recently in the SNP with altitudinal limits of 1960 m asl (Ova dal Fuorn) and 1510 m asl (lower Spöl), respectively.

## DISCUSSION

The results of the present study emphasized the stability of the stonefly fauna in the SNP over more than half a century. With one exception, all species, including endemic and rare species, were still sheltered in the protected area. Except for the River Spöl, this could be attributed to low impact on streambed morphology and the pristine runoff regimes, which are, in addition to high permeability of the riverbank substrate, important biodiversity drivers (Oswald 1990; Burgherr *et al*. 2003). Refuge habitats were provided by high streambed structure diversity combined with different stream types, which enhance ecosystem stability.

With 34 Plecoptera species, the present diversity reached the expected level, taking into account the harshness of the environmental conditions induced by nival flow regimes, dynamic stream morphology, low water temperatures, biogeographic region of the central Alps; all are important drivers of the stonefly species composition. Biodiversity of the three aquatic insect orders Ephemeroptera, Plecoptera and Trichoptera in Switzerland is the highest between 700 and 1300 m asl (Altermatt *et al.* 2013) and then decreases with increasing altitude. These results were supported by different studies, like the pre-alpine Sense catchment study between 577 and 1400 m asl that registered 52 stonefly species (Zurwerra *et al.* 2000). Similar situations were observed in the Italian western Alps (Malicky *et al.* 2007) and the Isar catchment in Germany (Hering 1995).

Similarity of total Plecoptera species composition between streams was very low, except for a few streams of various types. Presence of some species seemed highly influenced by typology, like e.g. several crenophilic species present in a small group of similar brooks. Other factors may be important, like stream morphology or distance between sites. The three torrents with similar species composition had large gravel beds and catchment areas limited to a few km$^2$, but differed in their exposition (Haller 2013). The only similar spring brooklets in the Val Spöl had similar morphology and were situated very close. Springs in the SNP are of various types due to very different chemical and physical characteristics (Schlüchter *et al.* 2013). An extensive study of 20 springs and their direct surroundings in the Park, taking into account the entire macroinvertebrate fauna, was conducted recently (Felder 2013). Neighbouring springs were shown to have similar faunistical assemblage in contrast to springs situated farther away.

The recently confirmed presence of *Perla grandis* in the SNP needs a focus on its altitudinal distribution in Switzerland. First evidence of its presence in the larval stage above 1800 m asl was provided in the 1990s (national database, CSCF, Neuchâtel). Proportionally, *P. grandis* has been found more often at altitudes ≥ 1400 m asl after 1990 than before. The development of *P. grandis* larvae takes up to 3 years until emergence in spring, preferring streams with water temperatures from 8

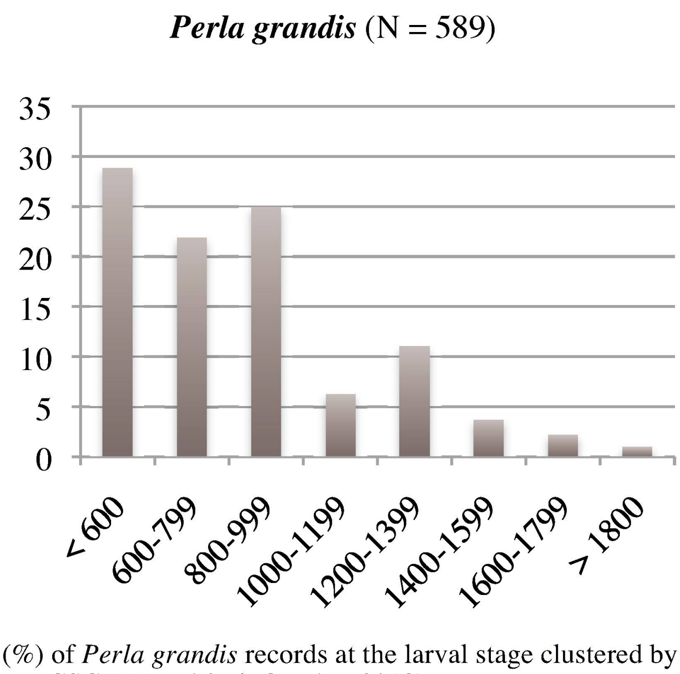



Fig. 4: Distribution (%) of *Perla grandis* records at the larval stage clustered by altitudinal classes (m asl) (national database, CSCF, Neuchâtel, October 2013).

to 20 °C, while maximum growth occurs during the warm season (Frutiger & Imhof 1997). As the species was not found before 2008 in the SNP despite the important collecting effort (Aubert 1965) and as grown larvae were found in 2012, we conclude that *P. grandis* colonized the Ova dal Fuorn. As water temperature has major influence on egg development duration and larval growth (Lillehammer *et al.* 1989), influence of temperature increase has to be considered. There is clear evidence for warming in the SNP since 1917, with a raise of annual air temperature of 1.6 °C per 100 years and a more pronounced seasonal air temperature increase of 1.7 to 5 °C (Bundesamt für Meteorologie und Klimatologie Meteoschweiz, 2013). Warming is higher in spring, during increase of larval growth that follows winter growth slowdown. As water temperature is related to air temperature (e.g. Mohseni & Stefan 1999), stream temperatures increased from 0.8 to 1 °C in lowland rivers (Hari *et al.* 2006). In small mountain streams, in absence of glacier melt-water as in the SNP, warming is also visible and mainly due to solar and long wave radiation, heat exchange with the sediment and dissipation of kinetic energy (Meier *et al.* 2003). Increase of water temperature in the SNP streams due to climate change is therefore highly probable and the possible impact on the freshwater fauna has to be documented further. Issues are for example the ability of species to maintain viable populations in the SNP and the consequences on cold stenotherm species living at high altitudes, which are expected to come under increasing physiological stress because they will not be able to migrate to higher elevations. The immigration of species from lower locations is expected to be a major driver of the freshwater biodiversity in the Alps (Burgherr *et al.* 2003; Robinson & Oertli 2009). Migration of eurytherm species to higher locations has already been observed as illustrated by the following examples. The eurytherm mayfly *Habrophlebia eldae*, has immigrated from Italy to the canton of Ticino (CH) (Wagner *et al.* 2007). North of the Alps, in the catchment area of the River Rhine, the stonefly *Leuctra geniculata* recently spread to higher locations (Vittoz *et al.* 2013).

The importance of long-term monitoring in freshwater systems, especially in protected areas, has been recently emphasized (Robinson *et al.* 2011). Biodiversity monitoring in Switzerland already includes Plecoptera species diversity on a systematic sampling grid covering the whole country (Altermatt *et al.* 2013). As some changes are only perceptible at the species level, the present SNP stonefly species data is of unique value since it allows long term comparisons with a historical data set over more than half a century time span. A SNP Plecoptera monitoring program would therefore benefit from both Swiss large scale program and the detailed SNP database (box 13.1 in Scheurer *et al.* 2014). Such a data base is also valuable for the assessment of climate change effects, the control monitoring after rehabilitation measures (Mürle & Ortlepp 2012) and other possible impacts. Alpine streams in Switzerland are particularly threatened by the country's much higher hydroelectric power production density (kWh/year and $km^2$) than in other neighbouring countries (Kissling *et al.* 2007) and in fact they are coming under increasing pressure through the planned energy transition from nuclear to non-fossil. The actual data base on the SNP is an important basis for a future reference system for the Swiss freshwater typology (Schaffner *et al.* 2013).

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