UPDATE OF THE AQUATIC TRUE BUG (HETEROPTERA) AND BEETLE (COLEOPTERA) FAUNA OF THE SEEFELD PLATEAU WITH COMPARISON TO HISTORICAL FINDINGS

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ABSTRACT

Aquatic true bugs (Heteroptera) and beetles (Coleoptera) are valuable indicators for assessing the ecological integrity of freshwater habitats, yet long-term standardized datasets for Alpine regions remain scarce. The Seefeld Plateau (Northern Tyrol, Austria) provides a unique opportunity to reassess faunal change owing to historical records dating back to 1911. In 2024, twelve lentic waterbodies representing a mosaic of natural, semi-natural, and artificial habitats were surveyed using standardized bottle-trapping, net-sampling, and supplementary pitfall trapping. A total of 1,851 individuals representing 123 taxa were recorded, including 59 beetle and 24 true bug species. Red List taxa were well represented, with the notable rediscoveries of the true bug species *Sigara semistriata* and *Cymatia bonsdorffii*, previously considered regionally extinct in Austria. Historical comparisons revealed the loss of 12 heteropteran and 16 coleopteran species, with declines most pronounced among stenotopic, bog-associated taxa. Species assemblages were strongly influenced by fish stocking, littoral structure, and surrounding land use. Several non-protected ponds, particularly those on the Gschwandtkopf and Wildmoosalm, were identified as valuable refugia for regionally rare and specialized taxa. The findings highlight the importance of including small, anthropogenically influenced waterbodies in conservation and monitoring frameworks and provide a standardized baseline for future assessments of Alpine aquatic biodiversity.

ZUSAMMENFASSUNG

Aquatische Wanzen (Heteroptera) und Käfer (Coleoptera) sind wertvolle Indikatoren zur Bewertung der ökologischen Integrität von Süßwasserlebensräumen, doch langfristig standardisierte Datensätze für alpine Regionen sind nach wie vor selten. Das Seefelder Plateau (Nordtirol, Österreich) bietet eine einzigartige Gelegenheit, die faunistische Veränderung neu zu bewerten, da historische Aufzeichnungen bis ins Jahr 1911 zurückreichen. Im Jahr 2024 wurden zwölf stehende Gewässer, die ein Mosaik aus natürlichen, halbnatürlichen und künstlichen Lebensräumen darstellen, mittels standardisierter Flaschenfallen, Netzproben und ergänzender Bodenfallen untersucht. Insgesamt wurden 1.851 Individuen aus 123 Taxa erfasst, darunter 59 Käfer- und 24 Wanzenarten. Rote-Liste-Taxa waren gut vertreten, darunter die bemerkenswerte Wiederentdeckung der Wanzenarten *Sigara semistriata* und *Cymatia bonsdorffii*, die zuvor als regional ausgestorben in Österreich galten. Historische Vergleiche zeigten den Verlust von 12 Heteroptera- und 16 Coleoptera-Arten, wobei die Rückgänge besonders ausgeprägt bei stenotopen, moorassoziierten Taxa waren. Die Artenzusammensetzungen wurden stark durch Fischbesatz, Uferstruktur und die umgebende Landnutzung beeinflusst. Mehrere nicht geschützte Teiche, insbesondere jene am Gschwandtkopf und auf der Wildmoosalm, wurden als wertvolle Refugien für regional seltene und spezialisierte Taxa identifiziert. Die Ergebnisse unterstreichen die Bedeutung, kleiner, anthropogen beeinflusste Gewässer in Schutz- und Monitoringkonzepte einzubeziehen, und liefern eine standardisierte Grundlage für zukünftige Bewertungen der alpinen aquatischen Biodiversität in der Region.

Keywords: Aquatic Heteroptera and Coleoptera, faunistics, anthropogenic landscapes, rediscoveries

INTRODUCTION

Freshwater habitats are among the most species-rich yet threatened ecosystems globally. Their high spatial and temporal dynamic, combined with high regional variability, allow even small standing waters and bogs to function as critical biodiversity reservoirs, often supporting highly specialized taxa (Williams et al. 2004; Dudgeon et al. 2006; Grossart et al. 2023). Among the inhabitants of such stagnant waters, aquatic beetles (Coleoptera) and true bugs (Heteroptera) stand out as ecologically diverse, highly mobile, and disturbance-sensitive taxa, making them valuable indicators in faunistic surveys and conservation assessments (Klausnitzer 1996; Schmidl 2003; Strauss & Niedringhaus 2014).

However, anthropogenic pressures – including shoreline development, fish stocking, drainage, and recreational activities – have led to widespread degradation or loss of freshwater habitats and communities in many industrialized regions (Dudgeon et al. 2006; Küster 2010; Reid et al. 2019; Grossart et al. 2023). Reflecting this, 155 beetle and 34 true bug species are currently listed on regional or national Red Lists of threatened taxa (Hebauer et al. 2003; Heckes et al. 2006; Rabitsch & Friess 2024). Recognition of the ecological value of small natural and artificial waterbodies has increased in recent decades, accompanied by faunistic monitoring efforts aimed at assessing habitat integrity (Niedringhaus 1999; Bloechl et al. 2010; Liao et al. 2020). Nevertheless, long-term standardized datasets that would allow for robust evaluation of faunal change remain rare, and many sites have yet to be surveyed or were never systematically investigated.

The Seefeld Plateau in Northern Tyrol, Austria, offers a unique opportunity to examine long-term faunal shifts due to the existence of historical species records dating back to 1911. The last monitoring focused on the EU Habitats Directive species *Dytiscus*

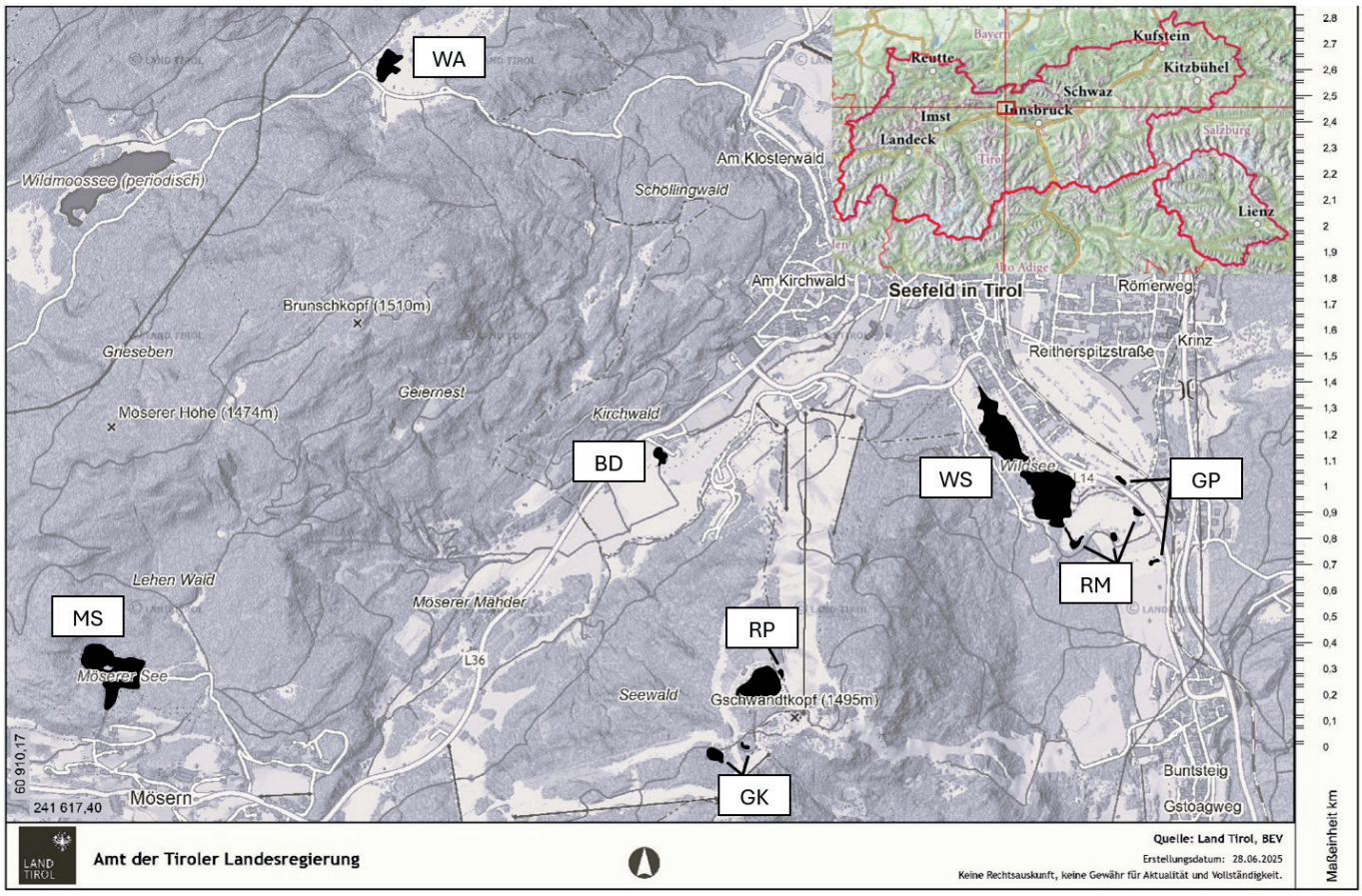


Fig. 1: Study area with all sampled waterbodies (black). (WS = Wildsee, MS = Mösersee, WA = Wildmoosalm, GK = Gschwandtkopf, RM = Reithermoor, BD = Beaverdam, GP = Golfponds and RP = Reservoir-pond). Top right: location of the area in Tyrol. Depending on their size, the waterbodies each had between one and four sampling points (Image obtained from: Tiris-Maps 2024).

latissimus Linnaeus 1758 in the two major lakes in 2014 (Glaser & Eckelt 2014), leaving the status of many species in smaller waterbodies unresolved.

The present study aims to (1) update the inventory of aquatic Heteroptera and Coleoptera across twelve waterbodies of the Seefeld Plateau, (2) compare contemporary assemblages with historical records to assess faunal changes, and (3) identify habitats of particular conservation value within this tourism-influenced montane landscape. By providing a standardized methodological baseline, this work establishes a foundation for future monitoring and for evaluating the long-term trajectories of Alpine freshwater biodiversity.

MATERIAL AND METHODS

The study was conducted on the Seefeld Plateau (Tyrol, Austria), located in the Northern Limestone Alps at elevations of 1,180–1,460 m a.s.l. The geology of the area is predominantly Wetterstein limestone (Ampferer 1904). Following the retreat of the Inn Glacier, a series of lakes formed, of which the Wildsee and Mösersee remained. Other basins silted up over time, leaving bog remnants (Buchner et al. 1993). Historically, the region supported a diverse aquatic insect fauna, with records dating back to 1911 for the major lakes and peaking in the 1960s with surveys of additional smaller waterbodies. These records include several stenotopic and Red List species (Heiss 1971; Kahlen 1987; Eckelt & Glaser 2014).

In 2024, twelve lentic waterbodies were surveyed for aquatic Heteroptera and Coleoptera (Fig. 1). The sites represented a mosaic of natural, semi-natural, and artificial systems differing in origin, management, size, and surrounding land use:

Postglacial lakes (Wildsee, Mösersee): The largest waterbodies in the study area, both are subject to recreational use (bathing, angling) and have undergone shoreline modification and fish stocking (e.g., trout, perch, carp). Habitat continuity has been fragmented, although some littoral refugia persisted. Due to their heterogeneity, three and four sampling sites were established per lake, respectively.

Natural and semi-natural ponds (Gschwandtkopf, Wildmoosalm, Reithermoor, Raabach): These pond-sized systems were mostly of natural or semi-natural origin. Several were peat-influenced (e.g., former drainage ponds in the Reithermoor) and at advanced stages of terrestrialization, whereas others resembled forest ponds. A unique site was a beaver-dam pond complex along the Raabach. These young systems were generally sunlit and rich in vegetation.

Artificial ponds (golf course ponds, snow reservoir): Constructed 20–40 years ago for ornamental or snowmaking purposes (pers. comm. Golfclub Seefeld; municipality of Telfs), these ponds varied in structure and vegetation cover.

All waterbodies were characterized prior to sampling in terms of morphology, riparian structure, vegetation, fish presence, and abiotic parameters (dissolved oxygen, conductivity, pH).

Each site was sampled twice in 2024, during early summer (June–July) and early autumn (September–October), covering major phenological windows of the target taxa. At each sampling site, three baited bottle traps (1.5 L PET bottles baited with chicken liver) were installed along the littoral zone and retrieved after 48–72 h, following established protocols (Aiken & Roughley 1985; Hilsenhoff & Tracy 1985; Turic et al. 2017; Brojer 2023).
In addition, all sites underwent semi-quantitative net sampling using a hand net (40 × 28 cm, 1 mm mesh) stratified across microhabitats, including substrate, submerged vegetation, quaking bog mats, open water, and woody debris (Hilsenhoff & Tracy 1985; Turner 2008; Hess & Heckes 2021; Iannuzzi et al. 2021). Sampling duration ranged from 1 to 2.5 h per site and was adjusted to diel and seasonal activity patterns.
In early summer, two pitfall traps (diameter 10 cm, depth 7 cm) were additionally deployed per site to target riparian beetles, using saturated saline water with acetic acid and detergent as a killing solution (Renner 1980; Plunger et al. 2022). Due to high ant activity and low additional capture rates, pitfall traps were omitted in autumn. All specimens were euthanized in 70 % ethanol and identified to species level using standard regional keys (Freude et al. 1964–1983; Zimmermann 1987; Savage & Sutcliffe 1999; Strauss & Niedringhaus 2014; Brojer et al. 2021; Raupach et al. 2024) and reference collections of the Tiroler Landesmuseum Ferdinandeum (hereafter TLMF) stored at the Collection and Research Centre (hereafter SFZ), Hall in Tirol. For all taxa, the Austrian Red List for Heteroptera (Heckes et al. 2006; Rabitsch & Friess 2024) and the Bavarian Red List for Coleoptera (Hebauer et al. 2003) were used, and the degree of ecological specialization (e.g., bog dependence) and body size were recorded. For Coleoptera, the Bavarian Red List was used due to the incompleteness of the Austrian Red List.
Historical records (1911–2014) were compiled and evaluated from the literature (Heiss et al. 1969; Koch 1989; Savage 1989; Vondel & Brauer 1997; Hebauer et al. 1998; Strauss & Niedringhaus 2014; Spitzenberg & Malchau 2021) and curated collections of the TLMF. Species with uncertain historical records (e.g., based on phenologically unlikely or cryptic observations) were excluded from direct comparisons.
Analyses focused on (1) current species richness and composition across waterbodies, (2) comparison of present assemblages with historical records, and (3) interpretation of faunal patterns in relation to habitat characteristics and known anthropogenic changes. Absence of species that should have been detectable with the applied methods was interpreted as evidence of population decline or local extinction.



Fig. 2: *Sigara semistriata* found in the pond on the Wildmoosalm.



Fig. 3: *Cymatia bonsdorffii* found in the pond on the Wildmoosalm.

RESULTS

Across all 12 surveyed waterbodies and the 17 surveyed sampling sites, a total of 1,851 individuals representing 123 taxa were identified (including the bycatch). For further details see Appendices 1 and 2 with the complete species lists. These comprised 59 species of aquatic beetles (Coleoptera) and 24 species of aquatic bugs (Heteroptera). Among the Coleoptera, 18.6 % (11) were listed on the Bavarian Red List and 29 % (7) of Heteropteran species on the Austrian Red List. The bycatch included mainly terrestrial invertebrates obtained from the pitfall traps and single specimens of other aquatic taxa (e.g., Trichoptera).

Particularly noteworthy were the rediscoveries of *Sigara semistriata* (Fieber 1848) (Fig. 2) in the Wildmoosalm pond and *Cymatia bonsdorffii* (C.R. Sahlberg 1819) (Fig. 3) in a forest pond on the Gschwandtkopf. Both species are classified as "Regionally Extinct" in Austria but were represented by several individuals in this survey. These waterbodies also harboured the "Endangered" species *Notonecta reuteri* Hungerford 1928 and the "Vulnerable" *Notonecta lutea* Müller 1776. Additionally, the "Vulnerable" *Arctocorisa carinata* (C.R. Sahlberg 1819) was found in the reed belt of the Wildsee and the artificial storage pond on the Gschwandtkopf. "Near Threatened" taxa such as *Gerris odontogaster* (Zetterstedt 1828) and *Corixa dentipes* Thomson 1869 occurred at several natural and artificial ponds. Widespread species including *Notonecta glauca* Linnaeus 1758, *Microvelia reticulata* (Burmeister 1835), *Gerris lacustris* (Linnaeus 1758), and *Hesperocorixa sahlbergi* (Fieber 1848) dominated the heteropteran assemblages and are listed as "Least Concern".

Among the Coleoptera, "Endangered" species included *Graphoderus zonatus* (Hoppe 1795) (Fig. 4) in several ponds, *Nebrioporus assimilis* (Paykull 1798) (Fig. 5) on the Gschwandtkopf, *Plateumaris sericea* (Linnaeus 1758), and *Bagous frit* (Herbst 1795), the latter representing the first record for Seefeld, found in the *Menyanthes* belt of the Wildsee. "Vulnerable" taxa included *Agabus congener* (Thunberg 1794) in the Reithermoor, *Haliplus confinis* Stephens 1829 on the Gschwandtkopf, and *Hydroporus longulus* Mulsant et Rey 1860 (first record) in the Mösersee. Larger lakes with more extensive riparian vegetation supported several Donaciinae species categorized as "Near Threatened". The most frequently recorded beetles were *Hydroporus palustris* (Linnaeus 1761), *H. erythrocephalus* (Linnaeus 1758), *Hygrotus inaequalis* (Fabricius 1777), *Haliplus ruficollis* (DeGeer 1774), *H. heydeni* Wehncke 1875, *Dytiscus marginalis* Linnaeus 1758, and *Acilius sulcatus* (Linnaeus 1758). The Habitats Directive species *Dytiscus latissimus* was not detected.

Species richness and assemblage composition varied markedly among sites. The two largest lakes generally supported few species, except in unmodified littoral zones undergoing later successional stages. These areas still hosted stenotopic taxa dependent on specific host plants and bog- or temporary-pond specialists, e.g., Donaciinae and *Hydroporus obscurus* (Sturm 1835).

The forest pond on the Gschwandtkopf (Fig. 1, GK) and the Wildmoosalm pond exhibited the highest heteropteran richness and high beetle diversity (Figs. 6–7). Both sites supported a large



Fig. 4: *Graphoderus zonatus* found in the pond on the Wildmoosalm.



Fig. 5: *Nebrioporus assimilis* found in the pond on the Wildmoosalm.

proportion of Red List taxa, most of which are stenotopic species with high ecological specialization, typically associated with acidic, oligotrophic bog habitats, rich vegetation, or spring-fed systems. Despite some overlap in species composition, each pond displayed distinct characteristics: the Wildmoosalm pond was shallow, sunlit, and influenced by surrounding bogland, with mild eutrophication likely due to adjacent grazing. The Gschwandtkopf pond was a semi-shaded forest pond with gravel substrate and mire-like zones, maintaining cool, spring-fed conditions (presumably also due to altitude). However, besides their location in the same region, both ponds lacked fish and had largely unmodified riparian zones.

The Reithermoor waterbodies supported beetle assemblages of comparable richness but were dominated by generalist species. Despite the area's bog-like character, few obligate bog specialists were recorded. Assemblages were largely comprised of species with facultative associations with bog habitats.

The Raabach pond complex, shaped by nutrient-rich surroundings, displayed a eutrophic character. Although most taxa were generalists without strong habitat specialization, species richness was relatively high in the heterogenous system.

Artificial ponds exhibited marked variation in structure and species composition. The overflow reservoir, with its pioneer character,

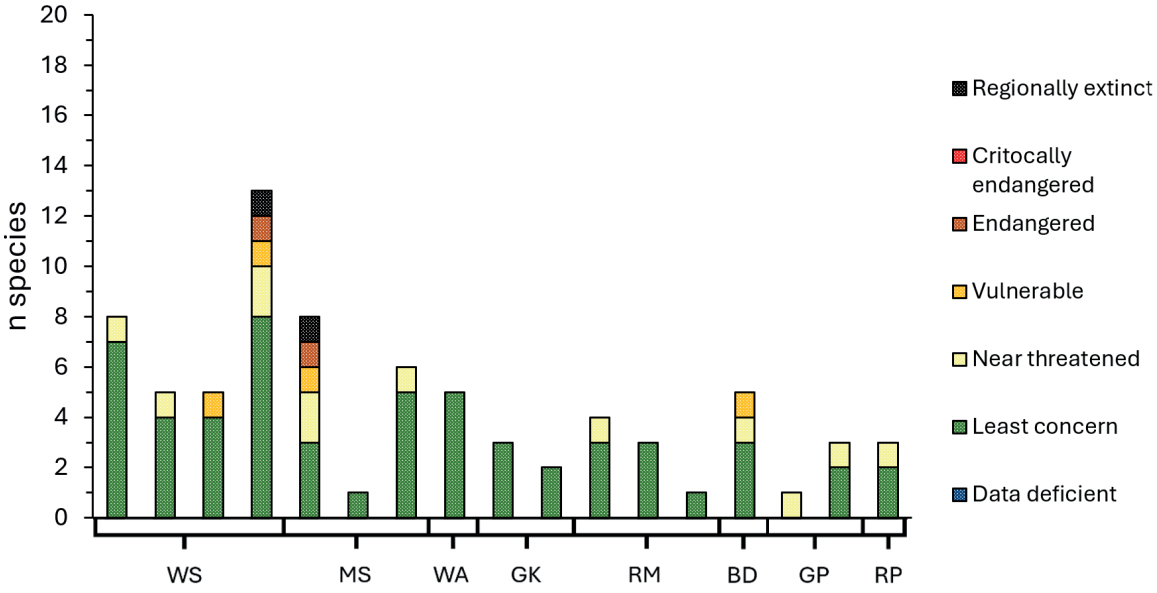


Fig. 6: Species numbers of the Heteroptera found in this study at every sampling site and their classification in the Red List of Heteroptera in Austria (WS = Sites on the Wildsee, MS = Mösersee, WA = Wildmoosalm, GK = Gschwandtkopf, RM = Reithermoor, BD = Beaverdam, GP = Golfponds and RP = Reservoir-pond).

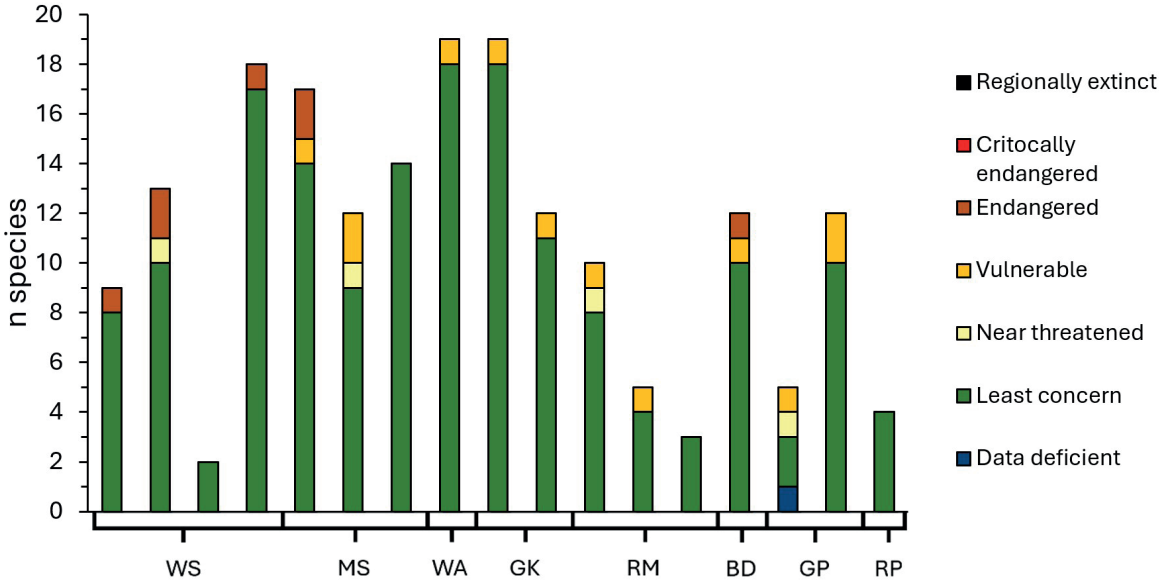


Fig. 7: Species numbers of the Coleoptera found in this study at every sampling site and their classification in the Red List of Coleoptera in Bavaria (with supplementary literature) (WS = Sites on the Wildsee, MS = Mösersee, WA = Wildmoosalm, GK = Gschwandtkopf, RM = Reithermoor, BD = Beaverdam, GP = Golfponds and RP = Reservoir-pond).

supported a small suite of ubiquitous taxa but also pioneer species. Golf course ponds, in contrast, harboured moderate species richness, benefiting from substantial riparian and aquatic vegetation; notably, several species typically associated with bogland habitats were present.

Relative to historical surveys, 12 heteropteran and 16 coleopteran species that were expected to be found were not recorded (Fig. 8). Missing heteropterans were mostly species of intermediate Red List status, e.g., *Callicorixa praeusta* (Fieber 1848), *Hesperocorixa moesta* (Fieber 1848), and *Notonecta obliqua* Thunberg 1787. Among the beetles, a greater proportion of high-ranking Red List taxa were absent, including "Critically Endangered" and "Endangered" species such as *Dytiscus latissimus*, *Rhantus notaticollis* (Aubé 1837), several *Hydroporus* spp., and *Nebrioporus elegans* (Panzer 1794). Most of the missing species are strongly dependent on *Sphagnum*-dominated, vegetation-rich, cool bog habitats (Koch 1989).

Some generalist species were also not rediscovered and sites of some detected species also declined. For example, *Nebrioporus assimilis* now persists at only a single site, whereas it was historically recorded from other locations like the Mösersee. Conversely, two species not previously documented in the region, *Dryops auriculatus* (Geoffroy 1785) and *Notonecta maculata* Fabricius 1794, were recorded for the first time. Both are more commonly associated with lowland or lower-latitude regions (Heiss 1971; Kahlen 1987; Koch 1989).

DISCUSSION

Despite the comparatively late onset of the early-summer survey period, the sampling likely captured the majority of the regional species pool within the phenological activity window, due to the high abundances found in some species (Bloechl et al. 2010; Strauss & Niedringhaus 2014; Spitzenberg & Malchau 2021). The relatively high elevation of the sampling area and cooler preceding weather conditions (Meteoblue 2025) may have prolonged phenological peaks. Also, the complementary autumn campaign coincided with the principal period of species detectability, which typically yields the highest species richness (Hill et al. 2016).

Most of the taxa present should have been detected by the multi-method sampling design (Bloechl et al. 2010; Iannuzzi et al. 2021). Nevertheless, stochasticity, narrow emergence windows, and occupation of cryptic habitats may account for the non-detection of some historically recorded species (Gotelli & Colwell 2001; Snell et al. 2017). Increasing sampling intensity or extending the temporal coverage (March–October) would improve completeness but at the cost of greater effort, reduced comparability with historical datasets and a higher loss of specimens of rare species from the waterbodies. Incorporating eDNA metabarcoding in future surveys could enhance detection accuracy and standardization (reviewed in Rishan et al. 2023).

This survey represents the first methodologically standardized investigation of aquatic beetle and bug diversity in the Seefeld Plateau region. Unlike recent surveys confined to designated Natura 2000 sites (e.g., Reithermoor) and the nature-monument lakes (Wild- and Mösersee), the present study covered a broader array of aquatic habitats, revealing a mosaic of still-water ecosystems that collectively contribute substantially to regional biodiversity. These habitats act both as ecological entities in their own right and as stepping-stone biotopes facilitating species dispersal across the landscape.

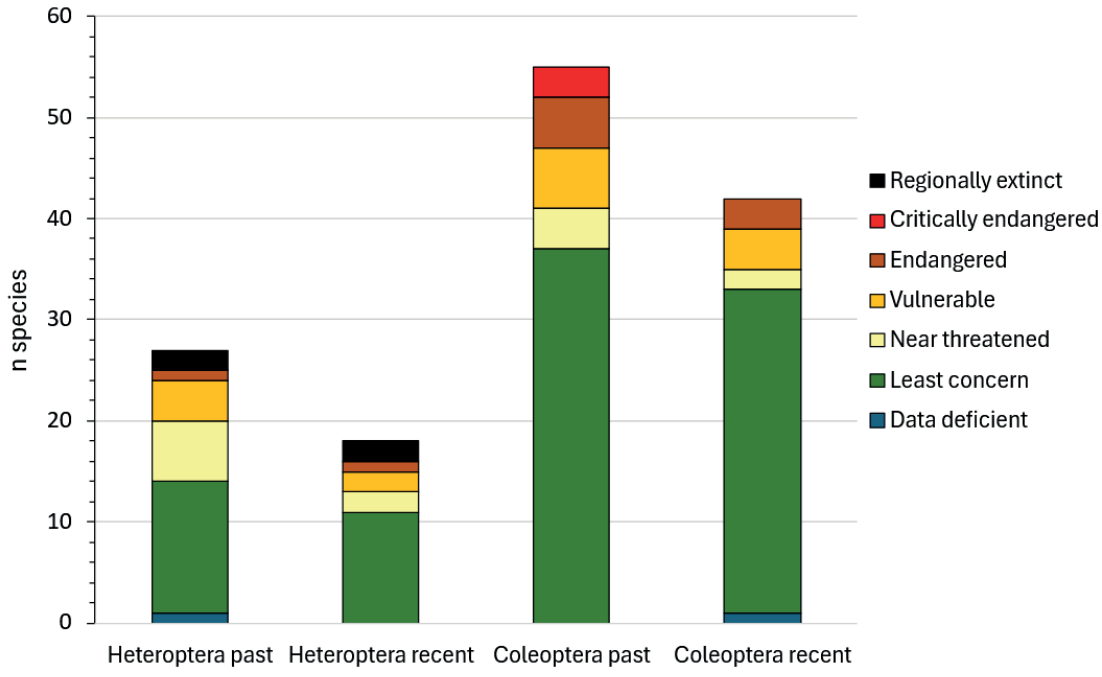


Fig. 8: Species numbers of the Coleoptera and Heteroptera found in the recent and previous surveys in the study area and their classification after the Red List of Heteroptera in Austria and Coleoptera in Bavaria (with supplementary literature). Due to methodological comparison only the species are displayed where a detection would have been expected in the past or recently.

Despite methodological differences between historical and present data, a general decline in species richness and the disappearance of ecologically demanding taxa are evident. This trend is most pronounced among species with intermediate or high ecological specialization, reflecting the homogenization of aquatic assemblages under anthropogenic pressures (Dudgeon et al. 2006; Roth et al. 2020). Several historically recorded water bug species with intermediate tolerance and a suite of beetles requiring structurally complex, *Sphagnum*-dominated habitats were not rediscovered.

On one hand, local absences may be attributed to emigration from later-successional waterbodies (Fairchild et al. 2000; Bloechl et al. 2010), or a population could drop below the detection threshold because of other factors such as disease, predation or resource pulses (Dettner & Peters 2010). On the other hand, the unsuccessful detection of a species might indicate either an extinct population or just a very small one vulnerable to extinction (reviewed in Mills 2007) due to alteration or loss of the habitat in the area (Bloechl et al. 2010; Roth et al. 2020; Grossart et al. 2023). Repeated surveys may rule out stochastic variations over time, but the past data and recent findings imply generally rather deteriorated conditions for the species' subsistence.

Variation among sites reflected environmental gradients, particularly fish stocking, littoral zone structure, and surrounding land use, all of which influence habitat availability, predation pressure, and water chemistry (Eyre & Foster 1989; Fairchild et al. 2000; Binckley & Resetarits 2005; Liao et al. 2020). Fish-stocking effects were most pronounced in the large, heavily managed lakes, where degraded littoral zones and dense fish populations corresponded with lower species richness and a shift toward mobile gerrids and ground-dwelling hydrophilids. Littoral simplification reduces breeding and pupation substrates (Klausnitzer 1996) and shelter from predation (Soldán et al. 2012; Gleason et al. 2018). Additionally, competitive interactions with fish for prey may further suppress populations of specialized taxa such as *Dytiscus latissimus*, whose larvae preferentially consume caddisfly larvae and a limited set of other aquatic invertebrates (Scholten et al. 2018). The larvae of *D. latissimus* prefer colder water temperatures (Scholten et al. 2018), so that rising temperatures could place them at a competitive disadvantage, further accelerating their decline. Besides this Habitat Directive species, the disappearance of the spring-associated *Nebrioporus assimilis* in the Möserersee also suggests direct habitat loss or transformation, particularly of some bog-like shallow water areas described in earlier surveys, which could not be located again.

Nevertheless, some remnant high-quality habitats persist along the littoral zones of both the Möserersee and Wildsee. Notably, the detection of *Hydroporus longulus* at the Möserersee shows the continued presence of cold, well-oxygenated spring-fed microhabitats. Also, the occurrences of some Donaciinae species and *Hydroporus obscurus* indicate areas with still intact aquatic vegetation and mire-like areas with bog communities (Koch 1989; Klausnitzer 1996). These findings demonstrate that recreational use of lakes can be compatible with conservation goals if riparian modifications are moderate and fish stocking is carefully managed. However, some smaller waterbodies stand out for their exceptional conservation value. This underlines the broader ecological importance of including non-protected and less noted habitats in biodiversity assessments.

The pond at Gschwandtkopf, despite its proximity to a gravel road, exhibits a good ecological condition. The main benefits are its isolation from agriculture, high elevation, and structural heterogeneity, supporting bog- and spring-associated specialists. The rediscovery of *Cymatia bonsdorffii*, typically linked to vertically structured habitats (Hess & Heckes 2021), in shallow, sunlit, vegetation-rich areas suggests that its ecological requirements may be more flexible under high-altitude, low-competition conditions. Such findings are important, as they underscore the role of geographic and climatic context in shaping the realised ecological niches of some aquatic insect species (reviewed in Robert 1959; Chen et al. 2024).

Similarly, artificial waterbodies such as golf course ponds can support demanding species of conservation interest when structurally intact, as evidenced by the presence of *Graphoderus zonatus* and *Corixa dentipes*. These findings emphasize the potential role of anthropogenic waterbodies in maintaining regional biodiversity.

The biogeographic setting of Tyrol, with its high-altitude terrain and relative isolation, may act as a refuge for species that are declining elsewhere in Central Europe (Heiss et al. 1969; Kahlen 1987; Strauss & Niedringhaus 2014; Rote Liste Zentrum 2025). Such local strongholds can play a pivotal role in conserving genetic diversity and ecological resilience (Dudgeon et al. 2006; Roth et al. 2020; Grossart et al. 2023).

At Wildmoosalm, the pond surveyed appears to be shaped more strongly by bogland conditions than that at Gschwandtkopf. However, unlike the latter, it is surrounded by pasture, and signs of eutrophication were evident. Although a high species richness was found, the fauna is also composed of tolerant generalists rather than true bog specialists. This raises concerns about potential long-term turnover, where habitat degradation leads to replacement of specialist taxa by more common species (Roth et al. 2020). Mitigation measures could include reduced grazing pressure and protective fencing.

The Reithermoor, despite its remaining bog character, supports a rather generalist aquatic community, likely reflecting elevated pH levels attributable to local limestone (Ampferer 1904; Rydin & Jeglum 2006). This suggests that factors beyond the bog itself, such as surrounding waterbodies (e.g., Wildsee, Haglbach), landscape context, *Phragmites*- and *Equisetum*-dominated vegetation, and stochastic colonisation events significantly shape local assemblages.

As shown in this study, artificial waterbodies and modified streams such as the Raabach can also play important roles in supporting aquatic biodiversity, provided they maintain or develop near-natural shoreline structures and sufficient habitat complexity (Bloechl et al. 2010; Roth et al. 2020; Liao 2022). While these systems may not support the most specialized species, they contribute substantially to the ecological network of the area, acting as corridors or stepping stones that enhance connectivity and resilience (Céréghino et al. 2008; Bloechl et al. 2010). They may even provide key habitats for rare or declining species (Fairchild et al. 2000; Pakulnicka 2008; Deacon et al. 2018).

CONCLUSION AND OUTLOOK

The Seefeld Plateau still harbours a network of relict habitats capable of sustaining specialist aquatic assemblages despite demonstrable habitat deterioration and the disappearance of numerous small wetlands. These habitats contribute to the stability of regional metapopulations and may facilitate recolonization events. However, exogenous drivers such as atmospheric nutrient deposition and climate warming cannot be mitigated locally (Dudgeon et al. 2006; Schindler 2006; Roth et al. 2020). At the waterbody scale, targeted management actions can yield tangible ecological benefits, including:

Shoreline restoration: Where compatible with recreational use, gently sloping, vegetated banks should be restored. Compromise solutions can enhance both aesthetic value and habitat quality, particularly when linked to species-rich meadows or charismatic taxa (e.g., *Donacia* spp., *Dytiscus marginalis*) that engage public interest (Serjeant 2013).

Reduced or adapted fish stocking: In particular, shallow littoral zones should remain free of heavy stocking, especially with disruptive species like large cyprinids or predatory perch (Binckley & Resetarits 2005; Hendrich & Gebert 2025).

Creation and care of artificial ponds: As demonstrated by the Gschwandtkopf overflow basin, artificial waterbodies can function as ecological stepping stones or long-term refugia for rare species when structurally intact and appropriately managed (Pakulnicka 2008; Deacon et al. 2018; Liao et al. 2020; Roth et al. 2020).

Passive rewilding: Rather than constructing artificial habitats, natural succession in zones like lake edges should be allowed where possible. Yet, outcomes are not fully predictable due to stochastic colonisation and habitat filtering effects (Pakulnicka et al. 2013; Pintar & Resetarits 2020).

This study can be viewed as a baseline for a structured monitoring programme covering the plateau and, more broadly, Alpine and Tyrolean freshwater biodiversity. Also, future research should explore tourism-compatible conservation frameworks that integrate recreational use with long-term ecosystem integrity, ensuring that human interaction with aquatic habitats supports rather than undermines regional biodiversity.

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Appendix 1: Total species list

Total species list of the target taxa in the study area. Given is the taxonomic affiliation as far as possible to determine. Additionally given is the Red-List-Status of each species (RL) and the number of caught individuals (Num.). The Red-List-Status in coded with DD = "Data deficient" LC = "Least concern" NT = "Near threatened" VU = "Vulnerable" EN = "Endangered" CR = "Critically Endangered" and RE = "Regionally Extinct".

Family/Taxa	Species/Taxa	RL	Num.
Adult			
Heteroptera			
Gerridae	*Aquarius paludum* (Fabricius 1794)	LC	1
	Gerris lacustris (Linnaeus 1758)	LC	31
	Gerris odontogaster (Zetterstedt 1828)	NT	17
	Gerris argentatus Schummel 1832	LC	1
Veliidae	*Microvelia reticulata* (Burmeister 1835)	LC	13
	Velia caprai Tamanini 1947	LC	2
Corixidae	*Arctocorisa carinata* (C.R. Sahlberg 1819)	VU	2
	Cymatia coleoptrata (Fabricius 1777)	LC	11
	Cymatia bonsdorffi (C.R. Sahlberg 1819)	RE	6
	Corixa dentipes Thomson 1869	NT	9
	Corixa punctata (Illiger 1807)	LC	1
	Hesperocorixa sahlbergi (Fieber 1848)	LC	36
	Sigara nigrolineata (Fieber 1848)	LC	29
	Sigara distincta (Fieber 1848)	LC	11
	Sigara semistriata (Fieber 1848)	RE	5
	Sigara striata (Linnaeus 1758)	LC	1
Notonectidae	*Notonecta glauca* Linnaeus 1758	LC	20
	Notonecta viridis Delcourt 1909	LC	7
	Notonecta maculata Fabricius 1794	LC	2
	Notonecta lutea Müller 1776	VU	4
	Notonecta reuteri Hungerford 1928	EN	3
Pleidae	*Plea cryptica* (Raupach Charzinksi et Hendrich 2024)	LC	14
Nepidae	*Ranatra linearis* (Linnaeus 1758)	LC	1
	Nepa cinerea Linnaeus 1758	LC	1
Coleoptera			
Haliplidae	*Haliplus confinis* Stephens 1828	VU	16
	Haliplus flavicollis J. Sturm 1834	LC	1
	Haliplus lineatocollis (Marsham 1802)	LC	7
	Haliplus heydeni Wehncke 1875	LC	71
	Haliplus sibiricus Motschulski 1860	LC	7
	Haliplus obliquus (Fabricius 1787)	LC	2
	Haliplus ruficollis (DeGeer 1774)	LC	36
Noteridae	*Noterus clavicornis* (DeGeer 1774)	LC	3

Dytiscidae	*Rhantus suturalis* (W. S. MacLeay 1825)	LC	6
	Rhantus exsoletus (Forster 1771)	LC	15
	Laccophilus minutus (Linnaeus 1758)	LC	1
	Hydaticus seminiger (DeGeer 1774)	LC	48
	Dytiscus marginalis Linnaeus 1758	LC	105
	Acilius sulcatus (Linnaeus 1758)	LC	28
	Graphoderus zonatus Hoppe 1795	EN	19
	Ilybius fuliginosus (Fabricius 1792)	LC	2
	Agabus affinis (Paykull 1798)	LC	3
	Agabus bipustulatus (Linnaeus 1767)	LC	20
	Agabus congener (Thunberg 1794)	VU	7
	Agabus paludosus (Fabricius 1801)	LC	3
	Agabus sturmii (Gyllenhal 1808)	LC	21
	Agabus undulatus (Schrank 1776)	LC	23
	Hygrotus inaequalis (Fabricius 1777)	LC	65
	Hygrotus impressopunctatus (Schaller 1783)	LC	1
	Nebrioporus assimilis (Paykull 1798)	EN	13
	Nectoporus sanmarkii (C.R. Sahlberg 1826)	LC	1
	Hydroporus erythrocephalus (Linnaeus 1758)	LC	39
	Hydroporus memnonius Nicolai 1822	LC	2
	Hydroporus obscurus J. Sturm 1835	VU	4
	Hydroporus palustris (Linneaus 1760)	LC	94
	Hydroporus nigrita (Fabricius 1792)	LC	4
	Hydroporus longulus Mulsant et Rey 1860	VU	3
	Hydroporus tristis (Paykull 1798)	LC	1
	Graptodytes pictus (Fabricius 1787)	LC	6
	Hyphydrus ovatus (Linnaeus 1760)	LC	19
Hydrophilidae	*Helochares obscurus* (O.F. Müller 1776)	LC	1
	Cercyon impressus (J. Sturm 1807)	LC	1
	Cercyon sternalis (Sharp 1918)	DD	2
	Coelostoma orbiculare (Fabricius 1775)	LC	4
	Hydrobius fuscipes (Linnaeus 1758)	LC	15
	Enochrus affinis (Thunberg 1794)	LC	1
	Enochrus ochropterus (Marsham 1802)	LC	5
	Anacaena lutescens (Stephens 1829)	LC	40
	Laccobius minutus (Linnaeus 1758)	LC	3
	Laccobius bipunctatus (Fabricius 1775)	LC	18
Hydraenidae	*Hydraena melas* Dalla Torre 1877	LC	5
Scirtidae	*Contacyphon coarctatus* (Paykull 1799)	LC	1
	Contacyphon variabilis (Thunberg 1787)	LC	2
Elmidae	*Limnius perrisi* (L. Dufour 1843)	LC	3
Dryopidae	*Dryops ernesti* Gozis 1886	LC	6
	Dryops auriculatus (Goffroy 1785)	LC	3
	Dryops nitidulus (Heer 1841)	LC	1
Chrysomelidae	*Plateumaris rustica* (G. Kunze 1818)	NT	3
	Plateumaris sericea (Linnaeus 1761)	EN	1
	Donacia clavipes Fabricius 1792	VU	2
	Donacia versicolorea (Brahm 1790)	NT	4

Curculionidae	*Bagous frit* (Herbst 1795)	EN	1
Larvae			
Heteroptera			
Gerridae	*Aquarius paludum* (Fabricius 1794)	LC	4
	Gerris odontogaster (Zetterstedt 1828)	NT	4
	Gerris lacustris (Linnaeus 1758)	LC	15
Corixidae	*Cymatia coleoptrata* (Fabricius 1777)	LC	3
	Corixa dentipes Thomson 1869	NT	3
	Hesperocorixa sahlbergi (Fieber 1848)	LC	10
	Sigara nigrolineata (Fieber 1848)	LC	1
	Sigara distincta (Fieber 1848)	LC	11
Coleoptera			
Dytiscidae	*Rhantus exsoletus* (Forster 1771)	LC	1
	Dytiscus marginalis Linnaeus 1758	LC	58
	Graphoderus zonatus Hoppe 1795	EN	4
	Agabus affinis (Paykull 1798)	LC	1
	Agabus bipustulatus (Linnaeus 1767)	LC	1
	Agabus sturmii (Gyllenhal 1808)	LC	3
	Hyphydrus ovatus (Linnaeus 1760)	LC	8

Appendix 2: Bycatch total species list

Total species list of the bycatch in the study area. Given is the taxonomic affiliation as far as possible to determine and the Number of caught individuals (Num.)

Family/Taxa	**Species/Taxa**	**Num.**
Adult		
Gastropoda		
fam.	gen. sp.	16
Arionidae	gen. sp.	82
Helicidae	*Cepaea nemoralis* (Linnaeus 1758)	1
Annelida		
fam.	gen. sp.	3
Hirundinea		
fam.	gen. sp.	3
Isopoda		
Trichonoscidae	gen. sp.	7
Porcellidae	gen. sp.	134
Acari		
fam.	gen. sp.	12
Araneae		
Gnaphosidae	gen. sp.	3
Lycosidae	gen. sp.	31
Linyphiidae	gen. sp.	30
Opiliones		
fam.	gen. sp.	3
Chilopoda		
Lithobiidae	gen. sp.	1

Diplopoda		
Glomeridae	gen. sp.	4
Julida	gen. sp.	3
Polydesmidae	gen. sp.	7
Collembola		
fam.	gen. sp.	>100
Odonata		
Coenagrionidae	*Coenagrion hastulatum* (Charpentier 1825)	1
Plecoptera		
Leuctridae	gen. sp.	2
Sternorrhyncha		
fam.	gen. sp.	1
Auchenorrhyncha		
Cicadellidae	*Cicadella viridis* (Linnaeus 1758)	1
Heteroptera		
Rhyparochromidae	gen. sp.	1
Caelifera		
Agrididae	gen. sp.	1
Hymenoptera		
Symphyta	gen. sp.	1
Ampulicidae	*Dolichurus corniculus* (Spinola 1808)	1
Formicidae	*Myrmica rubra* (Linnaeus 1758)	14
	Formicinae	>1000
Ichneumonidae	gen. sp.	1
Coleoptera		
Carabidae	Dyschirius globosus (Herbst 1784)	1
	Agonum thoreyi Dejean 1828	4
	Agonum fuliginosum (Panzer 1809)	16
	Agonum viduum (Panzer 1796)	10
	Chlaenius nigricornis (Fabricius 1787)	4
	Pterostichus rhaeticus Heer 1837	3
	Pterostichus diligens (Sturm 1824)	5
	Pterostichus minor (Gyllenhal 1827)	1
Staphylinidae	gen. sp.	1
	Stenus pubescens Stephens 1833	1
	Stenus juno (Paykull 1789)	4
	Stenus bifoveolatus Gyllenhal 1827	1
	Stenus bimaculatus Gyllenhal 1810	2
	Stenus cicindeloides (Schaller 1783)	1
	Xantholinus laevigatus Jacobsen 1849	1
	Staphylinus erythropterus Linnaeus 1758	9
	Anotylus rugosus (Fabricius 1775)	2
	Pella limbata (Paykull 1789)	1
	Quedius fuliginosus (Gravenhorst 1802)	1
Nitidulidae	*Meligethes* sp.	1
Tenebrionidae	*Nalassus convexus* (Comolli 1837)	1
Histeridae	gen. sp.	1
Chrysomelidae	gen. sp.	2

Curculionidae	gen. sp.	1
	Otiorhynchus ovatus (Linnaeus 1758)	1
	Phyllobius arborator (Herbst 1797)	2
	Phyllobius viridicollis (Fabricius 1792)	1
	Limnobaris dolorosa (Goeze 1777)	1
Apionidae	*Perapion marchicum* (Herbst 1797)	1
Diptera		
fam.	gen. sp.	1
Nematocera	gen. sp.	5
Tipulidae	gen. sp.	8
Psychodidae	gen. sp.	1
Brachycera	gen. sp.	1
Sciomyzidae	cf. Limnia sp.	1
Dolichopodidae	gen. sp.	2
Calliphoridae	gen. sp.	7
Larvae		
Odonata		
Aeshnidae	*Aeshna grandis* (Linnaeus 1758)	1
Ephemeroptera		
fam.	gen. sp.	1
Hemiptera		
fam.	gen. sp.	1
Megaloptera		
Sialidae	*Sialis lutaria* (Linnaeus 1758)	1
Trichoptera		
Phryganeidae	*Agrypnia picta* Kolenati 1848	1
	Phryganea bipunctata Retzius 1783	1
Leptoceridae	gen. sp.	1
Baereidae	*Beraea pullata* (Curtis 1834)	1
	Ernodes vicinus (McLachlan 1879)	1
Limnephilidae	gen. sp.	40
Adephaga		
Adephaga	gen. sp.	2
Diptera		
fam.	gen. sp.	1
Ceratopogonidae	gen. sp.	5
Psychodidae	gen. sp.	4
Tipulidae	gen. sp.	1
Stratiomyidae	gen. sp.	13
Dolichopodidae	gen. sp.	2
Pediciidae	gen. sp.	2
Pupa		
Ord.		
fam.	gen. sp.	1

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