TECHNISCHE
UNIVERSITÄT
DRESDEN

Faculty of Environmental Sciences

Life cycles and secondary production of Ephemeroptera, Plecoptera, and Trichoptera (Insecta) under an extreme continental climate (River Kharaa, Mongolia)

Dissertation for awarding the academic degree
Doctor rerum naturalium (Dr. rer. nat.)

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Dresden, 2013

Defense date: 12 December 2013

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„Life cycles and secondary production of Ephemeroptera, Plecoptera, and Trichoptera (Insecta) under an extreme continental climate (River Kharaa, Mongolia)“

Magdeburg, 24.05.2013
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Acknowledgements

The thesis described here was performed within the research and development project 'Integrated Water Resources Management in Central Asia: Model Region Mongolia' (IWRM-MoMo) funded by the German Ministry of Education and Research (BMBF Grant 0033L003A) under the "Research for Sustainability" Programme and supported by the German Academic Exchange Program-DAAD (A/07/99089).

Foremost, I owe my deepest gratitude to my supervisor Prof. Dr. Dietrich Borchardt for giving me the chance to accomplish my Ph.D research under his supervision. He opened the door for me to find the diverse cultural environment of researchers and students and enjoyable scientific atmosphere at the Center for Environmental Systems Research (CESR), University Kassel and at the Department of Aquatic Ecosystem Analysis and Management (ASAM) at the Helmholtz Centre for Environmental Research (UFZ) in Magdeburg. I thank him especially for introducing me to the scientific branch known as aquatic ecology. Also for his assistance in my understanding of Mongolia's unique ecological conditions in running water ecosystems and how different they are in Mongolia compared to European conditions. Further, special thanks for his time and countless hours of scientific discussions and proofreading of my research article and thesis.

I also extend my sincere thanks to Dr. Ch. Javzan from the Institute of Geoecology, Mongolian Academy of Science and Prof. Dr. R. Samiya, and Prof. Dr. N. Soninkhishig from the National University of Mongolia for giving me the opportunities to work in this research field, encouraging my ideas and accepting my requests.

I am indebted to all my current and former colleagues at CESR and UFZ including Daniel, Madlen, Philipp, Ralf, Rehan and other colleagues in the ASAM group for their friendship and encouragement. I am grateful to Melanie Hartwig and Michael Schäffer for the translation of my theses and summary into German and Andrew Kaus and Philipp Theuring for helping me correct my writing in English. I am very thankful to Michael Schäffer and Mario Brauns for the review of my thesis and giving valuable comments. I would like to express my special thanks to my handling supervisor, colleague and friend Michael Schäffer. I have got uncountable and invaluable knowledge from him. He accompanied me working in the field, analyzing the samples in the laboratory, analyzing the data and writing the research article. Beside the research work, he has shared in my happiness, troubles and sorrows.

Further, I would like to express my appreciation to Ts. Batchuluun and N. Natsagnyam, A. Jargal, Emee, Zorigoo as well as several Mongolian students for their help during the expeditions and laboratory analysis. I sincerely thank B. Byambajav and Ts. Otgonkhuu and I call them as sisters. Thank you very much for your moral support and patience when I have expressed different personal characteristics of mine. I also wish to thank all of my friends for being there for me when I needed them; they all know who they are.

Finally, and most importantly, my deepest appreciation and love to my parents, my sister and brother. I would never reach this far in my academic career without the support of my parents. I dedicate this dissertation to my sister Erkyegul, you are in my heart every day since you left us. I am never disillusioned from my deepest hope to meet you again one day.

Theses

1. Since the 1990s water quality monitoring projects using aquatic insects or macroinvertebrates as bioindication in Mongolia has mostly occurred in rivers drainage to the Arctic Ocean. They have been conducted to identify different anthropogentic stressors and impacts upon these running water ecosystems. However, there are still knowledge gaps and uncertainties concerning the research of these macroinvertebrates, in particular, a life cycle study of representative species are one such section of information missing. Therefore, this study was conducted within the framework of the biomonitoring program in the Kharaa River Basin under the research aims of the project entitled 'Integrated Water Resources Management (IWRM) in Central Asia: Model Region Mongolia (MoMo)'.

2. The specific aim for the study was to determine their life cycles and secondary production of selected species in the Kharaa River Basin, Mongolia, where these animals are exposed to harsh environment conditions. Mongolia's climate is characterised by long, dry and cold winters and hot summers with low precipitation and a high number of clear, sunny days per year. An important hydrological characteristic of the Kharaa River is the occurrence of complete ice coverage from November to April. The seasonal variation in the Kharaa River has been documented by the continuous air and water temperature recordings during the sampling years of 2007 - 2009. Another character of the Kharaa River is the substrate composition which changes substantially from upstream to downstream.

3. The main challenges for the research project were selecting the most suitable methods for use in the field sampling campaigns as well as establishing biomonitoring criteria for the target species under the extreme harsh climatic conditions. The research also sorts to address the pre-existing taxonomical identification problems. Consequently, a multi-habitat quantitative sampling method, and emergence traps type 'Model week' were selected. Five specific traits were chosen as selection criteria from the literature, where the life cycles of numerous species were investigated under comparable conditions to this study. Based on those five distinct criteria, a total of 18 species from EPT group (Ephemeroptera, Plecoptera, and Trichoptera) were selected for deeper analysis.

4. The main purpose of this study was to provide basic autecological information of 18 EPT species in the Kharaa River Basin, Mongolia, focusing on *(i)* larval and emergence densities, *(ii)* life cycle periods, and *(iii)* secondary production and growth rates. The key hypothesis was to test whether or not EPT species in the Kharaa River have special adaptations to survive the harsh winter conditions in Mongolia and reduced secondary production. Diverse life cycles and estimations of density, secondary production and growth rates from field data showed a wide spectrum of structural responses to a variety of natural and anthropogenic stressors in the aquatic ecosystem.

5. The 3-year study (2007-2009) of the life cycles of eighteen selected species according to the larval body size distribution and emergence period showed five different life cycle types including strict univoltinism, a flexible life cycle, a short and a long life cycle. The results of these life cycles for the selected 18 species and their development periods were compared to other studies at different taxonomical levels. However, a comparison at a species level was only possible for one macroinvertebrate (Ephemeroptera: *Ephemera orientalis*) within the literature available. On the one hand, it indicated a characteristic biogeographic distribution of these species; while on the other hand, it illustrated a knowledge gap within the species description. Considering the above mentioned hypothesis, *Ephemera orientalis* had a flexible life cycle that displayed an extended larval development period in the Kharaa River.

6. The production parameters were available to estimate the total of 15 species based on data from one year of sampling. The estimated annual productions of larvae at three investigated sites in the upper and middle stretches of the river in the year 2009 was in the range from 0.08 g DW m^{-2} y^{-1} to 18.7 g DW m^{-2} y^{-1}. Biomass was in the range from 10.6 mg DW m^{-2} to 907.8 mg DW m^{-2}, and the annual production to biomass rate (P/B) was in the range from 0.6 y^{-1} to 23.5 y^{-1} respectively. The value from the secondary production estimates from 13 species was lower than pre-determined criteria for low production (5.4 g DW m^{-2} y^{-1}). The growth rates were calculated only for univoltine summer and winter cycle species. According to the general classification of growth rate for macroinvertebrates, all univoltine winter cycle species were classified as species with a low growth rate (up to 1.4% day^{-1}) and univoltine summer cycle species were slightly higher than the criteria range.

7. This thesis provided the first quantitative results on the life cycle, production, growth rate and emergence of aquatic insects from Mongolia, to allow comparisons with studies in other regions using the same methods. However, it still needs more quantitative research of population dynamics for a wider range of species including fecundity, accurate development rates, mortality losses (e.g., due to predation), and food availability across environmental gradients of hydraulic conditions and substrate types. In particular, an intensive investigation on a smaller spatial scale is essential to be carried out. In order to quantify fecundity and development rates it is essential to develop new methods of sampling eggs and earliest instar larvae in the field and to conduct laboratory experiments.

8. In conclusion, autecological information of aquatic insects in the river systems under the extreme continental climate is essential knowledge to interpret the biological assessment data. Considering the urgent need of management measures in disturbed or endangered aquatic ecosystems due to the current development in the urbanisation, agricultural and mining sectors and pending climate change effects, the importance of the development of integrated biological invertebrate traits for the assessment of stressor effects on running water ecosystems in Mongolia appears crucial. Last not least it is essential to obtain knowledge especially about life cycle strategies of macroinvertebrates to identify the

indicator-properties of single species and to predict re-colonisation potential of disturbed habitats and to evaluate the efficiency of management measures.

Thesen

1. Seit den 1990er Jahren wird in der Mongolei Biomonitoring anhand von aquatischen Makroinvertebraten hauptsächlich in Flussgebieten durchgeführt, die zum Arktischen Ozean entwässern. Dabei lag der Fokus auf der Identifizierung von anthropogenen Stressoren in diesen Fließgewässer-Ökosystemen. Allerdings existieren immer noch Wissenslücken und Unsicherheiten bezüglich der Ökologie wichtiger Indikatorganismen, wobei insbesondere die Lebenszyklen repräsentativer Arten unbekannt sind. Um diese Wissenlücken zu schließen, wurde die vorliegende Studie im Einzugsgebiet des Kharaa im Norden der Mongolei im Rahmen des Biomonitoring-Programmes des Projektes „Integriertes Wasserressourcen-Management (IWRM) in Zentralasien: Modellregion Mongolei (MoMo)" durchgeführt.

2. Zentraler Inhalt dieser Untersuchung ist die Bestimmung der Lebenszyklen ausgewählter aquatischer Insektenarten sowie deren Sekundärproduktion im Einzugsgebiet des Kharaa in der Mongolei, wo diese Tiere extremen Umweltbedingungen ausgesetzt sind. Das mongolische Klima ist charakterisiert durch lange, trockene und kalte Winter und heiße Sommer mit geringen Jahresniederschlagsmengen und einer hohen Zahl an wolkenfreien, sonnigen Tagen. Als weitere hydrologische Bedeutsamkeit des Kharaa Flusses ist die komplette Eisbedeckung von November bis April anzuführen. Die saisonale Variabilität wurde durch kontinuierliche Messung von Luft- und Wassertemperatur in den Jahren 2007-2009 erfasst. Außerdem zeigte sich eine sich im Längsverlauf des Kharaa eine charakteristische Verschiebung der Substratzusammensetzung.

3. Große Herausforderungen innerhalb dieser Untersuchung lagen in der Auswahl von geeigneten Methoden für die Feldbeprobungen sowie die Etablierung von Kriterien für die Zielarten für ein Biomonitoring unter den rauen klimatischen Bedingungen. Auch widmete sich die Arbeit bereits vorhandenen taxonomischen Bestimmungsschwierigkeiten. Folglich wurde eine Kombination aus einem quantitativen Multi-Habitat-Sampling und Emergenzfängen mittels Emergenzfallen „Modell Week" gewählt. Basierend auf den Auswahlkriterien vergleichbarer Untersuchungen zu den Lebenszyklen vergleichbarer Arten unter ähnlichen Bedingungen wurden fünf spezifische Kriterien ausgewählt und dienten dazu, 18 EPT-Arten (Ephemeroptera, Plecoptera, Trichoptera) als geeignet einzugrenzen.

4. Hauptgegenstand der Untersuchung war es dann autökologische Informationen der ausgewählten 18 EPT-Arten aus dem Kharaa zu erarbeiten. Dabei waren besonders *(i)* die Larvendichten, *(ii)* die Stadien der Lebenszyklen sowie *(iii)* die Sekundärproduktion und Wachstumsraten von Interesse. Die zentrale Hypothese war es, zu testen ob EPT-Arten im Fluss Kharaa spezielle Anpassungen, um die harten Winterbedingungen in der Mongolei zu überleben, sowie eine reduzierte Sekundärproduktion haben. Anhand der Analyse der diversen Lebenszyklen und der Abschätzung von Larvendichten, Sekundärproduktion und Wachstumsraten aus den Freilanddaten konnten ein weites

Spektrum von strukturellen Antworten auf verschiedene Stressoren im aquatischen Ökosystem des Kharaa identifiziert werden.

5. Im Ergebnis der 3-jährigen Untersuchung der Lebenszyklen von 18 ausgewählten Arten (2007 bis 2009) hinsichtlich von Längen-Häufigkeitsverteilung der Larven und der Emergenzperiode konnten fünf unterschiedliche Lebenszyklen-Typen identifiziert werden, wobei sowohl strikter Univoltinismus (eine Generation pro Jahr), flexible Zyklen als auch verkürzte oder verlängerte Zyklen zu beobachten waren. Diese Ergebnisse wurden mit anderen publizierten Ergebnissen auf unterschiedlichem taxonomischen Niveau verglichen. Ein Vergleich auf Artniveau war nur für eine Art möglich (*Ephemera orientalis*, Ephemeroptera), für alle anderen waren keine Literaturangaben verfügbar. Einerseits wurde dadurch die charakteristische biogeographische Verbreitung dieser Arten deutlich, andererseits wurde dadurch der lückenhafte Kenntnisstand innerhalb der Artbeschreibungen untermauert. Unter Berücksichtigung der zuvor genannten Hypothese zeigte *Ephemera orientalis* einen flexiblen Lebenszyklus mit verlängertem Larvalstadium im Fluss Kharaa.

6. Aufgrund der Datenlage aus dem letzten Probenahmejahr mit engermaschigem Probenahmeraster konnten die Produktionsparameter für 15 Arten abgeschätzt werden. Die jährliche Produktion an den drei Untersuchungsstellen im Ober- und Mittellauf des Kharaa schwankte im Jahr 2009 zwischen 0.08 g DW m^{-2} y^{-1} und 18.7 g DW m^{-2} y^{-1}. Die Biomasse bewegte sich zwischen 10.6 mg DW m^{-2} und 907.8 mg DW m^{-2} beziehungsweise das Verhältnis von jährlicher Produktion zur Biomasse (P/B) zwischen 0.6 y^{-1} und 23.5 y^{-1}. Die Abschätzung der Sekundärproduktion ergab bei 13 Arten geringere Werte als für Arten mit geringer Produktion in der Literatur beschriebenen wird (5.4 g DW m^{-2} y^{-1}). Die Wachstumsraten wurden für die Arten mit einjährigem Generationszyklus berechnet, unabhängig davon, ob es sich um einen Sommer- oder, Winterzyklus handelte. Unter Berücksichtigung der generellen Klassifikation für aquatische Insekten zeigten alle Arten mit einem univoltinen Winterzyklus geringe Wachstumsraten (< 1,4 % d^{-1}).

7. In dieser Arbeit wurden erstmals für die Mongolei quantifizierte Ergebnisse der Lebenszyklen, Produktion, Wachstumsraten und Emergenz von aquatischen Insekten veröffentlicht. Diese legen ein Grundlage für einen Vergleich mit ähnlichen Untersuchungen in anderen Regionen. Allerdings bedarf es immer noch einer Reihe von quantitativen Untersuchungen zur Populationsdynamik für eine größere Artenzahl, die auch die Bestimmung von Fekundität, exakten Entwicklungsraten, Mortalitätsverlusten (z.B. durch Prädation) und Nahrungsverfügbarkeit beinhalten, und Abhängigkeit von hydraulischen Umweltgradienten und Substrattypen. Insbesondere ist es dabei erforderlich, intensive Untersuchungen auf kleinerer räumlicher Skala durchzuführen. Um Fekundität und Entwicklungsraten exakt zu quantifizieren, ist es einerseits notwendig, dass neue Methoden zum Aufsammeln von Eiern und ersten Larvenstadien im Freiland entwickelt und angewendet werden, andererseits sind zusätzliche Laborexperimente erforderlich.

8. Schlussfolgernd kann gesagt warden, für die Interpretation von biologischen Bewertungsdaten sind autökologische Informationen über aquatische Insekten in Flussgebieten unter dem Einfluss von extremen, kontinentalen Klimabedingungen unerlässliches Basiswissen. Berücksichtigt man die dringliche Notwendigkeit von Managementmaßnahmen in gestörten bzw. gefährdeten aquatischen Ökosystemen durch die derzeitigen rasanten Entwicklungen mit einhergehender Urbanisierung, dem Ausbau des Landwirtschafts- und des Bergbau-Sektors sowie bevorstehenden Klimawandeleffekten, wird die große Bedeutung der Erarbeitung von integrierten biologischen traits von aquatischen Invertebraten zur Bewertung von Stressoren in Fließgewässer-Ökosystemen der Mongolei deutlich. Nicht zuletzt ist besonders die Kenntnis der Lebenszyklen von Makroinvertebraten unerlässlich, um die Indikatoreigenschaften einzelner Arten zu identifizieren, das Wiederbesiedlungspotential von gestörten Habitaten abzuschätzen und die Effizienz von Managementmaßnahmen zu beurteilen.

Theses in Mongolian: Диссертацийн хураангуй

1. Монгол оронд усны шавжаар усны чанарыг үнэлэх судалгааны ажлууд 1990-ээд оноос хойш, ихэвчлэн Хойд мөсөн далайн ай савд хамаарагдах урсгал усны экосистемд үзүүлэх сөрөг хүчин зүйлийн нөлөөлөлүүдийг тогтоох зорилгын дор хийгдсэн байна. Гэвч макросээрнуруугүйтэний талаархи эрдэм шинжилгээний ажлуудад дутагдалтай талууд, мэдлэгийн цоорхой ажиглагдсаар байх ба төлөөлөл зүйлүүдийн амьдралын эргэлт дэх судалгаа нь энэхүү цоорхойг бөглөх нэгэн ажил болж чадах юм. Иймд “Төв Азийн Усны Нөөцийн Нэгдсэн Менежмент: Загвар бүс Нутаг Монгол (MoMo)” төслийн зорилтуудын нэг болох биомониторингийн хөтөлбөрийн хүрээнд энэхүү судалгааны ажлыг явуулсан болно.

2. Хараа голын сав газар дахь эрс тэс уур амьсгал, хүрээлэн буй орчны хүчин зүйлийн нөлөөний дор оршин байгаа зүйлүүдийн амьдралын эргэлт, хоёрдогч бүтээмжийг тодорхойлох нь энэ судалгааны ажлын онцлог байв. Нэн урт, хуурай, хүйтэн өвөл, халуун зун, хур тунадасны хомсдол, жилийн нартай өдрийн тоо харьцангуй өндөр зэрэг нь Монгол орны уур амьсгалын онцлогийг бүрэлдүүлдэг. Хараа голын усзүйн чухал шинж чанар гэвэл 11 дүгээр сараас 4 дүгээр сарыг хүртэл үргэлжлэх мөсөн бүрхүүлийн тогтоц юм. Хараа гол дахь улиралын өөрчлөлтийг агаарын болон усны температурын тогтмол хэмжилтээр илэрхийлсэн. Голын эхээс адаг хүртэлх голын ёроолын хурдасны огцом өөрчлөлт нь Хараа голын бас нэг онцлог болдог.

3. Уг судалгааны ажлын гол шаардлага нь хээрийн судалгааны хамгийн тохиромжит арга зүйг сонгох, эрс тэс уур амьсгалын нөхцөл дор оршин амьдрах төлөөлөл зүйлийг сонгох шалгуурыг үндэслэх байв. Түүнчлэн энэ судалгааны ажлыг гүйцэтгэхэд тулгарсан бас нэгэн хүндрэлтэй тал бол бүрэн тодорхойлогдоогүй ангилал зүйн судалгааны асуудал байлаа. Эдгээрийг авч хэлэлцсэний дүнд олон төрлийн орчны тооны дээж авах арга зүй, бие гүйцсэн шавжийн судалгааны “Долоо хоног Загвар” торыг сонгосон. Тус судалгааны ажлын онцлог нөхцлүүд болон олон тооны зүйлийн амьдралын эргэлтийг тодорхойлсон бусад судалгааны ажлуудад өгөгдсөн шалгууруудад тулгуурлан таван төрлийн шалгуурыг үндэслэв. Эдгээр шалгууруудад суурилж EPT (Ephemeroptera, Plecoptera, Trichoptera) бүлгийн нийт 18 зүйлийг сонгосон.

4. Монгол орны Хараа голын сав газар дахь 18 EPT зүйлийн аутэкологийн суурь мэдээлэлийг олгох үндсэн зорилгын хүрээнд *(i)* авгалдайн болон бие гүйцсэн бодгалиудын нягтшил, *(ii)* амьдралын эргэлтийн хугацаа, *(iii)* хоёрдогч бүтээмж болон өсөлтийн эрчмийг тогтоох зорилтуудыг тодорхойлон ажилласан. Энэхүү эрс тэс уур амьсгалын нөхцөл нь эдгээр зүйлүүдийн өвлийн улиралын даван туулах онцлог зохилдлогоотой болох, хоёрдогч бүтээмжээ бууруулах нөхцөл болдог хэмээх үндсэн таамаглалыг дэвшүүлж, шалган тогтоосон. Амьдралын эргэлтийн олон янз байдал, нягтшил, хоёрдогч бүтээмж, өсөлтийн эрчмийг тодорхойлоход

хээрийн судалгааны үр дүн, мэдээлэлийг ашиглах нь бүтцийн өргөн цар хүрээтэй хариу үйлчлэл, цаашлаад усан орчны экосистем дэх сөрөг хүчин зүйлүүдийн нөлөөлөлийг харуулж болох юм.

5. Сонгон авсан 18 зүйлийн авгалдайн биеийн хэмжээний түгэлт, бие гүйцсэн цаг хугацаан дээр үндэслэсэн амьдралын эргэлтийн талаархи гурван жилийн (2007-2009) судалгааны үр дүнгээс үзэхэд эрс униволтинизм буюу жилийн туршид нэг генераци явагдах байдлын зонхилол, уян харимхай амьдралын эргэлт, богино болон урт амьдралын эргэлтийг багтаасан ялгаатай чиг хандлага бүхий амьдралын эргэлтийн таван төрлийг харуулав. Эдгээр 18 зүйлийн амьдралын эргэлт, тэдгээрийн хөгжлийн хугацааг бусад судалгааны ажилтай харьцуулахдаа ангилал зүйн өөр өөр түвшинд хийх шаардлага тулгарав. Хэвлэгдэн нийтлэгдсэн мэдээ, материалын цар хүрээнд зүйлийн түвшинд харьцуулалт хийхэд зөвхөн ганцхан зүйл (Ephemeroptera: *Ephemera orientalis*) дээр боломжтой байсан юм. Энэ нь нэг талаас эдгээр зүйлүүдийн тархац нутаг дэвсгэрийн онцлогийг харуулна. Нөгөө талаас тухайн бүс нутагт тархсан зүйлүүдийн талаарх мэдээлэл хомс болохыг илтгэнэ. Дээр дурдсан таамаглалыг харгалзан үзэхэд Хараа голд тархсан *Ephemera orientalis* зүйл нь харимхай буюу хөдөлгөөнт амьдралын эргэлттэй, авгалдайн хөгжлийн хугацаагаа уртасгасан үр дүнг үзүүлсэн.

6. Бүтээмжийн үзүүлэлтүүдийг нэг жилийн судалгааны үр дүнд үндэслэн нийт 15 зүйл дээр тогтоох боломжтой байлаа. 2009 онд голын эхэн, дунд хэсэгт судалгааны нийт 3 цэгт авгалдайн жилийн бүтээмжийг тооцоход 0.08 гр хуурай жин м$^{-2}$ жил$^{-1}$ -ээс 18.7 гр хуурай жин м$^{-2}$ жил$^{-1}$ –ийн хооронд хэлбэлзсэн үр дүн гарав. Биомассын хувьд 10.6 мг хуурай жин м$^{-2}$ –ээс 907.8 мг хуурай жин м$^{-2}$ байв. Жилийн бүтээмж, биомассын харьцаа (P/B) 0.6 жил$^{-1}$ – ээс 23.5 жил$^{-1}$ –ийн хооронд хэлбэлзэв. 13 зүйл дээр тодорхойлогдсон хоёрдогч бүтээмжийн утгууд бага бүтээмжийг илтгэх шалгуур хэмжээнээс (5.4 гр хуурай жин м$^{-2}$ жил$^{-1}$) бага байв. Өсөлтийн эрчмийг униволтин өвлийн болон униволтин зуны амьдралын эргэлттэй зүйлүүдэд тодорхойлсон. Макросээрнуруугүйтэний өсөлтийн эрчмийн ерөнхий ангилалын дагуу бүхий л униволтин өвлийн амьдралын эргэлттэй зүйлүүд бага эрчимтэй (1.4% өдөр$^{-1}$ хүртэлх) зүйлийн ангилалд багтсан.

7. Энэхүү диссертацийн ажил нь Монгол оронд тархсан усны шавжийн зарим зүйлүүдийн амьдралын эргэлт, бүтээмж, өсөлтийн эрчим, усны шавжийн бие гүйцэх шатны талаарх тооны судалгааны үр дүнг анх удаа тогтоож, түгээмэл хэрэглэгддэг судалгааны арга зүйг ашигласанаараа бусад судалгааны ажлуудтай харьцуулагдах түвшинд хийгдсэн хэдий ч гидравлик нөхцөл, хүрээлэн буй орчны градиентийн дагууд, субстратын төрлөөс хамааруулан зүйлийн үр төлөрхөг байдал, хөгжлийн эрчмийн нарийн нягт тооцоо, үхэл хорогдол (махчлал гэх мэтчилэн), идэш тэжээлийн нөөцийг оролцуулан ойлгох популяцын динамикын талаархи судалгааны ажил зайлшгүй хийгдэх шаардлага байгааг харуулав. Ялангуяа бага орон зайн түвшинд эрчимжүүлсэн судалгааг хийх шаардлагатай байна. Үр төлөрхөг байдал, хөгжлийн эрчмийг тооцохын тулд хээрийн нөхцөлд өндөг болон авгалдайн

эхэн шатуудад байгаа бодгалиудыг цуглуулах шинэ арга зүйг боловсруулах, лабораторийн туршилтыг үндэслэх нь нэн чухал.

8. Эцэст нь дүгнэхэд Хараа голын сав газрын өдөрч, хаварч, болон хоовгоны багийн зүйлүүдийн амьдралын эргэлтийн чиг хандлага нь эрс тэс уур амьсгал дах тэдгээрийн зохилдлогоо болох эрс унивольтинизм, мөн хоёрдогч бүтээмжээр бага гэх үр дүнгээр маш тодорхой илэрхийлэгдсэн болно. Усны шавжийн аутэкологийн талаархи мэдээлэлийг бүрдүүлэх нь биологийн үнэлгээний үр дүнг дэлгэрэнгүй тайлбарлахад нэн тустай юм. Уур амьсгалын өөрчлөлтийн чиг хандлага бүхий Монгол орны өнөөгийн хотжилт, хөдөө аж ахуй, уул уурхайн салбарын хөгжлийн нөлөөллийн улмаас доройтсон эсвэл өндөр эрсдэлтэй урсгал усны экосистем, түүнд сөргөөр нөлөөлөгч хүчин зүйлүүдийн нөлөөлөлийг үнэлэх сээрнуруугүйтэний биологийн шинж чанарын нэгдсэн шалгууруудыг үндэслэх нь цаашид авч хэрэгжүүлэх менежментийн арга хэмжээний нэн тулгамдаж буй хэрэгцээ шаардлага болохыг зөвлөмж болгон дэвшүүллээ. Эдгээр доройтсон орчныг сэргээх менежментийн арга хэмжээг авч хэрэгжүүлэх, тухайн орчин дахь биологийн бүлгэмдлүүдийн эргэн нутагшин чадамжийг тогтооход макросээрнуруугүйтэний амьдралын эргэлтийн талаархи мэдлэг нэн чухал болохыг эцэст нь онцлон тэмдэглэв.

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ABBREVIATIONS

AFDM	Ash free dry mass
AP	Annual secondary production (g DW $m^{-2} y^{-1}$)
CPI	Cohort Production Interval (days)
DIC	Dissolved Inorganic Carbon
DOC	Dissolved Organic Carbon
DW	Dry Weight (mg or g)
EPT	Ephemeroptera, Plecoptera, and Trichoptera
IWRM	Integrated Water Resource Management
Kh_2	Kharaa_2, site in the down reach of the Kharaa River Basin
Kh_4	Kharaa_4, site in the middle reach of the Kharaa River Basin
Kh_5	Kharaa_5, site in the middle reach of the Kharaa River Basin
Kh_7	Kharaa_7, site in the middle reach of the Kharaa River Basin
Kh_8	Kharaa_8, site in the middle reach of the Kharaa River Basin
Kh_8.5	Kharaa_8.5, site in the middle reach of the Kharaa River Basin
MoMo	Integrated Water Resource Management in Central Asia: Model Region Mongolia
P/B	Production to Biomass Ratio
SD	Standard Devation
SE	Standard Error
Sg	Summer generation
SP	Secondary Production (g DW m^{-2})
Sug_1	Sugnugur_1, site in the upper reach of the Kharaa River Basin
TOC	Total Organic Carbon
Wg	Winter generation

Chapter 1

INTRODUCTION

1.1 BACKGROUND AND MOTIVATION

Mongolia's total surface water resources have been estimated at 599 km^3 yr^{-1} and more than 80% of this is stored in the countries lakes. The rivers are divided into three main basins, depending on their drainage course and include: the Arctic Ocean Basin, the Pacific Ocean Basin, and the Internal Drainage Basin. The Kharaa River Basin is in the Arctic Ocean Basin where about 50% of the surface water resources of Mongolia originate and form the major inflow into Lake Baikal (Davaa *et al.*, 2006). The Kharaa River basin plays an important role in the regions freshwater habitat functioning as well as providing a significant socio-economic role due to its close proximity to large cities and towns. Since the 1990s, water quality monitoring projects using the aquatic insects in Mongolia, mostly rivers in the Arctic Ocean Basin, has been conducted with different aims and methods (Morse *et al.*, 2007) to identify the impacts of waste water discharge or organic pollution (Avlyush & Bayansan, 2006), grazing and bank erosion (Hayford & Gelhaus, 2010; Maasri & Gelhaus, 2011), open-placer gold mining (Krätz *et al.*, 2010; Avlyush, 2011) and climate change (Maasri & Gelhaus, 2012). The ecological status in the different eco-regions of the Kharaa River has been investigated based on the macroinvertebrate communities using a multi-metric approach (Hofmann *et al.*, 2011). However, there are still knowledge gaps and uncertainties concerning the study of macroinvertebrates. Certainly, a life cycle study of representative species was one of these information holes. The following three points of concern should be addressed; firstly, for comprehensive interpretation of the results in order to develop monitoring and management measures from ecological knowledge, i.e. information regarding a species life cycle is essential. Secondly, emergence and life cycle studies of aquatic insects under the extreme continental conditions of Mongolia may show additional and remarkable results compared with other regions. Thirdly, life cycle information is required in addition to the continual sampling as data from this research are significant for the practical sampling of the biomonitoring programs.

1.1.1 Harsh environmental condition

Mongolia is a landlocked country, surrounded by high mountain ranges in the north and southwest and it is located in the transition zone between the great Siberian taiga and the

Central Asian desert, which belongs to the central parts of the Eurasian continent (Nandintsetseg *et al.*, 2007). Its climate is characterised by long, dry and cold winters (120-150 days with stable snow cover in the mountainous regions, about 85% of total precipitation falls from April to September and average air temperatures of –15 °C to –35 °C in January), and hot summers (average air temperatures of 15 °C to 25 °C in July), low precipitation (50 mm to 400 mm depending on the region) and a relatively high number of sunny days per year (260 d y^{-1}, average) for the years 1961 to 2001 (Batima *et al.*, 2005; Nandintsetseg *et al.*, 2007). The annual average temperature for Mongolia is 0.7 °C (Batima *et al.*, 2005), and -0.4 °C in the study region of Kharaa river basin (Törnros & Menzel, 2010). Major characteristics of extreme continental climates are long and cold winters with mean air temperatures below 0°C (Danks, 2007) with corresponding ice coverage of surface waters, which result in harsh environmental conditions for all aquatic life (Milner & Petts, 1994; Chambers *et al.*, 2000). For instance, an important hydrological character of surface waters in Mongolia is the occurrence of an ice cover with a thickness of 0.8 to 3.2 meters for five to six months of the year and some rivers freeze into the bed (Batima *et al.*, 2004). Depending on the species and besides habitat quality and food availability, general adaptations of aquatic insects to survive these conditions were described as a prolonged or staggered development and programmed life cycles with diapause, often resulting in strict univoltinism (Danks, 2007). However, synecological studies of aquatic insects in extreme cold continental climates and in particular Mongolian river systems are still limited (e.g., Hofmann *et al.*, 2011; Maasri & Gelhaus, 2011; 2012) the most recent studies have been focused on taxonomy and species diversity (Hayford, 2009; Purevdorj, 2009; Soldán *et al.*, 2009; Judson & Nelson, 2012).

1.2 BACKGROUND ON EPT GROUP

Among the aquatic insects, Ephemeroptera (mayflies), Plecoptera (stoneflies), and Trichoptera (caddisflies), commonly referred to as EPT, contain a rich assemblage of taxa in low and medium order cobble streams. These organisms are sensitive to environmental perturbations and occur, mainly, in clean and well-oxygenated waters. Due to those characteristics, these organisms are frequently considered as good indicators of water quality (Rosenberg & Resh, 1993).

Ephemeroptera (mayflies) are an ancient order of insects. About 3000 species within more than 400 genera and 42 families have been described (Barber-James *et al.*, 2008) with the number of species increasing by over 500 since the 1990's (Brittain & Sartori, 2003). Representatives of Ephemeroptera can be found in almost all types of freshwater environments (Brittian, 1982) and the greatest diversity of Ephemeroptera is found in second- and third-order streams in temperate regions (Edmunds & Waltz, 1996). Mayflies are used as potential indicators of pollution, and environmental changes as they are important links within the food chain between primary producers and secondary consumers in aquatic ecosystems (Brittain & Sartori, 2003). The biology and ecology of mayflies has been well documented by Brittian (1982) and Brittain and Sartori (2003). A recent updated database on Ephemeroptera is available from the website http://www.insecta.bio.pu.ru which consists of 'Ephemeroptera of the World' and 'Phylogeny of Ephemeroptera' (Kluge, 2011).

Plecoptera (stoneflies) is a small order of hemimetabolous insects and has a possible sister group relationship with Neoptera (Zwick, 2009). Over the last 30 years, the number of known

Plecoptera species has massively increased and more than 3497 species from 286 genera and 16 families have been described so far in the world (Fochetti & Tierno de Figueroa, 2008). Stoneflies are distributed over all continents except Antarctica, and provide a significant ecological component of running water ecosystems. Nymphs are aquatic and live mainly in cold, well-oxygenated running waters (Hynes, 1976). Plecoptera play a major role as bioindicators of water quality as they are good indicators of ecological and environmental conditions. Due to the water quality degradation and physical variation of streams and rivers, there has been a decrease in the number of stonefly species, particularly those inhabiting lowland rivers of industrialized countries of Central Europe or highly populated countries like those in Asia (Fochetti & Tierno de Figueroa, 2008).

Trichoptera (caddisflies) comprises a group of holometabolous insects and the larval and pupal stages that are totally dependent on an aquatic environment, with a few exceptions, and usually abundant in all freshwater ecosystems. In total 14,548 species, 616 genera and 49 families have been recorded so far (Morse, 2013). The phylogeny of Trichoptera is explained in detail by Morse (1997). Caddisflies have been broadly used in biomonitoring assessments with selected species or communities, both case- and shelter constructing larvae, are useful indicators of organic pollution, or broadly based on the family level of identification to assess the health status of aquatic ecosystems (de Moor & Ivanov, 2008). From an ecological perspective, caddisflies also form an important link in the food chain and thus form a major component of aquatic ecosystems.

1.2.1 EPT group studies in Mongolia and the Kharaa River Basin

The hydrobiological and aquatic insect surveys in Mongolia were established by the beginning of the twentieth century with the aim to identify and determine the present taxonomic groups. Since 1990, aquatic insects have been monitored in order to assess effects of changes in water quality. Morse *et al.* (2007) have been issued on current practices of freshwater biomonitoring with macroinvertebrates in Mongolia, and delivered recommendations for the implementation of biomonitoring within water resource management. Up to now, aquatic insects from 69 families of eight orders have been recorded (Gantigmaa *et al.*, 2010).

Ephemeroptera in Mongolia: O. A. Tschernova was the first to study the Mongolian mayflies and since then, a lot of work has been carried out mainly on the taxonomic diversity of the Mongolian mayfly (Enkhtaivan, 2004). The major collection expeditions were led by joint Hungarian-Mongolian teams (in 1964, 1965, 1966 and 1968), Soviet-Mongolian teams (in 1970-1980) and German-Mongolian teams (in, 1962, 1964 and 1977). Most recently, Soldán *et al.*, 2009, published a review of the taxonomic work carried out on the Ephemeroptera communities of Mongolia, and included 96 species in 34 genera and 14 families (Table 1-1). The Mongolian mayfly fauna consists of large area species (about 1%), Holarctic species (about 12%), Palaearctic species (about 22%), East Palaearctic species (about 60%) and East Palaearctic species so far found only in insufficiently known regions of Mongolia (about 5%) (Soldán *et al.*, 2009).

Plecoptera in Mongolia: East Palaearctic (Asian) Plecoptera diversity is much greater than all the remaining continents (Fochetti & Tierno de Figueroa, 2008). The last updated species list and recent nomenclatural changes and a history of Mongolian stonefly studies are presented in detailed by Judson and Nelson (2012) which report that there are 54 stonefly species and subspecies recorded belonging to 27 genera in eight families (Table 1-1). More than 60% of the stoneflies of Mongolia belong to the East Palaearctic Region and only four species are Mongolian endemics (Purevdorj, 2009). A history of Mongolian stoneflies research is divided into three phases, the first phase has been described before the second half of the twentieth century (1901-1936) by Klapálek, Navás and Wu, the second phase (1963-1998) by Z. Kaszab who did the first systematic investigation of stoneflies of Mongolia, then continued by Rauśer, Joost, Zwick, Zhiltzova, and Varykhanova. The third phase began after 1998 by national scientists.

Trichoptera in Mongolia: At least 129 valid, extant species in 16 families of caddisflies (Table 1-1) have been reported from Mongolia (Morse *et al*., 2006). A caddisfly study has been well-known since 1964 and sufficient numbers of papers have been published (Gantigmaa *et al*., 2010). In general, the Trichoptera fauna of Mongolia so far appears to be composed mostly of cosmopolitan species, distributed widely in the East Palearctic Biogeographic Region and often in neighboring regions, with only 6 (4.6%) of these species endemic to Mongolia. Most Mongolian caddisflies (60%) are Siberian, with smaller portions Holarctic (16%), Asian (7%), Palearctic (6%), or Siberian-Nearctic (3%) (Morse *et al*., 2006).

EPT in the Kharaa River Basin: A total of 140 taxa (Schäffer, 2014; own data) from EPT group are recorded during the years 2006 to 2009 with four endemic species. EPT taxa richness in the Kharaa River Basin is significantly high considering known number of EPT species from Mongolia. It is slightly higher than 50% of the total recorded for Mongolia (Table 1-1).

Table 1-1: The number of taxa recorded in EPT group in the Kharaa River Basin in 2006-2009 compared with records in Mongolia. The distrubutions in Mongolia were given by Judson & Nelson (2012), Morse *et al*. (2006), and Soldán *et al.* (2009). The distributions in the Kharaa River Basin were based on the long term research within the MoMo project (Schäffer, 2014; own data).

Order	Number of species		Rate of taxa in the Kharaa River Basin (%)
	Mongolia	Kharaa River Basin	
EPT	278	140	**50.3**
EPHEMEROPTERA	96	63	**65.6**
PLECOPTERA	54	20	**37.0**
TRICHOPTERA	129	57	**44.1**

1.3 LIFE CYCLE

'Life cycle' is often confused with 'Life history'. Butler (1984) defines life cycle as 'The sequence of morphological stages (egg, larvae, pupae, and adult) and physiological processes (metamorphosis, dormancy, regional dispersal, and reproduction) that link one generation to the next. Life cycles are species specific. Life history comprises the quantitative and qualitative details of the variable events that are associated with the life cycle such as fecundity, growth phenology and growth rate, mortality, and emergence patterns (Butler, 1984). Thus, life history information is the fundamental importance for virtually all ecological studies of freshwater invertebrates. Variation in life history patterns is due to: (a) intrinsic factors such as physiology, behaviour, and morphology which tend to restrict life-history traits within certain genetically determined ranges; and (b) extrinsic factors such as temperature, nutrition, photoperiod and other taxa (predators, prey, hosts, and parasites) present in the environment. It is often quite difficult to attribute life- history patterns to either intrinsic origins or extrinsic influences (Giller & Malmqvist, 1998).

Since the 1950's information on aquatic invertebrate life cycles has been rapidly accumulated and numerous conferences were held concerning to life cycles. Taylor (2001) stated in his thesis as "Trends in ecological research began shifting from descriptive autecology toward more holistic discipline dedicated to solving broad ecological and increasingly applied environmental problems. These trends lead to a decline in studies dedicated to basic life history descriptions". A number of publications along a time series could easily demonstrate this statement. However, it still can be essential to obtain the knowledge from regions where not even a basic study exists. Furthermore, unpredicted results can be found from the rivers under natural hydromorphological conditions.

1.3.1 Life cycle types

Three main categories of life cycles are described and these are univoltine, multivoltine and semivoltine (Butler, 1984). Each of these three major life cycle types are separated into more specific life cycle categories (Table 1-2) by Clifford (1982) based on Landa's (1968) classification system.

1) *Univoltine:* This category groups those species (populations), with a single generation per year, with no overlapping between generations. This category is the most common life cycle type for the EPT group.

2) *Multivoltine:* The populations complete their entire cycle more than one time per year and involve several generations. Depending on the number of generations, this pattern is called bivoltine (two generations a year) or polyvoltine (three or more generations a year). This type of life cycle is more common in mayflies than stoneflies and caddisflies.

3) *Semivoltine:* These species complete the life cycle in more than one year. Semivoltine life cycle is more frequent in stoneflies, mainly belonging to the families of Perlidae and Perlodidae. The individuals from this type of cycle usually present a bigger body size and increased individual fecundity.

1.3.2 Life cycles of EPT group

Hemimetabolous insects of Ephemeroptera, Plecoptera, and holometabolous insects of Trichoptera groups have a complex life cycle, and involve the transition between two distinct environments, the aquatic and terrestrial.

Table 1-2: Life cycle categories of EPT group are based on Landa's classification (1968) system.

UNIVOLTINE	MULTIVOLTINE	SEMIVOLTINE
Uw: Seasonal univoltine winter cycle; the population overwinters in the nymphal stage. **Us:** Seasonal univoltine summer cycle; hatching, growth and emergence take place in summer; the population overwinters in the egg stage. **Us-Uw:** seasonal univoltine cycle; the most of the new generation overwinters in the egg stage, and a small part of the population overwinters in the nymphal stage.	**MB:** seasonal bivoltine cycle, two generations a year. **MBss:** seasonal bivoltine summer cycle; following summer generations, the population overwinters in the egg stage. **MBws:** Seasonal bivoltine winter-summer cycle; overwintering generation in the nymphal stage and one summer generation. **MP:** Seasonal polyvoltine cycle; three or more generations a year.	**S_{2y}:** seasonal semivoltine cycle with a generation time of about two years. **S_{3y}:** seasonal semivoltine cycle with a generation time closer to three years. **$S_{4 \text{ or } 5y}$:** seasonal semivoltine cycle with a generation time closer to four or five years.

Ephemeroptera (mayflies): Since the 1950's, mayfly life cycle data has rapidly accumulated (Clifford, 1982) with the extensive literature mostly from temperate areas in Europe and North America (Brittain & Sartori, 2003). Clifford (1982) published a paper on the life cycles of mayflies, and for that reviewed about 400 papers and included about 718 life cycles for 297 species. About 60% of all, mayfly life cycles were reported as univoltine, 30% multivoltine, 4% semivoltine, and 3% were judged variable. The univoltine winter cycle is the most common single life cycle type. Mayfly life cycles are varied from the tropics to the arctic, i.e. nonseasonal multivoltine cycles predominate in the tropics and seasonal cycles becoming more common in the mountainous and continental areas (Brittain & Sartori, 2003). Many mayfly species demonstrate the flexible life cycle, and it is shown by the most recent study of Sand and Brittain (2009) on *Baetis rhodani* Pictet 1843.

Plecoptera (stoneflies): There is an absence of any summary publications on the life cycle of stoneflies. However, Brittain (1990) concluded that the univoline life cycle is the most common, and larvae of the smaller species complete their growth within a year. Multivoltine life cycles are almost unknown in the Plecoptera (Hynes, 1976). Stoneflies show much greater ability to lengthen their life cycles at low temperatures to obtain a larger adult size, and increased individual fecundity. Therefore, the semivoltine life cycle is well-known in stoneflies, especially from the Northern Hemisphere (Brittain, 1990). A life cycle lasting 3, 4 or even 5 years has been recorded from northern Norway and Sweden. Stoneflies are flexible on their life cycle as well as mayflies; in fact, *Nemurella pictetii* changes from univoltine to a two-year cycle at higher altitudes and latitudes (Brittain & Saltveit, 2005).

Trichoptera (caddisflies): Caddisflies have univoltine, multivoltine, and semivoltine life cycles (Solem & Gullefors, 2005). A little comparative publication on life cycles of caddisflies is available concerning their massive taxa diversity. Life cycle studies on Trichoptera can be found typically for the families of Glossosomatidae, Hydropsychidae, Limnephilidae and Brachycentridae. Most species in North Europe are univoltine or semivoltine. Some of the caddisflies have an inflexible life cycle, although there are some with flexible cycles also that may alternate between univoltine and semivoltinism (for example, *Apatania muliebris* and *Apatania zonella*) (Solem & Gullefors, 2005).

1.4 EMERGENCE

Terrestrial and aquatic ecosystems exchange nutrients and energy and emergence is a prime link between these two ecosystems (e.g., Poepperl, 2000a; Power & Rainey, 2000). For instance, Jackson and Fisher (1981) found approximately 3% of emergent insect biomass returned to the aquatic habitat. The majority (up to 95%) of emerging insects was found to belong to the dipteran family and EPT group contributed with up to 10% into total emergence density (Füreder *et al.*, 2005) in alpine streams. Environmental factors such as photoperiod and water temperature are considered as the main drivers regulating the emergence (Sweeney, 1984; Nylin & Gotthard, 1998). Füreder *et al.* (2005) found that one of the life cycle adaptations to the harsh environmental condition was the continuous emergence throughout the summer.

The emergence of aquatic insects are well-known from small streams in Germany and Austria and massive data have been accumulated (e.g., Illies & Masteller, 1977; Zwick, 1984; Becker & Wagner, 2004). Particularly, Prof. Joachim Illies emphasized importance of the emergence of aquatic insects on the measurement of stream productivity (Illies, 1975). However, Statzner and Resh (1993) criticized large data set from emergence studies and examined the predictions from ecological theory for emergence data.

1.5 SECONDARY PRODUCTION & GROWTH RATE

Aquatic insects are important for the energy flow in aquatic systems, as they constitute the link between algae, detrital food and the higher trophic levels, including benthivorous fish (Benke, 1984). Secondary production is a measure of biomass creation over time and depends on individual growth and life-history attributes as well as population abundance and survivorship (Benke, 1984; Huryn & Wallace, 2000). Understanding of the secondary production is of considerable ecological importance from both a population and a community perspective and its information can further be utilized in determining how life history parameters are influenced by ecosystem processes (Benke, 1996). The voltinism and length of aquatic life are the two most critical life history features necessary for obtaining good estimates of secondary production (Waters, 1979). Actual cohort, size-frequency, and laboratory methods are known. Some used field data only (e.g., López-Rodrǐguez *et al.*, 2009b; 2010), whereas others used combination of field and laboratory growth data (Hwang et al., 2009). Most of the field methods are closely related to one another, and an understanding of key-life history features is essential to all field methods (Benke, 1984). Huryn and Wallace (2000) classified low and high growth rates of macroinvertebrate species based on annual P/B (production and biomass ratio) and growth rate. The authors found that high P/B rates are typically associated with fast life cycles and rapid individual growth.

Temperature was identified to be the principal factor regulating growth and development of aquatic insects. On the one hand, it is essential to discuss the nutrition together with water temperature. On the other hand, the quality and quantity of food resources are strongly linked to temperature (Vannote & Sweeney, 1980; Newbold *et al.*, 1994).

1. 6 HYPOTHESES AND OBJECTIVES OF THE STUDY

The hypothesis was to test whether or not EPT species in the Kharaa River have special adaptations to survive the harsh winter conditions in Mongolia and reduced secondary production.

- Because of the longitudinal changes and extreme continental climate conditions or high temporal variables the life cycles of the selected species display low type diversity in the Kharaa River Basin.
- The specific climatic and hydrological condition of ice coverage of the river during the period from November to April causes extended larval development period or long egg or larval stage with diapause.
- A short and hot summer forms the continuous emergence throughout the summer.
- Caused by low temperatures the secondary production of selected macroinvertebrate species at chosen sites is low.
- Because of low water temperature throughout the year, the larval developments with the lowest growth rates compared to the literature in other region.

In order to proof these hypotheses, it was necessary to provide basic autecological information on the *(i)* larval and emergence densities, *(ii)* life cycle periods, and *(iii)* secondary production, growth rates of selected macroinvertebrate organisms under an extreme continental climatic environment.

In more detail, the following objectives were addressed:

- To suitable the methods for benthic and emergence studies,
- To determine the emergence patterns and density of EPT group,
- To determine the larval density and biomass,
- To establish the criteria for choosing the target species from the EPT group for a life cycle study,
- To determine life cycles stages for selected macroinvertebrate species,
- To identify times of emergence for these species,
- To provide information on the secondary production and growth rate of selected macroinvertebrate species where data were sufficient for the estimations,
- To discuss the distinct consequences of secondary production and growth rates of selected species with various life cycle strategies.

Chapter 2

DESCRIPTION OF STUDY AREA

The current study was conducted under the framework of the Project named 'Integrated Water Resource Management in Central Asia: Model Region Mongolia (MoMo Phase I & II)' (www.iwrm-momo.de). Numerous scientific reports and articles have been subsequently published providing comprehensive information on the Kharaa River basin. This chapter will give an overview regarding the environmental variables relevant to the study area.

2.1. TOPOGRAPHY OF THE KHARAA RIVER BASIN

The Kharaa River basin is located in Northern Mongolia, not far from the capital Ulaanbaatar, between latitudes 47°53′ and 49°38′ N and longitudes 105°19′ and 107°22′ E. The catchment is 14,534 km^2 and the main channel is 362 km long (Fig. 2-1) and flows into the Orkhon River (catchment area 133,000 km^2) which is a tributary of the Selenge River (459,000 km^2) (MoMo Consortium, 2009a). The Selenge is the main source of Lake Baikal with most of its catchment situated in Mongolia, approximately 63 percent (Mun *et al*., 2008). The lowest elevation within the catchment is near the outlet and is 654 m a.s.l. while the highest point is located in the vicinity of the Asralt Hairhan, the highest peak of the Khentii Mountains (2799 m a.s.l.). The headwaters of some important Mongolian rivers are located in these mountains, including the Onon. Approximately 60 % of the basin has an elevation between 900 and 1300 m a.s.l., with the average altitude of the whole catchment being 1,167 metres. The Kharaa River Basin is divided into 10 sub- catchments of 338–2944 km^2 in area (MoMo Consortium, 2009a). The hydromorphology (longitudinal or cross-sectional profiles) of the Kharaa River is mainly undisturbed and meandering, only controlled by the geomorphological settings. A detailed description of the study region is given by Hofmann *et al*. (2011).

2.1.1 Study sites in the Kharaa River

During the years 2007 to 2009, a total of five sites were chosen along the main channel of the river in order to study the life cycle of the rivers macroinvertebrates (Fig. 2-2). A principle for the selection of sampling points was to display the life cycle of species distributing in the upper, middle and downstream reaches of the basin. However, additional two sites referred by Schäffer (2014) in the middle region were included in this thesis because of increasing data source in the middle region.

Fig. 2-1: The Kharaa River Basin (in black) is shown as part of the Selenge River Catchment (striped) being the main source region for Lake Baikal (**Source:** Map from e.g., Hofmann *et al*. 2011).

Three biocoenotic regions have been distinguished based on a) biological components, b) chemical, physico-chemical components and c) hydrological, hydromorphological components (Berner, 2007; MoMo Consortium, 2009a). Concerning the biocoenotic regions of the Kharaa River, one site was located in the upper region, five sites in the middle regions and one site in the lower region (Table 2-1; Photo 1). The GPS distance on the study sites using the data referred by Berner (2007) was estimated from the confluence of the Kharaa and Orkhon Rivers and ranges between 8.91 km at the downstream to 364.24 km at the upstream site (Fig. 2-3).

Table 2-1: GPS data of the study sites in the Kharaa River with their concerning river sections and biocoenotic regions are presented. Boldface sites refer to additional data (Schäffer, 2014) from a joint data base considered in this thesis.

River Section	Bioocoenotic regions	Study sites	Short name	GPS North	GPS East	Nearby settlements
Upper reaches	Epi-/Metarhithral	Sugnugur_1	Sug_1	48° 23' 48.23"	106° 53' 2.04"	Batsumber
Middle reaches	Hyporhithral	Kharaa_8.5	Kh_8.5	48° 32' 38.62"	106° 49' 37.88"	Village
		Kharaa_8	Kh_8	48° 48' 12.06"	106° 41' 32.49"	Village
		Kharaa_7	**Kh_7**	**48° 50' 4.56"**	**106° 30' 32.72"**	Zuunkharaa
		Kharaa_5	Kh_5	48° 52' 47.49"	106° 7' 47.64"	Baruunkharaa
		Kharaa_4	**Kh_4**	**48° 54' 57.20"**	**106° 3' 37.55"**	Baruunkharaa
Down reaches	Epipotamal	Kharaa_2	Kh_2	49° 31' 15.99"	105° 53' 40.88"	Darkhan city

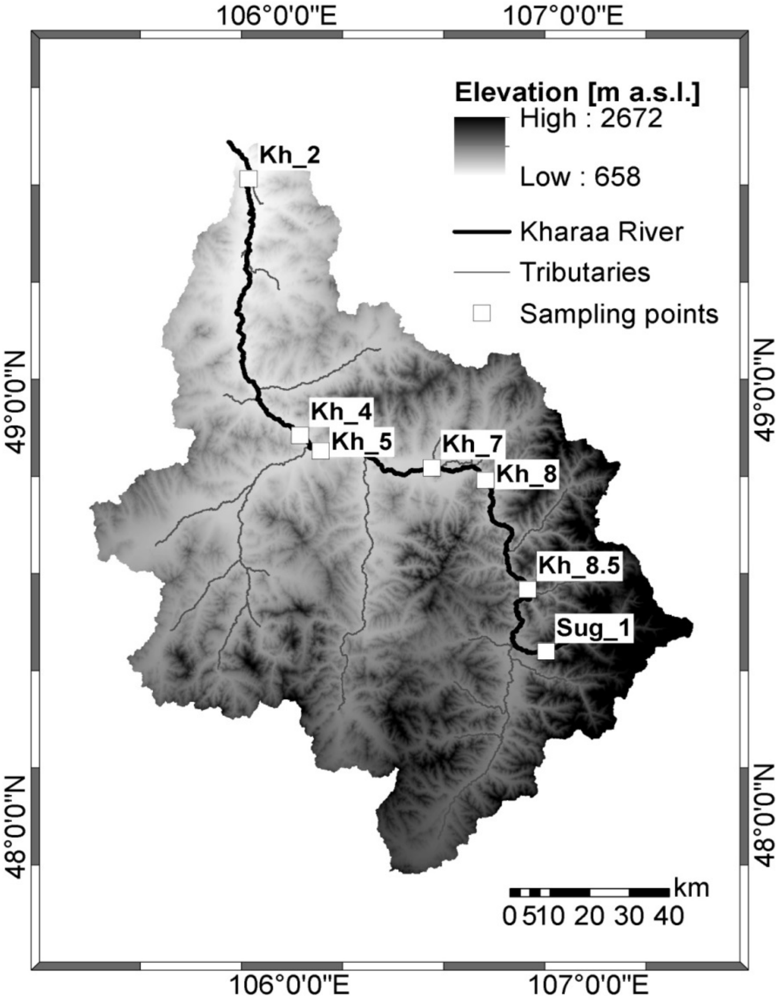


Fig. 2-2: The Kharaa River catchment and the sampling locations are given with the short names. **Note:** Additional two sites (*Kh_7*; *Kh_4*) in the middle reach referred by Schäffer (2014) are included in this map.

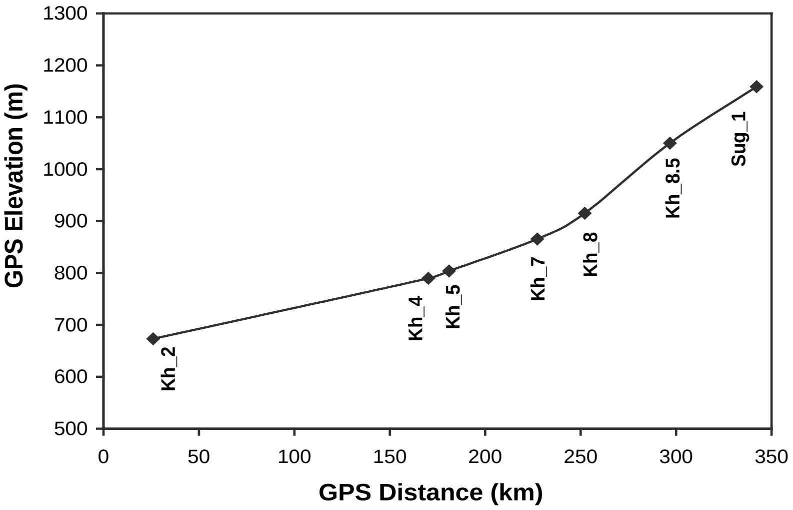


Fig. 2-3: The GPS distance [km] on the study sites from the confluence of the Kharaa and Orkhon Rivers and elevation [m]. **Note:** Additional two sites (*Kh_7*; *Kh_4*) in the middle reach referred by Schäffer (2014) are included in this figure.

2.2 CLIMATIC AND HYDROLOGIC CONDITIONS

The Kharaa River basin is characterized by an extreme continental climate with harsh, very cold and dry winters and short, hot summers (Fig. 2-4). Based on data from six weather stations, the annual mean temperature is – 0.4 °C. Ranging from -3.7 °C in the mountains and 0.6 °C in the Kharaa valley (Törnros & Menzel, 2010). A minimum temperature reaches -40 °C while maximum temperatures may rise up to 40 °C during daylight hours of the summer months. Daily water temperature fluctuations occur in the range of 10 °C during summer (Hofmann *et al.*, 2011). Precipitation has an annual mean value of 250 to 330 mm but a high inter-annual variability (Törnros & Menzel, 2010).

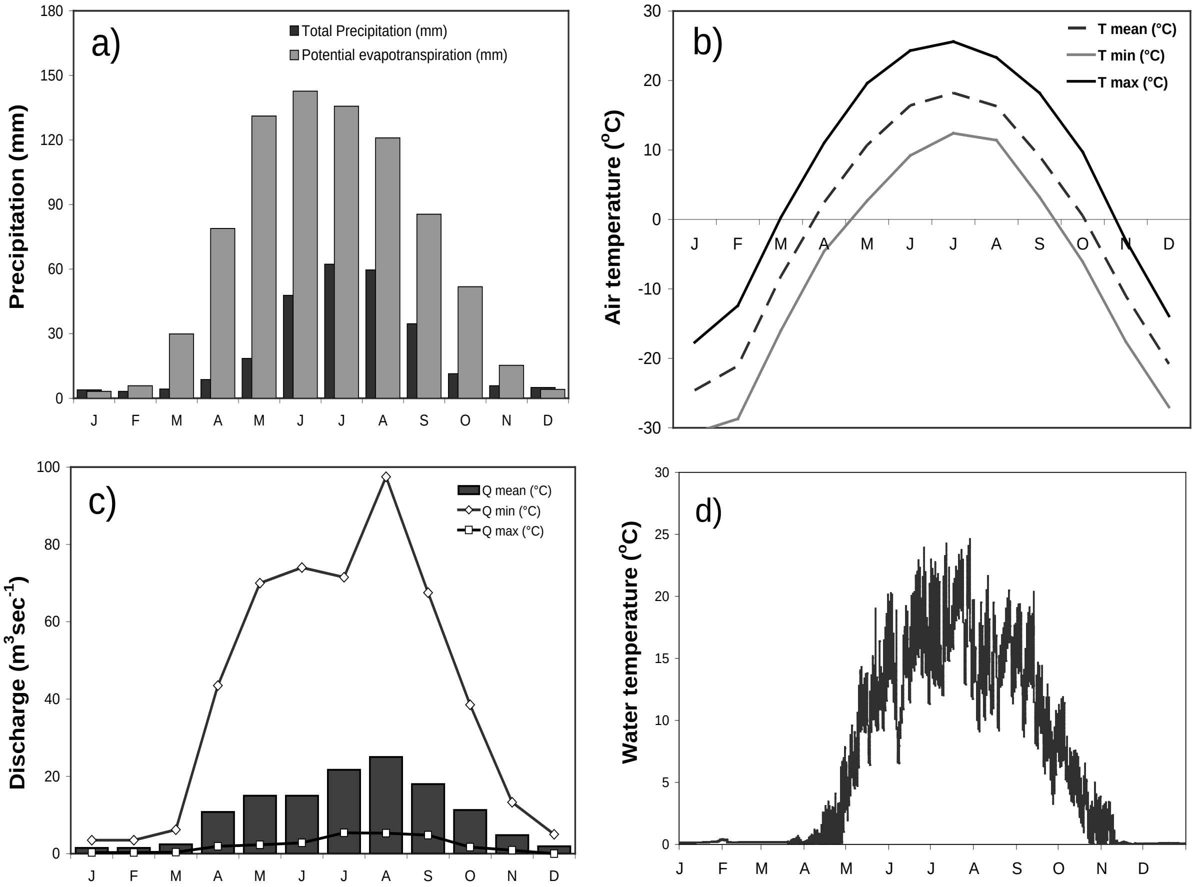


Fig. 2-4: Climatic and hydrological parameters are figured for Baruunkharaa where the study sites of Kharaa_4 (*Kh_4*) and Kharaa_5 (*Kh_5*) are located. **a)** Total precipitation and potential evapotranspiration in 1961 to 1990; **b)** Monthly mean, minimum, and maximum air temperature in 1961 to 1990; **c)** Mean, and the lowest and highest monthly discharge based on daily observed data in 1951-2001; **d)** water temperature in every half hour during 01.01.2010 to 31.12.2010.

Data source: The figures of a) and b) from FAO ClimNET; c) Menzel & Munkhtsetseg 2008; d) Theuring, unpublished.

Mean annual relative humidity ranges between 58 % and 72 % which was strongly influenced by elevation and wind speed and averaged 1.9 m s^{-1} in 1986-2006 (MoMo Consortium, 2009a). Runoff in the basin is characterized by two peaks; one minor in spring due to snowmelt when melt waters from the Khentii temporarily raise the water levels and one major in summer due to rainfall. In winter, the rivers are covered with ice and runoff is almost non-existent (Törnros & Menzel, 2010). In recent years the discharge at the Kharaa river basin outlet has dropped significantly, discussed by Menzel *et al.* (2008). The long-term mean annual discharge between the 1990 and 2008 was 11.8 m^3 sec^{-1} recorded at the gauge station Buren Tolgoi (8.91 km from the outlet of the basin; Hofmann *et al.*, 2011). The mean specific runoff (ratio of mean annual discharge and total catchment area) was 0.81 l s^{-1} km^{-2}.

2.3 SURFACE WATER QUALITY

Chemical status of surface waters is well-recognized in the Kharaa River Basin and the results have been published (e.g., Hofmann *et al.*, 2010; 2011). Water quality parameters at 19 sites along the Kharaa River by Ibisch (unpublished data) have been investigated within the framework of the 'Integrated Water Resource Management in Central Asia: Model Region Mongolia (MoMo I&II) and the results from seven sites are presented here (Fig. 2-5 & Table 2-2).

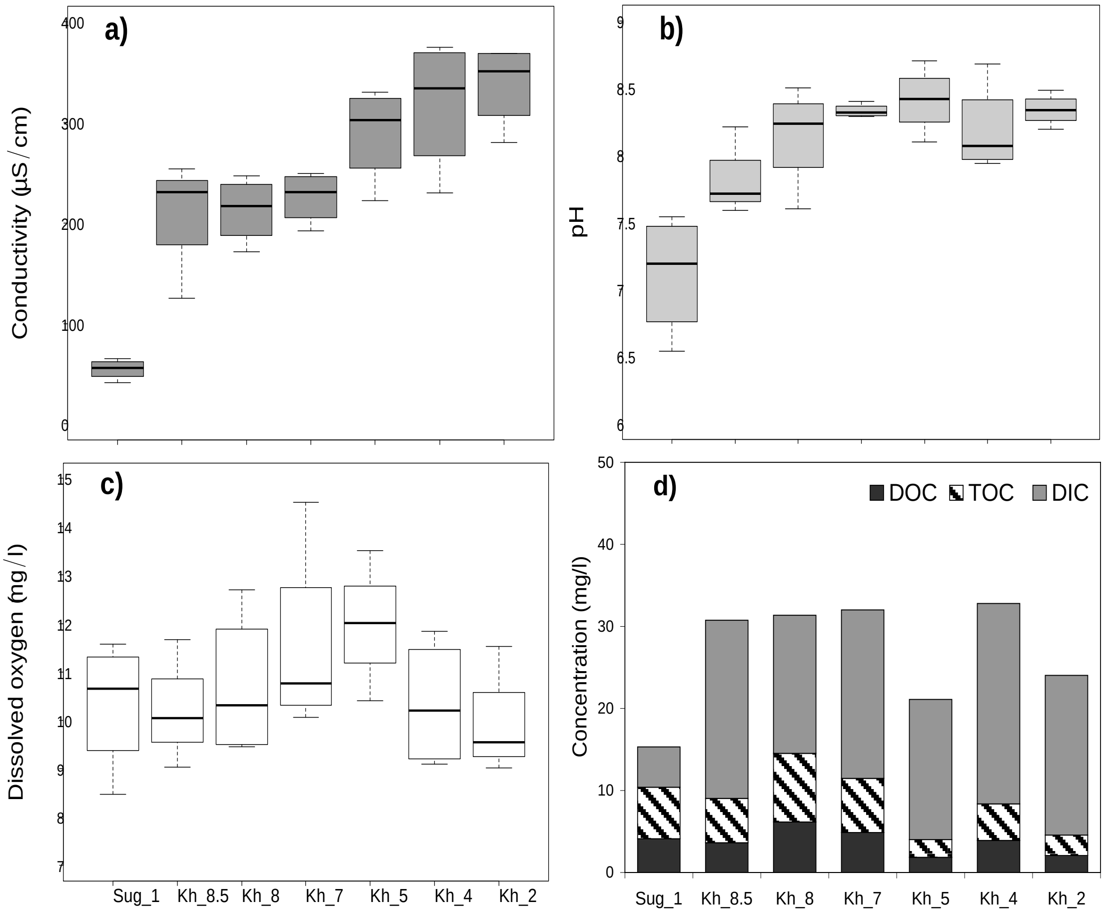


Fig. 2-5: Boxplots (a, b, c) and bar graph (d) displays the physio-chemical parameters at the study sites in the Kharaa River in autumn (2006 and 2007) and spring (2007 and 2008). **a)** Conductivity; **b)** pH; **c)** Dissolved oxygen; **d)** Concentrations of DOC, TOC and DIC.

Note: Measurements of organic and inorganic carbon was measured only once in spring 2008.
Data source: Ralf Ibisch, unpublished.

Conductivity and pH increased from upstream to downstream (Fig. 2-5a & b). Mean conductivity was 55 µS/cm in the most upper reach of the Kharaa River. However, it rapidly increases in the middle reaches to a maximum of 340 µS/cm in the downstream sites. There was the same increasing trend for measured pH along the river in the range from 7.1 to 8.3 (Table 2-2). Mean dissolved oxygen levels ranged between 9.9 mg/l and 12.0 mg/l. It increased slightly in the middle reaches but again decreased in the downstream reaches of the river (Fig. 2-5c, Table 2-2). The lowest concentrations of DOC, TOC and DIC were recorded in the upper reaches, with elevated levels at other sites in the middle and downstream regions (Fig. 2-5d).

Table 2-2: General chemical-physical parameters at seven sites along the Kharaa River in the period 2006-2008 (SD= standard error; n= number of measurements).

		Conductivity (µS/cm)		pH		Dissolved oxygen (mg/l)			DOC (mg/l)	TOC (mg/l)	DIC (mg/l)
	n	Mean	*SE*	Mean	*SE*	Mean	*SE*	*n*			
Sug_1	4	54.5	5.1	7.1	0.22	10.3	0.55	1	4.1	6.3	4.9
Kh_8.5	3	203.3	39.7	7.8	0.19	10.2	0.67	1	3.6	5.4	21.7
Kh_8	4	213.0	16.5	8.1	0.19	10.7	0.63	1	6.2	8.4	16.8
Kh_7	4	225.5	13.0	8.3	0.02	11.5	1.01	1	4.9	6.6	20.5
Kh_5	4	289.2	24.2	8.4	0.12	12.0	0.76	1	1.8	2.2	17.1
Kh_4	4	318.2	33.3	8.2	0.17	10.3	0.76	1	3.9	4.5	24.4
Kh_2	4	337.7	20.9	8.3	0.06	9.9	0.67	1	2.1	2.5	19.5

Data source: Ralf Ibisch, unpublished.

2.4 LAND AND WATER USE

The issues of land and water use in the Kharaa River Basin have been investigated and determined within the framework of the project 'Integrated Water Resource Management in Central Asia: Model Region Mongolia (MoMo Phase I & II)'.

In the Kharaa River basin the main types of land-cover are grasslands (60%), forests (26%) and croplands (11%) (Schweitzer & Priess, 2009). Spatially, the most important land-use activities in the river basin are *i)* livestock grazing, *ii)* crop farming, mostly wheat, potatoes and vegetables, *iii)* open pit mining, mainly gold, *iv)* forest use, legal and partially illegal timber extraction, and *v)* urbanization. Each of these major land-use activities is subject to a number of driving forces, resulting in considerable land and water-use dynamics (MoMo Consortium, 2009b). Additional detailed information of water and land use in the Kharaa River Basin is given by MoMo Consortium (2009 a; b) and Schweitzer (2012).

The 2012 water law of Mongolia addressed the establishment of River Basin Management (RBM) and RBM plans for 29 major river basins in Mongolia. Therefore, the results of the MoMo project can be the basic model for other river basins and provide a broad scientific basis and measures for river basin management (RBM).

2.5 MULTIPLE STRESSORS

Four cases of multiple stressors can be discussed in the Kharaa River Basin: *(i)* heavy metal pollution; *(ii)* eutrophication; *(iii)* fine-grained sediment, and *(iv)* climate change.

(i) Heavy metal pollution in the Kharaa River Basin has been investigated by Hofmann *et al*. (2010) and Javzan (2011). Both authors identified the heavy metal pollution in the basin. Hofmann *et al*. (2010) studied the heavy metal concentration along the river and found values below detection limits for dissolved heavy metals in the upper and middle reaches. However, an increased level of heavy metal concentrations (in particular, arsenic and mercury concentration) was detected in the down parts of middle reach and down reach. The concentration of toxic heavy metals or arsenic and mercury in surface waters (Hofmann *et al*., 2010) and sediment (Javzan, 2011) was correlated to the illegal mining and increased in the downstream reaches that feature open placer mining areas. A significant high concentration of arsenic (508 pg/l) was measured in the ash deposit area of the Thermal Power Plant in Darkhan (Hofmann *et al*., 2010).

(ii) The main sources of nutrients in the basin are households without connection to wastewater treatment plants and agricultural land use. Nutrient emissions into the Kharaa River Basin were identified (Hofmann *et al*., 2011) and the results indicated natural background conditions in the headwaters and an increased amount of nutrients in the middle and lower reach. Nutrient emissions into the Kharaa River basin were approximately 301 t N yr^{-1} and 56 t P yr^{-1} which increases the likelihood for eutrophication. Although there was a high dissolved oxygen fluctuation in the middle reach of Kharaa River, the chlorophyll a level found on stones (1.046 mg chl a m^{-2}-3.482 mg chl a m^{-2}; Khurelbaatar, 2011) did not show a considerable sign of eutrophication compared to reported studies (Welch *et al*., 1992; Ibisch *et al*., 2009).

(iii) The ecological situation of the Kharaa River basin was assessed based on an investigation of the fish and macroinvertebrate fauna considering their habitats (MoMo Consortium, 2009a; Hofmann *et al*., 2011). This biological assessment indicated 'Good' ecological status in the headwaters and most sections of the middles reaches. Nevertheless, ecosystem degradation and biodiversity loss were detected in the lower reaches. Fine sediment deposition had been hypothesized to be the main causal factor responsible for the loss of macroinvertebrate biodiversity and increased diversity and abundance of fine sediment colonizers (Hofmann *et al*., 2011). Hartwig *et al*. (2011) concluded that fine grained sediment was identified as the cause of habitat loss in the hyporheic zone and benthic oxygen limitation in the Kharaa River. A dominant source of suspended sediment is river bank erosion which generates 74.5% of the suspended sediment load. Other predominant sources were surface erosion with 21.7% and gully erosion with only 3.8% (Theuring *et al*., 2012). As a result of overgrazing, the riverbanks have been significantly eroded and riparian vegetation exists on approximately only 20% of the riverbank at the mid and downstream reaches (MoMo Consortium, 2009b).

(iv) In Mongolia, annual mean temperatures have risen by 2.14 °C and autumn and winter precipitation has increased by 4 to 9%, while spring and summer precipitation has decreased by 7 to 10% during the last 70 years. Winter temperatures have increased by 3.6 °C, spring by 1.8 °C, autumn by 1.3 °C and summer by 0.5 °C (Batima *et al.*, 2011). The results from climate variability in the Kharaa River Basin during the period 1986-2006 do not indicate a significant increase in mean annual air temperature since warmer summers (+0.65 °C) and colder winters (-1.1 °C) leveled out (MoMo Consortium, 2009b). Nevertheless, annual precipitation decreased by 13% in the same period (MoMo Consortium, 2009b). In addition, a significant decrease of mean annual discharge from 21.8 m^3 s^{-1} in the period of 1990-1995 to 8.8 m^3 s^{-1} in the period of 1996-2002 was observed (Hofmann *et al.*, 2011).

Chapter 3

MATERIAL AND METHODS

Between 2007 and 2009, three projects were conducted in order to determine the life cycle period, secondary production and growth rate of important macroinvertebrate species from the EPT group. The structure of the following sub-chapters is presented in figure 3-1.

This study was conducted under the long term biomonitoring program of the 'Integrated Water Resource Management in Central Asia: Model Region Mongolia (MoMo I&II)'. A joint data base was established for macroinvertebrate community in the Kharaa River Basin within the biomonitoring program. Therefore, a part of the data was provided by project team. The use of existing data set is presented in the following sub-chapters.

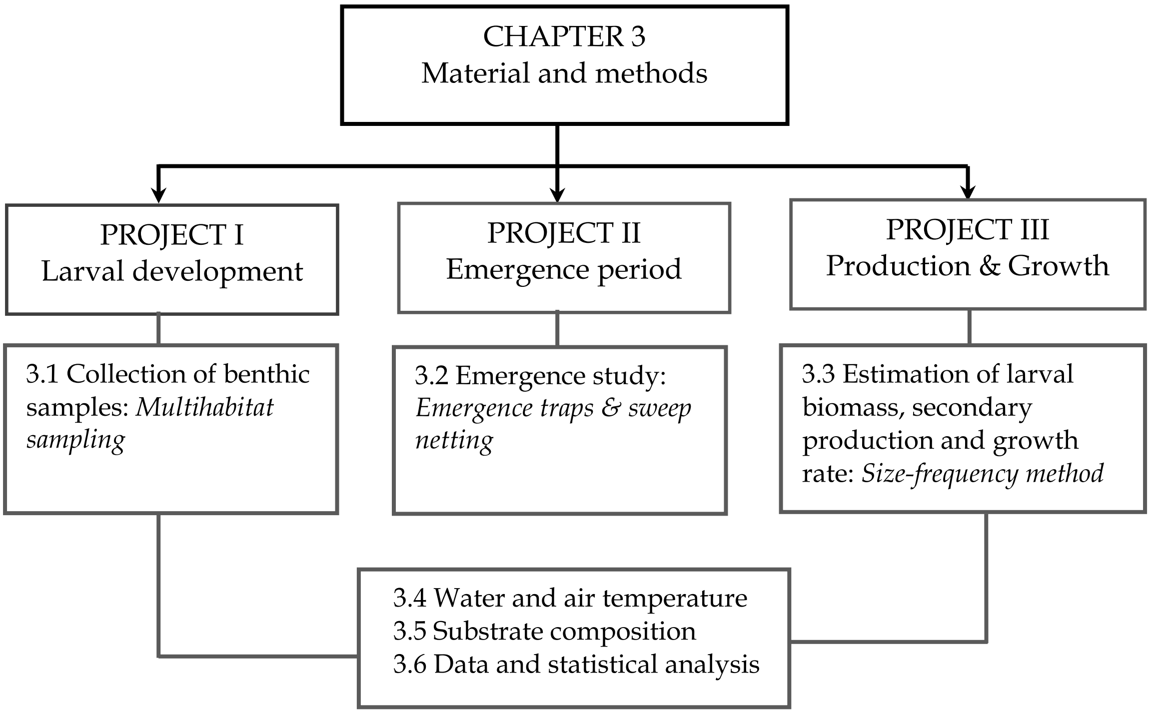


Fig. 3-1: A structure of sub-chapters identifying the sampling and estimation methods, abiotic measurements and data analysis.

3.1 COLLECTION OF BENTHIC SAMPLES

For benthic sampling (Project I), a multi-habitat quantitative sampling method was used according to the procedure given by Haase *et al.* (2004).

Field sampling: The method is based on sampling microhabitats according to their representation at the sampling site and requires an estimation of microhabitats in accordance with a site protocol developed by Haase *et al.* (2004). Macroinvertebrates from all occurring microhabitats were sampled using a kick net (mesh size of 500 µm) by way of facing upstream and perpendicular to the sampled substrate (Fig. 3-2). Before sampling, the site protocol was completed. All microhabitats were recorded in 5% intervals. Every 5% interval represents one 'sampling unit' which covers an area of 25 x 25 cm (0.0625 m^2) based on a net frame area size. A complete sample comprises 20 'sampling units' or represents a total area of 1.25 m^2 per site. Microhabitats with an occurrence of less than 5% were sampled as an additional 21st 'sampling unit', consequently the total sampled area increased to 1.3125 m^2. Sampling units took into consideration that microhabitats may be unequally distributed between riffle-fast flowing and pool-slow flowing zones and covers the whole width of the river. Further sampling procedures can be found on the AQEM (2002) and Haase *et al*. (2004). One complete sample was washed in the field and preserved with 96% ethanol immediately after collection. The ethanol was changed two to three times as required by the protocol.

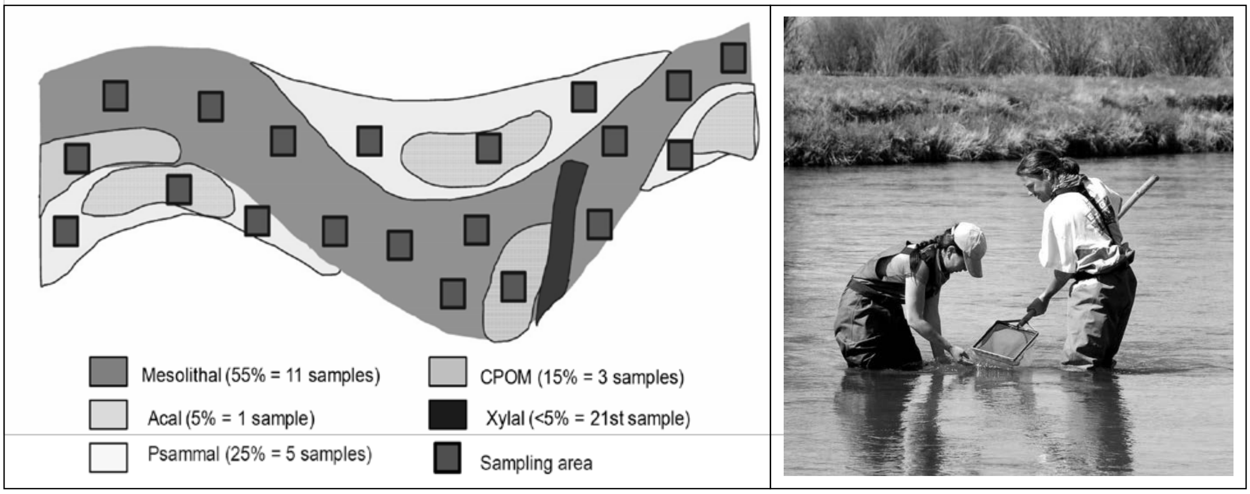


Fig. 3-2: Sampling procedure according to the protocol, right side picture (photo by Ibisch, R): Sampling in the field using by kick net (0.0625 m^2, 500 µm mesh size) and left side picture: Example of substrate composition of sampling units in the river (**Source:** AQEM Consortium, 2002).

Laboratory procedure: All organisms were removed from the organic coarse fractions in the samples using a dissecting stereomicroscope (Stemi DV4/Dr, Carl-Zeiss AG), and stored in 80 % ethanol. A sub-sampling technique was required and completed according to the procedure on Haase *et al*. (2004). After identification, total body length without cerci and antennae and width of head (only for selected taxa) to the nearest 0.05 mm was measured using a micrometer on a dissecting stereomicroscope (Stemi DV4, Carl-Zeiss AG). The number of individuals for each identified taxa was counted.

Taxonomical identification: Identification on larvae and pupal stages were completed to the taxonomic lowest level as much as possible using the literatures of Malicky (1983), Tsalolikhin (Ed.) (1997; 2001), Nilsson (Ed.) (2005), Sivec *et al.* (2005), Zwick (2004), and Zwick and Surenkhorloo (2005).

Sampling sites and period: The sampling replicates and dates were different among the sites and a total of 77 samples (Table 3-1) were taken between the years 2007 and 2009 for seven sites including two additional sites referred by Schäffer (2014). As mentioned before, this study was conducted under the long-term biomonitoring program in the Kharaa River Basin and the joint data was established as a result of project. Therefore, the samples in the study years and at the sites are distinguished to the referring authors (Table 3-1). Benthic samples were taken monthly during the ice free period from May to October in 2007 and 2008. However, due to severe environmental conditions, e.g. flooding events, sampling was not conducted in May and August 2007 and October 2008. The sampling frequency was increased to every second week at three sampling sites (*Sug_1*, *Kh_8.5*, and *Kh_5*) to focus on secondary production estimations in 2009.

Table 3-1: The benthic sampling replicates at seven sites along the Kharaa River during the years of 2007-2009. Boldface sampling sites refer to additional study sites from Schäffer (2014).

Ecoregion	Site	Year 2007	Year 2008	Year 2009	SUM (n)
Upper reach	Sug_1	4 (2)	4 (2)	7 (0)	**15 (4)**
Middle Reach	Kh_8.5	4 (2)	5 (2)	7 (0)	**16 (4)**
	Kh_8	4 (2)	5 (2)	2 (2)	**11 (6)**
	Kh_7	1 (1)	1 (1)	2 (2)	**4 (4)**
	Kh_5	4 (2)	5 (2)	8 (0)	**17 (4)**
	Kh_4	1 (1)	2 (2)	2 (2)	**5 (5)**
Down reach	Kh_2	4 (2)	5 (2)	0 (0)	**9 (4)**
Summe					**77 (31)**

Note: The numbers given in the brackets with gray color display data provided by Schäffer (2014) under the long term biomonitoring program of MoMo Project.

3.2 EMERGENCE STUDY

Field sampling: For project II, three pyramidal emergence traps of type 'Model week' (LeSage & Harrison, 1979), with a free internal surface of 0.37 m^2 and commercial fly screen approximately 1.0 mm mesh size were installed at each site. Emergence traps were positioned relatively close to the river bank due to the high velocity and river depth (Fig. 3-3; Photo 2). The emergence collecting bottle which had a volume of 500 ml was filled by 250 mm of 80% ethanol and ethylene glycol (3:1) and emptied every week (Fig. 3-3). Additionally, sweep-netting collection was also completed in order to collect adults while insects were swarming or sitting on the grass or trees along the river bank in order to (i) catch the taxon, which was not found in the emergence traps, and (ii) to compare the taxa diversity from sweep netting collections with the results from emergence traps.

Laboratory procedure: The samples had been transferred to 80% ethanol and sorted under a dissecting microscope (Stemi DV4/Dr, Carl-Zeiss AG). Taxonomic identification for individuals in the EPT group was completed. After correct taxonomic determination, the individuals for each identified taxa were counted.

Taxonomical identification: Identification on sub-imago and imago stages was completed to the species level, except for some individual females at the genera level. The literature of Malicky (1983), Lera (Ed.) (1986; 1997), Bauernfeind and Humpesch (2001), Nilsson (Ed.) (2005), Sivec *et al*. (2005), and Zwick and Surenkhorloo (2005) were used during the identification process.

Sampling sites and period: In both study years of 2008 and 2009, the emergence traps were installed from the beginning of May until the end of October (Table 3-2). Nevertheless, the emergence traps were taken out for 20 to 44 days, during the strong run-off period at the study sites (Photo 3) and installed again when it returned to normal flows. Initially all five sampling sites along the Kharaa River were planned for the emergence study, the site *Kh_8* was excluded due to a lack of working capacity at this site. The study was conducted at 4 different sites (*Kh_2*, *Kh_5*, *Kh_8.5*, and *Sug_1*) in 2008 and 3 sites (*Kh_5*, *Kh_8.5*, and *Sug_1*) in 2009. There were two reasons reducing the sampling sites in 2009. Firstly, the results obtained in 2008 presented that emergence abundance at the site *Kh_2* was insufficient for identifying the emergence period of selected species at the site. Secondly, the benthic sampling campaign was conducted at only these three sites. Sweep net collections were carried out in 2009 at selected five sites.

Table 3-2: Date and duration of emergence traps installed in the Kharaa River, 2008-2009

Site	Started date	Ended date	Absent days
Kh_2	01.05.2008	14.09.2008	23
Kh_5	03.05.2008	26.09.2008	23
	09.05.2009	23.09.2009	44
Kh_8.5	06.05.2008	30.09.2008	40
	10.05.2009	24.09.2009	35
Sug_1	05.05.2008	01.10.2008	20
	11.05.2009	25.09.2009	41

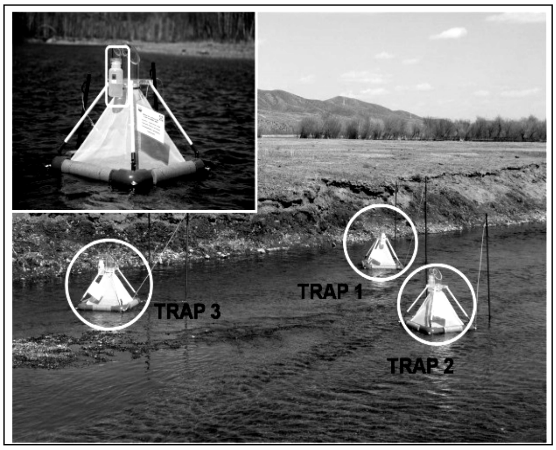


Fig. 3-3: Three emergence traps at the Site *Kh_5*; Collecting bottles are shown principally (upper left corner), photo by Kraetz, D.

3.3. ESTIMATION OF LARVAL BIOMASS, SECONDARY PRODUCTION AND GROWTH RATE OF THE SELECTED SPECIES

Biomass: Larval biomass (mg dry weight = DW) of selected species for was calculated using the length-mass equation 1:

$$\boxed{\mathbf{DW = aL^b}} \qquad (1)$$

where '*a*' and '*b*' are constants, and *L* is the larval body length in mm or head in mm width, but it is only for *Hydropsyche* (*Ceratopsyche*) *kozhantschikovi*. The references for the constants of selected species are listed in table 3-3. In order to estimate the percentage of larval biomass of selected species in the total biomass of Ephemeroptera, Plecoptera, and Trichoptera, additional biomass data of EPT group were provided by Schäffer (2014).

Table 3-3: The values of *a*, and *c* constants from length-mass regression equation are used for the dry mass calculation of selected species in the Kharaa River. The values are known from different sources.

No	Taxon	*a*	*b*	Source
1	*Agapetus jakutorum**	0.0092	2.888	Benke *et al.* (1999)
2	*Agnetina brevipennis/extrema*	0.0082	2.819	Schäffer (2014); *Agnetina* sp.
3	*Alaskaperla longidentata**	0.0062	2.724	Benke *et al.* (1999); *Sweltsa sp.*
4	*Baetis ussuricus*	0.0075	2.423	Wallace & Gurtz (1986); *Baetis spp.*
5	*Brachycentrus americanus*	0.0025	2.600	Benke *et al.* (1999); *Brachycentrus sp.*
6	*Brachycercus harrisellus*	0.0054	2.842	Benke *et al.* (1999); *Caenis sp.*
7	*Drunella cryptomeria*	0.0019	3.460	Hawkins (1986); *Drunella sp.*
8	*Epeorus pellucidus*	0.0056	2.926	Benke *et al.* (1999); *Epeorus sp.*
9	*Ephemera orientalis*	0.1236	1.610	Schäffer (2014); *Ephemera sp.*
10	*Ephoron nigridorsum*	0.0020	3.050	Giberson & Galloway (1985); *Ephoron album*
11	*Glossosoma nylanderi**	0.0092	2.888	Benke *et al.* (1999)
12	*Goera tungunensis*	0.0109	4.245	Meyer (1989); *Goeridae*
13	*Hydropsyche kozhantschikovi*	0.0082	2.819	Benke *et al.* (1999); *Hydropsyche spp.*
14	*Leuctra fusca*	0.0025	2.744	Benke *et al.* (1999); *Leuctra sp.*
15	*Micrasema gelidum**	0.0181	2.410	Benke *et al.* (1999); *Micrasema sp.*
16	*Paraleptophlebia chocolata*	0.0061	2.624	Benke *et al.* (1999); *Paraleptophlebia sp.*
17	*Psychomyia flavida*	0.0039	2.873	Benke *et al.* (1999); *Lype diversa*
18	*Uracanthella lenoki*	0.0088	2.584	Benke *et al.* (1999); *Seratella sp.*

Note: *indicates that ash-free dry mass (AFDM) was used instead of dry mass. % ash content of dry mass is given by Benke *et al.* (1999). The factors of AFDM are 1.071 for *A. jakutorum*, 1.041 for *A. longidentata*, 1.071 for *G. nylanderi*, and 1.078 for *M. gelidum*.

Secondary production: The secondary production was calculated using the size frequency method (the non-cohort technique) after Benke and Huryn (2006) (Equation 2). The non-cohort technique was used for samples collected throughout the year to approximate a mortality curve of the average cohort.

$$\boxed{P=c\sum(N_j-N_{j+1})(W_jW_{j+1})^{0.5}365/CPI} \qquad (2)$$

where P is the annual-production, c is the number of size classes (j=1 to c), N_j is the mean number of individuals of size-class j during the year, W_j is the mean mass of size-class j and CPI is the cohort production interval (mean time from hatching to the final size class).

Instantaneous growth rate: The noncohort method was used for the estimation of growth rate as well. Equation 3 displays the daily instantaneous growth rate (Benke & Huryn, 2006):

$$\boxed{g= \frac{\ln (W_{t+\Delta t} / Wt)}{\Delta t} \times 100\%} \qquad (3)$$

where W_t is the mean mass of an individual at time t, $W_{t+\Delta t}$ is the mean mass of an individual at time $t+\Delta t$, and Δt is the length of the time interval.

3.4 WATER AND AIR TEMPERATURE

Air temperature data was measured at 15 minute intervals using the HOBO H21 weather station (Massachusetts, USA) set up at the site *Kh_8.5* (in the middle reach). The air temperature results only from 2008 and 2009 were compared due to emergence studies (Table 3-6).

Water temperature was recorded at 30 minute intervals at sites *Sug_1*, *Kh_8.5*, *Kh_7*, *Kh_5*, and *Kh_4*, using water temperature loggers (EBI 85-A from Ebro Electronic GmbH & Co. KG, Ingolstadt, Germany). The measurement duration differed among the sites (Table 3-6). Continuous data of water temperature is only available at the sites *Sug_1* and *Kh_8.5* containing one year of data (24/08/2008 to 25/08/2009). For the remaining sites (*Kh_7*, *Kh_5*, and *Kh_4*), the temperature loggers were installed only in 2009 by the end of May. Therefore, a set of simultaneously water temperature data were obtained during a 3 month period (from 05/28 to 08/25) at five sites and a comparison among the sites was completed (Table 3-6).

Data on air and water temperature were provided by MoMo project (Schäffer, 2014).

3.5 SUBSTRATE COMPOSITION

The substrate composition at the sites was estimated based on the microhabitat list given in the site protocol (Haase *et al.*, 2004). This was assessed by repeated visual assessments from the coverage of the river bank wherever possible in order to not disturb the substrate. The visual assessments were tested while sampling the macroinvertebrate. Thirteen different mineral and organic substrate types were distinguished and the descriptions on substrate category and abbreviations are shown in Table 3-4.

Table 3-4: Description on the mineral and organic substrate classification and short description of substrate composition.

No	Substrate classification	Short description
	MINERAL SUBSTRATES	
1)	Megalithal (large boulders, size of >40 cm)	Megalithal
2)	Macrolithal (boulders size of >20 cm-40 cm with smaller fractions)	Macrolithal
3)	Mesolithal (cobbles size of >6 cm -20 cm with smaller fractions)	Mesolithal
4)	Microlithal (course gravel, size of >2 cm -6 cm)	Microlithal
5)	Acal (gravel, size of >0.2 cm -2 cm)	Acal
6)	Psammal / Psammopel (sand or mineral mud, size of >6 µm-2 mm)	Psamm
	ORGANIC SUBSTRATES	
7)	Algae	Algae
8)	Submerged macrophytes	Sub/Mac
9)	Emergent macrophytes	Emerg/Mac
10)	Living parts of terrestrial plants	Terr/P
11)	Xylal (coarse woody debris)	Xylal
12)	CPOM (coarse particulate organic matter)	CPOM
13)	FPOM (fine particulate organic matter)	FPOM

3.6 DATA AND STATISTICAL ANALYSIS

3.6.1 Data analysis

The data analysis in this thesis is based on the joint data base (Table 3-5) and the following given parameters, sampling sites and years are presented (Table 3-6). The findings are demonstrated in the result section as well as the appendix.

Table 3-5: Relevant references for data sources in this thesis.

	Parameters	**Source**
1	Air temperature	Schäffer (2014)
2	Water temperature	Schäffer (2014)
3	Substrate composition	Own data & Schäffer (2014), see table 3-1
4	Emergence (taxa richness & density)	Own data
5	EPT taxa richness from benthic data	Own data & Schäffer (2014), see table 3-1
6	Larval density	Own data & Schäffer (2014), see table 3-1
7	Larval biomass of selected species	Own data
8	Larval biomass of EPT group	Schäffer (2014)
9	Larval body length and head width of selected species	Own data & Schäffer (2014), see table 3-1
10	Secondary production	Own data
11	Growth rate	Own data

Table 3-6: Relevant parameters, study periods and sampling sites.

		Parameter & unit	Period	Site
1	*Air temperature*	temperature [°C]	2008 & 2009	*Kh_8.5*
2	*Water temperature*	temperature [°C]	24/08/2008-25/08/2009 3 months in 2009: 05/28-08/25	*Sug_1* & *Kh_8.5* *Sug_1*; *Kh_8.5*; *Kh_7*; *Kh_5*; *Kh_4*
3	*Emergence patterns of EPT group*	emergence density [ind m^{-2} $week^{-1}$]	2008 & 2009	4 sites in 2008 & 3 sites in 2009
4	*Distribution of selected EPT species at the sites*	larval mean density [ind m^{-2}] & biomass [mg DW m^{-2}] emergence density [ind m^{-2} $week^{-1}$]	2007-2009 2008-2009	all seven sites 3 sites in 2008 & 2009 without *Kh_2*
5	*Life cycle development of selected EPT species*	larval body length [mm], head capsule width [mm], larval [ind m^{-2}] & emergence [ind m^{-2} $week^{-1}$] densities	2007-2009	all seven sites for benthic data; 3 sites for emergence data
6	*Productions of selected EPT species*	mean individual biomass [mg DW m^{-2}] & density [ind m^{-2}] at identified larval stages	2009	*Sug_1*; *Kh_8.5*; *Kh_5*
7	*Growth rates of EPT species*	mean mass of an individual at time t [mg DW m^{-2}]	2007-2009	*Sug_1*; *Kh_8.5*; *Kh_5*

Temperature and substrate composition: Mean annual and monthly (from May to October) results with maximum and minimum air temperatures were displayed in 2008 and 2009. Daily maximum and minimum temperatures in 2008 and 2009 are shown in the results chapter using line plot graphs (Fig. 4-1). The continuous water temperatures over a year were presented at two sites and simultaneously water temperature data obtained during a 3-month period at five sites (Table 3-6). As for microhabitat distributions at seven sites along the Kharaa River, the mean percentage of mineral and organic substrates were calculated using the data (see Table 3-1) from all sampling periods from 2007 to 2009.

Emergence patterns of EPT group: Emergence patterns were displayed for Ephemeroptera, Plecoptera and Trichoptera at 4 sites in 2008 and 3 sites in 2009 (Table 3-6). The emergence period was considered for a total of 21 weeks in 2008 and 20 weeks in 2009 during the ice free period. The mean emergence of three emergence traps at each site was calculated for per week. Therefore, the mean emergence densities of Ephemeroptera, Plecoptera, and Trichoptera were estimated at each site by the total sampling number of n=63 (21 weeks x 3 traps) in 2008 and n=60 (20 weeks x 3 traps) in 2009. Overall mean emergence of EPT group and each selected species at all three sites during the years of 2008 and 2009 was estimated by the total sampling number of n=369 (41 weeks x 3 traps x 3 sites). Note the periods with flood events were included in the estimations.

Distribution of selected EPT species at the sites: To present the distribution of selected species and differences among the sites, the mean larval (n=77) and emergence densities (n=369) at each site were calculated using the data from all sampling periods.

Life cycle development: Due to the location of the sampling sites, a similar temperature regime and a synchronised emergence period between years, large longitudinal differences in larval development within the basin were not expected. In order to enhance the validity of the results, data were pooled from all sampling sites, where the selected species were distributed, to create the life cycle development figures (Table 3-6). A main reason of extending data source from two sites (*Kh_7* and *Kh_4*) in the middle reach referred by Schäffer (2014) was insufficient abundance of certain species with high individual biomass.

To plot the length distribution showing life cycle development, two types of figures were created. The body length and head-capsule width data were pooled from three years (2007-2009) of results at all sites, and the weekly results were shown in the results chapter (Fig. 4-13a to 28a; 30a; 32a) using the box-and-whisker graphs. However, the size-frequency graphs for each species at each year are attached to the appendix (Fig. A-7 to A-24) in order to present the differences among years and validate the identified life cycle types. These two types of graphs were created using the open source R (R Development Core Team 2010, Version 2.10.1). The temporal fluctuation in larval and emergence density was presented together for each selected species. The larval density data were pooled from 2007 to 2009 and all sites. Bi-weekly results were shown for the period 25 April to 10 October in the results chapter using line plot graphs (Fig. 4-13b to 28b; 30b; 32b). The total sampling number for larval densities of all species, at all sites for three years was 77. One exception included three particular species (Fig. 4-20b; 4-23b; 4-27b) due to their dominant distribution at only one or two sites. The emergence periods for selected species were determined using the weekly emergence density at the sites. The emergence density data were pooled from 2008 and 2009 and all sites. Weekly results were shown in the results chapter using bar plot graphs (Fig. 4-13b to 28b; 30b; 32b). Within the selected species for life cycle study, four mayfly species were not caught in the emergence traps. Therefore, the emergence period was estimated by using the adults found in the sweep netting collections in co-occurrence with mature larvae showing dark wing pads of mayflies in the benthic samples. The sex ratio for adults of each species was estimated for all individuals in the emergence traps and sweep netting collection.

Secondary production and growth rate: The secondary production could only be estimated in 2009 for three sites (*Sug_1*; *Kh_8.5*; *Kh_5*) where the sampling frequency was increased (Table 3-6). However, the secondary production could not be estimated for all selected species and at all three sites due to insufficient abundance.

The growth rates of selected species with univoltine life cycle were estimated for the same three sites (*Sug_1*; *Kh_8.5*; *Kh_5*) in 2007-2009. However, to display a growth rate difference among the sites was not possible due to insufficient abundance and sampling replicates, in particular, during 2007 and 2008. As a result, a total number of estimated data from these univoltine species was 150 (n=65 for summer cycle species; n=85 for winter cycle species). Therefore, the median, minimum, and maximum daily growth and growth rate were calculated for selected species. Using the daily growth (median and maximum) and cohort production interval (CPI) or mean time from hatching to the final size class, the individual biomass was calculated. These calculated results were compared to the results from measurements.

3.6.2 Statistical analysis

Data normality for water and air temperatures was assessed with the Shapiro-Wilk test. Depending on normal or non-normal distribution of the variables, the statistical tests were chosen. A paired Wilcoxon test was used to assess whether there were differences in the daily mean, maximum, and minimum air temperatures at the site *Kh_8.5* between two years of 2008 and 2009 and months from May to September for each year. The paired Wilcoxon test was also performed on the daily mean, maximum, and minimum water temperatures at two sites (*Sug_1* and *Kh_8.5*) in the period of 24 Aug 2008 and 25 Aug 2009. However, Related Samples Friedman's Two-Way ANOVA test was used to assess whether there were differences in the water temperature at five sites (*Sug_1*, *Kh_8.5*, *Kh_7*, *Kh_5*, and *Kh_4*) during the months June to August in 2009. A Kruskal–Wallis one-way analysis of variance was used to assess whether there were differences in the emergence density of Ephemeroptera, Plecoptera, and Trichoptera sampled at weekly intervals, from three sites during the years 2008 and 2009. Data normality was assessed with the Shapiro–Wilk test. All statistical analyses were completed using the SPSS statistical software (IBM SPSS Statistics 2011, Version 20).

Chapter 4

RESULTS

4.1 TEMPERATURE

4.1.1 Air temperature

The air temperature record in 2008 and 2009 at the most upstream site in the middle-reaches is shown in figure 4-1. The annual mean air temperature was -2.04 °C in both years (Table 4-1) and there was no significant difference for daily mean ($P>0.05$), maximum ($P>0.05$), and minimum ($P>0.05$) temperatures between the years (Table 4-2). The mean air temperature from May to September in the two years showed the same result of 12.9 °C while emergence traps were installed (Table 4-1) and there were no differences between the years as well ($P>0.05$ for daily mean, maximum and minimum temperatures; Table 4-2). The monthly mean temperatures for May to September did not show a high variance between the two years (Table 4-1). Nevertheless, statistically there were significant differences for the daily mean ($P<0.005$), maximum ($P<0.005$), and minimum ($P<0.05$) temperatures in May and the daily minimum temperatures in June ($P<0.05$) between the years 2008 and 2009 (Table 4-2).

Table 4-1: Annual and monthly mean air temperature at the site *Kh_8.5* in 2008 and 2009 (*SE*= standard error; Max= maximum temperature; Min= minimum temperature). Monthly temperatures from May to September are shown and emergence traps were installed in these months in both years.

	Air temperature (°C) in 2008					Air temperature (°C) in 2009				
	n	Mean	*SE*	Max	Min	*n*	Mean	*SE*	Max	Min
Annual	35136	-2.04	0.09	34.0	-43.2	35040	-2.04	0.09	31.1	-41.3
May-Sep	14590	12.90	0.07	34.0	-8.91	14590	12.89	0.06	31.1	-6.81
May	2977	6.76	0.14	27.9	-7.9	2977	10.47	0.16	30.3	-6.8
Jun	2880	15.60	0.12	34.0	-1.1	2880	14.29	0.13	29.5	-2.4
Jul	2976	17.92	0.11	32.8	5.4	2976	17.25	0.10	30.7	3.7
Aug	2975	15.12	0.14	32.8	-2.0	2975	14.54	0.12	31.1	-0.6
Sep	2880	8.95	0.14	25.6	-8.9	2880	7.61	0.14	27.5	-6.8

There is a distinct daytime variability of air temperature during the year (Fig. 4-1). For instance, maximum temperature reached up to 14 °C during daylight hours, while the minimum temperature was -8 °C on 05 May 2008. Air temperatures of below 0 °C during night hours were measured until early June in both years. From middle of September, the nights became cold and temperatures with lower than 0 °C were often measured.

Table 4-2: The results of a paired Wilcoxon test for differences of daily mean, minimum, and maximum temperatures at the site *Kh_8.5* among the months and years. Boldface numbers refer to the significant levels.

	Daily mean temperature		Daily maximum temperature		Daily minimum temperature	
Factors	Z	P value	Z	P value	Z	P value
2008 x2009	-0.453	0.650	-0.885	0.376	-0.174	0.862
May-Sep 2008 x May-Sep 2009	-0.383	0.701	-0.122	0.903	-0.006	0.995
May 2008 x May 2009	-3.037	**0.002**	-3.198	**0.001**	-2.411	**0.016**
Jun 2008 x June 2009	-1.183	0.237	-0.463	0.644	-2.004	**0.045**
Jul 2008 x Jul 2009	-1.098	0.273	-1.803	0.071	-0.082	0.934
Aug 2008 x Aug 2009	-0.510	0.610	-0.757	0.449	-0.514	0.607
Aug 2008 x Aug 2009	-1.697	0.090	-0.946	0.344	-0.751	0.453

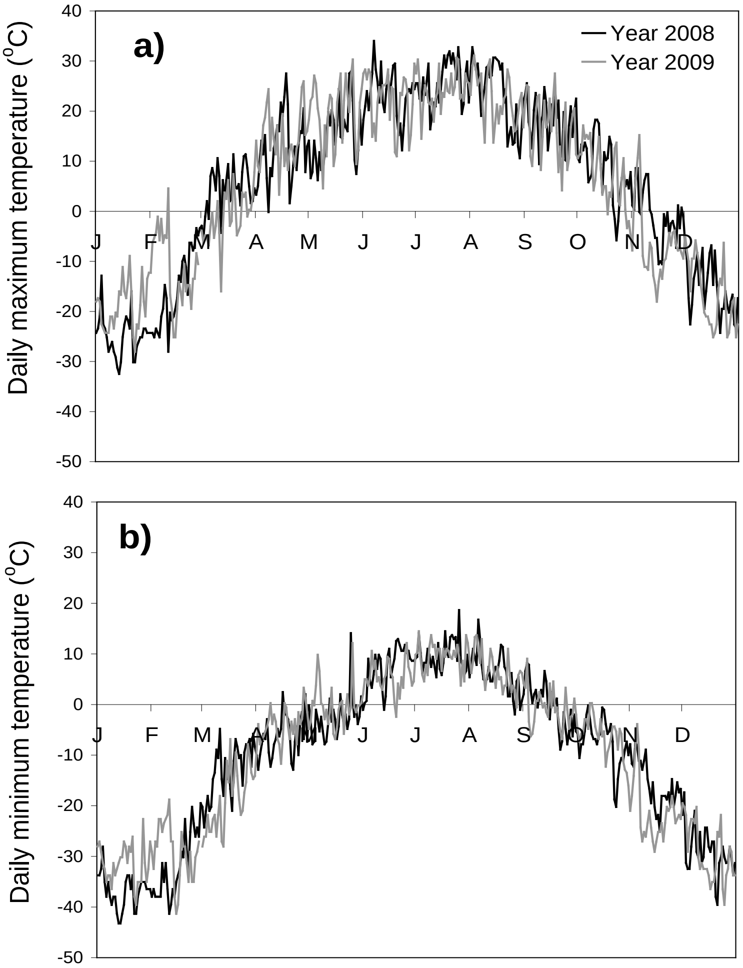


Fig. 4-1: Daily **a)** maximum and **b)** minimum air temperatures [°C] at the site *Kh_8.5* from 01 January to 31 December in 2008 and 2009.

4.1.2 Water temperature

Water temperatures measured at two upstream sites (Fig. 4-2) and the mean annual water temperature (±*SE*) was 4.38 ± 0.04 °C (*n*=17548) at the site *Sug_1* and 5.03 ± 0.06 °C (*n*=17523) at the site *Kh_8.5* during the period starting the 24th of August 2008 until the 25th August 2009. Furthermore, there were significant different (with a paired Wilcoxon test) daily mean (*Z*=-5.920; *P*<0.001), maximum (*Z*=-6.126; *P*<0.001), and minimum (*Z*=-4.819; *P*<0.001) were measured. Water temperatures with 0 °C (Fig. 4-2a) and below (Fig. 4-2b) were measured from October to April.

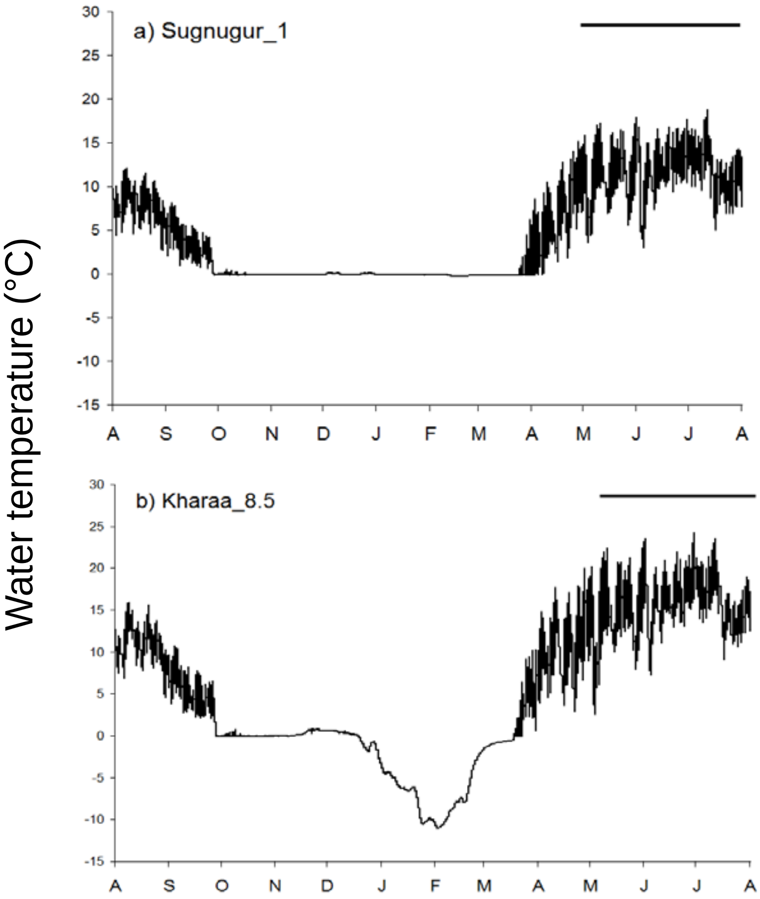


Fig. 4-2: Water temperature [°C] from 24 August 2008 to 25 August 2009 at the sites of **a)** *Sug_1* (Sugnugur_1) and **b)** *Kh_8.5* (Kharaa_8.5) in the Kharaa River. The black line displays the period for comparative results of temperature at five sites (*Sug_1*, *Kh_8.5*, *Kh_7*, *Kh_5* and *Kh_4*).

The longitudinal gradient for water temperature is displayed for five sites along the Kharaa River during the period from the 28th of May until the 25th of August 2009 (Fig. 4-3). The mean monthly water temperatures from June to August (Table 4-3) showed the minimum water temperatures were recorded in the upper reach for each month and increased at the sites in the middle reaches. The results of Related Samples Friedman's Two-Way ANOVA test indicated a significant difference for daily mean temperatures between the sites for each month or June (χ^2 or chi-square=82.773; *P*<0.001), July (χ^2=110.978; *P*<0.001), and Aug (χ^2=86.533; *P*<0.001). Post-hoc analysis with a paired Wilcoxon test did not show any differences only between the sites *Kh_5* and *Kh_4* for three months (Table 4-4).

Table 4-3: Mean monthly water temperature [°C] at five sites along the Kharaa River (mean±*SE*) for the period starting from the 01 June 2009 to 25 August 2009.

	n	Sug_1	Kh_8.5	Kh_7	Kh_5	Kh_4
Jun	1440	11.32±0.08	14.96±0.09	12.93±0.08	14.68±0.08	14.69±0.08
Jul	1488	12.88±0.05	17.09±0.06	17.08±0.05	18.29±0.05	18.24±0.06
Aug	1183	11.26±0.08	15.41±0.08	15.37±0.07	17.15±0.06	17.13±0.07
Jun-Aug	4111	11.87±0.04	15.86±0.05	15.14±0.05	16.7±0.05	16.7±0.05

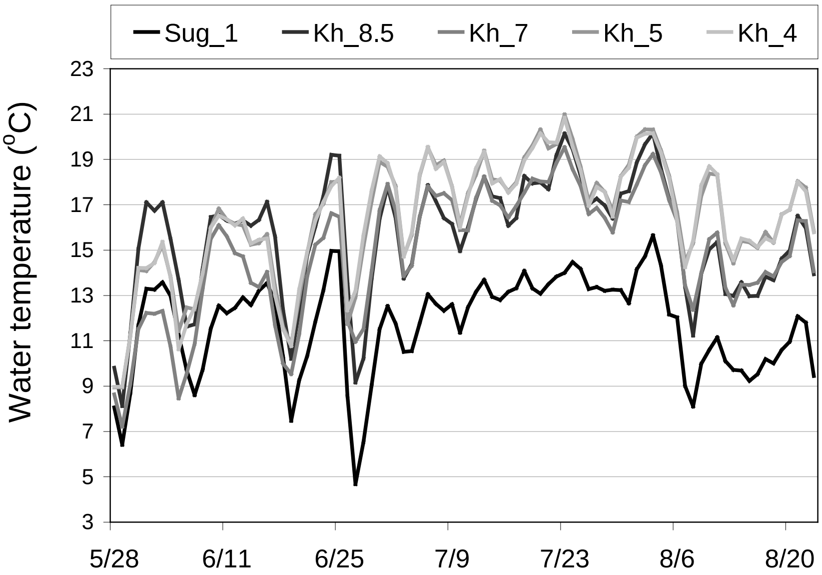


Fig. 4-3: Daily mean water temperature [°C] from the 28 May 2009 to the 25 August 2009 at five sites along the Kharaa River.

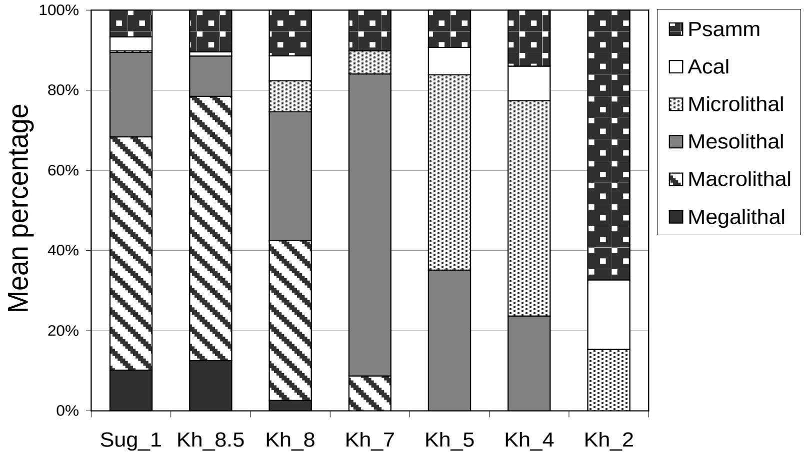
Table 4-4: The results of Post-hoc analysis with a paired Wilcoxon test for differences in the water temperatures between the sites during the months from June to August in 2009. Boldface numbers refer to the significant levels.

JUNE	*Sug_1*	*Kh_8.5*	*Kh_7*	*Kh_5*	*Kh_4*
Sug_1	-	-	-	-	-
Kh_8.5	**<0.001**	-	-	-	-
Kh_7	0.221	**<0.001**	-	-	-
Kh_5	**<0.001**	0.327		-	-
Kh_4	**<0.001**	0.514	**<0.001**	0.744	-
JULY	*Sug_1*	*Kh_8.5*	*Kh_7*	*Kh_5*	*Kh_4*
Sug_1	-	-	-	-	-
Kh_8.5	**<0.001**	-	-	-	-
Kh_7	**<0.001**	0.872	-	-	-
Kh_5	**<0.001**	**<0.001**	**<0.001**	-	-
Kh_4	**<0.001**	**<0.001**	**<0.001**	0.335	-
AUGUST	*Sug_1*	*Kh_8.5*	*Kh_7*	*Kh_5*	*Kh_4*
Sug_1	-	-	-	-	-
Kh_8.5	**<0.001**	-	-	-	-
Kh_7	**0.001**	0.893	-	-	-
Kh_5	**<0.001**	**<0.001**	**<0.001**	-	-
Kh_4	**<0.001**	**<0.001**	**<0.001**	0.623	-

4.2 SUBSTRATE COMPOSITION

Mineral substrate classes contributed 75 to 100 % of the benthic surface at the study sites from 2007-2009 in the Kharaa River. Organic substrates consisting of algae, submerged macrophytes, emergent macrophytes, living parts of terrestrial plants, 'Xylal', CPOM and FPOM contributed to the substrate with 0 to 25 %. The substrate composition in the Kharaa River changes significantly from upstream to downstream (Schäffer, 2014, own data; Fig. 4-4).

a) Mineral substrates



b) Organic substrates

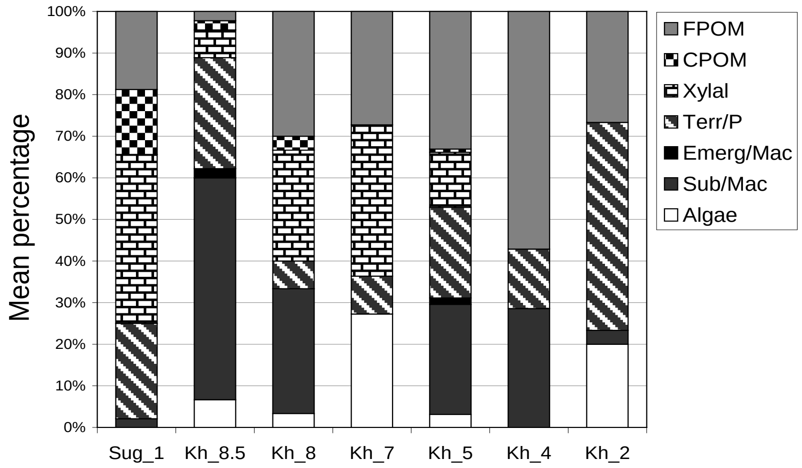


Fig. 4-4: Benthic mineral **(a)** and organic **(b)** substrate compositions at seven selected sites in the Kharaa River as mean values from all samplings (*n*=77) in the years 2007-2009.

Large boulders and rocks are the dominate substrate from the upstream to upper middle reaches. At the sites of *Sug_1*, *Kh_8.5*, and *Kh_8* the substrates of 'Megalithal' and 'Macrolithal' were dominant with variable percentages of smaller fractions, i.e. 'Mesolithal' and 'Psammal/Psammopelal' in between. Then the substrate changes to cobbles and course gravel in the lower middle reach. The substrates classified as 'Mesolithal' and 'Microlithal' were predominantly distributed at the sites *Kh_7*, *Kh_5*, and *Kh_4* as shown by the composition of the sampled substrate of this multi-habitat approach (Fig. 4-4a). The downstream reaches (*Kh_2*) were dominated by finer grain sizes, i.e. sand where the substrate types of 'Microlithal', 'Acal' and 'Psammal/Psammopelal' were identified. Concerning the organic substrates, CPOM was found in the most upstream sites in the upper and middle reaches (*Sug_1*, *Kh_8.5*, and *Kh_8*). In contrast, the percentage of FPOM and algae increased in the middle and downstream reaches of the river (Fig. 4-4b).

4.3 EMERGENCE PATTERNS OF EPT GROUP

During the years of 2008 and 2009, a total of 43 species belonging to the EPT group were identified in the samples from 21 emergence traps (Table 4-5). The majority of emerging insects among the EPT group was consisting of Trichoptera belonging to 23 species with 62% of total EPT abundance. Twelve species of Ephemeroptera were found with an abundance of 27%. Only 8 species of Plecoptera distributed by 11% within the EPT group. Fourteen species from the EPT group which were found in the emergence traps were analyzed further on the life cycle and secondary production studies. *Agnetina brevipennis* and *A. extrema* were considered as a single taxa. These 14 species contribited over 85% of the total EPT abundance in the emergence traps. The results from emergence traps were compared to the collections of sweep netting along the Kharaa River (Table 4-5). A total of 45 EPT species consisting of 13 species of Ephemeroptera, 9 species of Plecoptera, and 23 species of Trichoptera were found in the sweep net. There were 32 EPT species distributing in both sampling methods.

Table 4-5: Total catches of EPT species from emergence traps (12 traps in 2008 and 9 traps in 2009) in the Kharaa River and from sweep netting collections in 2009 along the river. Their percentage in the total EPT abundance is presented. Boldface taxa refer to taxa regarded as life cycle and secondary production in this thesis.

		Emergence trap			Sweep net		
Order/Family	**Species**	♀	♂	%	♀	♂	%
EPHEMEROPTERA							
Baetidae	*Acentrella* sp.	9		0.30			
	Baetis fuscatus (Linnaeus, 1761)					1	0.12
	Baetis tuberculatus (Kazlauskas, 1963)		1	0.03			
	Baetis ussuricus (Kluge, 1983)	**339**	**233**	**18.8**	6	12	2.22
	Baetis vernus (Curtis, 1834)	19	15	1.12			
	Procloeon bifidum (Bengtsson,1912)	1	1	0.07			
Ephemerellidae	***Drunella cryptomeria*** (Imanishi, 1937)	**38**	**16**	**1.77**	17	18	4.33
	Drunella sp.(Needham, 1905)	3	1	0.13			
	Ephemerella ignita (Poda, 1761)				5	1	0.74
	Ephemerella nuda (Tshernova,1949)				2	1	0.37
Ephemeridae	***Ephemera orientalis*** (McLachlan,1875)				5	2	0.87
Heptageniidae	*Cinygmula putoranica* (Kluge, 1980)	20	8	0.92		1	0.12
	Ecdyogymnurus inversus (Kluge, 1980)	12	10	0.72			
	Epeorus pellucidus (Brodsky, 1930)	**17**	**10**	**0.89**	7	6	1.61
	Heptagenia flava (Rostock, 1877)	3	6	0.30	2	2	0.49
	Nixe joernensis (Bengtsson, 1909)	18	10	0.92	1	12	1.61
	Rhitrogena lepnevae (Brodsky, 1930)	10	10	0.66	26	34	7.42
Leptophlebiidae	***Paraleptophlebia chocolata*** (Imanishi,1937)	**7**	**6**	**0.43**			
Polymitarcyidae	***Ephoron nigridorsum*** ((Tshernova, 1934)				50	76	15.60
Siphlonuridae	*Siphlonurus chankae* (Tshernova, 1952)					2	0.25
PLECOPTERA							
Chloroperlidae	***Alaskaperla longidentata*** (Raušer, 1968)	**27**	**24**	**1.67**	2	4	0.74

Table: Continued.

		Emergence trap			Sweep net		
Order/Family	**Species**	♀	♂	%	♀	♂	%
	Haploperla lepnevae ((Zhiltzova et Zwick, 1971)	20	11	1.02	2	2	0.49
Leuctridae	***Leuctra fusca*** (Linnaeus, 1758)	**82**	**46**	**4.20**	37	25	7.66
Nemouridae	*Amphinemoura standfussi* (Morton, 1894)		1	0.03	7	5	1.48
Perlidae	***Agnetina brevipennis*** (Navás, 1912)	**31**	**17**	**1.58**	10	15	3.09
	Agnetina extrema (Navás, 1912)	**20**	**25**	**1.48**	5	14	2.35
Perlodidae	*Diura bicaudata* (Limnaeus, 1758)				3	1	0.49
	Isoperla kozlovi (Zhiltzova, 1971)	17	15	1.05	19	14	4.08
	Kaszabia spinulosa (Raušer, 1968)	4	5	0.30	1	1	0.25
TRICHOPTERA							
Apataniidae	*Apatania majuscula* (McLachlan, 1872)	7	1	0.26	2		0.25
	Apatania zonella (Zetterstedt, 1840)					1	0.12
Brachycentridae	***Brachycentrus americanus*** (Banks, 1899)	**111**	**9**	**3.94**	12	4	1.98
	Brachycentrus subnubilus (Curtis, 1834)	72	1	2.40			
	Micrasema gelidum (McLachlan, 1876)	**10**	**4**	**0.46**	3	28	3.83
Glossosomatidae	***Agapetus jakutorum*** (Martynov, 1934)	**48**	**44**	**3.02**	4	25	3.58
	Glossosoma intermedium (Klapalek, 1892)	9	4	0.43			
	Glossosoma nylanderi (McLachlan, 1879)	**130**	**78**	**6.83**	6	4	1.24
Goeridae	*Goera squamifera* (Martynov, 1909)				1		0.12
	Goera tungusensis (Martynov, 1909)	**17**	**23**	**1.31**	20	44	7.91
Hydropsychidae	***Hydropsyche kozhantschikovi*** (Martynov, 1924)	**994**	**56**	**34.5**	21	31	6.43
	Hydropsyche newae (Kolenati,1858)					6	0.74
Lepidostomatidae	*Lepidostoma hirtum (*Fabricius, 1775)	1	1	0.07			
Leptoceridae	*Ceraclea excise* (Morton, 1904)				1	2	0.37
	Ceraclea hastata (Botosaneanu, 1970)					1	0.12
	Ceraclea nigronervosa (Retzius, 1783)					1	0.12
	Ceraclea sibirica (Ulmer, 1906)	2	2	0.13	25	8	4.08
	Triaenodes levanidovae (Morse & Vshivkova, 1997)	9	11	0.66	7	4	1.36
Limnephilidae	*Anabolia servata* (McLachlan, 1880)	17	1	0.59		1	0.12
	Anabolia appendix (Ulmer, 1905)	20	13	1.08	1	3	0.49
	Asynarchus lapponicus (Zetterstedt, 1840)				2		0.25
	Brachypsyche rara (Martynov, 1914)		1	0.03			
	Hydatophylax nigrovittatus (McLachlan, 1872)				5	4	1.11
	Limnephilus politus (McLachlan, 1865)	1		0.03	1	1	0.25
	Limnephilus sp.(Leach, 1815)	5		0.16			
Phryganiidae	*Semblis atrata* (Cmelin, 1788)		1	0.03	2	1	0.37
Psychomyiidae	***Psychomyia flavida*** (Hagen, 1861)	**122**	**22**	**4.73**	13	44	7.05
Rhyacophilidae	*Rhyacophila egijnica* (Schmid, 1968)					1	0.12
	Rhyacophila lata (Martynov, 1918)	7	1	0.26		2	0.25
	*Rhyacophila mongolica (*Levanidova, 1993)	1	1	0.07			
	Rhyacophila nana (Levanidova, 1993)	5	1	0.20	1	3	0.49
	Rhyacophila sibirica (McLachlan, 1879)	3	9	0.39		4	0.49
	Rhyacophila sp.	4		0.13	3		0.37

The emergence patters of Ephemeroptera, Plecoptera, and Trichoptera differed between the sites and years (Fig. 4-5 & 4-6).

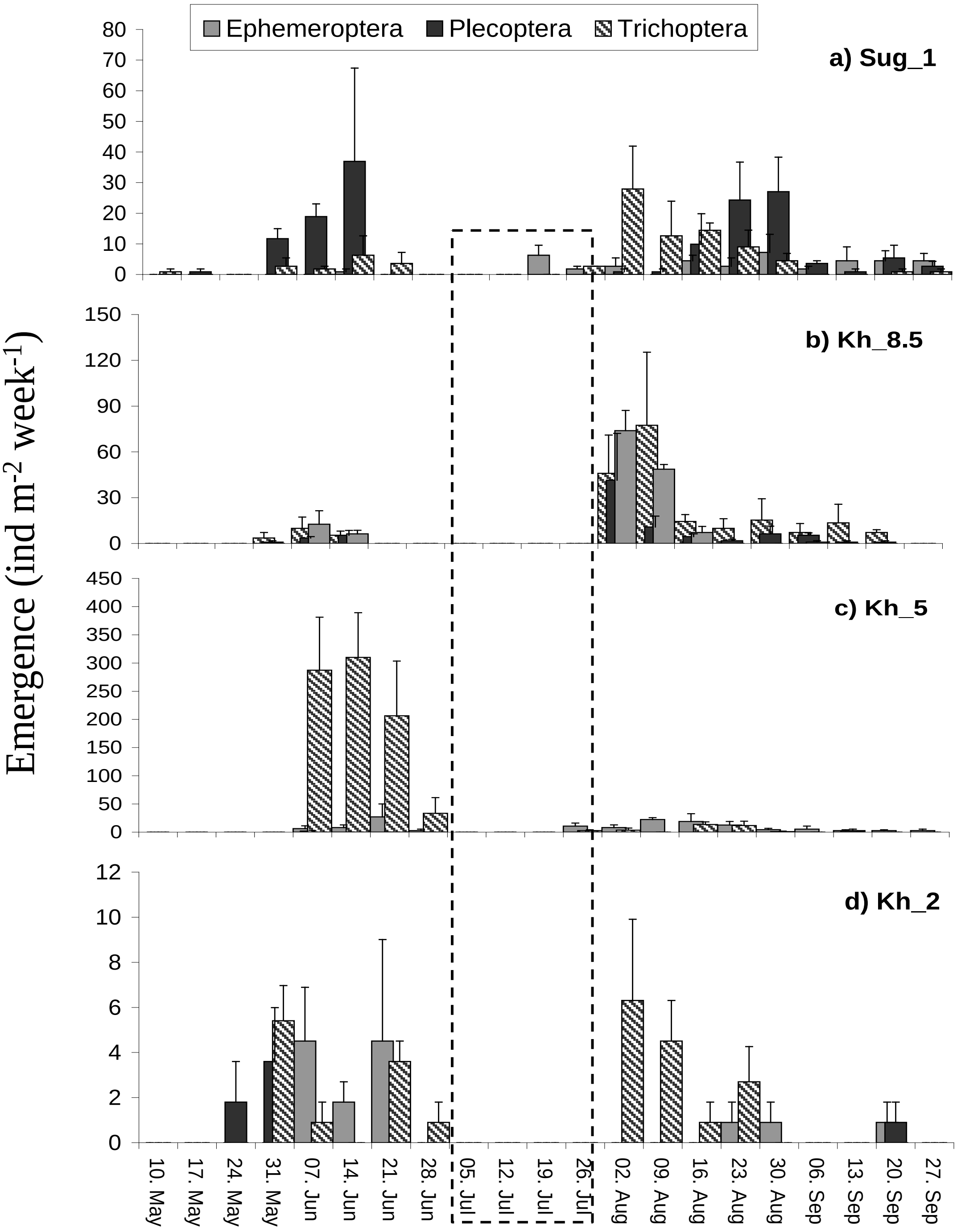


Fig. 4-5: Emergence development of EPT group at four sites in the Kharaa River from May to September in 2008. A dotted box presents the strong run-off period without sampling. Note unequal scaling of y-axis in the figure.

Emergence of EPT group in 2008 started at the site *Sug_1* earlier than other three sites (*Kh_8.5*, *Kh_5*, and *Kh_2*), but only single individuals of Plecoptera and Trichoptera were captured. A continuous emergence of Plecoptera and Trichoptera throughout the months from May to September could be identified at the site *Sug_1* in 2008. An emergence peak of these two orders could be recognized before and after the flood event in July. However, emergence of Ephemeroptera started from middle of July and continued until late September at the site *Sug_1*. Emergence density of Plecoptera decreased along the Kharaa River. The emergence peak of the EPT group occurred during August and September at the *site Kh_8.5* while it took place in June at the site *Kh_5*. The emergence time of Ephemeroptera, Plecoptera and Trichoptera at the site *Kh_8.5* was very similar, but emergence of Ephemeroptera ended earlier. The highest emergence density was found for Trichoptera in 2008 at the site *Kh_5*. Emergence density of the EPT group was the lowest at the site *Kh_2* in the down reach of the Kharaa River.

Emergence patterns of the EPT group at three sites in 2009 differed than the results found in 2008 (Fig. 4-5 and 4-6). There was a clear pattern of longtidtunal changes along the river. The emergence of EPT group at the site *Kh_5* started earlier than two other sites. Emergence density of Trichoptera decreased and Ephemeroptera were abundant at the site *Kh_5* compared to the results from 2008. It seemed that the emergence peak of EPT group at the most upstream site (*Sug_1*) could be much later and could occur in August and September.

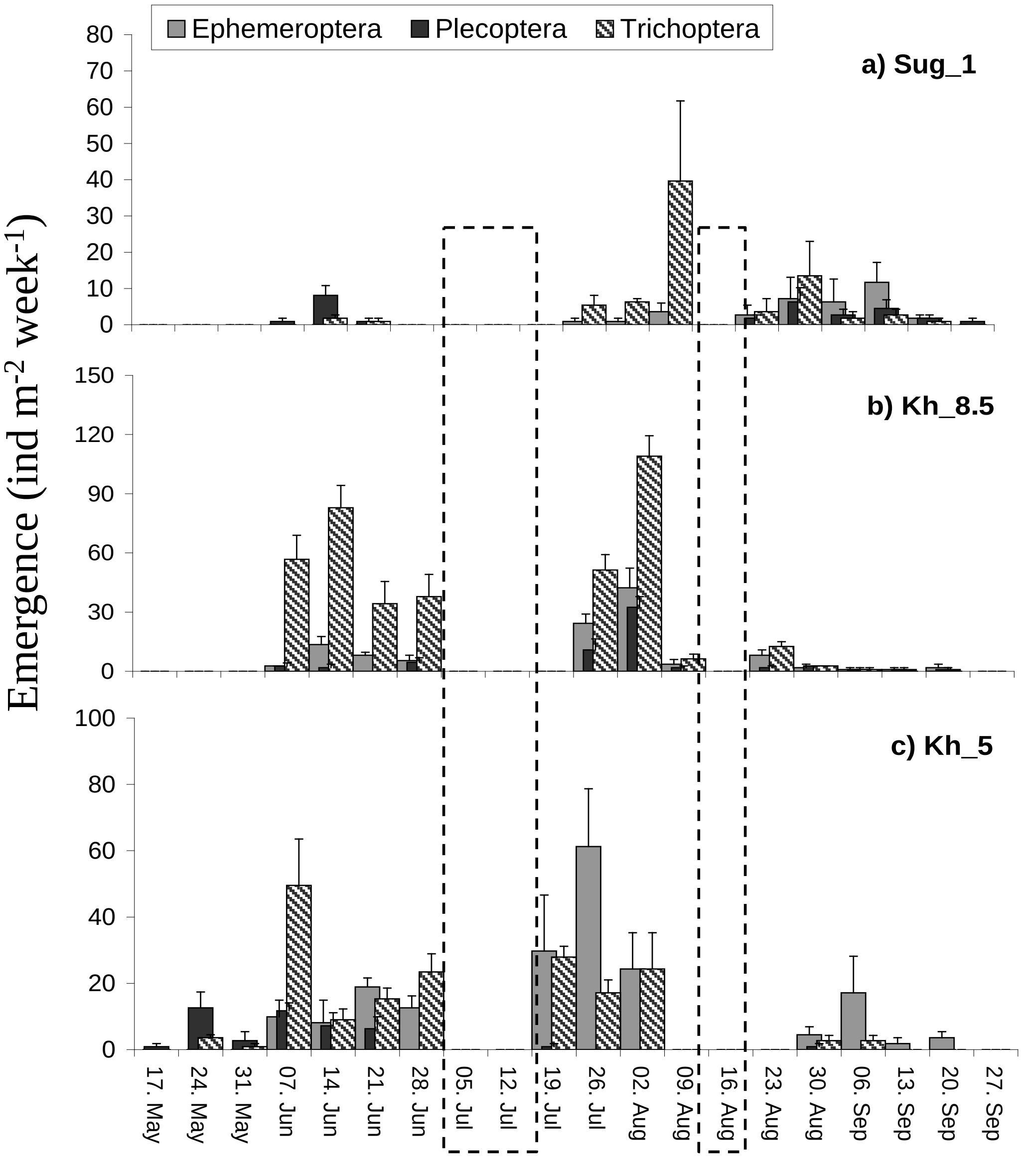


Fig. 4-6: Emergence development of EPT group at three sites in the Kharaa River from May to September in 2008. A dotted box presents the strong run-off period without sampling. Note unequal scaling of y-axis in the figure.

Sampling of the mayfly (Ephemeroptera) emergence in 2008 and 2009 resulted in a density of 6 ± 0.8 ind m^{-2} $week^{-1}$ (mean±*SE*; *n*=369). The highest emergence density was found at site *Kh_8.5* with 94 ind m^{-2} $week^{-1}$ in August 2008. The mean density of mayflies differed among the years at the three sites. The results of a Kruskal-Wallis test indicated a significant difference for mayfly emergence between the sites density but not between the years (Table 4-6). Post-hoc tests showed significant differences between the sites *Sug_1* and *Kh_8.5* (*P*=0.002), or *Sug_1* and *Kh_5* (*P*=0.000), but not between *Kh_8.5* and *Kh_5* (*P*=0.616).

Stoneflies (Plecoptera) in the emergence traps were found with a mean density of 3 ± 0.5 ind m^{-2} $week^{-1}$ (mean±*SE*; *n*=369). The highest emergence density was found at site *Kh_8.5* with 103 ind m^{-2} $week^{-1}$ in August 2008. Similar to the results of mayfly emergence the mean density of stoneflies differed between the years at the three sites. The results of a Kruskal-Wallis test indicated a significant difference for stonefly emergence density between the sites but not between the years (Table 4-6). Post hoc tests showed the significant differences between the sites *Kh_5* and *Sug_1* (*P*=0.001), or *Kh_5* and *Kh_8.5* (*P*=0.001), but not between *Sug_1* and *Kh_8.5* (*P*=0.961).

Sampling of the caddisfly (Trichoptera) emergence resulted in a density of 14 ± 2.6 ind m^{-2} $week^{-1}$ (mean±*SE*; *n*=369) in the years of 2008 and 2009. The highest emergence density was found at site *Kh_5* with value of 384 ind m^{-2} $week^{-1}$ in June 2008. The mean density of caddisflies also differed among the years at the three sites. The results of a Kruskal-Wallis test indicated a significant difference for caddisfly emergence density among the years but not among the sites (Table 4-6).

Table 4-6: Emergence density (ind m^{-2} $week^{-1}$; mean and standard error) of EPT group at three sites in the Kharaa River in 2008 and 2009 with the results of a non-parametric Kruskal-Wallis test for differences among sites and years.

		Ephemeroptera		**Plecoptera**		**Trichoptera**	
	n	**Mean**	***SE***	**Mean**	***SE***	**Mean**	***SE***
2008 DENSITY *Sug_1*	63	1.97	0.49	6.86	1.97	4.20	1.17
2008 DENSITY *Kh_8.5*	63	9.99	3.26	3.90	1.69	7.12	2.41
2008 DENSITY *Kh_5*	63	6.43	1.54	0.21	0.14	41.39	13.5
2009 DENSITY *Sug_1*	60	1.75	0.60	1.39	0.38	3.83	1.53
2009 DENSITY *Kh_8.5*	60	5.67	1.44	3.06	1.00	19.73	4.22
2009 DENSITY *Kh_5*	60	9.59	2.30	2.16	0.6	8.82	1.89
	df	**Chi-square**	**P value**	**Chi-square**	**P value**	**Chi-square**	**P value**
DENSITY *Sites*	2	15.7	0.000	14.8	0.001	4.01	0.135
DENSITY *Years*	1	0.130	0.718	0.004	0.953	4.73	0.030
DENSITY *Sites x Years*	5	16.4	0.006	25.98	0.000	14.64	0.012

4.4 LIFE CYCLE OF EPT SPECIES

4.4.1 Establishing the criteria for choosing species

A total of 140 EPT species consisting of 63 species of Ephemeroptera, 20 species of Plecoptera and 57 species of Trichoptera from 84 genera have been recorded in the benthic samples at seven sites (*Sug_1*; *Kh_8.5*; *Kh_8*; *Kh_7*; *Kh_5*; *Kh_4*; *Kh_2*) along the Kharaa River during 2007 to 2009 (Schäffer, 2014; own data). In this sampling period and at these sites, the mean EPT larval density (±*SE*) was 1867 ± 145.5 ind m^{-2} (n=77). Their mean biomass (±*SE*) was estimated by 1.42 ± 0.11 g DW m^{-2} (n=77). A total of 43 EPT species including 12 species of Ephemeroptera, 8 species of Plecoptera, and 23 species of Trichoptera were recorded in the emergence traps at four sites (*Sug_1*; *Kh_8.5*; *Kh_5*; *Kh_2*) along the Kharaa River. The mean EPT emergence density (±*SE*) was 23± 3.0 ind m^{-2} $week^{-1}$ (n=369) at three sites (*Sug_1*; *Kh_8.5*; *Kh_5*) in 2008 and 2009.

According their percentage in the EPT group the number of species from mayflies and caddisflies for the life cycle and secondary production study was higher than from stoneflies (Fig. 4-7).

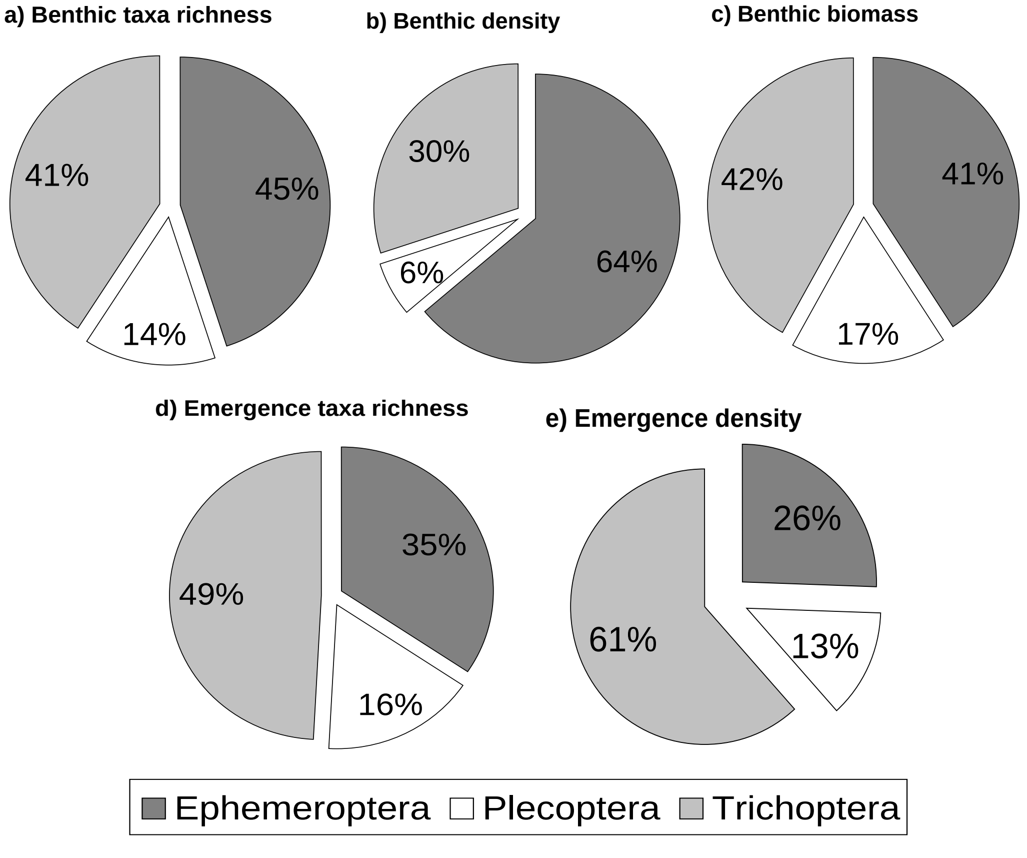


Fig. 4-7: The proportion of Ephemeroptera, Plecoptera and Trichoptera on all EPT species in five different categories. The percentages of Ephemeroptera, Plecoptera and Trichoptera in the group were based on data of **a)** taxa richness in the larval stages **b)** mean larval density **c)** mean larval biomass at seven sampling sites during 2007-2009, **d)** emergence taxa richness and **e)** mean emergence density at three sites during 2008-2009 are also shown.

Five criteria were established to select the species for the life cycle study (Table 4-7 & 4-8). The criteria 1, 2, and 5 are based on the quantity parameters or benthic density (ind m^{-2}), biomass (mg DW m^{-2}) and emergence density (ind m^{-2} week^{-1}). The results were displayed with the percentage of mean larval density of the selected species in the entire EPT groups from seven sites of the Kharaa River during 2007-2009. The criteria 3 and 5 are considered the most likely qualitative parameters or taxonomical determinability on the larval stages and the existence of literature data on life cycle and secondary production. Consequently, eighteen species including 8 species of Ephemeroptera, 3 species of Plecoptera and 7 species of Trichoptera were selected for inclusion in the study (Table 4-7 & 4-8).

Table 4-7: CRITERIA 1 to CRITERIA 4 used to select the species from Ephemeroptera, Plecoptera and Trichoptera in the Kharaa River Basin for the life cycle and secondary production study.

	No	Selected taxon	**CRITERIA 1** High larval density & biomass in the EPT group		**CRITERIA 2** High emergence density in the EPT group	**CRITERIA 3** Good taxonomical determinability on the larval stages	**CRITERIA 4** Larval and adult occurrence at different sites	
Ephemeroptera	1	*Baetis ussuricus*	++	+	+ +	+	++	+ +
	2	*Brachycercus harrisellus*	+	+	-	++	++	-
	3	*Drunella cryptomeria*	++	++	++	++	++	++
	4	*Epeorus pellucidus*	+	++	+	++	++	+ +
	5	*Ephemera orientalis*	+	++	-	++	++	-
	6	*Ephoron nigridorsum*	++	++	-	++	++	-
	7	*Paraleptophlebia chocolata*	+	-	+	++	+	+
	8	*Uracanthella lenoki*	++	++	-	++	++	-
Plecoptera	9	*Agnetina brevipennis/extrema*	++	++	++	-	++	++
	10	*Alaskaperla longidentata*	+	-	+	++	+	+
	11	*Leuctra fusca*	++	+	++	++	+	+
Trichoptera	12	*Agapetus jakutorum*	+	+	++	++	+	+
	13	*Brachycentrus americanus*	++	++	++	+	+	+
	14	*Glossosoma nylanderi*	+	+	++	-	+	+
	15	*Goera tungusensis*	+	++	++	+	+	+
	16	*Hydropsyche kozhantschikovi*	++	++	++	+	++	++
	17	*Micrasema gelidum*	++	++	+	++	+	+
	18	*Psychomyia flavida*	++	+	++	++	++	++

Note: (++) significant; (+) considerable; (-) insignificant. These results were not based on any statistical analysis.

Life cycle and secondary production of only one species (*Ephemera orientalis*) within selected eighteen EPT species in the Kharaa River Basin are efficiently comparable to other regions (Table 4-8). A comparison on life cycle of selected 18 species with taxa from other regions at the genera level is considerably obtainable than information on secondary production (Table 4-8). Therefore, the criteria 5 displays the importance of this study providing the information on life cycle and secondary production of numerous species from EPT group under an extreme continental climate. The results from 'Criteria 5' are discussed in the Chapter 5.

Table 4-8: CRITERIA 5: The existence of literature data on life cycle and secondary production of selected species at the different taxonomical levels.

			Life cycle			Secondary production		
		Taxon	Family	Genera	Species	Family	Genera	Species
Ephemeroptera	1	*Baetis ussuricus*	++	++	-	++	++	-
	2	*Brachycercus harrisellus*	++	+	+ !	++	-	-
	3	*Drunella cryptomeria*	++	+	+ !	++	-	-
	4	*Epeorus pellucidus*	++	+	-	++	+	-
	5	*Ephemera orientalis*	++	++	++	++	++	++
	6	*Ephoron nigridorsum*	++	++	-	+	+	-
	7	*Paraleptophlebia chocolata*	++	++	-	++	-	-
	8	*Uracanthella lenoki*	++	+	-	++	-	-
Plecoptera	9	*Agnetina brevipennis/extrema*	++	+	-	+	-	-
	10	*Alaskaperla longidentata*	++	-	-	+	-	-
	11	*Leuctra fusca*	++	++	+ !	+	+	-
Trichoptera	12	*Agapetus jakutorum*	++	++	-	++	++	-
	13	*Brachycentrus americanus*	++	++	-	++	+	-
	14	*Glossosoma nylanderi*	++	+	-	++	+	-
	15	*Goera tungusensis*	+	+	-	-	-	-
	16	*Hydropsyche kozhantschikovi*	++	++	-	++	++	-
	17	*Micrasema gelidum*	++	-	-	++	-	-
	18	*Psychomyia flavida*	+	-	-	-	-	-

Note: (++) sufficient; (+) existed, but very few; (-) no existence; (+!) existed, insufficient information.

4.4.1.1 Criteria 1: High larval density and biomass

The result on larval density is essential to display the abundant taxa within entire EPT group. The larval biomass and their percentage in the entire EPT group show the importance of selecting the species with high individual biomass even though they distributed with low abundance. The mean larval density (±*SE*; *n*=77) of the eighteen selected species in 2007-2009 from the seven Kharaa River sites was in the range of 3 ± 0.9 ind m^{-2} to 263 ± 50.1 ind m^{-2} (Fig. 4-8). Their mean biomass (±*SE*; *n*=77) was between 1.23 ± 0.4 mg DW m^{-2} and 259.04 ± 48.1 mg DW m^{-2} (Fig. 4-9). The total density and biomass of the eighteen selected species was approximately 60% of the total EPT density and biomass (Table 4-9 & 4-10). The percentage of their mean density and biomass composed 47% to 89% of the total amount within the groups (Table 4-9 & 4-10). There was a high variation of density and biomass amongst the eighteen species (Fig. 4-8 & 4-9).

Table 4-9: CRITERIA 1 - The percentage of mean larval density of the selected species in the entire EPT groups from seven sites of the Kharaa River during 2007-2009.

No	Taxon	Larval density (%)			
		EPT	Mayfly	Stonefly	Caddisfly
1	*Baetis ussuricus*	8.1	12.3		
2	*Brachycercus harrisellus*	0.8	1.3		
3	*Drunella cryptomeria*	3.6	5.5		
4	*Epeorus pellucidus*	3.6	5.4		
5	*Ephemera orientalis*	1.0	1.5		
6	*Ephoron nigridorsum*	2.2	3.3		
7	*Paraleptophlebia chocolata*	0.9	1.4		
8	*Uracanthella lenoki*	10.8	16.4		
9	*Agnetina brevipennis/extrema*	2.5		46.9	
10	*Alaskaperla longidentata*	0.1		2.6	
11	*Leuctra fusca*	0.7		12.2	
12	*Agapetus jakutorum*	0.5			1.8
13	*Brachycentrus americanus*	7.9			27.3
14	*Glossosoma nylanderi*	0.9			3.0
15	*Goera tungusensis*	0.4			1.5
16	*Hydropsyche kozhantschikovi*	14.1			48.6
17	*Micrasema gelidum*	1.1			3.7
18	*Psychomyia flavida*	0.9			3.2
	SUM	**60**	**47**	**62**	**89**

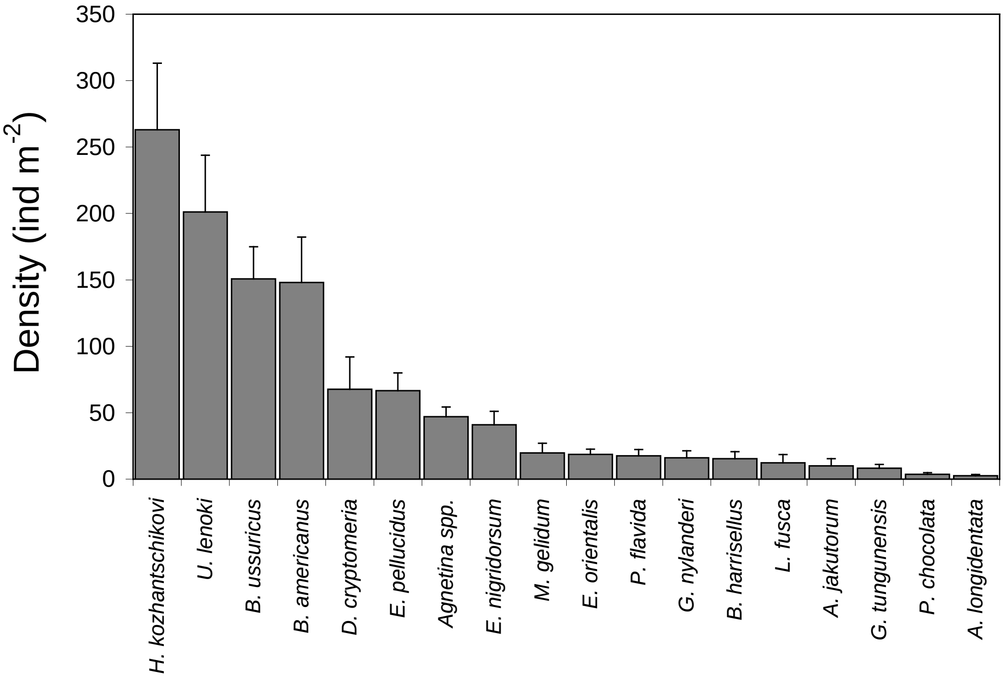


Figure 4-8: Larval density of the eighteen selected species [ind m^{-2}] (mean±*SE*; *n*=77 per species) in the Kharaa River from the years 2007 to 2009.

Table 4-10: CRITERIA 1 - The percentage of mean larval biomass of the selected species in the entire EPT groups from seven sites of the Kharaa River during 2007-2009.

		Larval biomass (%)			
No	Taxon	EPT	Mayfly	Stonefly	Caddisfly
1	*Baetis ussuricus*	2.4	5.8		
2	*Brachycercus harrisellus*	0.4	1.0		
3	*Drunella cryptomeria*	3.3	2.3		
4	*Epeorus pellucidus*	4.1	9.9		
5	*Ephemera orientalis*	7.4	18.1		
6	*Ephoron nigridorsum*	4.2	10.4		
7	*Paraleptophlebia chocolata*	0.1	0.2		
8	*Uracanthella lenoki*	3.2	7.7		
9	*Agnetina brevipennis/extrema*	8.9		51.6	
10	*Alaskaperla longidentata*	0.2		1.0	
11	*Leuctra fusca*	0.1		0.8	
12	*Agapetus jakutorum*	0.3			0.6
13	*Brachycentrus americanus*	1.8			4.3
14	*Glossosoma nylanderi*	1.4			3.4
15	*Goera tungusensis*	0.9			2.2
16	*Hydropsyche kozhantschikovi*	18.3			43.8
17	*Micrasema gelidum*	1.3			3.1
18	*Psychomyia flavida*	0.6			1.3
	SUM	**60**	**62**	**57**	**58**

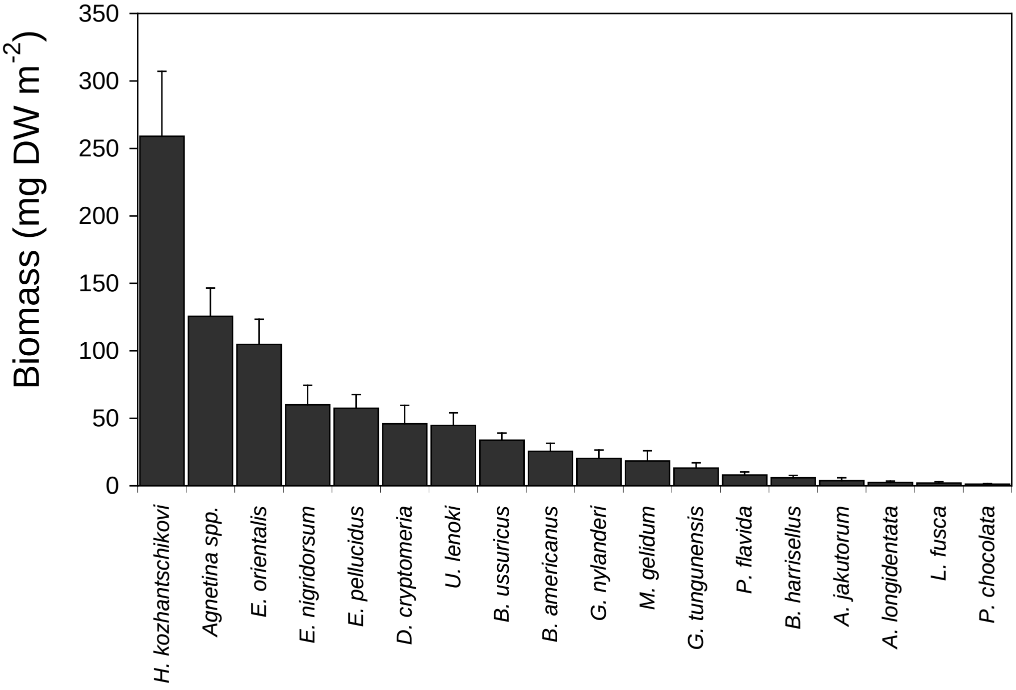


Figure 4-9: Larval biomass of eighteen selected species [mg DW m^{-2}] (mean±*SE*; *n*=77 per species) at seven sites in the Kharaa River from the years 2007 to 2009.

4.4.1.2 Criteria 2: High emergence density

A total of fourteen species from the original eighteen selected EPT species were captured in the emergence traps with the mean densities (±*SE*) of 0.09 ± 0.5 ind m^{-2} $week^{-1}$ (*n*=369) to 7 ± 2.24 ind m^{-2} $week^{-1}$ (*n*=369) (Fig. 4-10). No individuals of *Brachycercus harrisellus*, *Ephemera orientalis*, *Ephoron nigridorsum*, or *Uracanthella lenoki* were captured in the emergence traps. Although, the fourteen recorded species covered only 32% of the total EPT taxa richness known from the region their relative abundance amounted 77% to 86% to the total relative EPT abundance (Table 4-11).

4.4.1.3 Criteria 3: Taxonomical determinability on the larval stages

EPHEMEROPTERA:
The distribution of Ephemeroptera in Mongolia is referred by Soldán *et al*. (2009).

1. *Baetis ussuricus* (Kluge, 1983) (Baetidae): The family of Baetidae, it contains altogether 21 species in Mongolia and five species belong to the genus *Baetis*. On the larval stage of *B. ussuricus*, it was possible to identify up to *Baetis fuscatus* group using the reference by Tsalolikhin (Ed.) (1997). Two species (*B. fuscatus* and *B. ussuricus*) in the subgroup were identified on the larval stage. However, only one individual of *B. fuscatus* was found in the sweep net. Due to the high abundance of *B. ussuricus* in the emergence traps (572 individuals) and sweep nets (18 individuals), the life cycle study was performed for *B. ussuricus*.
2. *Brachycercus harrisellus* (Curtis, 1834) (Caenidae): Nine species from Caenidae and three species from the genus *Brachycercus* are recorded in the Kharaa River basin. There was no difficulty to identify *B. harrisellus* from the larval stages.
3. *Drunella (Tribrochella) cryptomeria* (Imanishi, 1937) (Ephemerellidae): Three species from the genus *Drunella* are recorded in the Kharaa River basin. The taxonomical reference for the identification of *D. cryptomeria* was sufficient for all larval stages.
4. *Epeorus (Belovius) pellucidus* (Brodsky, 1930) (Heptageniidae): A total of 12 species are identified in the Kharaa River basin. Thus the taxonomic difficulties for this family are often related to the accurate identification down to species level. The subgenus *Belovius* contains two species, with *E. pellucidus* having already been confirmed as present in the Kharaa River. Results from the emergence traps assisted with the identification of the larval stages.
5. *Ephemera orientalis* (McLachlan, 1875) *(*Ephemeridae): Only *Ephemera orientalis* is confirmed to be a resident species of this genus based on adult collections.
6. *Ephoron (Eopolymitarcys) nigridorsum* (Tshernova, 1934) (Polymitarcyidae): There are two species (*E. nigridorsum* and *E. virgo*) of *Ephoron* distributed in Mongolia. *E. nigridorsum* in the Kharaa River was confirmed from the collection of adults of both sexes.
7. *Paraleptophlebia chocolata* (Imanishi, 1937) (Leptophlebiidae): The family of Leptophlebiidae contains three species in Mongolia and only *P. chocolata* is distributed in the Kharaa River. The identification was confirmed using the reference by Tsalolikhin (Ed.) (1997).
8. *Uracanthella lenoki* (Tschernova, 1952) (Ephemerellidae): Because of its unique morphological characters *U. lenoki* was one of the easiest species for identification.

Table 4-11: CRITERIA 2 - The percentage of mean emergence density of the selected species in the entire EPT groups from four sites in 2008 and three sites 2009 of the Kharaa River during 2007-2009.

No	Taxon	Emergence abundance (%)			
		EPT	Mayfly	Stonefly	Caddisfly
1	*Baetis ussuricus*	18.6	69.0		
2	*Brachycercus harrisellus*	0.0	0.0		
3	*Drunella cryptomeria*	1.9	7.0		
4	*Epeorus pellucidus*	0.9	3.2		
5	*Ephemera orientalis*	0.0	0.0		
6	*Ephoron nigridorsum*	0.0	0.0		
7	*Paraleptophlebia chocolata*	0.4	1.6		
8	*Uracanthella lenoki*	0.0	0.0		
9	*Agnetina brevipennis/extrema*	3.0		26.3	
10	*Alaskaperla longidentata*	1.7		14.4	
11	*Leuctra fusca*	4.2		36.3	
12	*Agapetus jakutorum*	3.0			4.8
13	*Brachycentrus americanus*	2.3			3.7
14	*Glossosoma nylanderi*	7.2			11.6
15	*Goera tungusensis*	1.3			2.1
16	*Hydropsyche kozhantschikovi*	34.0			55.3
17	*Micrasema gelidum*	0.5			0.7
18	*Psychomyia flavida*	4.7			7.6
	SUM	**84**	**81**	**77**	**86**

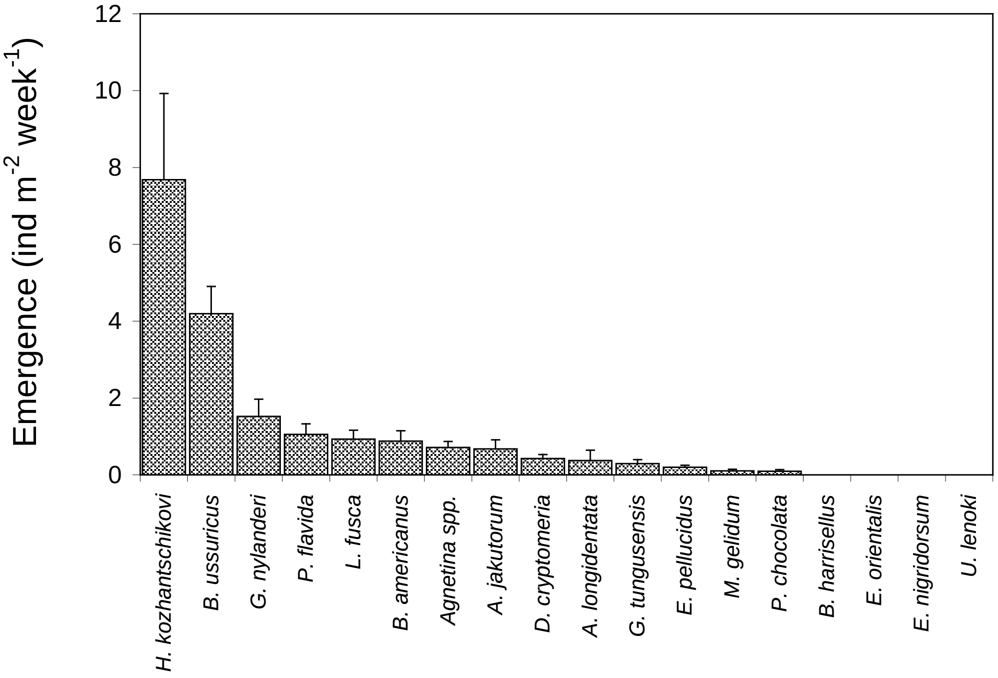


Fig. 4-10: Mean emergence density (±*SE*) of the eighteen selected species [ind m^{-2} week^{-1}] (ind m^{-2} week^{-1}; n=369 per species) at the sites of *Kh_5, Kh_8.5* and *Sug_1* in the Kharaa River from the year 2008 to 2009.

PLECOPTERA:

The distribution of Plecoptera in Mongolia is referred by Purevdorj (2009).

1. *Agnetina breviipennis* (Navás, 1912) and *A. extrema* (Navás, 1912) (Perlidae): Three *Agnetina* species are known from Mongolia with two of them (*A. brevipennis* and *A. extrema*) identified from the Kharaa River basin. Only the adults of these two species can be easily identified to species level. A taxonomical reference by Sivec *et al*. (2005) on *Agnetina* species shows the morphological differences among the two species. However, it is only suitable for identification regarding the last larval stages. However, these two Perlid species had the similarity in timing of the occurrence of the adults (Fig. 4-34 & 4-35) and recognized as a dominant species among the order (Plecoptera) with 47% of larval and 27% of emergence abundances. Therefore, in this study these two species were treated as a species group.
2. *Alaskaperla longidentata* (Rauśer, 1968) (Chloroperlidae): family, Chloroperlidae, has eight species in Mongolia, with only one species from the genus *Alaskaperla*. The taxonomical identification was confirmed with identification of adults of both sexes.
3. *Leuctra fusca*, (Linnaeus 1758) (Leuctridae): Two species are reported from this family in Mongolia with only *L. fusca* distributed in the Kharaa River basin based on the emergence and sweep net collections.

TRICHOPTERA:

The distribution of Trichoptera in Mongolia is referred by Chuluunbat and Morse (2007).

1. *Agapetus jakutorum* (Martynov, 1934) (Glossosomatidae): A total of seven species are found from the family Glossomatidae in Mongolia and from this genus only *A. jakutorum* could be verified for the Kharaa catchment using sweep netting and emergence trapping.
2. *Brachycentrus americanus* Banks, 1899 (Brachycentridae): Four species from the family of Brachycentridae in Mongolia are recorded. Three species have been found in the Kharaa River basin. According to the reference of Tsalolikhin (Ed.) (2001), it was possible to differentiate between the species within the genera on larval stage.
3. *Glossosoma nylanderi* (McLachlan, 1879*)* (Glossosomatidae): there are seven species in this family that are mentioned above, and three species from the genera of *Glossosoma* are found in Mongolia. In our study, *G. intermedium* (13 individuals) and *G. nylanderi* (208 individuals; 94% of genus *Glossosoma*) were identified within the emergence study. But it was not able to distinguish between the two species during their larval stage. Due to abundant emergence of *G. nylanderi*, this study was labeled to *G. nylanderi.*
4. *Goera tungusensis* (Martynov, 1909) (Goeridae): two species are recorded at the study sites. All individuals (40 individuals; sex ratio 1:1) were in the emergence traps and sweep nets were identified as *G. tungusensis* except one female individual of *G. squamifera* which was collected in the sweep net. Because of the high proportion of adult *G. tungusensis* individuals (97%) it appears reasonable to treat also the larvae as this species and disregard biases caused by single individuals of *G. squamifera* larvae in this study.
5. *Hydropsyche (Ceratopsyche) kozhantschikovi* (Martynov, 1924) (Hydropsychidae): seven species from Hydropsychidae are known from Mongolian rivers and three of them belong to the subgenera of *Ceratopsyche*. Only *H. kozhantschikovi* was collected in the emergence traps. A few individuals (6 male) of *H. newae* were found in the sweep netting (99.5%; 1015 female & 87 male). Therefore, this study was focused on *H. kozhantschikovi.*

6. *Micrasema gelidum* (McLachlan, 1880) (Brachycentridae): there are four species from two genera and only *M. gelidum* was recorded in the emergence study.
7. *Psychomyia flavida* (Hagen, 1861) (Psychomyiidae): only two species from the genus *Psychomyia* are distributed in Mongolia. *P. flavida* was recorded in both the benthic and the emergence samples.

4.4.1.4 Criteria 4: Larval and adult occurrence at different sites

The relative abundance (Fig. 4-11) of the larvae of the selected eighteen species showed three distinct groups with their distribution patterns. Five species, *A. jakutorum*, *A. longidentata*, *E. pellucidus*, *L. fusca*, and *P. chocolata*, can be included in the first group with main occurence at the site *Sug_1* in the upper reach (Table 4-12; Fig. A-1). The second group is consisted of eight species (*A. brevipennis/extrema*, *B. americanus*, *B. harrisellus*, *E. nigridorsum*, *G. nylanderi*, *G. tungusensis*, *M. gelidum* and *P. flavida*). The main distribution of these eight species is at the site *Kh_8.5* or the most upstream site in the middle reach of the Kharaa River (Table 4-12; Fig. A-2). The remaining five species (*B. ussuricus*, *D. cryptomeria*, *E. orientalis*, *H. kozhantschikovi*, and *U. lenoki*) are included in the third group. Those species were mainly distributed in the middle reach, in particular at the sites of *Kh_8*, *Kh_7*, *Kh_5* and *Kh_4* (Table 4-12; Fig. A-3). In the downstream reach of the river (*Kh_2*), only seven species of the selected species were distributed at low densities.

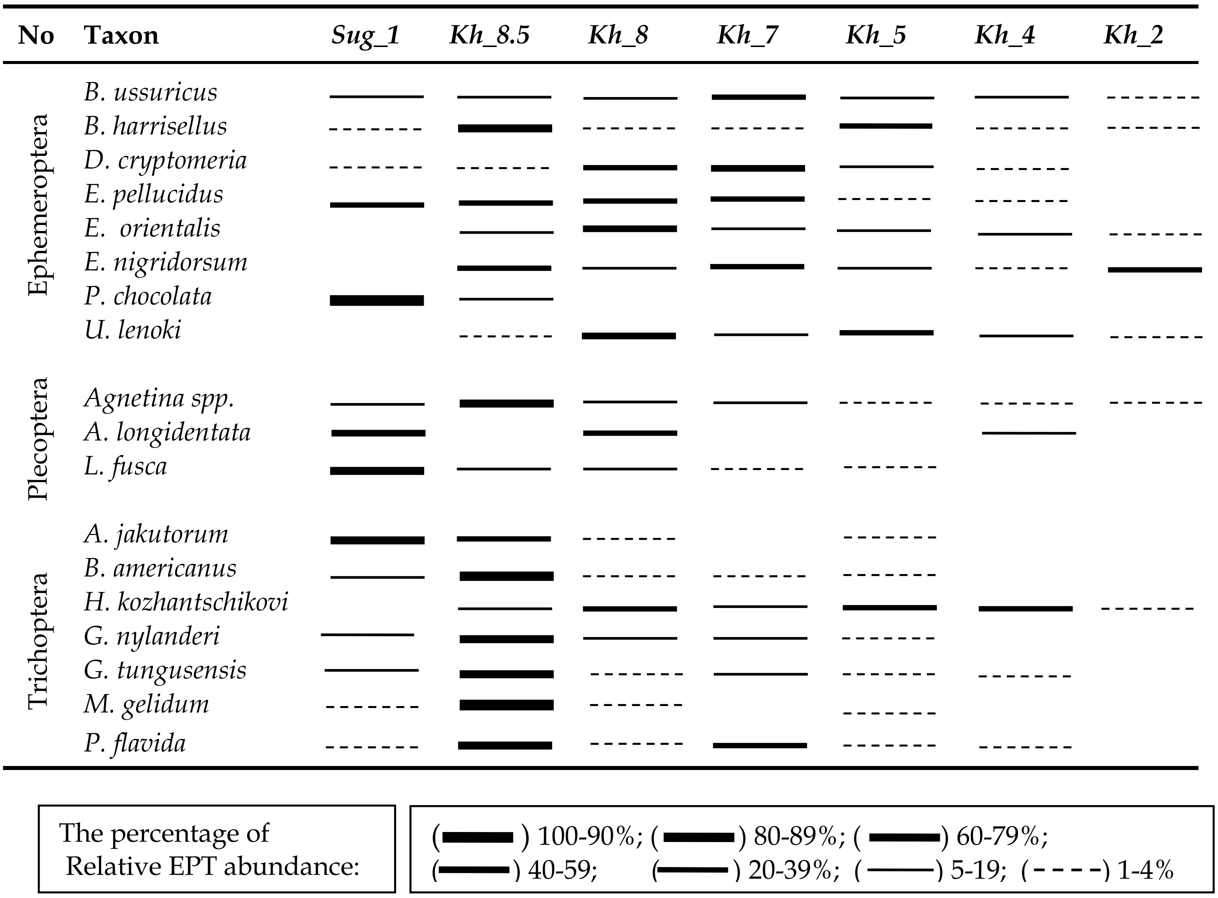


Fig. 4-11: The relative abundance of eighteen species from the EPT group at each sampling site expressed as a percentage of the monthly mean density in 2007-2009 in the Kharaa River (Applied from Hauer *et al.* 2000).

Table 4-12: Larval distribution and density [ind m^{-2}] (mean±*SE*) of eighteen species at seven sites in three distinct (upper, middles and down) reaches of the Kharaa River Basin in the period of 2007-2009.

	Upper	**Middle**					**Down**
Taxon	*Sug_1* (n=15)	*Kh_8.5* (n=16)	*Kh_8* (n=11)	*Kh_7* (n=4)	*Kh_5* (n=17)	*Kh_4* (n=5)	*Kh_2* (n=9)
A. jakutorum	34.1±26.4	15.8±6.8	1.3±1.2	-	0.5±0.5	-	-
A. longidentata	9.5±4.1	-	3.95±1.5	-	-	3.05±3.1	
E. pellucidus	130.6±55.3	91.4±23.7	94.9±21.4	99.2±54.2	16.5±4.6	9.2±3.9	-
L. fusca	50.2±31.0	8.5±3.8	3.7±2.4	1.6±1.6	0.4±0.4	-	-
P. chocolata	16.8±4.6	1.5±0.6	0. 6±0.3	-	-	-	-
A.brevipennis/ extrema	28.9±4.3	159.8±13.3	28.2±4.7	17.5±6.4	9.7±2.1	12.4±3.9	2.8±1.3
B. americanus	125.5±36.2	578.0±101.3	7.6±2.0	3.2±3.2	1.6±0.8	-	-
B. harrisellus	0.8±0.3	50.4±22.2	4.1±2.0	1.6±0.9	16.7±7.4	0.2±0.2	4.0±2.7
E. nigridorsum	-	93.2±31.2	23.3±12.2	66.0±51.3	24.3±11.2	0.8±0.6	80.4±51.2
G. nylanderi	10.2±3.5	58.0±22.2	10.4±5.5	10.2±5.9	0.1±0.1	-	-
G. tungusensis	2.6±1.2	33.0±12.4	2.0±0.8	2.4±1.5	1.6±1.2	0.6±0.6	-
M. gelidum	0.7±0.3	91.8±29.5	3.8±1.6	-	0.1±0.1	-	-
P. flavida	0.6±0.5	69.6±16.5	3.9±1.7	27.2±19.6	4.4±3.3	0.6±0.6	-
B. ussuricus	64.6±21.2	154.2±54.5	144.7±42.3	456.8±127.7	217.3±65.7	157.2±128.3	30.2±18.2
H. kozhantschikovi	-	112.3±52.6	552.1±120.2	349.5±158.1	464.6±153.8	617.1±264.2	0.35±0.35
D. cryptomeria	6.2±3.8	5.3±2.5	207.2±104.8	408.8±326.3	48.6±16.3	58.2±45.7	-
E. orientalis	-	23.0±7.0	69.1±18.5	16.5±7.5	11.2±2.9	9.4±3.1	0.1±0.1
U. lenoki	-	25.1±15.3	579.6±158.7	194.7±61.1	393.0±122.1	249.1±69.6	0.1±0.1

Table 4-13: Emergence density [ind m^{-2} $week^{-1}$] (mean±*SE*) of eighteen species at four sites in the three distinct (upper, middles and down) reaches of the Kharaa River Basin within the period of 2008-2009.

	Upper	**Middle**		**Down**
Taxon	*Sug_1* (*n*=123)	*Kh_8.5* (*n*=123)	*Kh_5* (*n*=123)	*Kh_2* (*n*=63)
A. longidentata	1.12±0.80	-	-	-
P. chocolata	0.28±0.12	-	-	-
A. brevipennis/extrema	0.09±0.07	1.98±0.45	0.06±0.04	0.06
B. ussuricus	0.61±0.20	6.24±1.85	5.73±0.95	-
H. kozhantschikovi	0.02±0.02	0.55±0.18	22.47±6.54	-
D. cryptomeria	0.20±0.08	0.61±0.22	0.46±0.20	-
G. tungusensis	0.02±0.02	0.74±0.30	0.10±0.05	-
A. jakutorum	1.45±0.66	0.57±0.26	-	-
B. americanus	0.31±0.14	2.33±0.78	-	-
L. fusca	2.13±0.64	0.66±0.22	-	-
G. nylanderi	-	4.57±1.30	-	-
M. gelidum	0.17±0.11	0.13±0.07	-	-
P. flavida	0.17±0.13	2.98±0.77	-	-
E. pellucidus	-	0.42±0.12	0.17±0.09	-
B. harrisellus	-	-	-	-
E. orientalis	-	-	-	-
E. nigridorsum	-	-	-	-
U. lenoki	-	-	-	-

Twelve to thirteen EPT species selected for the life cycle study were captured in the emergence traps at the sites *Sug_1* and *Kh_8.5*. Only six species were collected at site *Kh_5*. One species (*A. brevipennis*) was found in the emergence traps at all four sites in the Kharaa River. *A. longidentata* and *P. chocolata* were recorded only in the upper reach or site *Sug_1*. Four species, *B. ussuricus, D. cryptomeria, G. tungusensis,* and *H. kozhantschikovi* were distributed at three sites in the upper and middle reaches of the river. *E. pellucidus* was distributed only in the middle reach (Table 4-13; Fig. 4-12).

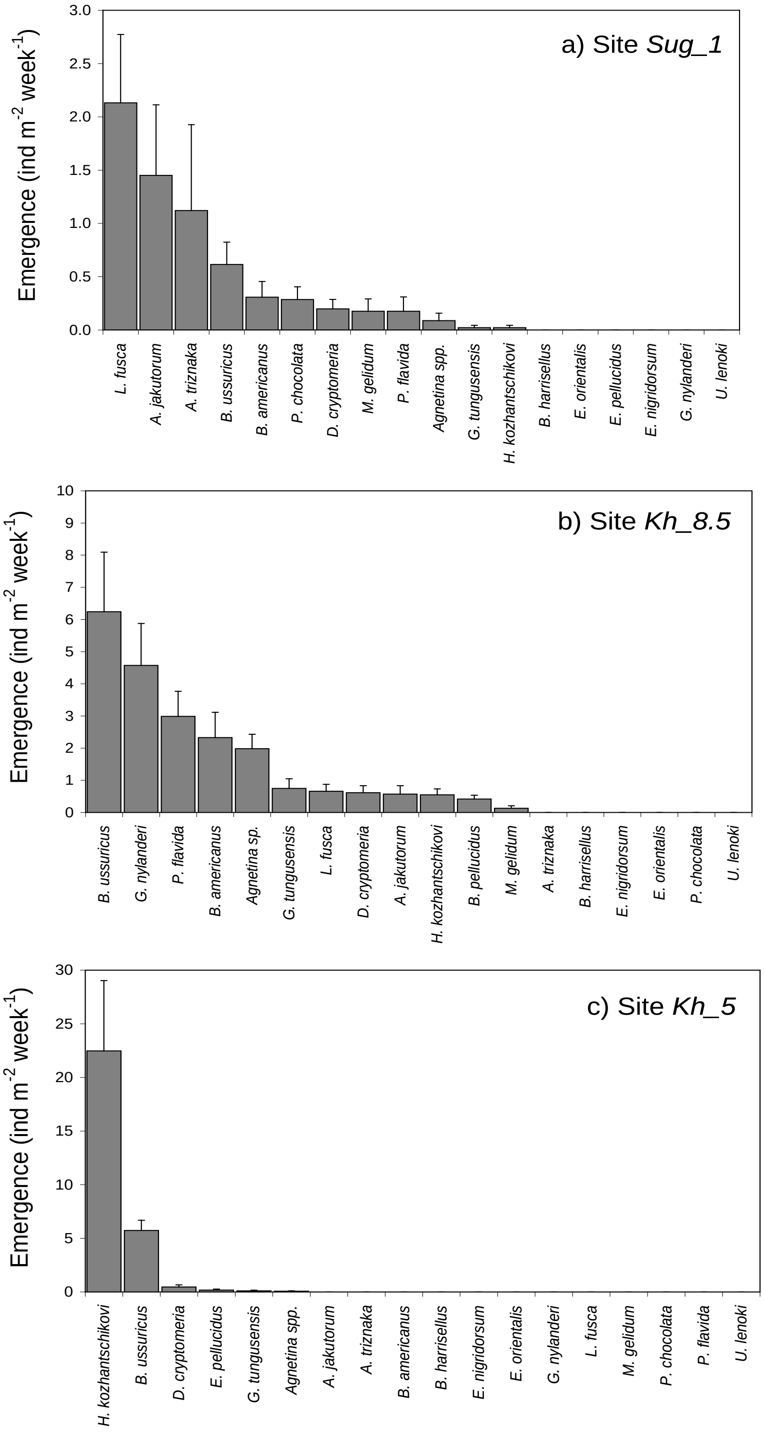


Fig. 4-12: Mean emergence density [ind m^{-2} week^{-1}] (mean±*SE*; *n*=123 per site) of selected eighteen species found in the emergence traps at three sites (*Sug_1*; *Kh_8.5*; *Kh_5*) in the period of May to October in 2008 and 2009.

4.4.2 Life cycle types

Five different life cycle types in three major categories (univoltine, multivoltine, and semivoltine) have been identified for the eighteen selected species in the Kharaa River basin. The life cycle types were distinguished based on larval body size distribution and emergence period (see figures A-7 to A-24). Generally, the most abundant taxa in the Kharaa River have evolved strict univoltinism under the extreme climatic conditions (78% of the discussed species). Univoltine life cycles were mostly evident in mayflies. About 33% or six out of the total selected species displayed a univoltine summer life cycle with hatching, growth and emergence taking place during the ice free period from May to October. Winter univoltine cycles are the most common life cycle type with 45% of the selected species (eight) showing this type of cycle. For this life cycle type individuals overwintered in the nymphal or egg stage. Caddisflies had the most representatives for the univoltine winter cycle. The remaining three life cycle types (seasonal univoltine, bivoltine, and semivoltine), two species from Ephemeroptera and one species from Plecoptera, and one species from Trichoptera were considered (Table 4-14).

Table 4-14: Life cycle categories of eighteen species from Ephemeroptera, Plecoptera, and Trichoptera in the Kharaa River Basin, Mongolia.

Major category	Subcategory	Species	Order
Univoltine	Us	*Baetis ussuricus*	Ephemeroptera
Univoltine	Us	*Brachycercus harrisellus*	Ephemeroptera
Univoltine	Us	*Drunella cryptomeria*	Ephemeroptera
Univoltine	Us	*Ephoron nigridorsum*	Ephemeroptera
Univoltine	Us	*Leuctra fusca*	Plecoptera
Univoltine	Us	*Agapetus jakutorum*	Trichoptera
Univoltine	Uw	*Ephemera orientalis*	Ephemeroptera
Univoltine	Uw	*Uracanthella lenoki*	Ephemeroptera
Univoltine	Uw	*Alaskaperla longidentata*	Plecoptera
Univoltine	Uw	*Brachycentrus americanus*	Trichoptera
Univoltine	Uw	*Glossosoma nylanderi*	Trichoptera
Univoltine	Uw	*Goera tungusensis*	Trichoptera
Univoltine	Uw	*Micrasema gelidum*	Trichoptera
Univoltine	Uw	*Psychomyia flavida*	Trichoptera
Univoltine	Us-Uw	*Epeorus pellucidus*	Ephemeroptera
Univoltine	Us-Uw	*Paraleptophlebia chocolata*	Ephemeroptera
Multivoltine	MBws	*Hydropsyche kozhantschikovi*	Trichoptera
Semivoltine	S_{3y}	*Agnetina brevipennis/extrema*	Plecoptera

Note: Us-Univoltine, summer cycle; Uw- Univoltine, winter cycle; Us-Uw- Seasonal univoltine cycle (most of the new generation overwinters in the egg stage, and a small part of the population overwinters in the nymphal stage); MBws: Seasonal bivoltine winter-summer cycle (overwintering generation in the nymphal stage and one summer generation); **S_{3y}-** Seasonal semivoltine cycle with a generation time of about three years.

4.4.2.1 Univoltine summer cycle

Six species including *Baetis ussuricus*, *Brachycercus harrisellus*, *Drunella cryptomeria*, *Ephoron nigridorsum* from Ephemeroptera, *Leuctra fusca* from Plecoptera, and *Agapetus jakutorum* from Trichoptera displayed a univoltine summer life cycle with a likely egg diapause of seven to nine months.

(i) Life cycle of *Baetis ussuricus* (Ephemeroptera: Baetidae)

In total 6,057 individuals from the *Baetis ussuricus* in the Kharaa River were analysed during the three sampling years (see Fig. A-10). The body length of sampled larvae ranged between 0.8 mm and 8.0 mm (Fig. A-4). The larval density increased from late May, and the highest density occurred in late June and August. There was a rapid decrease during July (Fig. 4-13b). In total only eleven individuals were collected in late May during the earliest sampling for each study year, with a mean body length (±*SE*) of 2.75 ± 0.2 mm (25 May to 28 May; *n*=11). It indicated that hatching had started in early to mid-June. The size distribution was comparable during the summer months (Fig. 4-13a) with larvae up to 2 mm in length still present in early September. The emergence period began in the beginning of June and ended by the end of September (Fig. 4-13b). Therefore, it is reasonable that the *B. ussuricus* has a univoltine summer cycle and that the larval development was asynchronous, with continuous growth and overlapping generations. Larval development ended by October with the next generation overwintered in the egg stage from October to May.

The mean body length (±*SE*) of *B. ussuricus* during the subimago and imago stages was 5.8 ± 0.05 mm for females (*n*=345) and 5.5 ± 0.05 mm for males (*n*=245). The sex ratio was 3:2 (females: males).

(ii) Life cycle of *Brachycercus harrisellus* (Ephemeroptera: Caenidae)

In total, 979 individuals of *B. harrisellus* were analysed from the Kharaa River (Fig. 4-14a) and their size-frequency for the years 2007 to 2009 were displayed (Fig. A-12). The body lengths of larvae ranged from 0.3 mm to 9.4 mm (Fig. A-4). *B. harrisellus* was first found in late May with ten individuals were identified with a body length range of 1.3 mm to 2.5 mm. During June and July the nymphs developed rapidly and the last instars appeared between mid-July and mid-August (Fig. 4-14a). The larval density decreased from early August and only single individuals occurred from the middle of August until September (Fig. 4-14b). No adult *B. harrisellus* were captured in the emergence traps or sweep net collections during the study years. To estimate the emergence period for the species, the occurrence of mature larvae, identified by the dark wing pads, in the benthic samples was used. The emergence peak is likely to have occurred between mid-July and mid-August. Therefore, it appears that the eggs were deposited in August and hatched in May of the following year. It is reasonable then to conclude that *B. harrisellus* had a univoltine summer life cycle with approximately eight month egg diapause.

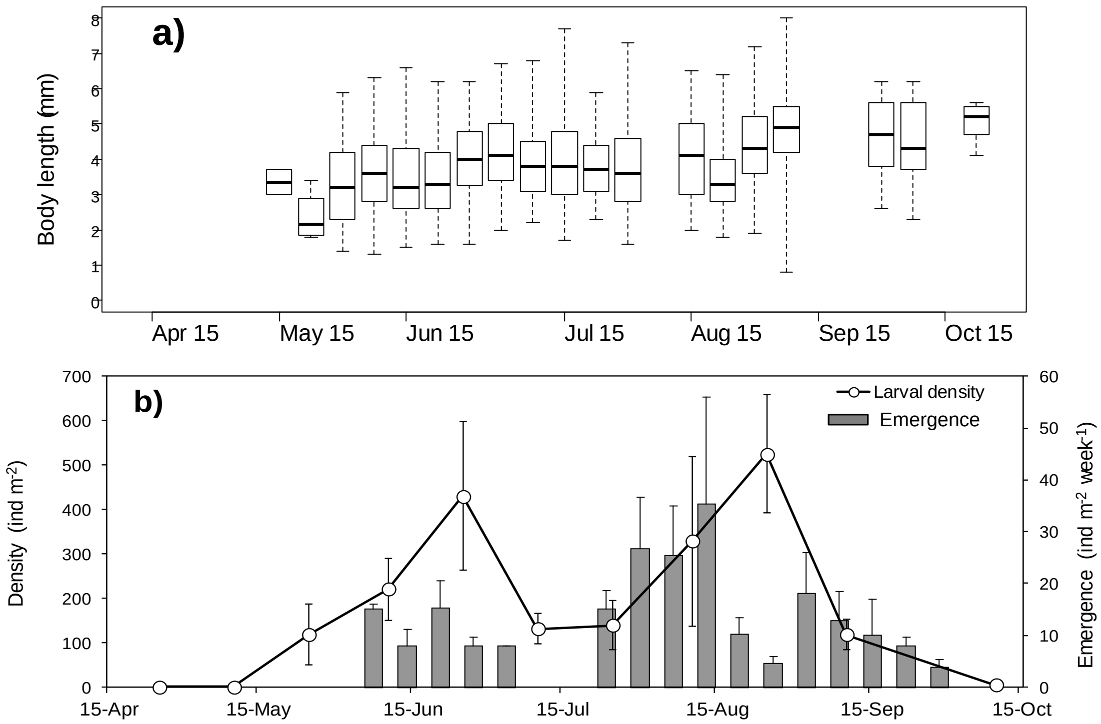


Fig. 4-13: The summarized results of the *B. ussuricus* (Ephemeroptera) during the ice free period in the years 2007 to 2009. **a)** Box-and-whisker plots (median, 25/75 percentile and 10/90 percentile) of larval body length [mm] and **b)** Line and bar plots of larval [ind m^{-2}] (mean±*SE*; *n*=77) and emergence [ind m^{-2} week^{-1}] (mean±*SE*; *n*=99) densities.

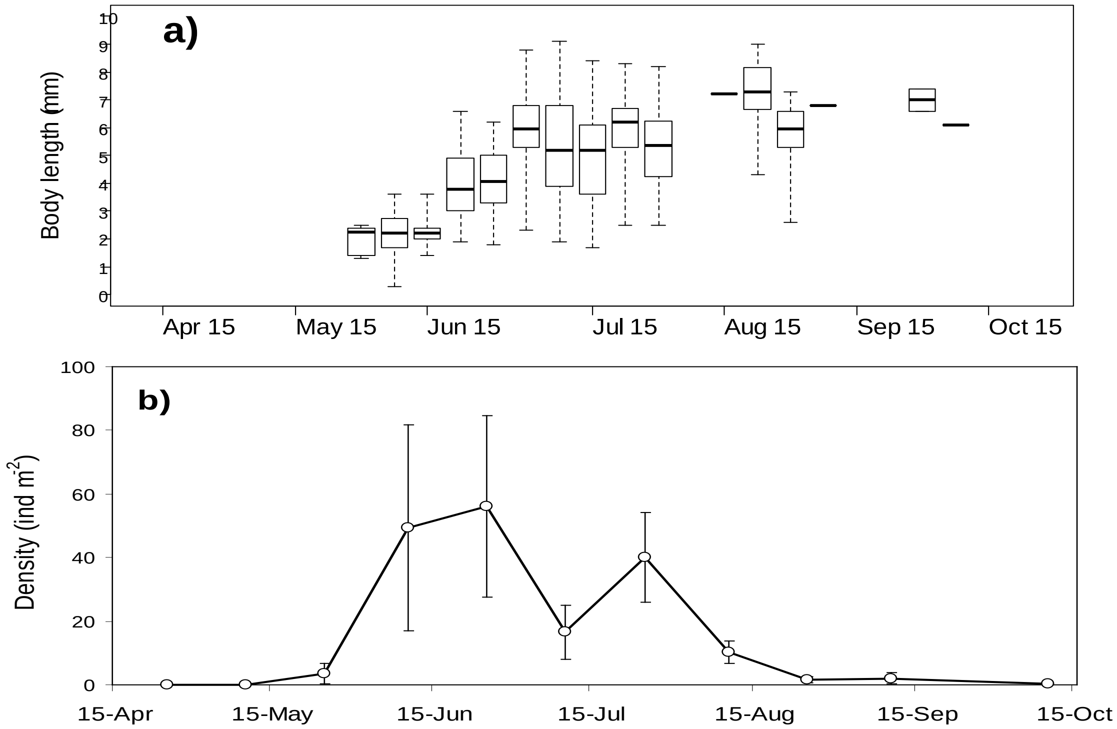


Fig. 4-14: The summarized results of *B. harrisellus* (Ephemeroptera) during the ice free period in the years 2007 to 2009. **a)** Box-and-whisker plots (median, 25/75 percentile and 10/90 percentile) of larval body length [mm] and **b)** Line plot of larval density [ind m^{-2}] (mean±*SE*; *n*=77).

(iii) Life cycle of *Drunella cryptomeria* (Ephemeroptera: Ephemerellidae)

In total, 2,064 individual *D. cryptomeria* were sampled from the Kharaa River between 2007 and 2009 (Fig. 4-15a & Fig. A-13). The body length of larvae ranged between 1.5 mm and 12.1 mm (Fig. A-5). The earliest first instars were found in early May (9th and 10th of May, 2009) with a body length of 1.5 mm to 2.9 mm. The mean body length (±*SE*) was 2.2 ± 0.03 mm (*n*=79). Therefore, it was concluded that eggs hatch around late April or early May. The nymphs exhibited very fast growth during May and June and the last instars first appeared at the end of June. The highest larvae density occurred between late May and early June (Fig. 4-15b). Emergence started from the beginning of June and ended by late August. The life cycle of mayfly *D. cryptomeria* showed a univoltine summer cycle with approximately an eight to nine month egg diapause.

In total, 137 individuals of the last larval stage of *D. cryptomeria* were analysed and the sex ratio of 1:1 determined (females: males). The mean body length (±*SE*) was 10.5 ± 0.08 mm for females (*n*=76) and 9.1 ± 0.09 mm for males (*n*=61). In total, 89 individuals of *D. cryptomeria* in the subimago and imago stages were analysed. The mean body length (±*SE*) of *D. cryptomeria* was 6.7 ± 0.16 mm for females (*n*=55) and 6.4 ± 0.16 mm for males (*n*=34). The sex ratio was 2:1 (females: males).

(iv) **Life cycle of *Ephoron nigridorsum* (Ephemeroptera: Polymitarcyidae)**

In total 2,080 individual *E. nigridorsum* were analysed during the three sampling years in the Kharaa River (Fig. 4-16a & Fig. A-16). The body length of sampled larvae ranged between 1.4 mm and 23.0 mm (Fig. A-5). Although nymphs were first recorded at the end of May, their body length already had reached a maximum length of 4.9 mm (28 May, 2007) and mean length (±*SE*) of 2.9 ± 0.05 mm (25 May to 29 May; *n*=140). During June and July, nymphs developed rapidly with the highest larval density during this period (Fig. 4-16a, b). The last instars appeared from mid-July up until mid-August. No individuals were caught in the emergence traps. The results from sweep netting suggested that emergence occurred from late July until mid-August in 2008 and it continued until the end of August in 2009. The larval density decreased during the emergence period (Fig. 4-16b). Consequently, this burrowing mayfly, *E. nigridorsum,* had a univoltine summer cycle with approximately an eight month egg diapause in the Kharaa River.

In total, 582 individuals of the last larval stage of *E. nigridorsum* were analysed and the sex ratio was 2:3 (females: males). The mean body (±*SE*) length was 13.0 ± 0.13 mm for females (*n*=245) and 11.2 ± 0.07 mm for males (*n*=337). In total there were 126 individuals in the sweep netting collection. The mean body length (±*SE*) of *E. nigridorsum* on the subimago and imago stages was 10.0 ± 0.18 mm for females (*n*=50) and 11.3 ± 0.11 mm for males (*n*=76). The sex ratio was the same as in the mature larval stage (2:3; females: males).

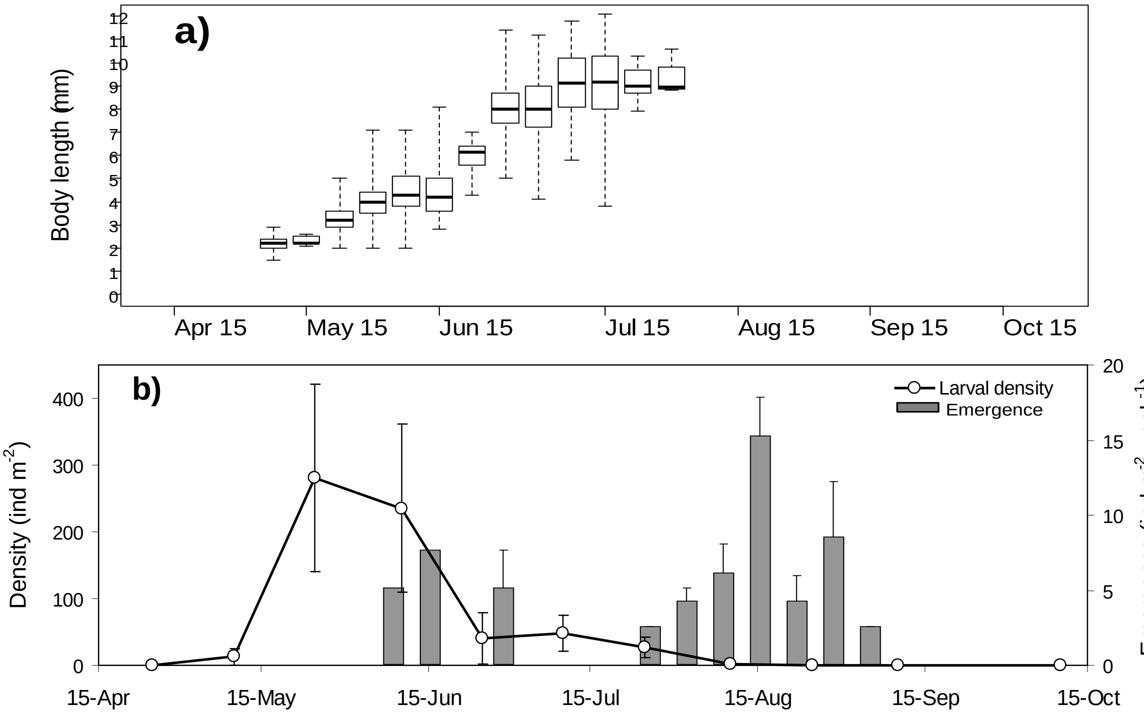


Fig. 4-15: The summarized results of *D. cryptomeria* (Ephemeroptera) during the ice free period in the years 2007 to 2009. **a)** Box-and-whisker plots (median, 25/75 percentile and 10/90 percentile) of larval body length [mm] and **b)** Line and bar plots of larval [ind m^{-2}] (mean±SE; *n*=77) and emergence [ind m^{-2} week^{-1}] (mean±*SE*; n=25) densities.

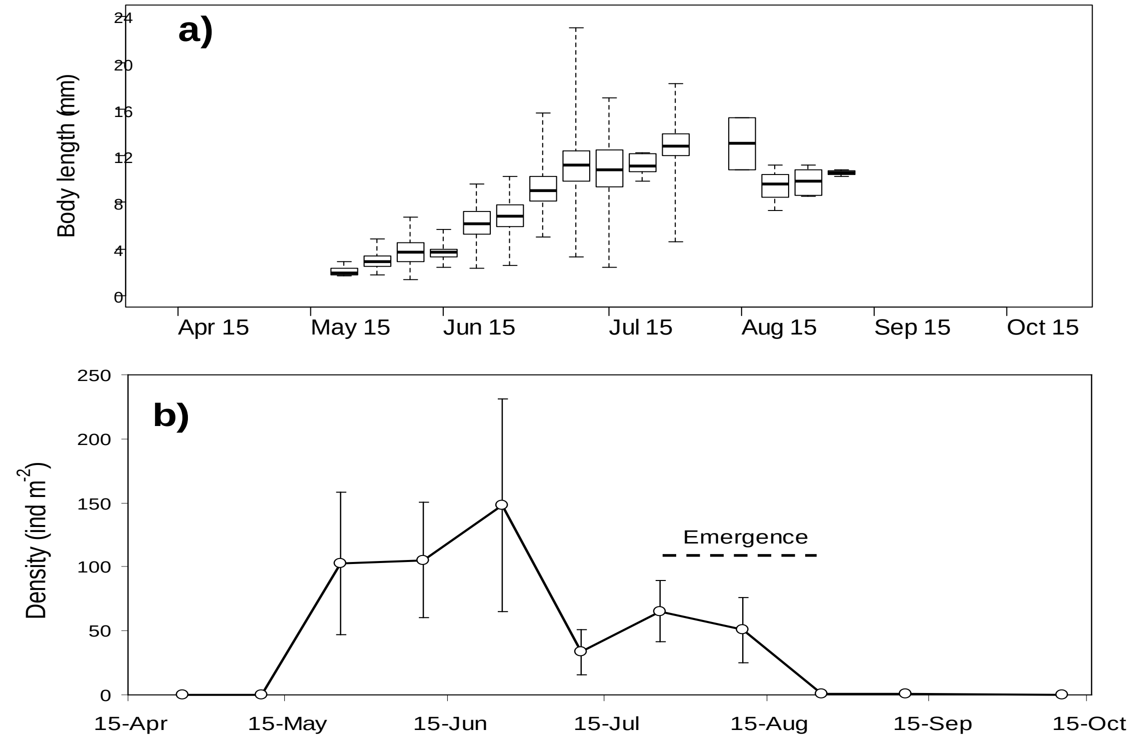


Fig. 4-16: The summarized results of *E. nigridorsum* (Ephemeroptera) during the ice free period in the years 2007 to 2009. **a)** Box-and-whisker plots (median, 25/75 percentile and 10/90 percentile) of larval body length [mm] and **b)** Line plot of larval density [ind m^{-2}] (mean±*SE*; n=77). Emergence period is presented with a dotted-line based on the sweep netting data.

(v) Life cycle of *Leuctra fusca* (Plecoptera: Leuctridae)

A total of 704 individual *L. fusca* were analysed during the three sampling years in the Kharaa River (Fig. 4-17a & Fig. A-20). The body length of sampled larvae ranged between 2.0 mm and 8.2 mm (Fig. A-5). Although nymphs were first recorded at the end of May, their body length had already reached a maximum length of 5.5 mm (28 May), although only four individuals were recorded. During June and July the nymphs developed until reaching the highest larval densities in late July and early August (Fig. 4-17a, b). The last instars were found during the middle of July. The emergence period began at the beginning of August and ended by the end of September (Fig. 4-17b). Consequently, the stonefly species, *Leuctra fusca,* showed a univoltine summer cycle with approximately an eight month egg diapause in the Kharaa River.

The mean body length (±*SE*) of *L. fusca* adults was 5.1 ± 0.07 mm for females (*n*=119) and 4.7 ± 0.07 mm for males (*n*=71). The sex ratio was 3:2 (females: males).

(vi) Life cycle of *Agapetus jakutorum* (Trichoptera: Glossosomatidae)

In the Kharaa River, 421 individual *Agapetus jakutorum* were analysed between 2007 and 2009 (Fig. 4-18a & Fig. A-7). The body length of larvae ranged between 1.2 mm and 5.4 mm (Fig. A-4). Only nine individuals with pupae stage were sampled and their body lengths ranged from 3.6 mm to 4.5 mm. The first larvae were found in the samples from the 06 of June and the highest mean density was recorded in early - mid June. By the end of June, the density decreased rapidly and almost no larva was recorded by the end of July (Fig. 4-18b). The pupae of *A. jakutorum* were collected throughout July with the emergence period beginning in late July and ending by the end of August (Fig. 4-18b). Therefore, it can be concluded that *A. jakutorum* had a univoltine summer cycle with approximately an eight month egg diapause in the Kharaa River.

The mean body length (±*SE*) of *A. jakutorum* adults was 3.2±0.1 mm for females (*n*=52) and 2.8±0.05 mm for males (*n*=69). The sex ratio was 1:1 (females: males).

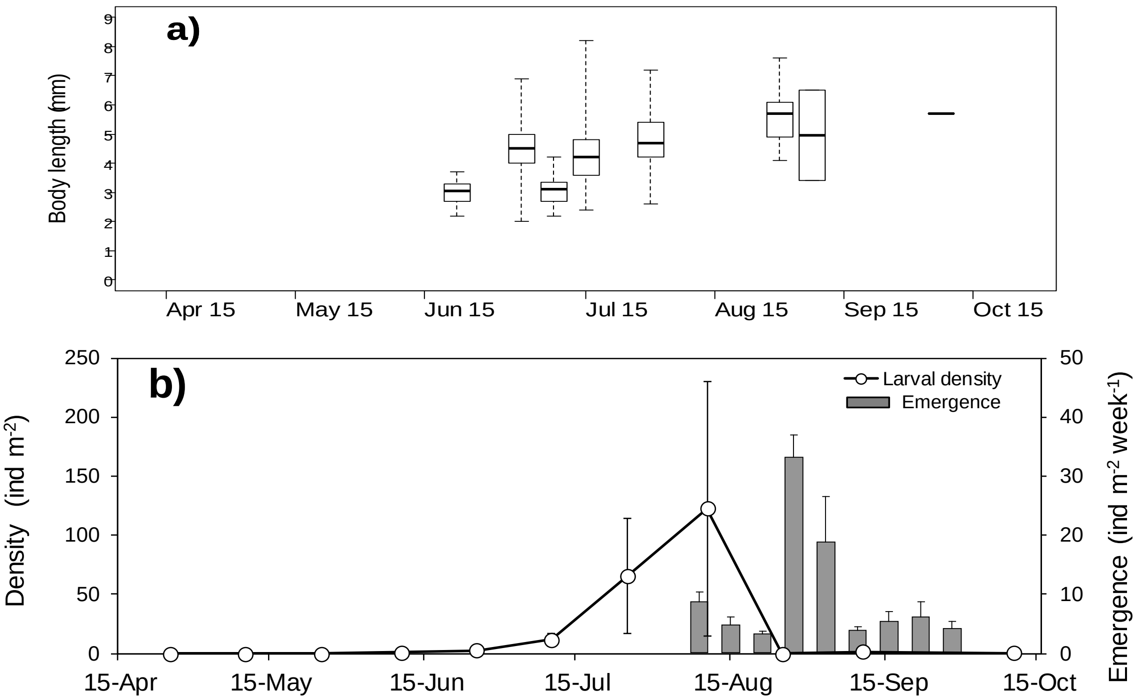


Fig. 4-17: The summarized results of *L. fusca* (Plecoptera) during the ice free period in the years 2007 to 2009. **a)** Box-and-whisker plots (median, 25/75 percentile and 10/90 percentile) of larval body length [mm] and **b)** Line and bar plots of larval [ind m^{-2}] (mean±*SE*; n=77) and emergence [ind m^{-2} week^{-1}] (mean±*SE*; *n*=37) densities.

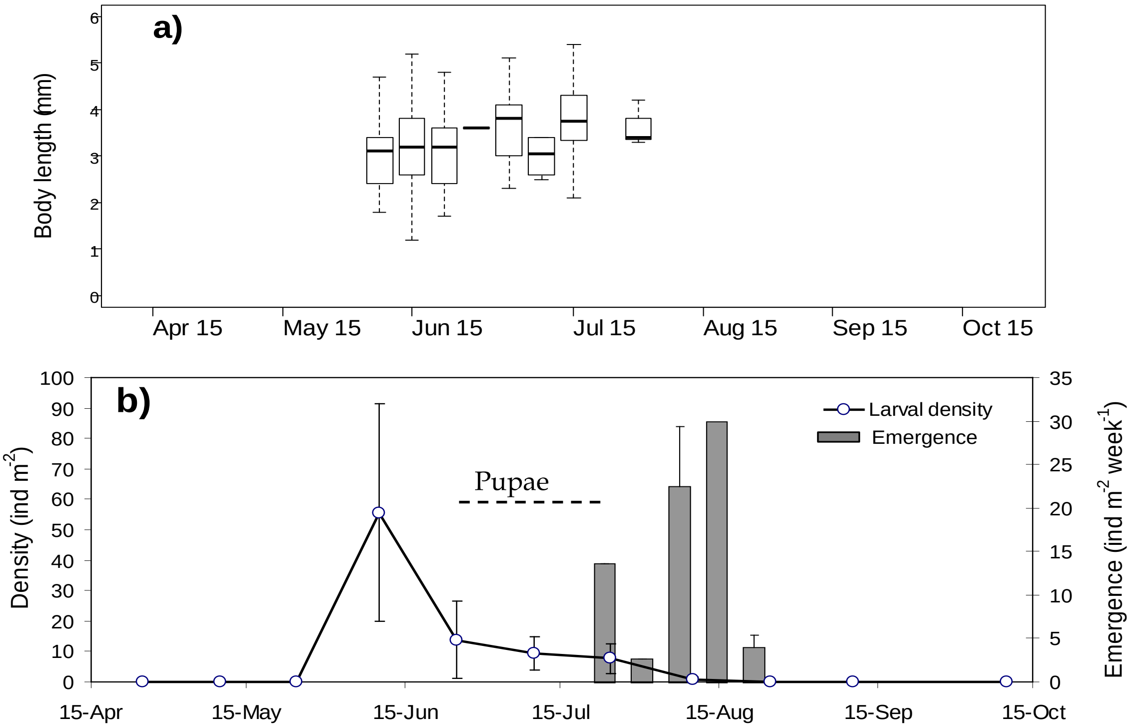


Fig. 4-18: The summarized results of *A. jakutorum* (Trichoptera) during the ice free period in the years 2007 to 2009. **a)** Box-and-whisker plots (median, 25/75 percentile and 10/90 percentile) of larval body length [mm] and **b)** Line and bar plots of larval [ind m^{-2}] (mean±*SE*; *n*=77) and emergence [ind m^{-2} week^{-1}] (mean±*SE*; *n*=15) densities. The duration of pupa stage period is presented with a dotted-line.

4.4.2.2 Univoltine winter cycle

Eight species including *Ephemera orientalis* and *Uracanthella lenoki* from Ephemeroptera, *Alaskaperla longidentata* from Plecoptera, *Brachycentrus americanus*, *Glossosoma nylanderi*, *Goera tungusensis*, *Micrasema gelidum*, *Psychomyia flavida* from Trichoptera displayed univoltine winter cycle with larval development of approximately 10 to 11 months.

(i) Life cycle of *Ephemera orientalis* (Ephemeroptera: Ephemeridae)

E. orientalis (*n*=1,082) sampled from the Kharaa River are plotted in weekly (Fig. 4-19a) and monthly size-frequency histograms for the years from 2007 to 2009 (Fig. A-15). The body length of larvae ranged from 1.7 mm to 27.7 mm (Fig. A-5). In the earliest samples during the study years, which were taken after the ice breakup, the mean body length (±*SE*) was 14.2 ± 0.5 mm (25 April to 10 May; *n*=63). The mean body length (±*SE*) increased to 15.4 ± 0.4 mm by the beginning of June (26 May to 10 June; *n*=283). No individuals were caught in the emergence traps. Based on observations of mature larva and sweep net collections, the main emergence period began in late May and ended by the end of June. Single mature larvae could still be found in July with the same mean length. All small larvae with a body size of less than 5 mm were collected towards the end of July to the end of September. The maximum mean larval body length reached 6.9 ± 0.2 mm in early September (28 July to 05 Sep; *n*=298) and 9.6 ± 0.2 mm by October (23 Sep to 20 Oct; *n*=418). The larval density between mid-June and late July as well as the very fast growth during autumn indicated that *E. orientalis* had a univoltine, winter life cycle with larval development of approximately 10 months (Fig. 4-19b). Furthermore, it can be deduced that eggs hatched from late June until early July as newly hatched nymphs appeared from the middle of July in the samples.

In total, 153 individuals in the last larval stage were analysed and the sex ratio was determined to be 1:1 (females: males). The mean body length (±*SE*) was 18.0 ± 0.31 mm for females (*n*=69) and 15.6 ± 0.24 mm for males (*n*=84).

(ii) Life cycle of *Uracanthella lenoki* (Ephemeroptera: Ephemerellidae)

In total 4,434 individual *U. lenoki* were collected and analysed during the study period in 2007 - 2009 (Fig. 4-20a & Fig. A-24). The body lengths of larvae ranged from 1.1 mm to 9.0 mm (Fig. A-6). From the 25th to the 29th of April during the study years, the mean body length (±*SE*) was 3.2 ± 0.06 mm (*n*=261). The larval body length increased during May and June to 3.6 ± 0.06 mm (*n*=226) reaching 6.3 ± 0.1mm (*n*=139) in late June. In July, a total of only 40 individuals of *U. lenoki* with a body length of 1.8 mm to 7.6 mm were collected (Fig. 4-20a). The decreased density during July is evident in Figure 4-20b. From the middle of August, a new generation of *U. lenoki* appeared in the Kharaa River and the mean body length (±*SE*) was 1.9 mm (±0.03 mm, *n*=114). Larval body length slowly increased until the last sampling campaign in autumn. The mean body length (±*SE*) was 3.3 mm (±0.02 mm, *n*=789) in early October and 3.7 mm (±0.03 mm, *n*=217) in late October. No adults were caught in the emergence traps or sweep netting. Based on observations of mature larva, the emergence is likely to occur in July. Considering the larval body length distribution and density, *U. lenoki* had a univoltine winter cycle with a larval development of 11 months.

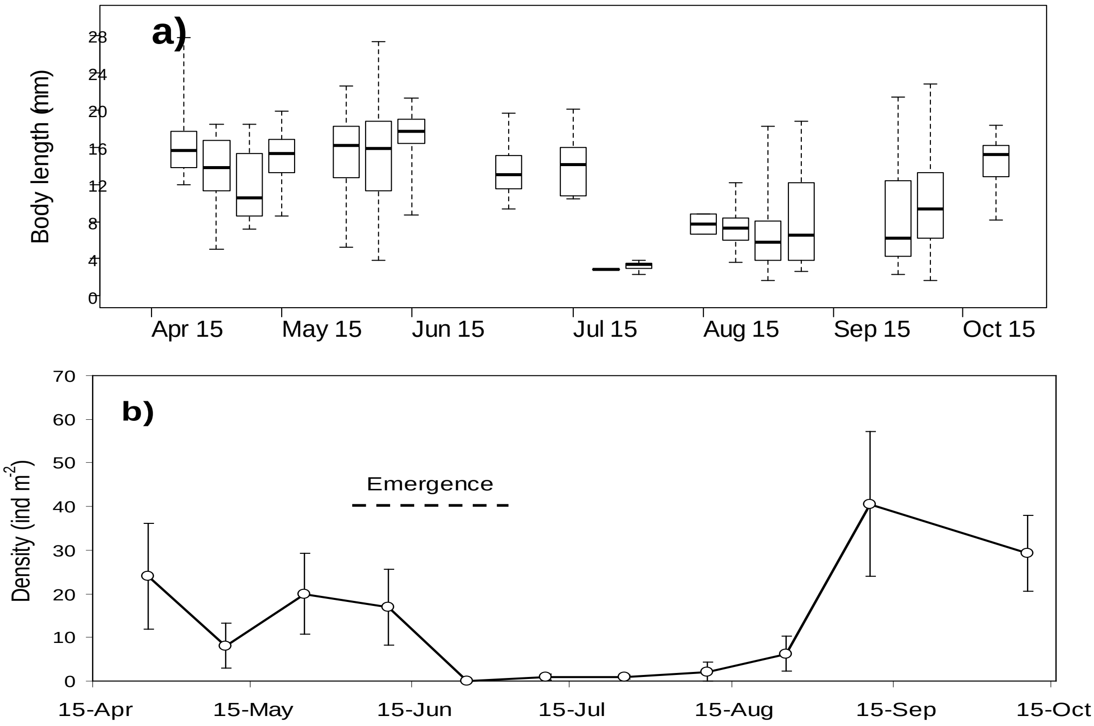


Fig. 4-19: The summarized results of *E. orientalis* (Ephemeroptera) during the ice free period in the years 2007 to 2009. **a)** Box-and-whisker plots (median, 25/75 percentile and 10/90 percentile) of larval body length [mm] and **b)** Line plot of larval density [ind m^{-2}] (mean±*SE*; *n*=77). Emergence period is presented with a dotted-line based on the sweep netting data.

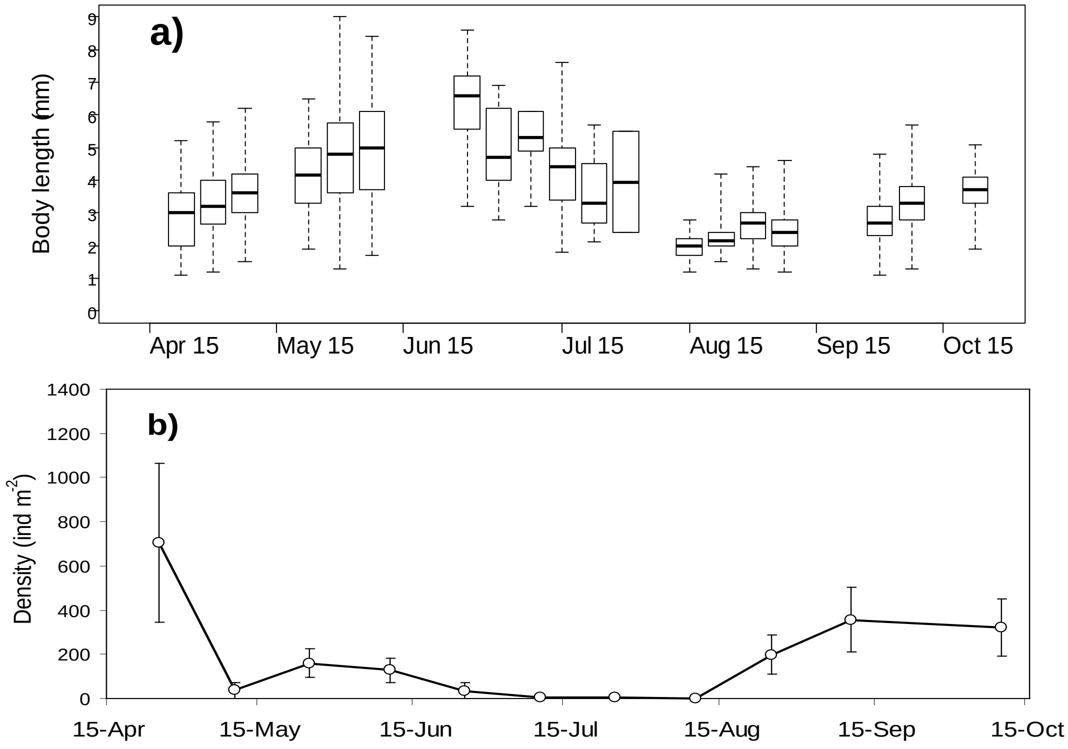


Fig. 4-20: The summarized results of *U. lenoki* (Ephemeroptera) during the ice free period in the years 2007 to 2009. **a)** Box-and-whisker plots (median, 25/75 percentile and 10/90 percentile) of larval body length [mm] and **b)** Line plot of larval density [ind m^{-2}] (mean±*SE*; *n*=77).

(iii) Life cycle of *Alaskaperla longidentata* (Plecoptera: Chloroperlidae)

One of the selected eighteen species with the lowest larvae abundance was *A. longidentata*. Only 211 individuals were sampled during the entire three year sampling effort (Fig. 4-21a & Fig. A-9). The body lengths of larvae ranged from 2.4 mm to 10.4 mm (Fig. A-4). From the first sampling of the year on the 11th of May resulted a high variation with the larval body length ranging from 3.6 mm to 8.9 mm. The mean body length (±*SE*) was 5.02 ± 0.18 mm (*n*=58). During May and June, the mean body length (±*SE*) increased from 4.02 ± 0.23 mm (early May) to 7.01 ± 0.14 mm (late June), respectively. Depending on the life cycle type of *A. longidentata*, there is a temporal fluctuation in larval density (Fig. 4-21b). Emergence occurred over a two week period in June, although it was not possible to accurately estimate the entire duration of emergence including its peak. The first larvae were sampled in late August in very low densities with only six individuals ranging in body length from 2.8 mm to 6.1 mm. Therefore, the larval hatching is likely to occur in late July or early August. However, it still can be evaluated that based on their body length distribution and larval density, *A. longidentata* had a univoltine winter cycle in the Kharaa River basin. It seems that the egg incubation period is longer than other univoltine winter cycle species in this study.

(iv) Life cycle of *Brachycentrus americanus* (Trichoptera: Brachycentridae)

Over the three year study period 5,727 *B. americanus* were collected and analysed in the Kharaa River (Fig. 4-22a and Fig. A-11). The body lengths of larvae ranged from 0.7 mm to 15.9 mm and the five larval instars were distinguished (Fig. A-4). From early May to late July, the mean body length increased with time together with a decrease in larval density (Fig. 4-22a). In total, 79 individuals in the pupa stage were collected between early June and late July. The results from the emergence traps suggested that the emergence duration was relatively short for *B. americanus* in the Kharaa River. Emergence was likely to have begun in late July and ended by the end of August (Fig. 4-22b). The emergence density was much lower compared to the larval density (Fig. 4-22b). Individuals (*n*=571) with a larval body length of up to 2.5 mm were collected between late August and early October. Based on the body length distribution, larval density, pupa stage duration and emergence data, it can be concluded that *B. americanus* had a univoltine winter cycle in the Kharaa River. Therefore, most individuals overwintered in the larval stages I to III and the larval growth continued from spring in the following year.

The 126 individual adults that were caught in the emergence traps had a skewed sex ratio of 10:1 (females and males). The mean body length (±*SE*) was 6.09 ± 0.07 mm for females (*n*=123) and 5.96 ± 0.13 mm for males (*n*=13).

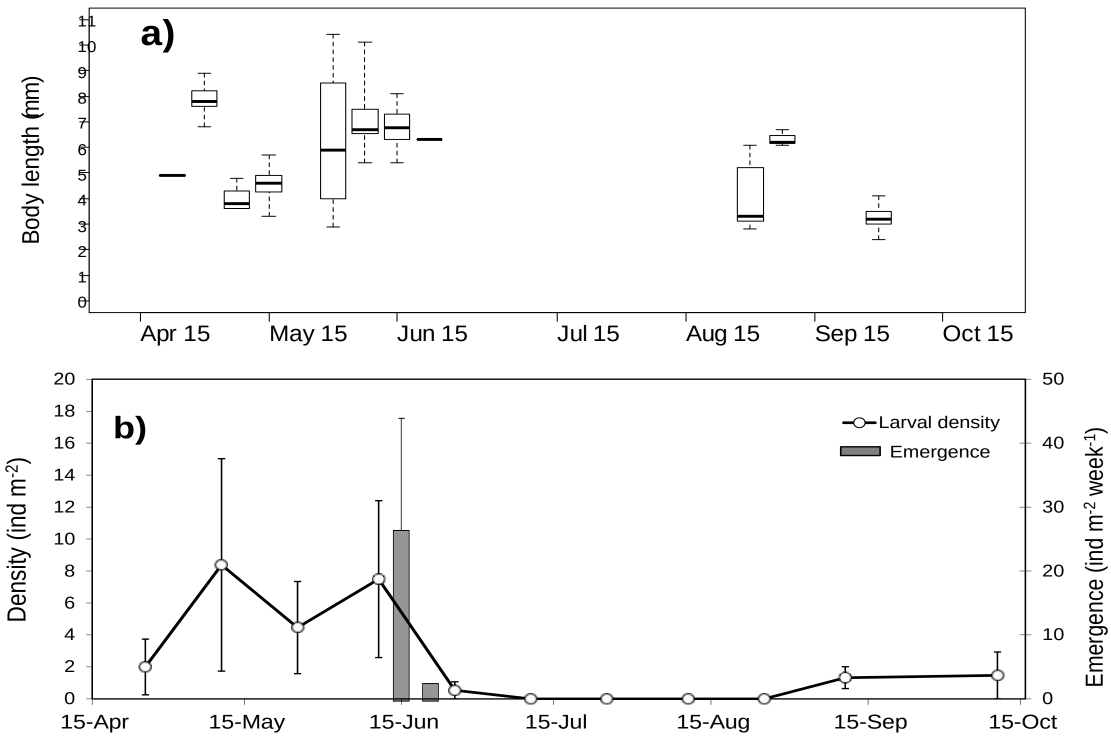


Fig. 4-21: The summarized results of *A. longidentata* (Plecoptera) during the ice free period in the years 2007 to 2009. **a)** Box-and-whisker plots (median, 25/75 percentile and 10/90 percentile) of larval body length [mm] and **b)** Line and bar plots of larval [ind m^{-2}] (mean±*SE*; *n*=77) and emergence [ind m^{-2} week^{-1}] (mean±*SE*; *n*=6) densities.

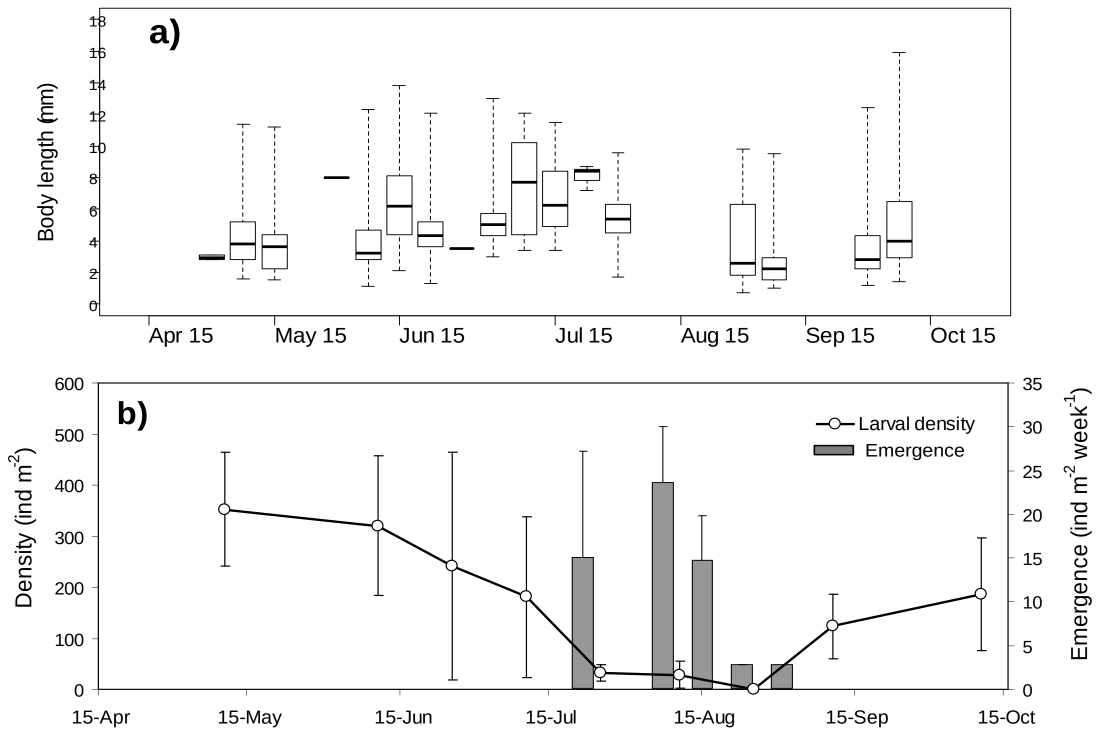


Fig. 4-22: The summarized results of *B. americanus* (Trichoptera) during the ice free period in the years 2007 to 2009. **a)** Box-and-whisker plots (median, 25/75 percentile and 10/90 percentile) of larval body length [mm] and **b)** Line and bar plots of larval [ind m^{-2}] (mean±*SE*; *n*=72) and emergence [ind m^{-2} week^{-1}] (mean±*SE*; *n*=20) densities.

(v) Life cycle of *Glossosoma nylanderi* (Trichoptera: Glossosomatidae)

Sampled *G. nylanderi* in the Kharaa River altogether counted 1,029 and were analysed in each year from 2007 to 2009 (Fig. 4-23a and Fig. A-17). The body lengths of larvae ranged from 1.2 mm to 9.4 mm. Each of the five larval stages could be accuractly distinguished (Fig. A-5). Until early May, the mean body length (±*SE*) was 6.14 ± 0.43 mm (*n*=9). During June and July, there was a high variation in the total body length, mean length (±*SE*) was 3.80 ± 0.08 mm (*n*=393). Small larvae with a body size of less than 2.5 mm could still be found in June and July. From the end of August, the mean body size increased continuously together with a rapid increase of larval abundance. Emergence density was considerably higher compared to the larval density (Fig. 4-23b). The emergence occurred between late May and the middle of August. Therefore, it can be concluded that *G. nylanderi* had a univoltine winter cycle in the Kharaa River.

In total 218 individual adults of G. *nylanderi* were analysed. The sex ratio was approximately 2:1 (females and males). 134 female adults with a mean body length of 6.02 ± 0.05 mm and 84 male adults with a mean body length (±*SE*) of 5.56 ± 0.07 mm were collected.

(vi) Life cycle of *Goera tungusensis* (Trichoptera: Goeridae)

A relatively low number of *G. tungusensis* individuals (*n*=556) in the Kharaa River were analysed for the years from 2007 to 2009 (Fig. 4-24a and Fig. A-18). The body lengths of larvae ranged from 1.0 mm to 12.8 mm across the five larval instars that could be distinguished (Fig. A-5). In the spring samples of each year, the second to fifth instars of *G. tungusensis* were present. It was one reason for the high larval body length variation detected (Fig. 4-24a). The low number of individuals, extended pupation and emergence period is likely to have also contributed to the high variation measured (Fig. 4-24b). Individuals at the pupa stage were found during June and July with a mean body length (±*SE*) of 8.11 ± 0.16 mm (*n*=48). From late July, the first instars appeared and grew very fast during autumn (Fig. 4-24). Due to the life cycle type, there was no temporal fluctuation in larval density during the year. Larval density was relatively low compared to the emergence density (Fig. 4-24b). The results of the body length distribution, larval density and emergence data, suggested that *G. tungusensis* had a univoltine winter cycle in the Kharaa River. A broad overlap in the larval stages of both generations was primarily due to the extended emergence period of the adults (Fig. 4-24b; Fig. A-18).

A total of 104 adults with a sex ratio of 1:2 (females and males) were collected. The mean body length (±*SE*) was 7.09 ± 0.25 mm for females (*n*=37) and 6.53 ± 0.12 mm for males (*n*=67).

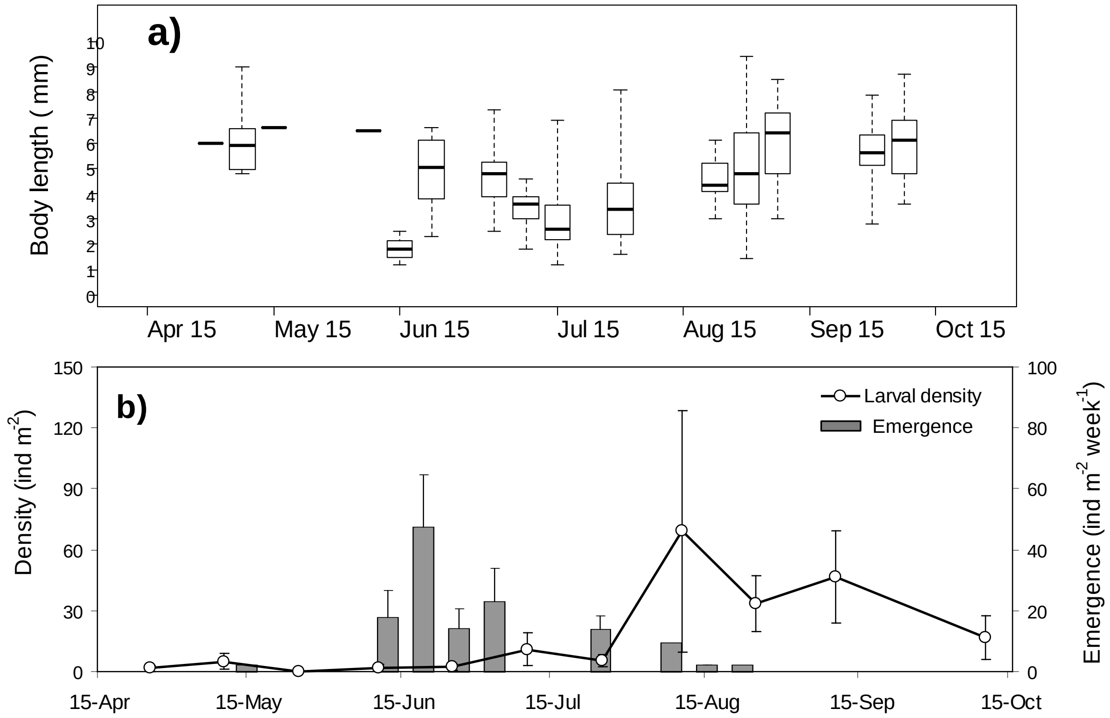


Fig. 4-23: The summarized results of *G. nylanderi* (Trichoptera) during the ice free period in the years 2007 to 2009. **a)** Box-and-whisker plots (median, 25/75 percentile and 10/90 percentile) of larval body length [mm] and **b)** Line and bar plots of larval [ind m^{-2}] (mean±*SE*; *n*=77) and emergence [ind m^{-2} week^{-1}] (mean±*SE*; *n*=29) densities.

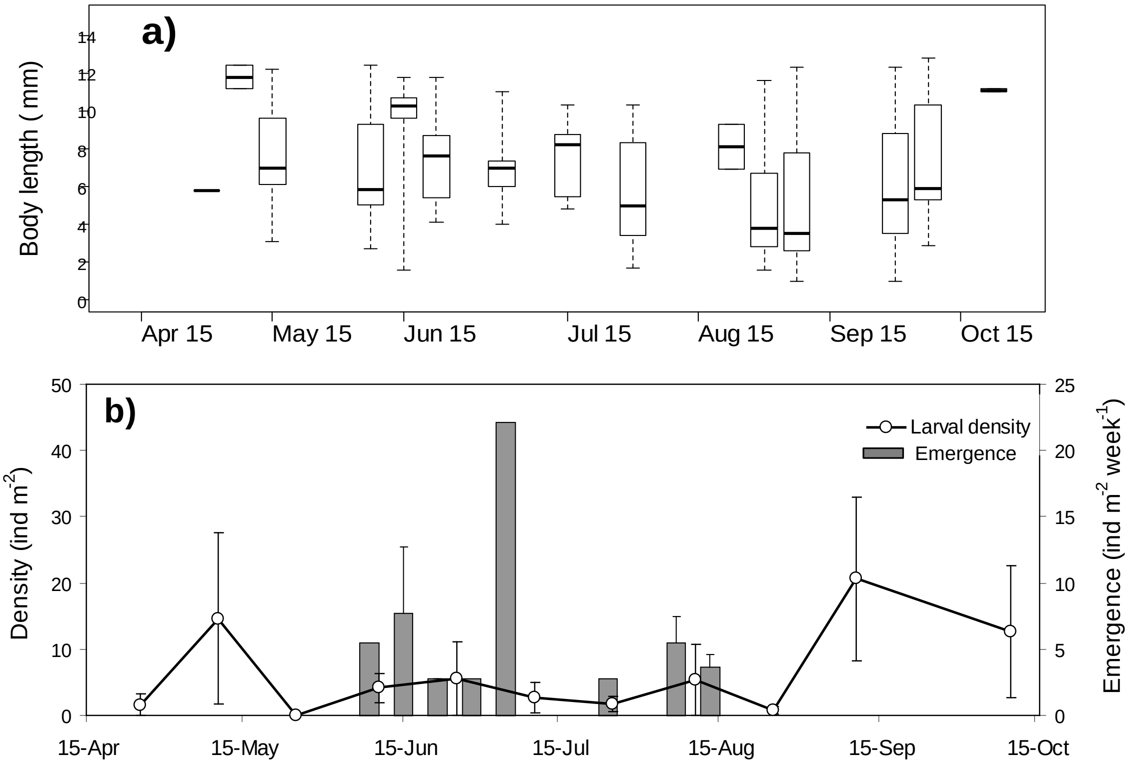


Fig. 4-24: The summarized results of *G. tungusensis* (Trichoptera) during the ice free period in the years 2007 to 2009. **a)** Box-and-whisker plots (median, 25/75 percentile and 10/90 percentile) of larval body length [mm] and **b)** Line and bar plots of larval [ind m^{-2}] (mean±*SE*; n=77) and emergence [ind m^{-2} week^{-1}] (mean±*SE*; *n*=18) densities.

(vii) Life cycle of *Micrasema gelidum* (Trichoptera: Brachycentridae)

In total, 1,283 individual *M. gelidum* were analysed from the Kharaa River for the years from 2007 to 2009 (Fig. 4-25a and Fig. A-21). The body lengths of larvae ranged from 1.3 mm to 9.8 mm and five larval stages could be distinguished (Fig. A-6). The high variation of body size in both the early and late samples was observed. The mean body length (±*SE*) was 7.57 ± 0.17 mm (*n*=44) for individuals sampled in early May and 5.33 ± 0.17 mm (*n*=497) for individuals in late September. These results suggested that there was larval growth during the winter October to April. There were only 14 pupa individuals counted and they were collected in May and June. According to the results from the emergence traps, emergence occurred during June (Fig. 4-25b). In the middle of July, the mean body length (±*SE*) of *M. gelidum* larvae was 1.68 ± 0.02 mm (*n*=50). The body length grew together with increasing larval density (Fig. 4-25). Based on the body length distribution, larval density and emergence data, it can be concluded that *M. gelidum* had a univoltine winter cycle in the Kharaa River. The expected time of larval hatching was considerably earlier than other univoltine winter cycle species, thus the emergence took place earlier as well.

Adults (n=45) were caught with a sex ratio of 1:2 (females and males). The mean body length (±*SE*) was 5.35 ± 0.16 mm for females (*n*=13) and 4.43 ± 0.06 mm for males (*n*=32).

(viii) Life cycle of *Psychomyia flavida* (Trichoptera: Psychomyiidae)

In total, 921 *P. flavida* were sampled in the Kharaa River during the years 2007 to 2009 (Fig. 4-26a and Fig. A-23). The body lengths of larvae ranged from 1.3 mm to 10.3 mm with five larval stages being distinguishable (Fig. A-6). In early May, the third to fifth instars of *P. flavida* were present with a mean body length (±*SE*) of 3.6 ± 0.20 mm (*n*=50). The mean body length (±*SE*) increased until it reached 6.5±0.16 mm (*n*=48) by the end of June. Although, there were only two individuals on pupation, the pupa stage occurred during June and July based on emergence period (Fig. 4-26b). The mean body length of *P. flavida* was 3.9 ± 0.37 mm (*n*=5) when measured in the middle of July, but increased to 4.7±0.10 mm (*n*=214). Emergence began in the first week of June and ended by the middle of August with an emergence peak possibly occurring during late July and early August (Fig. 4-26b). Depending on the life cycle type of *P. flavida*, there was a temporal fluctuation in larval density over the year (Fig. 4-26b). Based on the body length distribution, larval density and emergence data, it can be concluded that *P. flavida* had a univoltine winter cycle in the Kharaa River. An overlap of emergence and larval hatching of the new generation was also detected.

A total of 201 adult individuals were caught and their sex ratio determined to be 2:1 (females and males). Mean body length (±*SE*) was 3.98 ± 0.05 mm for females (*n*=135) and 3.54 ± 0.05 mm for males (*n*=66).

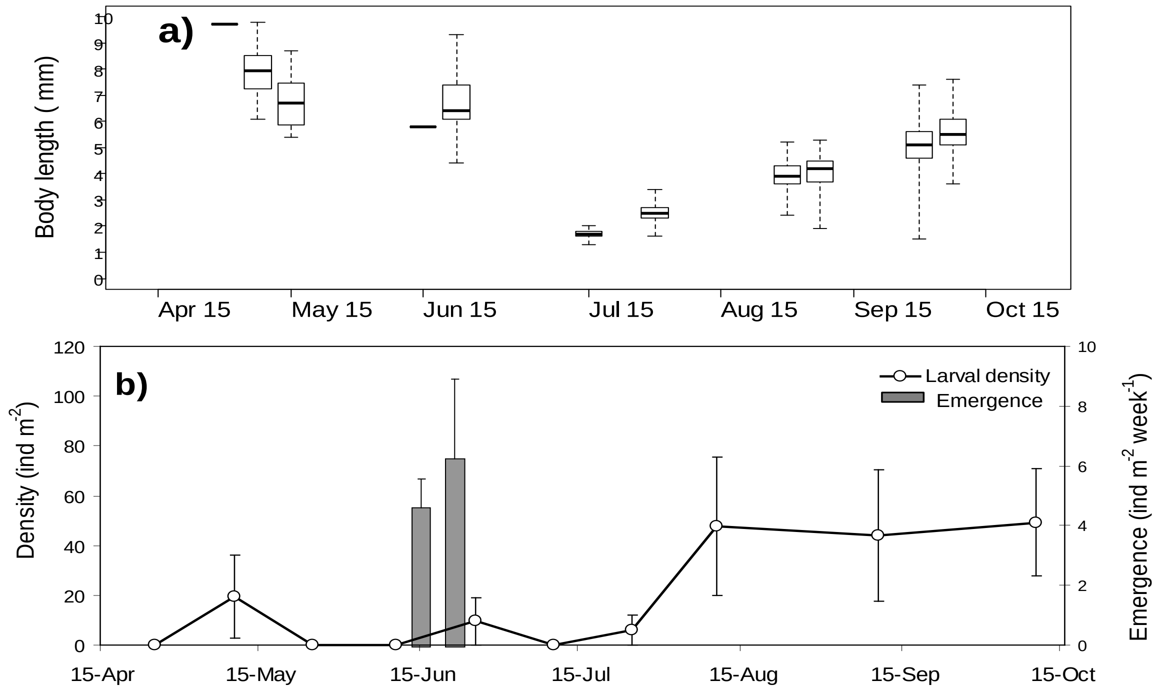


Fig. 4-25: The summarized results of *M. gelidum* (Trichoptera) during the ice free period in the years 2007 to 2009. **a)** Box-and-whisker plots (median, 25/75 percentile and 10/90 percentile) of larval body length [mm] and **b)** Line and bar plots of larval [ind m^{-2}] (mean±*SE*; *n*=77) and emergence [ind m^{-2} week^{-1}] (mean±*SE*; *n*=7) densities.

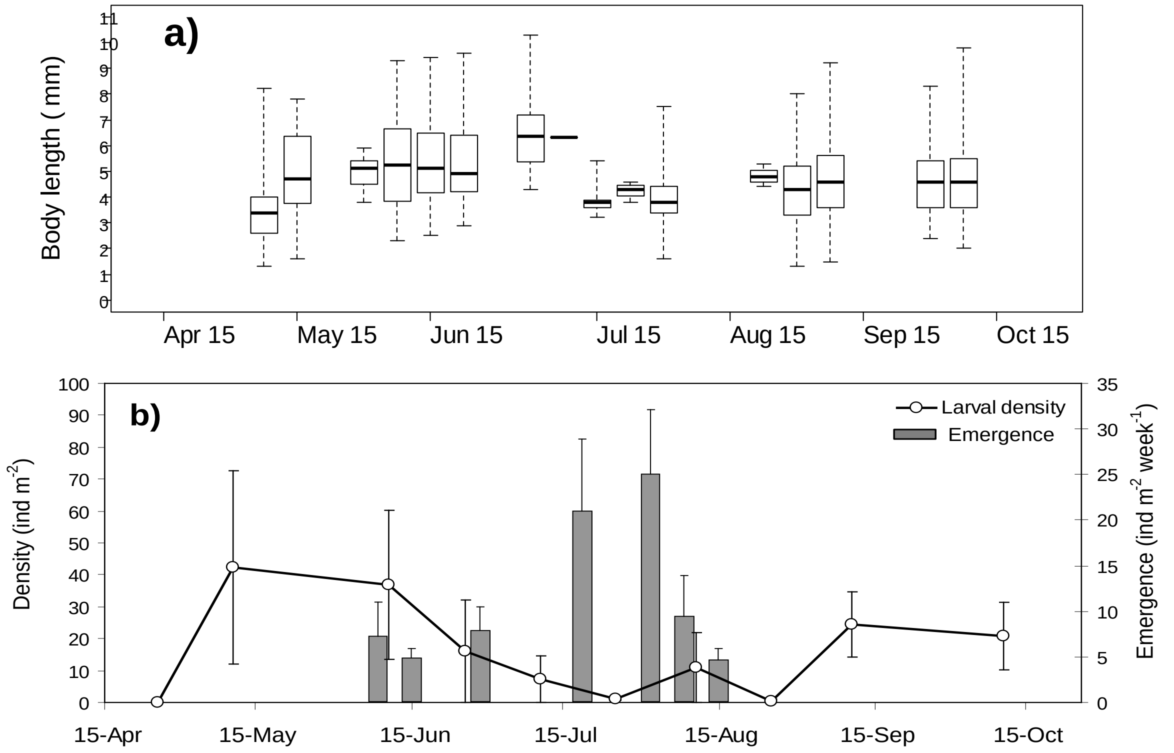


Fig. 4-26: The summarized results of *P. flavida* (Trichoptera) during the ice free period in the years 2007 to 2009. **a)** Box-and-whisker plots (median, 25/75 percentile and 10/90 percentile) of larval body length [mm] and **b)** Line and bar plots of larval [ind m^{-2}] (mean±*SE*; n=71) and emergence [ind m^{-2} week^{-1}] (mean±*SE*; *n*=31) densities.

4.4.2.3 Seasonal univoltine cycle

Two Ephemeroptera species (*Epeorus pellucidus* and *Paraleptophlebia chocolate*) within the selected 18 species was included in the seasonal univoltine cycle.

(i) Life cycle of *Epeorus pellucidus* (Ephemeroptera: Heptageniidae)

Individuals of *E. pellucidus* (n=3,626) from the Kharaa River were sampled between 2007 and 2009 (Fig. 4-27a and Fig. A-14). The body lengths of larvae ranged from 0.9 mm to 16.7 mm (Fig. A-5). Between late April and early May, mean body length (±*SE*) was 2.5 ± 0.3 mm (*n*=18). From late May to early June there was a high variation in body length for *E. pellucidus*. Approximately 20% (*n*=89) of the total individuals during this period were greater than 5.0 mm in body length with an individual maximum length of 16.7 mm. However, the density rapidly increased from late July to its highest density in early August (Fig. 4-27b). Although, the mean body length increased with time from late June until the beginning of September, it again decreased from early September (Fig. 4-27a). The first adults were collected from the beginning of August and the emergence period ended by the end of September. Consequently, the results illustrated that *E. pellucidus* had a seasonal univoltine cycle in the Kharaa River where most of the new generation overwinters in the egg stage, but a small part of the population overwinters in the nymphal stage. Therefore, depending on the life cycle type of *E. pellucidus*, there was a temporal fluctuation in the larval density during the year (Fig. 4-27b). In order to provide a detailed overview for this life cycle type, a hypothetical life cycle pattern for *E. pellucidus* is proposed in Figure 4-28. Winter and summer generations of *E. pellucidus* could be distinguished by their larval body length distribution.

In total, 318 individuals of the last instars of *E. pellucidus* were identified with a sex ratio of 1:1 (females: males). Mean body length (±*SE*) was 9.3 ± 0.16 mm for females (*n*=172) and 8.3 ± 0.15 mm for males (*n*=14). However, the mean body length (±*SE*) for adults was 10.7 ± 0.18 mm for males (*n*=16) and 11.1 ± 0.20 mm for females (*n*=24). The sex ratio of adults was 3:2 (females and males).

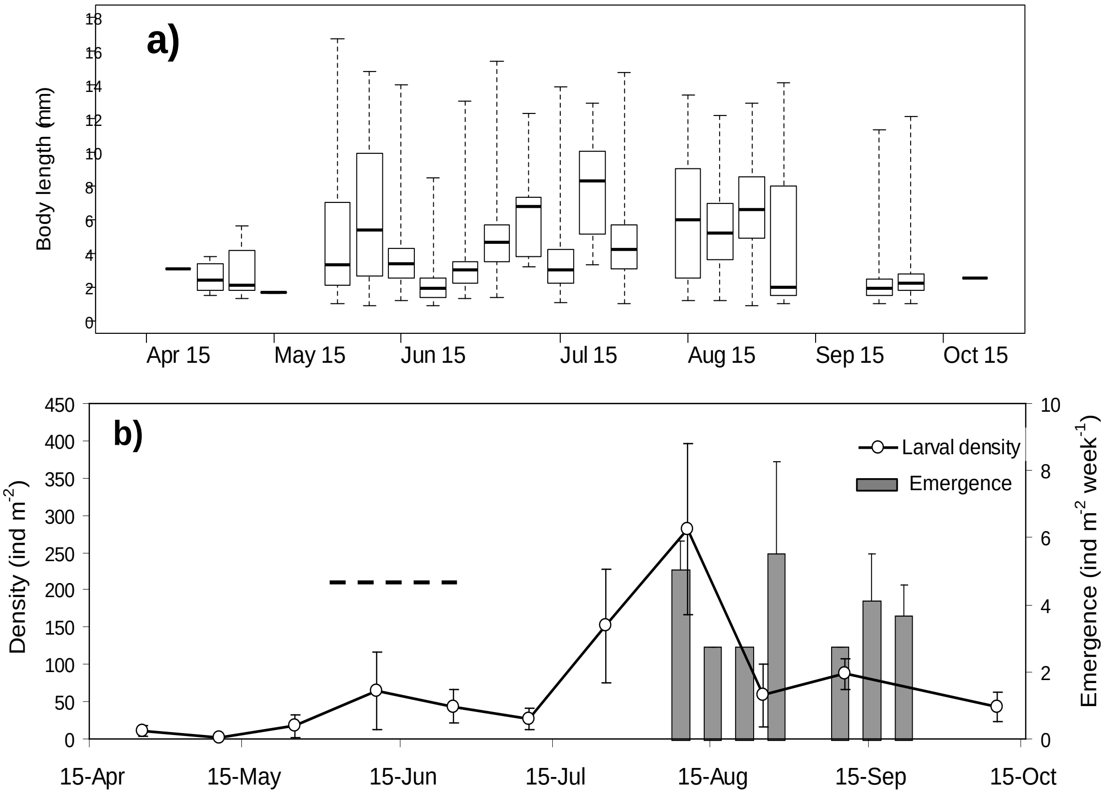


Fig. 4-27: The summarized results of *E. pellucidus* (Ephemeroptera) during the ice free period in the years 2007 to 2009. **a)** Box-and-whisker plots (median, 25/75 percentile and 10/90 percentile) of larval body length [mm] and **b)** Line and bar plots of larval [ind m^{-2}] (mean±*SE*; *n*=77) and emergence [ind m^{-2} week^{-1}] (mean±*SE*; *n*=18) densities. Hypothetical emergence period is presented with a dotted line.

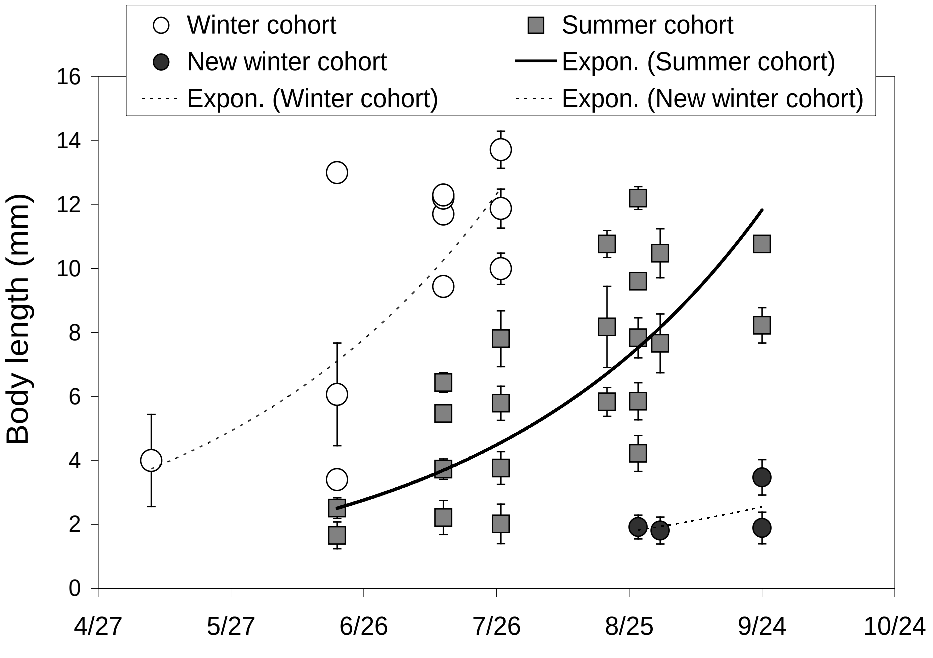


Fig. 4-28: The body length distribution [mm] (mean±*SD*) of *E. pellucidus* larvae (Ephemeroptera) with the winter and summer generations at site Kh_5 in 2009 (*n*=167 for winter cohort; *n*=453 for summer cohort; *n*=180 for new winter cohort). Note: R^2=0.57 (summer cohort); R^2=0.55 (winter cohort); R^2=0.33 (new winter cohort).

(ii) Life cycle of *Paraleptophlebia chocolata* (Ephemeroptera: Leptophlebiidae)

P. chocolata was observed in low abundances with only 317 individuals collected and analysed in the Kharaa River between 2007 - 2009 (Fig. 4-29a and Fig. A-22). The body lengths of the larvae ranged from 1.4 mm to 10.8 mm (Fig. A-6). In the first samples of each study year, the mean body length (±*SE*) was 5.6 ± 0.2 mm (05 May to 11 May; *n*=24) by the middle of June it had increased to 7.4 ± 0.4 mm (till 13 June; *n*=25). It indicated that the last instars of larvae could be recognized in May and June. By the end of June, the mean body length (±*SE*) varied greatly, with many size classes of *P. chocolata* present in the samples. Larval body length ranged from 1.8 mm to 6.4 mm during the autumn (30 Aug to 02 Oct). Density increased in autumn whereas the mean density was low throughout sampling months (Fig. 4-29b). The adults were collected from late August and emergence continued until early October. Considering the size distributions during May and June or late June to October and emergence in autumn, it could be possible distributing the two generations (summer and spring) of *P.chocolata.* The spring emergence could not detect with this study. Therefore, it can be suggested that *P. chocolata* had a seasonal univoltine cycle in the Kharaa River where most of the new generation overwinters in the egg stage, but a small part of the population overwinters in the nymphal stage. A hypothetical life cycle pattern was not displayed for *P. chocolata* because of low abundance. However, the size frequency histograms (Fig. A-22) displayed obviously.

The mean body length (±*SE*) of *P. chocolata* adults was 6.0 ± 0.2 mm for females (*n*=7) and 6.0 ± 0.3 mm for males (*n*=6). The sex ratio was 1:1 (females: males).

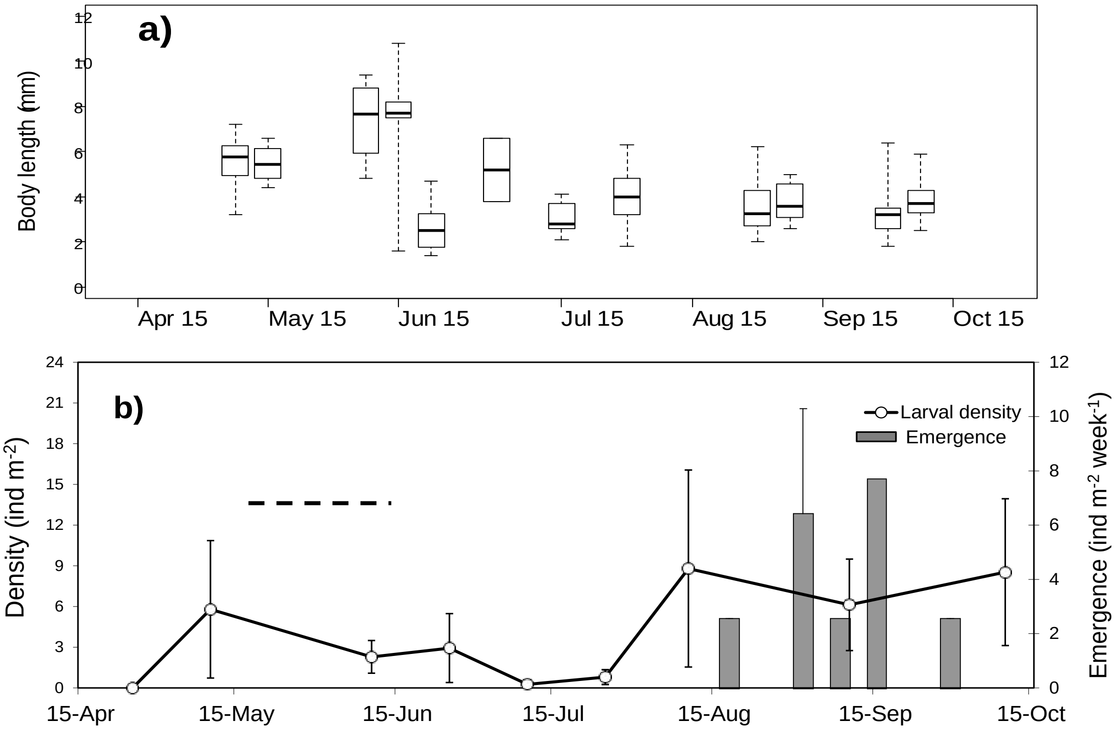


Fig. 4-29: The summarized results of *P. chocolata* (Ephemeroptera) during the ice free period in the years 2007 to 2009. **a)** Box-and-whisker plots (median, 25/75 percentile and 10/90 percentile) of larval body length [mm] and **b)** Line and bar plots of larval [ind m^{-2}] (mean±*SE*; *n*=72) and emergence [ind m^{-2} $week^{-1}$] (mean±*SE*; *n*=8) densities. Hypothetical emergence period is presented with a dotted line.

4.4.2.4 Seasonal bivoltine cycle

Hydropsyche kozhantschikovi appears to be one species that has a seasonal bivoltine life cycle type due to its fast growth rate.

(i) Life cycle of *Hydropsyche* (*Ceratopsyche) kozhantschikovi* (Trichoptera: Hydropsychidae)

Hydropsyche kozhantschikovi (n=5,596) in the Kharaa River were analysed between the years 2007 and 2009 (Fig. A-19 and Fig. 4-30a). The larval head capsule width ranged from 0.20 mm to 1.60 mm within the five larval instars that could be distinguished (Fig. A-6). Between late April and June the third to fifth larval instars were sampled and the mean head capsule width (±*SE*) measured (1.15 ± 0.00 mm, *n*=1140). The individuals in the pupa stage were collected between late May and late June. The emergence period lasted the entire month of June (Fig. 4-30b). The larval hatching period for the summer generation of *H. kozhantschikovi* began in June that was followed by rapid growth during July and August. The second emergence period started from the middle of July and ended by the beginning of September (Fig. 4-30b). To provide a detailed overview of this life cycle type, a hypothetical life cycle pattern of *H. kozhantschikovi* was proposed (Fig. 4-31) based on the larval body length distribution in 2009 in the middle reach of the Kharaa River (*Kh_5*) where winter and summer generations were separated. Consequently, seasonal head capsule growth of *H. kozhantschikovi* larvae, larval density and emergence data suggested a bivoltine seasonal life cycle, with an overwintering generation spanning from late August to late June and a shorter summer generation occurring from late June to early September. A considerable broad overlap in the larval stage is exhibited in both generations, primarily due to an extended emergence period of adults.

Depending on the life cycle type of *H. kozhantschikovi* there was a temporal fluctuation in larval density during the year (Fig. 4-30b), showing higher larval and emergence densities of the winter generation and lower larval and emergence densities of the summer generation.

An unexpected result for the first emergence period was the sex ratio of *H. kozhantschikovi* in the emergence traps. Until the end of the last week in June, a total of 946 adults were collected and their sex ratio determined to be 20:1 (females: males). The mean body length (±*SE*) was 8.55 ± 0.02 mm for females (*n*=899) and 7.58 ± 0.14 mm for males (*n*=14). For the second emergence period, 155 individuals were caught in the emergence traps and the sex ratio was 3:1 (females and males). The mean body length (±*SE*) had decreased for both females and males to 7.69 ± 0.08 mm (*n*=116) and 6.12 ± 0.18 mm (*n*=39), respectively.

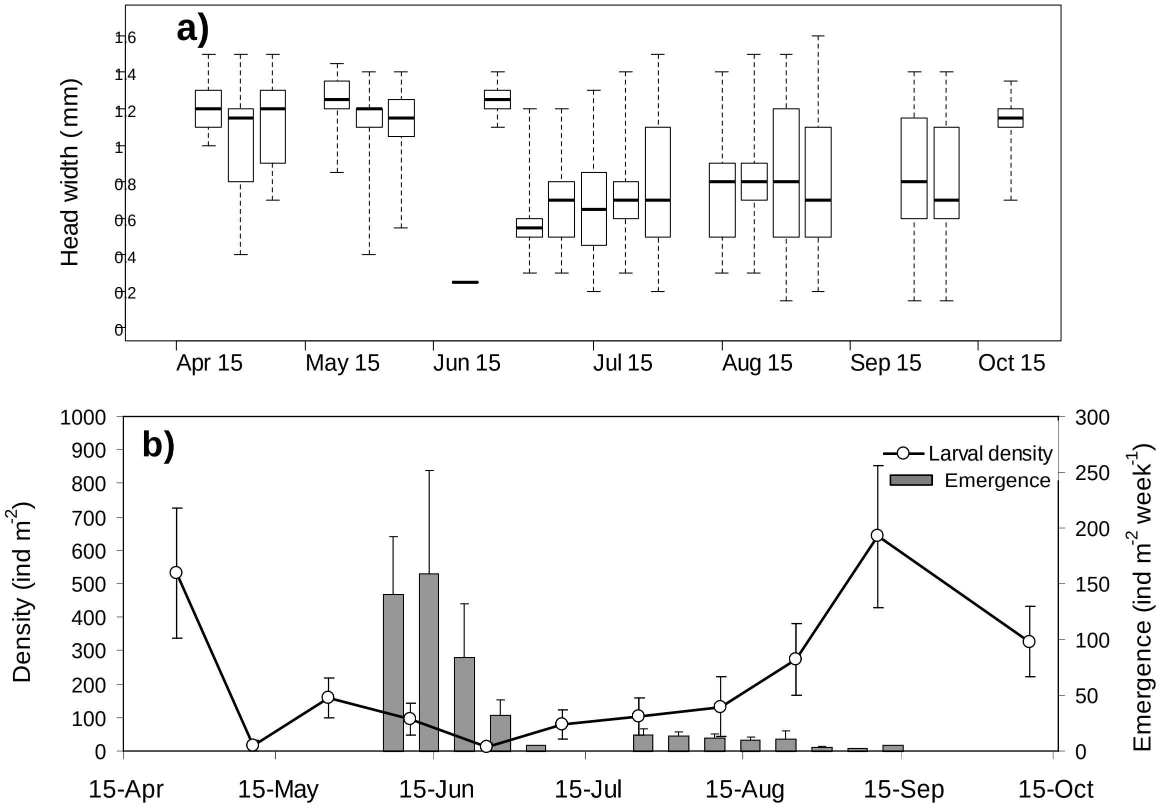


Fig. 4-30: The summarized results of *H. kozhantschikovi* (Trichoptera) during the ice free period in the years 2007 to 2009. **a)** Box-and-whisker plots (median, 25/75 percentile and 10/90 percentile) of larval body length [mm] and **b)** Line and bar plots of larval [ind m^{-2}] (mean±*SE*; *n*=77) and emergence [ind m^{-2} week^{-1}] (mean±*SE*; *n*=56) densities.

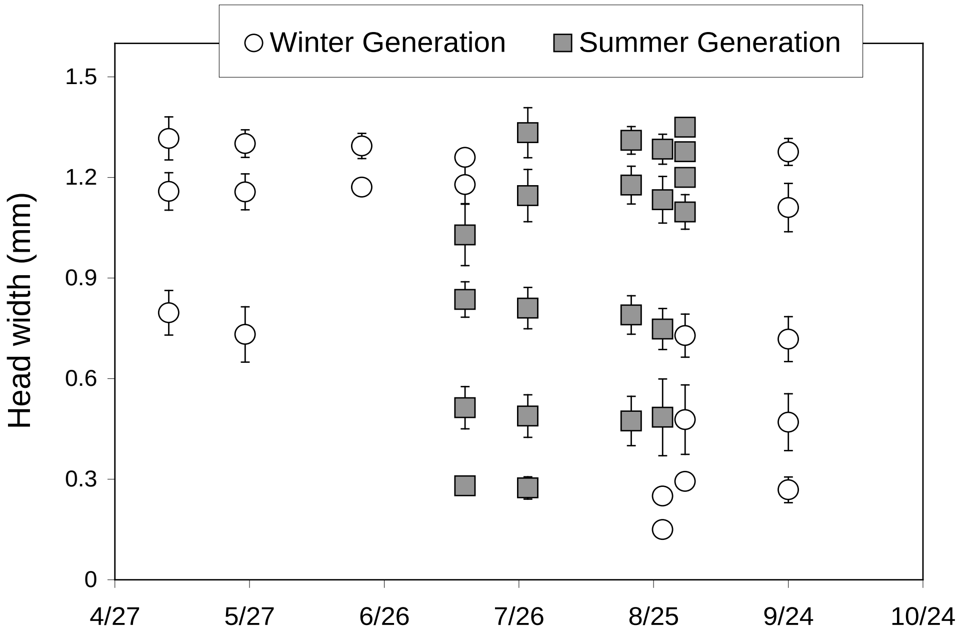


Fig. 4-31: The body length distribution [mm] (mean±*SD*) of *H. kozhantschikovi* larvae (Trichoptera) with the winter and summer generations at the site *Kh_5* in 2009 (*n*=327 for winter generation; *n*=884 for summer generation; *n*=724 for new winter generation).

4.4.2.5 Seasonal semivoltine cycle

The life cycle of all selected species was the longest for the species group *Agnetina brevipennis/extrema* as it lasted multiple seasons with the emergence taking place over the entire summer. Thus *Agnetina brevipennis/extrema* has a semivoltine life cycle.

(i) Life cycle of *Agnetina sp.* (Plecoptera: Perlidae)

In total 3,638 individuals of the species group *Agnetina brevipennis/extrema* were analysed in the Kharaa River for the years from 2007 to 2009 (Fig. 4-32a and Fig. A-8). Larval body length ranged from 0.7 mm to 26.3 mm with approximately 70% of the individuals less than 6 mm body length (Fig. A-4). The mean body length (±*SE*) of *Agnetina brevipennis/extrema* larvae throughout the ice free period was measured in weekly increments and were relatively similar ranging between 4.3 ± 0.3 mm and 7.5 ± 0.7 mm except for a single week in June (Fig. 4-32a). The larval density from different months did not show great variation, however, the body length distributions throughout the year showed separate cohorts (Fig. A-8). Three distinct cohorts could be distinguished. Based on their body length distributions a hypothetical life cycle pattern of *Agnetina brevipennis/extrema* was proposed (Fig. 4-33). It is very likely that the samples collected between April and late June included individuals from two different cohorts from previous years. In late June, the emergence period for the summer had begun. The first adults were collected from the beginning of June and ended by late September (Fig. 4-32b). Based on the above mentioned results it can be concluded that *Agnetina brevipennis/extrema* had a seasonal semivoltine cycle with a generation time of approximately three years in the Kharaa River.

Two species within the *Agnetina* genus were collected in the emergence traps in the Kharaa River. A total of 73 individuals of *A. brevipennis* were collected and the sex ratio determined to be 1:1 (females: males). The mean body length (±*SE*) was 17.2 ± 0.26 mm for females (*n*=41) and 13.0 ± 0.0.26 mm for males (*n*=32). Sixty-four *A. extrema* were also caught in the emergence traps. The mean body length (±*SE*) for *A. extrema* was shorter than for *A. brevipennis* being 16.1 ± 0.29 mm for females (*n*=25) and 11.6 ± 0.12 mm for males (*n*=39). The sex ratio of *A. extrema* was 2:3 (females and males). Emergence of *A. brevipennis* started from late July to early June and continued until end of September. It seemed that *A. extrema* emerged earlier than *A. brevipennis* in both years or 2008 and 2009 (Fig. 4-34 and 4-35). But, the emergence density and frequency is still insufficient to determine accurate emergence period of *A. extrema*.

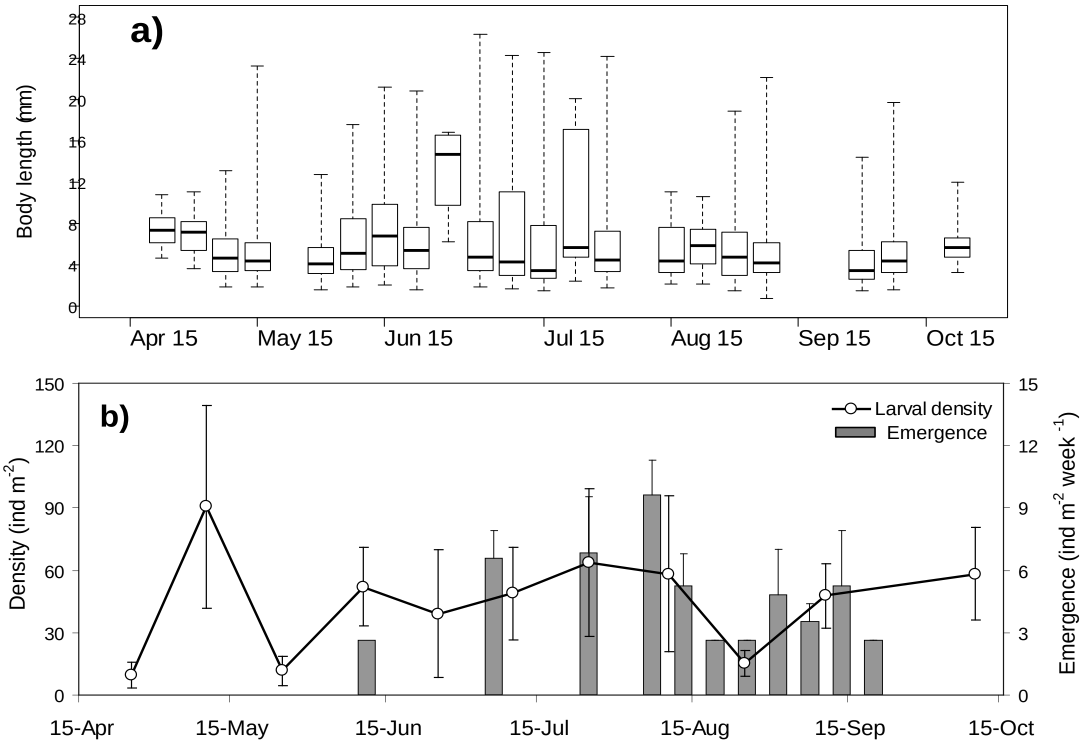


Fig. 4-32: The summarized results of *A. brevipennis/extrema* (Plecoptera) during the ice free period in the years 2007 to 2009. **a)** Box-and-whisker plots (median, 25/75 percentile and 10/90 percentile) of larval body length [mm] and **b)** Line and bar plots of the density of larvae [ind m^{-2}] (mean±*SE*; *n*=77) and emergence [ind m^{-2} week^{-1}] (mean±*SE*; *n*=43).

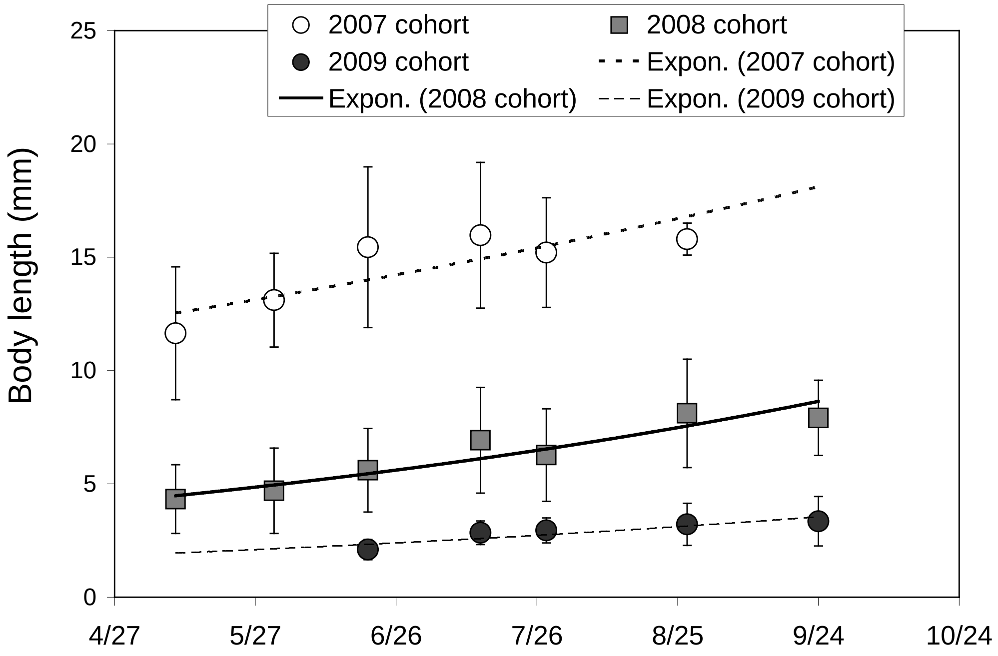


Fig. 4-33: The body length distribution [mm] (mean±*SD*) of *A. brevipennis/extrema* larvae (Plecoptera) with the cohorts in the years of 2007, 2008, and 2009 at the site Kh_8.5 in 2009 (*n*=114 for 2007 cohort; *n*=812 for 2008 cohort; *n*=557 for 2009 cohort). Note: R^2=0.70 (2007 cohort); R^2=0.90 (2008 cohort); R^2=0.79 (2009 cohort).

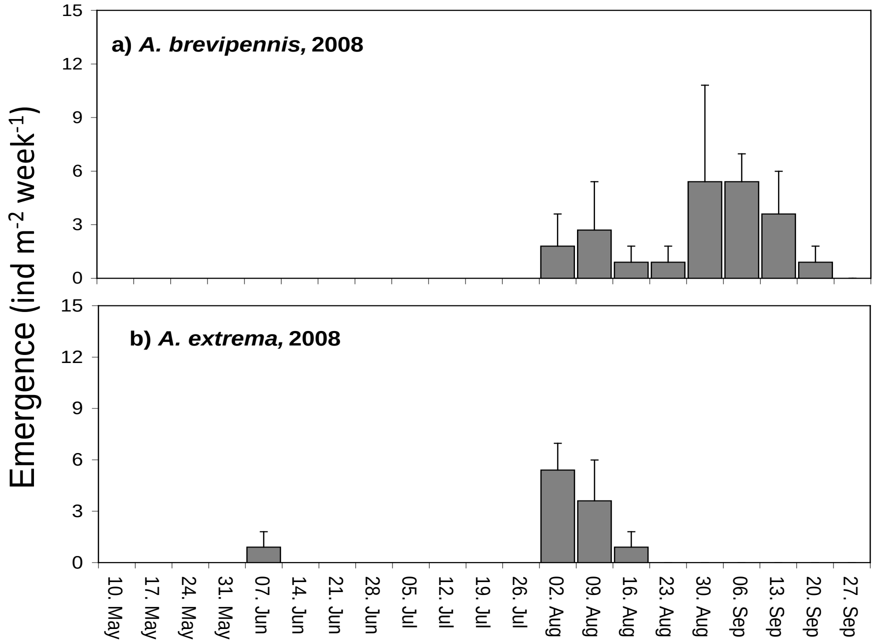


Fig. 4-34: Emergence patterns of **a)** *Agnetina brevipennis* and **b)** *Agnetina extrema* at the *site Kh_8.5* from early May to late September in 2008.

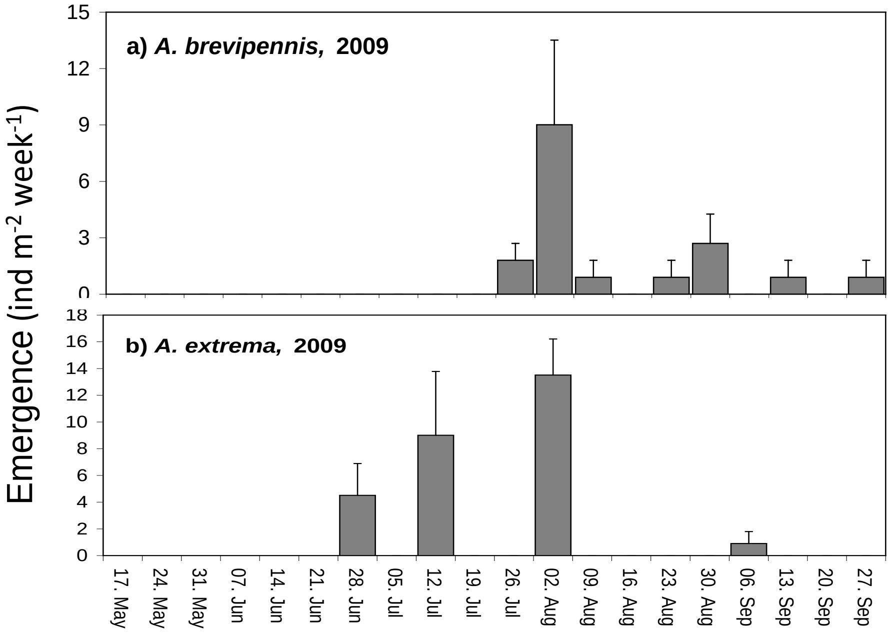


Fig. 4-35: Emergence patterns of **a)** *Agnetina brevipennis* and **b)** *Agnetina extrema* at the *site Kh_8.5* from early May to late September in 2009. Note unequal scaling of y-axis in the figure.

4.5 SECONDARY PRODUCTION AND GROWTH RATE

4.5.1 Secondary production

It was not possible to calculate the secondary production estimates for all eighteen species and at each site (*Sug_1*; *Kh_8.5*; *Kh_5*) due to the partially low numbers of individuals in the samples in 2009.

Enough individuals were available for secondary production calculations for four out of six mayfly species with a univoltine summer cycle at three Kharaa River sites (Table 4-15). The estimation of cohort production intervals (CPI) ranged between 90 and 120 days based upon the interpretation of life cycles from the size-frequency histograms of these four univoltine summer cycle mayfly species. The highest annual secondary production (7.89 g DW m^{-2} $year^{-1}$) was estimated for the burrowing mayfly *Ephoron nigridorsum* with a high individual biomass at the site *Kh_8.5*. *Brachycercus harrisellus* had the lowest annual secondary production displaying 0.41g DW m^{-2} $year^{-1}$ at the site *Kh_5* and 0.58 g DW m^{-2} $year^{-1}$ at the site *Kh_8.5*. The cohort production/biomass ratios (P/B) were calculated to be 3.6 to 6.8. However, the annual P/B rates increased by three to four times (10.9 $year^{-1}$ to 27.3 $year^{-1}$) compared to the cohort P/B ratios. Mayfly species *Baetis ussuricus* had the highest cohort and annual P/B rates (Cohort P/B ratios 6.5 and 6.8; Annual P/B rates 25.8 $year^{-1}$ and 27.3 $year^{-1}$). Unfortunately, production estimations of the small body sized univoltine summer cycle stonefly (*Leuctra fusca*) and caddisfly (*Agapetus jakutorum*) species were not possible based on the small amount of individuals collected from 2009 at all three sites.

Table 4-15: Larval production parameters of four species with a univoltine summer cycle from May to October 2009; CPI = cohort production interval (days); BM = biomass (mg DW m^{-2}); SP = secondary production (g DW m^{-2}); AP = annual secondary production (g DW m^{-2} $year^{-1}$); P/B = production to biomass rate: Cohort P/B & Annual P/B ($year^{-1}$).

	Taxon	Study site	CPI	Biomass	SP	AP	P/B	
							Cohort	Annual
1	*Baetis ussuricus*	Sug_1	-	-	-	-	-	-
		Kh_8.5	90	85.4	0.58	2.33	6.8	27.3
		Kh_5	90	192.1	1.24	4.96	6.5	25.8
2	*Brachycercus harrisellus*	Sug_1	-	-	-	-	-	-
		Kh_8.5	120	53.2	0.19	0.58	3.6	10.9
		Kh_5	120	30.9	0.13	0.41	4.4	13.1
3	*Drunella cryptomeria*	Sug_1	-	-	-	-	-	-
		Kh_8.5	-	-	-	-	-	-
		Kh_5	90	452.4	1.80	7.20	3.9	15.9
4	*Ephoron nigridorsum*	Sug_1	-	-	-	-	-	-
		Kh_8.5	110	443.2	2.38	7.89	5.4	17.9
		Kh_5	110	281.2	1.59	5.27	5.7	18.7

The secondary production values of univoltine winter cycle species, except for the caddisfly species *Glossosoma nylanderi*, are estimated (Table 4-16). Estimates of the cohort production intervals (CPI) ranged between 300 and 310 days. The annual secondary production was measured between 0.18 g DW m^{-2} $year^{-1}$ (*Psychomyia flavida*) and 2.25 g DW m^{-2} $year^{-1}$ (*Ephemera orientalis*). The burrowing mayfly, *Ephemera orientalis,* with a high individual biomass, displayed the highest annual biomass at the site *Kh_5*. The cohort P/B ratios of the eight species with a univoltine winter cycle in the Kharaa River were calculated to be 3.7 to 7.8. The annual P/B rates were slightly increased (4.5 $year^{-1}$ to 9.0 $year^{-1}$) compared to the cohort P/B ratios. The caddisfly species, *Brachycentrus americanus,* had the highest cohort and annual P/B rates (cohort P/B of 7.6 and 7.8; annual P/B of 9.0 $year^{-1}$ and 9.2 $year^{-1}$). Even though, *E. orientalis* displayed the highest annual secondary production (2.25 g DW m^{-2} $year^{-1}$), its cohort and annual P/B rates (3.7 and 4.5 $year^{-1}$) were the lowest within the univoltine winter cycle species (Table 4-16).

Table 4-16: Larval production parameters of nine species with univoltine winter cycle species from May to October 2009; CPI = cohort production interval (days); BM = biomass (mg DW m^{-2}); SP = secondary production (g DW m^{-2}); AP = annual secondary production (g DW m^{-2} $year^{-1}$); P/B = production to biomass rate: Cohort P/B & Annual P/B ($year^{-1}$).

	Taxon	Study site	CPI	Biomass	SP	AP	P/B	
							Cohort	Annual
1	*Ephemera orientalis*	Sug_1	-	-	-	-	-	-
		Kh_8.5	300	294.8	1.35	1.65	4.6	5.6
		Kh_5	300	490.3	1.85	2.25	3.7	4.5
2	*Uracanthella lenoki*	Sug_1	-	-	-	-	-	-
		Kh_8.5	-	-	-	-	-	-
		Kh_5	300	231.0	1.45	1.74	6.3	7.5
3	*Alaskaperla longidentata*	Sug_1	300	59.1	0.31	0.37	5.2	6.2
		Kh_8.5	-	-	-	-	-	-
		Kh_5	-	-	-	-	-	-
4	*Brachycentrus americanus*	Sug_1	310	28.1	0.21	0.25	7.6	9.0
		Kh_8.5	310	103.0	0.81	0.95	7.8	9.2
		Kh_5	-	-	-	-	-	-
5	*Goera tungusensis*	Sug_1	-	-	-	-	-	-
		Kh_8.5	300	194.0	0.79	0.95	4.1	4.9
		Kh_5	-	-	-	-	-	-
6	*Micrasema gelidum*	Sug_1	-	-	-	-	-	-
		Kh_8.5	300	260.5	1.55	1.80	5.9	7.1
		Kh_5	-	-	-	-	-	-
7	*Psychomyia flavida*	Sug_1	-	-	-	-	-	-
		Kh_8.5	310	32.9	0.15	0.18	4.6	5.4
		Kh_5	-	-	-	-	-	-

Agnetina brevipennis/extrema had the longest larval development with the cohort production interval (CPI) of 3 years or approximately 1080 days (Table 4-17). The annual secondary production of this species group ranged from 0.14 g DW m^{-2} y^{-1} to 2.07 g DW m^{-2} y^{-1}. The lowest annual P/B rate (0.6 $year^{-1}$) was found here as well. The secondary production estimates of the caddisfly species, *Hydropsyche kozhantschikovi,* were separated between summer and winter generations (Table 4-17). The CPI was estimated as 80 days for the summer generation and 300 days for the winter generation. The highest annual secondary production (18.7 g DW m^{-2} year^{-1}) of *H. kozhantschikovi* was estimated for the summer generation at the site *Kh_5* while the lowest annual secondary production (1.26 g DW m^{-2} year^{-1}) was estimated for the winter generation at the site *Kh_8.5*. The results of the cohort P/B ratio and the annual P/B rate of the winter generation were comparable (cohort P/B ratios 4.5 and 5.2; annual P/B rates 5.5 year^{-1} and 6.3 year^{-1}) between the sites of *Kh_8.5* and *Kh_5*. Although, the annual P/B rate of the summer generation ranged between 20.5 year^{-1} and 23.5 year^{-1}. Similar results were evident for the seasonal univoltine species of *Epeorus pellucidus* (Table 4-15). The CPI was estimated at 90 days for the summer cohort and 300 days for the winter cohort. The annual secondary productions values were higher for the summer cohorts (1.99 g DW m^{-2} year^{-1} and 4.39 g DW m^{-2} year^{-1}) and lower for the winter cohorts (0.59 g DW m^{-2} year^{-1} and 1.32 g DW m^{-2} year^{-1}). The results of the cohort P/B and annual P/B of the winter cohorts were similar (cohort P/B ratios 2.6 and 3.4; annual P/B rates 3.1 year^{-1} and 4.1 year^{-1}) between the sites of *Kh_8.5* and *Kh_5*, however, the annual P/B rates of the summer cohorts ranged between 10.5 year^{-1} and 13.6 year^{-1}. The lowest secondary production (0.08 g DW m^{-2} year^{-1}) was estimated for the winter generation of *Paraleptophlebia chocolata* at the site *Kh_8.5*.

Table 4-17: Larval production parameters of three species with seasonal univoltine, seasonal bivoltine and semivoltine cycle species from May to October 2009; CPI = cohort production interval (days); BM = biomass (mg DW m^{-2}); SP = secondary production (g DW m^{-2}); AP = annual secondary production (g DW m^{-2} year^{-1}); P/B = production to biomass rate: Cohort P/B & Annual P/B (year^{-1}).

	Taxon	Study site	CPI	Biomass	SP	AP	P/B	
							Cohort	Annual
1	*Agnetina brevipennis/ extrema*	Sug_1	1080	419.3	2.11	0.70	5.0	1.7
		Kh_8.5	1080	907.8	6.21	2.07	6.8	2.3
		Kh_5	1080	240.6	0.42	0.14	1.8	0.6
2	*Hydropsyche* (*Ceratopsyche*) *kozhantschikovi*	Sug_1	-	-	-	-	-	-
		Kh_8.5		230.2	1.04		4.5	
			80^{Sg}			4.73		20.5
			300^{Wg}			1.26		5.5
		Kh_5		798.0	4.11		5.2	
			80^{Sg}			18.7		23.5
			300^{Wg}			4.99		6.3
3	*Epeorus pellucidus*	Sug_1	-	-	-	-	-	-
		Kh_8.5		323.2	1.10		3.4	
			90^{Sg}			4.39		13.6
			300^{Wg}			1.32		4.1
		Kh_5		190.8	0.50		2.6	
			90^{Sg}			1.99		10.5
			300^{Wg}			0.59		3.1
4	*Paraleptophlebia chocolata*	Sug_1	-	-	-	-	-	-
		Kh_8.5		10.6	0.07		6.4	
			120^{Sg}			0.20		19.1
			300^{Wg}			0.08		7.6
		Kh_5	-	-	-	-	-	-

Note: Sg-summer generation; Wg-winter generation.

The annual secondary production values in 2009 were estimated for three sites in the Kharaa River (*Sug_1*; *Kh_8.5*; *Kh_5*) and were in the range 0.08 g DW m^{-2} y^{-1} to 18.7 g DW m^{-2} $year^{-1}$. Over 85 % of the total selected species contributed to the secondary production of less than 5 g DW m^{-2} $year^{-1}$. The remaining 15 % or 3 species had annual productions of 5 to 10 g DW m^{-2} $year^{-1}$ and one species had the annual production of above 15 g DW m^{-2} $year^{-1}$ (Fig. 4-36a). The frequency distribution of the annual P/B rate was more heterogeneous compared to the distributions of the annual secondary production (Fig. 4-36b). The highest percentage of species had an annual P/B rate of 5 $year^{-1}$ to 10 $year^{-1}$.

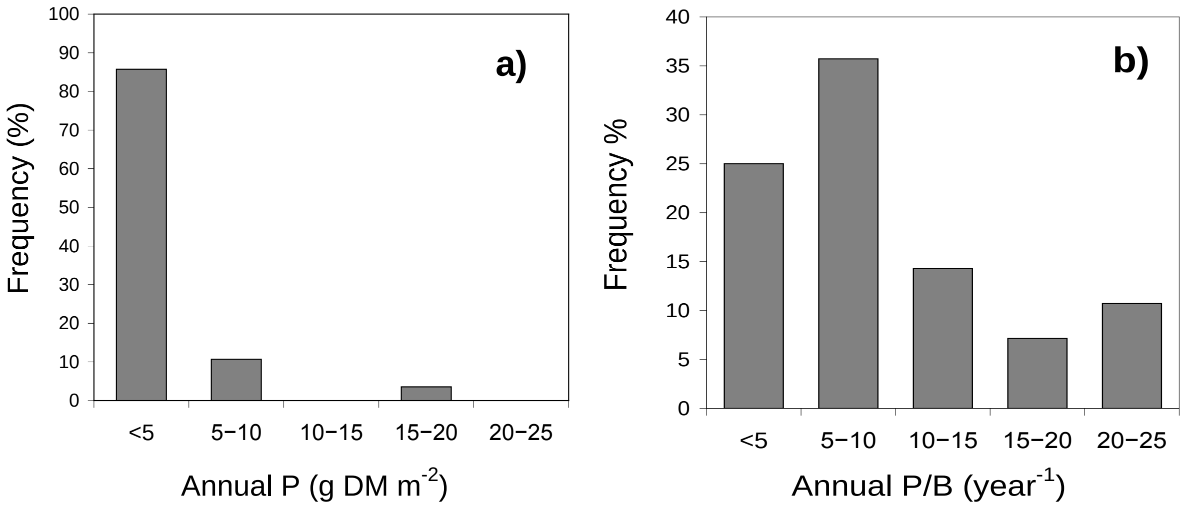


Fig. 4-36: Frequency distribution [%] of **a)** annual secondary productions (*n*=28) [g DM m^{-2}] and **b)** annual P/B rates (*n*=28) [$year^{-1}$] for the selected species in the Kharaa River, 2009.

4.5.2 Growth rate

The mean daily growth (± *SE*) of total univoltine summer cycle species was approximately 1.5 times higher (0.039 ± 0.007 mg DW day^{-1}; *n*=65) than the total univoltine winter cycle species (0.025 ± 0.0046 mg DW day^{-1}; *n*=85). The same result was estimated for growth rate. The total mean growth rate (± *SE*) of the univoltine summer cycle species was about 1.4 times higher (1.59 ± 0.12 % day^{-1}; *n*=65) than the total mean growth rate for the univoltine winter cycle species (1.12 ± 0.10 % day^{-1}; *n*=85).

A high variation of daily growth among the species was obtained for both univoltine summer and winter species (Fig. 4-37a; b) depending on their individual biomasses (Table 4-19). Two burrowing mayflies (*Ephemera orientalis* and *Ephoron nigridorsum*) with the highest individual biomasses (Table 4-19) demonstrated the highest maximum daily growths (Table 4-18). The highest mean growth rates (Fig. 4-37c) were estimated for univoltine summer cycle species (*Agapetus jakutorum* and *Drunella cryptomeria*) with the shortest larval development time or days from hatching to final size (CPI: 70 to 90 days) (Table 4-18; 19). The mean growth rates were similar among the winter cycle species (Fig. 4-37d). But, two species, *Brachycentrus americanus* and *Psychomyia flavida*, with the longest larval development periods (CPI: 310 to 330 days) (Table 4-19) showed the lowest growth rates (Table 4-18).

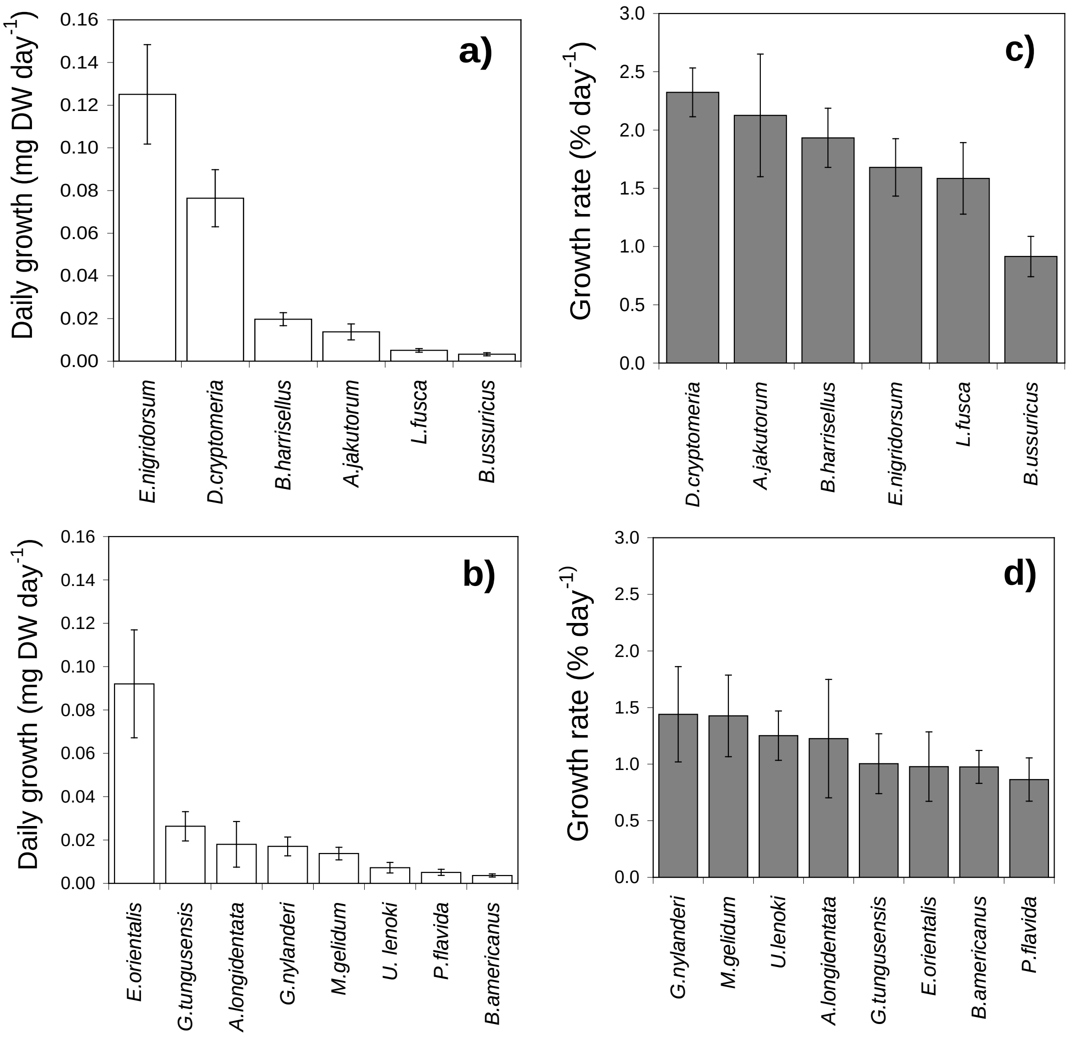


Fig. 4-37: The mean daily growth **(a, b)** and growth rate **(c, d)** [mean±*SE*] of univoltine summer and univoltine winter species in the Kharaa River Basin in 2007-2009.

The maximum individual biomasses of six univoltine summer cycle species were very close to the results of multiplication of maximum daily growth and cohort production interval (Table 4-19). Therefore, it can be concluded that the adaptation of univoltine summer cycle species to extreme continental climate is using the full benefit of the higher summer temperature for growth. In contrast, there were high differences among the measured and estimated results of univoltine winter cycle species Table 4-19). However, these results are not considering their daily growth during ice cover period but indicate very slow growth throughout the year or larval diapauses during the ice cover period.

Table 4-18: Daily growth (mg DW day^{-1}; median, min, and max) and growth rate (% day^{-1}; median, min, and max) of univoltine summer and winter cycle species in the Kharaa River Basin in 2007-2009.

Species		Daily growth (mg DW day^{-1})			Growth rate (% day^{-1})		
	n	Min	Median	Max	Min	Median	Max
Univoltine summer cycle							
Agapetus jakutorum	4	0.0049	0.0136	0.0229	1.00	2.01	3.49
Baetis ussuricus	22	0.0003	0.0026	0.0159	0.12	0.88	3.73
Brachycercus harrisellus	11	0.0101	0.0166	0.0414	0.81	1.66	3.50
Drunella cryptomeria	11	0.0071	0.0799	0.1407	1.42	2.18	3.60
Ephoron nigridorsum	11	0.0100	0.1152	0.2334	0.09	1.62	2.71
Leuctra fusca	6	0.0019	0.0053	0.0073	0.73	1.46	2.46
Univoltine winter cycle							
Alaskaperla longidentata	4	0.0005	0.0139	0.0438	0.15	1.13	2.50
Brachycentrus americanus	18	0.0002	0.0019	0.0103	0.10	0.77	2.26
Ephemera orientalis	14	0.0133	0.0604	0.3295	0.11	0.53	4.49
Glossosoma nylanderi	12	0.0024	0.0138	0.0478	0.10	0.83	3.85
Goera tungusensis	9	0.0070	0.0164	0.0527	0.21	0.89	2.80
Micrasema gelidum	8	0.0031	0.0119	0.0287	0.13	1.42	3.41
Psychomyia flavida	10	0.0004	0.0038	0.0132	0.07	0.72	1.98
Uracanthella lenoki	10	0.0005	0.0032	0.0220	0.16	1.27	2.71

Table 4-19: Comparison on the individual biomass (mg DW day^{-1}; median, and max) from the measurements and multiplication by daily growth (mg DW day^{-1}; median, and max) and cohort production interval (days) of univoltine summer and winter cycle species.

Species	Individual biomass (mg DW)			CPI (days)	Individual biomass (Daily growth x CPI) (mg DW)	
	n	Median	Max		Median	Max
Univoltine summer cycle						
Agapetus jakutorum	421	0.338	**1.128**	70	0.952	**1.603**
Baetis ussuricus	6057	0.191	**1.158**	90	0.234	**1.431**
Brachycercus harrisellus	979	0.258	**2.871**	120	1.992	**4.968**
Drunella cryptomeria	2064	0.432	**10.597**	90	7.191	**12.663**
Ephoron nigridorsum	2080	0.756	**28.464**	110	12.672	**25.674**
Leuctra fusca	704	0.137	**0.804**	110	0.583	**0.803**
Univoltine winter cycle						
Alaskaperla longidentata	211	0.930	**3.804**	300	4.17	**13.14**
Brachycentrus americanus	5727	0.104	**3.323**	310	0.59	**3.193**
Ephemera orientalis	1082	4.954	**25.966**	300	18.12	**98.85**
Glossosoma nylanderi	1029	0.860	**6.365**	300	4.14	**14.34**
Goera tungusensis	556	0.823	**7.790**	300	4.92	**15.81**
Micrasema gelidum	1283	0.656	**4.775**	300	3.57	**8.61**
Psychomyia flavida	921	0.322	**3.169**	310	1.18	**4.09**
Uracanthella lenoki	4434	0.178	**2.571**	300	0.96	**6.60**

Chapter 5

DISCUSSION

5.1 METHOD DISCUSSION

5.1.1 Sampling design concepts

Previous macroinvertebrates studies in Mongolia employed different sampling techniques, using qualitative and quantitative methods. Quantitative sampling was proposed for the *Surber sampler,* which was attached with 32 x 42 cm and 30x30 cm frames. Samples were collected from two to three different microhabitats in order to estimate the density of macroinvertebrate communities in the rivers (Avlyush, 2011; Bolortsetseg, 2011). The qualitative sampling method in certain studies (Enkhtaivan, 2004; Chuluunbat & Morse, 2007; Bolortsetseg, 2011) consisted of *D-frame DIP net* based on the modified Rapid Bioassessment Protocol (RBP) and *kick net* (1m x 1m) at riffles and pools. Using these sampling methods, 100 to 200 specimens of macroinvertebrates were randomly chosen for further analysis. However, all of these sampling methods were limited to the sampling areas, and microhabitat distributions. Therefore, another sampling method had to be employed in this study. In particular, considering the data for secondary production of benthic invertebrates (Benke & Huryn, 2006) quantitative sampling was required in this study. A multi-habitat quantitative sampling method was developed by Haase *et al*. (2004) based on testing different sampling methods. One of the significant findings using the multi-habitat quantitative sampling method was an increase in knowledge, including extensions to species ranges, and discoveries of new species. In fact, a record of EPT species in the Kharaa River was slightly higher than 50 % (Schäffer, 2014; own data) of the total record for Mongolia. Buffagni *et al*. (2003) has been specified a similar statement as well.

However, the application of a quantitative multi-habitat sampling approach in combination with the use of a net with a mesh size of 500 µm may have caused insufficient trapping of individuals of certain species distributed in the microhabitats with a minor percentage in total sampling area and the absence of the smallest size classes. This was challenging for the determination of the precise egg and larval hatching periods based on few individuals of the first instars. A loss of the first instars cannot solely be associated to mesh size. Several studies (e.g., Dixon & Wrona, 1992; Perán *et al*., 1999; Hwang *et al*., 2009) showed the absence of the smallest size classes even though a net with a mesh size of 250 to 350 µm was used. To avoid this, Watanabe and Ohkita (2000) selected a supplementary sampling method and sampled eggs and first instars by taking sediment using a shovel. The alternative hypothesis was followed that the first instars inhabit deeper sediment layers, which could not be reached with other sampling methods. Therefore, in order to quantify fecundity and development rate it is essential to sample eggs and earliest instar larvae, e.g. by taking sediment samples.

Although this was the first quantitative method for emergence density of EPT group in the river systems in Mongolia throughout months from May to September, several disadvantages were evident while using the weekly sampling with emergence traps in this study. The traps were mostly installed close to the bank. Thus there is a potential risk to miss the significant abundance of stoneflies in the selected emergence traps because of their emergence behavior. Mature nymphs crawl out of the water and onto the river banks and continue to move several meters away from the trap (Hynes, 1976). Nevertheless, *Agnetina brevipennis* and *Agnetina extrema* were the abundant large stoneflies among the order (Plecoptera) with 47% of total stonefly larval abundance and they were caught in the emergence traps with 27% of total stonefly abundance. No individual of large burrowing mayflies (*Ephemera orientalis* and *Ephoron nigridorsum*) were captured in the emergence traps, but were caught with the sweep net. Therefore, the absence of large burrowing mayflies in the emergence traps could be traced back to their emergence behavior. Another difficulty was flood conditions in the Kharaa River that restricted the use of the traps. In both study years (2008 and 2009), the emergence traps had to be removed for 20 to 44 days during high water stages in late June and July. The duration of possible emergence is considerably short in Mongolia and limited to the vegetation period between May to October. Therefore, the sampling break during high runoff events for more than 20 days could be a weakness of this study. On the one hand, it seemed that these pyramidal traps are designed to be adapted and effective to use them in the standing water (Walton, 2009), and streams (Petersen *et al.*, 1999; Petersen & Hildrew, 2003). On the other hand, these pyramidal emergence traps still can be a useful tool to quantify the emergence since similar taxa richness of EPT group compared to the results from sweep net. Furthermore, reasonable higher emergence density of EPT species have been found in the Kharaa River compared to the results obtained in a stream (Hellmann, 2010) in mid mountainous region. Nevertheless, the additional method should be applied in the rivers and Malaise (1937) traps could be chosen for flood condition in rivers like the Kharaa River.

There were two restriction factors for sampling period and frequency. The first factor was extreme climatic conditions leading to ice cover in spring and strong run-off events during summer. An important hydrological character of the Kharaa River is the occurrence of ice cover with a maximum thickness of 1.3 m between November to April and average ice cover duration of 132 days (Batima *et al.*, 2004) and it can be supported with water temperature results at the sites *Sug_1* and *Kh_8.5*. Therefore, the sampling campaigns could not take place from November to April. Considering the conceptual model by Milner and Petts (1994) based on the investigations in the glacier-fed rivers, only dipteran individuals could be expected in the rivers with water temperatures of below 2 °C. The mean water temperatures were among 2.2 °C to 3.2 °C in October 2008 and 0.6 °C to 3.1 °C in April 2009 in the upper and middle reaches of the Kharaa River. Therefore, the period with non-sampling in November to April was meaningful. During the summer in the sampling years, several rainfall events resulted in a high frequency of flood pulses in the Kharaa River (personal observation). Therefore, benthic sampling was not conducted in May and August 2007 and October 2008 and no sampling period for emergence traps as mentioned before. A flood effect in the sampling from the periods of increased discharge was assumed in this study. Aquatic macroinvertebrates are known to drift downstream (Brittain & Eikeland, 1988) or migrate to more stable deeper sediment layers for refuge (Palmer *et al.*, 1992; Wood *et al.*, 2010) during flood events. The low densities of macroinvertebrates during the periods with high discharge could present the phenomenon of refuge. Additionally, no emergence trapping of two species (*Brachycercus harrisellus* and *Uracanthella lenoki*) with very narrow emergence period in July may possible caused by flood events in both years.

Another limitation was a laboratory working capacity. This study was carried out under the frame of a biomonitoring study in the Kharaa River Basin and more than 10 sampling sites were chosen. Some of the study sites could not be sampled in the high temporal frequency because of the insufficient laboratory capacity to analyze the complete communities for each sampling site and period. Therefore, the sampling frequency was increased to every second week at three sites (*Sug_1*, *Kh_8.5*, and *Kh_5*) to focus on secondary production estimation in 2009. Insufficient sampling frequency has a strong impact on the estimation of growth rates of selected species whether there was a difference among the sites in the Kharaa River.

5.1.2 Selection of the target species for life cycle study

The majority of studies dealing with life cycle period and production focused on single taxa or less than 5 species within the EPT group. The main selection criteria were *(i)* abundant species (e.g., Derka *et al.*, 2004; Li *et al.*, 2009), *(ii)* well-known taxa from other regions for comparison (e.g., Cid *et al.*, 2008; Hwang *et al.*, 2009), *(iii)* co-existing species (e.g., Poepperl, 2000b; López-Rodríguez *et al.*, 2010), *(iv)* high individual biomass (e.g., Heise & Flannagan, 1987; Feeley *et al.*, 2009), *(v)* endemic species (López-Rodríguez *et al.*, 2009d). The above mentioned specific criteria except the endemic species exist for 18 species from the EPT group in the Kharaa River. Consequently, the existence of literature data was considered itself as a fifth selection criterion for this study. The abundance was the most positive criteria for this study. Even though there were some taxa with low abundance in the EPT group, these were also selected due to their importance as representative species from the upper reach (*Alaskaperla longidentata, Paraleptophlebia chocolata)*, taxonomic identification without uncertainty (*Brachycercus harrisellus*), high individual biomass (*Ephemera orientalis*) and occurrences in the emergence traps (*Agapetus jakutorum, Goera tungusensis*). According to the review, a comparison of the life cycle type and period was only possible for *Ephemera orientalis* at the species level and the remaining 17 species could be only reviewed at the genera and family level. The detailed information on life cycle and secondary production of the co-existing burrowing mayflies (*Ephemera orientalis* and *Ephoron nigridorsum*) in the Kharaa River has been delivered (Avlyush *et al.* 2013). A main motivation of this research article was on the distribution of these sympatric burrowing mayflies at the same sites in the Kharaa River. Several publications are available describing the co-existence of these burrowing mayflies, their distribution and ecology in running water habitats (Kuroda *et al.*, 1984; Ban & Kawai, 1986; Lee *et al.*, 1999; Hwang *et al.*, 2003). However, none of these publications have investigated the larval distribution at the same site nor habitat preference and spatial or temporal shift. A high individual biomass was measured for several species (e.g., *Agnetina brevipennis/extrema*, *E. orientalis*, and *E. nigridorsum*).

Relatively few numbers of studies on life cycle studies of numerous species from EPT group exist. The main criteria for the selection of the target species from these studies were *(i)* sufficient abundance for analysis of their life cycle and production dynamics (e.g., Dobrin & Giberson, 2003; Salas & Dudgeon, 2003), *(ii)* taxa diversity (Huryn & Wallace, 1987), *(iii)* widespread distribution and comparable to other geographical localities (López-Rodríguez *et al.*, 2008). Those three criteria were considered in this study as well. Although, information about abundance is discussed in the previous paragraph, the mean biomass of species at each sampling was considered additionally together with abundance as a one of the selection criteria for this study, due to high individual biomass and production of some species. The criteria of taxa diversity was carefully considered and selected 18 species from 16 distinct families display clearly. Two additional criteria consisting of emergence density and taxonomic determinability were considered in this study due to the conditions of extreme harsh climate, a lack of basic studies, and taxonomic identification problems. Taxonomical identification is always difficult at the larval stages if there are no base studies in the region. Although, the emergence is a part of the life cycle study, adult collections of abundant EPT taxa in the benthic samples were essential from different sites. Advantage of taxonomical identification on adult individuals to the species level was considered additionally.

5.1.3 The length of egg and larval development period

The specific information on length of egg and larval development period, instar number and size are known to be essential for understanding the seasonal timing of various life cycle processes, population synchrony, distributional pattern, and the persistence under disturbance (Becker, 2005). Information on the length of egg development was not specified in this study but would have been valuable for interpreting life cycles. In particular, it is necessary for an unequivocal determination of life cycle lengths and also crucial for correct production estimates. The literature review on the measurements of egg size (e.g., Sweeney *et al.*, 1995) could have been provided information of head capsule width or hatching period of the first instars. Unfortunately, there exist few studies containing information on egg length or width of the selected taxa. Results on egg morphology (Watanabe & Ohkita, 2000) and number of eggs (e.g., Willis & Hendricks, 1992; Vásquez *et al.*, 2009) could be found only for certain species. Since there were few individuals of the first instars for all selected taxa in the samples, the hypothetical abundances or development periods of the first instars can be purposed and discussed with further studies.

It is common that the larval development periods are determined using the frequency histograms of the body length without cerci or pronotum length or head width. This approach on the larval development period can be found in every life cycle study. Comparing the body length measurements of caddisflies from this study with other studies was problematic due to different measurements of head width and body length. The larval development period for caddisflies is recognized in their different larval distinct instars. The number of instars for caddisflies can be easily identified, compared to mayflies and stoneflies due to their low number of instars (Butler 1984). Instar numbers are known to be indeterminate in mayflies (Brittain 1982) and stoneflies (Hynes 1976). In conclusion, the length of egg and first instars of larval development period cannot be measures in this study.

5.1.4 Estimation of secondary production and growth rate

There are two major methods for the estimation of secondary production which are cohort and non-cohort techniques (Benke & Huryn, 2006). Both methods require quantitative sampling. Using the cohort-technique is uncommon because of the populations where individual cohorts cannot be distinguished, and where larval size spread is high. The study results showed that certain populations had a complex life cycle and many size classes of individuals were collected at the same sampling date which was used to estimate the negative individual growth values. But, it cannot be followed for the growth of any individuals. Therefore, a non-cohort technique was chosen for this study. The second non-cohort technique was used to estimate the instantaneous growth rate using the equation given by Benke & Huryn (2006). While using the method of instantaneous growth rate, a negative growth rate was estimated for several species in some periods. Therefore, uncertainties were remaining and reliable values for the growth rate requiring more quantitative research of accurate development rates. Contrariwise, a decrease in body size of the individuals (Ephemeroptera and Plecoptera) at the end of their life cycle due to synchronized nymphal development during the last instar can be a reason as well (e.g., Vannote & Sweeney, 1980; Cid *et al.*, 2008).

An increased number of studies tend to an estimation of the accumulated day-degrees to detect a difference on the larval development among the cohorts. For instance, the accumulated day-degrees are known for burrowing mayflies with a high individual biomass (e.g., Cid *et al.*, 2008; Hwang *et al.*, 2009), stoneflies (López-Rodrĭguez, 2009b; López-Rodrĭguez, 2009c; López-Rodrĭguez, 2009d), caddisflies (Jin & Ward 2007). The determination of degree day displaying thermal diversity of aquatic habitats could have been valuable for this study. From the literature, two different calculations of degree days could be used. The first equation (Southwood, 1978) required data on daily mean temperature and threshold temperature for egg development. The daily maximum and minimum temperature and threshold temperature were used in the second equation (Lee *et al.*, 1999). The continuous data (over one year) of water temperature was only available for the sites *Sug_1* and *Kh_8.5*. But, it was not possible to determine the threshold temperature for egg hatching without laboratory experiments. The threshold temperatures for selected species from literature sources cannot be used due to significant different values and incomparability to Mongolian species. In fact, the threshold temperature of *Ephoron* species was between -2 °C to 14.5 °C (e.g., Giberson & Galloway, 1985; Cid *et al.*, 2008). Studies from the closest geographical locations and climatic conditions would have been very useful in this context. Unfortunately there was only one publication from Russian Far East (Tiunova, 1997) on *Drunella cryptomeria*. Thus, the threshold temperature for egg development and accumulated degree days cannot be discussed here and remain as context of further studies.

5.1.5 Statistical analysis

Statistical analysis was used to assess whether there were differences in the water and air temperatures between the sites and years or months. As for biological data, the statistical analysis was performed only for the emergence density of EPT group at three sites in the two sampling years. The larval or emergence densities of selected 18 species at different sites were not discussed statistically. A detailed description of the life cycles of the 18 species in the Kharaa River was not available. A main aim of this study was to provide basic autecological information of EPT group from different regions of the Kharaa River. In order to enhance the validity of the results, data were pooled from all sampling sites, where the selected species were distributed, to create the life cycle development figures. Moreover, large longitudinal differences in larval development within the basin were not expected to the location of the sampling sites and a similar temperature regime at the sites. Therefore, it was not possible to present the difference in the density, and biomass of the selected species sampled at monthly intervals from different sites during the years using the pooled data for life cycle studies. Nevertheless, it was possible to use statistical analysis for a small number of species if neccessary. Based on the data in this thesis, a research article on sympatric burrowing mayflies from three sites, investigating the differences in the density, and biomass among the sites and the years and in habitat distribution was published giving information about the two species *Ephemera orientalis* and *Ephoron nigridorsum* at three different sites in the middle reaches of the Kharaa River (Avlyush *et al.*, 2013).

5.2 DISTRIBUTION OF SELECTED SPECIES

This thesis is not restricted to the investigation of life cycle and secondary production. Consequently, it was decided to include the distribution of selected 18 species from the EPT group along the river and display their larval/emergence density. Hofmann *et al.* (2011) provided the genus list of macroinvertebrate community of the Kharaa River Basin. However, this study does not distinguish between different ecoregions or sites. The decreasing number of species and their larval/emergence density within 18 species from upper reach to the lower reach could be influenced by the gradual change of physical environmental conditions and availability or exploitation of food resources. In particular, the significant changes on mineral substrate composition along the Kharaa River can play an important role. According to the results on microhabitat distributions of burrowing maylfies in the Kharaa River (Avlyush *et al.,* 2013), macroinvertebrates densely inhabit organic substrates. However, the application of the microhabitat protocol given in Haase *et al.* (2004) gave robust results on substrate composition. Within the 18 selected species, there are several co-existing species known. Therefore, the quantitative research on microhabitat distributions on a smaller spatial scale might deliver unexpected results.

5.2.1 Distribution of Ephemeroptera

In terms of biogeographic distribution, five of eight Ephemeroptera species (*Drunella cryptomeria*, *Epeorus pellucidus*, *Ephemera orientalis, Paraleptophlebia chocolata*, *Uracanthella lenoki*) are distributed in the East Palaearctic, including Japanese Islands (Soldán *et al.*, 2009). *Baetis ussuricus* and *Ephoron nigridorsum* are known from the East and West Palaearctic (Kluge, 2011). The most wide distributed species is *Brachycercus harrisellus* inhabiting mainly Palaearctic and Nearctic subarctic areas with an evident southern area extension to Mongolia in East Palaearctic (Soldán *et al.*, 2009). These eight mayflies were abundant in the middle reach of the Kharaa River except *Paraleptophlebia chocolata.*

Paraleptophlebia chocolata (Leptophlebiidae) was the only representative mayfly taxon from the upper reach of the Kharaa River. The mayflies in the family Leptophlebiidae are recognized as the frequently dominant components of collector-gatherers assemblages inhabiting hard substrata in headwater streams of cool-temperate zones (e.g., Huryn, 1996; López-Rodríguez *et al.*, 2010). *Epeorus pellucidus* (Heptageniidae) was distributed in the upper and middle reach of the Kharaa River and more abundant in the upper reach and upper parts of the middle reach. Their preferred microhabitat can be considered as boulders and cobbles close to the river banks. According to previous studies, nymphs belonging to the heptageniid mayfly genus *Epeorus* are abundant in midstream (Dudgeon, 1996) and fast-flowing streams (Edmunds & Allan, 1964). Hoover and Ackerman (2011) observed larvae moving to the underside of stones during the day and interpreted this behaviour as a proximate response to near-bed flows rather than biotic factors of food availability or predation.

The distribution of *Brachycercus harrisellus* (Caenidae) was recorded in the middle and down reaches of the Kharaa River and the species was abundant at the most upstream site in the middle reach. There were no comparative results of distribution or microhabitats on *Brachycercus* species and the *B. harrisellus*. *Baetis ussuricus* (Baetidae), *Drunella cryptomeria* (Ephemerellidae), and *Uracanthella lenoki* (Ephemerellidae) were distributed with the highest densities in the middle reach of the Kharaa River where the substrate compositions of cobbles and coarse gravels. The mayflies in the family Baetidae are more evenly distributed among the bioregions, making up 20–25% of the species. An exception are the Afrotropical and Oriental regions, where they represent 47% and 36% of the population (Barber-James *et al.* 2008) and occupy a wide range of different lotic habitats and microhabitats (e.g., Humpesch 1979; Vásquez *et al.* 2009). This result can be displayed with *Baetis ussuricus* from the Kharaa River Basin. *B. ussuricus* was distributed with approximately 70% of the total mayfly emergence abundance in the emergence traps and 12% of the total larval abundance in the benthic samples. It seemed that *Drunella cryptomeria* and *Uracanthella lenoki* from Ephemerellidae may have restrictive use of available habitats of sand-gravel, cobble, and boulder considering their high densities in the middle reach and mineral substrate compositions at the sites in the middle reach. Therefore, further studies on the microhabitat distributions and trophic resources of *D. cryptomeria* and *U. lenoki* are needed to investigate the niche segregation or competition between them because of their synchronized larval development with high density.

Due to high individual abundances in lowland streams and rivers in Japan and Korea, particularly during the emergence period, *Ephemera orientalis* is accepted as a representative species for these river types (Kuroda *et al.*, 1984; Hwang *et al.*, 2009). Hwang *et al.* (2003) concluded that the macro-distribution of *E. orientalis* is concentrated in downstream sections of lowland streams and rivers where their micro-habitats are characterized by low current and substrate consisting of sand, gravel and organic matter. Species of *Ephoron* are reported to inhabit finer sediments in larger rivers (Kureck & Fontes, 1996; Cid *et al.*, 2008). The downstream reaches of the Kharaa River are dominated by finer grain sizes, i.e. sand. In contrast to information given by Hwang *et al.* (2009), the main distribution of *E. orientalis* in the Kharaa River was located in the middle regions where mid to large size mineral substrates are dominant. The highest concentration of *Ephoron nigridorsum* was found in the upstream sections of the middle reaches of the Kharaa River, characterized by a high proportion of macrolithal or boulders, consisting of a size range between 20 cm to 40 cm. Microhabitat distributions of these co-existing burrowing mayflies are presented by Avlyush *et al.* (2013).

5.2.2 Distribution of Plecoptera

Three species of stoneflies are considered in this study. According to the biogeography of stoneflies, *Agnetina brevipennis/extrema (*Perlidae) and *Alaskaperla longidentata* (Chloroperlidae) are distributed in the East Palaearctic and *Leuctra fusca* (Leuctridae) in the Trans-Palaearctic (throughout Asia, Europe, and East and West Palaearctic) (Teslenko 2009). Judson & Nelson (2012) reported on the regional distribution of stoneflies in Mongolia and discussed their microhabitats on the family level.

In the Kharaa River *Alaskaperla longidentata* (Chloroperlidae) and *Leuctra fusca* (Leuctridae) were abundant in the upper reach and can be considered as representative species in headwaters of cool-temperate zones inhabiting the interstices of stones and gravel. *Agnetina brevipennis* and *A. extrema* were a wide-spread in the Kharaa River from upper reach to middle reach, and the highest density was assessed at the most-upstream site in the middle reach. The preferred microhabitats of *Agnetina brevipennis/extrema* were boulders and stone, logs and snags (personal observation) where sufficient prey can be found. Although autecological information on the genus *Leuctra* (e.g., Elliot & Humpesch, 1987; Pařil *et al.*, 2008; López-Rodrĭguez, 2009b), and taxonomical publications of the genus *Agnetina* (Sivec *et al.*, 2005; Zhiltzova, 2009) can be found, there are still uncertainties concerning the microhabitat distributions of these stoneflies.

5.2.3 Distribution of Trichoptera

The seven species of caddisflies in this study were distributed in a wide range of biogeographical regions (Morse, 2013), including East-Palaeartic (*Agapetus jakutorum* and *Hydropsyche kozhantschikovi*), East and West Palaeartic (*Glossosoma nylanderi*), East-Palaearctic and Nearctic (*Goera tungusensis*, *Micrasema gelidum*, and *Psychomyia flavida*), East and West Palaearctic and Nearctic (*Brachycentrus americanus*). The distribution of caddisflies in the Selenge River Basin is presented by Chuluunbat and Morse (2007).

Agapetus jakutorum (Glossosomatidae) was one of the representative species from headwater of the Kharaa River. The genus *Agapetus* is known for its presence in pristine streams (Nijboer 2004) and first-order upland streams (Becker, 2005). The mean density (lower than 40 ind m^{-2}) of *A. jakutorum* was very close to the density of *A. monticolus* (between 8 and 59 ind m^{-2}) in the Acheron River, south-east Australia (Marchant & Hehir, 1999) whereas *A. quadratus* (Álvarez & Pardo 2005) is known with its high density (more than 1000 ind m^{-2}). One of the remarkable results for caddisflies in the Kharaa River was the high colonization of five caddisfly species (*B. americanus*, *G. nylanderi*, *G. tungusensis*, *M. gelidum*, and *P. flavida*) at only one site at the most upstream site (*Kh_8.5*) in the middle reach. This site was characterized by a great proportion of mega and macrolithal of rocks, boulders with a variable percentage of smaller fractions in between and submerged macrophytes on the mineral substrates. Abundant caddisflies with high individual biomass may form the food of many species of fishes and can be an important component of the energy flow. The remaining species *H. kozhantschikovi* (Hydropsychidae) within the selected seven caddisfly species was abundant at sites in the middle reach. In particular, their highest density was recorded at the most downstream sites in the middle reaches. The family of Hydropsychidae or net-spinning filter feeders is well documented for their importance for energy flow (e.g., Willis & Hendricks, 1992; Alexander & Smock, 2005) and their tolerance of poor water quality (e.g., Stuijfzand *et al.*, 1999; Ratia *et al.*, 2012). A wide-spread distribution of *H. kozhantschikovi* and its high density in the middle reaches of the Kharaa River would indicate their wide ecological niche.

5.3 LIFE CYCLE PATTERNS

Previous studies identified temperature as one of the main factors regulating the life cycle of aquatic insects (Vannote & Sweeney, 1980; Newbold *et al.*, 1994). Under the extreme continental climate, abundant and representative species from the EPT group in the Kharaa River Basin group displayed a strictly univoltine cycle or completed their growth within a year (Fig. 5-1). Both univoltine summer and winter cycles were common. A diapause of egg stage for summer cycle species and larval diapause stage of winter cycle species during ice cover period cannot be confirmed with this study and remains as uncertainties for further studies. There were eight species within 18 EPT species having a univoltine winter life cycle and these winter cycle species overwintered with a variety of larval instars. The questions of how they prepare for winter and which habitats they live in during winter were raised from this study after describing different life cycle types for further studies. There was a tendency of fast growth of those winter cycle species during autumn, or mature growth before the intense cold started. Considering the minimum air temperature of over -40.0 °C in the basin and ice cover with a maximum thickness of 1.3 m (Batima *et al.*, 2004), a long egg and larval stage with diapause would absolutely necessary.

The flexibility of life cycles can be identified as extended life cycle stages in this region and it will be discussed for *Ephemera orientalis* (Ephemeroptera) in the next subchapter. The findings of short life cycle or seasonal bivoltine life cycle (one summer generation and one overwintering generation) and long life cycle or semivoltine life cycle identified for only one species suggest that the potential statement of water temperature change may occur in the Kharaa River Basin (Fig. 5-1). This study is displaying the life cycles of important EPT species with their secondary productions and growth rates for Mongolia for the first time and compares results to other regions using of the most common methods. In particular, the emergence period of selected EPT species are well-defined.

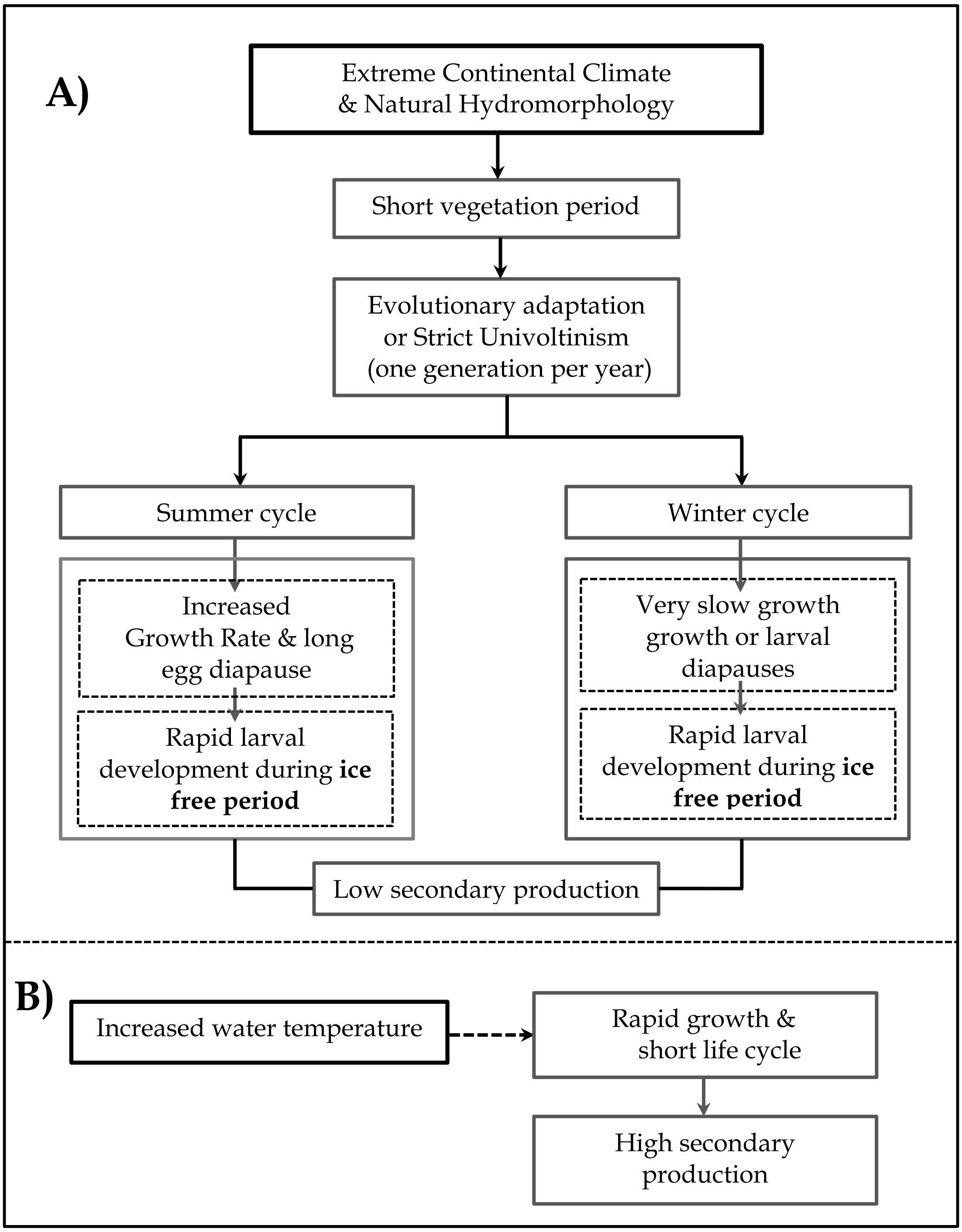


Fig. 5-1: The schema presents **a)** the main findings of life cycle of EPT species and secondary production in the Kharaa River Basin under an extreme continental climate and natural hydromorphology and **b)** recognized temperature change, its impact on life cycle pattern and secondary production.

5.3.1 Strict univoltinism

Danks (2007) specified that cold climate enforces strict univoltinism. A life cycle study of the abundant and representative species from different reaches of the Kharaa River indicated this univoltinism. Fourteen species in a total of eighteen species from the EPT group in the Kharaa River had a univoltine life cycle. Mayflies were representative for univoltine summer cycle and four of six species mayfly species (*Baetis ussuricus*, *Brachycercus harrisellus*, *Drunella* *cryptomeria* and *Ephoron nigridorsum*) exhibit this life cycle type. The life cycles of *Agapetus jakutorum* (Trichoptera) and *Leuctra fusca* (Plecoptera) are determined by a univoltine summer cycle. Eigth species, including three mayfly species (*Ephemera orientalis* and *Uracanthella lenoki*), one stonefly species (*Alaskaperla longidentata*), and five caddisfly species (*Brachycentrus americanus*, *Glossosoma nylanderi*, *Goera tungusensis*, *Micrasema gelidum*, and *Psychomyia flavida*) showed a univoltine winter cycle. The results indicated (Fig. 5-1) that the evolutionary development of univoltine cycle can be understood as a specific adaptation to extreme continental climate or short vegetation period. Although, this study cannot approve the egg or larval diapause stages for these investigated species, but it can be strongly suggested because of the results on air or water temperatures and growth rate estimations. A longitudinal pattern of life cycle types along the Kharaa River can be can be assumed, as the dominance of univoltine slow growing (winter cycle) species changes to univoltine fast growing (summer cycle) species along the river from the upper reach to the downstream reach, based on their abundance distribution.

5.3.2 Flexible life cycle

Brittain (2008) discussed the flexibility of mayflies to alter their life cycle characteristics depending on temperature and climate zone. The identification of flexible life cycles should be based at species level in different regions because of it is a common phenomenon of species at genus or family level (see Clifford, 1982). There was only one species (*Ephemera orientalis*) from this study which that has been studied at the species level in other regions.

The flexibility in the life cycle in this study indicated as extended larval development period and shortened emergence period. The taxa, *E. orientalis* is a common burrowing mayfly which is distributed throughout temperate East Asia, including the Russian Far East, North-Eastern China, the Korean Peninsula, Japan and Mongolia (Hwang *et al.*, 2008). Several studies have discussed the high flexibility in the life cycle of this species, ranging from one to three different generations in a year (e.g., Kuroda *et al.*, 1984; Lee *et al.*, 2008; Hwang *et al.*, 2009) with distinct cohorts representing slow and fast groups within one population. The flexibility in the life cycle of *E. orientalis* shown in this study indicated a univoltine winter life cycle with single generations overwintering in the nymphal stage in the Kharaa River. This was supported by the lack of distinct cohorts and the fact that emergence only occurred from late May until the middle of June. The associated results of the late October sampling in 2007 and the early spring sample in 2008 suggested a rapid larval growth in autumn and most likely a larval diapause or strong retardation of growth during ice coverage in winter, until the beginning of spring (Fig. A-15). Even though there was evidence for this hypothesis in the data, uncertainties remain, since replication of the late sampling in October of the years 2008 and 2009 was not possible.

5.3.3 Rapid growth and short life cycles

Nine species (*Agapetus jakutorum*, *Baetis ussuricus*, *Brachycercus harrisellus*, *Hydropsyche kozhantschikovi*, *Drunella cryptomeria*, *Epeorus pellucidus*, *Ephoron nigridorsum*, *Leuctra fusca,* and *Paraleptophlebia chocolata*) in three different life cycle types in the Kharaa River showed rapid growth or short life cycles belonging to the univoltine summer cycle (six species), seasonal univoltine (two species) and seasonal bivoltine (one species) cycles. The length of larval development was in a range from 2 months to 4 months for univoltine summer cycle species and summer generations of seasonal univoltine and bivoltine cycle species. However, it required about 10 months for the winter generations of seasonal univoltine and bivoltine species. Therefore, a short life cycle can be discussed for the summer generations of these species. Several patterns of species with short life cycles have been recognized. The nine species can be divided into two groups of non-egg diapause and egg diapause. Another pattern is flexible and rigid life cycles within species with short life cycle.

It is assumed that only the net-spinning, filter feeder caddisfly (*H. kozhantschikovi*) did not have a stage with egg diapause. Its life cycle is determined by a seasonal bivoltine cycle (bivoltine winter-summer cycle) or an overwintering generation in the larval stage and one summer generation (see Fig. A-19) in the middle reach of the Kharaa River. The larval development period of the summer generation was about two to three months while the overwintering generation of *H. kozhantschikovi* in the larval stage occurred for approximately ten months. There was a rapid development during the pupal stage and a massive emergence in short period during May and early June was observed for the winter generation. The length of egg incubation was very short for the summer generation. The summer generation could start immediately after oviposition. In fact, considering the time period between two samplings (21 June to 14 July in 2009), the pupal stage, emergence and oviposition would follow within 2 to 3 weeks. Mackay (1979) found almost the same results for the bivoltine *Hydropsyche* species. The life cycles are comparably well-known for the genus *Hydropsyche* and the family Hydropsychidae in other regions and shows flexible life cycles. Numerous studies describe the life cycle, production and emergence pattern of species in the family of Hydropsychidae (e.g., Willis & Hendricks, 1992; Poepperl, 2000b; Alexander & Smock, 2005). Their life cycles vary from univoltine to mulivoltine (Table 5-1). It seems that these net-spinning filter feeders distribute in cold-climate to warm-climate ecosystems and show variability in their tolerance of increasing water temperature (Table 5-1). Mackay (1979) stated as 'Many species of hydropsychids will be bivoltine or multivoltine in warm rivers where summer temperatures exceed 24 ^{0}C for at least 2 months'. Moreover, two different life cycle types of the same species of Hydropsychidae at different study sites of the river are possible according to the water temperature differences (Mackay, 1979). The water temperature regime (Table 5-1) in the middle reach (*Kh_5*) of the Kharaa River could be a reason for bivoltine life cycle. The development periods of different life cycle stages of the net-spinning caddisfly (*H. kozhantschikovi*) in the Kharaa River was very close to three species of *Hydropsyche* with bivoltine life cycles displayed by Mackay (1979). It is very likely that a rapid abundance decrease of last instars for the summer generation of *H. kozhantschikovi* (see Fig. A-19) displays the synchronization of nymphal development. This means that smaller individuals entered the last instar and the shorter instar duration of smaller nymphs occurred. This could be an adaptation to the pronounced drop in water temperature in late August. The life cycle pattern of filter feeding caddisfly species (*H.*

kozhantschikovi) and its high abundance demonstrated an effect of increased water temperature (Fig. 5-1) in summer in the middle reach of the Kharaa River.

T**able 5-1:** Life cycle type comparison of species of the genus *Cheumatopsyche* and *Hydropsyche* in family of Hydropsychidae in terms of water temperature variations in the rivers.

Water temperature	**Species**	**Life cycle**	**Location**	**Author**
T_{min} = below 2 ^{0}C T_{max} = 21 ^{0}C	*H. siltalai* & *H. pellucidula;*	Univoltine	West Norwegian River	Andersen & Klubnes (1983)
T_{min} = 2 ^{0}C T_{max} = 16 ^{0}C	*C. pettiti*, *H. slossonae* & *H. riola;*	Univoltine	Spring-fed Stream, Minnesota	Mackay (1986)
T_{max} = 22^{0}C-28^{0}C T_{min} = 0^{0}C	*H. betteni, H. dicantha, H. slossonae,* & *H. sparna*	Bivoltine	The Credit and Himber Rivers, In Southern Ontario	Mackay (1979)
$T_{mean(VI-VIII)}$ = 14°C-18°C T_{max} = 24 ^{0}C T_{min} = below 0^{0}C	*H. kozhantschikovi*	Bivoltine	Kharaa River, Mongolia	this study
$T_{annual\ mean}$ = 15.7 ^{0}C T_{max} = 26^{0}C -28 ^{0}C	*C. analis* & *H. betteni*	Trivoltine	Urban Virginia Stream	Alexander & Smock (2005)

Epeorus pellucidus (Heptagenidae) and *Paraleptophlebia chocolata* have a seasonal univoltine cycle. Most of the new generation overwintered in the egg stage, and a small part of the population overwintered in the nymphal stage (see Fig. 4-27 & A-14). Considering their summer generation, *E. pellucidus* and *P. chocolata* are species with short life cycle. A high abundance and a clear shape of body length distributions, *E. pellucidus* had a seasonal univoltine cycle and it was one of the consequences on flexible life cycle (Clifford, 1982) of genus *Epeorus*. As for *Paraleptophlebia chocolata*, only univoltine summer and winter cycle of the genus *Paraleptophlebia* have been known so far (e.g., Clifford, 1982; González, 2003b). Nevertheless, this study stated the seasonal univoltine cycle even though there were relatively low larval and emergence abundances of *P.chocolata* (see Fig. 4-29 & A-22).

A typical fast seasonal univoltine life cycle requires the presence of a diapause stage during the embryonic development (Hynes, 1976). The short period of larval development in this study supports the possible existence of an embryonic diapause under extreme climate conditions. Therefore, it is assumed that the remaining six species with univoltine summer cycle have an egg diapause of approximately seven to nine months in the Kharaa River. It can be suggested that a long egg stage with diapause is a typical for certain species throughout the regions. Burrowing mayflies of the genus *Ephoron* (Polymitarcyidae) are well-investigated throughout the Palaeartic region and show a long egg stage with diapause under univoltine summer cycles (e.g., Phillips *et al.*, 1994; Kureck & Seredszus, 2007; Sekine *et al.*, 2007). *Ephoron nigridorsum* in the Kharaa River has a univoltine summer life cycle with an assumed egg diapause of approximately eight months. The eggs were deposited during emergence period from end of July to August and it appeared to be presumable that the first instars hatched in early May of the following year. An egg diapause was reported also for other species of this genus and the duration concluded for the Kharaa River matches these given time frames (Table 5-2). In particular, the length of larval development and emergence period of *E. nigridorsum* in the Kharaa River was very close to *E. album* from the Valley River, Manitoba (Giberson & Galloway, 1985).

Table 5-2: Time period comparison on the egg-diapause stage of the genus *Ephoron.*

Water temperature	**Species**	**Period of egg stage**	**Location**	**Author**
$T_{(V-VI)}$ = 15°C-20°C T_{max} = ≥20 ^{0}C T_{min} = below 0^{0}C	*E. album*	9 months (Aug-May)	Valley River, Manitoba, Canada	Giberson & Galloway (1985)
$T_{mean(VI-VIII)}$= 14°C-18°C T_{max} = 24 ^{0}C T_{min} = below 0^{0}C	*E. nigridorsum*	9 months (Aug-May)	Kharaa River, Mongolia	this study
$T_{(VI-VIII)}$= 12°C-22°C T_{max} = 25 ^{0}C	*E. leukon*	8-9 months (Aug-May)	South River, Virginia, USA	Snyder *et al.* (1991)
	E. virgo	8-9 months (Aug-May)	Lower Ebro River, Spain	Cid *et al.* (2008)
$T_{(V-IX)}$= 5°C-27°C T_{max} = 29 ^{0}C	*E. shigae*	6 months (Sep-Mar)	Asahi-gawa River, Japan	Watanabe & Ohkita (2000)

It was problematic to discuss the flexible and rigid life cycles for two mayfly species (*Brachycercus harrisellus* & *Drunella cryptomeria*; Table 4-8) due to limited comparable studies from other regions. *D. cryptomeria* (Ephemerellidae) has a univoltine summer cycle with larval development periods of about 3 months. It is reasonable to conclude that *D. cryptomeria* remained in the egg stage for up to nine months. Nevertheless, a univoltine winter cycle is identified as a common life cycle type in the overall assessment by Clifford (1982). Tuinova (1997) declared the univoltine winter cycle for *D. cryptomeria* from Vladivostok, but the results on size frequency distribution pointed to a univoltine summer cycle. The larval development period considerably extended for *D. cryptomeria* from Vladivostok compared to the populations from Kharaa River. The second mayfly species is *B. harrisellus* (Caenidae) who has a univoltine summer cycle with a larval development period of up to five months in the Kharaa River. Considering the literature knowledge (Clifford, 1982; Jaždžewska, 1997) and the results from this study, a short summer nymphal growth and long egg diapause is typical for *B. harrisellus.*

Lillehammer *et al*. (1989) distinguished numerous species of the genus *Leuctra* into two groups based on their egg incubation period. The first group has a short egg incubation period in summer and a relatively long nymphal growth period during autumn, winter and spring. Species in the second group display a long egg incubation period during the winter and a short nymphal growth during summer. Species in the first group can, under special climatic conditions, change to the second group. The authors specially discussed *Leuctra fusca* and its flexible life cycle as an example of this modification. In the Kharaa River Basin, *L. fusca* had a univoltine summer cycle with a larval development of 5 months and an egg incubation period of 7 months and can be included in the second group of this classification. Therefore, the results for *L. fusca* in the Kharaa River support the statement by Lillehammer *et al*. (1989) on the changes of life cycle type.

The caddisfly species *Agapetus jakutorum* (Glossosomatidae) (Nijboer, 2004) and the mayfly species *Baetis ussuricus* (Baetidae) (Clifford, 1982) often show flexible life cycles at the genus level in regions under a wide variation of climates. The larval development period was the shortest for *A. jakutorum* within 18 selected species (see Fig. A-7) and shorter than for other species of the genus *Agapetus* (Nijboer, 2004). A univoltine cycle is common for *Agapetus* species (e.g., Nijboer, 2004; Becker, 2005), while a multivoltine cycle has been known (Àlvarez & Pardo, 2005). Life cycles of the genus *Baetis* is well known as univoline to multivoltine species throughout the regions and bivoltine and multivoltine life cycles are dominant (Clifford, 1982). The life cycle of the *Baetis ussuricus* in the Kharaa River increases the knowledge on univoltine life cycle of the genus *Baetis*.

5.3.4 Slow growth and long life cycles

Stoneflies are well-known as semivoltine species by their long life cycles and stonefly species with a life cycle lasting 3, 4 or even 5 years were reported in Northern Norway and Sweden (Brittain & Saltveit 2005). Semivoltine life cycles for certain mayfly large burrowing mayfly species (Svensson 1977; Sweeney *et al*., 1995) can be discussed. However, this life cycle type is not rigid for mayflies. The life cycle of *Ephemera danica* has been studied by different authors (see Clifford 1982) and different life spans were observed. These ranged from univoltine to semivoltine species with two to three years life development period *(e.g.*, Whelan 1980, Svensson 1977, López-Rodrĭguez 2009b).

The long life cycle for the EPT group in the Kharaa River Basin is considered for *Agnetina brevipennis/ extrema*. Although there was potential taxa diversity for semivoltine life cycles in the Kharaa River Basin, their relative abundance was not sufficient for the selection. About 20 stonefly species from 7 families are distributed in the Kharaa River Basin (Schäffer, 2014; own data). Semivoltine life cycle is known for some species of the families of Leuctridae, Nemouridae, Chloroperlidae, Perlidae, Perlodidae and Pteronarcyidae (see Hynes 1976) and numerous species in these families were distributed in the Kharaa River Basin. Nevertheless, the flexibility of life cycle of many stoneflies depends on species and water temperature (*e.g.*, Brittain 1978, Willams *et al*. 1995). The largest stonefly (Pteronarcyidae: *Pteronarcys reticulata*) from Mongolia was recorded at only two sites in the middle reach of the Kharaa River with low abundance and a maximum body length of 46 mm (Schäffer, 2014; own data). A three year life cycle has been identified for *Pteronarcys scotti* (Folsom & Manuel 1983) and *P. californica* (Freilich 1991). Zwick and Teslenko (2002) recorded five years of life cycle for co-existing stoneflies *P. reticulata* and *P. sachalina* from Far East Russia. Hence, it is reasonable to assume that *P. reticulata* may require a minimum of four years of larval development (personal observation) in the Kharaa River Basin.

A nymphal development period of two to three years is common for perlid species (e.g., Moreira & Peckarsky 1994; Feeley *et al*., 2009). The comparable result for *A. brevipennis/extrema* in the Kharaa River was published by Moreira and Peckarsky (1994) for *Agnetina capitata*. The authors found a complex life cycle that is characterized by multiple developmental pathways. They distinguished two sub-groups. The individuals belonging to the first subgroup hatched early and oviposition began during the summer, completing the life cycle in two years. The individuals in the second subgroup emerged later in fall or early spring and three years of life cycle was needed from oviposition to emergence. The observations on life cycles of a population of the genus *A. brevipennis/extrema* in the Kharaa River Basin in this study showed three years of larval development (see Figure A-8). There was considerable variation in larval body length which displays the overlapping of cohorts and last instars appearing throughout the sampling periods in May to October. On the one hand, it was difficult to discuss the concept of multiple development pathways (Moreira & Peckarsky 1994) for the co-existing of two *Agnetina* species (*A. brevipennis* and *A. extrema*) due to their synchronized emergence of *A. brevipennis* and *A. extrema* in the Kharaa River from June to September. On the other hand, it (multiple development pathways) could exist to *A. brevipennis/extrema* due to early emergence time of *A. extrema* compared to *A. brevipennis*. However, the emergence abundance of both species was still low to discuss about it. Consequently, the finding of long life cycles with narrow ecological niche (esp. *Pteronarcys reticulata*) in the river systems in Mongolia is essential to support the importance of monitoring for assessing the running water ecosystem health and water quality. Information on the egg development and growth rate of semivoltine life cycle species should be considered in further studies.

Eight species (*Ephemera orientalis* and *Uracanthella lenoki* from Ephemeroptera, *Alaskaperla longidentata* from Plecoptera, *Brachycercus americanus*, *Glossosoma nylanderi*, *Goera tungusensis*, *Micrasema gelidum*, and *Psychomyia flavida* from Trichoptera) in the life cycle types of univoltine winter cycle are classified as slow growth species. However, they cannot be called a true representative species of slow growth. The reason is rapid larval growth during autumn. In addition, these species (e.g., *E. orientalis*, *G. nylanderi*, & *G. tungusensis*) were fully grown before the intense cold starts. Therefore, harsh environmental condition or extreme cold winter was the limiting factor for their growth.

5.4 SECONDARY PRODUCTION AND GROWTH RATE

Similar annual P/B rates have been reported for 15 species of EPT group from the Kharaa River compared to other regions and for other species of the genus or family (Table A-1, A-2, & A-3). Unfortunately it was not possible to estimate secondary production for three taxa, including *Agapetus jakutorum* and *Glossosoma nylanderi* from Glossosomatidae (Trichoptera) and *Leuctra fusca* from Leutridae (Plecoptera). These results could have been valuable for comparison because the secondary productions of these families are well-known from other regions by Georgian and Wallace (1983), Marchant and Hehir (1999) and López-Rodríguez *et al.* (2009b). The highest annual P/B rate (23.5 y^{-1}) and secondary production (18.7 g DW m^{-2} y^{-1}) in this study was estimated for the summer generation of *H. kozhantschikovi* (Hydropsychidae), with the results being close to *Cheumatopsyche analis* (Hydropsychidae) distributing in a stream with an annual P/B rates of 19.7 y^{-1} and a secondary production of 18.2 g DW m^{-2} y^{-1} (Alexander & Smock 2005). The secondary productions of numerous species in the Kharaa River were much lower than in other studies (Table A-1, A-2, & A-3).

The growth rates here were estimated only for univoltine life cycle species in the Kharaa River and the results from univoltine summer cycle and winter cycle species are presented separately. Three species in other life cycle types (seasonal univoltine, seasonal bivoltine and semivoltine species) were not displayed and discussed here due to their complicated cohorts for the growth rate assessment. Brittain (1990) provided the mean growth rates for univoltine summer and winter cycle species from Norway. These results were very similar to the

Kharaa River. Generally, a pattern of individual growth of selected species in the Kharaa River was similar throughout the region (Table A-4). It seems that the adaptation of both winter and summer cycle species to low temperature is using the full benefit of the higher summer temperature for growth during the short vegetation period. A comparison on the maximum individual biomasses of univoltine summer cycle and results of multiplication of maximum daily growth and cohort production interval (CPI) or mean time from hatching to the final size class (Table 4-19) can support above mentioned statement. Because, the maximum individual biomasses of six univoltine summer cycle species were very close to the results of multiplications. However, the univoltine winter cycle species have to deal with a long ice cover period of several months by applying very slow growth throughout the intense cold period or larval diapauses as trade-off.

Consequently, it is essential to compare the results with the general classification of growth of macroinvertebrates. Huryn and Wallace (2000) classified the low and high levels of production for macroinvertebrate communities in streams and rivers. Moreover, he also presented the classification of low and high growth rates of macroinvertebrate species with annual P/B rate and daily growth rate. The results demonstrated that the Kharaa River can be classified as a river with a low production. In summary, the values of secondary production, annual P/B rates and growth rates from the Kharaa River Basin are still comparable, but slightly lower than in other regions (Table A-1, A-2, A-3 & A-4). The abundant species in the Kharaa River had a relatively rapid larval growth during short vegetation period and lower production which may be due to the extreme climatic conditions (Fig. 5-1).

Table 5-3: Secondary production (annual secondary production and annual P/B rate) and growth rate comparison with the classification by Huryn and Wallace (2000). The results from Kharaa River Basin are given with percentage of total estimated values.

Parameters	**Classification**	**Range**	**Kharaa River Basin**
Secondary production	Low production	Up to 5.4 g DW m^{-2} y^{-1}	≈ 90% of total estimation
	High production	From 121.0 g DW m^{-2} y^{-1}	-
Annual P/B rate	Low growth rate	Up to 5.1 y^{-1}	25% of total estimation
	High growth rate	From 62.0 y^{-1}	-
Growth rate	Low growth rate	Up to 1.4% day^{-1}	≈ 55% of total estimation
	High growth rate	From 17.0 % day^{-1}	-

5.5 AUTECOLOGICAL INFORMATION AND BIOMONITORING PROGRAM

The long-term biomonitoring program has been conducted under the research aims of the project entitled 'Integrated Water Resources Management (IWRM) in Central Asia: Model Region Mongolia (MoMo Phase I & II)'. As a result of the biomonitoring program, a joint data base was established for macroinvertebrate community in the Kharaa River Basin by the involved scientists. An importance of this large set of data base in the frame of biomonitoring program is a wide-range of knowledge in running water systems in Mongolia. The long-term assessment of the ecological status in the Kharaa River Basin based on the indicator species (MoMo Consortium, 2009a; Hofmann *et al.*, 2011) and autecological information or life cycle and secondary production of important macroinvertabrates (Avlyush *et al.*, 2013; this study) have been delivered using this large set of data base. Autecological information provided in this study increased the ecological knowledge of the indicator species and supported conclusions concerning the interpretation of biological assessment in aquatic ecosystems.

As discussed in the Chapter 2, four cases of multiple stressors (heavy metal pollution; eutrophication; fine sediment deposition; climate change) in the Kharaa River Basin are identified. Among these four multiple stressors, fine sediment deposition was identified initially using the macroinvertebrate biodiversity with increased diversity and abundance of fine sediment colonizers (Hofmann *et al*., 2011). The remaining three stressors in the Kharaa River Basin could be identified using the macroinvertebrate community. Certain major publications (Dolédec *et al*., 2006; Townsend, *et al*., 2008; Statzner & Beche, 2010) purposed the most responded biological traits using the macroinvertebrates resolving effects of multiple stressors on running water ecosystems. Numerous parameters from life cycle studies were considered in those biological traits. Considering the amount of data and their quality from biomonitoring program, the traits obtained by above mentioned authors would possibly allow an assessment and may indicate the symptoms of stressors in the Kharaa River Basin. The first study (Maasri & Gelhaus 2012) used biological traits in order to assess the vulnerability of stream macroinvertebrate communities in two major watersheds in Mongolia to ongoing climate change. Ten biological traits were described and maximal body size, dispersal, life cycle duration, and potential number of life cycle per year were included in the traits. However, there was no information about whether or not these traits were presented either by their own study or other studies because each stream site (114 streams) was sampled once during the 8 years' timeframe. Therefore, it is very likely that these authors used the literature data for these traits (e.g., life cycle duration) from other regions. Nevertheless, this study displayed the importance of consideration on the extreme continental climate in Mongolia in terms of life cycle evolutionary adaptation.

The multiple stressors, which were found in the Kharaa River Basin, have been known for other running water ecosystems in Mongolia with the different levels of impact. The heavy metal pollution from the Orkhon (Javzan 2011) and Selenge River Basins (Pavlov *et al*. 2008), high nutrient concentration and eutrophication from the Tuul River (*e.g.*, Altansukh 2009; Itoh *et al*. 2011), fine grained sediment input from open placer gold mining (Krätz *et al*. 2010) and increased annual mean temperature (Nandintsetseg *et al*. 2007; Batima *et al*. 2011), degradation of permafrost (Sharkhuu *et al*. 2007; Sharkhuu, N & Sharkhuu, A 2012) under climate warming, and intensive water extraction near urban areas (Dolgorsuren *et al*. 2012) are known. Two studies addressed the impact of grazing in macro-scale (Hayford & Gelhaus 2010) and small-scale catchments (Maasri & Gelhaus 2011) using the macroinvertabrates in the river systems. Both studies found that the increased grazing pressure causes intermediate levels of disturbance in the streams and driving stronger impacts on the riparian range health.

Accordingly, accurately assessing the effects of anthropogenic stressors (multiple or single) of freshwater ecosystems in Mongolia is a political requirement and essential moving forward with the rapid development of mining, urbanization and agriculture. Using the macroinvertebrate communities and their biological traits as indicators of multiple stressor effects should be established as early as possible to support ongoing river basin management and to help identify early signs of of *(i)* eutrophication, especially in the heavily polluted

Tuul River P, *(ii)* fine sediment deposition associated with land use (over grazing, bank erosion and open placer gold mining throughout Mongolia), *(iii)* intensive water extraction near urban areas, including a planned water pipeline diversion to arid regions where water resources are scarce, *(iv)* heavy metal contamination and *(v)* various stressors associated with climate change. These biomonitoring tools can be effective at large scales. The parallel projects in the field and laboratory as making an experiment are essential. In addition, the trait patterns of natural communities which represent reference conditions are very important and still available in Mongolia until now. Therefore, establishing the biomonitoring based on biological traits of macroinvertebrates can be a useful tool in Mongolia that can be transferred to other similar geographical regions.

Ecosystem disturbances could persist for short term to long term periods. In particular, the increase in open-placer mining activities in the floodplain areas of large rivers in Mongolia has resulted in a long term damage of natural resources such as fine sediment inputs to streams as major contributors to the degradation of freshwater habitats (Janchivdorj & Semjim, 2002; Avlyush, 2011). According to the 2012 water law of Mongolia, open placer mining activities are forbidden in running water systems. New established River Basin Administrations are planning to conduct the management measures including the rehabilitation of aquatic ecosystem. However, there is no practice of rehabilitation in the river systems in Mongolia. Therefore, life cycle traits, in particular the generation time, are very important topic when considering the capability of macroinvertabrates to recover from disturbances in terms of management measures for disturbed or endangered aquatic ecosystems. This capability is determined by regional life histories dispersal abilities, and the position within the river network. This study displayed that communities differ significantly with respect to various life cycles and many species have narrow ecological niche.

Chapter 6

SUMMARY

1. Autecologic information of aquatic insects in river systems under extreme continental climatic conditions is limited. There was no existence of literature data on the macroinvertebrate communities in the Kharaa River Basin in Mongolia. Therefore, the long-term biomonitoring program has been conducted under the research aims of the project entitled 'Integrated Water Resources Management (IWRM) in Central Asia: Model Region Mongolia (MoMo Phase I & II)'. As a result of the biomonitoring program, a joint data base was established for macroinvertebrate community in the Kharaa River Basin by the involved scientists. Macroinvertebrate assemblages at seven sites including sites and samplings referred to Schäffer (2014) along the Kharaa River Basin in Mongolia, at altitudes between 673 m to 1159 m were investigated during the ice free period from 2007 to 2009. Three specific objectives were examined for selected species: *(i)* the development of the larval and emergence densities, *(ii)* to determine the life cycle periods consisting of larval development and emergence and *(iii)* to calculate the secondary production and growth rate values. Before commencing the study, two major problems needed to be addressed. Developing the most appropriate methods to conduct the field surveys correctly and after the sampling of the entire macroinvertebrate community from the sites, the criteria for selecting the target species from the EPT (Ephemeroptera, Plecoptera, and Trichoptera) group for the life cycle study needed to be established. The characteristic extreme continental climate in the Kharaa River basin are cold and dry winters and short, hot summers. The annual mean temperature was approximately – 0.4 °C. The ice coverage duration on the Kharaa River surface is 132 days per year and its maximum thickness can reach 1.3 meters.

2. For benthic sampling, a multi-habitat quantitative sampling method was used. The method is based on sampling microhabitats according to their representation at the sampling site. The adults were collected in three pyramidal emergence traps in order to estimate the emergence density. Additionally, sweep netting was used in order to i) catch taxa occurring in the benthic but not in the emergence samples, and ii) to compare the taxa diversity from sweep netting collections with the results from emergence traps. After laboratory analysis of the benthic organisms and the adults, were inserted into a joint data base for the entire macroinvertebrate community sampled in the Kharaa River. Based on this more than 140 species from 84 EPT genera were identified in the Kharaa

River Basin which is slightly higher than 50 % of the total record for Mongolia. It was then necessary to select appropriate EPT species for further data analysis concerning the life cycle study. Thereby the focus was on EPT species because of the high suitability as water quality indicators of many of these species. Furthermore, species from the EPT group are the most widespread with regards to their taxa richness, density and biomass within the macroinvertebrate community.

3. Five criteria were established to select the species for the life cycle study. The criteria include *(i)* high larval mean density or biomass, *(ii)* high emergence density, *(iii)* good taxonomic determinability of the larval stages, *(iv)* adult and larval occurrence at different sites, and *(v)* the existence of literature data on life cycle and secondary production. Based on these criteria, eighteen species including 8 species of Ephemeroptera, 3 species of Plecoptera and 7 species of Trichoptera were chosen. These eighteen species were belonging to 16 different families representing high taxonomic diversity, more than 60% of the total EPT larval density and biomass, and 84% of the total EPT emergence density in the emergence trap samples.

4. The mean density of the selected species rapidly decreased in the middle and downstream reaches due to the gradual change of physical environmental conditions. In particular, this variability could be related to habitat quality or substrate composition in the river. The substrate composition in the Kharaa River changed significantly from upstream to downstream. Large boulders and rocks were the dominating substrates from the upstream to upper middle reaches. Then the dominant substrate changes to cobbles and course gravels in the lower middle reach. The downstream reach was dominated by finer grain sizes, i.e. sand. Another variation along the river was identified in water temperature. The mean monthly water temperatures from June to August in 2009 showed the lowest values recorded in the upper reach for each month and increased values at the sites in the middle reaches.

5. The 3-year life cycle study of the eighteen selected species investigating the larval body size, distribution and emergence period determined five different life cycle types within three major categories. Six species, *Baetis ussuricus, Brachycercus harrisellus, Drunella cryptomeria, Ephoron nigridorsum* from Ephemeroptera, *Leuctra fusca* from Plecoptera, *Agapetus jakutorum* from Trichoptera, had a univoltine summer cycle with short larval development and asynchronized emergence. However, univoltine winter cycle with prolonged larval development during winter was identified for eight species: *Ephemera orientalis, Uracanthella lenoki* from Ephemeroptera, *Alaskaperla longidentata* from Plecoptera, *Brachycentrus americanus, Glossosoma nylanderi, Goera tungusensis, Micrasema gelidum, Psychomyia flavida* from Trichoptera. There were two species that showed a rapid development with a one summer generation period. A seasonal univoltine for *Epeorus pellucidus* and *Paraleptophlebia chocolata* (Ephemeroptera) and a seasonal bivoltine cycle for *Hydropsyche* (*Ceratopsyche) kozhantschikovi* (Trichoptera) were identified. The large stonefly species group *Agnetina brevipennis/extrema* (Plecoptera) had the slowest larval development of the investigated species and displayed a semivoltine life cycle prolonged nearly over three years.

6. Emergence of adult mayflies (Ephemeroptera), stoneflies (Plecoptera) and caddisflies (Trichoptera) from the Kharaa River were studied over two five month periods (from May to October) in 2008-2009. A total of 43 EPT species including 12 species of Ephemeroptera, 8 species of Plecoptera, and 23 species of Trichoptera were recorded in the emergence traps at four sites. The mean EPT emergence density (±*SE*) was 23± 3.0 ind m^{-2} $week^{-1}$ at three sites from May to September in 2008 and 2009. The composition of the EPT species in the emergence differed between the sites in the study years. Unfortunately, only 14 species from 18 species included in the life cycle study were captured in the emergence traps. But the emergence periods of these species were well-defined. More females than male were identified for 8 species with a sex ratio from 3:2 to 10:1 (♀:♂). The sex ratio of the remaining species deviated from 2:3 to 1:2 (♀:♂). Within remaining four species, large burrowing mayflies *Ephemera orientalis* and *Ephoron nigridorsum* were caught with the sweep net. Therefore, the absence of these large mayflies in the emergence traps could be traced back to their emergence behavior. Two other mayflies (*Brachycercus harrisellus* and *Uracanthella lenoki*), which were rather abundant in the benthic samples, were not captured as adults at all. Considering the occurrence of mature larvae showing dark wing pads it seemed reasonable that these two species had very narrow emergence periods in July. During this period no emergence trapping was possible caused by flood events in both years.

7. Secondary production was estimated by means of the size-frequency method. The estimated annual production of larvae at three investigated sites in the upper and middle reaches of the Kharaa River, Mongolia in the year 2009 was in the range of 0.41 g DW m^{-2} y^{-1} to 7.89 g DW m^{-2} y^{-1} for univoltine summer cycle species and in the range of 0.18 g DW m^{-2} y^{-1} to 2.25 g DW m^{-2} y^{-1} for univoltine winter cycle types. The highest secondary production was estimated for the summer generation of seasonal bivoltine species *Hydropsyche* (*Ceratopsyche) kozhantschikovi* with an annual production of 18.70 g DW m^{-2} y^{-1}. The secondary production of the species with the longest larval development (*Agnetina extrema/brevipennis*) ranged from 0.14 g DW m^{-2} y^{-1} and 2.07 g DW m^{-2} y^{-1}. Over 85 % of the total selected species contributed to the secondary production of less than 5 g DW m^{-2} y^{-1}. This result demonstrated that the Kharaa River can be classified as a river with a low production.

8. The growth rate as increase in body weight and the daily growth as increase in body length was determined for univoltine summer cycle (6 species) and univoltine winter cycle (8 species) at the three sites over the three study years. Both parameters, mean growth rate as well as daily growth, had higher values for univoltine summer cycles species and lower values for univoltine winter cycle species. In general, compared to the Kharaa River similar growth rates have been reported for EPT species from other regions. The results indicated that the evolutionary development of univoltine summer cycles can be understood as an adaptation to extreme continental climate. This species are using the full benefit of the higher summer temperature for growth. In contrast, the univoltine winter cycle species have to deal with a long ice cover period of several months by applying very slow growth throughout the intense cold period or larval diapauses as trade-off. Nevertheless, the difference in growth rate and daily growth values between the sites and among the sampling periods are not presented in detail in this study due to

not enough individuals being sampled and insufficient sampling replicates. Therefore, it still needs more quantitative research on this topic.

9. The life cycles of the selected species displayed low type diversity or strict univoltinism from 14 of the 18 species because of the harsh climatic conditions in the basin. The specific hydrological conditions with ice coverage of the river during the period from November to April result in extended larval development periods with most likely diapauses either in egg or larva stage. The low secondary production due to the short vegetation period can be interpreted as another adaptation to the extreme continental climate. The autecological information provided in this study increases the ecological knowledge of these species and support conclusions concerning the interpretation of biological assessment in aquatic ecosystems.

10. Accurately assessing the effects of multiple anthropogenic stressors of freshwater ecosystems in Mongolia is a political requirement and essential moving forward with the rapid development of mining, urbanization and agriculture. On the one hand, using the macroinvertebrate communities and their biological traits as indicators of multiple stressor effects should be established as early as possible to help identify early signs of *(i)* eutrophication, especially in the Tuul River which flows through the capital city Ulaanbaatar and is already heavily polluted due to waste water discharge from the CWWTP, *(ii)* fine sediment deposition associated with land use (over grazing, bank erosion and open placer gold mining throughout Mongolia), *(iii)* Intensive water extraction near urban areas, including a planned water pipeline diversion to arid regions where water resources are scarce, *(iv)* Heavy metal contamination (mining development) and *(v)* various stressors associated with climate change. These biomonitoring tools can be effective at large scales. On the other hand, ecosystem disturbances could persist for short term to long term periods. In terms of management measures for disturbed aquatic ecosystems, it is necessary to obtain the knowledge of the capability of macroinvertebrates to re-colonize these habitats. This capability is mainly determined by regional life histories dispersal abilities, and the position within the river network. The trait patterns of natural communities which represent reference conditions are very important and still available in Mongolia until now. Further research works should be conducted to differentiate the anthropogenic pressures and natural impacts along the environmental gradients.

ZUSAMMENFASSUNG

1. Autökologische Informationen über aquatische Insekten in Fließgewässern unter extremen kontinentalen Klimabedingungen sind bislang nur begrenzt verfügbar. Daten zu den Makrozoobenthos-Lebensgemeinschaften im Einzugsgebiet des Kharaa in der Mongolei waren bislang in der Literatur gar nicht verfügbar. Im Rahmen des Projektes „Integriertes Wasserressourcen-Management in Zentralasien: Modellregion Mongolei (MoMo Phase I & II) wurde deshalb ein Langzeit-Biomonitoring Programm durchgeführt, in dessen Ergebnis durch die beteiligten Wissenschaftler eine gemeinsame Datenbank zum Makrozoobenthos des Kharaa-Einzugsgebietes etabliert wurde. Makrozoobenthos-Lebensgemeinschaften wurden an sieben Probestellen des Flusses Kharaa in der Mongolei während der eisfreien Periode untersucht, wobei Probestellen und Probenahmen von Schäffer (2014) eingeschlossen wurden. Die Probestellen befanden sich in Höhenlagen zwischen 673 m und 1159 m. Dabei standen für die ausgewählten Insektenarten folgende Forschungsschwerpunkte im Vordergrund: *(i)* die Entwicklung der Larven- und Emergenzdichten, *(ii)* die Typen der jeweiligen Lebenszyklen auf der Basis der larvalen Entwicklung und Emergenzmessungen und *(iii)* Kenngrößen der Sekundärproduktion sowie die Wachstumsrate zu bestimmen. Bevor die Studie durchgeführt werden konnte, mussten zunächst zwei Probleme gelöst werden. Einerseits mussten die am besten geeigneten Methoden für die korrekte Durchführung der Felduntersuchungen ausgewählt werden. Andererseits die Kriterien für die Auswahl der EPT-Arten für die Lebenszyklus-Untersuchung aus den Ergebnissen der Beprobung der gesamten Makrozoobenthos-Gesellschaft festgelegt werden. Das extreme kontinentale Klima im Einzugsgebiet des Kharaa ist geprägt von einem kalten, trockenen Winter und einem kurzen, heißen Sommer. Die mittlere Jahrestemperatur war ca. -0,4 °C und die Dauer der Eisbedeckung des Flusses beträgt 132 Tage im Jahr, wobei Eisdicken von bis zu 1,3 m erreicht werden.

2. Die Beprobung der aquatischen Stadien wurde mittels eines Multi-Habitat-Samplings durchgeführt, bei dem alle vorkommenden Mikrohabitate in Abhängigkeit ihrer Häufigkeit beprobt werden. Um die Emergenzdichte abschätzen zu können, wurden Imaginalstadien mittels pyramidaler Emergenzfallen gefangen. Zusätzlich wurden Netzfänge durchgeführt, um i) Arten zu erfassen, die im Benthos, nicht aber in den Emergenzproben auftraten und ii) die Ergebnisse der beiden Probenahmetechniken zu vergleichen. Nachdem die Proben aus den benthischen und der Emergenz-Probenahmen im Labor analysiert worden sind, wurden die Daten in eine gemeinsame Datenbank für die gesamte Makrozoobenthos-Fauna des Kharaa eingefügt. Auf dieser Basis konnten im Kharaa und seinen Zuflüssen mehr als 140 Arten aus 84 EPT-Gattungen identifiziert werden, was etwas mehr als 50 % des für die Mongolei erfassten Arteninventars ist. Im Anschluss war es notwendig geeignete Arten für die Analyse der Lebenszyklen auszuwählen. Dabei wurde der Focus auf EPT-Arten gelegt, da in dieser Gruppe viele Arten enthalten sind, die als Wasserqualitäts-Indikatoren dienen können. Außerdem sind EPT-Arten weit verbreitet mit hohen Artenzahlen, Individuendichten und Biomassen innerhalb der invertebraten Lebensgemeinschaft.

3. Die Auswahl der Arten für die Untersuchung der Lebenszyklen erfolgte anhand von drei Kriterien, *(i)* hohe mittlere larvale Individuendichte oder Biomasse, *(ii)* hohe Individuendichte in der Emergenz, *(iii)* gute taxonomische Bestimmbarkeit der

Larvenstadien, *(iv)* larvale und Imaginalvorkommen an mehreren Probestellen sowie *(v)* das Vorhandensein von Literatur zu Lebenszyklus und Sekundärproduktion. Basierend auf diesen Kriterien wurden 18 Arten ausgewählt, wobei acht Ephemeropteren-Arten, drei Plecopteren-Arten und sieben Trichopteren-Arten enthalten waren. Diese 18 Arten gehörten zu 16 verschiedenen Familien, wodurch die Diversität der Lebensgemeinschaft unterstrichen wird. Sie repräsentierten über 60 % der gesamten larvalen EPT-Individuendichte und Biomasse sowie 84 % der EPT-Individuendichte aus den Emergenzproben.

4. Die mittleren Individuendichten der ausgewählten Arten nahmen stark in Abhängigkeit der longitudinalen Veränderung der physikalischen Umweltfaktoren ab. Insbesondere wird diese Variabilität auf abnehmende Habitatqualität in Zusammenhang mit der Substratzusammensetzung im Verlauf des Flusses Kharaa zurückgeführt. Die Substratzusammensetzung verändert sich deutlich von Ober- zu Unterlauf, wobei größere Blöcke und Steine das Substrat des Oberlaufs und des oberen Mittellaufs dominierten, während Schotter und Grobkies das dominante Substrat des Mittellaufes repräsentierten und der Unterlauf durch feinere Substarte, wie z.B. Sand charakterisiert war. Außerdem konnte ein longitudinaler Temperaturgradient festgestellt werden. Die mittleren monatlichen Wassertemperaturen in den Monaten Juni bis August im Jahr 2009 zeigten die geringsten Werte im Oberlauf und erhöhte Werte an de Probestellen im Mittellauf.

5. Die Untersuchung der Lebenszyklen der 18 ausgewählten Arten über die Dauer von drei Jahren unter Berücksichtigung von Larvengröße, Verbreitung und Emergenzperiode ergab fünf unterschiedliche Lebenszyklentypen innerhalb von drei Hauptkategorien. Sechs Arten (*Baetis ussuricus, Brachycercus harrisellus, Drunella cryptomeria*, *Ephoron nigridorsum* als Vertreter der Ephemeroptera, *Leuctra fusca* als Vertreter der Plecoptera und *Agapetus jakutorum* als Vertreter der Trichoptera) zeigten einen univoltinen Sommerzyklus mit schneller Larvalentwicklung und unsynchronisierter Emergenz. Univoltine Winterzyklen wurden für acht Arten identifiziert (*Ephemera orientalis*, *Uracanthella lenoki* als Vertreter der Ephemeroptera, *Alaskaperla longidentata* als Vertreter der Plecoptera, *Brachycentrus americanus, Glossosoma nylanderi, Goera tungusensis, Micrasema gelidum, Psychomyia flavida* als Vertreter der Trichoptera). Bei zwei Arten wurde ein schnelles Wachstum mit einer Generation pro Vegetationsperiode (Sommer) festgestellt. Dabei folgte *Epeorus pellucidus* und *Paraleptophlebia chocolata* (Ephemeroptera) einem saisonalen univoltinem Zyklus während *Hydropsyche* (*Ceratopsyche) kozhantschikovi* (Trichoptera) einem saisonal bivoltinem Zyklus folgte. Die Artengruppe großer Steinfliegen *Agnetina brevipennis/extrema* (Plecoptera) zeigte die langsamste Entwicklung der betrachteten Arten und einen auf nahezu drei Jahre verlängerten semivoltinen Lebenszyklus.

6. Die Emergenz von Imagines der Familien der Eintagsfliegen (Ephemeroptera), der Steinfliegen (Plecoptera) und der Köcherfliegen (Trichoptera) im Flusss Kharaa wurden jeweils während der 5-monatigen Vegetationsperiode (Mai-Oktober) in den Jahren 2008 und 2009 durchgeführt. Insgesamt 43 EPT-Arten, bestehend aus 12 Ephemeroptera-Arten, 8 Plecoptera-Arten und 23 Trichoptera-Arten, konnten mit den Emergenzfallen an den vier Probestellen gefangen werden. Die mittlere EPT-Individuendichte in der Emergenz (±*SE*) an drei der Probestellen jeweils im Zeitraum von Mai bis September in den Jahren 2008 und 2009 war 23± 3.0 ind m^{-2} $week^{-1}$. Die Zusammensetzung der EPT-Arten

unterschied sich in der Emergenz zwischen den Probestellen in den Untersuchungsjahren. Unglücklicherweise konnten nur Individuen von 14 der 18 ausgewählten Arten mittels der Emergenzfallen gefangen werden, aber die Emergenzzeiten dieser Arten waren klar definiert. Bei acht Arten war das Geschlechterverhältnis mit 3:2 bis 10:1 (♀:♂) zu den Weibchen verschoben, das Geschlechterverhältnis der anderen Arten schwankte zwischen 2:3 und 1:2 (♀:♂). Zu den vier Arten, die nicht mit den Emergenzfallen erfasst wurden, gehörten die beiden grabenden Eintagsfliegenarten *Ephemera orientalis* und *Ephoron nigridorsum*. Diese konnten aber durch Netzfänge nachgewiesen werden und deshalb wird das Fehlen der Arten in den Emergenzproben auf das Emergenzverhalten zurückgeführt. Zwei andere Eintagsfliegenarten (*Brachycercus harrisellus* und *Uracanthella lenoki*), welche in den Benthosproben in recht hoher Abundanz auftraten, konnten überhaupt nicht als Imaginalstadien gefangen werden. Unter Berücksichtigung des Auftretens von reifen Larven mit dunklen Flügelscheiden, kann eine kurze Emergenzperiode im Juli angenommen werden. Aufgrund von Hochwasserereignissen konnte während dieser Zeit in beiden Jahren keine Emergenz erfasst werden.

7. Die Sekundärproduktion wurde anhand der Längen-Häufigkeitsmethode abgeschätzt. An den drei Untersuchungsstellen im Oberlauf und im Mittellauf schwankte die geschätzte jährliche Produktion im Jahr 2009 bei Arten mit univoltinem Sommerzyklus von 0.41 g DW m^{-2} y^{-1} bis 7.89 g DW m^{-2} y^{-1} und zwischen 0.18 g DW m^{-2} y^{-1} bis 2.25 g DW m^{-2} y^{-1} bei Arten mit univoltinem Winterzyklus. Die höchste Sekundärproduktion ergab die Schätzung für die Sommergeneration von *Hydropsyche* (*Ceratopsyche) kozhantschikovi* mit einer jährlichen Produktion von 18.70 g DW m^{-2} y^{-1}. Für die Art mit der längsten Larvenentwicklung (*Agnetina extrema/brevipennis*) schwankte die Sekundärproduktion zwischen 0.14 g DW m^{-2} y^{-1} und 2.07 g DW m^{-2} y^{-1}. Über 85 % aller ausgewählten Arten trugen zu einer Sekundärproduktion von nur 5 g DW m^{-2} y^{-1} bei. Dies verdeutlicht, dass der Kharaa als ein Fluss mit einer geringen Sekundärproduktion eingestuft werden kann.

8. Die Bestimmung der Wachstumsrate als Prozent Gewichtszunahme sowie der mittleren täglichen Zunahme der Körperlänge erfolgte für alle Arten mit univoltinem Lebenszyklus (Sommerzyklus: sechs Arten; Winterzyklus: neun Arten) an den drei Probestellen im Kharaa. Beide Wachstumsparameter zeigten höhere Werte bei den Arten mit univoltinem Sommerzyklus als bei denen mit univoltinem Winterzyklus. Generell waren die für den Kharaa errechneten Werte mit denen von EPT Organismen aus anderen Regionen vergleichbar. Die Ergebnisse verdeutlichen, dass die evolutionäre Ausbildung eines univoltinen Sommerzyklus als Anpassung an das extreme, kontinentale Klima verstanden werden kann. Diese Arten nutzen den vollen Vorteil der höheren Sommertemperaturen für ihr Wachstum aus. Im Gegensatz dazu müssen Arten mit univoltinem Winterzyklus während der mehrmonatigen Eisbedeckung einen Kompromiss mit sehr langsamem Wachstum über den stark kalte Jahreszeiten bzw. mit larvalen Diapausen eingehen. Aufgrund der geringen Individuenzahl in den Proben und unzureichender Replizierung, kann auf die Unterschiede in den Wachstumsparametern zwischen den Beprobungsstellen und den einzelnen Probenahmekampagnen nicht im Detail eingegangen werden. Hier muss auf weiteren Forschungsbedarf bezüglich quantitativer Untersuchungen hingewiesen werden.

9. Die Ergebnisse der Untersuchung der Lebenszyklen der ausgewählten Arten im Einzugsgebiet des Kharaa verdeutlichten, dass die rauen klimatischen Bedingungen in einer geringen Diversität in den Lebenszyklen und einer deutlichen Dominanz univoltiner Lebenszyklen (14 der 18 Arten) resultierten. Die besonderen hydrologischen Bedingungen mit Eisbedeckung zwischen November bis April führen zu verlängerten Larvalphasen mit sehr wahrscheinlichen Diapausen entweder im Ei- oder Larvenstadium. Die geringe Sekundärproduktion in Folge der kurzen Vegetationsperiode kann als weitere Anpassung an das extreme, kontinentale Klima interpretiert werden. Das ökologische Basiswissen über die behandelten Arten wird durch die in dieser Studie aufgeführten autökologischen Informationen erweitert. Weiterhin werden damit Schlussfolgerungen bezüglich der Interpretation von biologischen Bewertungsdaten in aquatischen Ökosystemen unterstützt.

10. Die genaue Beurteilung von Effekten durch multiple anthropogene Stressoren in Gewässerökosystemen in der Mongolei ist eine politische Forderung und unabdingbar unter Berücksichtigung der raschen Entwicklung auf dem Bergbau-, Städtebau- und Landwirtschaftssektor. Einerseits sollten Makrozoobenthos-Gesellschaften und ihre biologischen Eigenschaften (traits) so bald als möglich als Indikatoren für Effekte multipler Stressoren etabliert werden, um möglichst frühzeitig Auswirkungen durch *(i)* Eutrophierung, besonders im Fluss Tuul, der durch die Hauptstadt Ulaanbaatar fließt und bereits durch Abwassereinleitung aus der Zentralkläranlage erheblich verschmutzt ist, *(ii)* Feinsedimentablagerungen in Zusammenhang mit Landnutzung (Überweidung, Ufererosion und Goldtagebau in der gesamten Mongolei), *(iii)* intensive Wasserentnahmen im Bereich von Siedlungsschwerpunkten, eingeschlossen geplanter Pipeline-Vorhaben zur Umleitung von Wasser in aride Gebiete mit knappen Wasserressourcen, *(iv)* Schwermetallkontaminationen (Ausbau des Bergbausektors) und *(v)* verschiedenen Stressoren im Klimawandelkontext erkennen zu können. Solche Biomonitoring-Werkzeuge können auf größeren Skalen effektiv arbeiten. Andererseits können Störungen in Ökosystemen von kürzerer oder längerer Dauer sein. Im Zusammenhang mit Management-Maßnahmen in gestörten aquatischen Ökosystemen ist es zwingend erforderlich, Kenntnisse über das Wiederbesiedlungspotenzial der Makrozoobenthos-Organismen in solchen gestörten Habitaten zu haben. Dieses Wiederbesiedlungspotenzial wird zum einen durch die Position im Fließgewässernetz, zum anderen auch maßgeblich durch life-history-Charakteristika, wie die Art des Lebenszyklus bestimmt. Das Erfassen von ökologischen Eigenschaften (traits) natürlicher Lebensgemeinschaften mit Referenzcharakter, die bislang in der Mongolei noch existieren, ist dabei besonders wichtig. Weitere Arbeiten müssen entlang von Umweltgradienten erfolgen, damit kansole Zusammenhänge zuerst von antropogenen Belastungen und ökologischen Wirkungen unterscheidet werden können.

Chapter 7

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Photos

Photos on the sampling sites along the Kharaa River, Mongolia

Photo 1: The selected study sites. A) Sugnugur_1 (*Sug_1*) in the upper reach, B) Kharaa_8.5 (*Kh_8.5*) or the most upstream site in the middle reach, C) Kharaa_8 (*Kh_8*) in the middle reach, D) Kharaa_5 (*Kh_5*) in the middle reach, E) Kharaa_4 (*Kh_4*) or the most downstream site in the middle reach, F) Kharaa_2 (*Kh_2*) in the down reach.

Photos on the emergence traps at the study sites

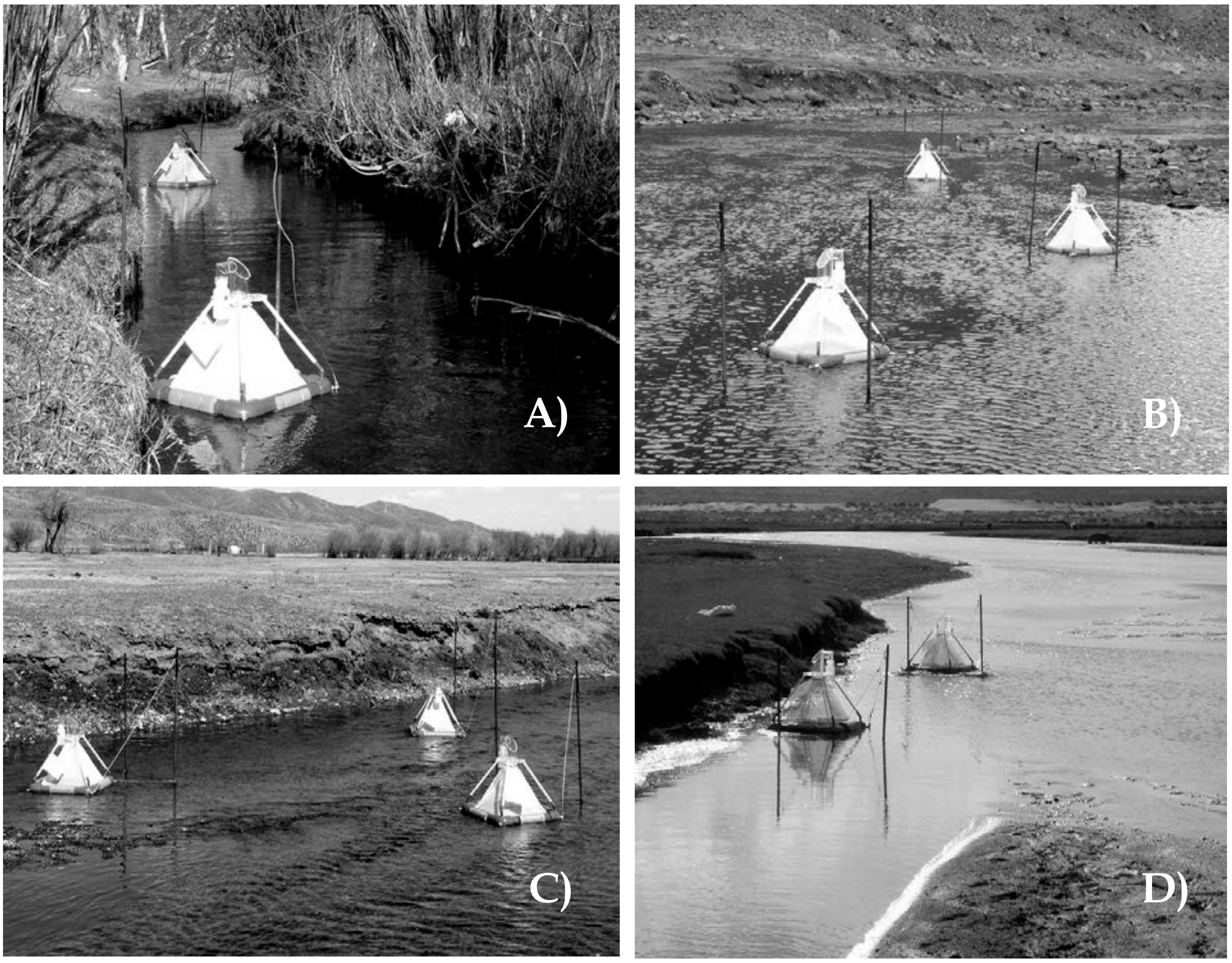

Photo 2: Emergence traps at four different sites. A) Sugnugur_1 (*Sug_1*) in the upper reach, but in the side channel, B) Kharaa_8.5 (*Kh_8.5*) in the middle reach, C) Kharaa_5 (*Kh_5*) in the middle reach, D) Kharaa_2 (*Kh_2*) in the down reach.

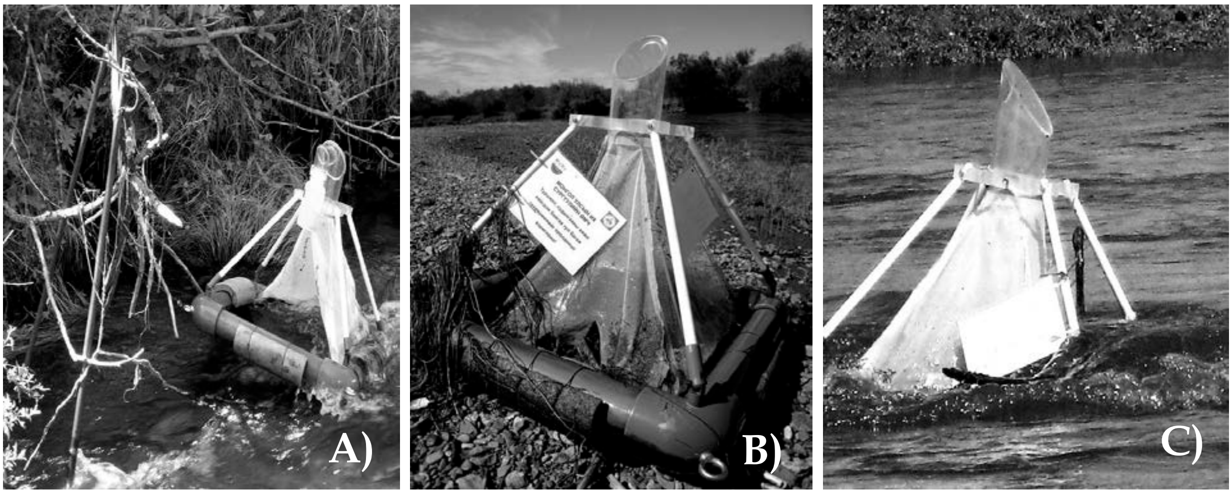

Photo 3: A view of emergence traps after the flood events during June and July, 2009. A) Sugnugur_1 (*Sug_1*), B) Kharaa_5 (*Kh_5*), C) Kharaa_5 (*Kh_5*).

Appendix

Table A-1: Secondary production comparison of selected Ephemeroptera species in the Kharaa River Basin within the taxonomical level of family.

Species	Annual P ($g\ DW\ m^{-2}y^{-1}$)	Annual P/B (y^{-1})	Location	Author
Baetis ussuricus	1.75-3.72	19.4-20.5	River, Mongolia	This study
Baetis fuscatus	1.6	11.2	Stream, Czech	Zelinka (1984)
Baetis rhodani	2.45	8.0-8.9	Stream, Czech	Zelinka (1984)
Baetis rhodani	0.27	3.4	Stream, Slovakia	Bottova *et al.* (2012)
Baetis vernus	0.14	2.5	River, Slovakia	Deván & Krno (1996)
Baetis vernus	0.05	1.2	Stream, Slovakia	Bottova *et al.* (2012)
Brachycercus harrisellus	0.41-0.58	10.9-13.1	River, Mongolia	This study
Caenis latipennis	0.03	8.0	Stream, USA	Stagliano & Whiles (2002)
Caenis luctuosa	6.35	15.9	Stream, Spain	Perán *et al.* (1999)
Drunella cryptomeria	7.20	15.9	River, Mongolia	This study
Ephemerella ignita	48.9	18.4	Stream, Spain	López-Rodríguez *et al.* (2009a)
Uracanthella lenoki	1.74	7.5	River, Mongolia	This study
Epeorus pellucidus	0.59-4.39	3.1-13.6	River, Mongolia	This study
Epeorus sinensis	0.38-28.08	14.0-16.8	Stream, China	Yan & Li (2006)
Epeorus torrentum	0.06-0.19	7.2-9.6	Stream, Spain	González *et al.* (2003a)
Ephemera orientalis	1.65-2.25	4.5-5.6	River, Mongolia	This study
Ephemera orientalis	1.35	4.2	River, Korea	Hwang *et al.* (2009)
Ephemera orientalis	0.05	6.4	Stream, Korea	Lee *et al.* (2008)
Ephemera spp.	18.2	11.8	Stream, China	Xiaoyun & Yunjun (2008)
Ephoron album	5.92-6.70	17.3-19.5	River, USA	Phillips *et al.* (1994)
Ephoron nigridorsum	5.27-7.89	17.9-18.7	River, Mongolia	This study
Ephoron virgo	0.44	5.6-5.6	River, Spain	Ibáñez *et al.* (1991)
Habroleptoides confusa	0.04-0.41	4.6-5.7	Stream, Spain	González *et al.* (2003b)
Habrophlebia lauta	0.02-0.20	8.7-11.3	Stream, Spain	González *et al.* (2003b)
Paraleptophlebia chocolata	0.07	7.0	River, Mongolia	This study
Paraleptophlebia submarginata	1.95	9.21	Stream Spain	López-Rodríguez *et al.* (2010)

Table A-2: Secondary production comparison of selected Plecoptera species in the Kharaa River Basin within the taxonomical level of family.

Species	**Annual P ($g\ DW\ m^{-2}y^{-1}$)**	**Annual P/B (y^{-1})**	**Location**	**Author**
Agnetina brevipennis/extrema	0.20-3.10	0.9-3.4	River, Mongolia	This study
Isoperla signata	0.50	3.6	Stream, USA	Jop & Szcytko (1984)
Isoperla curtata	0.38	4.4	Stream, Spain	López-Rodríguez *et al.* (2009d)
Alaskaperla longidentata	0.37	6.2	River, Mongolia	This study
Isoptena serricornis	0.69	4.1	River, Slovakia	Derka *et al.* (2004)

Table A-3: Secondary production comparison of selected Trichoptera species in the Kharaa River Basin within the taxonomical level of family.

Species	**Annual P ($g\ DW\ m^{-2}y^{-1}$)**	**Annual P/B (y^{-1})**	**Location**	**Author**
Brachycentrus americanus	0.25-0.95	9.0-9.2	River, Mongolia	This study
Brachycentrus subnubilus	4.43	5.7	River, Poland	Majecki *et al.* (1997)
Micrasema gelidum	1.80	7.1	River, Mongolia	This study
Hydropsyche (*Ceratopsyche*) *kozhantschikovi*	1.26-18.7	5.5-20.5	River, Mongolia	This study
Cheumatopsyche analis	7.2-18.2	18.4-19.7	Stream, USA	Alexander & Smock (2005)
Hydropsyche angustipennis	0.48	4.2	Stream, Germany	Poepperl (2000b)
Hydropsyche betteni	0.30-2.50	20.7-22.7	Stream, USA	Alexander & Smock (2005)
Hydropsyche pellucidula	0.43	1.9	Stream, Germany	Poepperl (2000b
Goera tungusensis	0.95	4.9	River, Mongolia	This study
Psychomyia flavida	0.18	5.4	River, Mongolia	This study

Table A-4: Growth rate comparison of selected species in the Kharaa River within the taxonomical level of genus and family. The results (mean value) on univoltine summer and winter cycle species are displayed. Due to given information in the literature, two different values (variation and mean) of growth rates are presented.

Taxa	**Growth rate**	**Location**	**Author**
UNIVOLTINE LIFE CYCLE			
Summer cycle species	0.9 to 2.3% day^{-1}	Kharaa River, Mongolia	this study
Summer cycle species	3.0 to 3.6% day^{-1}	Rivers in Norway	Brittain (1990)
Winter cycle species	0.9 to 1.4% day^{-1}	Kharaa River, Mongolia	this study
Winter cycle species	1.2 to 1.8% day^{-1}	Rivers in Norway	Brittain (1990)
EPHEMEROPTERA			
Baetis ussuricus	0.11 to 3.72% day^{-1}	Kharaa River, Mongolia	this study
Baetis sp. (3sps)	0.79 to 3.41% day^{-1}	Stream, Austria	Humpesch (1979)
Baetis sp. (3sps)	2.10 to 7.80% day^{-1}	Prealpine Stream, Northern Italy	Erba *et al*. 2003
Brachycercus harrisellus	0.80 to 3.80% day^{-1}	Kharaa River, Mongolia	this study
Caenis luctuosa	0.29 to 3.07% day^{-1}	Small pond, France	Cayrou & Céréghino (2003)
Drunella cryptomeria	1.41 to 3.59% day^{-1}	Kharaa River, Mongolia	this study
Uracanthela lenoki	0.15 to 2.71% day^{-1}	Kharaa River, Mongolia	this study
Serratella sp. (2sps)	0.41 to 1.73% day^{-1}	Mountain Stream, Sierra Nevada, Southern Spain	López-Rodríguez *et al.* (2008)
TRICHOPTERA			
Agapetus jakutorum	Mean: 2.12% day^{-1}	Kharaa River, Mongolia	this study
Agapetus quadratus	Mean: 1.74% day^{-1}	Spring-fed stream, Majorca	Àlvarez & Pardo (2005)
Agapetus sp.	Mean: 1.74% day^{-1}	Southern Appalachian stream, North America	Georgian & Wallace (1983)
Glossosoma nylanderi	Mean: 1.44% day^{-1}	Kharaa River, Mongolia	this study
Glossosoma nigrior	Mean: 2.79 & 3.11% day^{-1}	Southern Appalachian stream, North America	Georgian & Wallace (1983)
Goera tungusensis	Mean: 1.00% day^{-1}	Kharaa River, Mongolia	this study
Goera fuscula	Mean: 2.22% day^{-1}	Southern Appalachian stream, North America	Georgian & Wallace (1983)

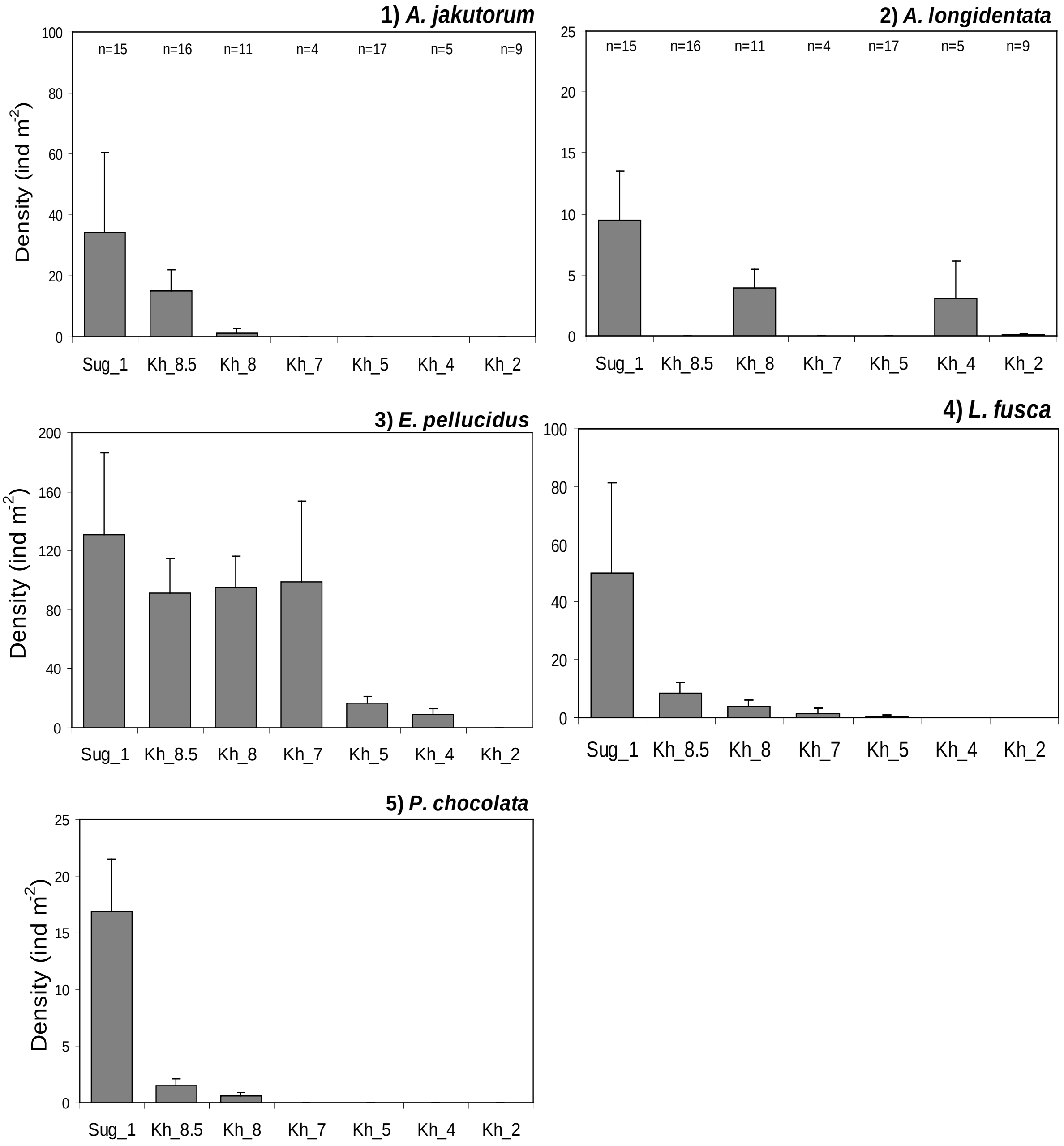

Fig. A-1: Larval density [ind m^{-2}] (mean±*SE*; *n*=77) of five species dominated in the upper reach (*Sug_1*) of the Kharaa River Basin in the period of 2007-2009.

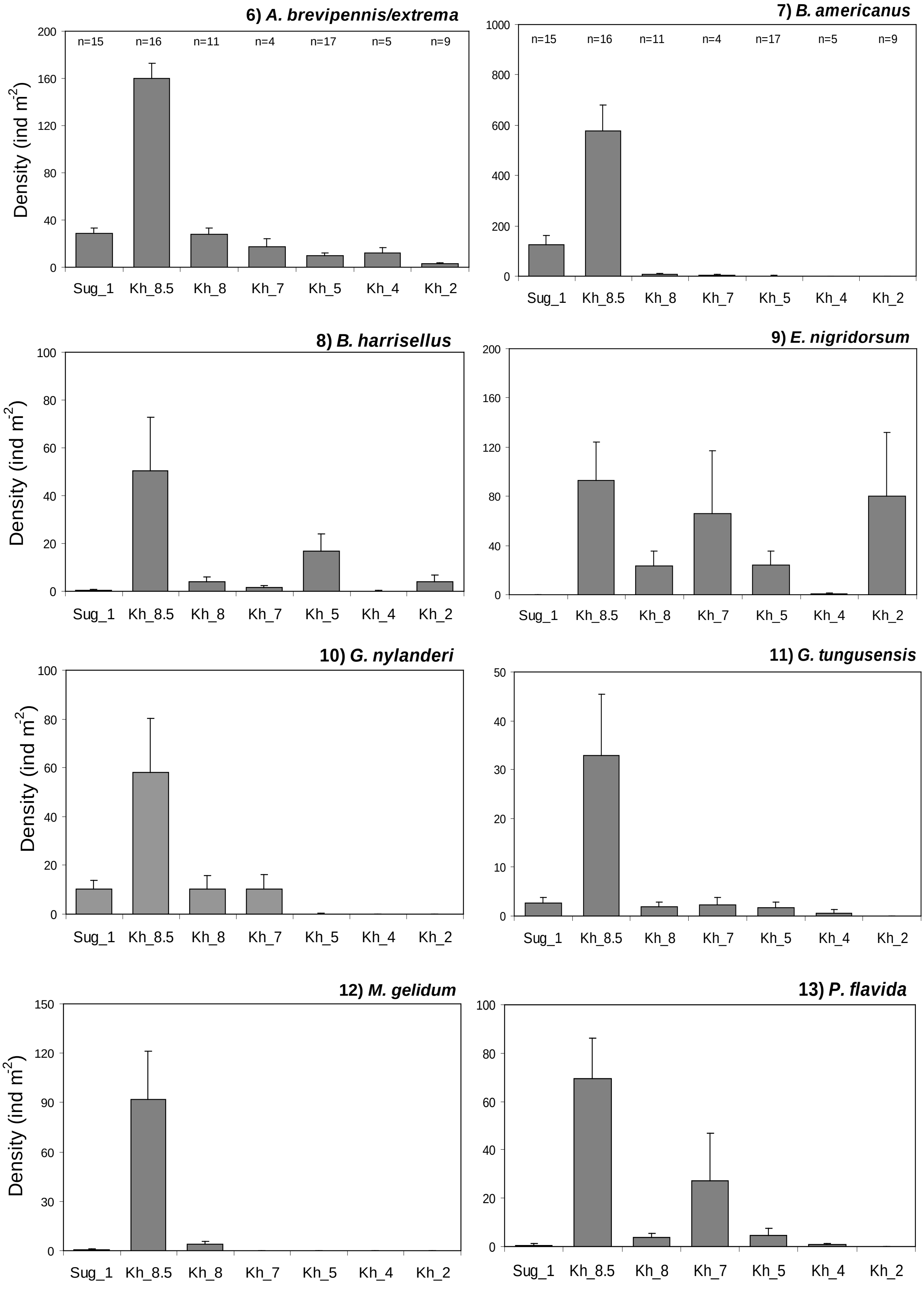

Fig. A-2: Larval density [ind m^{-2}] (mean±*SE*; *n*=77) of eight species dominated in the most upstream site (*Kh_8.5*) in the middle reach of the Kharaa River in the period of 2007-2009.

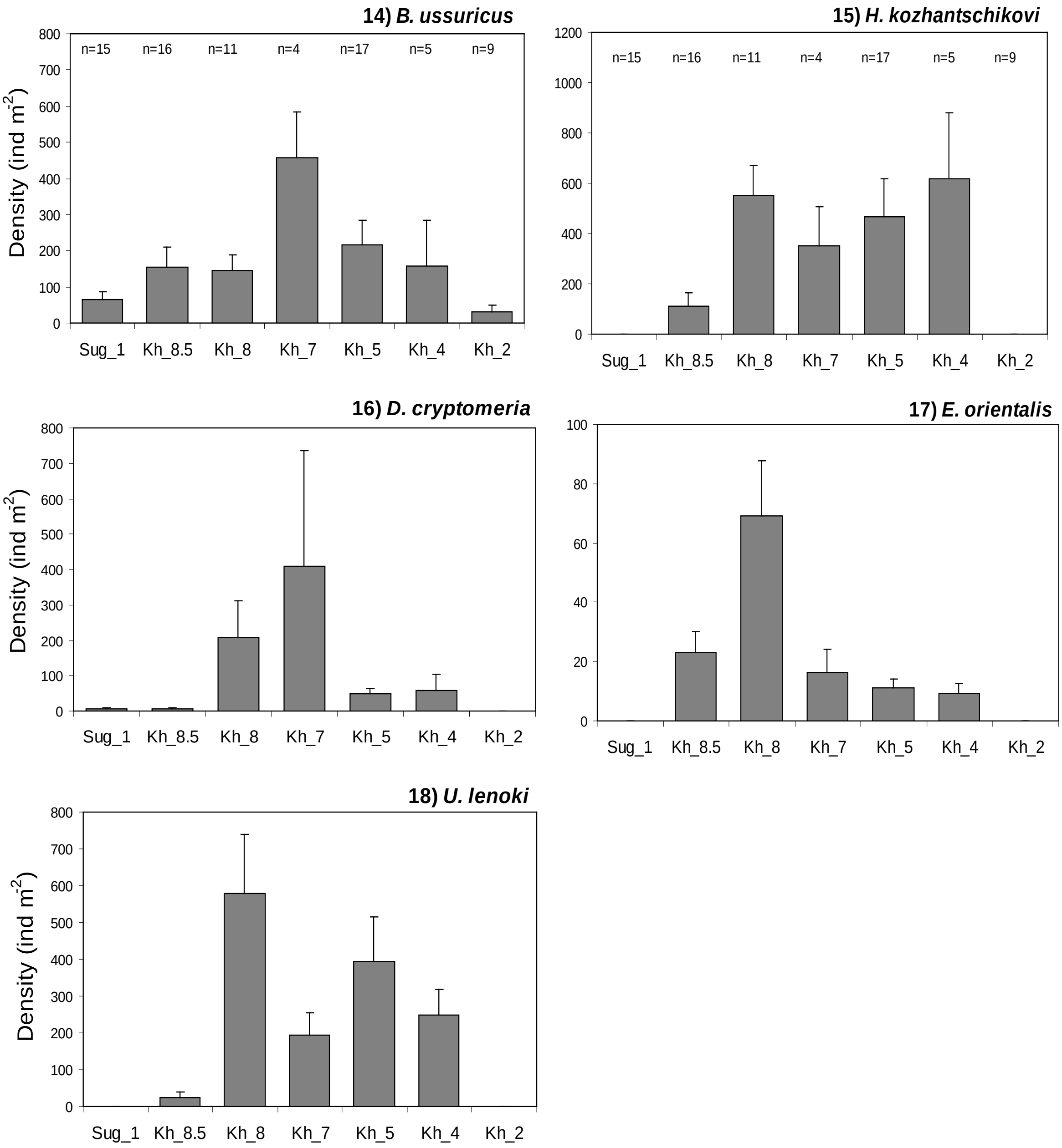

Fig. A-3: Larval density [ind m-2] (mean±*SE*; *n*=77) of five species dominated in the middle reach (*Kh_8*, *Kh_7*, *Kh_5*, & *Kh_4*) of the Kharaa River in the period of 2007-2009.

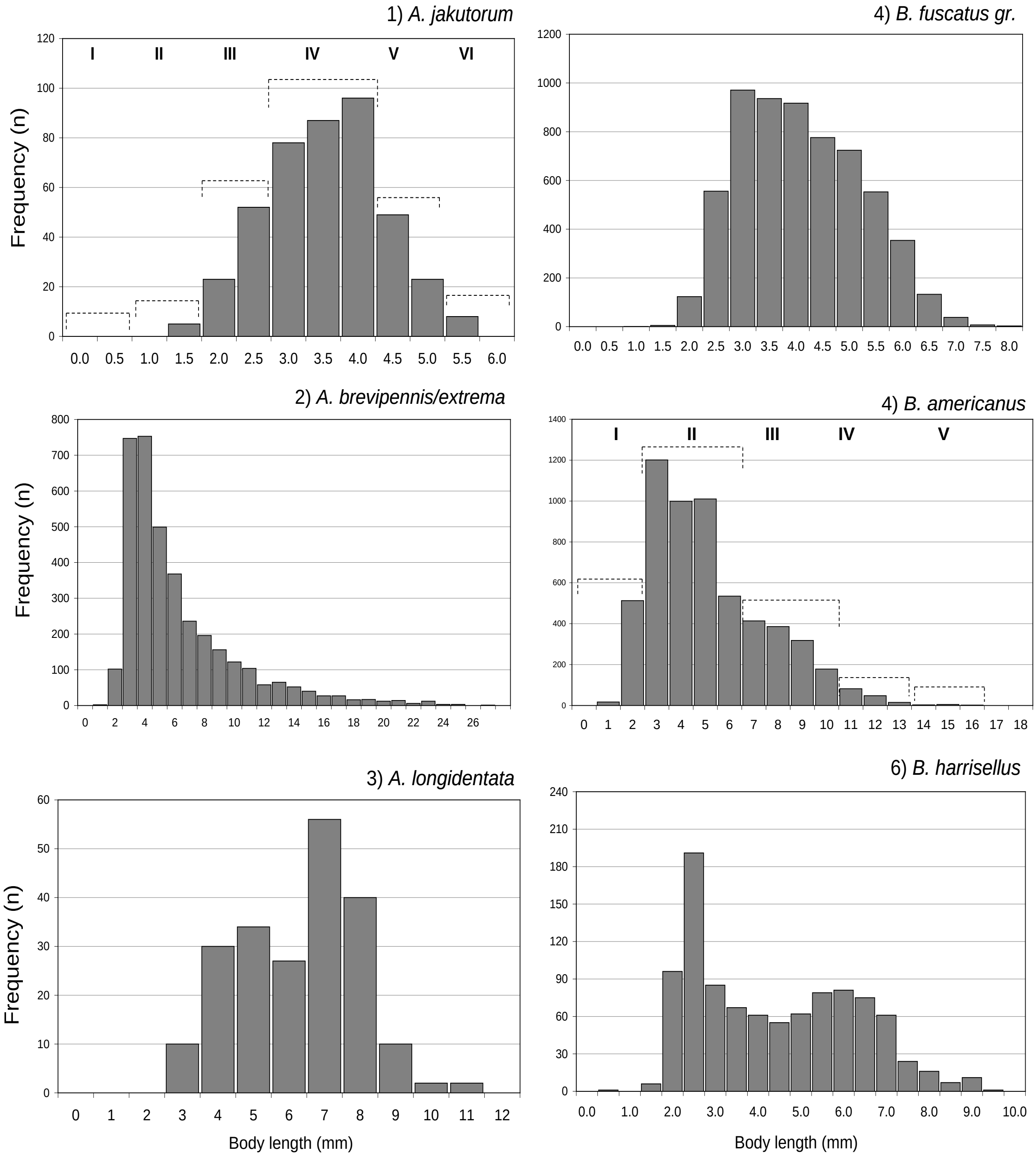

Fig. A-4: Frequency distributions of larval body length. 1) *Agapetus jakutorum*, Trichoptera (larval instars I-VI; *n*=421); 2) *Agnetina brevipennis/extrema* Plecoptera (*n*=3638); 3) *Alaskaperla longidentata*, Plecoptera (*n*=211); 5) *Baetis ussuricus*, Ephemeroptera (*n*=6057); 5) *Brachycentrus americanus*, Trichoptera (larval instars I-V; *n*=5727); 6) *Brachycercus harrisellus* Ephemeroptera (*n*=979).

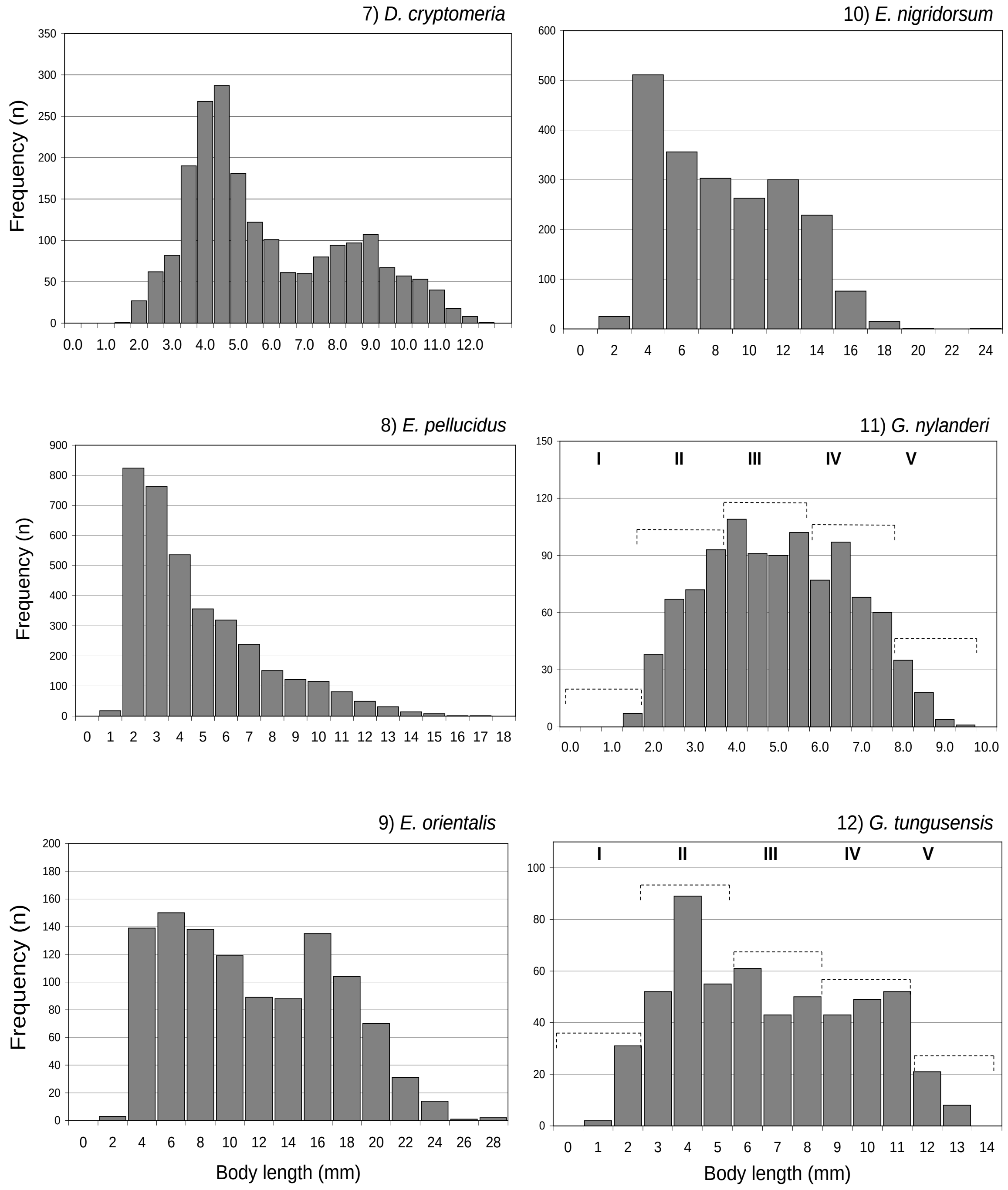

Fig. A-5: Frequency distributions of the body length. 7) *Drunella cryptomeria,* Ephemeroptera (*n*=2064); 8) *Epeorus pellucidus*, Ephemeroptera (*n*=3626); 9) *Ephemera orientalis*, Ephemeroptera (*n*=1082); 10) *Ephoron nigridorsum*, Ephemeroptera (*n*=2080); 11) *Glossosoma nylanderi*, Trichoptera (larval instars I-V; *n*=1029); 12) *Goera tungusenis*, Trichoptera (larval instars I-V; *n*=556).

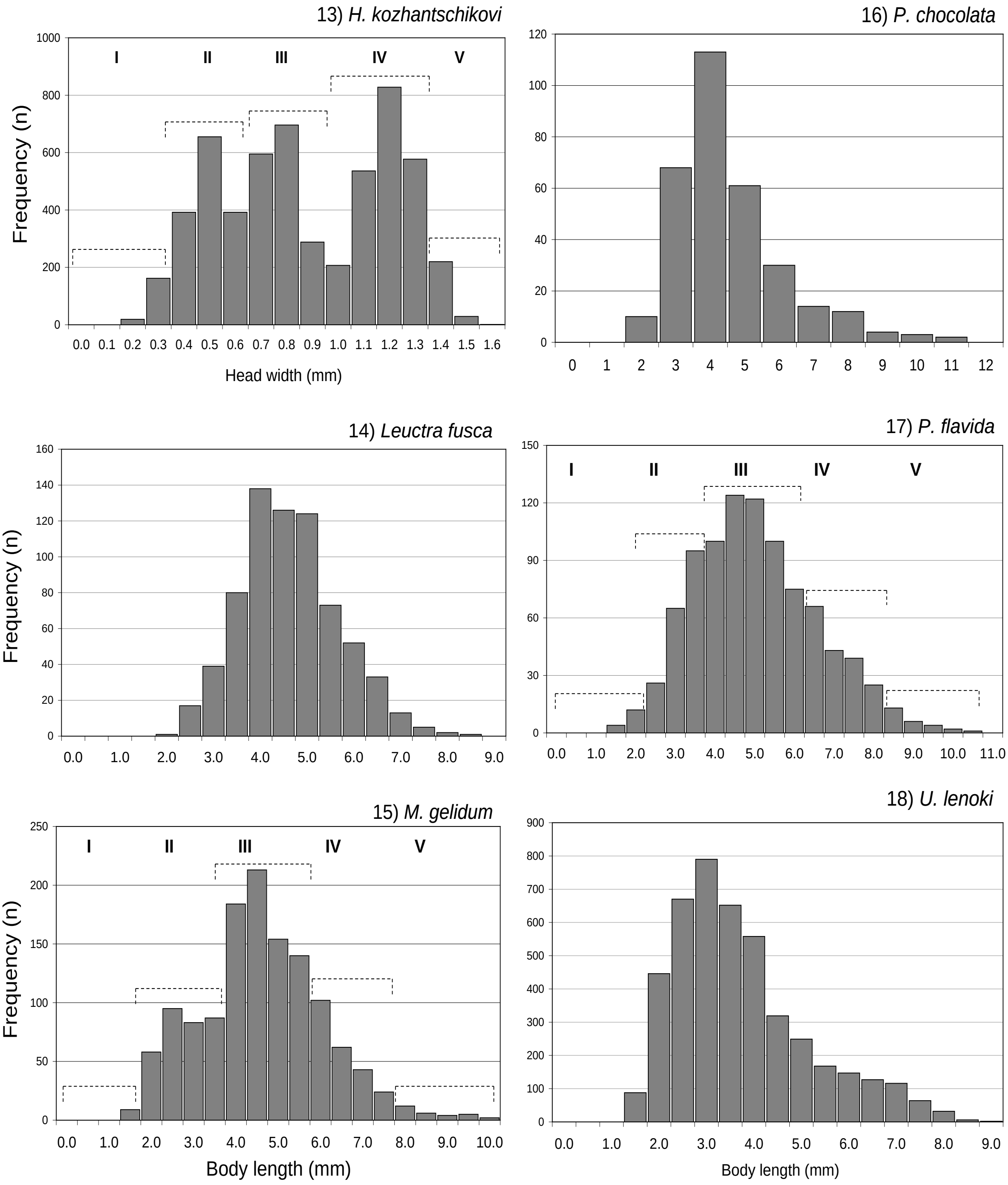

Fig. A-6: Frequency distributions of the body length. 13) *Hydropsyche (Ceratopsyche) kozhantschikovi*, Trichoptera (larval instars I-V; *n*=5596); 14) *Leuctra fusca,* Plecoptera (*n*=704); 15) *Micrasema gelidum*, Trichoptera (larval instars I-V; *n*=1283); 16) *Paraleptophlebia chocolata*, Ephemeroptera (*n*=317); 17) *Psychomyia flavida*, Trichoptera (larval instars I-V; *n*=921); 18) *Uracanthella lenoki,* Ephemeroptera (*n*=4434).

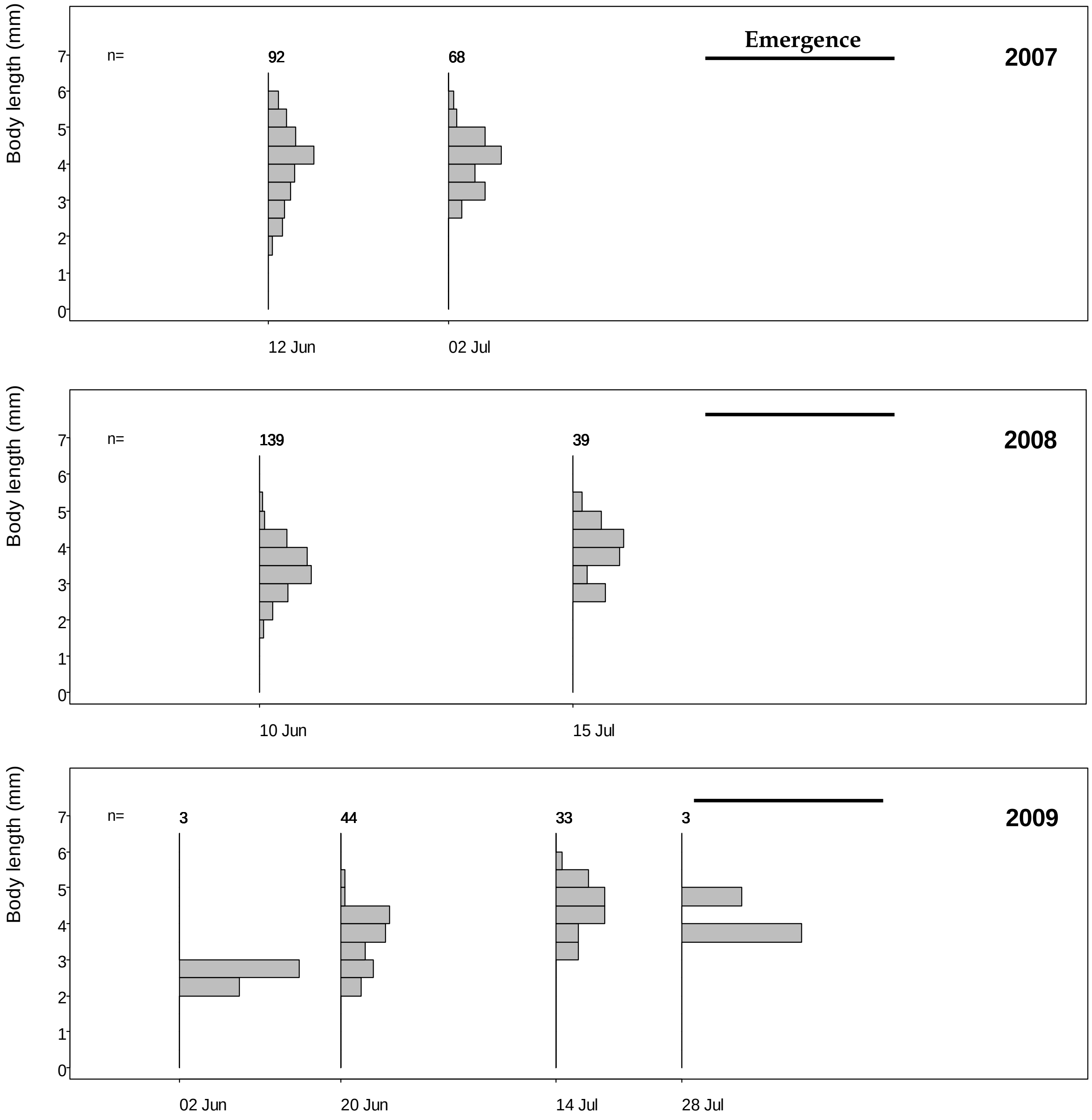

Fig. A-7: Relative size frequency histograms for *Agapetus jakutorum* (Trichoptera: Glossosomatidae) in the Kharaa River, 2007-2009. Emergence period is presented with a black coloured-line.

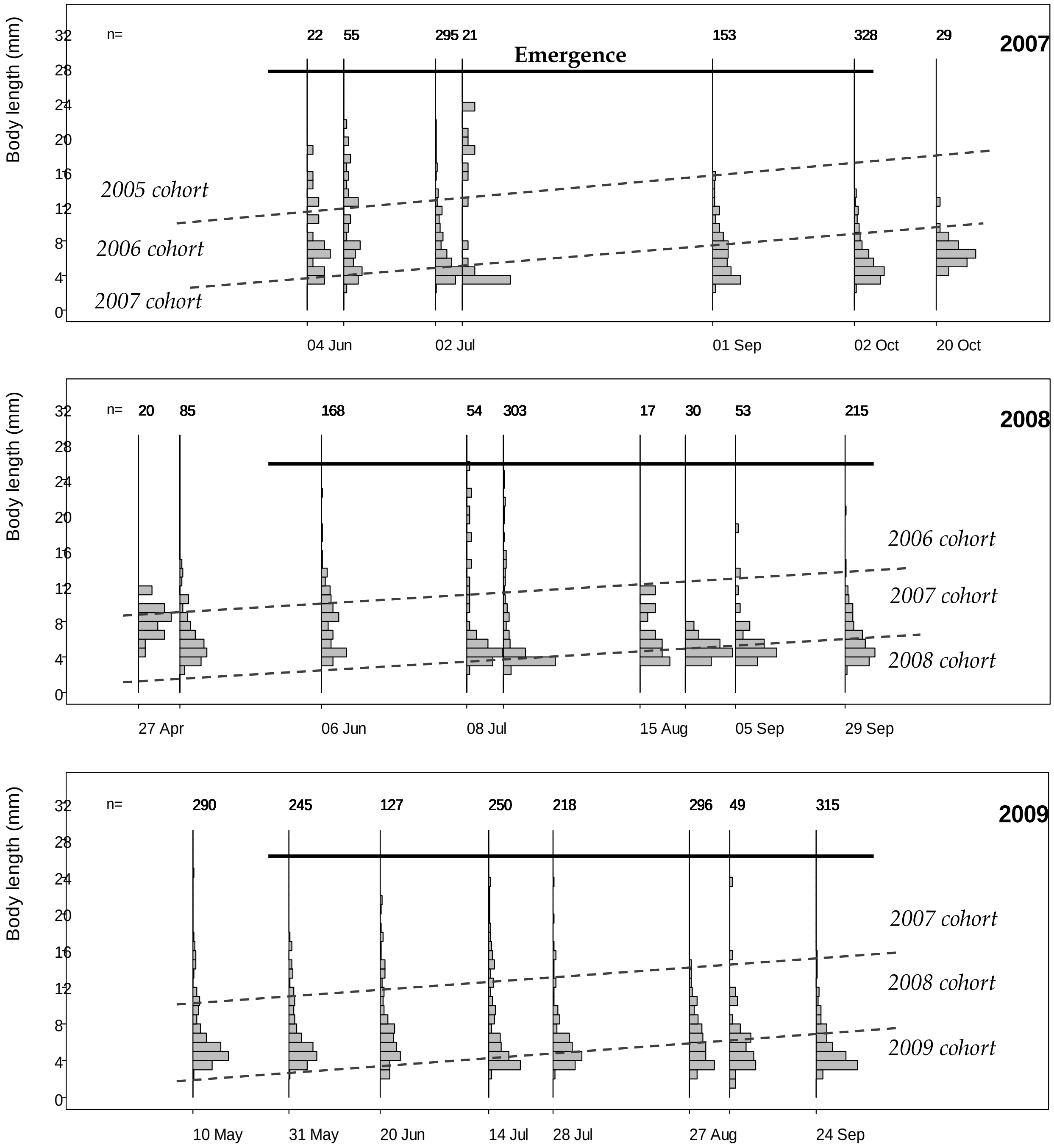

Fig. A-8: Relative size frequency histograms for *Agnetina brevipennis/extrema* (Plecoptera: Perlidae) in the Kharaa River, 2007-2009. Emergence period is presented with a black coloured-line. The cohorts in different years are distinguished with a dotted-line.

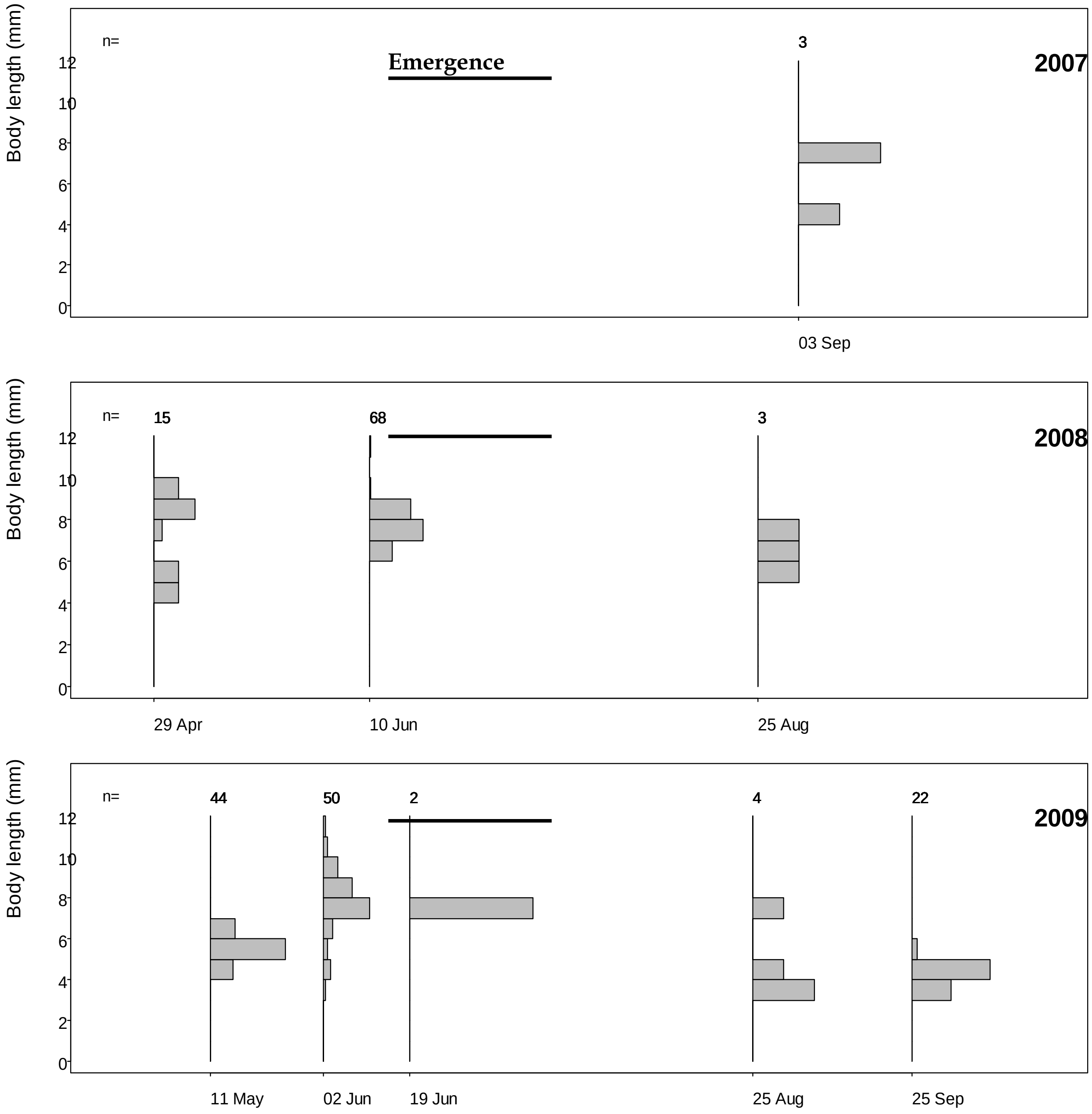

Fig. A-9: Relative size frequency histograms for *Alaskaperla longidentata* (Plecoptera: Chloroperlidae) in the Kharaa River, 2007-2009. Emergence period is presented with a black coloured-line.

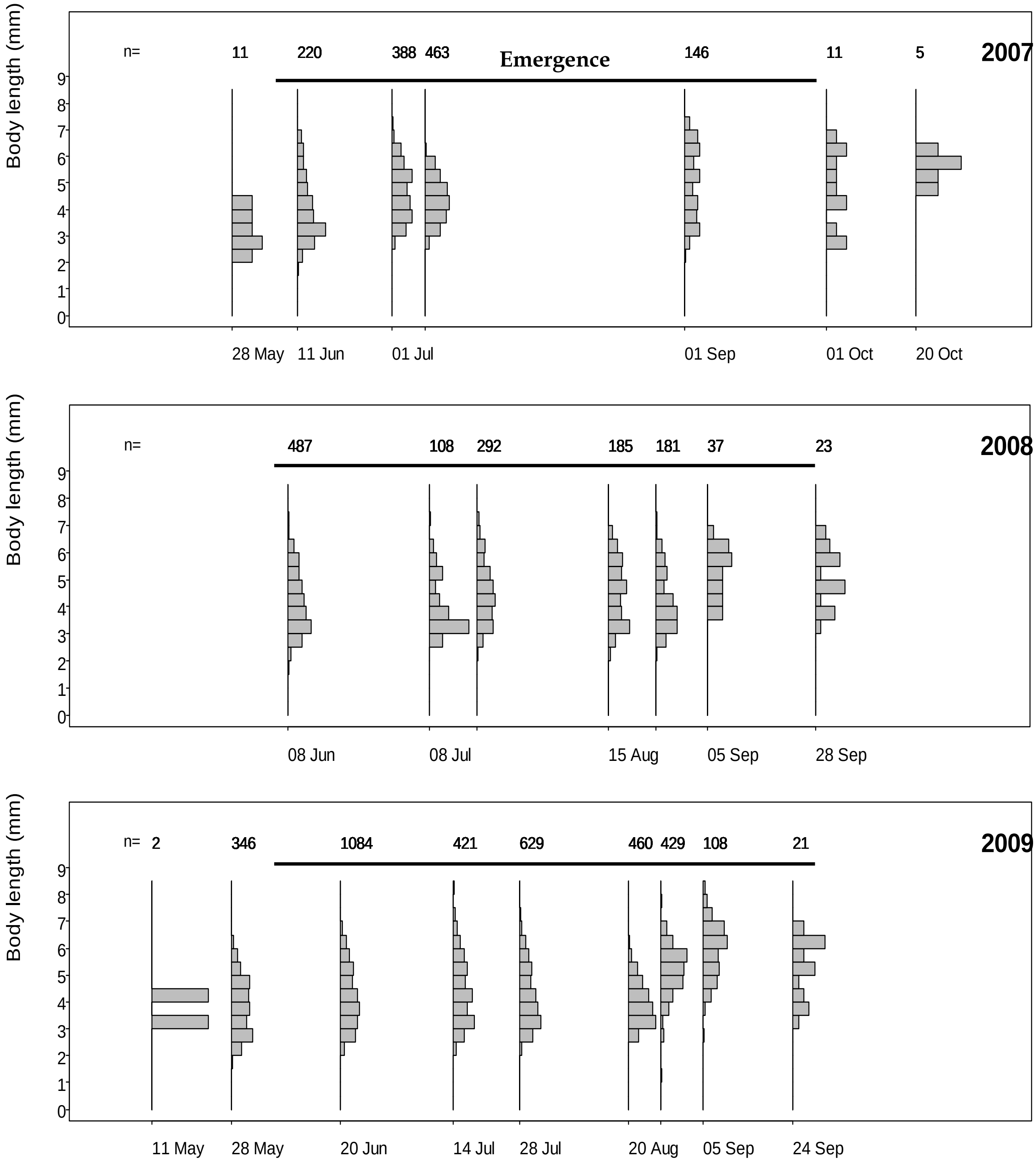

Fig. A-10: Relative size frequency histograms for *Baetis ussuricus* (Ephemeroptera: Baetidae) in the Kharaa River, 2007-2009. Emergence period is presented with a black coloured–line.

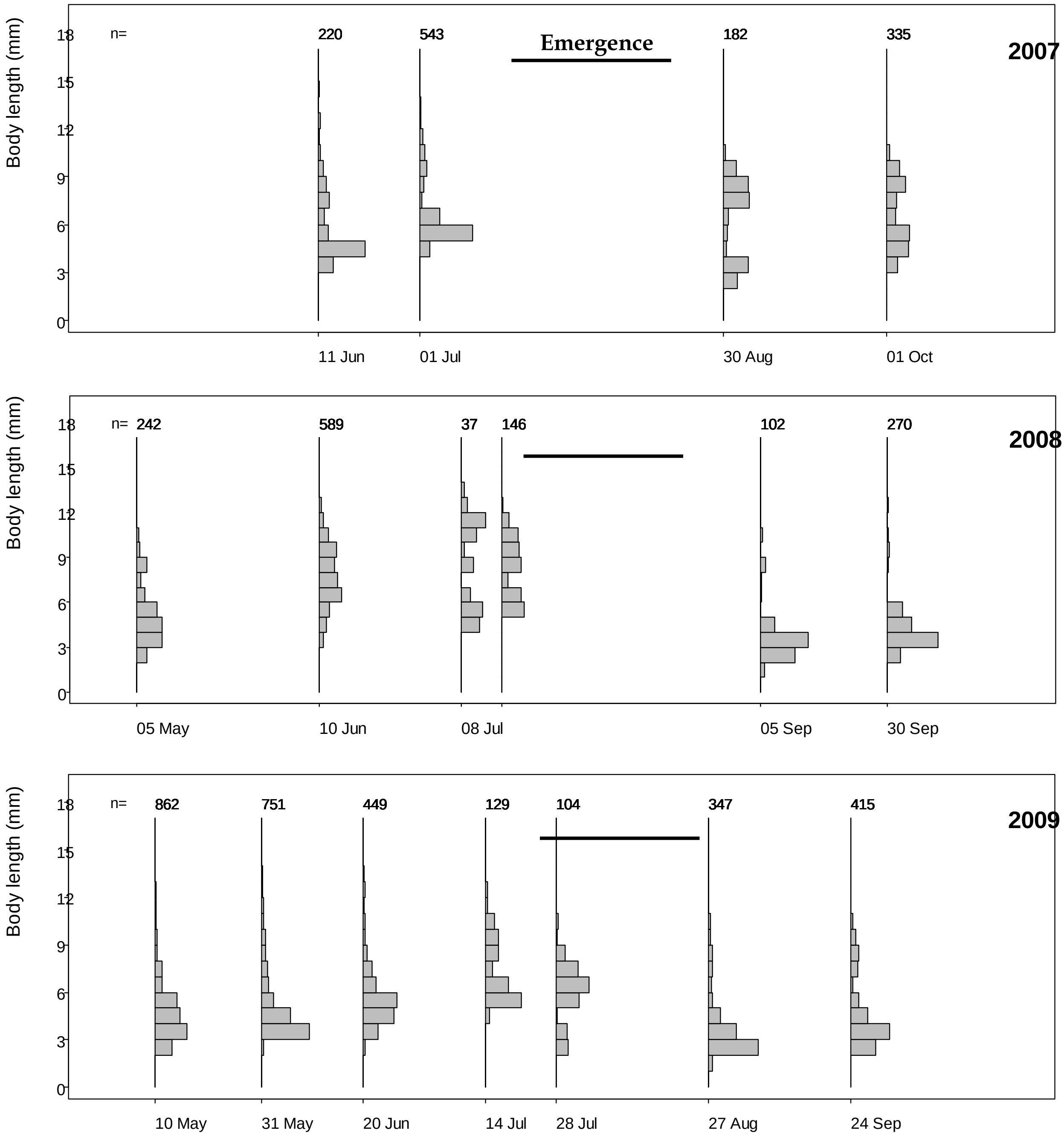

Fig. A-11: Relative size frequency histograms for *Brachycentrus americanus* (Trichoptera: Brachycentridae) in the Kharaa River, 2007-2009. Emergence period is presented with a black coloured–line.

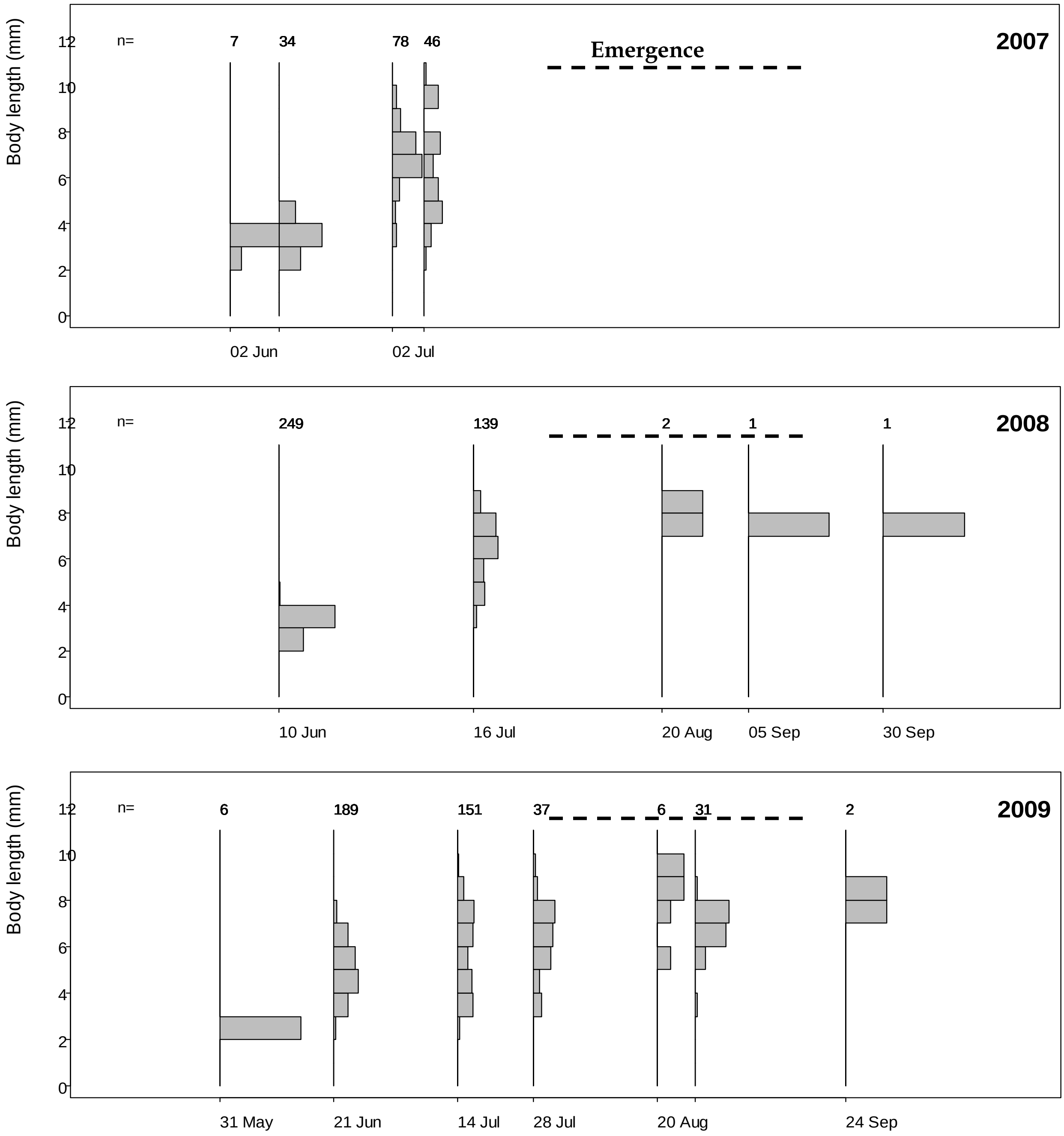

Fig. A-12: Relative size frequency histograms for *Brachycercus harrisellus* (Ephemeroptera: Caenidae) in the Kharaa River, 2007-2009. Hypothetical emergence period is presented with a dotted -line.

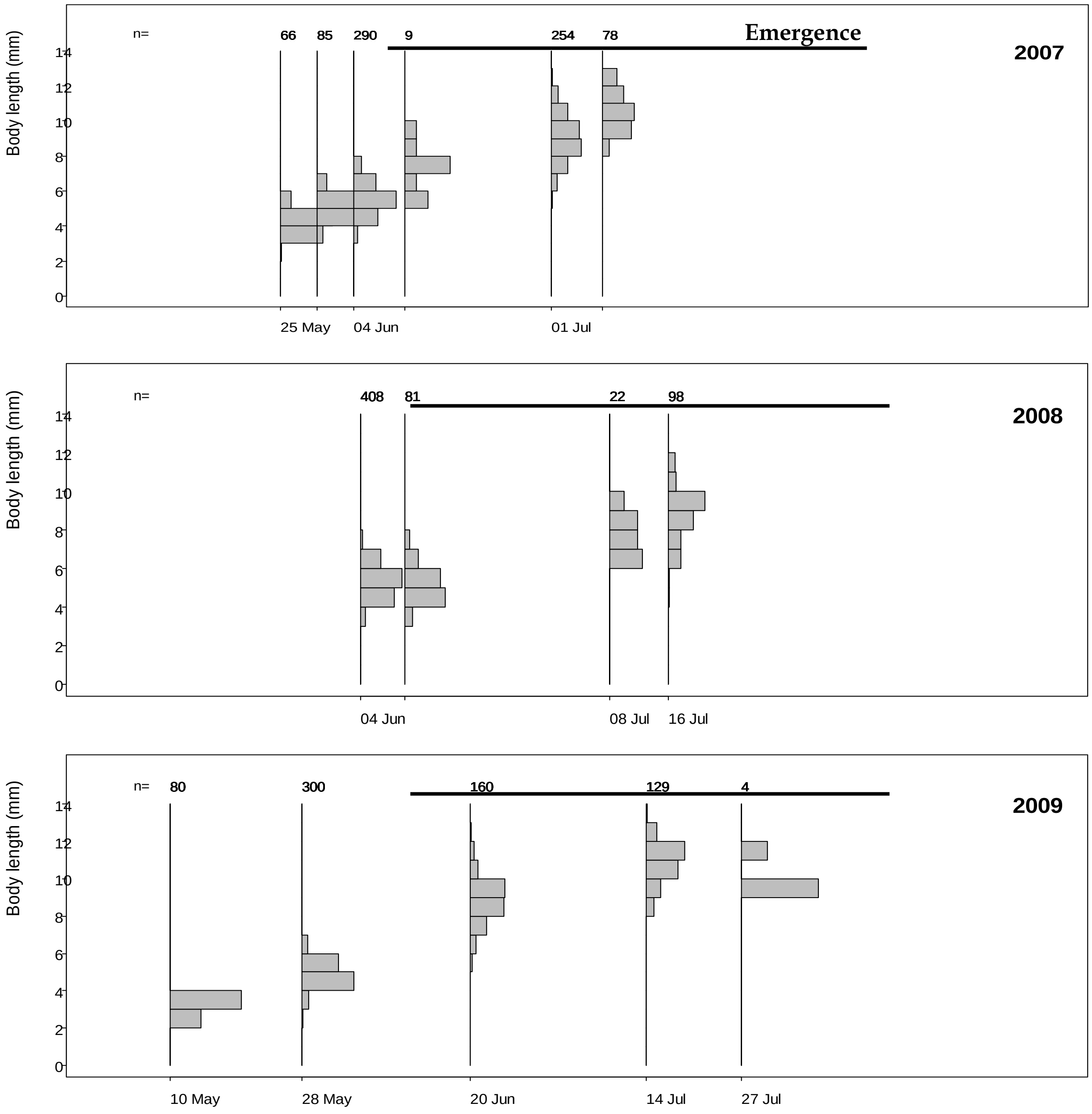

Fig. A-13: Relative size frequency histograms for *Drunella cryptomeria* (Trichoptera: Ephemerellidae) in the Kharaa River, 2007-2009. Emergence period is presented with a black-coloured line.

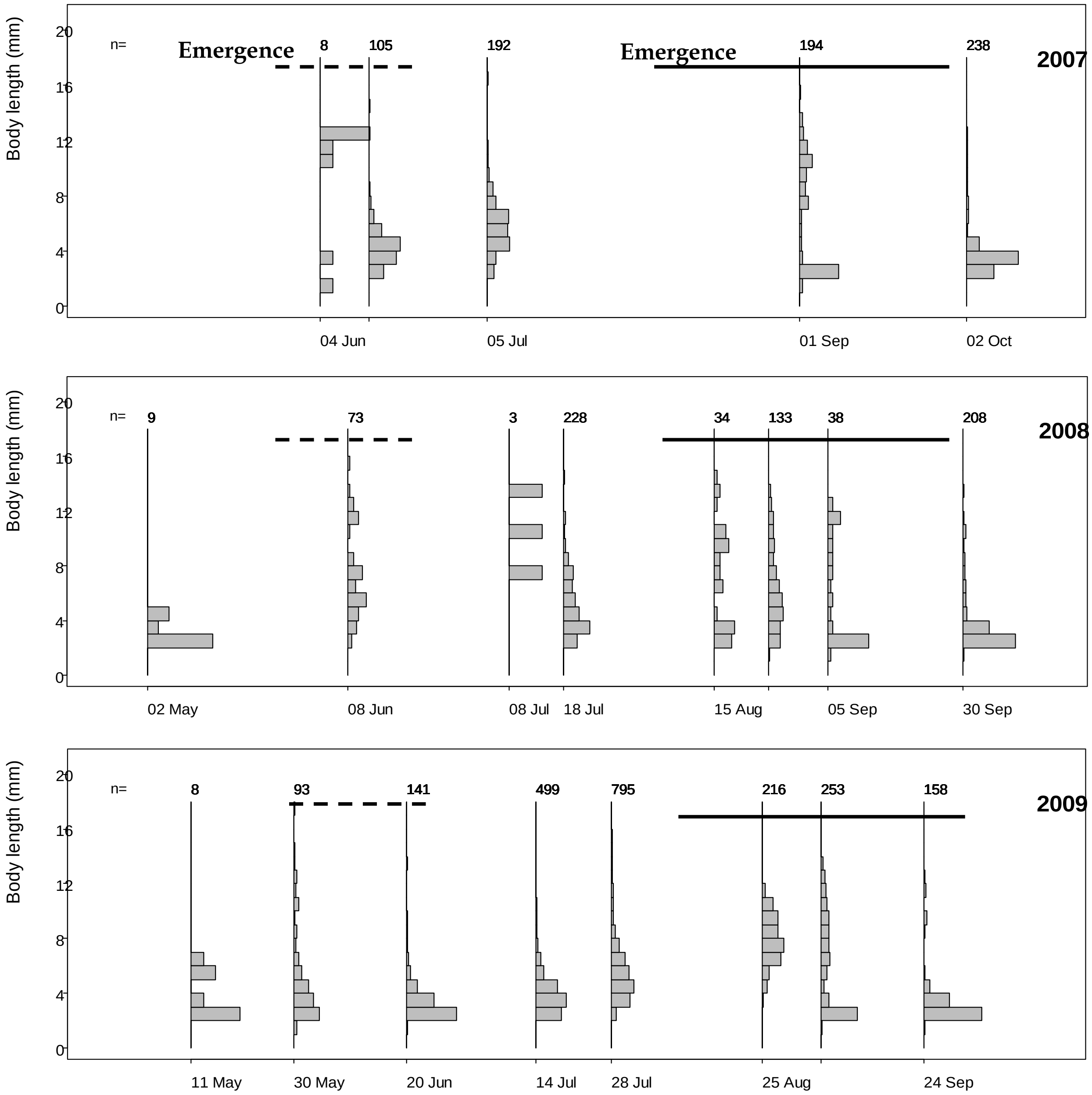

Fig. A-14: Relative size frequency histograms for *Epeorus pellucidus* (Ephemeroptera: Heptageniidae) in the Kharaa River, 2007-2009. Emergence period is presented with a dotted (hypothetical) and black-coloured (study results) line.

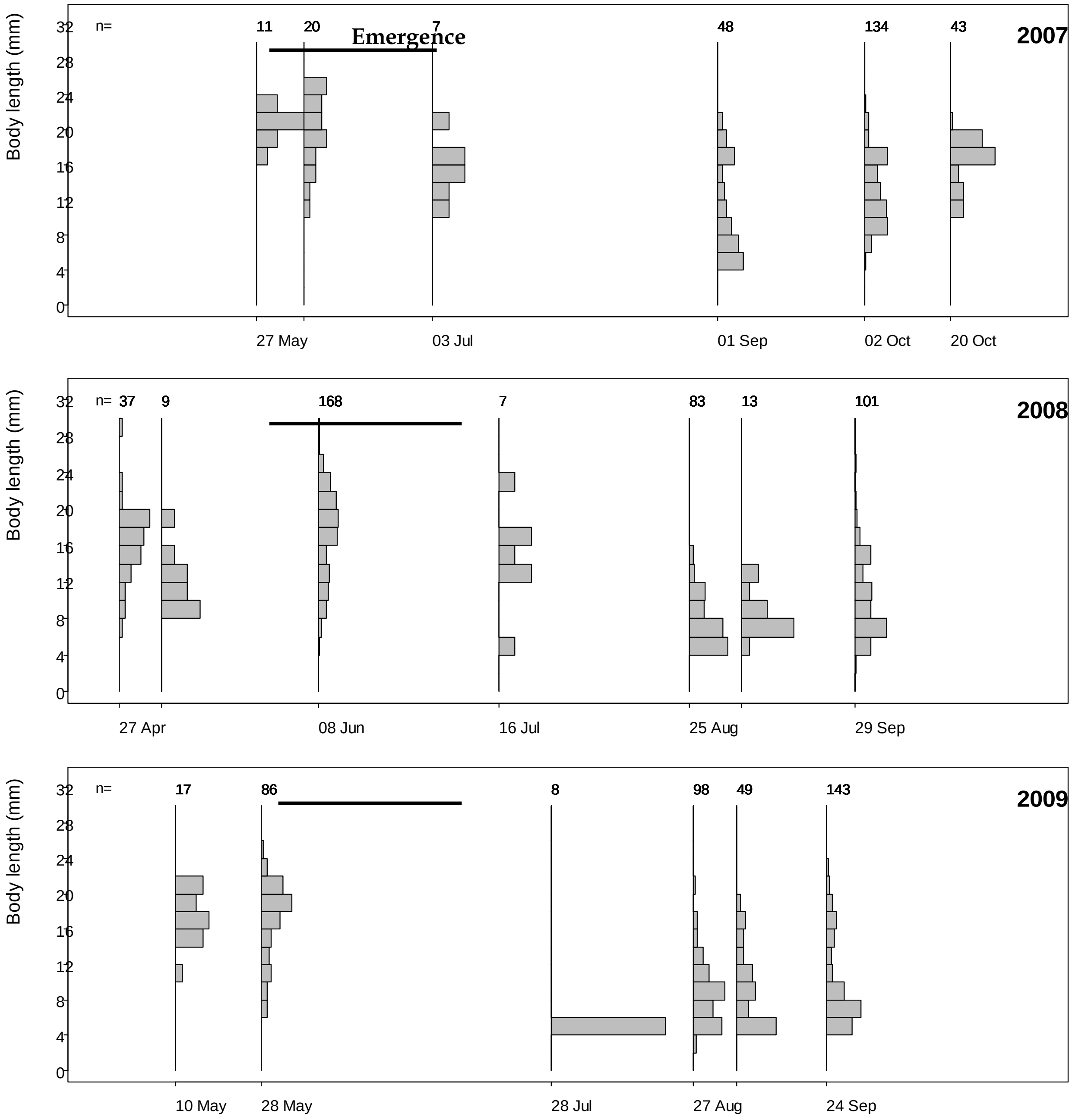

Fig. A-15: Relative size frequency histograms for *Ephemera orientalis* (Ephemeroptera: Ephemeridae) in the Kharaa River, 2007-2009. Emergence period is presented with a black-coloured line.

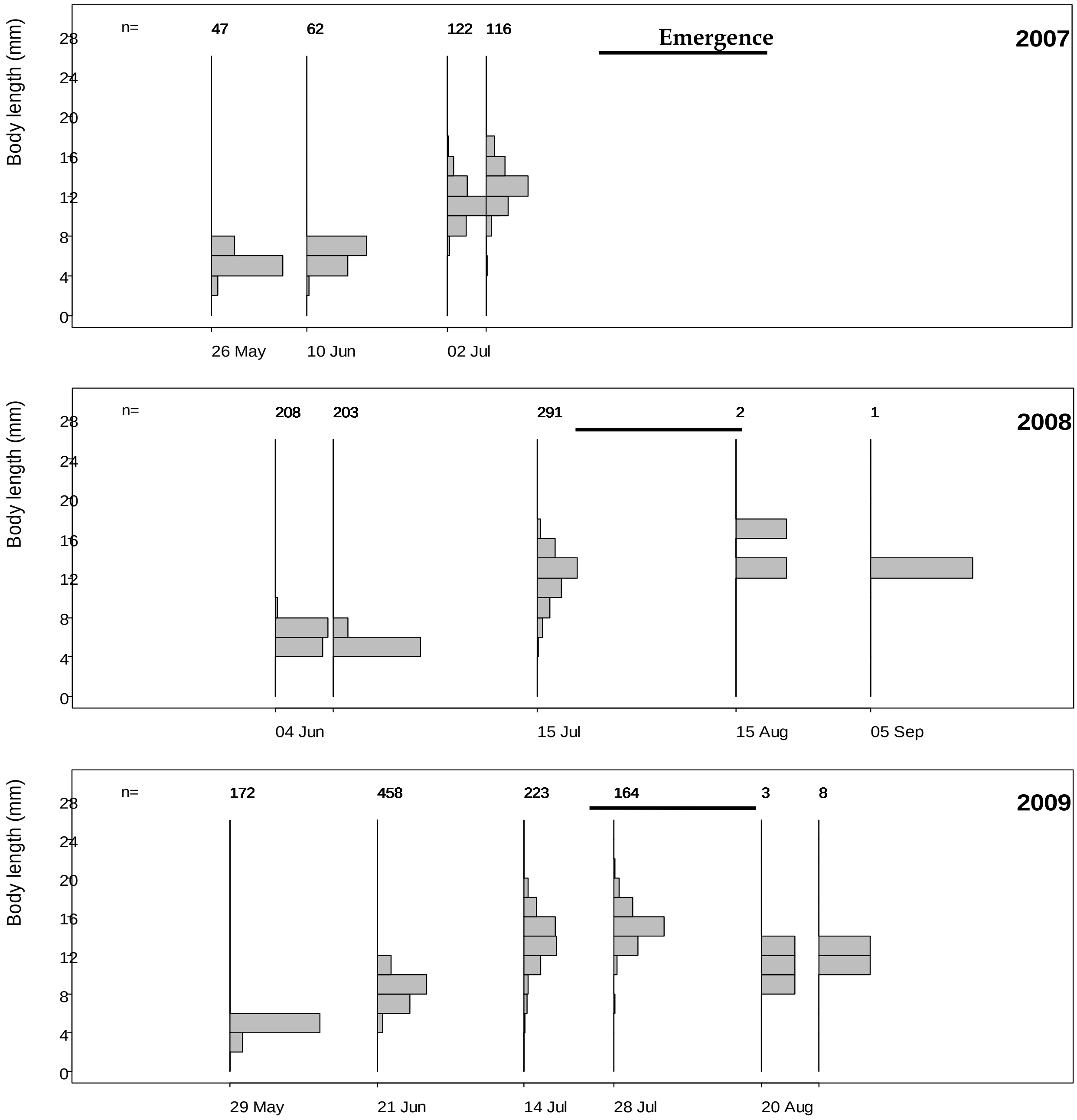

Fig. A-16: Relative size frequency histograms for *Ephoron nigridorsum* (Ephemeroptera: Polymitarcyidae) in the Kharaa River, 2007-2009. Emergence period is presented with a black-coloured line.

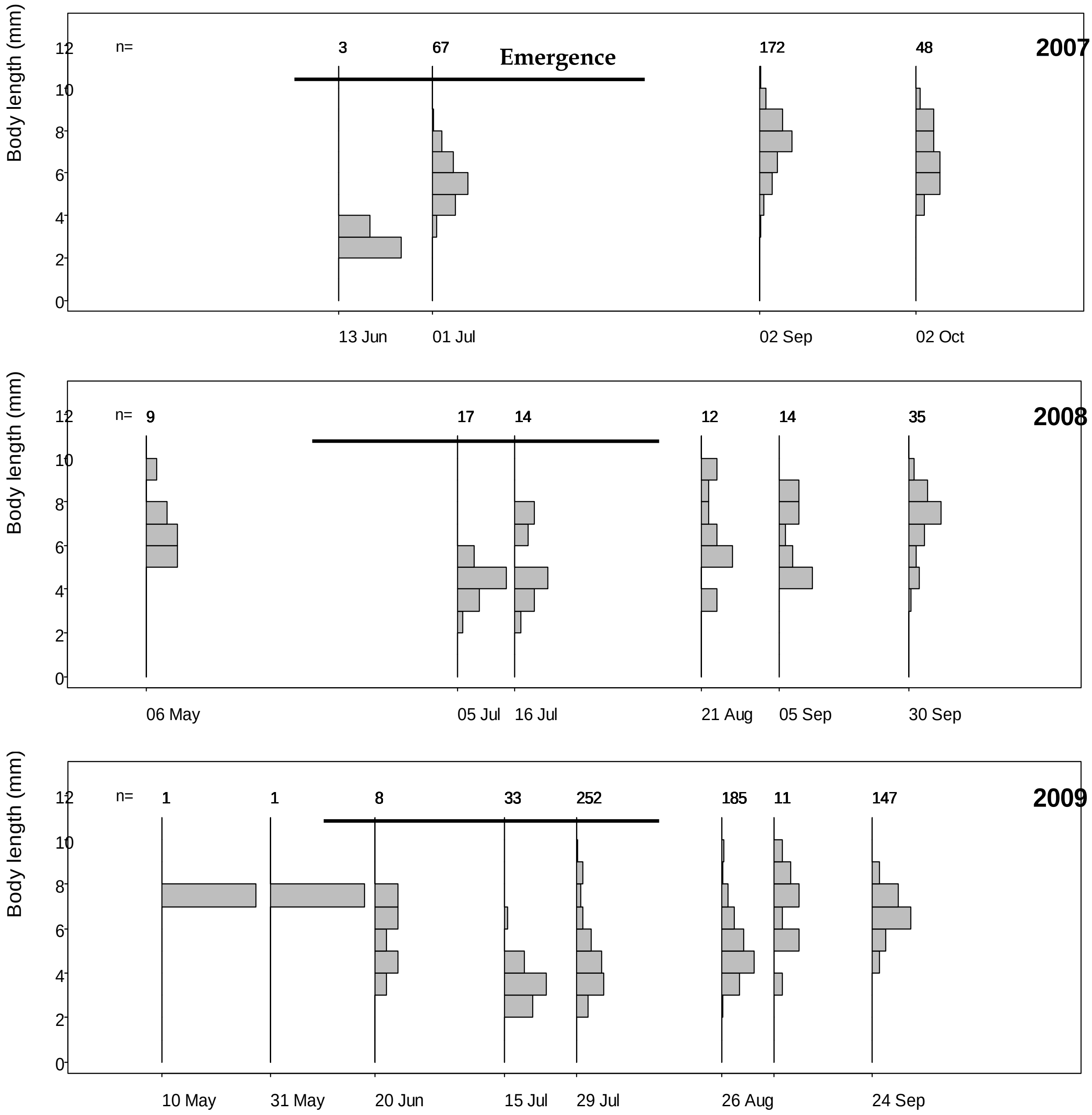

Fig. A-17: Relative size frequency histograms for *Glossosoma nylanderi* (Trichoptera: Glossosomatidae) in the Kharaa River, 2007-2009. Emergence period is presented with a black-coloured line.

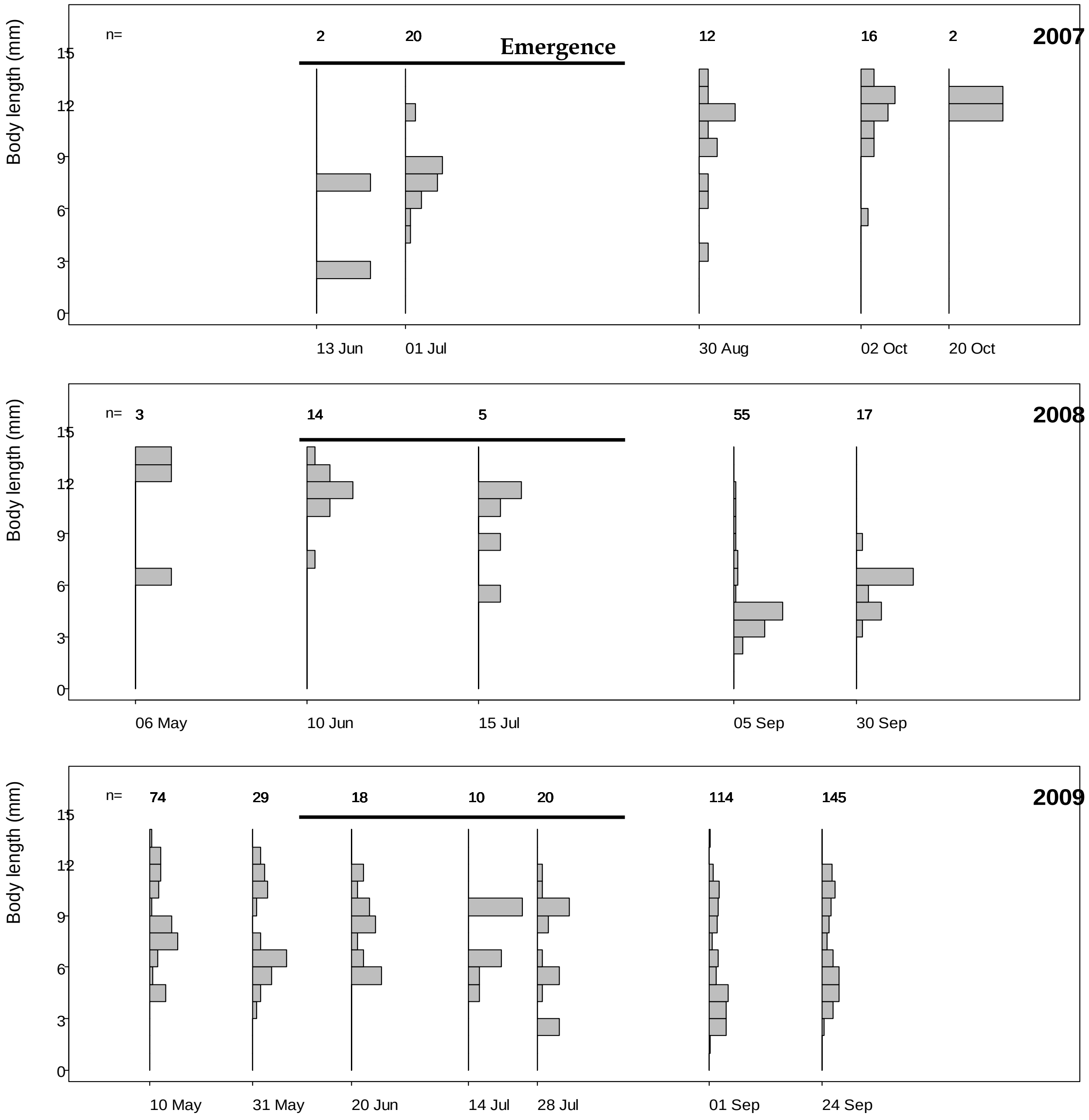

Fig. A-18: Relative size frequency histograms for *Goera tungusensis* (Trichoptera: Goeridae) in the Kharaa River, 2007-2009. Emergence period is presented with a black-coloured line.

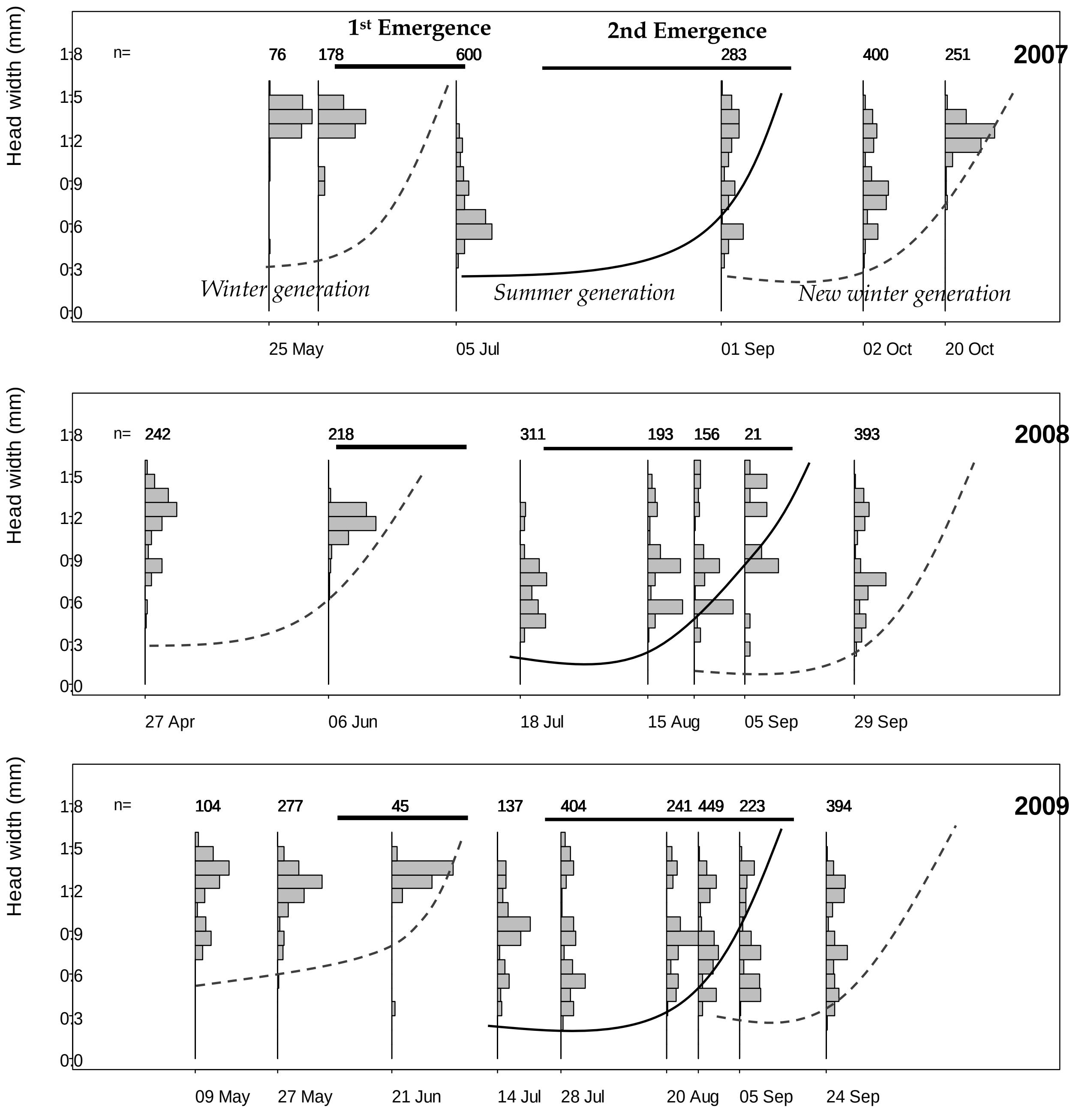

Fig. A-19: Relative size frequency histograms for *Hydropsyche* (*Ceratopsyche*) *kozhantschikovi* (Trichoptera: Hydropsychidae) in the Kharaa River, 2007-2009. Two distinct emergence periods are presented with a black-coloured line. The winter (dotted) and summer (solid) generation are illustrated with a grey line.

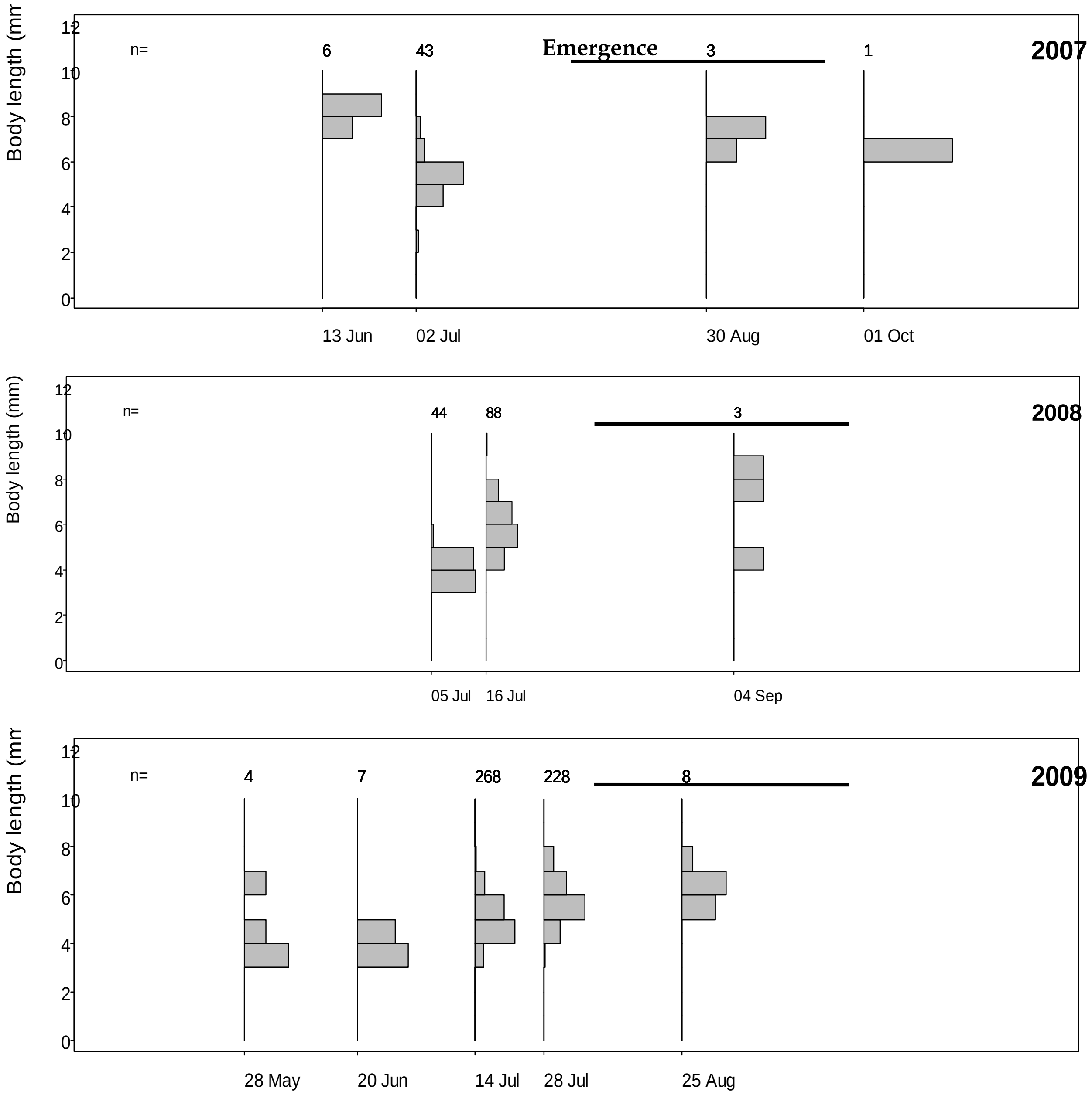

Fig. A-20: Relative size frequency histograms for *Leuctra fusca* (Plecoptera: Leuctridae) in the Kharaa River, 2007-2009. Emergence period is presented with a black-coloured line.

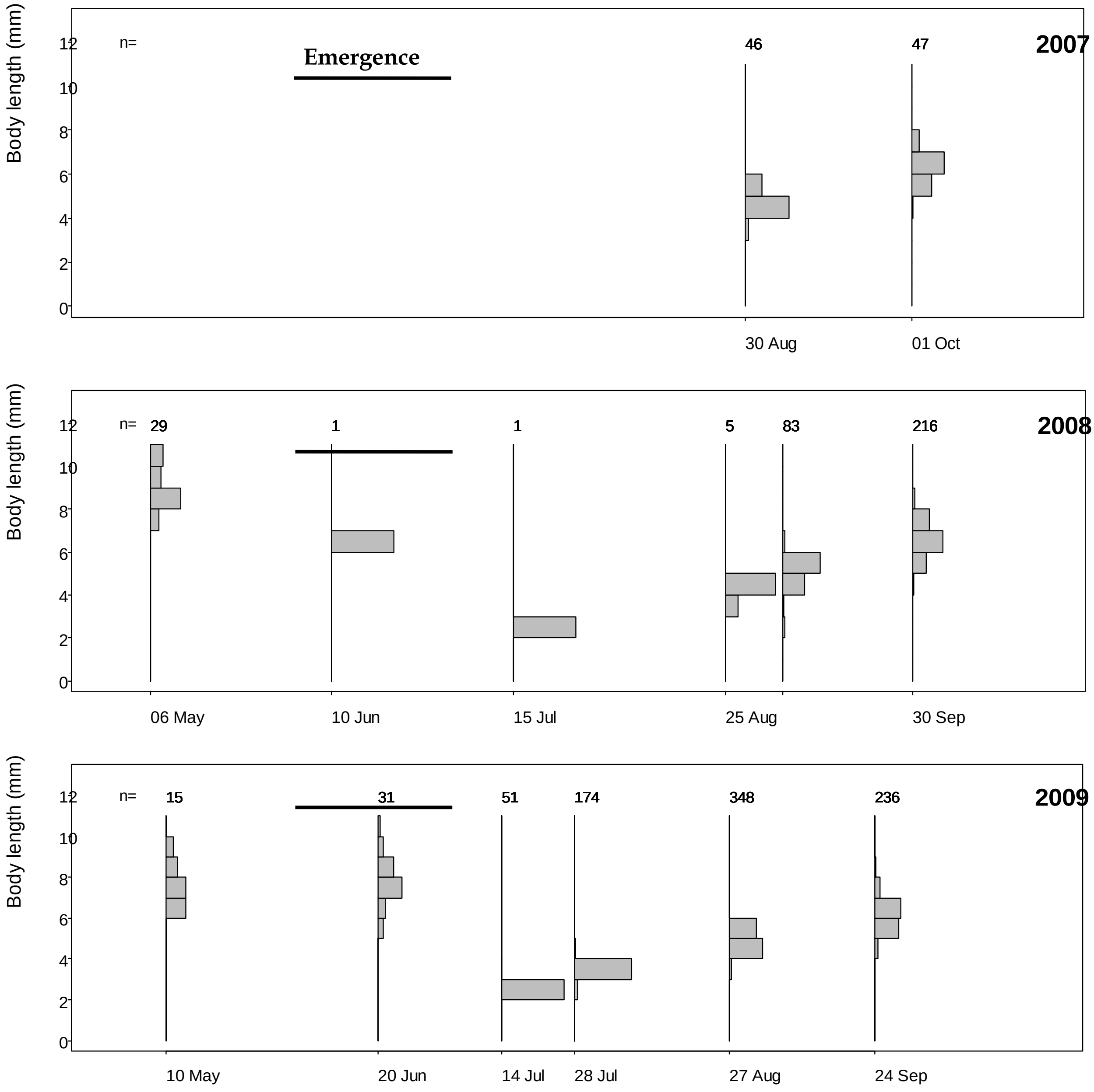

Fig. A-21: Relative size frequency histograms for *Micrasema gelidum* (Trichoptera: Brachycentridae) in the Kharaa River, 2007-2009. Emergence period is presented with a black-coloured line.

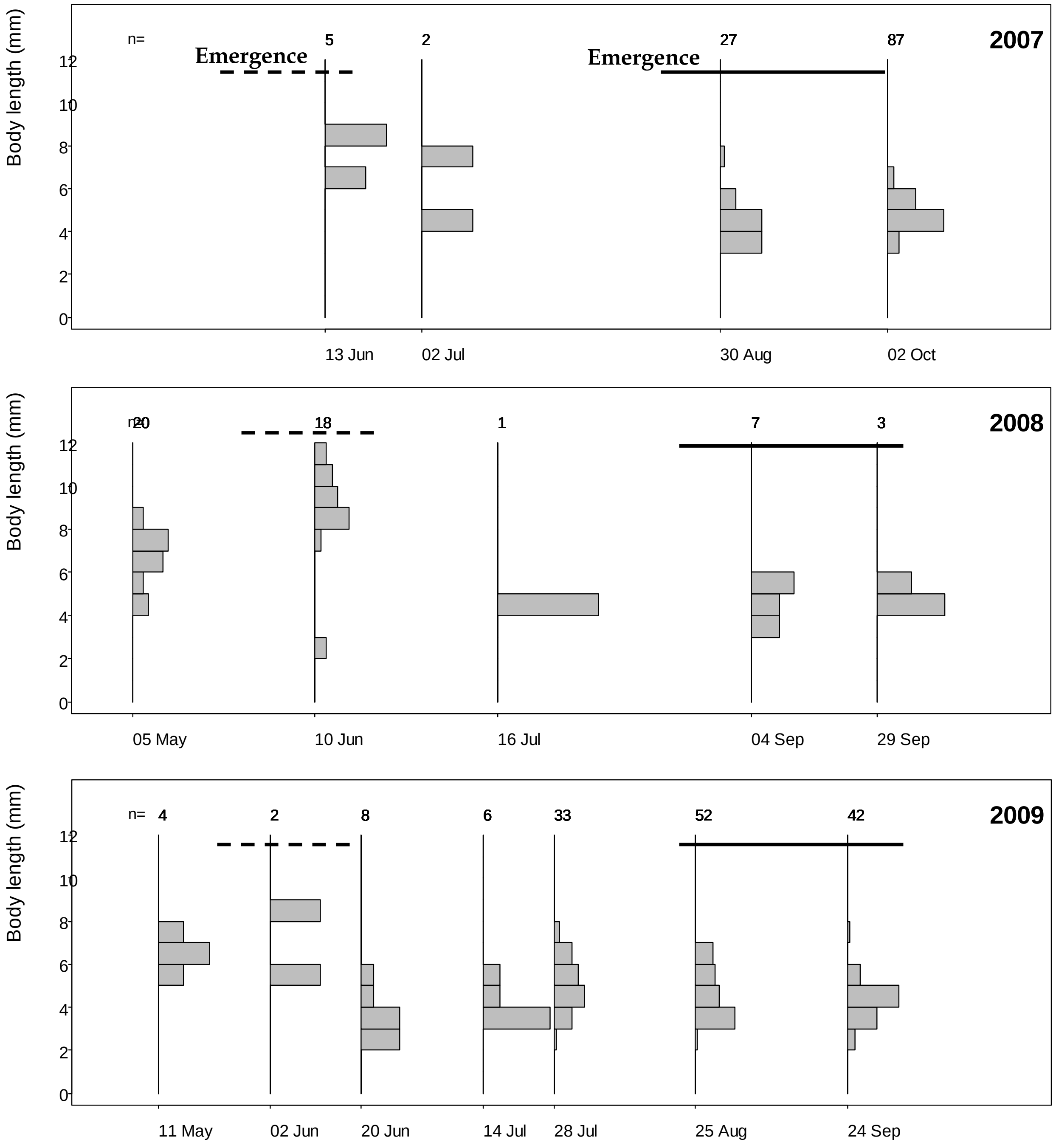

Fig. A-22: Relative size frequency histograms for *Paraleptophlebia chocolata* (Ephemeroptera: Leptophlebiidae) in the Kharaa River, 2007-2009. Emergence period is presented with a black-coloured line.

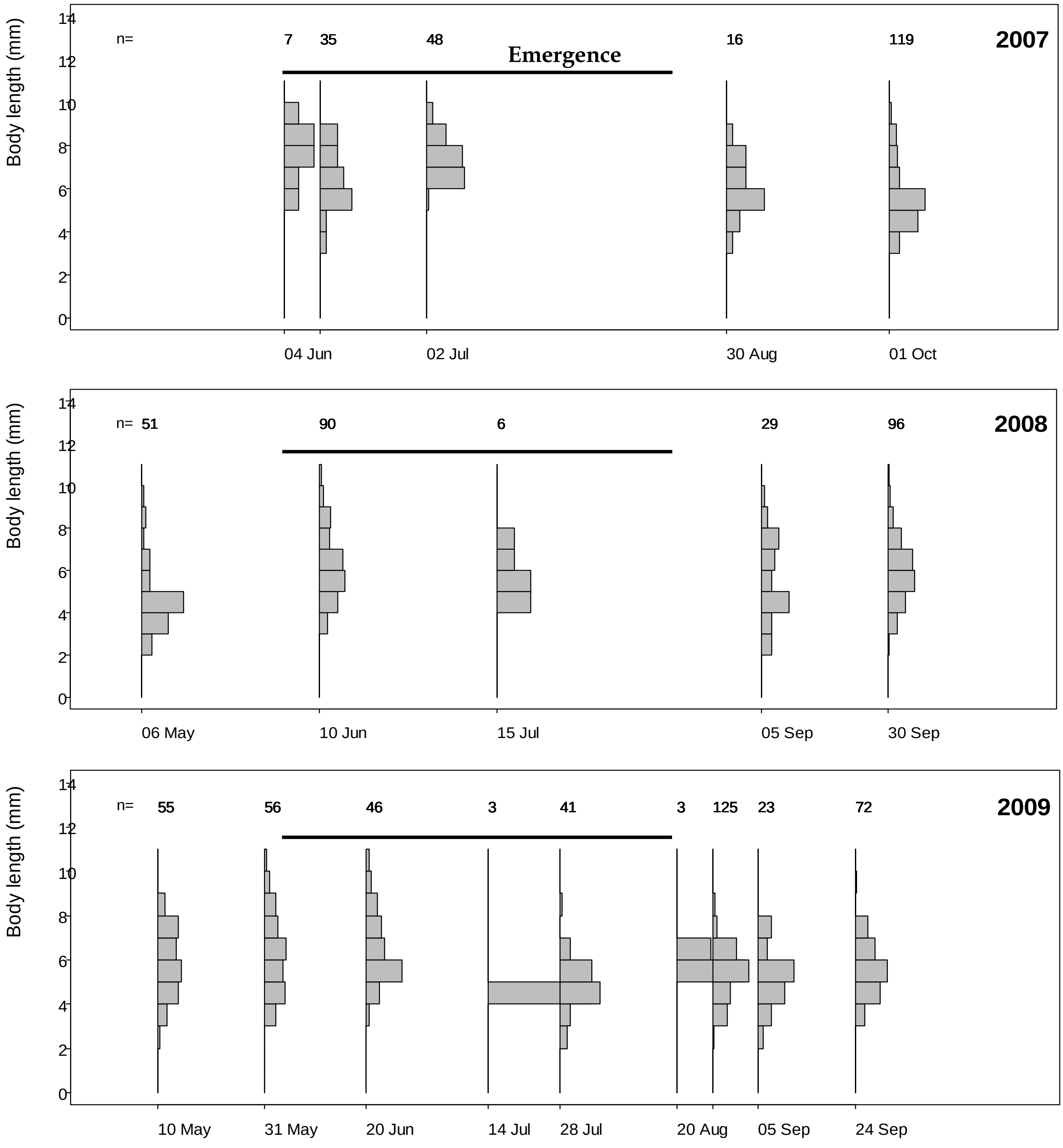

Fig. A-23: Relative size frequency histograms for *Psychomyia flavida* (Trichoptera: Psychomyiidae) in the Kharaa River, 2007-2009. Emergence period is presented with a black-coloured line.

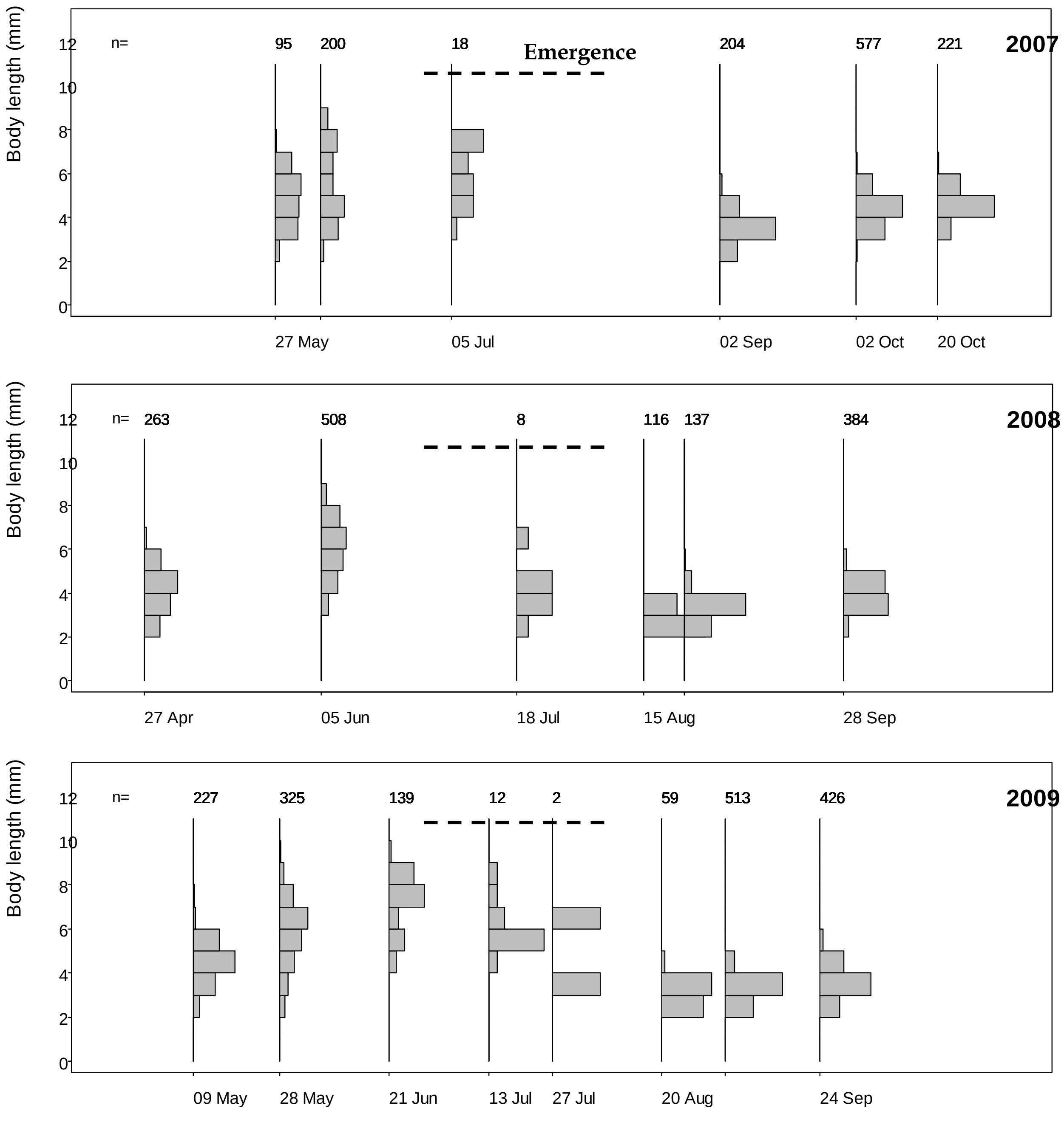

Fig. A-24: Relative size frequency histograms for *Uracanthella lenoki* (Ephemeroptera: Ephemerellidae) in the Kharaa River, 2007-2009. Hypothetical emergence period is presented with a dotted-line.