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Life cycle of *Pterostichus planipennis* R.F. Sahlberg, 1844 (Coleoptera, Carabidae) in the conditions of West Transbaikalia, Russia

Жизненный цикл *Pterostichus planipennis* R.F. Sahlberg, 1844 (Coleoptera, Carabidae) в условиях Западного Забайкалья

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Key words: *Pterostichus planipennis*, seasonal activity, sex-age structure, life cycle, WestTransbaikalia.

Ключевые слова: *Pterostichus planipennis*, сезонная активность, половозрастная структура, жизненный цикл, Западное Забайкалье.

Abstract. The life cycle of *Pterostichus planipennis* R.F. Sahlberg, 1844 in the conditions of West Transbaikalia in 2019 was realized as a one-year late summer with overwintering of larva. The most optimal population structure of the species is formed in a moistened meadow. An analysis of the timing of the phenological development of *P. planipennis* for 2019 compared to 2009 revealed an early onset of spring-summer activity of the species and an extension of seasonal activity, especially in the autumn period, by almost a month until mid-October.

Резюме. Жизненный цикл *Pterostichus planipennis* R.F. Sahlberg, 1844 в условиях Западного Забайкалья в 2019 г. был реализован как одногодичный позднелетний с зимовкой личинок. Наиболее оптимальная популяционная структура вида формируется на влажном лугу. Анализ сроков фенологии развития *P. planipennis* в 2019 г. по сравнению с 2009 г. выявил раннее начало весенне-летней активности вида и удлинение сезонной активности, особенно, осеннего периода, почти на месяц вплоть до середины октября.

Introduction

Pterostichus planipennis R.F. Sahlberg, 1844 is a meadow-marsh species with an Eastern Palearctic distribution. In the conditions of West Transbaikalia this species lives in intermountain basin in floodplains and river deltas [Khobrakova et al., 2014].

In the conditions of the Southern Baikal region, the life cycle of *P. planipennis* is characterized as a one-year autumn cycle with wintering of adults and larvae [Shilenkov, 1978]. In 2009, the life cycle of *P. planipennis* in the Mukhinskie swamps was realized as a one-year mid-summer with overwintering of adults [Khobrakova, 2017]. Ten years later, our research was repeated in the same site due to a prolonged aridness in West Transbaikalia. During this period, the Mukhinskii swamps decreased in size, and the coastal marshy meadows were transformed into steppe meadows.

In this regard, the objectives of the work were to study changes in the sex-age structure of *P. planipennis* in meadows with different moisture levels, to decipher the life cycle based on indicators of seasonal activity of adults and larvae, the peak activity of generative females, their egg production, and overwintering stages. Observations of different stages of development were also made in laboratory conditions.

Materials and methods

Stationary studies were conducted in West Transbaikalia in the Ivolginsky basin 15 km south-west of Ulan-Ude in 2019. Features of demographic structure and life cycle of *P. planipennis* were studied on three types of meadows — steppificated, moistened and marshy in the Mukhinskie swamps (TNI8). Soil and vegetation characterisation of meadow ecosystems in the Ivolginsky Basin was given according to [Ubugunova et al., 2011].

Insects were collected with ground soil traps and soil live traps without a retainer. In each line contained 20 soil traps placed every 5 m. A 4 % solution of formalin was used as a fixative. The material was collected every 7 days throughout the vegetation season from May 20 to October 30, 2019 (406 spec.): on true meadow (51 specimens), on steppe meadow (95 specimens), and on salt meadow (260 specimens).

The sex ratio index was calculated by Sustek [1984]. Index values close to 0 corresponded to approximately equal sex ratio and characterise optimum habitat conditions for the species.

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To characterise the demographic structure of ground beetle populations, the generative condition of imagoes was determined in all females and males according to Wallin's method [Wallin, 1987]. The juvenile individuals — teneral (t), immature individuals — immature (i), generative individuals — mature (m), and postgenerative individuals — spent (s) ages of imagoes were identified according to the degree of genital gonads development. The interpretation of species life cycle was based on spectra of demographic structure, duration of seasonal activity dynamics, reproduction periods of females, egg-laying, larva, pupa and wintering stages.

The present work is registered in ZooBank (www.zoobank.org) under urn:lsid:zoobank.org:pub:C0EC0DC5-7A18-4948-A73B-899500F48A04.

Results

The life cycle of *Pterostichus planipennis* in meadows with different types of moisture

Steppificated meadow, coastal part. This station is not typical for stable habitation and reproduction of beetles. The duration of seasonal activity of the species is short and amounts to 91 days — June 07 to September 06 (Fig. 1). The abundance of *P. planipennis* in this station is the lowest among the studied meadows (51 individuals per season). In the sexual structure, males predominate (31♂♂, 20♀♀), the sex ratio index is –0.2. In early June, single immature and generative individuals are noted. Juvenile individuals are noted from July 5–28. This is followed by a small peak of beetle activity associated with reproduction (late July). The peak of female reproductive activity is late summer (July 21 to August 16). Postgenerative beetles are noted in September 06. Oviposition is recorded over a period of 9 weeks, from June 21 to August 16, with a peak on July 21. Approximately 21 eggs are laid per female, with a maximum of 40 eggs per female. Overwintering occurs in the larval stage. Larval activity is recorded over a period of 7 weeks, from September 01 to October 11. First-instar larvae are recorded from September 01 to September 13, and second- and third-instar larvae are recorded from September 13 to October 11.

Moistened meadow. This biotope is more typical for *P. planipennis*. Here, the seasonal activity of the species, compared to the first biotope, increases by 15 days and amounts to 106 days — from May 31 to September 13 (Fig. 2). The number of beetles is 95 individuals. In the sexual structure, females slightly predominate (46♂♂, 49♀♀), the sex ratio index is 0.03. From the end of May, overwintered immature individuals are recorded, which soon enter the generative state and begin to reproduce. At the same time (from July 12 to August 10) juvenile individuals are noted, which are markers of beetles emerging from pupa. The peak of beetle activity is characterized as mid-summer and occurs on August 02. By mid-September, reproduced post-generative beetles are already recorded. Oviposition is recorded for 8 weeks, from June 28 to August 16, with a peak on July 21. Each female lays approximately 20 eggs, with the maximum number of eggs per female being 50. Third-instar larvae overwinter. Larval activity is recorded for 7 weeks, from September 01 to October 11. First-instar larvae are observed from September 01 to 13, and second- and third-instar larvae from September 13 to October 11.

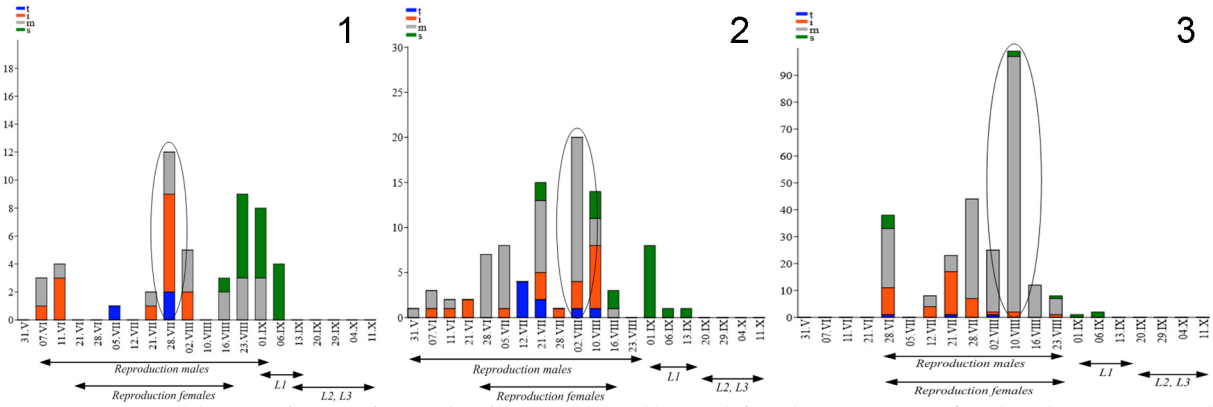
Marshy meadow. This biotope is the most optimal place for habitat and reproduction of *P. planipennis*. Seasonal activity of the beetles, compared to the moistened meadow, is shortened by 10 days and is 96 days from June 28 to September 06 (Fig. 3). The number of beetles is 260 individuals. In the sexual structure, males predominate (192♂♂, 68♀♀), the sex ratio index is –0.5. A late start of the season of beetle activity is noted (June 28). Seasonal activity of beetles is characterized as mid-summer. At the beginning of the season, immature and postgenerative beetles are noted. Juvenile individuals are noted from July 28 to August 02. The peak of reproduction occurs on August 10. Postgenerative individuals are registered in September 06. Oviposition lasts 9 weeks, from June 28 to August 23, with a peak on August 10. On average, one female lays ~16 eggs, with a maximum of 82 eggs per female. Larvae overwinter. Larval activity is recorded for 7 weeks, from September 01 to October 11. First-instar larvae emerge from September 01 to 13, and second- and third-instar larvae emerge from September 13 to October 11.

Long-term studies of the biology and ecology of *P. planipennis* have shown that this species prefers various meadows in the intermountain basins of West Transbaikalia. The beetles range in size from 18 to 24 mm, averaging 21 mm.

A study of the seasonal dynamics of *P. planipennis* activity in meadows with varying moisture levels in 2019 revealed the most favorable habitat for its habitation and reproduction — the moistened meadow. The optimal age-sex structure of adults was found here. The moistened meadow demonstrated the longest seasonal activity period (106 days), which is 10–15 days longer than in the steppificated and marshy meadows. Here, beetle activity begins earlier, in late May, while in other meadow biotopes, the onset of activity shifts to June. In this biotope, beetle activity ends later, closer to the second half of September, compared to the first half of September in other meadows.

A low beetle population was recorded in the moistened meadow, but the ratio of females to males was almost 1:1. In other meadows, the proportion of males was higher: 1.3 times higher in the steppificated meadow, despite having the low number of beetles, while the marshy meadow had the high number of beetles, 2.8 times higher. This is likely due to the mass reproduction of beetles in the marshy meadow, the overwintering of beetles in the moistened meadow, and subsequent active dispersal to the steppificated meadow.

The age structure of the species in all meadow biotopes is normal and complete, with all ages of adults and



Figs 1–3. Seasonal dynamics of activity of *Pterostichus planipennis* adult and larva in different biotops. 1 — steppificated meadow; 2 — moistened meadow; 3 — marshy meadow. Designations: Stages of beetles development: t — teneral, im — immature, m — mature, s — spent; L1 — first instar larva, L2 — second instar larva, L3 — third instar larva. The oval marks the peak of reproduction including females.

Рис. 1–3. Сезонная динамика активности имаго и личинок *Pterostichus planipennis* в различных биотопах. 1 — остепнённый луг, 2 — увлажнённый луг, 3 — заболоченный луг. Обозначения: стадии развития жуков: t — ювенильные, im — имматурные, m — генеративные, s — постгенеративные, L1 — личинка первого возраста, L2 — личинка второго возраста, L3 — личинка третьего возраста. Пик размножения, в том числе самок, выделен овалом.

larvae present. However, their ratios differ, with the most optimal structure being found in the moistened meadow, where the age ratio of juvenile (t) — immature (i) — generative (m) — post-generative (s) individuals is 1:2:6:2. In the steppificated meadow, the ratio of imago ages is almost equal, with the exception of juveniles — 1:5:6:5. In the swampy meadow, the ratio of imago ages is 1:14:68:4 due to the predominance of generative males.

Mature males begin to be caught in soil traps 2–4 weeks earlier than reproductive females in steppificated and moistened meadows, compared to the marshy meadow. In the latter biotope, reproductive females and males are encountered simultaneously. Judging by their relatively higher numbers compared to other biotopes, the marshy meadow may serve as a hunting and feeding biotope. Peak breeding activity is determined by reproductive females. The peak of reproductive female activity shifts to a later date depending on the moisture content of the meadows: July 28 in the steppificated biotope, August 02 in the moistened biotope, and August 10 in the marshy biotope. Approximately 20–21 eggs are laid per female, but the maximum number of eggs per female varies by meadow: 40 in the steppificated biotope, 50 in the moistened biotope, and 82 in the marshy biotope.

The stages of the development of *Pterostichus planipennis* in the laboratory conditions

Pterostichus planipennis larva collected from the wild were kept individually in the laboratory from October 11 at an average temperature of 21–22°C in the dark in Petri dishes on moistened filter paper, which was changed every other day. Larval sizes ranged from 23 to 25 mm (Fig. 4).

Larva were recorded in the wild for 41 days, from September 01 to October 11. Laboratory observations of the larva showed that they develop asynchronously. Last-instar larva removed from the wild remained in the laboratory for an additional 27–44 days, from October 11 to November 7–24. During this period, the larva prepare for pupation. Only one larva failed to shed its cuticle and died. The pupa stage lasts approximately 8 days, from November 10–16 to November 18–24 (Figs 5–9). Young beetles darken over the course of 24 hours, but almost all beetles have insufficiently hardened integuments with deformations (Figs 10–12).

On November 8, 2019, all 7 larva were lying on their backs from about 1:00 p.m.; when photographed, they turned over.

On November 9, 2019, at around 8:00 p.m., all larvae were lying on their backs in a semi-bent position, with only larva No.3 periodically rotating along the longitudinal axis.

On November 10, 2019, three larvae began pupation at different times. Larva No.1 pupated at 8:40 a.m., and by 8:45 a.m., pupa No. 1 was moving, bending its abdomen. Meanwhile, larva No.2 lay quietly on its side. Non-pupating larva can move backwards using their urogomphs. Larva No.2 began rolling along its longitudinal axis around 5:00 p.m., and then, from 5:25 p.m. to 5:41 pupation began, leading to shedding of the integument. This process begins with the dorsal suture separating, then the individual gradually sheds its integument with vigorous pulsation of its body. Initially, the pupa became more elongated and flattened, and by around 6:00 p.m., it began to bend slightly, assuming the appearance typical of beetle pupa. Larva No. 3 began turning over at 8:45 a.m., rotating along its longitudinal axis with rolls across the surface until around 12:00 p.m., and then pupated by 2:00 p.m. The remaining larva began the pupation process later.

On November 16, 2019, larva No. 5 pupated between 9:30 p.m. and 10:00 p.m. On November 17, 2019, larva No. 4 was lying on its back and turning over.

On November 18, 2019, imago No. 1 hatched between 8:30 a.m. and 8:45 a.m. The young beetle's wings

Figs 4–12. Developmental stages of *Pterostichus planipennis*. 4 — larva; 5 — crack on the dorsal part of the larval integument; 6, 7 — beginning and end of the pupa's emergence from the larval integument; 8, 9 — pupa; 10, 11 — young immature beetle; 12 — strengthened beetle. Photo by S.G. Rudykh and L.Ts. Khobrakova.

Рис. 4–12. Стадии развития *Pterostichus planipennis*. 4 — личинка; 5 — трещина на спинной части покрова личинки; 6, 7 — начало и конец выхода куколки из покровов личинки; 8, 9 — куколка; 10, 11 — молодой неокрепший жук; 12 — окрепший жук. Фото С. Г. Рудых, Л. Ц. Хобраковой.

were protruding. Observations of the pupa and imago No. 3 revealed the process of shedding the pupal case, with the young beetle pulling the case downwards sequentially using its mandibles and fore, middle, and hind legs between 12:00 p.m. and 12:30 p.m. Observations of larva No. 2 revealed that shedding of the integument began at 3:35 p.m. and ended at 3:54 p.m. Beetles No. 1, 2, and 3 remained on their backs throughout the day. Observations of larva No. 4 revealed a crack on its back from 1:30 p.m. to 2:00 p.m. An hour later, the larva died without fully pupating at 3:00 p.m.

On November 19, 2019, the beetles were in a normal position; their skin had turned black, but their skin was not firm enough even at 3:30 p.m. On November 20, 2019, the beetles' skin was still fragile at 4:15 p.m. On November 21, 2019, all hatched ground beetles, even after prolonged periods of exposure, had insufficiently hardened integuments at 1:30 p.m. On November 23, 2019, larva No. 6 lay on its back and rolled around until 12:20 p.m. On November 24, 2019, observations of larva No. 5 showed that the adult hatched after 1:15 p.m. Larva No. 6 was unable to shed its integument and died at 10:20 a.m. Larva No. 7 pupated in the evening at 9:40 p.m. November 30, 2019. Developing pupa No. 7 was preserved in ethanol.

Conclusion

Our 2009 *Pterostichus planipennis* studies were repeated 10 years later at the same site in the Mukhinskie marshes. Drought and warming observed in the region over the past decade have led to the transformation of marshy coastal meadows into moistened and steppificated meadows.

The analysis of the seasonal dynamics of the demographic structure of *P. planipennis* in the 2019 year allowed us to decipher its life cycle in the conditions of West Transbaikalia as a one-year late summer with overwintering of larvae.

Compared to our studies in 2009 [Khobrakova, 2017], under the conditions of a warm spring in 2019, an early onset of activity was observed from the end of May to the beginning of June, in contrast to 2009 (the first ten days of July), and a long warm autumn led to an extension of the seasonal activity of the species by almost a month.

The reduction of moistened habitats has led to the migration and resettlement of mesophilic ground beetle species deep into the Mukhinskie marshes. The most optimal population structure for this species is formed in the moistened meadow, while pessimal conditions have developed in the steppificated meadow due to overgrazing by cattle and small livestock, and in the marshy meadow due to excessive soil moisture.

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