Peculiarities of the development and seasonal dynamics of the activity of epigean beetles of the Polyphaga suborder (Coleoptera) in fields of winter wheat in the conditions of Southern Ukraine

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Introduction

The study of specifics of the seasonal changes in the abundance of insects, their mode of life and development in the conditions of agrocenoses is of special importance both for understanding the patterns of the formation of the structure of entomofauna and development of an integrated method of plant protection. One of the dominating orders of insects in fields is Coleoptera, especially the representatives of such a numerous group as the inhabitants of the upper layers of soil and litter – epigeal habitat. Despite the interest continuously shown over 50 years in the activity of epigean coleopterans of the Polyphaga order in winter wheat (as a model of separate transformed cenoses, including field crops. However, traditionally the ground beetles have received the most attention (Putchkov, 2018). Much less research has been conducted on other families of beetles: skin-beetles and carrion-beetles (Dermestidae, Silphidae) (Putchkov, 1985, 2010), lamellicorn-beetles (Scarabaeidae) (Putchkov et al., 2017), clown-beetles (Histeridae) (Putchkov & Komarnich, 2018), darkling beetles (Tenebrionidae) (Cherney, 2005), click-beetles (Elateridae) (Dolin, 1982, 1988), weevils (Curculionidae) (Komarnich et al., 2019) and others (Putchkov, 1991; Sunnarokov, 2009).

The objective of our study was the peculiarities of the development and patterns of seasonal changes in abundance of the main families of epigean coleopterans of the Polyphaga order in winter wheat (as a model agrocenosis) in various calendar and phenological periods of vegetation of the crop in the conditions of Southern Ukraine.

Materials and methods

Materials for this work were the authors’ collections, as well as collections of beetles kindly given to us for the laboratory studies by Prof. A. V. Putchkov, to whom the authors express sincere gratitude. The beetles were collected in 2008, 2009 and 2011 in winter wheat fields in the steppe zone of Ukraine: Bushanka Raion, Mykolaiv Oblast. During the studies, we used Barber pit-fall traps (plastic cups of 0.2 L capacity, filled with 10% solution of acetic acid). In 2008 and 2009, we examined three fields of wheat in each year (the total area of around 250 ha), and in 2011 – two fields (about 150 ha). In each field, we set 10–20 traps arranged in checkerboard pattern at the same distance one from another. The selection of insects was made with 10–15 days intervals during the period of vege-
tation of the crop: from late April to mid July and from mid September to mid October. In total, throughout the period of study, 220 counts were made.

The number of beetles caught in a certain period reflected their relative abundance (or dynamic density) which directly depends on the moving activity of beetles (Tkhororova, 1975). The abundance of the beetles was expressed in catching days, for example individuals captured (on average) in one trap during a day, in 10 traps per day, etc. The main attention was paid to the abundant and common species, i.e. the share of which exceeded 2% of the total number of coleopterans recorded in separate selections (Kornarorni et al., 2018; Putchikov, 2018). The counts were performed not only in calendar, but phenological periods of vegetation of wheat: from the phase of tillering to the phase of wax ripeness.

To study the daily activity of the beetles, in a separate field we set 20 traps, and selected the material after every 3–4 h. The measuring unit of daily activity of beetles was the amount of individuals captured during an hour and was expressed as a percentage of the total number of recorded coleopterans. The counts of daily activity were conducted several times in the period from mid May to mid June, i.e. during the mass activity of most epigean beetles.

The sex index was expressed as the ratio of females to the total number of beetles of each species in a sample. For the count of mature oviparous eggs, we selected no less than 20 females of beetles of a specific species, which we previously intensively moistened in desiccator. Then, the abdomens were separated and boiled in 5% solution of alkaline (NaOH or KOH), thus achieving the maceration of all the non-chitin tissues, and the eggs mature for laying which were covered with dense chorion were kept inside the abdomen. The abdomen taken out of alkaline and well rinsed with water was dissected with sharp blade or dissecting needle on the pleura. The residuals of the macerated eggs were removed with a brush by rolling the contents of the abdomen on filter paper, and then the eggs were counted using a binocular microscope. The selection of beetles for determining the sex index and counting oviparous eggs was carried out in different calendar periods, usually from the beginning of rise, peak and fall in the number of species.

We identified most of the beetles (using the Guide to Beetles of the European part of the USSR, 1965), but identifications of some species were confirmed by Prof. A. V. Putchikov, Ph.D. A. A. Petrenko and Ph.D. V. Y. Nazarenko (I. I. Schmalhausen Institute of Zoology of National Academy of Sciences of Ukraine).

**Results**

In total, in areas sown with winter wheat, we recorded 168 species of beetles, belonging to 25 families of the suborder Polyphaga. Among them, 116 were identified as epigean species, 14 of which were dominant, 32 subdominants, and the remaining beetles (around 70 species) occurred rarely and singularly. The main representatives of epigean beetles were staphylinids (Staphylinidae), carrion-beetles (Silphidae), skin-beetles (Derommatidae), clown-like flower beetles (Anthicidae), ant-like flower beetles (Anthicidae), less abundant scavenger-beetles (Latridiidae), silken fungus beetles (Cryptophagidae), some click-beetles (Elateridae), lamellicorn-beetles (Scarabaeidae) and most of the darkling beetles (Tenebrionidae). In 2011 were identified as epigean species, 14 of which were dominant, 32 subdominants, and the remaining beetles (around 70 species) occurred rarely and singularly. The main representatives of epigean beetles were staphylinids (Staphylinidae), carrion-beetles (Silphidae), skin-beetles (Derommatidae), clown-like flower beetles (Anthicidae), ant-like flower beetles (Anthicidae), less abundant scavenger-beetles (Latridiidae), silken fungus beetles (Cryptophagidae), some click-beetles (Elateridae), lamellicorn-beetles (Scarabaeidae) and most of the darkling beetles (Tenebrionidae). In 2011 we recorded 10 species, the total share of which which ranged 2–8% of the total number of all representatives of the suborder. Only two species were recorded, with *DERMESTES LANIAURUS* Illiger, 1810 identified to dominants, and *D. kazackii* Kalik, 1950 to subdominants. High activity of the beetles was observed already from the mid May, reaching its peak in the mid June (Fig. 1) or in the first decade of July (Fig. 1, 2). This was due to both biology of development of species and influence of weather conditions.

Ant-like flower beetles (*Anthicidae*) comprised 3–12% of the number of all epigean beetles. Within this family, three species were recorded (*Anthicus aterrimus* Fabricius, 1775, *Fornicinomus pedestris* Ross, 1790, *Hirticollis hispidus* Rossi, 1792), which were dominant or subdominants depending on the year and field in which the research was undertaken. The number of ant-like flower beetles was high almost over the entire spring-summer period (Fig. 1). In spring, the beetles occurred frequently, but their abundance at that period was 3–5 times lower than in summer. Maximum activity of beetles was observed in the first half of June (2009, 2011) or first decades of July (2010). In autumn (up to mid October), ant-like flower beetles were also frequently recorded in the wheat fields, but their number at that period was 5–6 times lower than in spring and 7–10 times in summer.

As for darkling beetles, we recorded 10 species, the total share of which reached 1.5–8.0% of the total number of epigean beetles. We recorded two abundant species – *Crypticus quasiliatus* Linnaeus, 1761 and *Opatrum sabulosum* Linnaeus, 1761, while *Pedinus femoralis* Linnaeus, 1767 and *Gonoclysmus pusillum* Fabricius, 1791 were recorded as common. Their populations significantly varied in different years (Fig. 1, 2). In 2008, the peak for those beetles was seen from the late May and almost throughout June, falling by over 5 times in July. In 2009, the number of darkling beetles in May was quite low compared with June, and especially July, and in 2011 high parameters of abundance of the beetles were observed in June (ten times higher than in May and July). In autumn, no representatives of the family were recorded.

Click-beetles were represented by 6 species, which comprised 1.5–7.0% of the trapped specimens of the suborder. The dominant species were *Aeolusoxus rossi* Germain, 1844 and *Agriotes spathular Linnaeus, 1758*, while *A. gurgistanus* Faldermann, 1835 and *Melanotus fiscipes* Gyllenhal, 1817 were classified to subdominants. The activity of beetles in the wheat fields (similarly to darkling beetles) significantly varied for different years, fields and calendar periods. The highest abundance was more often seen in June and July, but in spring the beetles occurred quite frequently as well (2008, 2011, Fig. 1, 2). However, according to counts in 2009, the number of click-beetles gradually increased from mid May to mid June and by early July reached its maximum (Fig. 1, 2). In autumn, the beetles were often recorded in September (2008) or recorded singularly (2009, 2011). Other beetles which were sporadically observed to be dominants or subdominants were represented mainly by lamellicorn-beetles (1.6–12.0%), weevils (1–4%), silken fungus beetles (Cryptophagi-
As common species in the epigeal habitat, the following may be identified: Aphodius distinctus Muller, 1776, Pleurophorus caesus Creutzer, 1796, Oothophagus vitulis Fabricius, 1776, Pentodon idiota Herbst, 1798 (Scarabaeidae), Giathornius saturifer Reitter, 1896, Margarinotus purpurascens Herbst, 1792 (Histeridae), species of genera Latridius, Coricorina (Latridiidae) and Cryptophagus (Cryptophagidae), Oiorhynchus ligustici Linnceus, 1758, Poalidius maximilane Fabricius, 1793 (Curculionidae). Their abundance in some fields of winter wheat diverged broadly in different years, therefore, the peculiarities of changes in the activity of these beetles could not always be determined.

Discussion

As seen in the quantitative data given above, epigean coleopterans in wheat fields are active and numerous during almost the entire vegetation period of the crop. The pattern and the course of the curve of the total occurrence of beetles in the traps is due to their belonging to various phenological groups, massive emergence or decrease in the number of which to a large extent depends on the vital cycles of the dominant species, their seasonal rhythms of reproduction, and also different activity of imagoes and larvae. This, in turn, is due to the peculiarities of the agrocenosis where the beetles develop and spend most of their life. A certain role in the fluctuation of quantity is often played by weather conditions in different periods of vegetation of the crop. It would be expedient to analyse these patterns regarding the dominant families of coleopterans.

**Staphylinids.** Most staphylinid species recorded in the wheat agrocenosis winter in the stage of imago (Tikhomirova, 1973; Nekulchyny et al., 1984; Andersen, 1997; Tzurkov, 2016) both directly in the fields of winter wheat and adjoining habitats in the upper soil layers and litter. Emergence of overwintered species is observed already in late March–early April and reaches the highest values in the first half of May. In the late spring, the staphylinids were observed to have the highest abundance and species diversity (late April – beginning of May) compared with other periods of the year. To a high degree, this is related to...
hygropreferendum of these beetles, most of which are mesohygrophilous elements (Tikhomirova, 1973).

Weather conditions of spring characterized by usually heightened moisture compared with the summer period are favourable for life and development of many species in wheat fields. In this period, not only is mass emergence of beetles after winter observed, but also a number of species start to reproduce. Increase in the number of the most numerous species T. hypnorum was also seen in spring, but somewhat later (usually in the II–III decades of May) compared to other species (Fig. 3). Therefore, females of T. hypnorum contained 2–4 eggs in late May, while the sex index equalled 0.50. Larvae of this species were recorded in wheat fields already in late May, and mass occurrence of them was seen in the first half of June.

Fig. 4. Changes in the proportion of some coleopterans in a wheat field during 24 h (data for 2011)

In the summer period, by the end of egg laying, the dynamic density of most species rapidly decreases due to natural death, as well as migration of mesohygrophilous species to other habitats. A similar pattern of changes in the seasonal number of staphylinids was observed in agroecosystems of Zakarpatska Oblast (Bogdanov, 1980), Moldova (Munteanu et al., 2014) and even North-Eastern Russia, but in the latter case in later periods (Guseva & Koval, 2020).

For most of the recorded species of staphylinids, two or more rarely three generations were characteristic (Tikhomirova, 1973; Nekulišyanu et al., 1987; Andersen, 1997). According to our data, in the wheat fields of the Steppe zone of Ukraine, T. hypnorum has enough time to develop only one generation. Singular emergence of beetles of new generation of this species was observed in late May – early June, but in colder years – in late June. Phenologically this coincides with the phase of booting-ear formation-flowering of wheat. Mass hatching of young beetles was observed in late June – early July, coinciding with the phase of wax ripeness of grain. The low number of staphylinids in autumn is associated with the development of many species in wheat fields. In this period, not only is mass occurrence of beetles was minimum (around 1 specimen per trapping day, Fig. 5). The period of egg-laying of S. obscura is prolonged and lasts for two months from late April to mid June (Putchkov, 2010). In mid May, 70–80% of captured females had mature eggs in their gonads, whereas in the early June this parameter decreased by 45–50%.

The eggs contained 2–15, more often 4–6 mature eggs, and the share of females in that period reached 0.50–0.55. Larvae of older ages (III–IV), which were typical epigeans, emerged already in late May (phase of booting of wheat), and their highest abundance was observed in late June (phases of tillering-flowering). Imagoes of new generation emerged in early July (phase of wax ripeness), and mass hatching from the pupae was observed in the middle – end of that month (phase of complete ripeness). Most often this occurred already after the harvest, though in some years, young imagoes of S. obscura were found in the period of wax-complete ripeness. Maximum of daily activity of imagoes was observed in the late-morning and early-evening hours, but in the day time the beetles were also recorded frequently (Fig. 4).

Fig. 5. Seasonal changes in the number of carrion beetles and skin beetles in wheat fields in different years of the research:
a – carrion beetles, b – skin beetles

Peculiarities of the development of the related species S. carinata are similar to such of S. obscura, but increase in the abundance of overwintered imagoes of this species was usually observed somewhat later – in mid – late May (Putchkov, 2010). The species Nicrophorus antennatus was seen more often in May – early June. After the harvest, carrion beetles leave the fields, migrating to windbreaks or crops with longer vegetation (maize, sunflower, perennial herbs), where they often winter. Skin beetles are univoltine species with obligatory imaginal diapause (Zhantriev, 1976; Pushkin, 1999). In the wheat fields, the first wintered beetles were recorded already in late April – early May (Pushkin, 1991) in the conditions...
of average daily temperatures of +10…+12 °C. Weather conditions had a significant effect on the activity of skin beetles. In warmer and drier years (2008), the abundance of the beetles was 2–3 times higher than in the years with more moderate weather (Fig. 5). In the conditions of primarily warm weather in spring, imagines left their wintering sites almost simultaneously, a high number was seen already in late May — early June (usually the end of tillering–flowering phase), and in early July (i.e. in the phase of wax ripeness), individuals were observed occasionally (Fig. 5). However, in the years (2009) with lower average-daily temperature (up to +11…+14 °C in mid May) and more frequent precipitations (up to 90 mm since mid June), we observed a prolonged period of beetles leaving their wintering sites, significant fluctuations of seasonal activity and a prolonged period of egg deposition. At the same time, differences regarding the phases of vegetation of crop almost coincided, and higher number of skin beetles in the fields was recorded during ear formation – early milk ripeness of grain.

Mating of skin beetles was observed from May to late June, and egg-laying – from mid May to late June. Maturation of eggs in the gonads was even, because the share of females with mature production did not exceed 15–20% in late May – early June. On average, 3–5 mature eggs were recorded. Larvae hatch from the eggs after 5–7 days, and their development (depending on the conditions of environment) lasts for 20–25 to 45–50 days. In the wheat fields, a high number of larvae was recorded from late May to early June (phases of tillering–flowering). Pupation of beetles occurred in the upper layer of soil, and the pupa phase lasts for 12–14 days (Zhaniev, 1976). Singular specimens of imagines of new generation were seen in the wheat fields in the first days of July. In that period, some combination of the number of young and overwintered imagines may be observed, as we saw in 2009 (Fig. 5). Mass hatching of imagos of new generation seems to occur after harvest, but beetles actively migrate to other habitats. In autumn, skin beetles often are seen in wheat fields in September and extremely rarely in October.

**Ant-like beetles.** Despite the fact that ant-like beetles are constant inhabitants of field crops (Putchkov, 1991; Sumarokov, 2009), the data on their seasonal dynamics are extremely fragmented. These beetles begin to emerge in the wheat fields already in late March – early April. The first to leave wintering sites (fields, sides of roads, windbreaks) are *Anthicus antherinus* and *Formicomus pedestris*, whereas the more xerothermophilic *Hirticollis hispidus* appears 7–10 days later. All the recorded species were characterized by day activity with some increase in the middle of the day (Fig. 4). The first, smaller, rise in the number of ant-like beetles in the sowings of wheat was seen in the first half of May and is associated with the reproduction period (Fig. 6). Coupling was observed already in the end of April to mid May. The period of egg deposition is probably prolonged, with females with mature eggs occurring during May–June. Therefore, in mid May, on average the number of mature eggs per one female of *H. hispidus* was 3.4, and in early June – 2.6, and the gonads contained 6–8, maximum 15 eggs. The sex index reached 0.45–0.53 in the period of maturation and egg-laying, whereas it equalled 0.33 at the beginning of their period of inhabitation of wheat fields.

Young imagos appeared already in late May – early June (ear formation–flowering), and the highest number of ant-like beetles was recorded in late June, but in some years and in the first decade of July (Fig. 6) it coincided with the phases of milk-wax and ripeness of grain. At the same time, as in the period of inhabiting the wheat fields lands, *A. antherinus* and *F. pedestris* emerged earlier with high numbers already observed in the II–III decades of June, while *H. hispidus* emerged n late June – early July (Fig. 6).

Abundance and activity of ant-like beetles increased, and their development intensified in warmer and drier years. Therefore, in 2008, the period of spring activity of beetles in the wheat fields was shorter, and mass emerging of young imagos was seen already starting from the second half of June. In the colder year 2009, the periods of appearance and development of beetles were prolonged, and imagos of new generation were recorded only beginning from early July, i.e. almost 10–15 days later. However, according to phases of phytology of wheat, emergence of young beetles differed less and corresponded to the phase of milk-wax ripeness of grain. Noticeable decrease in the number of ant-like beetles began directly before the harvest – usually in the first half of July, which is associated with migration of beetles from desiccated wheat fields to other habitats. In autumn (especially September), ant-like beetles were quite common in winter wheat (they also winter there), and their number was not much lower than in the early spring period.

**Fig. 6.** Seasonal changes in quantity of ant-like beetles in wheat fields in different years of the research

**Darkling-beetles.** The dominant species *Opatrum sabulosum* and *Gonocephalum psallium* overwinter in the adult phase, *Pedinus femoralis* — in the stages of imago and larva, and *Crypticus quisquilius* — only larvae (Cherny, 2005; Brygadyrenko & Nazimov, 2015). Different life cycles of these species underlie also differences in seasonal dynamics of their abundance in wheat fields in different years.

The spring awakening is related to the emergence of wintered beetles of *O. sabulosum* and *G. psallium*, which began in mid April and reached its maximum in May (Fig. 7). In some years, high abundance of these species was observed throughout May, up until early June, and decrease was seen only in the end of the month. The summer increase in the number of *C. quisquilius* darkling beetles was due to emergence of beetles from pupae, particularly *P. femoralis*. The first individuals of these species were recorded in the first decade of June, and mass appearance was seen after 8–12 days (Fig. 7). Significant decrease in the number of these species was observed in July. In the autumn period, *O. sabulosum*, *G. psallium* and *P. femoralis* were occasionally found, while *C. quisquilius* was absent.

**Click beetles.** All species of click beetles recorded in wheat fields overwinter in the stages of imago and larva (Dolin, 1982, 1988). Development of the dominant species *Aeolosomus rossi* and *Agriotes spurator* lasts — two and 3–5 years respectively. Increase in the number of imagos of *A. spurator* in wheat fields was recorded from May to mid June, but already at the end of this month, only isolated individuals occurred. Emergence of overwintered beetles of *A. rossi* in the fields was recorded already from mid April. Seasonal dynamics of the abundance of this species were characterized by gradual increase throughout May, with a peak at the end of the month and early June (Fig. 7).

At the same time, if the spring increase occurred gradually, the summer increase was more notable in more humid years (2009). We can presume that reproduction of *A. rossi* in wheat fields is sporadic, only in the conditions favourable for the development of larvae. In autumn, imagos of *A. rossi*, unlike *A. spurator*, were common in the wheat fields, but their abundance was significantly lower than in spring. Different dynamics of emergence of these two dominant species in wheat sowings underlie also the differences in increase-decrease in the number of click beetles in general during a season and depending on the year (Fig. 7).
The abundance of each species of the certain families was low. Throughout the vegetation period (Fig. 1), which is due to the varying revelation quite a high number of other epigean beetles in wheat fields almost in spring – darkling beetles, skin beetles, clown beetles, ant-like flower beetles, minute scavenger beetles, silken fungus beetles, some click beetles, lamellicorn beetles and most darkling beetles.

Among lamellicorn beetles, emergence of the dominant species *Pentodon idiota* was recorded in mid May, and increase in its abundance was recorded from mid April, but mating dance: in the first half of May and the second one in the second half of June. At the same time, in summer, young beetles which had just hatched increased gradually from mid May and reached maximum values at the end of the month – beginning or middle of June. Among darkling beetles, species of *Opatrum* and *Gonocephalum* genera were more abundant in spring than in summer, but in *Crypticus quisquilius*, the peak of activity was observed in midsummer. In click beetles, the increase in the number of *Agrionites spatular* was recorded from May to mid June, and emergence of *Aeloesoma rusti* was recorded from mid April, but with peak of abundance in the first half of summer. In spring, more often than in summer, lamellicorn beetles (*Geotrupinae*), clown beetles and some species of weevils were seen.

In years with different meteorological conditions, significant differences were recorded for calendar periods of rise and fall in numbers of many beetles. Lower differences of fluctuations of abundance were observed by comparison with phases of vegetation of wheat. Some peculiarities of the dynamics of sex index (increasing by the period of egg laying) and development of dominant species were considered briefly.

The authors are very grateful to the Prof. of the I. I. Schmalhausen Institute of Zoology of National Academy of Sciences of Ukraine (Kyiv) A. V. Puchkov for numerous consultations and check of identifications of a number of species of beetles. Special acknowledgement to the employees of the Department of Entomology and Scientific Fund Collections of the I. I. Schmalhausen Institute of Zoology of National Academy of Sciences of Ukraine (Kyiv), Ph.D. L. S. Chernei for the invaluable help in identification of the material.

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**Fig. 7.** Seasonal changes in the abundance of darkling beetles and click beetles in wheat fields in different years of the survey: a – darkling beetles, b – click beetles

**Conclusion**

In conclusion, the number of beetles in the fields of winter wheat, 168 species of beetles of 25 families of Polyphaga suborder were recorded. A total of 116 species were identified to herpetobionts, including 14 dominants, 32 subdominants and about 70 species were rare or occurred singularly. The main representatives of the epigean beetles were staphylinids, carri-on beetles, skin beetles, clown beetles, anti-like flower beetles, minute scavenger beetles, silken fungus beetles, some click beetles, lamellicorn beetles and most darkling beetles.

Most staphylinids were abundant in spring (late April – first half of May). In summer, for some species (*Tachyporus hypnorum*), the second peak in abundance is possible due to the emergence of beetles of new generation. A high number of carri-on beetles was seen by mid May, but they decreased in the summer months, and mass emergence of young beetles was seen in midsummer. Anti-like flower beetles, minute scavenger beetles, silken fungus beetles were characteristic of two peaks in abundance: the lesser one in spring (first half of May) and the greater in summer (second half of June – early July). The abundance of skin beetles increased gradually from mid May and reached maximum values at the end of the month – beginning or middle of June. Among darkling beetles, species of *Opatrum* and *Gonocephalum* genera were more abundant in spring than in summer, but in *Crypticus quisquilius*, the peak of activity was observed in midsummer. In click beetles, the increase in the number of *Agrionites spatular* was recorded from May to mid June, and emergence of *Aeloesoma rusti* was recorded from mid April, but with peak of abundance in the first half of summer. In spring, more often than in summer, lamellicorn beetles (*Geotrupinae*), clown beetles and some species of weevils were seen.

In years with different meteorological conditions, significant differences were recorded for calendar periods of rise and fall in numbers of many beetles. Lower differences of fluctuations of abundance were observed by comparison with phases of vegetation of wheat. Some peculiarities of the dynamics of sex index (increasing by the period of egg laying) and development of dominant species were considered briefly.

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Biosyst. Divers., 2020, 28(3)
