*Proceedings of the Tenth International Conference on Urban Pests*
*Rubén Bueno-Marí, Manuel, Tomas Montalvo, and Wm. H Robinson (editors) 2022*
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# *KORYNETES CAERULEUS* (COLEOPTERA: CLERIDAE) FOR BIOLOGICAL CONTROL OF *ANOBIUM PUNCTATUM* (COLEOPTERA, PTINIDAE)

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**Abstract** Larvae and adults of *Korynetes caeruleus* (de Geer 1775) (Coleoptera: Cleridae) were collected from old churches and reared in the laboratory on *Anobium punctatum* (de Geer 1774) (Coleoptera, Ptinidea, formerly Anobiidae). Breeding success of *K. caeruleus* was low, but basic parameters of this species' developmental cycle were identified. At 21 °C and 75 % relative humidity and a four-month cold period at 4 °C, the development of *K. caeruleus* from egg to adult appearance lasted 2 years. The pupal stage may be reached and completed after one and a half years. Feeding on larvae of *A. punctatum* by larvae of *K. caeruleus* was observed and consisted of a combination of sucking haemolymph and consuming body parts. The sickle-like mandibles of larvae of *K. caeruleus* penetrate the cuticle of prey larvae followed by pumping and sucking body movements. Adult beetles of *A. punctatum* were not attacked by *K. caeruleus* larvae. Feeding behavior of adult *K. caeruleus* was not investigated.

**Key Words** biological pest control, life history data, wood protection, cultural heritage.

## INTRODUCTION

Biological control of pests is one cornerstone of Integrated Pest Management (IPM). To evaluate the potential of a predator as biological control agent of a pest species in the field, autecological studies and reliable life history data of the beneficial species are needed. Although several parasitoids and predators of wood boring pest insects are well known (Becker, 1954; Paul et al., 2008), their utilization in biological control to protect structural timbers, wooden furniture or art is still limited and unexploited (Steidle et al., 2007; Schöller, 2010; Schöller and Prozell, 2011; Auer and Kassel, 2014; Biebl and Auer, 2017; Querner, 2017). Major reason for this is the lack of detailed knowledge of their biology, absence of standard procedures for their mass rearing and reliable data on their pest control efficiency (Haustein et al., 2014). Establishing a sustainable laboratory culture of beneficial insects in order to determine their life histories is therefore an important prerequisite before promoting the use of classical biological control for the protection of wooden structures (Faulds, 1987; Reeve et al., 2003; Kassel et al., 2018, Haustein et al. 2019).

*Korynetes caeruleus* (de Geer 1775) (Coleoptera: Cleridae) is known to be a predator of wood boring anobiids, including the major pest beetle *Anobium punctatum* (de Geer 1774) (Coleoptera, Ptinidae) (Becker, 1942; Vité, 1952; Hickin, 1963a; b; Belmain, 1998; Belmain et al., 1999a; Unger et al., 2001; Petzoldt, 2011). Adults of *K. caeruleus* are believed to feed on all stages (egg to imago) of *A. punctatum* (Becker, 1954). The larvae of *K. caeruleus* can consume all but the adults of *A. punctatum* when these are alive but may be able to consume dead ones (Ott, 2007). Predators in general can feed on a variety of different prey and are present in different habitats, but *K. caeruleus* seems to be strongly associated with pests of structures made of wood. This species is mainly a synanthrope (Becker, 1954; Gerstmeier, 1998; Belmain et al., 1999b; Belmain and Ridout, 2000; Franke, 2001; Haustein and von Laar, 2007; Haustein et al., 2007; Noldt, 2007; Mosneagu, 2012; Niehuis, 2013) because it is rarely recorded and if ever in outdoor faunistic surveys in Central and Northern Europe only in limited numbers (Anonymous, 2004; Müller et al., 2007;

Nikitsky and Schigel, 2004; Esser and Kielhorn, 2005; Ostrauskas and Ferenca, 2010; Johansson, 2011; Niehuis,, 2013; Finch 2015; Háva and Kovařík, 2015).

We collected adult beetles and large larvae of *K. caeruleus* in old, small village churches in north-eastern Germany and fed them on a laboratory culture of *A. punctatum*. Although mass rearing of this predator was not achieved, reproduction of *K. caeruleus* under controlled laboratory conditions was successful and reliable life history data were recorded.

## MATERIAL AND METHODS

### Collection of *K. caeruleus*

*Korynetes caeruleus* was collected from small churches in Mecklenburg-Vorpommern (north-east Germany). Many of these churches are currently not regularly used with only four to five services per year. Most of them were erected or largely restored during the late 18$^{th}$ and middle 19$^{th}$ century. Building materials were local boulder and cobble stones combined with bricks and wood. The interior, mainly the seating and the choir stalls, were made from wood. Today, the buildings are unheated with high relative humidity in the inside resulting in a high moisture content of the wood throughout the year (Franzen and Löther, 2009; Haustein, 2010). At the time when the beetles were collected in spring (see below) ambient temperatures ranged from 9.5 to 20.3 °C (mean 14.0 °C), and relative humidity of 47.5 to 67.5 % (mean 54.8 %).

Manual collection of late instar larvae and adult beetles of *K. caeruleus* was carried out in five consecutive years from 2013 to 2017, twice during mid and late spring for two to three days, respectively (Table 1). Live adult beetles of *K. caeruleus* occurred at the collection site in high numbers from the beginning of May for about four weeks and then declined. They were regularly observed on the surfaces of wooden structures, where they mated. Identification of *K. caeruleus* was based on the description provided by Gerstmeier (1998), who also personally verified the identity of provided specimens. Late instar larvae of *K. caeruleus* occurred about two to three weeks earlier in the year than the adults. They were also found on the surface of wood structures, where they presumably search for suitable prey by frequently entering and exiting from the flight holes made by their prey. Wood worm (*A. punctatum*) frass which fills the flight holes and the connecting tunnels is ejected during this process and yellowish wood powder piles up near flight holes (Ott, 2007). Often other larvae of *K. caeruleus*, while searching the surface of wood, move through these piles of powder leaving typical tracks. This kind of larval activity lasted until late summer, however with declining frequency over time.

**Table 1**. Number of larvae and adults of Korynetes caeruleus collected 2013 to 2017.

| Larvae | | Adult beetles | |
|---|---|---|---|
| Time of collection | Total (n) | Time of collection | Total (n) |
| 2013 May 6 | 12 | 2013 May 6 | 14 |
| 2014 May 5 | 17 | 2014 May 5 | 54 |
| 2015 May 4 | 19 | 2015 May 11 | 60 |
| 2016 May 3 | 16 | 2016 May 13 | 54 |
| 2017 May 7 | 13 | 2017 May 24 | 50 |

Because the occurrence of larvae and adults of *K. caeruleus* partially overlapped each year, it was assumed this species takes several years to complete its development. Thus, at least two distinct generations at different developmental stages may co-occur. Adult beetles of the prey species, *A. punctatum*, were not detected before the end of June and the beginning of July and must therefore be excluded as a source of food for at least the mating and egg laying adult beetles of *K. caeruleus*.

### Breeding of *K. caeruleus* in Laboratory

After collection, insects were caged individually for transport to avoid cannibalism, especially among larvae. Beetles were only confined as pairs when captured in copulation. Insects were immediately transported to BAM (Federal Institute for Materials Research and Testing) in Berlin and placed in 3 to 4 months old cultures of *A. punctatum* larvae for further breeding. First, due to the difficulties associated with determining the sex of live *K. caeruleus*, all individually transported adult beetles were collectively released into a large petri-dish of approximately 9 cm in diameter for mating. Pairs or groups of four to six beetles were then added to the cultures of *A. punctatum* larvae. Individuals which did not mate after collection were pooled as one group. Five to six of these adults were added to cultures of *A. punctatum*.

Combined cultures of *A. punctatum* / *K. caeruleus* were kept at 21 ± 1°C and 75 ± 5 % r. h. on an artificial wood diet as described in the standard protocols for rearing *A. punctatum* (Cymorek, 1965; Baker & Bletchly, 1966; Cymorek, 1975). Part of that standard rearing protocol is the temporary storage of cultures for two to four months at 4 °C, when *A. punctatum* larvae reach the age of ten months. Bringing the cultures back to normal rearing conditions of 21 ± 1°C and 75 ± 5 % r. h. after cold storage triggers pupation and the development of adults in *A. punctatum*. It was assumed that the predator, *K. caeruleus*, needs the same abiotic conditions to complete its development, therefore, the *A. punctatum* / *K. caeruleus* cultures were treated similarly. The *A. punctatum* / *K. caeruleus* cultures were examined in intervals to determine the stage of development reached by *K. caeruleus* (Table 2 and Table 3). The larvae of *K. caeruleus* retrieved from these cultures were reintroduced into other *A. punctatum* cultures of similar age.

Feeding behavior of larvae:

For observing feeding behavior, some individual larvae of *K. caeruleus* were observed for long periods of time when continuously fed with larvae of *A. punctatum*. For this, one larva of each species (prey and predator) were confined in small Petri dishes of approximately 4 cm in diameter, which functioned as an arena for behavioral observation. The arena contained no wood or any other kind of matrix other than a small shelter made of corrugated paper. Live larvae of *A. punctatum* were placed in the open but were unable to move around. When they were consumed or killed by the predator they were replaced. Arenas were in a rearing room at 21 ± 1°C and 75 ± 5 % r. h.

Changes in body mass of each larva of *K. caeruleus* were recorded once every month by weighing them on a Sartorius LE 225D-OCE laboratory scale to the nearest 0.01 mg (Table 4).

For observing feeding behavior after adding *A. punctatum* larvae, the arenas were placed on a laboratory bench at ambient room temperature and under normal light conditions. When contact between predator and prey was established the arena was placed under a binocular for observation.

**Table 2**. Results of rearing field collected adult *Korynetes caeruleus* in five consecutive years. Those that were alive are listed.

| Year / Stage of development | 2013 | 2014 | 2015 | | 2016 | 2017 |
|---|---|---|---|---|---|---|
| | | | a | b | | |
| P-adults introduced | 14 | 54 | 10 | 50 | 49 | 24 |
| End of 1st year of breeding (21 ± 1°C and 75 ± 5% r. H.) | | | | | | |
| $F_1$- larvae retrieved | 3 | 16 | 3 | not disturbed | 1 | not disturbed |
| After 1st cold period (4°C) | | | | | | |
| $F_1$- larvae retrieved | 1 | 9 | 1 | 17 | 1 | 3 |
| End of 2nd year of breeding (21 ± 1°C and 75 ± 5% r. H.) | | | | | | |
| $F_1$- larvae retrieved | - | 0 | 0 | 1 | 0 | |
| $F_1$- cocoons retrieved | - | 3 | 1 | 15 | 1 | |
| $F_1$- adults retrieved | - | 2 | 0 | 1 | 0 | |
| After 2nd cold period (4°C) | | | | | | |
| $F_1$- adults retrieved | - | 1 | 1 | 4 | 1 | |

Scanning electron microscope (SEM) pictures of mouthparts of *K. caeruleus*: SEM was carried out at the University of Wismar, department of civil engineering, section building material technology, Germany. The head of a late instar larva of *K. caeruleus* with all its mouthparts was carefully straightened out and mounted on a specimen holder stub using a conductive adhesive pad. Specimens and holder were bridged with conductive silver and finally coated with gold using a BALZERS SCD 050 Sputter Coater (BAL-TEC AG), resulting in a coat thickness of 16 nm. SEM pictures were taken using a FEI Quanta FEG 250 s.e.m. in high vacuum mode at a magnification of 2040 times. An Everhart Thornlay Detector was used as a secondary electron detector.

## RESULTS

Total numbers of hand collected larvae and adult beetles are listed in Table 1. The size and weight of the *K. caeruleus* larvae collected in 2015, 2016 and 2017 did not differ statistically. The collected larvae of *K. caeruleus* were on average 7.1 mm long and weighed 3.3 mg (Table 5).

**Breeding From Collected Beetles (Table 2).** Although carried out very carefully the examinations of the *K. caeruleus* / *A. punctatum* cultures to record life history data of developing larvae, always severely damaged the cultures and stressed the individuals. Many of them did not recover and were unable to complete their development.

In 2013, fourteen beetles of *K. caeruleus* were placed in cultures of larvae of *A. punctatum.* After the first breeding season three active *K. caeruleus* larvae of the next generation were retrieved. One survived to be transferred to the

following cold period. This larva became active after the end of the cold period but died of unknown causes without developing further.

Breeding in 2014 started with twenty-seven pairs of adult beetles of *K. caeruleus*. After the first breeding season sixteen active larvae were collected and induced to a cold period of which nine became active when returned to standard breeding conditions. At the end of the second breeding season five adult beetles were found. Three of them were in cocoons. Adult beetles in cocoons were subjected to a second cold period, after which they were kept again under standard breeding conditions. Soon after one adult beetle had emerged, but the other two had died.

The thirty pairs of collected *K. caeruleus* in 2015 were split. Only the cultures of five pairs were examined after the first breeding season (Table 2/2015a). Three larvae were detected. Cultures were then transferred to cold conditions to induce dormancy and after returning them to standard breeding conditions only one larva had survived. At the end of the second breeding period, this larva had turned to a fully sclerotized adult beetle of blue color, which, however, remained inside its cocoon until the next cold period was initiated. When returned to the standard breeding conditions the adult became active the next day. The rest of the 2015 cultures were left undisturbed for one season and subjected to cold treatment before examining them (Table 2/2015b). Seventeen live larvae were detected. At the end of the second breeding season fifteen of these larvae had pupated and were in cocoons and only one larva was active, when the second cold period was initiated. When returned to standard rearing conditions four beetles emerged from their cocoons the next day. The rest had died. In addition, one adult beetle emerged before the second cold treatment.

**Table 3**. Results of rearing field collected adult *Korynetes caeruleus* in five consecutive years. Those that were alive are listed.

| Year / Stage of development | 2013 | 2014 | 2015 | 2016 | 2017 |
|---|---|---|---|---|---|
| $F_1$- larvae introduced | 9 | 15 | 19 | 12 | 14 |
| End of 1st year of breeding (21± 1°C and 75 ± 5% r. H.) | | | | | |
| $F_1$- larvae retrieved | 0 | 6 | 0 | not disturbed | 0 |
| $F_1$- cocoons retrieved | 0 | 0 | 3 | | 11 (all dead) |
| $F_1$- adults retrieved | 6 | 0 | 0 | | 0 |
| After 1st cold period (4°C) | | | | | |
| $F_1$- larvae retrieved | 1 | 2 | 0 | 0 | - |
| $F_1$- cocoons retrieved | 0 | 0 | 0 | 0 | - |
| $F_1$- adults retrieved | 0 | 0 | 3 | 3 | - |
| End of 2nd year of breeding (21 ± 1°C and 75 ± 5% r. H.) | | | | | |
| $F_1$- cocoons retrieved | - | 1 | - | - | - |
| $F_1$- adults retrieved | - | 0 | - | - | - |
| After 2nd cold period (4°C) | | | | | |
| $F_1$- adults retrieved | - | 1 | - | - | - |

The 2015 cultures produced a total of five beetles. For the 2016 and 2017 cultures, the *K. caeruleus* beetles were placed on pieces of wood previously infested with larvae of *A. punctatum*. For the 2016 culture, the duration of the cold treatment was shortened. However, this did not shorten the period to the emergence of active adults, because the beetles did not emerge immediately after the end of the cold treatment.
It appears that cold treatment is not the only stimulus inducing adult emergence. Under moderate conditions a period of about four months between the onset of dormancy and emergence of adult beetles from their cocoons seems equally important (see below).

**Breeding From Collected Larvae (Table 3).** Of the nine *K. caeruleus* larvae collected in 2013, six completed their development and emerged as adults without being subjected to cold treatment.
Six larvae of *K. caeruleus* collected in 2014 survived the first breeding season and two of them survived the first period of cold treatment. In the next season one of them completed development to the adult stage, remained in its cocoon during the following cold period and emerged immediately at the end of the second cold treatment.
From the 2015 collection three adults emerged after the cold treatment, which they entered as dormant adults in their cocoons.

The 2016 collection of *K. caeruleus* larvae were left undisturbed during breeding and when subjected to a cold period. On returning to standard breeding conditions three beetles emerged.
*Korynetes caeruleus* larvae collected in 2017 were examined at the end of the first breeding when eleven of them were dead. However, each of them had spun a cocoon in preparation for pupation.

**Table 4.** Biometric data, development and number of larvae and adults *A. punctatum* consumed by four larvae of *Korynetes caeruleus* collected in the field in 2016.

| Date | Recorded | Larvae of *Korynetes caeruleus* | | | |
|---|---|---|---|---|---|
| | | Larva 1 | Larva 2 | Larva 3 | Larva 4 |
| 17.05.16 | Initial weight (mg) | 1.9 | 3.6 | 4.0 | 6.9 |
| 1st month | consumption of *A. punctatum* | 3 large larvae 0 adult beetle | 3 large larvae 0 adult beetle | 2 large larvae 0 adult beetle | 4 large larvae 0 adult beetle |
| 17.06.16 | weight (mg) | 8.2 | 8.7 | 8.0 | 17.7 |
| | Δ weight (mg) | 6.3 | 5.1 | 4.0 | 10.8 |
| | no. of molts | 0 | 0 | 0 | 0 |
| 2st month | consumption of *A. punctatum* | 0 large larvae | 1.5 large larvae | 2x0.5 large larvae | 0 large larvae |
| 21.07.16 | weight (mg) | 10 | 9.1 | 14.6 | 20.6 |
| | Δ weight (mg) | 1.8 | 0.4 | 6.6 | 2.9 |
| | no. of molts | 0 | 1 | 1 | 1 |
| 3rd month | consumption of *A. punctatum* | 1 large larva | 1 large larva | 2 large larvae | 2 large larvae |
| 11.08.16 | weight (mg) | 9.1 | 11.1 | 14.2 | 26.2 |
| | Δ weight (mg) | -0.9 | 2 | 0.4 | 5.6 |
| | no. of molts | 0 | 0 | 0 | 0 |
| 4rd month | consumption of *A. punctatum* | died during 4th month | 0 large larva | 0 large larva | 0 large larva |
| 28.09.16 | weight (mg) | | 12.1 | 11.8 | 23.4 |
| | Δ weight (mg) | | 1 | -2.4 | -2.8 |
| | no. of molts | | 0 | 0 | 0 |
| 5th - 9th month | Placed in saw dust and transferred to cold conditions of 4°C | | | | |
| 06.04.17 | weight (mg) | | 11.2 | death during cold period | 17.6 |
| | Δ weight (mg) | | -0.9 | | -5.8 |
| | no. of molts | | 1 | | 0 |
| 10th month | consumption of *A. punctatum* | | 1 large larva | | 3 large larvae |
| 11th - 12th month | consumption of *A. punctatum* | | 0 large larva | | died during 11th month |
| 13th month | No. of molts | | 1 pupated followed by emergence of 1 adult | | |
| 14th - 15th month | | | cold treatment of 4°C | | |
| 16th month | | | adult emerged | | |

Summary. With unlimited access to larvae of *A. punctatum*, large larvae of *K. caeruleus* completed their development to the adult stage during the breeding season following collection. Subjection to a period of cold triggered the emergence of adult beetles that remained inside their cocoon after emerging from pupae. Emergence of adults may also occur without their experiencing a period of cold (Table 3/2013).

**Table 5**. Number, size and weight of the larvae of *Korynetes caeruleus* collected from 2015 to 2017. Same letters indicate no significant difference.

| Year | Total (n) | Body size (mm) | | Body weight (mg) | |
|---|---|---|---|---|---|
| | | min. - max. | Average ± standard deviation | min. - max. | Average ± standard deviation |
| 2015 May 4 | 19 | 5 - 9 | 6.9 ± 1.2[a] | not determined | not determined |
| 2016 May 3 | 16 | 5 - 9 | 7.0 ± 1.2[a] | 0.82 – 6.90 | 3.3 ± 1.6[b] |
| 2017 May 7 | 13 | 5 - 9 | 7.5 ± 1.4[a] | 0.92 – 5.56 | 3.3 ± 1.6[b] |

Observation and description of feeding behavior: Four larvae of *K. caeruleus* collected in 2016 were kept individually in small arenas. They were continuously fed with *A. punctatum* (Table 4). Food was successively replaced when previous larvae were completely or partially consumed. When larvae of *K. caeruleus* were confined with one mature larva of *A. punctatum* in an arena, they initially sought refuge in the shelter provided for several minutes and then slowly moved around the arena. First contact with prey did not automatically result in an attack, even though all the *K. caeruleus* larvae had not been fed since they were collected. Eventually a larva of *K. caeruleus* initiated an attack by driving its sickle-like-mandibles into the abdomen of a larva of *A. punctatum*. Due to their being in the open the larvae of *A. punctatum* were unable to escape. Observation under a binocular microscope at 10-fold magnification revealed pumping motions in the body of the predator once its mandibles penetrated the prey's cuticle. These repeated motions are interpreted as results of the muscular contractions involved in injecting digestive enzymes into the body cavity of the prey followed by the ingestion of predigested food. There is a depressed grove in the proximal part of each mandible (Figure 1), which presumably function as a canal for injecting digestive enzymes into the prey's body and ingesting predigested food. The woodworm larvae markedly shrank during this process and finally the larva was consumed almost completely. The entire process was not observed. However, it can readily be deduced from the subsequent absence of the body of the prey other than the indigestible parts, such as the head capsule and parts of the outer cuticle. Adult beetles of *A. punctatum* were also offered once, but after a week none had been attacked.

## DISCUSSION

Development of *K. caeruleus* does not follow a particular pattern. Like its most important prey *A. punctatum* and other wood boring beetles, *K. caeruleus* is also able to adapt its growth and molting intervals to existing biotic and abiotic conditions (Amman, 1970; Niehuis, 2013; Youssef et al., 2013; Ott 2007; Petzoldt 2011). Within this range of conditions for development, it is likely we have identified the minimum requirements for the fastest possible life cycle under controlled laboratory conditions.

Our data indicates that in *K. caeruleus* the development from the mating of adults to the appearance of active adult beetles of the next generation takes two years (Figure 2: 1-13), given it is reared at 21 °C and a relative humidity of approximately 75 %, and provided with sufficient food in the form of live prey larvae, shelter and subjected to two cold periods. Currently, we have not observed egg laying and only ten adult beetles have completed development under these laboratory conditions (Table 2). Some basic life history data revealed it takes approximately six months for the eggs to become larvae of about 7 to 9 mm in length and a weight of around 8 mg (Figure 2: 3-6). At this stage a larva is large enough to enter dormancy when subjected to a period of low temperature (Figure 2: 6).

When returned to laboratory rearing conditions after approximately two to four months at a low temperature, larvae feed and complete their development in about six to eight months (Figure 2: 7-8) then spin a cocoon (Figure 2: 9), pupate (Figure 2: 10) and, finally, emerge as an adult (Figure 2: 11). However, if subjected to low temperature again, the adult beetles remain in their cocoons (Figure 2: 12) and on returning to standard rearing conditions emerge from their cocoons after a few days (Figure 2: 13).

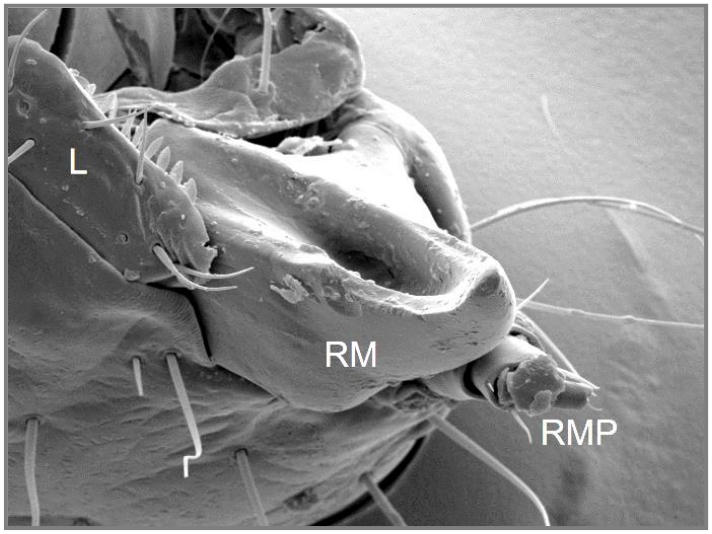


**Figure 1.** SEM photograph of the head of a larva of *Korynetes caeruleus*. Dorsal/frontal view of the open right mandible (RM) showing its prominent proximal groove (L=labrum; RMP=right maxillary palpus).

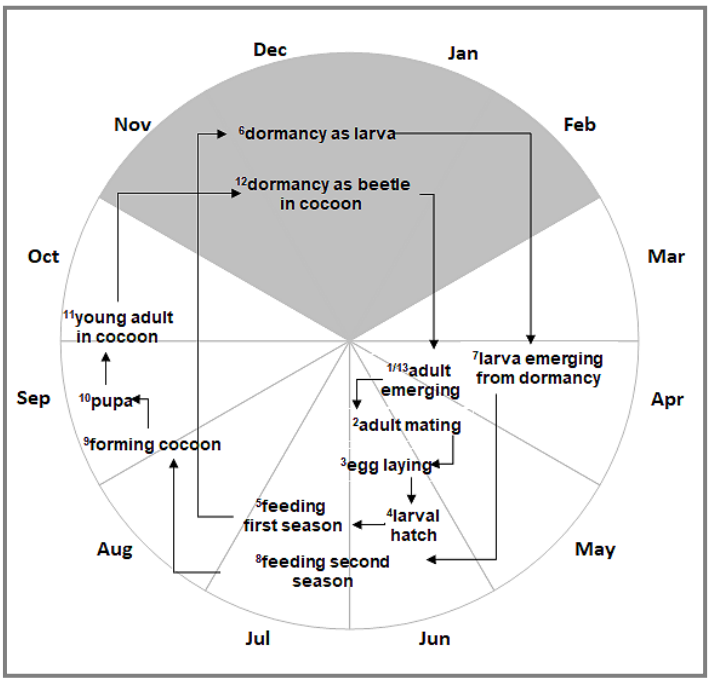


**Figure 2**. Postulated two-year developmental cycle of *Korynetes caeruleus* with active life stages (white part of the pie-chart) and inactive dormant life stages (grey part of the pie-chart), starting with 1 "adult emerging" at the end of April and ending with 13 "adults emerging", which during the second cold treatment were dormant in their cocoons.

Development lasted only one and a half to two seasons (10 months) with one cold period in between. The need for a second cold period seems to be facultative with young adults remaining inside their cocoons when temperatures start to decrease. A minimum duration of approximately three to four months appears optimal for the second cold period. Shortening the cold period did not result in an early emergence of adult beetles. If the onset of declining temperature, which triggers the entering of dormancy, is delayed, e. g. by being transferred to favorable conditions in the laboratory, adult beetles may emerge at the end of the second season. This was recorded for three adults, two in the 2014 culture (Table 2/2014) and one in the 2015 culture (Table 2/2015b).

Timing of development recorded accords with naturally occurring seasonal conditions if the mating of parental beetles occurs around mid to late spring as temperatures are increasing (Figure 2: 2). Feeding and growth of larvae occurs from late spring to late summer. Before temperatures decrease in autumn, larvae have sufficient reserves to survive in a dormant state to the following year (Figure 2: 6). The following spring these larvae start feeding again and prepare to complete their metamorphoses (Figure 2: 7-11) at which time temperatures are slowly decreasing, which results in adult emergence being delayed to next spring (Figure 2: 13). The second dormant phase in effect synchronizes adult emergence in the next season. Early emergence of adults in the field is therefore very unlikely. The observations of Haustein and von Laar (2007) and Haustein (2010) on the occurrence of active larvae and beetles in old churches and those of Noldt (2007) in historic houses seem to fit this model.

Number and duration of the larval instars in *K. caeruleus* are still unknown. In other clerid beetles there are three larval instars before pupation (Amman, 1970; 1972; White and Franklin, 1982). And three larval instars may also be the minimum with *K. caeruleus* unless conditions are unfavorable. As was the case reported by Haustein (2010) in which large second season larvae of *K. caeruleus* molted up to six times without pupating and finally died. In that study, food was continuously available but there was nowhere where the larvae could construct pupal chambers. Without suitable material (wood, saw dust or similar material) larvae of *K. caeruleus* are probably incapable of forming and fixing cocoons for metamorphoses. Forming "free pupae" might not be possible and larvae continue to feed and grow and eventually die. When saw dust was provided in our breeding experiments, suitable matrices were available and full-grown larvae of *K. caeruleus* eventually stopped foraging for food and started to prepare cocoons for metamorphosis.

The cocoon is made of a thin layer of a sticky whitish secretion. Inside wood, the secretion is attached to the inner wall of the pupal chamber, loosely surrounding the pupa inside. Becker (1942) postulates that *K. caeruleus* does not build a pupal chamber but readily lines old pupal chambers of *A. punctatum* or other anobiids with its secretion. In our experiments, when constructed in the diet, small wooden particles adhered to the sticky outer surface and thus provided anchoring supports for the cocoon before it hardened. The inner layer of a cocoon appears glossy.

The feeding behavior of larvae of *K. caeruleus* is best described as a combination of sucking haemolymph and consuming small body parts. This method of feeding is called extra-oral digestion (EOD) and is typical of many predaceous arthropods (Lövei and Sunderland, 1996; Cohen, 1998). We recorded all the classical processes of EOD (Frazier et al., 1981; Cohen, 1995) when larvae of *A. punctatum* were provided as food. The sickle shaped mandibles of larvae of *K. caeruleus* with their depressed groove for injecting digestive enzymes are well suited for EOD and are similar morphologically to the mandibles of other predatory clerid larvae, e. g. *Thanasimus dubius* (White and Franklin, 1982) and *Dermestoides sanguinicollis* (Kolibáč, 2002).

We present a method for rearing *K. caeruleus* successfully in the laboratory. Field collected adults and larvae should be placed on soft wood infested with all stages of *A. punctatum*. Rearing should be done at approximately 21 °C and 75 % relative humidity. A period at 4 °C lasting for four months should be provided after six months. This should be followed by another six months of rearing under standard condition and then a second period at 4 °C for four months. After which beetles can be expected to emerge, when cultures are returned to standard rearing conditions. Using this method, the total time to reproduction in *K. caeruleus* is less than two years and could be even less than one and a half years, if the second cold period is shortened. When using artificial diets instead of wood, growth of mold and mites are a serious problem.

We are confident that it will be possible to mass produce *K. caeruleus* in the future and determine whether this beetle can be used as a biological control agent of *A. punctatum*. It is possible that the mass release of predators and parasitoids will slow down *Anobium* infestations in historical buildings, such as small churches in northern Germany, and provide the time necessary for obtaining the funding for sustainable restoration. Furthermore, it is likely that conventional pest control using biocides will become less popular in the future and IPM and biological pest control will increase in importance in the preservation of our cultural heritage.

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