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Phenology of Protura in a northwestern Italian forest soil (Hexapoda: Protura)

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Abstract. Protura extracted from soil and litter samples collected monthly in a *Quercus suber* wood (from February 2007 to January 2008) near Bergeggi (Liguria, NW Italy) were studied. Of 786 mounted specimens, 682 were determined to specific level and attributable to 11 species: *Proturentomon minimum*, *Acerentulus confinis*, *Acerentulus terricola*, *Gracilentulus gracilis*, *Acerentomon affine*, *Acerentomon doderoi*, *Acerentomon italicum*, *Acerentomon maius*, *Acerella tiarnea*, *Eosentomon noseki* and *Eosentomon transitorium*. *A. terricola* is a new record for the Italian fauna. Two peaks of Protura abundance were found (March-April and June, respectively); however they were still substantial throughout the winter and spring, while in August and September there was a minimum, probably due to summer drought. Phenology of the dominant species (*Acerentulus confinis*, *Acerentomon italicum*, *Acerentomon maius*, *Acerella tiarnea* and *Eosentomon transitorium*) was examined.

Key words: phenology, Protura, cork-oak, Liguria (NW Italy).

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I. INTRODUCTION

Soils are probably the most species-rich habitat of terrestrial ecosystems (WOLTERS 2001; DECAËNS et al. 2006) and soil microarthropods are undoubtedly one of the most abundant and diverse wildlife groups (HISHI et al. 2008). One of the main problems in studies of biodiversity and ecology of soil communities is that they are strongly influenced by several factors simultaneously, which may have combined, opposite or, otherwise, non-additive effects (PFLUG & WOLTERS 2001). Some authors suggest that the hypogean faunas are less sensitive to climatic variations than epigean ones (BALE et al. 2002; RICHARDSON et al. 2002), and that this difference is highly related to their reproductive and trophic strategies (STALEY et al. 2007). On the other hand there is no doubt that some factors, especially rainfall patterns, can have heavy impacts on the soil fauna (STALEY et al. 2007).

Soil moisture affects species reproductive behaviour and their ability to feed and, therefore, their abundance and survival (ANDERSON 1987; BROWN & GANGE 1990; SETÄLÄ et al. 1995).

Through this study we tried to assess the influence of seasonal weather changes on Protura and then to define their phenology in a geographical area of considerable natural history interest.

II. MATERIAL AND METHODS

The study area was a *Quercus suber* wood on a southeast slope near the seashore, at about 150 m alt. close to Bergeggi (Province of Savona, Liguria, NW Italy: 44°15'27" N, 08°26'35"E). The sampled area's vegetation consisted of some cork-oak trees, a few downy oak *Quercus pubescens*, and a shrub undergrowth dominated by *Erica arborea* and *Ruscus aculeatus* on a plot of several hectares of siliceous terrain within garigue and Mediterranean scrub vegetation (*Quercus ilex*, *Erica arborea*, *Arbutus unedo*) (MARIOTTI 2008).

The climate of this area has been accurately monitored at a nearby meteorological station (Capo di Vado – Fig. 1). According to the Worldwide Bioclimatic Classification System (1996-2009) its bioclimate is Pluvioseasonal Oceanic Mediterranean.

Samplings were carried out near the centre of the cork-oak woods to avoid possible edge effects. From February 2007 to January 2008 ten soil samples 10x10x10 cm from the surface and five litter samples of 2 liters each were collected monthly, protected against thermal shock, transported to the laboratory and placed in Berlese-Tullgren funnels (2.5 mm mesh size) for few hours. Funnels operated for at least five days (PARISI et al. 2005) for extraction of soil fauna into 70% ethanol. All the specimens of the less abundant collections and a subsample of the largest ones (approximately 30% of all the collected Protura) were incubated at 40-50° C for 24 hours in lactic acid to clear them, then mounted on slides

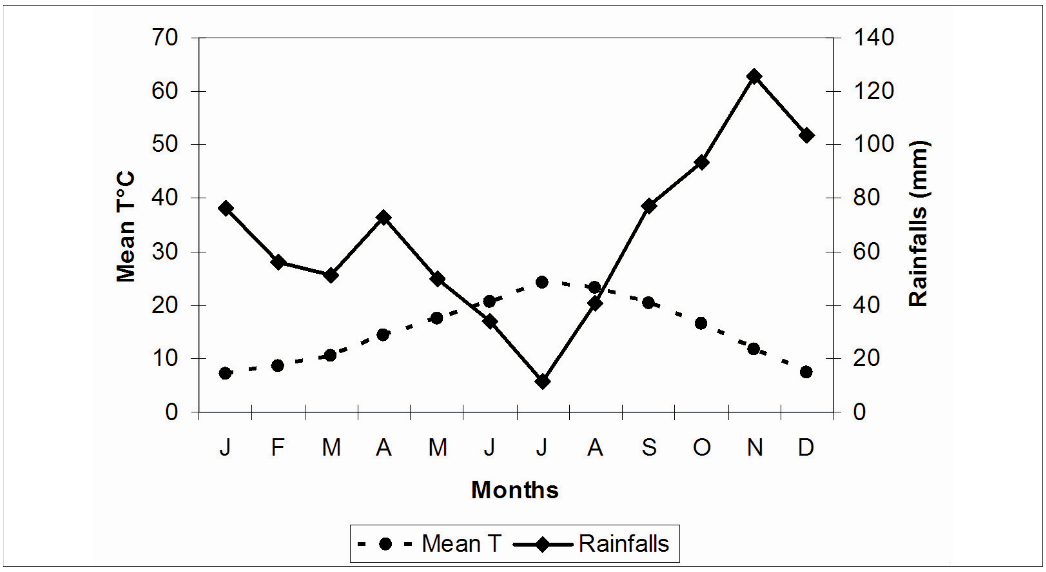

Fig. 1. Climate of the study area: ombrothermic diagram from monthly temperature and rainfalls data collected by the Capo di Vado meteorological station.

in Marc André medium. Specimens were observed and identified to species and life stage levels (prelarva, larva I, larva II, maturus junior, preimago and imago) with the aid of an interference contrast microscope.

Software PAST (PAleontological STatistics ver. 2.12) (HAMMER et al. 2001) was used to perform the following statistical analysis:

1. Multiple regression of Protura abundance (log-transformed data) extracted from soil and litter samples vs cumulated rainfalls and mean temperatures recorded in the 15 days prior to collecting.

2. Ordinary Least Squares (OLS) regression of Protura abundance (log-transformed data) extracted from soil and litter samples vs mean temperatures recorded in the 15 days prior to collecting.

3. Chi-square test to assess the statistical significance of the differences from the expected value (1) of the most numerically abundant species sex ratio.

4. Chi-square test to assess the statistical significance of the year-round differences of sex and age ratios.

III. RESULTS

A total of 2653 specimens were extracted from soil and litter samples. Protura abundances signed two maximum peaks in March-April and June, but were consistent in the winter and spring as well; on the other hand, numbers were very low in August and September (Fig. 2).

Log-transformed Protura numbers were nearly correlated to rainfalls and mean temperatures (multiple R = 0.67, F = 3.7471, p = 0.065479). Mean temperatures, in particular,

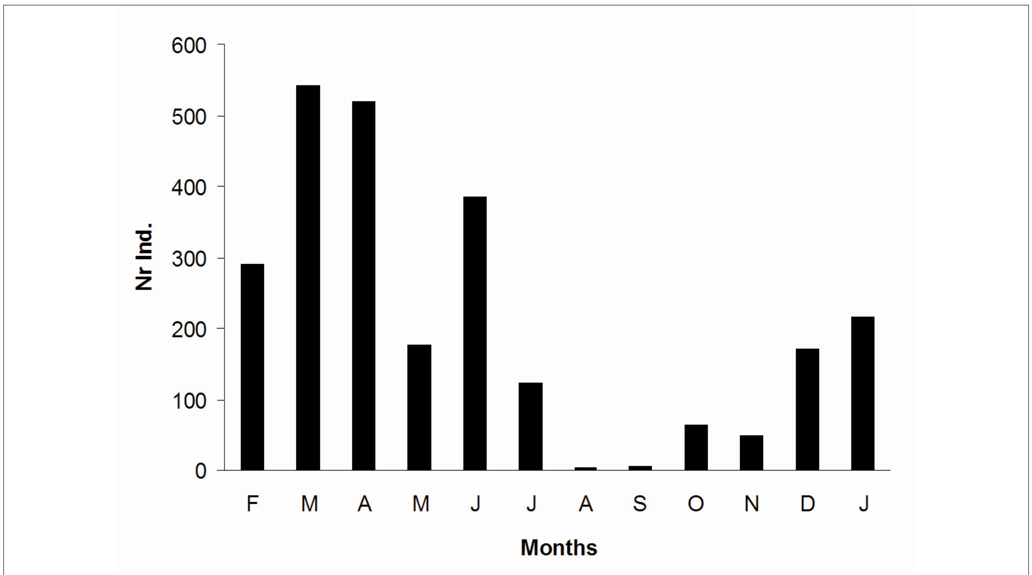

Fig. 2. Total number of Protura collected each month in soil and litter samples from Bergeggi.

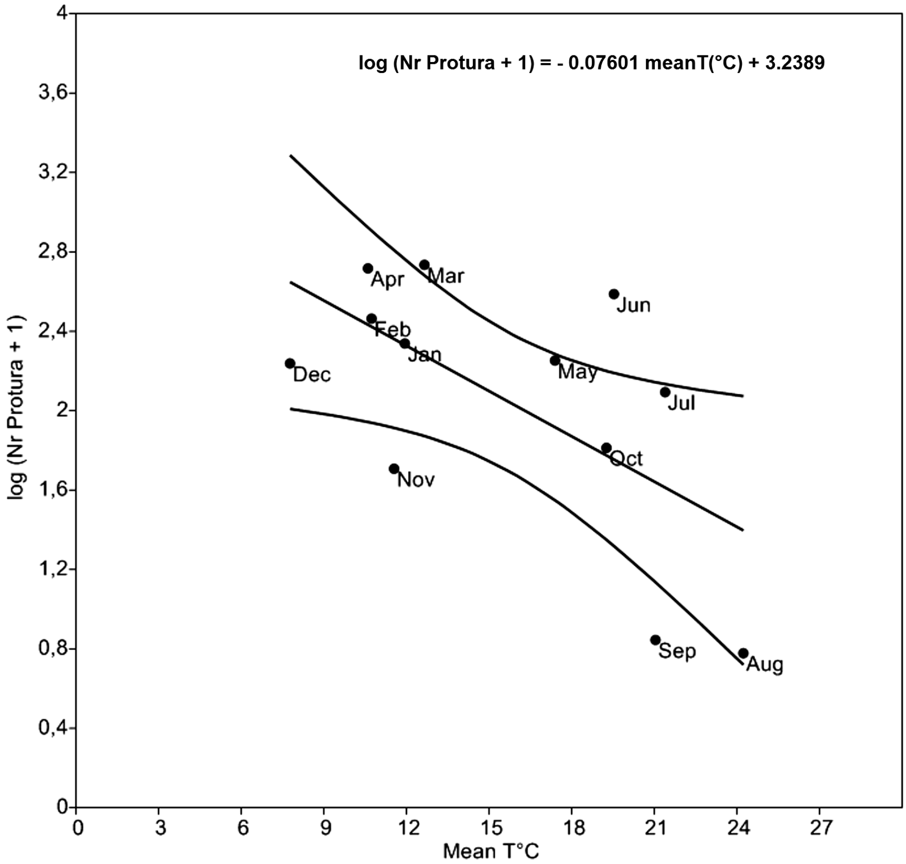

Fig. 3. OLS regression of the Protura abundance (log-transformed data) extracted from soil and litter samples vs mean temperatures recorded in the 15 days prior to the collections.

resulted well correlated to Protura abundances ($R^2 = 0.38464$, $p<0.05$) and consequently we decided to perform a linear regression (OLS) of log-transformed data about Protura numbers vs mean temperatures recorded in the 15 days prior to collecting, obtaining a confirmation of such statistically significant relationship ($\chi^2 = 2.9405$, $P<0.05$) (Fig. 3).

Of the 786 mounted specimens, 682 were determined to specific level, resulting in a fauna of 11 species (Table 1). *Acerentulus terricola* was a new record for the Italian fauna (GALLI et al. 2011).

The phenology of the five most commonly collected species (*Acerentulus confinis*, *Acerentomon italicum*, *Acerentomon maius*, *Acerella tiarnea* and *Eosentomon transitorium*) was illustrated in Figs 4-8 and discussed below. In *Acerentulus confinis* (n = 69) few maturi juniores have been detected from March to May, whereas in *Acerentomon italicum* (n = 293) juveniles (LII, maturus junior), which were less frequent than adults, were recorded from March to July and also in January, as better shown by the monthly age ratio

Table 1

Checklist of Protura collected in Bergeggi

Family	Species	No. of individuals
Protentomidae	*Proturentomon minimum* (BERLESE, 1908a)	2
Acerentomidae	*Acerentulus confinis* (BERLESE, 1908a)	69
	Acerentulus terricola RUSEK, 1965	2
	Gracilentulus gracilis (BERLESE, 1908b)	2
	Acerentomon affine BAGNALL, 1912	3
	Acerentomon doderoi SILVESTRI, 1907	1
	Acerentomon italicum NOSEK, 1969	295
	Acerentomon maius BERLESE, 1908b	211
	Acerella tiarnea (BERLESE, 1908b)	46
Eosentomidae	*Eosentomon noseki* TUXEN, 1982	5
	Eosentomon transitorium BERLESE, 1908a	46

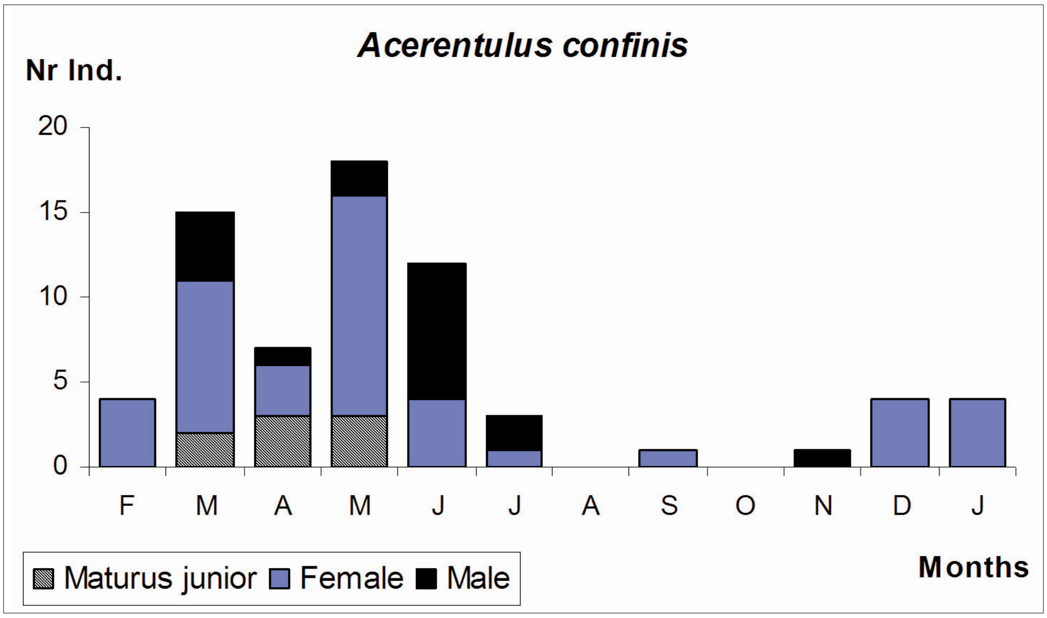

Fig. 4. *Acerentulus confinis* phenology in the soil of the Bergeggi cork-oak wood.

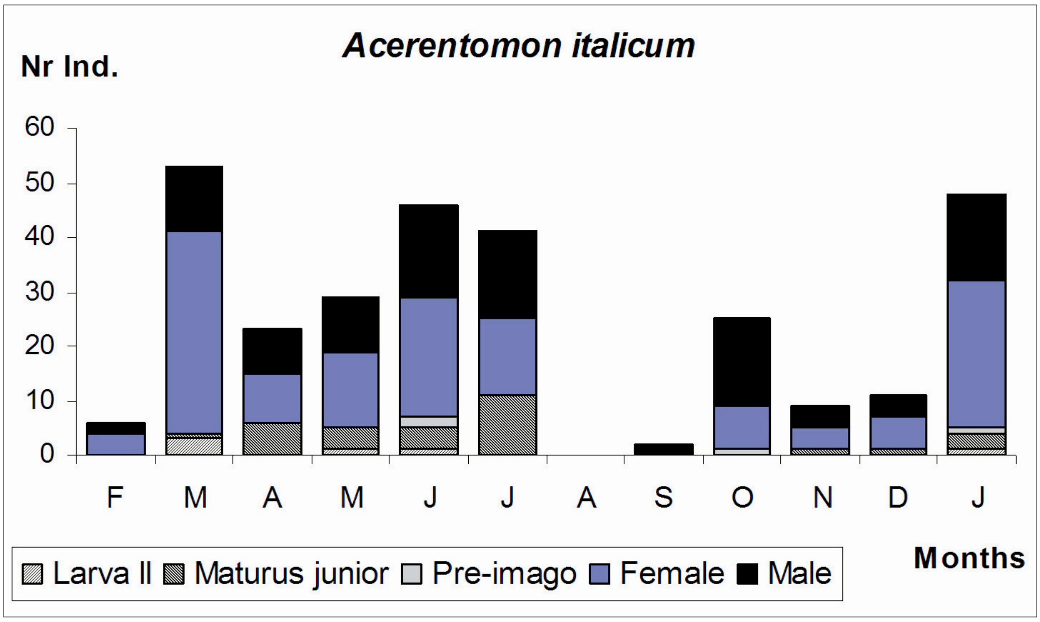

Fig. 5. *Acerentomon italicum* phenology in the soil of the Bergeggi cork-oak wood.

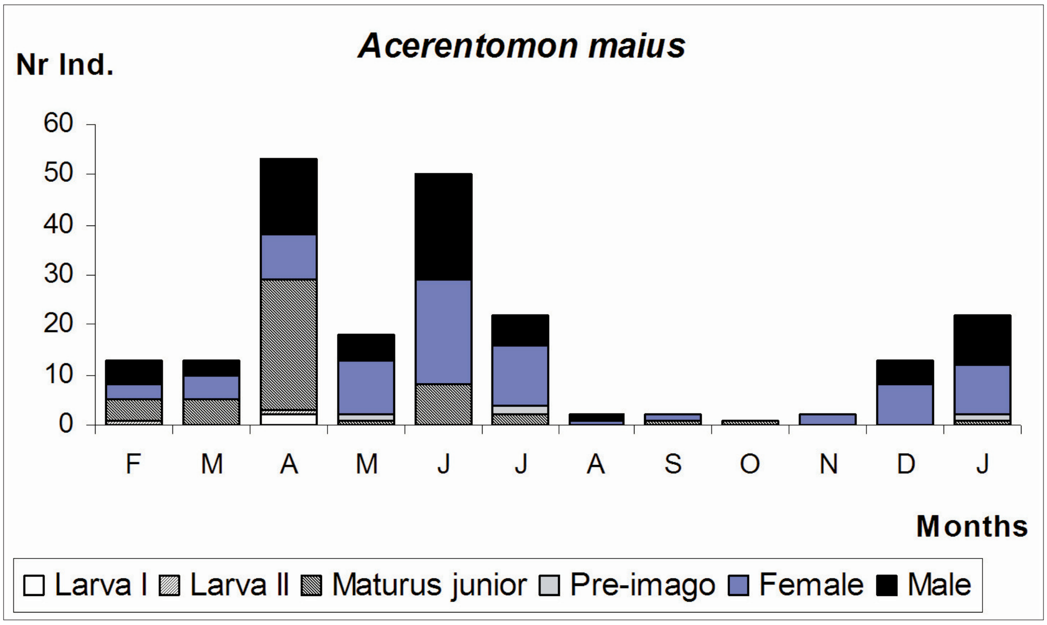

Fig. 6. *Acerentomon maius* phenology in the soil of the Bergeggi cork-oak wood.

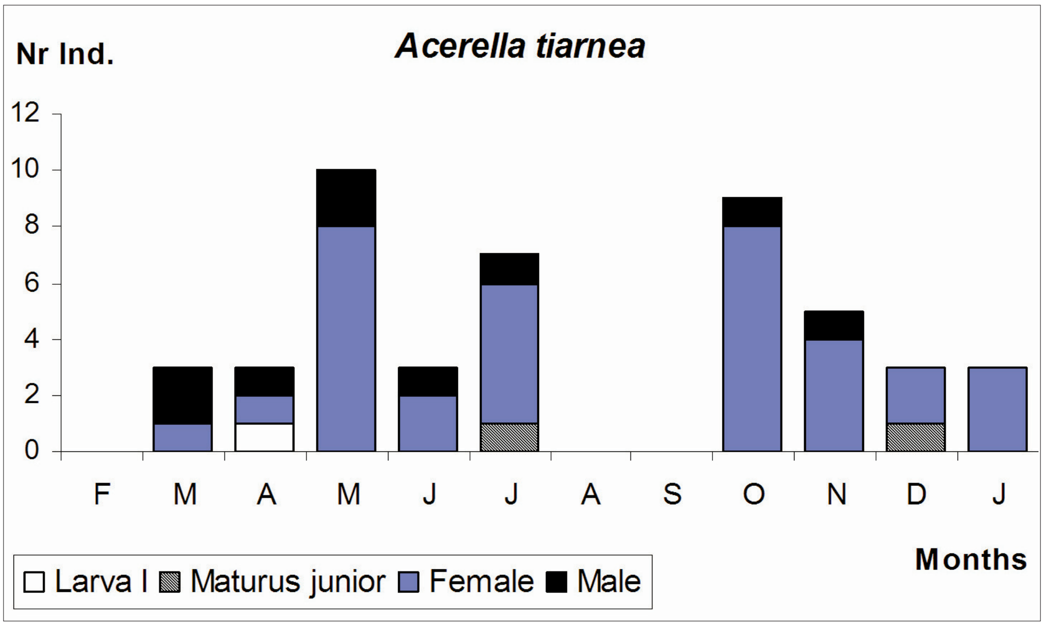

Fig. 7. *Acerella tiarnea* phenology in the soil of the Bergeggi cork-oak wood.

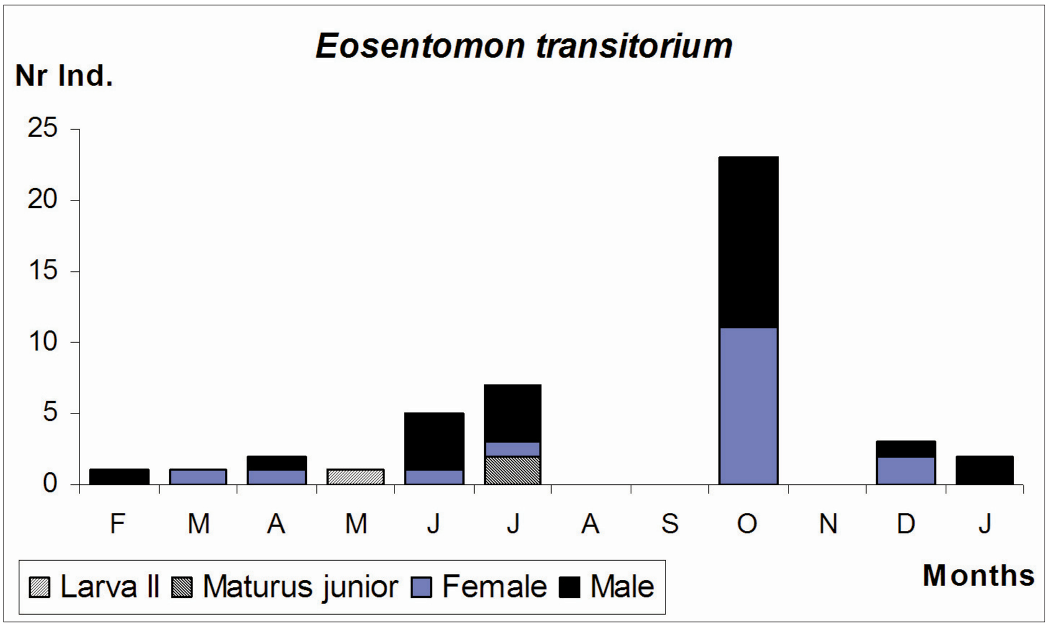

Fig. 8. *Eosentomon transitorium* phenology in the soil of the Bergeggi cork-oak wood.

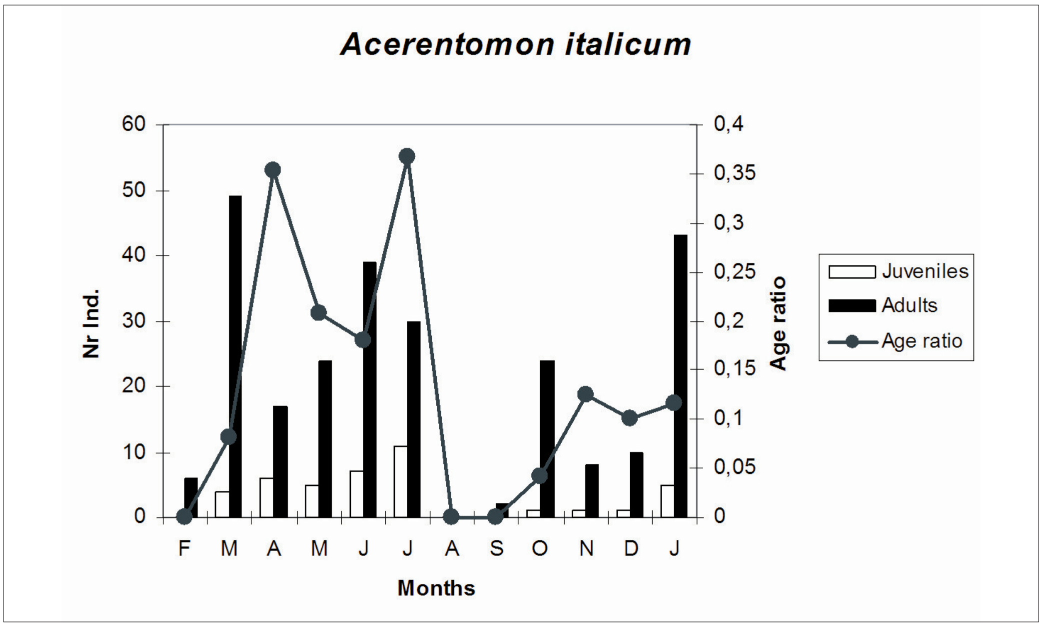

Fig. 9. *Acerentomon italicum* phenology (Juveniles vs Adults – see text) and monthly age-ratio in the soil of the Bergeggi cork-oak wood.

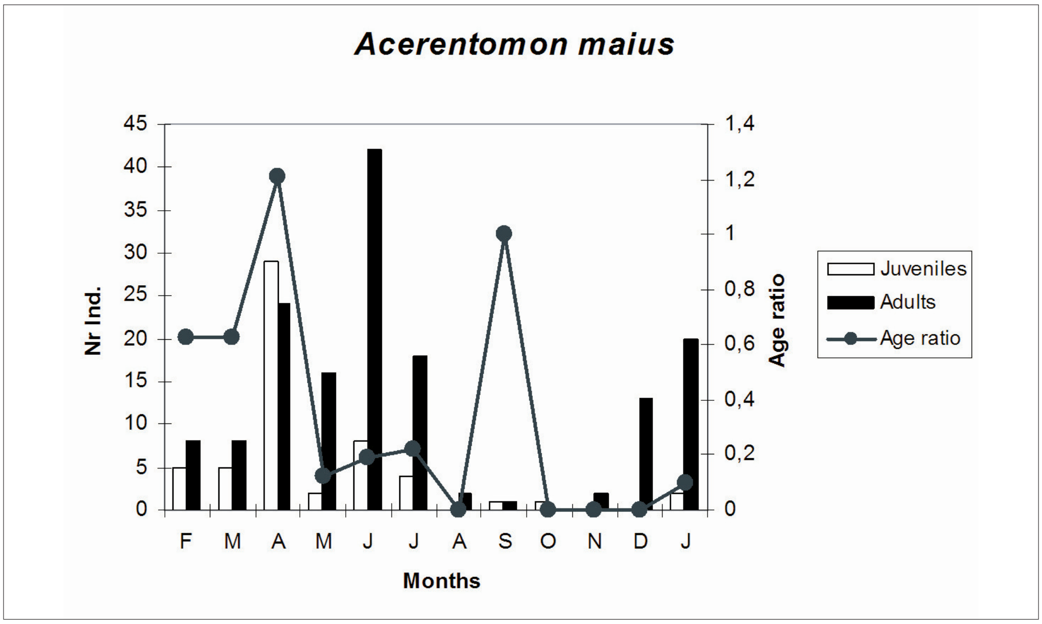

Fig. 10. *Acerentomon maius* phenology (Juveniles vs Adults – see text) and monthly age-ratio in the soil of the Bergeggi cork-oak wood.

variations in Fig. 9. *Acerentomon maius* (n = 211) had a peak of juveniles (26 mature juniores, 3 larvae) in April, while only single juvenile specimens have been sampled for *A. tiarnea* and *E. transitorium*. The age ratio of *Acerentomon maius* shown in Figure 10 confirms what above reported, with exception of the misleading peak of September, due to the small number of sampled individuals (1 adult and 1 maturus junior).

Sex ratios unbalanced towards females were found for *Acerentulus confinis* (M:F = 0.42, $\chi^2 = 10.246$, 1 d.f., $p<0.01$), *Acerentomon italicum* (M:F = 0.74, $\chi^2 = 5.7302$, 1 d.f., $p<0.05$) and *Acerella tiarnea* (M:F = 0.26, $\chi^2 = 14.535$, 1 d.f., $p<0.01$). In *Acerentomon maius* the M:F ratio was 0.86, and in *Eosentomon transitorium* it as 1.47; neither of these ratios were significantly different from a value of 1.

IV. DISCUSSION

Phenology of Protura is poorly known. IMADATÉ (1974), studying the Protura populations in an evergreen mixed broadleaf trees and conifers forest in Tokyo, evidenced different patterns of seasonal fluctuations in the collected species. A double peaked pattern with a first culmination in spring and the second one in autumn was recorded in *Eosentomon sakura* IMADATÈ & YOSII, 1959, while a single peaked pattern, with the only culmination relieved in autumn, was highlighted in *E. kumei* IMADATÈ & YOSII, 1959, *Baculentulus morikawai* (IMADATÈ & YOSII, 1956), *B. tosanus* (IMADATÈ & YOSII, 1956), *Kenyentulus japonicus* (IMADATÈ, 1961) and *Nippoentomon nippon* (YOSHII, 1938). *Eosentomon asahi* IMADATÈ, 1961 populations seemed to be constant all over the year, showing no conspicuous culminations.

We have not been able to characterise the single species phenology according to IMADATÈ (1974) patterns, but, on the whole, we have stated that Bergeggi populations of Protura species investigated appear to decrease during the summer probably as a consequence of the withdrawal of individuals in the deeper layers of the soils and in more humid niches under the pressure of drought. A similar pattern of proturan abundance was observed by MITROVSKI-BOGDANOVIĆ & BLESIĆ in an oak forest (2006, 2011): the authors detected a first decreasing period in the number of specimens sampled in March and April and then a new rapid fall in August, that they explained by summer drought; this trend was observed in both layers they considered (0-10 and 10-20 cm depth). At higher temperatures, soil and litter layers are more likely to desiccate because of faster evaporation, leading to drought with adverse effects on soil fauna (FROUZ et al. 2004). As a matter of fact, according to our data, a negative linear relationship between abundance of Protura and temperatures has been stressed. Soil invertebrates have limited capacity to prevent desiccation when exposed to dry air and the water content of soil influences also solubility and availability of oxygen in these habitat (HALL & CHERRY 1993; SHAPIRO et al. 1997). Temporal variability in different soil layers communities, principally related to seasonal environmental variation, may be common as suggested by the occurrence in many different systems of vertical migration in diverse soil inhabiting taxa (DOWDY 1944; JIMENEZ & DECAËNS, 2000; FROUZ et al. 2004).

We detected an unbalanced sex ratio in favour of females in three of the dominant species: *Acerentulus confinis*, *Acerentomon italicum* and *Acerella tiarnea*. Considering data about those three species in our whole database counting more than 5000 specimens of Italian Protura (GALLI et al. 2011), male/female ratio results 0.56, 0.76 and 0.32, respectively. Moreover, GUNNARSSON (1980) in oak wood soil samples in Sweden recorded that females of *Eosentomon germanicum* PRELL, 1912 were more than twice as numerous as the males. It can therefore be assumed that such a bias (or a bigger likeliness to collect females) is a common feature of population structure among Protura.

It is furthermore interesting to note how we detected the highest concentration of juvenile specimens from February to July. This pattern was chiefly evident in *Acerentomon italicum* and *A. maius*, whereas in *Acerentulus confinis* an apparentely shorter period of juveniles presence was recorded (March-May). This observation allow us to hypothesize this as the main reproductive season, probably due to more favourable climatic conditions for juvenile survival.

Finally it should be emphasized the fair level of species richness (11) recorded in this site, compared with those of other localities: for example, in a similar study carried out in an oak forest MITROVSKI-BOGDANOVIĆ & BLESIĆ (2011) found only two species (i.e. *Acerentomon balcanicum* and *Eosentomon transitorium*). This confirm the interest of such area in terms of soil fauna biodiversity as evidenced by the collection of many interesting Pseudoscorpionida and Coleoptera species (G. GARDINI & R. POGGI unpub.) as well as by the co-occurrence of two Palpigradi species (CHRISTIAN et al. 2010), one of which described from material collected here (*Eukoenenia gallii* CHRISTIAN 2009).

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REFERENCES

ANDERSON D. C. 1987. Below-ground herbivory in natural communities: a review emphasising fossorial animals. *The Quarterly Review of Biology*, **62**: 261-286.

BAGNALL R. S. 1912. Some primitive British Insects. I. The Protura. *Knowledge* (N. S), **35**(527): 215-216.

BALE J. S., MASTERS G. J., HODKINSON I. D., AWMACK C., BEZEMER T. M., BROWN V. K., BUTTERFIELD J., BUSE A., COULSON J. C., FARRAR J., GOOD J. E. G., HARRINGTON R., HARTLEY S., JONES T. H., LINDROTH R. L., PRESS M. C., SYMRNIOUDIS I., WATT A. D., WHITTAKER J. B. 2002. Herbivory in global climate change research: direct effects of rising temperature on insect herbivores. *Global Change Biology*, **8**: 1-16.

BERLESE A. 1908a. Nuovi Acerentomidi. *Redia*, **5**: 16-19, Pl. I.

BERLESE A. 1908b. Osservazioni intorno agli Acerentomidi. Nota preventiva. *Redia*, **5**: 110-122.

BROWN V. K., GANGE A. C. 1990. Insect herbivory below ground. *Advances in Ecological Research*, **20**: 1-58.

CHRISTIAN E. 2009. A new soil-dwelling palpigrade species from Northern Italy (Palpigradi: Eukoeneniidae). *Zootaxa*, **2136**: 59-68.

CHRISTIAN E., CAPURRO M., GALLI L. 2010. Phenology of two syntopic *Eukoenenia* species in a northern Italian forest soil (Arachnida: Palpigradi). *Revue Suisse de Zoologie*, **117**(4): 829-834.

DECAËNS T., JIMÉNEZ J. J., GIOIA C., MEASEY G. J., LAVELLE P. 2006. The values of soil animals for conservation biology. *European Journal of Soil Biology*, **42**: S23-S38.

DOWDY W. W. 1944. The influence of temperature on vertical migration of invertebrates inhabiting different soil types. *Ecology*, **25**: 449-460.

FROUZ J., ALI A., FROUZOVA J., LOBINSKE R. J. 2004. Horizontal and vertical distribution of soil macroarthropods along a spatio-temporal moisture gradient in Subtropical Central Florida. *Community and Ecosystem Ecology*, **33**: 1282-1295.

GALLI L., CAPURRO M., TORTI C. 2011. Protura of Italy, with a key to species and their distribution. *ZooKeys*, **146**: 19-67.

GUNNARSSON B. 1980. Distribution, abundance and population structure of Protura in two woodland soils in Southwestern Sweden. *Pedobiologia*, **20**(4): 254-262.

HALL D. G., CHERRY R. H. 1993. Effect of temperature in flooding to control wireworm *Melanotus communis* (Coleoptera: Elateridae). *Florida Entomologist*, **76**: 155-160.

HAMMER Ø., HARPER D. A. T., RYAN P. D. 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis. Palaeontologia Electronica, 4: 9 pp. http://palaeo-electronica.org/2001_1/past/issue1_01.htm

HISHI T., FUJIMAKI R., MCGONIGLE T. P., TAKEDA H. 2008. Relationships among fine roots, fungal hyphae and soil microarthropods among different soil microhabitats in a temperate coniferous forest of *Chmaecyparis obtusa*. *European Journal of Soil Biology*, **44**: 473-477.

IMADATÉ G. 1961. A new species of Protura, *Eosentomon asahi* n. sp., from Japan. *Kontyû*, **29**: 123-131.

IMADATÉ G. 1974. Protura (Insecta). Fauna Japonica. Keigaku Publishing Co, Tokyo, 351 pp.

IMADATÉ G., YOSII R. 1956. Two new species of Protura from Japan. *Insecta matsumurana*, **20**: 11-16.

IMADATÉ G., YOSII R. 1959. A synopsis of the Japanese species of Protura. *Contributions from the biological Laboratory Kyoto University*, **6**: 1-43, Pls I-VIII.

JIMENÉZ J. J., DECAËNS T. 2000. Vertical distribution of earthworms in grassland soils of the Colombia Llanos. *Biology and Fertility of Soils*, **32**: 463-473.

MARIOTTI M. G. 2008. Atlante degli Habitat. Natura 2000 in Liguria. Regione Liguria, 590 pp.

MITROVSKI-BOGDANOVIĆ A., BLESIĆ B. 2006. Investigation of soil Apterygota (Insecta) in Memorial Park Šumarice (Kragujevac). *Kragujevac Journal of Science*, **28**: 77-81.

MITROVSKI-BOGDANOVIĆ A., BLESIĆ B. 2011. Seasonal dynamics of Protura in an oak forest in Kragujevac (Serbia). *Kragujevac Journal of Science*, **33**: 77-82.

NOSEK J. 1969. Three new species of Protura from Italy. *Atti dell'Istituto veneto di Scienze, Lettere ed Arti*. Classe di Scienze matematiche e naturali, **127**: 485-494.

PARISI V., MENTA C., GARDI C., JACOMINI C., MOZZANICA E. 2005. Microarthropod communities as a tool to asses soil quality and biodiversity: a new approach in Italy. *Agriculture Ecosystem and Environment*, **105**: 232-333.

PFLUG A., WOLTERS V. 2001. Influence of drought and litter age on Collembola communities. *European Journal of Soil Biology*, **37**: 305-308.

PRELL H. 1912. Beiträge zur Kenntnis der Proturen. III. Gliederung und eigne Muskulatur der Beine von *Acerentomon* und *Eosentomon*. *Zoologischen Anzeiger*, **40**: 33-50.

RICHARDSON S. J., PRESS M. C., PARSON A. N., HARTLEY S. E. 2002. How do nutrients and warming impact on plant communities and their insect herbivores? *Journal of Ecology*, **90**: 544-556.

RUSEK J. 1965. Zur Proturen-Fauna der Tschechoslowakei. *Věstník československé Společnosti zoologické*, **29**: 223-235.

SETÄLÄ H., MARSHALL V. G., TROFYMOW J. A. 1995. Influence of micro- and macro-habitat factors on collembolan communities in Douglas-fir stumps during forest succession. *Applied Soil Ecology*, **2**: 227-242.

SHAPIRO J. P., HALL D. G., NIEDZ R. P. 1997. Mortality of the larval root weevil *Diaprepes abbreviatus* (Colepotera: Curculionidae) in simulated flooding. *Florida Entomologist*, **80**: 277-285.

SILVESTRI F. 1907. Descrizioni di un novo genere d'insetti apterigoti, rappresantante di un novo ordine. *Bollettino del Laboratorio di Zoologia generale e agraria della R. Scuola superiore d'Agricoltura*. Portici, **1**: 296-311.

STALEY J. T., HODGSON C. J., MORTIMER S. R., MORECROFT M. D., MASTERS G. J., BROWN V. K., TAYLOR M. E. 2007. Effects of summer rainfall manipulations on the abundance and vertical distribution of herbivorous soil macro-invertebrates. *European Journal of Soil Biology*, **43**: 189-198.

TUXEN S. L. 1982. The Protura (Insecta) of Madeira. *Bocagiana*, **65**: 1-20.

WOLTERS V. 2001. Biodiversity of soils animals and its function. *European Journal of Soil Biology*, **37**: 221-227.

WORLDWIDE BIOCLIMATIC CLASSIFICATION SYSTEM, 1996-2009, S. RIVAS-MARTINEZ & S. RIVAS-SAENZ, *Phytosociological Research Center*, Spain. www.globalbioclimatics.org

YOSHII R. 1938. The first record of Protura from Japan. *Zoological Magazine*, Tokyo, **50**: 398-400.