

**Diversity of Ground Beetles and Saproxyllic Beetles  
(Coleoptera: Carabidae + div. Saproxyllic)  
in East Mediterranean Ecosystems (Israel)**

- Dispersal, Habitat, Activity and Reproduction -



**Academic Dissertation**

Doktor der Naturwissenschaften

(Dr. rer.nat.)

Presented by

**Anika Timm**

with the permission of the  
Faculty of Environmental Science  
of the Leuphana University of Lüneburg





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**Kumulative Dissertationsschrift**  
zur Erlangung des akademischen Grades  
Doktor der Naturwissenschaften  
(Dr. rer. nat.)

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## Artikel

Die folgende Tabelle stellt die Beiträge der jeweiligen Autoren für die dieser Arbeit zugrunde liegenden wissenschaftlichen Zeitschriftenartikel dar. Die verwendeten Kürzel folgen den Anfangsbuchstaben der Autoren; die römischen Zahlen geben den jeweiligen Artikel an. Die Autoren wurden gemäß ihres Arbeitsanteils an den Entstehungsschritten der Artikel eingeordnet.

|                            | I          | II             | III        | IV                     | V                      | VI                     |
|----------------------------|------------|----------------|------------|------------------------|------------------------|------------------------|
| Initiative                 | AT, TA, TD | AT, TA, TD     | AT, TA, TD | JB, TA, TD             | JB, TA, TD             | TA, AF, TD             |
| Untersuchungsdesign        | AT, TA, TD | AT, TA, TD, WH | AT, TA, TD | JB, TA, TD             | JB, TA, TD             | TA, AF                 |
| Datenerhebung              | AT, TA, DW | AT, TL, JB     | AT, TL, JB | JB, TL                 | JB, TL                 | TA, AT, JB, AF, TL, DW |
| Analyse                    | AT         | AT             | AT, WP     | JB, BF, TD, TL, AT, TA | JB, BF, TD, TL, AT, TA | TA, CD, AM             |
| Verfassen des Manuskriptes | AT         | AT             | AT         | JB                     | JB                     | TA                     |

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## Papers

The following table shows the respective contributions of the various authors (shown by their initials) to the published papers on which this thesis is based. The roman numerals correspond to the six chapters of the thesis.

|                     | I          | II             | III        | IV                     | V                      | VI                     |     |
|---------------------|------------|----------------|------------|------------------------|------------------------|------------------------|-----|
| Initiation          | AT, TA, TD | AT, TA, TD     | AT, TA, TD | JB, TA, TD             | JB, TA, TD             | TA, TD                 | AF, |
| Experimental design | AT, TA, TD | AT, TA, TD, WH | AT, TA, TD | JB, TA, TD             | JB, TA, TD             | TA, AF                 |     |
| Collection of data  | AT, TA, DW | AT, TL, JB     | AT, TL, JB | JB, TL                 | JB, TL                 | TA, AT, JB, AF, TL, DW |     |
| Analysis            | AT         | AT             | AT, WP     | JB, BF, TD, TL, AT, TA | JB, BF, TD, TL, AT, TA | TA, AM                 | CD, |
| Manuscript writing  | AT         | AT             | AT         | JB                     | JB                     | TA                     |     |

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## Einleitung

Die Landschaften und Ökosysteme des Mittelmeerraums unterliegen bereits seit Jahrtausenden dem Einfluss des Menschen. In vielen Gebieten führte die zu starke Nutzung der Lebensräume zum Verschwinden der natürlichen Vegetation, z. B. immergrüner Eichenwälder (GROVE und RACKHAM 2003). In einigen Arealen des östlichen Mittelmeerraums war die Landnutzung derart intensiv, dass Waldgebiete nur kurzzeitig und in kleinen Vegetationszonen bestehen bleiben konnten.

Die Levanteküste, insbesondere der Mittelmeeranteil Israels, ist ein gutes Beispiel für die Instabilität von Waldbeständen. Bereits seit über 5000 Jahren wurden und werden die betreffenden Areale durch den Menschen bewohnt und genutzt (NAVEH und DAN 1973). Bis auf einige kleine Haine, i. d. R. sakrale Orte, wurde die natürliche Waldvegetation ständig verändert und nicht selten nahezu vollständig zerstört. Ehemals bewaldete Flächen wurden zu steppenartigen Naturräumen umgeformt; intensiv beweidete Habitate (Batha-Flächen) und landwirtschaftlich genutzte Gebiete, die bis heute bestehen, bildeten sich heraus (LIPHSCHITZ und BIGER 1990).

Aufgrund unterschiedlich starker Bevölkerungsdichten wechselten sich Phasen intensiver Landnutzung, begleitet von der Zerstörung der Waldflächen, mit Perioden weniger starker Bewirtschaftung ab (ZOHARY 1960). Bei geringerer Nutzung schafften es buschartige Eichen und Maquis, sich zu Bäumen zu entwickeln. Diese wurden in Zeitabschnitten intensiver Landkultivierung immer wieder eliminiert bzw. der Waldbestand wurde auf ein Minimum reduziert. Die skizzierte Grundsituation, d.h. der stete Wechsel in den Ökosystemen, blieb bis in die ersten beiden Jahrzehnte des 20. Jahrhunderts hinein unverändert.

Erst seit 1920 konnten sich im Raum des historischen Palästinas die Waldbestände erholen. Große Flächen wurden durch einwandernde europäische Siedler neu aufgeforstet (YOM-TOV und MENDELSSOHN 1988). Heute befinden sich die größten natürlichen Baumbestände Israels im nördlichen Galiläa. Viele der Wälder sind weniger als 100 Jahre alt. Obwohl alle öffentlichen Waldgebiete beweidet werden, unterscheiden sie sich nach Größe, Struktur und Aussehen in weitgehender Abhängigkeit von der konkreten gegenwärtigen Landnutzung (cf. DI PASQUALE et al., 2004; GROVE und RACKHAM 2003; WESTPHAL et al., 2009). In Israel wurden bisher

mehr als 100.000 ha offener Flächen mit Nadelbäumen bepflanzt (GINSBERG 2006; OSEM et al., 2008). Die Aleppo-Kiefer (*Pinus halepensis*) und die Kalabrische-Kiefer (*Pinus brutia*) sind die am häufigsten gepflanzten Baumarten, auch wenn letztgenannte Art in Israel nicht heimisch ist (BIGER und LIPHSCHITZ 1991). Bis ins 20. Jahrhundert machte auch die Aleppo-Kiefer nur einen geringen Prozentsatz der natürlichen Waldvegetation aus (LIPHSCHITZ und BIGER 2001). Heute sind mehr als 12% (256.000 ha) des israelischen Staatsterritoriums von Wäldern bedeckt; die Aleppo-Kiefer stellt 40% des Baumbewuchses.

Aus der historischen Landbewirtschaftung und den unterschiedlichen Waldnutzungsformen ergeben sich in Hinblick auf die Artenvielfalt der natürlichen und kulturellen Landschaften Israels zahlreiche Fragestellungen, von denen einige innerhalb des durch die German-Israeli Foundation for Scientific Research and Development (GIF) geförderten Projekts „Patterns of biodiversity in natural and cultural landscapes: a model Mediterranean forest ecosystem“ bearbeitet und partiell beantwortet werden konnten. Das Projekt zielte darauf ab herauszufinden, inwieweit verschiedene Landnutzungspraktiken die Artenvielfalt in Obergaliläa beeinflussen. Trotz seiner geringen Landfläche (ca. 22.000 km<sup>2</sup>) spielt Israel aufgrund seiner biogeografischen Lage und der Vielfalt von Naturräumen eine wichtige ökologische Rolle (FURTH 1975; POR 1975; YOM-TOV und MENDELSSOHN 1988). So erreichen Arten, die in der Klimaregion des nördlichen Mittelmeeres beheimatet sind, hier ihr südlichstes Verbreitungsgebiet. In der Sahara vorkommende Pflanzen und Tiere haben in Israel ihr nördlichstes Verbreitungsgebiet, irano-turanische Arten dagegen ihre westlichste Verbreitungszone. Israel fungiert somit als terrestrische Brücke, die die nördliche gemäßigte Zone mit den trockenen Wüstengebieten des Südens bzw. mit den regenreichen und heißen Wäldern Afrikas und Asiens verbindet.

Das allgemeine Ziel vorliegender Dissertation ist es, im Rahmen des o.g. GIF-Projekts ausgewählte Aspekte der Biodiversität zu bearbeiten, um daraus Empfehlungen für den Schutz der Insektenvielfalt in den Wäldern des Nahen Ostens abzuleiten. Der Hauptteil der Arbeit beschäftigt sich daher mit der Vielfalt von Laufkäfern in den Wäldern Obergaliläas (Kapitel I-III). Im Rahmen des Projekts und in



Zusammenarbeit mit anderen Wissenschaftlern wird darüber hinaus der Vielfalt von xylobionten Käferarten nachgegangen (Kapitel IV+V).

### *Laufkäfer*

Laufkäfer waren für vorliegende Studie besonders interessant, da sie bisher im Mittelmeerraum kaum untersucht wurden, in anderen Gebieten, z. B. in Europa, jedoch eine gut erforschte Käferfamilie mit hohem Indikatorwert darstellen. Bereits in den Recherchen der diesem Thema gewidmeten Diplomarbeit der Doktorandin hatten sich zahlreiche Fragen nach den Anpassungsmechanismen von Laufkäfern im Mittelmeerraum ergeben, insbesondere nach der Jahresrhythmik und den Flugfähigkeiten dieser Artengruppe – Fragen, die für den Mittelmeerraum kaum und für Israel bisher nicht erforscht worden sind. Die „weißen Flecken“ auf der biologischen bzw. ökologischen Wissenschaftskarte regten zu weiterführenden Feldrecherchen und zur wissenschaftlichen Aufarbeitung der betreffenden Befunde an.

Insbesondere der Flügelmorphismus gibt Auskunft über das Ausbreitungspotential der untersuchten Gruppen von Laufkäfern (DEN BOER 1970). Hinzu kommt, dass mehrere Arten als Indikatoren für Formen in der Landnutzungsgeschichte bekannt sind (ASSMANN 1999; DESENDER et al., 1999). Nicht zuletzt existiert eine hohe Bandbreite von eurytopen zu stenotopen Spezies; insbesondere die stenotopen Arten haben einen hohen Indikatorwert für bestimmte Lebensraumbedingungen (RAINIO und NIEMELÄ 2003).

Der Schwerpunkt der Arbeit lag darin zu ermitteln, ob für die Carabiden waldspezifische Arten trotz weitreichender Lebensraumveränderungen überlebt haben und - sollte diese Frage positiv beantwortbar sein - welchem Typ des Flügelmorphismus (brachypter, makropter oder dimorph) sie zuzuordnen sind. Um einen ersten Überblick über die Artenzusammensetzung in den unterschiedlichen Lebensräumen zu erhalten, wurden Barber-Fallen genutzt (Kapitel II). Das von BAARS (1979) u. a. beschriebene Sammeln von Laufkäfern mittels Barber-Fallen über einen längeren Zeitraum hinweg zählt zu den wichtigsten und am weitesten verbreiteten Methoden, um die Größe von Laufkäferpopulationen bestimmen zu können. Einige Studien zeigten jedoch, dass die Anzahl gefangener Individuen von

der epigäischen Aktivität der jeweiligen Art abhängt (ANDERSEN 1995; PERNER und SCHUELER 2004). In anderen themenrelevanten Studien wurden weitere Faktoren benannt, die die Effektivität von Barber-Fallen beeinflussen (z. B. ADIS 1979; HEYDEMANN 1955). Es existieren daneben seltener verwendete Methoden, um Laufkäfergemeinschaften zu untersuchen, z. B. das Fangen durch Ausieben, Handfänge, Lichtfallen oder Käschern (FREUDE et al., 1965; WHITE 1983) – Fangmethoden, die gut geeignet scheinen, wenn die Carabiden der untersuchten Habitate eine nur geringe epigäische Aktivität aufweisen.

Im Vorfeld vorliegender Studie existierten keine Untersuchungen, die sich mit der Effektivität der verschiedenen Fangmethoden im Mittelmeerraum beschäftigten. Um sicherzustellen, dass bei den Recherchen für das GIF-Projekt eine möglichst hohe Anzahl von Laufkäferarten erfasst werden konnte, wurde die Effektivität der Bodenfallen mit anderen Fangmethoden verglichen (Kapitel I). Mit dem Ziel, eine genauere Empfehlung für die beste Sammelzeit verschiedener Carabidenarten zu geben, wurde der Jahreszyklus der gesammelten Laufkäfer analysiert (Kapitel III). Der Minimierung von Problemen bei der Artenbestimmung diene die Mitarbeit an einem Bestimmungsschlüssel der Carabus-Arten Israels (Kapitel VI). Einige der in diesem Schlüssel aufgeführten Arten wurden zuvor nicht selten verwechselt.

### *Xylobionte Käfer*

Der zweite Teil der Dissertation beschäftigt sich mit xylobionten Käferarten. Diese dienen als Modell-Organismen, da sie eine große Anzahl an Taxa beinhalten und eine wichtige Rolle bei der Verrottung von Holz im Waldökosystem spielen (BUSE et al., 2009; GROVE 2002). Bisher existieren kaum Studien, die sich mit der Artenzusammensetzung xylobionter Insekten in Waldgebieten des Mittelmeerraumes auseinandersetzen. Insbesondere für Kiefernwälder des Mittelmeergebiets sind Informationen über xylobionte Käferarten, abgesehen von den häufigsten Schädlingsarten, selten (cf. BATTISTI 2005; MOUNA 2005). Andererseits vollzog sich angesichts der oben beschriebenen Veränderungen in der Landnutzung Israels innerhalb der letzten 50 Jahre eine Erholung der natürlichen Eichenwälder (DUFOUR-DROR 2005).

Die Gattung *Quercus* dominiert heute die Maquis-Vegetation; sie ist in Israel mit mehreren Arten vertreten: Die immergrüne Kermes-Eiche (*Quercus calliprinos*) gehört zu den häufigsten Baumarten im mediterranen Teil Israels (SHMIDA 2006). Durch ihre hohe Verbreitung und ihre evolutionäre Bedeutung als heimische Baumart tritt sie als besonders wichtiges Habitat holzbewohnender Insekten auf. Waldmanagementstrategien sollten daher auf die Artenzahl und die Artenzusammensetzung in den Wäldern des Mittelmeerraums ausgerichtet sein. Naturschutzmaßnahmen bzw. Entscheidungen bei der Landschaftsplanung sollten Erfahrungen der Totholzökologie und das Wissen über die dazugehörigen xylobionten Insektenarten einbeziehen. Die Untersuchungen über Ökologie und Vorkommen der betreffenden Insekten sind eine wichtige Voraussetzung dafür, eine genaue Aufnahme der Artenvielfalt im Mittelmeerraum zu ermöglichen und langfristige Naturschutzstrategien zu entwickeln bzw. umzusetzen.

Ziel des zweiten Teils der Arbeit war es, im Sinne o.g. Überlegungen, die Totholzstrukturen in verschiedenen Waldtypen des Mittelmeerraumes zu analysieren (Kapitel IV), die damit verbundenen xylobionten Käferarten zu bestimmen (Kapitel IV), die Wirkungen aus unterschiedlichen Waldmanagementpraktiken auf die Zusammensetzung der Käferarten zu recherchieren (Kapitel V) und die Unterschiede in der Artenzusammensetzung und Artenvielfalt in den untersuchten Waldtypen aufzuzeigen (Kapitel V).

Die vorliegende kumulative Dissertation umfasst fünf – z.T. bereits in wissenschaftlichen Fachzeitschriften publizierte - Beiträge zu den beiden oben beschriebenen Themenkomplexen. Der sechste in die Studie aufgenommene Aufsatz steht inhaltlich nur indirekt mit der Themenstellung der Dissertation in Verbindung; er wurde daher als zusätzlicher Artikel (Additional Chapter) gekennzeichnet.

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## Introduction

Mediterranean lands have been used by humans for thousands of years. In many regions utilization was very intensive and led to the disappearance of the natural evergreen oak woodlands (GROVE and RACKHAM 2003). In some areas of the Eastern Mediterranean, land use was so intensive that woodlands were only able to survive for short periods and in small areas. The Mediterranean part of Israel is an example of the interrupted habitat continuity of woodlands in the Eastern Mediterranean. This area has been intensively influenced by humans for at least 5000 years (cf. NAVEH and DAN 1973). Except for some very small stands surrounding sacred places, the natural woody vegetation has been almost completely transformed or destroyed, and now mostly comprises steppe-like, intensively grazed habitats (so-called batha) and arable fields (e.g. LIPHSCHITZ and BIGER 1990). Concurrent with changes in population density, phases of intensive land use, accompanied by the destruction of large woodland areas, alternated with phases of less intensive land use (cf. ZOHARY 1960). During the periods of marginal land use, small shrub-like oaks and maquis were able to develop into trees which could potentially have formed Mediterranean woodlands if they had not been destroyed during subsequent phases of intensive land use. This situation remained unchanged until the early years of the last century.

During the First World War the Turkish army cut down most of the few remaining or regenerated native woodlands in order to feed the railway steam engines. It is only since 1920 that woodlands have been able to recover and large areas have been afforested (YOM-TOV and MENDELSSOHN 1988). Today, Israel's largest native woodlands exist in the Galilee; most of these are less than 100 years old. All remnants of forests that survived are now grazed, but differ in size as well as in structure and shape, depending on current land-use management (cf. GROVE and RACKHAM 2003; DI PASQUALE et al., 2004; WESTPHAL et al., 2009). This applies particularly to Israel where foresters planted almost 100,000 ha of former open land with coniferous trees for several purposes (GINSBERG 2006; OSEM et al., 2008). Aleppo pines (*Pinus halepensis*) and Calabrian pines (*Pinus brutia*) are the most frequently planted tree species in Israel and elsewhere in the East Mediterranean, although the latter species is not native to Israel (BIGER and LIPHSCHITZ 1991) and the former constituted only a small percentage of the native arboreal vegetation before

plantations took place in the 20<sup>th</sup> century (LIPHSCHITZ and BIGER 2001). In Israel today more than 12% (256,000 ha) of the total land area is covered by forests and other woodlands, with Aleppo pine alone representing as much as 40% of the forest area.

As a result of the historical development of Israel's landscapes and of different forestry practices a number of questions arise with respect to diversity in natural and cultural landscapes. These questions were addressed by the GIF-Project "Patterns of biodiversity in natural and cultural landscapes: a model Mediterranean forest ecosystem". The project was designed to provide insight into the role of different land use practices in sustaining biodiversity in the Upper Galilee of Israel. Despite the fact that Israel is a small country (about 22,000 km<sup>2</sup>), it displays enormous ecological diversity originating from its peculiar biogeographic location in south-western Asia and its great physical variety (FURTH 1975; POR 1975; YOM-TOV and TCHERNOV 1988): it links the Sahara-Arabia desert belt, the Mediterranean region and the high Asian mountains (Irano-Turanian).

The aim of my PhD research was to study general patterns of biodiversity as part of the GIF-Project and to give recommendations for the conservation of insect diversity in the woodlands of the Middle East. The main part of this thesis deals with the diversity of ground beetles (Chapters I-III). As part of this project, I also worked with other scientists on the diversity of saproxylic beetles (Chapters IV + V).

#### *Diversity of carabid beetles*

Carabid beetles are interesting for this research because they had previously only rarely been researched under biodiversity aspects in the Mediterranean area, yet they are a frequently studied group of indicators elsewhere. During the research for my diploma thesis on this subject, it became clear that little was known about the different biodiversity aspects of ground beetles. In the course of this earlier research some new ground beetle species were found and many new questions concerning the wing morphism and the annual rhythm of ground beetles arose. These questions had only very rarely been addressed in other studies relating to the Mediterranean and never before for Israel.

The hindwing polymorphism, and thus the ability to fly, provides information about these beetles' power of dispersal (e.g. DEN BOER 1970). In addition, several species known from other regions are indicators of a particular kind of land-use history (ASSMANN 1999; DESENDER et al., 1999). Moreover, this group is known for its wide spectrum of diverging stenotypes, ranging from eurytopic to stenotopic species, and the representatives are easy to catch in pitfall traps. The stenotopic species in particular show a high indicator value for different environmental conditions (RAINIO and NIEMELÄ 2003).

The main focus of my work was to determine whether woodland ground beetle species have been able to survive due to habitat changes and if so, to which dispersal group do they belong. Pitfall traps were used in order to obtain initial data on the species composition in the different habitats (Chapter II). The use of continuous pitfall sampling as described by BAARS (1979) is the most important method employed in Europe to measure the size of carabid populations. Other studies have proved that the number of animals trapped also depends on their epigeic activity (ANDERSEN 1995; PERNER and SCHUELER 2004). Many other factors that also influence the effectiveness of pitfall traps have been described in the literature (e.g. ADIS 1979; HEYDEMANN 1955). Methods such as sifting, hand picking, light trapping or net sweeping can also be used to study ground beetle assemblages (e.g. FREUDE et al., 1965; WHITE 1983). Some of these techniques seem appropriate if the ground beetles in the given habitats do not show locomotor activity on the surface. Prior to this research, there were no studies which dealt with the efficiency of pitfall traps and other methods of collecting ground beetle assemblages for the Mediterranean region. Thus, in order to ensure that a diverse range of ground beetle species was found, the efficiency of pitfall trapping was compared with other collection methods (Chapter I). In order to be able to provide better advice for future studies regarding how and when to sample ground beetles, the seasonal cycles of the ground beetles found were studied (Chapter III). To overcome problems regarding species identification, I contributed to an identification key for the *Carabus* species of Israel, because some species have been confused in the past (Chapter VI).

*Diversity of saproxylic beetles*

The second part of this PhD thesis deals with saproxylic beetle assemblages. Saproxylic beetles (species associated with wood) were used as model organisms because they include a large number of taxa and play a key role in the decomposition of woody material in forest ecosystems (cf. BUSE et al., 2009; GROVE 2002). To date there have been very few systematic studies on saproxylic insect assemblages inhabiting Mediterranean forests. Information about saproxylic beetles, other than the common pest species, in Mediterranean pine forests is also very rare (cf. BATTISTI 2005; MOUNA 2005).

Due to the land-use changes of the last 50 years, as discussed above, there has been a natural recovery of the oak woodlands in the Mediterranean-type ecosystems of Israel (cf. DUFOUR-DROR 2005). The genus *Quercus* dominates this marquis vegetation and is represented in Israel by several native species. Today, the evergreen Palestine Oak (*Quercus calliprinos*) is the most common tree species of the Israeli Mediterranean region (SHMIDA 2006). This species, then, would appear to be potentially important for saproxylic insects because of its frequent distribution and its evolutionary significance as a native tree species. Different management strategies can be expected to have a considerable impact on patterns of saproxylic beetle species richness and community structure in Mediterranean woodlands. For nature conservation strategies and decision making in Mediterranean landscape planning, it is essential to incorporate the basics of dead wood ecology and their associated saproxylic insect fauna. Research on the occurrence and ecology of these insects is essential in order to study the distribution of diversity in this region and to develop conservation strategies with a long-term perspective.

The purposes of the second part of the thesis were to analyse dead wood structure in differently managed Mediterranean woodlands (Chapter IV), to research saproxylic beetle diversity in this context (Chapter IV), to study the impact of current forest management on saproxylic beetle assemblages in Israel (Chapter V), and to compare assemblage similarity and species richness between the studied forest types (Chapter V).

This academic thesis consists of five papers, all of which deal with ground beetle diversity or saproxylic beetle assemblages in Israel. Paper number six is an



additional chapter, not directly connected with the described subjects. All six papers are summarized below.

### Summary of the presented papers

#### *Chapter I: Towards combined methods for recording ground beetles: Pitfall traps, hand picking and sifting in Mediterranean habitats of Israel*

Knowledge of the detectability of ground beetle species in Mediterranean habitats and the most suitable methods for collecting are important for studying the significance of this animal group in landscape planning and biological conservation research approaches. Ground beetles are used increasingly for nature conservation strategies. The Convention on the Conservation of European Wildlife and Natural Habitats of the European Union (e.g. GUENTHER and ASSMANN 2004; MATERN et al., 2007; SSYMANK 1998) or the Endangered Species Act of the United States of America (e.g. MELLO 2005; TALLEY et al., 2007), for instance, explicitly protect habitats where ground beetle species are found. Methods for obtaining comprehensive knowledge of the existing fauna are a prerequisite for the development of nature conservation strategies. Such detailed knowledge is crucial for identifying changes and threats to the species concerned. Therefore, three different methods (pitfall traps, hand picking and sifting) were used to sample ground beetles in a woodland site and a batha site in Upper Galilee, Israel. Rarefaction procedures show that pitfall traps alone catch only half of the species detected by a combination of methods. Some guilds are not (or only rarely) found in pitfall traps. Among these are the myrmecophile (e.g. *Paussus turcicus*, *Macrocheilus saulcyi*), inhabitants of the superficial underground compartment (*Zuphium numidicum* and an undescribed microphthalmic *Parazuphium* species), and some litter inhabiting species (e.g. *Metadromius carmelitanus*).

*Metadromius carmelitanus* was found more frequently in the sifting samples than the *Trechus* species, but never occurred in pitfall traps, while this latter method served well to detect the Trechini. The tarsi of most lebiine beetles are equipped with a large number of adhesive setae, in contrast to the trechine beetles, which have only a few (cf. SCHÜRSTEDT et al., 2000). It is possible that, with the help of these setae, *M. carmelitanus* is able to escape from the traps. This would, in view of the fact that no

other carabid beetle has a higher density than *M. carmelitanus* in these woodlands, at least explain the absence of this beetle in pitfall traps. Although a large variety of species was recorded and different capture methods employed, the final data do not present a complete picture of ground beetle species in the region: species living in the canopy of the woodlands were not included. Further studies will be necessary to achieve a complete overview of all the species living in these Mediterranean habitats.

The most important methodological aspect of pitfall traps is that they sample the carabid assemblage independently of the scientist. This is the central aspect which has to be questioned for the other methods used (hand picking and litter sifting).

Given that the collectors only took a few hours to collect the additional samples by hand picking or sifting, these methods can be judged to be very efficient.

Generally, a combination of recording techniques is necessary to obtain a comprehensive overview of the diverse fauna of Mediterranean habitats. If the results of these "alternative" sampling methods are to be compared satisfactorily, standards have to be developed. The question is whether comparable standardization is possible for hand picking. However, this method should nonetheless be used, as it is a means of proving the presence of some species from certain ecological groups or guilds (e.g., myrmicophilic, endogeic species) that will not be caught with other methods.

*Chapter II: At the interface of historical and present-day ecology: Ground beetles in woodlands and open habitats in Upper Galilee (Israel)*

Recent studies have underlined the importance of woodlands with different habitat continuity in Central and Western Europe (e.g. GROVE and RACKHAM 2003; PETERKEN 1993). These studies distinguish between woodlands which have shown a long period of habitat continuity (ancient woodlands) and habitats which have developed over recent centuries due to afforestation or succession (recent woodlands). Some ground beetle species are restricted to ancient woodlands, whereas other ground beetle woodland species, especially those that are macropterous, live in both ancient and recent woodlands (ASSMANN 1999; DESENDER et al. 1999). However, some

brachypterous species have also been able to recolonise recent woodlands (DREES et al., 2008).

In contrast, land use in the Mediterranean region has varied a great deal over the centuries. Woodland regeneration was only possible during periods of low human population density and hence low levels of grazing. Therefore, batha and open habitats have longer habitat continuity than woodlands in this region. The aim of Chapter II is, therefore, to answer the question as to how woodland species have been able to cope with the rapidly changing habitats. The study sites are the same as in Chapters I and III and comprise two old-growth woodlands, two recent woodlands and two open habitats. Ground beetles were sampled over a period of one year, using 10 pitfall traps per study site. The wing development of all sampled species was analysed. Species richness differed considerably between old-growth woodlands and open habitats. While the rarefied species richness is clearly highest in open habitats and lowest in the old-growth woodlands, most individuals were found in old-growth woodlands. On the basis of a detrended correspondence analysis (DCA), the habitat preferences of three ground beetle groups were distinguished: old-growth woodland species, species of recent woodlands and species of open habitats. Two-thirds of the group of open habitat species are brachypterous, and three out of the four woodland species are macropterous. For the winged woodland species of this research area, it can be concluded that they have a good dispersal power and are able to colonize new habitats easily. The wide distribution of these species in the Middle East (LÖBL and SMETANA 2003) emphasizes that they are able to spread over vast areas. None of the three winged woodland species are found exclusively in woodlands, but also in habitats that have a special microclimate (e.g. the entrance area of caves, cf. PAWŁOWSKI 1979; personal observations at Alma Cave and Pa'ar Cave in Upper Galilee).

Therefore, it seems that habitat selection makes it possible for these species to survive outside of woodlands. From these hideaways the colonization of new woodland areas is possible. The carabid fauna in the studied habitats show major differences in hindwing morphism to temperate and boreal regions. These differences, the high percentage of winged species in woodlands and the high

number of unwinged species in open habitats, can be explained by the differences in habitat continuity between woodlands and open habitats.

The present study shows that there are species with preferences for old-growth, recent woodlands and open habitats, respectively. Therefore, it is necessary to protect all these habitats in future. High diversity, especially for old-growth woodlands, has been shown for other groups of organisms (cf. Chapter IV). Saproxylic beetles are one example of a greater species richness and unique assemblage composition in old-growth oak woodlands in the Upper Galilee. Thus, land use management must allow the natural aging of Israel's woodlands, such as the woodland of Bar'am, if species protection and nature conservation are to be ensured.

*Chapter III: Seasonality and reproduction of ground beetles (Carabidae: Coleoptera) in an Eastern Mediterranean region (Upper Galilee, Israel)*

Studies done in temperate zones have led to a better understanding of distribution trends, specific habitat adaptations of carabids and provided a basis for decisions in long-term monitoring research. In contrast to the temperate zones, little research has been done on the annual cycles of ground beetles in the Mediterranean climate region. The aims of the study are therefore (1) to describe the phenology of ground beetles in the Eastern Mediterranean climate region and (2) to determine whether only ground beetles with winter larvae or whether other reproduction types also exist in woodlands and open habitats of Israel.

This part of the research presents and discusses the seasonal activity of and the best sampling time for East Mediterranean ground beetle species. Three East Mediterranean habitat types (open landscape, recent woodland, old growth woodland) were sampled over the course of one year using pitfall traps. The females of the seven most common ground beetle species were dissected. During the sampling period, weather data were collected at Meron field school, close to the sampling sites. The results show that winter breeding seems to be the most important type in the Mediterranean. However, summer and spring breeders (*Orthomus sidonicus*, *Eucarterus sparsutus*, *Odotoncarus asiaticus*) were also found. Ten of the 34 species found had their annual maximum in spring, three in summer,

seven in autumn and ten in winter. Four species did not have a clear maximum. *Eucartermus sparsutus* and *Odontoncarus asiaticus* were found only during the summer months. For the other species, there seems to be a connection between the beginning of the rainy season and the beginning of the breeding season. In order to substantiate this hypothesis and to be able to give explanations for the fact that only a few species developed during the summer months, it is necessary to study the annual cycle of different ground beetle species, soil moisture and temperature as well as the annual precipitation over several years in this area.

Methods for obtaining comprehensive knowledge of the existing fauna are a prerequisite for nature conservation strategies. Such knowledge is crucial for identifying changes and threats. Knowledge of the detectability and the seasonality of ground beetle species in Mediterranean habitats and of the most suitable collecting methods and seasons is important for studying the significance of this animal group in landscape planning and biological conservation research. Therefore, it is not only necessary to use different sampling methods, as shown in Chapter I, but also to sample throughout the year in order to obtain a detailed spectrum of species for these habitats.

#### *Chapter IV: Saproxylic beetle assemblages of three managed oak woodlands in the Eastern Mediterranean*

Today the evergreen Palestine Oak (*Quercus calliprinos*) is the most common tree species in the Israeli Mediterranean region (SHMIDA 2006). This species, then, is potentially important for saproxylic insects because of its frequent occurrence and its evolutionary significance as a native tree species. It is likely that, under natural conditions, major parts of the Israeli landscape in the Mediterranean climate region would consist of oak-dominated woodlands. We used flight interception traps to analyse the impact of woodland management on dead wood and tree structures and the relevance for saproxylic beetle assemblages at three different sites in the East Mediterranean. Large trees also offer more stable microclimatic conditions, such as temperature and moisture. Different management strategies can also be expected to have a considerable impact on patterns of saproxylic beetle species richness and community structure in Mediterranean woodlands.

At present, we have information on how human impact affects plant diversity of woodlands (e.g. COWLING et al., 1996; SCHMITZ et al., 2007) or birds (e.g. VALLECILLO et al., 2008) in Mediterranean regions, but we know very little about how invertebrates respond to different management practices. Grazing either by cattle or goats and sheep and afforestations are considered to be the main human impacts on flora and fauna in the Mediterranean region (ALRABABAH et al., 2007; HENKIN et al., 2007; MAESTRE et al., 2003).

Studies from Northern and Central Europe have shown the relevance of ecological continuity and forest history for woodland structures that are important determinants of invertebrate richness associated with dead wood (cf. ALEXANDER 1998; JONSSON et al., 2005). However, similar investigations in the Mediterranean are still lacking, and ecological research on Mediterranean woodlands is as yet underrepresented (MARAÑÓN et al., 1999). Our results show significant differences in trunk diameter, stem density and dead wood diversity between the three sites.

Old oaks in the semi-open woodland are characterised by diverse stages of dead wood and harboured most saproxylic species (74 species of 98 in total) and most individuals. With regard to rarefied species richness, we found that the coppice woodland with a high stem density and medium-sized trees has the most diverse beetle assemblage (19.7 species per 100 individuals). Species richness was in general strongly associated with the diameter of the oaks, but, surprisingly, was also similar to the species numbers reported from studies in Central Europe. The large number of singletons, which comprised 40% of the entire sample, may indicate a considerable proportion of unseen species. Natural broad-leaved woodlands belong to the group of endangered habitats in the Mediterranean region (BALLETO and CASALE 1991). However, in spite of their threatened status we do not know much about dead wood and associated diversity in these woodlands. As many saproxylic beetle species are very specific in their habitat requirements, moderate grazing should generally be continued to maintain a diverse woodland structure with open and shaded habitats; however, some parts of the Mediterranean woodlands should be managed to allow natural aging of the oaks. Selective cutting may thus be an appropriate

management measure for Mediterranean woodlands because it promotes a combination of sustainable use and a high shrub and tree species richness (cf. TORRAS and SAURA 2008). Pollarding by cutting the branches at 2-6 m above ground level might be another suitable management measure for Mediterranean woodlands. However, traditional coppice management with selective cutting seems to be the most sustainable way to use wood resources and should also be beneficial to conservation issues.

*Chapter V: Saproxylic beetle assemblages in the Mediterranean region: Impact of forest management on richness and structure*

Forests cover almost 30% of the Mediterranean region today, yet forest management activities have influenced structure and composition of both natural and planted forests. However, there is a distinct lack of systematic studies on saproxylic insect assemblages inhabiting Mediterranean forests. Although the Mediterranean region is considered to be a biodiversity hotspot (MÉDAIL and QUÉZEL 1999; MYERS et al., 2000), only a few systematic studies report on the biodiversity of beetles in Mediterranean tree habitats (e.g. BRIN and BRUSTEL 2006; BUSE et al., 2008; DA SILVA et al., 2009; SIRAMI et al., 2008; TABOADA et al., 2006). There is evidence that coniferous forests have negative effects on species richness and community composition of some taxa, e.g. for woodland specialist birds (GIL-TENA et al., 2007) or plant communities (NAVEH and WHITTAKER 1979). Both faunal diversity and composition seem to be different in coniferous plantations compared with other forest types of the same region (AMO et al., 2007; GIL-TENA et al. 2007; VAN HALDER et al., 2008). Pine plantations are also known to spread into neighbouring habitats (LAVI et al., 2005) and may thus threaten adjacent natural ecosystems. Effects of Aleppo pine afforestations on faunal communities are only known from studies on birds, which show that pine plantations can reduce bird species diversity (cf. MAESTRE and CORTINA 2004). However, there is a clear lack of information on the impacts of these plantations on animal groups other than birds.

Our results show that pine afforestations in Israel do not affect species richness per se. However, we found that the composition of saproxylic beetle assemblages varied between pine and oak forests. A relatively large number of species are unique for each forest type, although many species also appeared in all three forest types

because of single scattered oaks in the studied pine stands. Although there are structural differences, the number of saproxylic beetle species did not differ between forest types. Scattered oaks in the studied pine forests are likely to increase species richness as some beetle species which develop in broadleaved trees were found in pine forests which contained scattered oaks. The scattered oaks in the pine forests as well as the oaks studied in the *Quercus calliprinos* forests were relatively young trees inhabited by only a few species. A far larger number of saproxylic beetle species can be expected in old-growth oak stands in the same region: BUSE et al. (2008) recorded 74 saproxylic beetle species in the old oak stand “The Fourties”, Mt. Carmel, whereas the maximum species number found here in all forest types with a larger investigative effort was 44 species per forest stand.

Only *Hylotrupes bajulus*, a widely distributed pest, is dependent on pines. Some longhorn beetle species dependent on broadleaved trees or shrubs were also found in the pine stands, indicating the mixed character of the investigated stands or the species' ability to cover relatively large distances by flight. The studied forest types differed in forest structure, but we found no significant difference in saproxylic beetle species richness. Aleppo pine forests showed the largest number of saproxylic beetle species. Forests dominated by *P. brutia*, a non-native tree species in Israel, showed the lowest species number of all three forest types. Species composition differed substantially between oak and pine forests, a third of the species found either in *P. halepensis* or in *Q. calliprinos* forests being unique to these habitats, while a smaller proportion of unique beetle species was found in *P. brutia* forests. Several beetle species that were found both in oak and pine plots in our study develop exclusively on broadleaved shrubs or trees. This may be explained by the small distances between the studied pine trees and oaks in their proximity.

Biodiversity in pine forests can be increased when these are mixed with broad-leaved trees, e.g. oaks in the understory layer, such as can be observed in the natural regrowth in most of the planted pine stands in our research area. There is some evidence from other studies that older successional stages of oak forests are likely to host more species overall than the mature pine forests studied here. In order to enhance structural diversity, foresters should allow for aging of single trees or stands, regardless of the tree species.



*Additional Chapter VI: The Carabus fauna of Israel – updated identification key, faunistics, and habitats (Coleoptera: Carabidae)*

Very few identification keys of the ground beetle fauna of Israel exist to date. Identification of the sampled ground beetles was only possible with the help of a number of keys from Europe (e.g. BATTONI and VERESCHAGINA 1984; HOLDHAUS 1912; HUBER and MARGGI 1997; JEANNEL 1942; MÜLLER-MOTZFELD 2004; TRAUTNER and GEIGENMÜLLER 1987). In addition, the material was compared with the collections of carabid taxonomists, e.g. David Wrase (Berlin). To make entomological work easier and to give a wider spectrum of scientists the opportunity to work on the beetle fauna of Israel, further identification keys, including an updated key for the *Carabus* species, are urgently needed.

The ground beetle genus *Carabus* with its preference for humid habitats reaches its southern distribution limit in Israel, and only some species occur there (cf. BOUSQUET et al., 2003). The *Carabus* fauna of Israel was first described in a fundamental work by SCHWEIGER (1970). Substantial additions, corrections and taxonomic changes were made by KLEINFELD and RAPUZZI (2004) and DEUVE (2004; 2005) in more recent years. Additional records of some species demonstrate the need for an update of our knowledge on the genus *Carabus* in Israel. Moreover, the increasing interest in the conservation biology, ecology, evolutionary biology and faunistics of ground beetles in Israel (BAR 1978; CHIKATUNOV et al., 2006; CHIKATUNOV et al., 1999, 2004; FINKEL et al., 2002; MIENIS 1978a, 1978b, 1978c, 1988; PAVLÍČEK and NEVO 1996) demonstrates the necessity for a new identification key and a short synopsis of the present day knowledge of the distribution, faunistics and habitats of Israeli *Carabus* species. At several locations in Galilee (including a site close to the Sea of Galilee, about 200 m below sea level), we detected *Carabus syrus* populations. The species' previously known distribution area in Israel covers the Golan Heights, parts of Mount Hermon and the Upper Jordan Valley close to Qiryat Shemona (SCHWEIGER 1970). We believe that large areas of Galilee (including Lower Galilee), the Golan Heights and Judean Foothills are still under-represented in faunistic studies. Therefore, it seems most likely that additional populations and, perhaps, species can be detected there.

## **Conclusions**

This thesis gives an overview on the diversity of some beetle species in different Mediterranean habitats as well as on the influence of forest management on insect diversity. Primarily, this work involved fundamental research, because very little research had previously been conducted under biodiversity aspects on either ground beetles or saproxylic beetles in the Mediterranean area of Israel. It was possible to prove that stenotopic ground beetles occur in different habitat types. Furthermore, the results of Chapter I and Chapter III show that additional research is needed to obtain a clear view of the beetle diversity in this area. Future studies should consider that a variety of catching methods are needed throughout the annual cycle in order to catch a good spectrum of ground beetles living in these habitats. It is clearly not sufficient to conduct a study of ground beetles using only pitfall traps and/or to restrict the study to the wet winter months.

The conclusions and management recommendations are therefore as follows: More studies on insect biodiversity are needed to obtain a comprehensive overview of insects in natural and planted Mediterranean woodlands. To facilitate this for a wide spectrum of scientists, identification keys for the Mediterranean insect fauna are urgently needed. Furthermore, foresters are in a position to decide which tree species composition has to be established and for what purpose. Nowadays, issues of forest management are primarily led by the objectives and potential uses of the forests. In times of global change, however, the potential future climatic situation and the ecosystem services provided by different woodlands also have to be considered when planning forest management (cf. also DUFOR-DROR 2005 for Israel). Forest management is therefore also a matter of regional development and must thus include social demands and conservation actions. In a recent paper, OSEM et al. (2008) propose that forest management should consider different objectives, e.g. forests as a provider of ecosystem services, such as water infiltration, carbon sequestration and biodiversity. For these reasons, foresters should take the opportunity to establish oak individuals as a woody understorey component in pine stands. This would not only increase forest diversity but also strengthen the forests' resistance and resilience to pest outbreaks, and would ensure better ecosystem functioning and soil stabilisation (cf. GINSBERG 2006; OSEM et al. 2008; PAUSAS et al.,

2004). Moreover, both old and recent woodlands provide unique sections of biodiversity, as revealed by the occurrence of species restricted to specific microhabitats.

However, not only forest management but the management of all natural or semi-natural habitats in northern Israel is important. Many, if not all of these habitats, have been severely affected or completely destroyed by urban, industrial and agricultural development and fragmentation or by dense afforestation with non-native trees (e.g. *Eucalyptus*). This development, especially the loss of open space, is continuing because of Israel's high human population density. For these reasons, all natural or semi-natural habitats are endangered (YOM-TOV & MENDELSSOHN 2004). This alarming development is in contrast with the overall importance of the region as a biodiversity hotspot (YOM-TOV and TCHERNOV 1988). This thesis demonstrates that there are numerous (also stenotopic) beetle species with preferences to specific habitats of open space (e.g. old-growth oak woodlands, recent oak woodlands, pine plantations, batha and old oak tree individuals). If Israel's beetle diversity is to be preserved in future, it will be vital to protect all habitats and their succession stages.

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## **I** Towards combined methods for recording ground beetles: Pitfall traps, hand picking and sifting in Mediterranean habitats of Israel

ANIKA TIMM, TAMAR DAYAN, TAL LEVANONY, DAVID W. WRASE & THORSTEN ASSMANN (2008) In: L.PENEV, T.ERWIN and T.ASSMANN (Eds.), *Back to the roots and back to the future? Towards a new synthesis amongst taxonomic, ecological and biogeographical approaches in Carabidology*. Pensoft, Sofia, Moscow, pp. 397-408

## Abstract

Three different methods (pitfall traps, hand picking and sifting) were used to sample ground beetles in a woodland site and a batha site in Upper Galilee, Israel. Better knowledge about the detectability of ground beetle species in Mediterranean habitats and the most suitable methods of collecting are important for studying the taxon in landscape planning or nature conservation research approaches. Rarefaction procedures show that pitfall traps alone catch only half of the species detected by a combination of methods. Some guilds are not (or only rarely) found in pitfall traps. Among these are the myrmecophile (e.g. *Paussus turcicus*, *Macrocheilus saulcyi*), inhabitants of the superficial underground compartment (*Zuphium numidicum* and a microphthalmic *Parazuphium* species), and some litter inhabiting species (e.g. *Metadromius carmelitanus*). The reasons for the different catchabilities are discussed. Generally, we recommend a combination of recording techniques to obtain a comprehensive overview of the diverse fauna of Mediterranean habitats.

Keywords: Upper Galilee, Israel, pitfall traps, hand picking, sifting

## 1. Introduction

Pitfall traps were first described by BARBER (1931) and are today one of the standard methods used to study ground beetles. Since this initial description, the use of pitfall traps as a sampling method has been discussed extensively. BAARS (1979) described the use of continuous pitfall sampling as an important method to measure the size of carabid populations. Other studies have proved that the number of animals trapped also depends on their epigeic activity (ANDERSEN 1995; PERNER and SCHUELER 2004). Many other factors that also influence the effectiveness of pitfall traps have been described in the literature (e.g. ADIS 1979; HEYDEMANN 1955). HALSALL and WRATTEN (1988) even state that pitfall trap catches are only poorly related to population densities and that the size or speed of movement of the beetle plays no role in capture efficiency.

Methods such as sifting, hand picking, light trapping or net sweeping can also be used to study ground beetle assemblages (e.g. FREUDE et al., 1965; WHITE 1983). Some of these techniques seem appropriate if ground beetles of the given habitats

do not show locomotor activity on the surface. For this reason, we compare the efficiency of pitfall trapping, sifting and hand picking. Most previous studies on the efficiency of different methods were conducted in temperate climate regions of Europe and North America (e.g. ANDERSEN 1995; PRASIFKA et al., 2007). For the Mediterranean region, to date, there have been no studies which deal with the efficiency of pitfall traps and other methods of collecting ground beetle assemblages. We chose two different East-Mediterranean habitats to determine the efficiency of three different methods. One study site is an evergreen oak woodland and the other is an open grazed habitat, a so-called batha. Knowledge of the detectability of ground beetle species in Mediterranean habitats and the most suitable methods for collecting are important for studying the significance of this animal group in landscape planning and biological conservation research approaches. Ground beetles are used increasingly for nature conservation strategies. The Convention on the Conservation of European Wildlife and Natural Habitats of the European Union (e.g. GUENTHER and ASSMANN 2004; MATERN et al., 2007; SSYMANK 1998) or the Endangered Species Act of the United States of America (e.g. MELLO 2005; TALLEY et al., 2007). ), for instance, explicitly protect habitats where ground beetle species are found. Prerequisites for nature conservation strategies are methods for obtaining comprehensive knowledge on the existing fauna. This is crucial for identifying changes and threats. Therefore, the main focus of our contribution is (1) to compare the efficiency of the methods in two widely distributed habitats of the East Mediterranean and (2) to derive from these results recommendations regarding monitoring of those types of habitats.

## **2. Materials and methods**

The two study sites are located in Upper Galilee, North Israel, near the Lebanese border and close to the villages of Bar'am and Ziv'on. The sites are on terra rossa soils on hard limestone. Here, we studied the ground beetle fauna for one year using 10 pitfall traps per site (first opened 14 March 2005; closed 17 March 2006). The traps were filled with approximately 2 cm RENNER (1980) liquid (30% ethanol, 20 % glycerol, 10% acetic acid) and emptied every second week. The sites were located on an open meadow (batha; geographic coordinates: N 033°01', E 035°25') with a

dominance of *Sarcopotherium spinosum* and two *Cistus* species, and in a woodland (geographic coordinates: N 033°02', E 035°25') dominated by *Quercus calliprinos*. In both habitats, ground beetles were also collected by hand (mainly beneath stones). The collection activities took the two collectors seven hours in the woodland and six hours in the open meadow. In the woodland, ground beetles were also collected by sifting the litter layer and the top mineral horizons of the soil down to a depth of approximately 8 mm. In most cases, the sifted litter was examined on the same day (while it was still relatively humid), but in a few cases it was not examined until the next day. For examination, the sifted litter was sifted again with a mesh size of 4 mm onto a white sheet. Most of the beetles in the sifted litter were found as a result of their running activity. The last step was to examine the rest of the sifted litter for inactive and larger specimens (cf. FREUDE et al., 1965; WHITE 1983).

Rarefaction was used to study the efficiency of the different collection methods. This was performed using the online calculator by BRZUSTOWSKI (<http://www2.biology.ualberta.ca/jbrzusto/rarefact.php#Inputs>) which is based on the program RAREFACT.FOR written by Charles J. Krebs. The nomenclature of the ground beetles follows LÖBL and SMETANA (2003) and DEUVE (2004). A few species are either not known to science or could not be determined (see Table 1 for further details).

### 3. Results

During the year cycle, 2978 specimens were caught in the woodland site and 552 ground beetles in the open meadow with pitfall traps. 196 and 226 specimens were captured by hand picking in the woodland and in the batha, respectively.

In the batha, 30 species were detected by hand picking and 16 by pitfall traps. Almost two-thirds of the species found by hand picking were not found in the pitfall traps, while 5 species were only caught in pitfall traps. On the woodland site, however, 22 species were found in pitfall traps, 14 by hand picking and 5 by sifting. Nearly half of the species found by sifting and hand picking were not caught in pitfall traps. Two species were found in the woodland exclusively by means of pitfall traps. At both sites, some species were caught using only one of the methods (Table 1).



Table 1: Catches in woodland and batha

|                                       | Woodland      |         |              | Batha         |              | Total specimens |
|---------------------------------------|---------------|---------|--------------|---------------|--------------|-----------------|
|                                       | Pitfall Traps | Sifting | Hand Picking | Pitfall Traps | Hand Picking |                 |
| <i>Amara pumilio</i>                  | .             | .       | .            | .             | 13           | 13              |
| <i>Amblystomus cephalotes</i>         | .             | .       | 2            | .             | .            | 2               |
| <i>Apotomus clypeonitens</i>          | .             | .       | .            | .             | 3            | 3               |
| <i>Bembidion leucoscelis</i>          | .             | .       | 1            | .             | .            | 1               |
| <i>Bembidion liliputanum</i>          | .             | 14      | .            | .             | .            | 14              |
| <i>Bembidion phoeniceum</i>           | 6             | 2       | .            | .             | .            | 8               |
| <i>Broscus laevigatus</i>             | 18            | .       | .            | 22            | 18           | 58              |
| <i>Broscus nobilis</i>                | 6             | .       | .            | 3             | 6            | 15              |
| <i>Calathus cinctus</i>               | 110           | .       | .            | 1             | 10           | 121             |
| <i>Calathus longicollis</i>           | 658           | .       | 6            | 50            | 42           | 756             |
| <i>Calathus mollis</i>                | .             | .       | 5            | .             | .            | 5               |
| <i>Carabus impressus</i>              | 8             | .       | 2            | 58            | 12           | 80              |
| <i>Carabus phoenix</i>                | 2             | .       | .            | .             | .            | 2               |
| <i>Carabus piochardi</i>              | 2             | .       | .            | 37            | 1            | 40              |
| <i>Carabus sidonius</i>               | 18            | .       | .            | 110           | 20           | 148             |
| <i>Carabus syrus</i>                  | 11            | .       | .            | 83            | 11           | 105             |
| <i>Carterus cribratus</i>             | .             | .       | 2            | .             | 9            | 11              |
| <i>Cymindis pallida</i>               | 7             | .       | 2            | 5             | .            | 14              |
| <i>Cymindis spec.</i> <sup>1</sup>    | 6             | .       | 2            | 2             | .            | 10              |
| <i>Eucaraterus sparsutus</i>          | .             | .       | .            | 15            | .            | 15              |
| <i>Harpalus caiphus</i>               | .             | .       | .            | 1             | 4            | 5               |
| <i>Laemostenus quadricollis</i>       | 60            | .       | .            | 1             | 1            | 62              |
| <i>Leistus caucasicus</i>             | 108           | .       | 1            | .             | .            | 109             |
| <i>Macrocheilus saulcyi</i>           | .             | .       | .            | .             | 5            | 5               |
| <i>Metadromius carmelitanus</i>       | .             | 89      | .            | .             | .            | 89              |
| <i>Microdaccus pulchellus</i>         | .             | .       | .            | .             | 4            | 4               |
| <i>Microlestes cf. apterus</i>        | .             | .       | .            | .             | 2            | 2               |
| <i>Microlestes baudii</i>             | .             | .       | .            | .             | 2            | 2               |
| <i>Microlestes maurus</i>             | 5             | .       | .            | 15            | 21           | 41              |
| <i>Nebria hemprichi</i>               | 66            | .       | 7            | .             | .            | 73              |
| <i>Notiophilus danieli</i>            | 3             | .       | .            | 3             | 2            | 8               |
| <i>Odontoncarus asiaticus</i>         | .             | .       | 5            | 65            | 9            | 79              |
| <i>Odontoncarus samson</i>            | .             | .       | 1            | .             | 2            | 3               |
| <i>Olisthopus glabricollis</i>        | 2             | .       | .            | .             | 1            | 3               |
| <i>Ophonus puncticeps</i>             | .             | .       | .            | .             | 2            | 2               |
| <i>Ophonus rufibarbis</i>             | .             | .       | .            | .             | 1            | 1               |
| <i>Orthomus berytensis</i>            | .             | .       | .            | 6             | .            | 6               |
| <i>Orthomus sidonicus</i>             | 1614          | .       | 16           | .             | .            | 1630            |
| <i>Parazuphium spec.</i> <sup>2</sup> | .             | .       | .            | .             | 1            | 1               |
| <i>Paussus turcicus</i>               | .             | .       | .            | .             | 8            | 8               |
| <i>Philorhizus notatus</i>            | .             | .       | .            | 1             | .            | 1               |
| <i>Platyderus spec.</i> <sup>3</sup>  | 1             | .       | 3            | .             | .            | 4               |
| <i>Platyтарus reichei</i>             | .             | .       | .            | .             | 7            | 7               |
| <i>Polyderis cardioderus</i>          | .             | .       | .            | .             | 2            | 2               |
| <i>Pseudaristus punctatissimus</i>    | .             | .       | .            | 1             | 33           | 34              |
| <i>Scarites saxicola</i>              | .             | .       | .            | 73            | 5            | 78              |
| <i>Trechus crucifer</i>               | 1             | 9       | .            | .             | .            | 10              |
| <i>Trechus quadristriatus</i>         | .             | .       | .            | .             | 3            | 3               |
| <i>Trechus saulcyanus</i>             | 266           | 27      | .            | .             | .            | 293             |
| <i>Zuphium numidium</i>               | .             | .       | .            | .             | 2            | 2               |
| Total                                 | 2978          | 141     | 55           | 552           | 262          | 3988            |
| Total species                         | 22            | 5       | 14           | 20            | 32           |                 |

<sup>1</sup> The determination of these beetles was impossible. We agree with MATEU (1956) that in the systematics and taxonomy of the *Cymindis axillaris* group only chaos exists.

<sup>2</sup> It is a microphthalmic *Parazuphium* species which has not been described yet.

<sup>3</sup> The determination of the Israeli *Platyderus* species is not possible for us. A revision of the south-European and southwest-Asian species is urgently necessary.

The ant nest beetle *Paussus turcicus*, the helluonine ground beetle *Macrocheilus saulcyi*, the zuphiine ground beetles *Zuphium numidicum*, *Parazuphium spec.*, and some other species (e.g. *Apotomus clypeonitens*, *Microdaccus pulchellus*) are examples of species found exclusively by hand picking. While only a few specimens of these species were recorded, litter sifting revealed high densities of one species which was not found in pitfall traps: the lebiine *Metadromius carmelitanus*. We also found this litter layer inhabiting ground beetle in high population densities in other woodlands of northern Israel (e.g. several woodlands in Upper Galilee, the Carmel Mountains and the Golan Heights), but not in pitfall traps. *Carabus phoenix* and *Eucarterus sparsutus* are examples of species recorded exclusively from pitfall trapping.

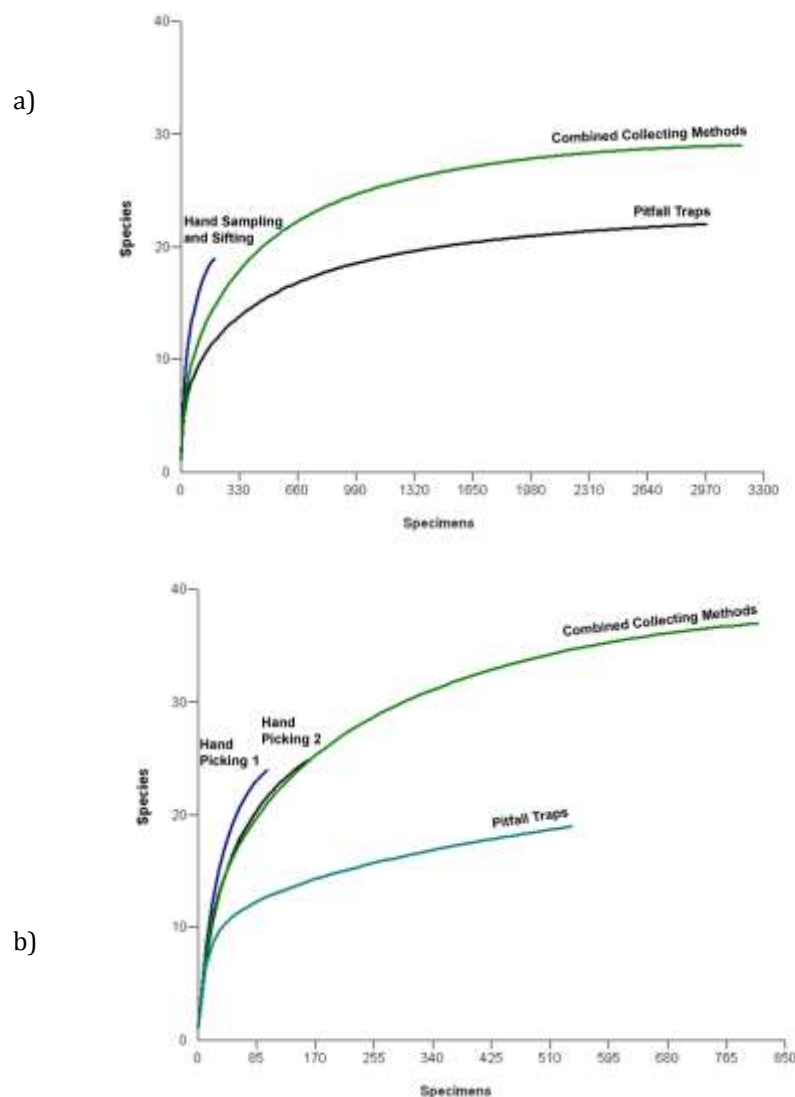
The rarefaction curves (Figures 1a and 1b) as well as Table 1 indicate that the efficiency of the methods used varies, especially in relation to the number of species and specimens recorded and in time required. Hand picking was carried out for a few hours, and the number of specimens collected was relatively low, but the number of species detected by this method was high in comparison to pitfall trapping. Hand picking and sifting raised the total number of species considerably for each site.

## 4. Discussion

### 4.1. Comparison of the methods

Using pitfall traps we caught only ground beetles which move on the ground. Species which inhabit the lower horizons of the soil or on the vegetation are only very seldom recorded. Moreover, the catch rate for epigeic species depends on the “environmental resistance” caused by the vegetation structure which obstructs the beetles in their locomotor activity (HEYDEMANN 1957). The physiological condition of the animals also has an effect on the intensity of locomotor activity and thus also on the catch rates (CHIVERTON 1984). The most important methodological aspect of pitfall traps is that they sample the carabid assemblage independent from the scientist. This is the central aspect which has to be questioned for the other methods we used (hand picking and litter sifting). The success of hand picking depends strongly on the experience of the collector. The species that were caught only by

pitfall traps could, with more intensive work, also have been caught by hand. These species are mostly rare species, some of which occur only during specific seasons (e.g. *Eucartermus sparsutus* in summer) when no hand picking took place. Furthermore, the beetle findings depend on the collector's subjective view and also on the point of collection. *Ophonus puncticeps* and *O. rufibarbis* as well as *Parazuphium spec.* from the batha site are good examples: each species was recorded by a different collector (but none by pitfall traps). Given the few hours that were invested to obtain the additional samples by hand picking or sifting, the efficiency of these "methods of beetle collecting" is substantial.



**Figure 1:** Species richness (rarefaction) in the woodland site (1a; above) and the batha sites (1b; below). 'Hand Picking 1' and 'Hand Picking 2' refer to the results of two collectors.

Nevertheless, using a variety of methods rather than only pitfall traps gives a different impression of the carabid assemblages in a study area. RENNER (1980) showed the difference between pitfall traps and some other catching methods (e.g. taking soil samples, checking tree trunks and mushrooms). He indicated that with a combination of different methods 25% more species were caught as if only pitfall traps were used. In our case, the combination of different methods doubled the species number in the batha and enabled us to catch nearly 50% more species in the woodland. In some other sclerophyllic woodlands of the Mediterranean region, species scarcity has also been demonstrated within the ground beetle assemblage (e.g. 4 species for the karst formation of Trieste, BRANDMAYR et al., 1983). In other regions of the Mediterranean the species number clearly seems to be higher (e.g. in Calabria: 26 species following PIZZOLOTTO et al., 2005; in Central Spain: 20 species following SERRANO et al., 2005). We found 30 species in the sclerophyllous oak woodland we studied in Upper Galilee. This number exceeds even those of some beech dominated stands of Mediterranean mountains (e.g. BRANDMAYR et al., 1983; PIZZOLOTTO et al., 2005). In general, species richness of our sclerophyllous woodland site is comparable to other habitats of the Mediterranean.

#### 4.2 Composition of the carabid assemblages

Digging ground beetles, such as harpalines and, to a lesser extent, zabrines, are characteristic for Mediterranean habitats. They carry seeds and other plant parts to underground chambers to supply their offspring with food (BRANDMAYR et al., 1983; BRANDMAYR and ZETTO BRANDMAYR 1987; ZETTO BRANDMAYR 1990). In Israel, we found several species from this guild (e.g. *Odontocarus samson*, *O. asiaticus*, *Pseudaristus punctatissimus*). These species exhibit epigeic activities when foraging and are therefore well represented in pitfall traps. In the Mediterranean habitat, some species of the subfamily Harpalinae can be found, especially during the brood care period, inside the soil and under large stones, as described by BRANDMAYR and ZETTO BRANDMAYR (1987).

Predominantly epigeic active species can be divided by their functional morphology into two groups: pushers and runners. These include, for example, species of the genera *Carabus*, *Orthomus* and *Nebria* (EVANS and FORSYTHE 1984) or visually hunting species e.g. *Notiophilus danieli* (cf. BAUER 1975). These species are not only known

from Mediterranean habitats, but also from temperate and boreal climate regions (e.g. GUENTHER and ASSMANN 2004; SPENCE et al., 1996; SROKA and FINCH 2006). Species that are associated with ant nests are not found at all in cooler regions but are very common in warmer areas, and we found two species of this group, *Paussus turcicus* and *Macrocheilus saulcyi*, on our batha sampling site. The relationship of ant nest beetles to ants is well documented. *Paussus turcicus*, for example, lives, like the common west Mediterranean *Paussus favieri*, in the ant nests of *Pheidole pallidula* (ESCHERICH 1898). We observed *Macrocheilus saulcyi* several times in Israel: in most cases the specimens were associated with ants. A trophic relationship between army ants (*Neivamyrmex nigrescens*) and adults of two Nearctic helluonine species (*Helluomorphoides latitarsis* and *H. ferrugineus*) has already been documented by TOPOFF (1969). REICHARDT (1974) dissected many South American species of this group and found fragments of ants in the gut. He took this as evidence that the group of Helluomorpha is a predator of ants. We assume that the representatives of this group in Africa and Asia also feed on ants. In addition to the Paussinae and the helluomorphines species, *Pseudotrechus mutilatus* is also found living in ant nests; in the Mediterranean this species lives in the nests of the ant *Messor barbarus* (cf. ANTOINE 1963).

We found this species frequently in southern Spain and in the Maghreb; it was not, however, caught in pitfall traps. The low epigeic activity of this ecological group could be the reason for their under-representation in pitfall trap catches.

Another group that is very characteristic for the Mediterranean region is that of the endogeic and hypogean species (cf. CASALE et al., 1998). The superficial underground compartment, described by JUBERTHIE et al., (1981), harbours not only blind species (DROVENIK et al., 2008) but also species with reduced eyes (e.g. *Limnastis galilaeus* and *Parazuphium chevrolati*, NITZU and DECU 1998). Both zuphiine species that were found in the batha site belong to these microphthalmic ground beetles. While only few species of the latter group can be found using non-trapping methods, the high densities of *Metadromius carmelitanus* detected this way are noteworthy. This lebiine species was found more frequently in the sifting samples than the *Trechus* species, but never occurred in pitfall traps, while this latter method served well to detect the Trechini. The tarsi of most lebiine beetles are equipped with a large

number of adhesive setae, in contrast to the trechine beetles, which have only a few (cf. SCHÜRSTEDT et al., 2000). It is possible that, with the help of these setae, *M. carmelitanus* is able to escape from the traps. This would, in view of the fact that no other carabid beetle has a higher density than *M. carmelitanus* in these woodlands, at least explain the absence of this beetle in pitfall traps. Although we recorded a large variety of species and employed different capture methods, our data do not present a complete picture of ground beetle species in the region: species living in the canopy of the woodlands were not included. Several species of *Calosoma* (LÖBL and SMETANA 2003) have been recorded for Israel and we also know *Lebia rutilicollis* from trees in Upper Galilee. Therefore, it is very likely that the real number of species at the study sites is still undocumented, in spite of the fact that various catching methods were used.

#### 4.3 Monitoring carabid beetles: Methodology

In Europe, but also in North America, beetles are increasingly being considered in conservation biology (e.g. Red Lists, the Habitat and Species Directive of the European Union). Ground beetles are also very important for the description of changes in habitats (BUTTERFIELD et al., 1995; PEARCE and VENIER 2006; RAINIO and NIEMELÄ 2003; SSYMANK 1994), because they appear in almost all terrestrial habitats and show some remarkable trends in their population-dynamic development (LINDROTH 1972). If Carabidae should receive comparable importance in Israel, we should not only use pitfall traps as a tracking method, but must also take other methods into consideration. If the results of these "alternative" sampling methods are to be compared satisfactorily, standards have to be developed for them. This might be possible for sifting if defined areas are sampled (for example, through screening and selection of 10 times 0.25 m<sup>2</sup>, cf. SPENCE and NIEMELÄ 1994 and a defined depth of 5 cm). We doubt whether comparable standardization is possible for hand picking. However, we suggest that this method nonetheless should be carried out, as it can at least prove the presence of some species of certain ecological groups or guilds (e.g., myrmicophilic, endogeic species).

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## **II At the interface of historical and present day ecology: Ground beetles (Coleoptera: Carabidae) in woodlands and open habitats in Upper Galilee (Israel)**

ANIKA TIMM, JÖRN BUSE, TAMAR DAYAN, WERNER HÄRDTLE, TAL LEVANONY & THORSTEN ASSMANN (2009):  
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## Abstract

Mediterranean landscapes have been used by humans for thousands of years, particularly as regards to some areas of the East Mediterranean, e.g. in Israel. This land use had profound effects on the dynamics of the woodlands in time and space, with the result that woodland regeneration was only possible during periods of low human population density and hence low levels of grazing. The aim of the paper is therefore to answer the question as to how woodland species have been able to cope with the rapidly changing habitats. The study sites are located in the Upper Galilee (northern Israel) and comprise two old-growth woodlands, two recent woodlands and two open habitats. Ground beetles were sampled over a period of one year using 10 pitfall traps per study site. The wing development of all sampled species was checked. Carabid beetles belonging to 21 genera and 34 species were found. Most individuals were found in old-growth woodlands. On the basis of a detrended correspondence analysis (DCA) habitat preferences of three ground beetle groups could be distinguished: old-growth woodland species, species of recent woodlands and species of open habitats. We found that two-thirds of the group of open habitat species are brachypterous and three out of the four woodland species are macropterous. Since woodlands with a long ecological continuity are also important for other groups of organisms such as saproxylic beetles, we recommend the conservation of all woodland development stages in the study area.

Keywords: habitat continuity, habitat selection, hindwing polymorphism, Mediterranean, Middle East, pitfall traps, *Quercus calliprinos*

## 1. Introduction

Mediterranean lands have been used by man for thousands of years. In many regions utilization was very intensive and led to the disappearance of the natural evergreen oak woodlands (GROVE and RACKHAM 2003). In some areas of the Eastern Mediterranean, land use was so intensive that woodlands were only able to survive for short periods and in small areas. The Mediterranean part of Israel is an example of the interrupted habitat continuity of woodlands in the Eastern Mediterranean. It has been intensively influenced by man for at least 5000 years (cf. NAVEH and DAN 1973). Except for some very small stands surrounding sacred places, the natural

arboreal vegetation has been almost completely transformed or destroyed, and now mostly forms steppe-like, intensively grazed habitats (so-called batha) and arable fields (e.g. LIPHSCHITZ and BIGER 1990). In correlation with population density, phases of intensive land use, accompanied by the destruction of large woodland areas, alternated with phases of less intensive land use (cf. ZOHARY 1960). During the periods of marginal land use, small shrub-like oaks and maquis were able to develop into trees which could potentially have formed Mediterranean woodlands if they had not been destroyed during the phases of intensive land use which followed. This situation remained unchanged until the early years of the last century. During the First World War the Turkish army cut down most of the few remaining or regenerated native woodlands in order to feed the train steam engines. Woodlands have been able to recover and large areas have been afforested only since 1920 (YOM-TOV and MENDELSSOHN 1988). Today, Israel's largest native woodlands exist in the Galilee and most of them are less than 100 years old.

In view of the historical development of Israel's Mediterranean landscape, the question arises as to how woodland species have been able to cope with the rapidly changing habitats. This field study addressed this question; carabid beetles were chosen as study objects for a number of reasons. The hindwing polymorphism and thus the ability to fly provides information about these beetles' power of dispersal (e.g. DEN BOER 1970). In addition, several species known from other regions are indicators of a particular kind of land-use history (ASSMANN 1999; DESENDER et al., 1999). Moreover, this group is known for its wide spectrum of diverging stenotypes ranging from eurytopic to stenotopic species and the representatives are easy to catch in pitfall traps. The stenotopic species in particular show a high indicator value for different environmental conditions (RAINIO and NIEMELÄ 2003).

Recent studies have underlined the importance of woodlands with different habitat continuity in Central and Western Europe (e.g. GROVE and RACKHAM 2003; PETERKEN 1993). These studies distinguish between woodlands which have shown a long period of habitat continuity (ancient woodlands) and habitats which have developed over recent centuries due to afforestation or succession (recent woodlands). Some ground beetle species are restricted to ancient woodlands, whereas other ground beetle woodland species, especially those that are macropterous, live in both ancient

and recent woodlands (ASSMANN 1999; DESENDER et al. 1999). However, some brachypterous species have also been able to recolonise recent woodlands (DREES et al., 2008).

GROVE AND RACKHAM (2003) define ancient woodlands in the Mediterranean area as woodlands that have expanded prior to the last one hundred and fifty years. This definition of ancient woodlands differs from that for ancient woodlands in Western and Central Europe. To avoid confusion between these two definitions, we use the term 'old-growth woodland' rather than ancient woodlands. Our definition of old-growth woodland is based on the first accurate maps of Palestine which were drawn by the Palestine Exploration Fund (P.E.F.) in the 1870s (1871-1878) and subsequent maps.

In view of Israel's specific landscape history, the two main questions asked in this study are whether woodland ground beetle species have been able to survive and, if so, to which dispersal group they belong.

## 2. Material and Methods

### 2.1. Study sites

The study sites are located in the Upper Galilee, northern Israel, near the Lebanese border and close to the villages of Bar'am, Ziv'on and Hurfesh. All sites are on terra rossa soils on hard limestone. We divided the research areas into old-growth woodlands (A, B), recent woodlands (C, D) and open habitats (E, F). The age of the stands was determined using historical maps (from 1878, 1928, 1966, 1976, 1986, 1990 and 2001), aerial photographs from the 1940s and 2000 and information from experts in landscape history of the Galilee (SALMON & TAUBER, personal communication). All sites were in the past temporarily open spaces, as numerous man-made terraces indicate.

The old-growth woodlands contain about 10 m tall trees of *Quercus calliprinos* (dominant tree species), *Pistacia palaestina* and *Quercus boissieri*. Accompanying tree and shrub species are *Pistacia atlantica*, *Laurus nobilis* and *Rhamnus punctatus*. Lianas such as *Smilax aspera* and many herbaceous species are widely distributed. The woodland of Bar'am (site A) is the oldest natural oak woodland in the Galilee

and is already indicated as woodland on the historical maps of the Palestine Exploration Fund (1878), showing that it is at least 130 years old. The old woodland close to Hurfesh (site B) was first depicted on maps edited by British Mandate authorities in 1925. Unfortunately, no maps or historical documentations are available for earlier periods, but from the width of the oak trunks it can be assumed that the woodland of Hurfesh is 80 years or older.

The two recent woodlands are less than 50 years old, and the trees are about 5 m high. The dominant tree species is *Quercus calliprinos*.

The open sites are treeless and the vegetation is dominated by grasses and semi-shrubs, especially *Sarcopoterium spinosum*, *Cistus salviifolius* and *Cistus creticus*. This vegetation formation is also known as 'batha' (DANIN and ORSHAN 1999). The open sites are about 300 m away from the woodlands.

## 2.2. Sampling

During the sampling period (March 2005 - March 2006) pitfall traps with a diameter of 10 cm were used. The traps were filled with the liquid (a mixture of ethanol, glycerol, acetic acid and water) described by RENNER (1980). A transect of 100 m comprising one pitfall trap every 10 m was used on every site. This resulted in a total of 60 pitfall traps. The traps were emptied every second week.

In winter the pitfall traps were filled with approximately 2 cm of the preserving liquid in order to prevent flooding. In summer they were filled with approximately 4 cm of the preserving liquid to prevent them drying out. The exact geographical position and sampling dates of the sites are given in Table 1. The raw number of individuals per species had to be corrected because of losses of pitfall traps caused by grazing animals and wild boars. When traps were lost, the method of standardisation with respect to seasonality as suggested by KOTZE and LEHVÄVIRTA (2005) was used: The average value of the catches of functioning pitfall traps on the respective site (from the same catching period) was taken as a value for the lost catches. The resulting value is called catch rate (specimens per pitfall trap, site or overall).

**Table 1:** Characterisation of the sampling sites

| Site | Name         | Characterisation    | Geographical Position   | Height Above Mean Sea Level | Date of Sampling                        | pH-value                                     |
|------|--------------|---------------------|-------------------------|-----------------------------|---|--|
| A    | Ya'ar Bar'am | Old-growth woodland | N 033°02',<br>E 035°25' | 674m                        | 14/03/2005<br>- 17/03/2006              | O-horizon 5.7<br>A <sub>h</sub> -horizon 7.2 |
| B    | Hurfesh      | Old-growth woodland | N 032°60',<br>E 035°22' | 664m                        | 07/03/2005<br>- 18/03/2006              | O-horizon 6.6<br>A <sub>h</sub> -horizon 7.2 |
| C    | Ziv'on       | Recent woodland     | N 033°02',<br>E 035°25' | 773m                        | 11/03/2005<br>- 17/03/2006              | O-horizon 6.1<br>A <sub>h</sub> -horizon 7.2 |
| D    | Hurfesh      | Recent woodland     | N 032°60',<br>E 035°22' | 706m                        | 08/03/2005<br>- 17/03/2006              | O-horizon 5.9<br>A <sub>h</sub> -horizon 7.2 |
| E    | Ziv'on       | Open site           | N 033°01',<br>E 035°25' | 712m                        | 14/03/2005<br>- 17/03/2006              | O-horizon 6.0<br>A <sub>h</sub> -horizon 7.4 |
| F    | Hurfesh      | Open site           | N 033°01',<br>E 035°21' | 675m                        | 09/03/2005<br>- 17/03/2006 <sup>1</sup> | O-horizon 5.9<br>A <sub>h</sub> -horizon 7.4 |

<sup>1</sup>Due to a high number of losses and disturbances during the sampling period, the study site had to be shifted to a neighbouring site.

### 2.3. Identification

Due to the lack of an identification key for the ground beetles of Israel, a large number of related published sources were used to identify the samples (for example: ASSMANN et al., 2008; BATTONI and VERESCHAGINA 1984; HOLDHAUS 1912; HUBER and MARGGI 1997; TRAUTNER and GEIGENMÜLLER 1987). In addition, we compared our material with the collections of carabid taxonomists, e.g. David Wrase (Berlin). We checked all caught specimens for their hindwing development and all relevant literature in order to obtain data on the power of dispersal.

### 2.4. Statistical methods

The number of individuals per species for each site was corrected with the rarefaction procedure for continuous sampling (HURLBERT 1971), which uses the sample with the smallest number of individuals in each group as reference. Rarefaction procedure was performed using the free statistical program Biodiversity Pro (MC ALEECE 1997). A detrended correspondence analysis (DCA) was used to differentiate the ground beetle assemblages. The analysis was performed using the program Canoco for Windows (TER BRAAK 1996). This method has been widely used in studies of the relationship between carabid distribution and environmental



characteristics (e.g. DESENDER and VAN DEN BUSSCHE 1998; IRMLER and HOERNES 2003). Since samples of species with less than ten individuals would contribute only insufficient information to the analysis, the study is based on species with at least ten specimens caught during the study period. For this reason, only 23 out of the 34 species recorded were used for the analysis.

### 3. Results

The catch rate for all the samples together is 5258.3 (real number of specimens was 4389) belonging to 21 genera and 34 species (Table 2). Most individuals (64%) were found in old-growth woodlands, 14% in recent woodlands and 22% in open habitats. In fact, 57% of all beetles were caught in the old-growth woodland of Bar'am (site A). The lowest number of beetles (5%) was caught in the recent woodland of site D. Most specimens belonged to the species *Orthomus sidonicus* (with a catch rate of 1897.8 specimens) and *Calathus longicollis* (with a catch rate of 1397.9 specimens). The species richness differed strongly between old-growth woodlands and open habitats. The rarefied species richness (Fig. 1) is clearly highest in open habitats, followed by recent woodlands, and the lowest species richness was estimated for the old-growth woodlands.

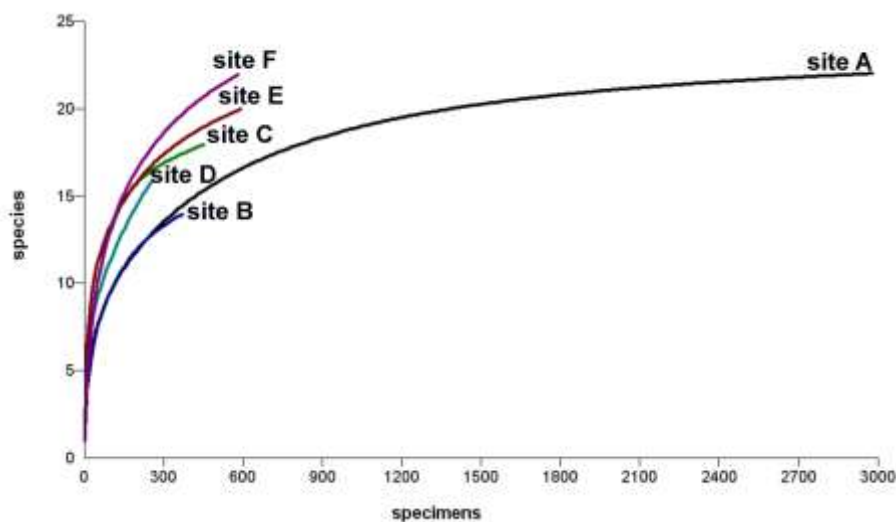


Figure 1: Species richness (rarefaction) in the different sampling sites.

**Table 2:** Catching rate for all species found at the different sampling sites, including wing polymorphism (WP): macropterous (m), dimorphic (d) and brachypterous (b)

| species   | site | A             | B            | C            | D            | E            | F            | WP | Total         |
|---|------|---------------|--------------|--------------|--------------|--------------|--------------|----|---------------|
| <i>Amara aenea</i> (DeGeer, 1774)                                 |      | .             | .            | .            | .            | .            | 3.8          | m  | 3.8           |
| <i>Bembidion liliputanum</i> (Sahlberg, 1908)                     |      | 1.3           | .            | 7.4          | .            | .            | .            | b  | 8.7           |
| <i>Bembidion leucoscelis</i> Chaudoir, 1850                       |      | .             | .            | .            | .            | .            | 11.0         | b  | 11.0          |
| <i>Bembidion phoeniceum</i> Huber & Marggi, 1997                  |      | 4.9           | 3.3          | 2.0          | 1.1          | .            | 1.0          | m  | 12.3          |
| <i>Brosicus laevigatus</i> (Dejean, 1828)                         |      | 18.0          | .            | .            | .            | 18.7         | 87.6         | m  | 124.3         |
| <i>Brosicus nobilis</i> (Dejean, 1828)                            |      | 5.8           | .            | .            | .            | 3.0          | 7.3          | m  | 16.1          |
| <i>Calathus cinctus</i> Motschulsky, 1850                         |      | 111.0         | 1.0          | 5.5          | 1.3          | 1.1          | 33.5         | b  | 153.4         |
| <i>Calathus longicollis</i> Motschulsky, 1865                     |      | 657.7         | 100.7        | 244.2        | 26.1         | 49.8         | 319.4        | d  | 1397.9        |
| <i>Carabus impressus</i> Klug, 1832                               |      | 7.6           | 2.0          | 46.6         | 42.2         | 59.1         | 16.1         | b  | 173.6         |
| <i>Carabus phoenix</i> Lapouge, 1925                              |      | 1.6           | 31.9         | .            | 19.7         | .            | 1.3          | b  | 54.5          |
| <i>Carabus piochardi</i> (Géhin, 1884)                            |      | 4.2           | .            | 6.3          | 1.0          | 70.2         | 12.3         | b  | 94.0          |
| <i>Carabus sidonius</i> Lapouge, 1907                             |      | 18.2          | 4.0          | 36.5         | 35.3         | 110.8        | 25.9         | b  | 230.7         |
| <i>Carabus syrus</i> Roeschke, 1898                               |      | 11.4          | .            | 3.3          | 5.0          | 83.8         | 2.1          | b  | 105.6         |
| <i>Cymindis pallida</i> Reiche, 1855                              |      | 7.0           | .            | 13.9         | .            | 5.1          | .            | b  | 26.0          |
| <i>Cymindis spec.</i> <sup>1</sup>                                |      | 6.4           | .            | 3.5          | 6.3          | 2.0          | .            | b  | 18.2          |
| <i>Eucarterus sparsutus</i> (Reitter, 1898)                       |      | .             | .            | .            | .            | 14.9         | .            | m  | 14.9          |
| <i>Harpalus caiphus</i> Reiche & Saulcy, 1855                     |      | .             | .            | .            | .            | 1.0          | 2.3          | m  | 3.3           |
| <i>Laemostenus cf. libanensis</i> (Piochard de la Brûlerie, 1876) |      | .             | .            | .            | 1.0          | .            | .            | b  | 1.0           |
| <i>Laemostenus quadricollis</i> (Redtenbacher, 1843)              |      | 60.0          | 2.1          | 51.9         | 2.1          | 1.1          | 3.5          | b  | 120.7         |
| <i>Leistus caucasicus</i> Chaudoir, 1867                          |      | 109.1         | 21.1         | 1.4          | 1.4          | .            | .            | m  | 133           |
| <i>Microlestes maurus</i> (Sturm, 1827)                           |      | 4.9           | 6.3          | 5.0          | 24.7         | 13.1         | 34.5         | b  | 88.5          |
| <i>Nebria hemprichi</i> Klug, 1832                                |      | 67.6          | 3.6          | 4.8          | .            | .            | .            | m  | 76.0          |
| <i>Notiophilus danieli</i> Reitter, 1897                          |      | 2.5           | 1.0          | 8.6          | .            | 3.0          | 9.5          | m  | 24.6          |
| <i>Ocys quinquistriatus</i> (Gyllenhal, 1810)                     |      | .             | .            | 1.0          | 1.3          | .            | 1.1          | m  | 3.4           |
| <i>Odotoncarus asiaticus</i> (Chaudoir, 1852)                     |      | .             | .            | .            | .            | 65.0         | .            | m  | 65.0          |
| <i>Olistopus glabricollis</i>                                     |      | 1.5           | .            | .            | .            | .            | 1.1          | m  | 2.6           |
| <i>Orthomus berytensis</i> (Reiche und Saulcy, 1855)              |      | .             | .            | .            | .            | 6.0          | 2.0          | b  | 8.0           |
| <i>Orthomus sidonicus</i> Chaudoir, 1873                          |      | 1614.1        | 175.0        | 9.9          | 91.4         | 2.8          | 4.6          | b  | 1897.8        |
| <i>Platyderus spec.</i> <sup>2</sup>                              |      | 1.4           | .            | .            | .            | .            | .            | b  | 1.4           |
| <i>Pseudaristus punctatissimus</i> (Baudi di Selve, 1894)         |      | .             | .            | .            | .            | 1.4          | .            | m  | 1.4           |
| <i>Scarites saxicola</i> Bonelli, 1813                            |      | .             | .            | .            | .            | 80.7         | .            | b  | 80.7          |
| <i>Trechus crucifer</i> Piochard de la Brûlerie, 1876)            |      | 1.4           | 1.0          | 4.1          | .            | .            | 1.0          | m  | 7.5           |
| <i>Trechus quadristriatus</i> (Schrank, 1781)                     |      | .             | .            | .            | .            | .            | 2.0          | m  | 2.0           |
| <i>Trechus sauleyanus</i> Csiki, 1928                             |      | 270.7         | 23.7         | .            | 2.0          | .            | .            | m  | 296.4         |
| <b>Total</b>  |      | <b>2988.3</b> | <b>376.7</b> | <b>455.9</b> | <b>261.9</b> | <b>592.6</b> | <b>582.9</b> |    | <b>5258.3</b> |

<sup>1</sup> The determination of these beetles was impossible.<sup>2</sup> The determination of the Israeli *Platyderus* species is impossible to date. A revision of the South European and Southwest Asian species is urgently needed.

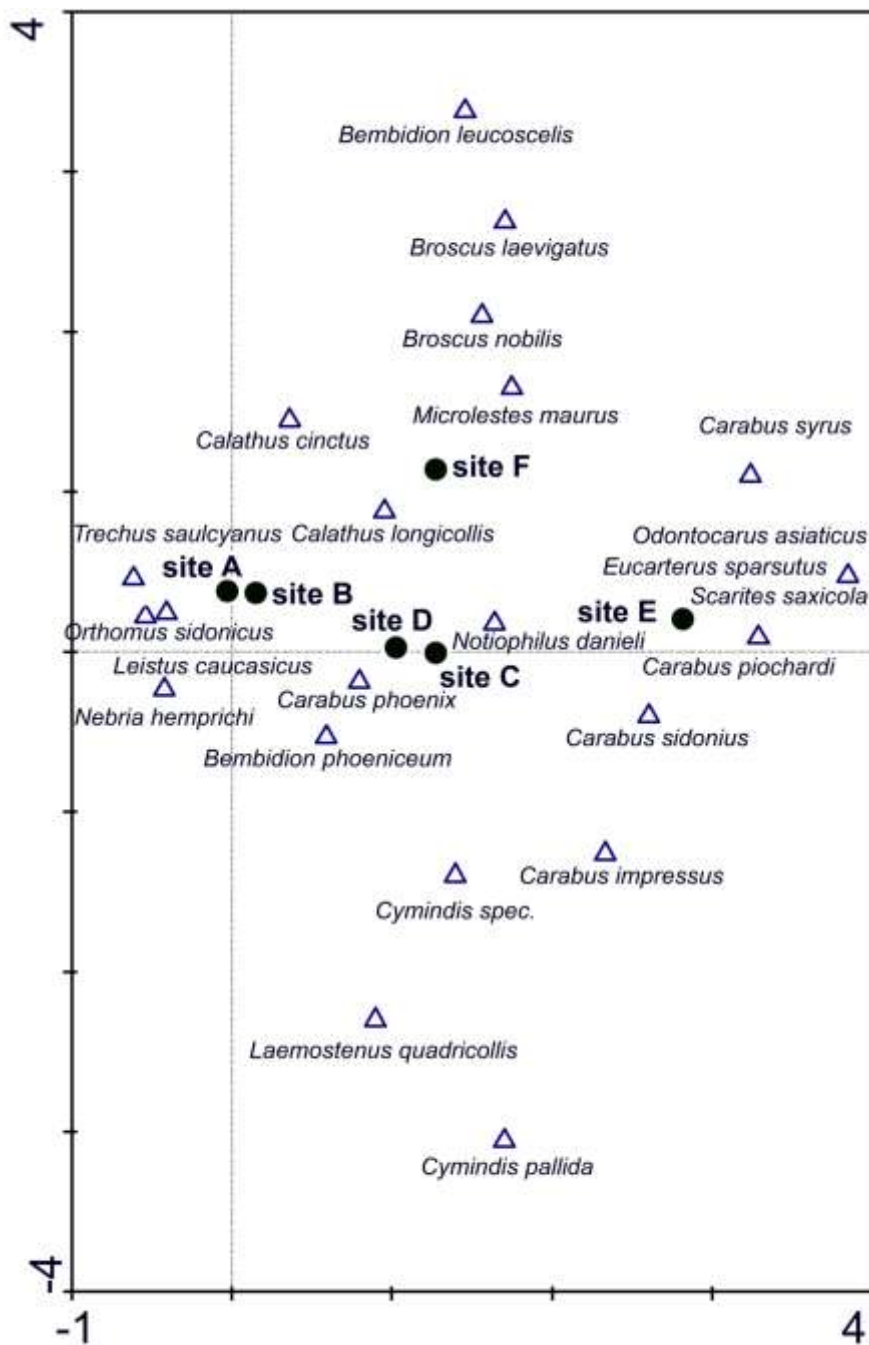
### 3.1. Habitat preferences

The detrended correspondence analysis (DCA) explains a total variation of 74.9% (total inertia 1.164, length of gradient 2.862 SD units). Of these, 63.1% (eigenvalue of 0.631) are explained by axis 1, whereas the second axis adds 11.8% (eigenvalue of 0.118). On the basis of the DCA it is possible to distinguish three ground beetle groups (Fig.2). Sites A and B (old-growth woodlands) show similar values in the ordination. Species with preferences for these sites are *Leistus caucasicus*, *Nebria hemprichi*, *Orthomus sidonicus* and *Trechus saulcyanus*, hereafter referred to as woodland species. *Carabus phoenix*, *Bembidion phoeniceum* and *Notiophilus danieli* seem to be characteristic for the recent woodlands (sites C, D). The variance of the carabid fauna of open habitats is greater and the species are more scattered in the ordination. These species are differentiated along the second axis. The species exclusively or more frequently found at site F are *Bembidion leucoscellis*, *Broscus laevigatus*, *Broscus nobilis*, *Calathus cinctus*, *Calathus longicollis* and *Microlestes maurus*. Another set of species with a preference for open habitats was found at site E (*Eucarterus sparsutus*, *Scarites saxicola*, *Odontocarus asiaticus*, *Carabus syrus*, *Carabus piochardi* and *Carabus sidonius*) on the second axis. Some species (*Carabus impressus*, *Cymindis pallida*, *Cymindis spec.* and *Laemostenus quadricollis*) cannot be attached clearly to one of the groups. These species occur in all three habitat types. In general, the first DCA axis coincides with a gradient from old-growth woodlands to open sites. The second axis differentiates the species of the two open habitat sites, indicating the heterogeneity of the ground beetle fauna of this habitat type.

### 3.2. Hindwing polymorphism

Altogether, half of the species found were brachypterous. Only one species is dimorphic (*Calathus longicollis*): this species was found on all sampling sites. In all sites there were more brachypterous than macropterous species. On sites A, C and E one third of the species found were macropterous and two thirds brachypterous. On sites B and F about 50% of the species found were macropterous and brachypterous respectively, and nearly 70% of all the species found on site D were brachypterous. Of the woodland species, defined by the DCA, 3 out of 4 species were macropterous.

All individuals of the genus *Trechus* were macropterous. Two of the three *Bembidion* species were brachypterous, one was macropterous.



**Figure 2:** DCA ordination diagram (species and sample scores together) along the first and second axis based on ground beetles in all the sampling sites.

## 4. Discussion

### 4.1. Habitat preferences

A number of studies on the ground beetle fauna of Mediterranean woodlands dealt with deciduous oak woodlands (BRANDMAYR et al., 1996; BRANDMAYR and PIZZOLOTTO 1990; SALGADO et al., 1997) or pine stands (TABOADA et al., 2008). Other studies investigated ecological factors such as slope aspects (CHIKATUNOV et al., 2004) or evaluated habitat management opportunities such as burning (NUNES et al., 2006). NITZU (1997) used the carabid fauna to compare different habitat types throughout Israel. To date, however, no study has been conducted on the ground beetle fauna of differently aged Mediterranean evergreen oak woodlands. We identified species which are restricted to woodlands (*Leistus caucasicus*, *Nebria hemprichi*, *Orthomus sidonicus* and *Trechus saulcyanus*). This is in agreement with other Mediterranean studies in which species restricted to woodlands were found (e.g. AVGIN 2006; BRANDMAYR et al., 1983; DE LA PEÑA et al., 2003; PAWŁOWSKI 1979). In our study *Trechus crucifer* preferred woodland habitats and *Trechus quadristriatus* was found in open habitats; this corresponds to the description given by PAWŁOWSKI (1979). Another *Trechus* species with a preference for woodland habitats is *Trechus saulcyanus*. SALGADO et al. (1997) found four *Calathus* species exclusively in evergreen oak woodlands in western Spain. Both *Calathus* species found in our study occur at high abundance in the woodlands but nevertheless they seem to show a preference for open habitats over woodlands. The two *Cymindis* species found in our study inhabit all three habitats and not predominantly open habitats as do most of the European species of this genus (cf. BRANDMAYR ET AL. 1996; TABOADA ET AL., 2004). Much the same seems to be true for the *Carabus* species. *Carabus* species in Europe are mainly specialists either of woodlands or open habitats (or of specific types of these habitats); some are even indicators of ancient woodlands (ASSMANN 1999). In our study only *Carabus phoenix* shows a clear tendency towards one of the habitats (recent woodlands). The other *Carabus* species were found in both open habitats and woodland habitats. Therefore, these species seem to be eurytopic. This statement is supported by other samplings from Israel (ASSMANN et al. 2008). *Carabus* species with a preference for woodlands are mentioned in other Mediterranean woodlands studies (e.g. *Carabus coriaceus* by BRANDMAYR et al. 1983,

*Carabus problematicus* by DE LA PEÑA et al. 2003 and *Carabus syriacus* by AVGIN 2006). However, these species occur, as shown in studies from other regions of the distribution areas or even from the Middle East (ASSMANN et al. 2008; TURIN et al., 2003), in open habitats as well and can therefore also be classified as eurytopic species.

Some studies conducted in Mediterranean evergreen oak woodlands conclude that this kind of woodland has only a low carabid species richness, compared to open habitats (AVGIN 2006) or to deciduous oak woodlands in montane elevations (BRANDMAYR et al. 1983; SALGADO et al. 1997) of the Mediterranean region. We agree with AVGIN (2006) that the species number is higher in the open habitats than in the woodlands.

Various species found in our study are restricted to open habitats (*Amara aenea*, *Bembidion leucoscellis*, *Broscus laevigatus*, *Broscus nobilis*, *Eucarterus sparsutus*, *Harpalus caiphus*, *Odotoncarus asiaticus*, and *Scarites saxicola*). This is in agreement with studies conducted in Europe (e.g. MÜLLER-MOTZFELD 2004; THIELE 1977) and the Mediterranean region (e.g. AVGIN 2006; BRANDMAYR et al. 1996; BRANDMAYR and PIZZOLOTTO 1990), where species of these genera are characterized as species of open habitats.

#### 4.2. Power of dispersal

In general, there was little variation in hindwing development, and thus dispersal power, among the species in the different habitats. However, it is noteworthy that three out of the four species characterized with the help of the DCA as woodland species are macropterous (*Leistus caucasicus*, *Nebria hemprichi*, *Trechus saulcyanus*). The same is true for other species which show a preference for woodlands in northern Israel (e.g. *Trechus crucifer*, PAWŁOWSKI 1979)

The proportion of full-winged woodland carabid species in the woodlands of the temperate and boreal zone is much smaller (cf. ASSMANN 1999; BRANDMAYR et al. 1996; DESENDER et al. 1999). A differentiation of the hindwing development in woodland species has been observed in northern Germany as well as in Flanders. For northern Germany, ASSMANN (1999) showed that the proportion of unwinged woodland species was much higher in ancient woodlands than in recent woodlands.

DESENDER et al. (1999) showed that in Flanders species of open habitats and ubiquitous are mainly macropterous: some are wing dimorphic but none is brachypterous. In contrast, most of the stenotopic woodland species are brachypterous. The observations of DESENDER et al. (1999) and ASSMANN (1999) are explained by winged species having a higher chance of colonizing younger and more instable habitats. With increasing habitat continuity the proportion of unwinged or dimorphic species rises (cf. BRANDMAYR et al. 1996; ROFF 1990; THIELE 1977). For the winged woodland species of our research area it can be concluded that they might have a good dispersal power and be able to colonize new habitats easily. The wide distribution of these species in the Middle East (LÖBL and SMETANA 2003) emphasizes that they are able to spread over vast areas. All three species mentioned above are not exclusively found in woodlands, but also in habitats that have a special microclimate (e.g. the entrance area of caves, cf. PAWŁOWSKI 1979; our observations at Alma Cave and Pa'ar Cave in Upper Galilee). Therefore, it seems that habitat selection makes it possible for these species to survive outside of woodlands. From these hideaways the colonization of new woodland areas is possible.

However, there are also brachypterous woodland species. *Orthomus sidonicus* and *Carabus phoenix* are examples of this. The former is the most common species found in pitfall traps of woodlands. For these species survival during times of woodland devastation was only possible in other habitats. Both species occur in old-growth and recent woodlands, but single specimens were also found in open habitats (Table 2). This suggests that it might be possible for them to survive in times of woodland devastation under strongly browsed shrubs and oaks that do not grow higher than knee height (DANIN 1988), and to spread again after the woodlands have recovered.

In open habitats of the temperate zone the proportion of winged ground beetle species is relatively high (DESENDER et al. 1999). In our study two-thirds of the open habitat species are unwinged. This can be explained with the long-lasting habitat continuity of the open habitats in Israel which leads to low dispersal power in the fauna of carabid beetles. This is true also for large-sized carabid species. The existence of numerous subspecies of *Carabus* species in northern Israel can only be explained with low dispersal power of the taxa. The carabid fauna in the studied habitats shows big differences in hindwing polymorphism to temperate and boreal

regions. These differences, high percentage of winged species in woodlands and high number of unwinged species in open habitats, can be explained by the differences in habitat continuity of woodlands and open habitats.

#### 4.3. Nature conservation

In northern Israel, many, if not all, natural or semi-natural habitats have been severely affected or completely destroyed by urban, industrial and agricultural development and fragmentation or by dense afforestation with non-native trees (e.g. eucalyptus). For this reason all natural or semi-natural habitats are endangered (YOM-TOV and MENDELSSOHN 2004). In the present study, we are able to demonstrate that there are species with preferences for old-growth, recent woodlands and open habitats. Therefore, we believe, that it is necessary to protect all these habitats in future. Some of the ground beetles found in these habitats prefer old-growth woodlands and at least one species prefers recent woodlands (*Carabus phoenix*). Therefore it is necessary to conserve all development stages of woodlands. A high diversity, especially for old-growth woodlands, can be shown for other groups of organisms. Saproxylic beetles are one example for a higher species richness and unique assemblage composition in old-growth oak woodlands in the Upper Galilee (BUSE et al., 2009). Oaks harbour a large number of species already in early successional stages and show a remarkable increase of species richness in later stages when the trees become thicker and have a higher diversity of microhabitats. The occurrence of late-successional beetle species – often with limited dispersal power – is characteristic for mature and old-growth stands in Europe (e.g. RANIUS and JANSSON 2000). Thus, it is very important to allow natural aging of woodlands in the present woodlands in Israel such as the woodland of Bar'am, when considering aspects of species protection and nature conservation in the current land use management. Furthermore, sclerophyllous oak woodlands play an important role for soil formation and stability and are more fire resistant than any other forest or woodland type in the region (DUFOUR-DROR 2005).



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# **III Seasonality and reproduction of ground beetles (Carabidae, Coleoptera) in an Eastern Mediterranean region (Upper Galilee, Israel)**

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(Manuscript)

## Abstract

Studies done in temperate zones have led to a better understanding of distribution trends and specific habitat adaptations of carabids and provided a basis for decisions in long-term monitoring research. In contrast to the temperate zones, little research has been done on the annual cycles of ground beetles in the Mediterranean climate region. In the present paper the seasonal activity and the best sampling period for East Mediterranean ground beetle species are presented and discussed. Three East Mediterranean habitat types (open landscape, recent woodland, old growth woodland) were sampled over one year using pitfall traps. The activity rhythms of the carabids during this period are presented and findings from the dissections of the most common ground beetle species are discussed. Although winter breeding is probably the most important type in the Mediterranean, there are also summer and spring breeders (*Orthomus sidonicus*, *Eucarterus sparsutus*, *Odotoncarus asiaticus*). Ten of the 34 species had their maximum in spring, three in summer, seven in autumn and ten in winter. Four species did not have a clear maximum. Knowledge of the detectability and the seasonality of ground beetle species in Mediterranean habitats and of the most suitable collecting methods and seasons are important for studying the significance of this animal group in landscape planning and biological conservation research approaches. Therefore, it is not only necessary to use different sampling methods, as shown in TIMM et al. (2008), but also to sample the whole year round in order to obtain a detailed spectrum of species for these habitats.

**Keywords:** *Quercus calliprinos*, Middle East, annual rhythms, activity patterns, pitfall traps, ground beetle diversity

## 1. Introduction

The annual rhythms of carabids are adapted to the seasons. Basic types of ground beetle annual rhythms were first described by LARSSON (1939) and later revised and refined by LINDROTH (1949), THIELE (1977) and by DEN BOER and DEN BOER-DAANJE (1990). Surveys of carabids in temperate and boreal climate zones show a clear differentiation between two groups: species with winter larvae and species with summer larvae. The reproduction period of these reproduction types varies over

most of the year. Some species have been predominantly found in one of the four seasons (including the winter, cf. DEN BOER and DEN BOER-DAANJE 1990). There is evidence that reproduction type is highly correlated with habitat preferences (e.g. SCHILLER and WEBER 1975) and activity patterns (THIELE and WEBER 1968). The ecophysiological basis of annual activity patterns, reproduction rhythms, previtellogenesis, vitellogenesis (=oogenesis) and spermatogenesis are well known for some ground beetles (e.g. cf. CÁRDENAS and HIDALGO 2000; FADL, et al. 1996; FERENZ 1975a, 1975b; FERENZ 1986). PAARMANN (1979) presented a model for the possible evolution of reproduction types. One of the key factors for different reproduction types in different habitats seems to be the low capacity of the larvae to survive periods of desiccation (e.g., PAARMANN 1966; THIELE 1964). In dry habitats of the temperate and boreal climate zone autumn breeders with winter larvae are the predominant reproduction type. The general sensitivity of larvae to flooding events (low ability to survive inundations) seems to be the reason why most riparian and wetland ground beetles have summer larvae (THIELE 1977).

Studies done in temperate zones have led to a better understanding of distribution trends, specific habitat adaptations of carabids and provided a basis for decisions in long-term monitoring research (DEN BOER and VAN DIJK 1996; FADL and PURVIS 1998; HARRY, et al.; HUTCHISON 2007; TRAUOGOTT 1998). In contrast to the temperate zones, few studies have been conducted on the annual cycles of ground beetles in the Mediterranean climate region. In the Mediterranean, summer is the hot and rainless season, and rain occurs mainly during winter. In the Mediterranean part of Israel, for example, about 92% of the mean annual precipitation is recorded during winter JAFFE (1988). Following the ecophysiological relationship cited above, the predominant season for larval development in a Mediterranean climate should be winter. However, only a few studies have dealt with the annual reproduction period (e.g. in the western Mediterranean: CÁRDENAS and HIDALGO 2000; COMANDINI and VIGNA TAGLIANTI 1990; PAARMANN 1975; TABOADA, et al. 2004), in particular the species-rich fauna of the East Mediterranean realm is still only poorly known (BODENHEIMER 1934; PAARMANN 1970).

In our study, carabids were sampled over the course of one year using pitfall traps. Analysis of the activity rhythms of the carabids during this period and ovary dissection of the females made it possible to determine the production period of

ground beetles (e.g. LÖVEI and SUNDERLAND 1996; MITCHELL 1963). The aims of our study are (1) to describe the phenology of ground beetles in the Eastern Mediterranean climate region and (2) to determine whether only ground beetles with winter larvae exist in woodlands and open habitats of Israel or whether other reproduction types are also to be found there. Recommendations for recording the maximum number of species for further research on ground beetle diversity in East Mediterranean climate regions were developed.

## 2. Methods

### 2.1. Study sites

The study sites are located in the Upper Galilee, northern Israel, near the Lebanese border and close to the villages of Bar'am, Ziv'on and Hurfesh. All sites are on terra rossa soils on hard limestone. The research areas consist of two old-growth woodlands, two recent woodlands and two open habitats.

The age of the stands was determined using historical maps (from 1878, 1928, 1966, 1976, 1986, 1990 and 2001), aerial photographs from the 1940s and 2000 and information from experts in the landscape history of the Galilee (Salmon and Tauber, personal communication). The old-growth woodlands are older than 80 years and contain about 10 m tall *Quercus calliprinos* (dominant tree species), *Pistacia palaestina* and *Quercus boissieri*. Accompanying tree and shrub species are *Pistacia atlantica*, *Laurus nobilis* and *Rhamnus punctatus*. Lianas such as *Smilax aspera* and many herbaceous species are widely distributed. The two recent woodlands are less than 50 years old, and the trees are about 5 m high. The dominant tree species is *Quercus calliprinos*. The open sites are treeless and the vegetation is dominated by grasses and semi-shrubs, especially *Sarcopoterium spinosum*, *Cistus salviifolius* and *Cistus creticus*. For a detailed description of the study sites see TIMM, et al. (2009).

### 2.2. Sampling

During the sampling period (March 2005 - March 2006) pitfall traps with a diameter of 10cm were used. The traps were filled with liquid as described by RENNER (1980), i.e. a mixture of ethanol, glycerol, acetic acid and water. A transect of 100 m



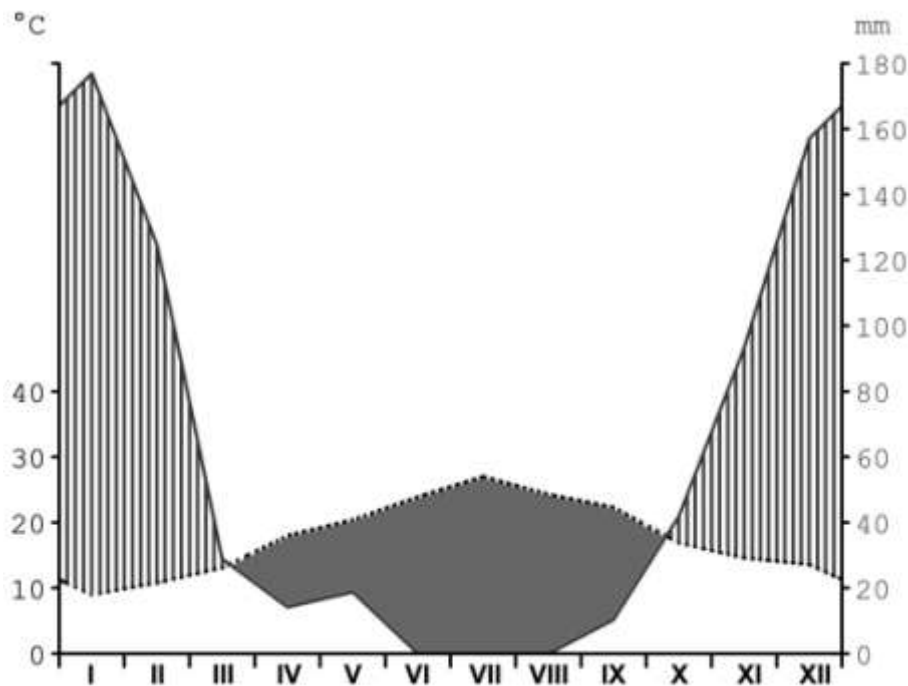
comprising one pitfall trap every 10m was used on every site. This resulted in a total of 60 pitfall traps. The traps were emptied every second week.

In winter the pitfall traps were filled with approximately 2cm of the preserving liquid in order to prevent flooding. In summer they were filled with approximately 4cm of the preserving liquid to prevent them drying out. The raw number of individuals per species had to be corrected due to losses of pitfall traps caused by grazing animals and wild boars. When traps were lost, the method of standardisation with respect to seasonality as suggested by KOTZE and LEHVÄVIRTA (2005) was used. The average value of the catches of functioning pitfall traps on the respective site (from the same catching period) was taken as a value for the lost catches.

### 2.3. Dissection

We dissected the females of the seven most common species (*Broscus laevigatus*, *Calathus cinctus*, *Calathus longicollis*, *Carabus impressus*, *Carabus sidonicus*, *Orthomus sidonicus*, *Trechus saulcyanus*). Whenever it was possible, at least ten female specimens per sampling date and species were dissected for chorionized eggs. In cases where we had less than ten females of the species, all females available were dissected. Additionally, we checked the available literature for the reproduction types of the species found.

According to JAFFE (1988) spring in Israel lasts from the first half of March to the first half of June; summer lasts from the first half of June to the first half of September; autumn from the second half of September to the first half of November, and winter from the second half of November to the first half of March. We follow this definition in our paper. During the sampling period, weather data was collected at Meron field school, close to the sampling sites. This data was used to create a climograph with the help of the computer program Geoklima (HANISCH and SCHULZ 1995-2008), see Figure 1.



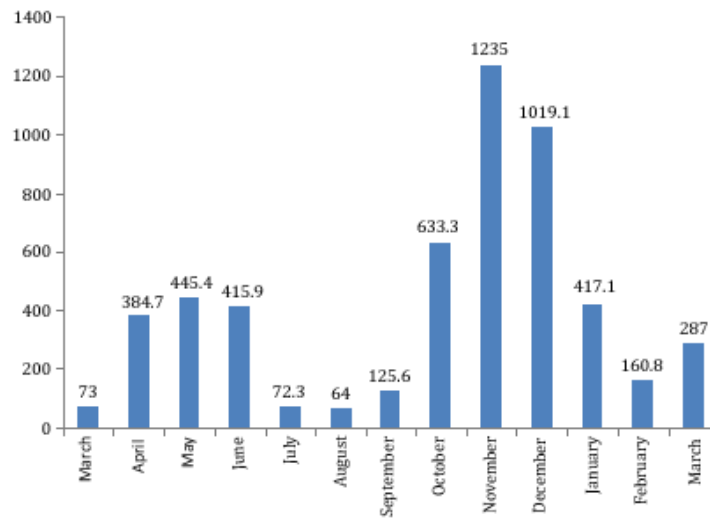
**Figure 1:** Climograph for Meron Field School (Upper Galilee, Israel), based on WALTER and LIETH (1960), with monthly average temperature (dotted line) and precipitation (continuous line) for March 2005 - February 2006; the hatched area is the wet period and the shaded area the dry period (dry period is the period when the precipitation line is below the temperature line).

### 3. Results

#### 3.1. Number of catches and dissected females

In total, 5333.2 individuals belonging to 34 species were caught. Most specimens (40%) were found in winter, 27% in autumn, 27% in spring and only 6% in summer. (Fig. 2)

A total of 680 female carabids were dissected (247 of which had eggs in their ovaries), mostly during the autumn and winter months. Most specimens with eggs were found between October and December (76% of all the females with eggs were found during these three months). Twenty-six of the dissected carabids belonged to the species *Broscus laevigatus*, 48 to *Calathus cinctus*, 194 to *Calathus longicollos*, 46 to *Carabus impressus*, 68 to *Carabus sidonius*, 205 to *Orthomus sidonicus*, and 93 to *Trechus saulcyanus*.



**Figure 2:** Catching rate of all ground beetle specimens found during each month

**Table 1:** Number of females with eggs (dissected females) per month and species

|                             | spring |       |       | summer |       |       |       | autum  |         |        | winter |        | spring | Total    |
|-----------------------------|--------|-------|-------|--------|-------|-------|-------|--------|---------|--------|--------|--------|--------|----------|
|                             | Mar.   | Apr.  | May   | Jun.   | Jul.  | Aug.  | Sep.  | Oct.   | Nov.    | Dec.   | Jan.   | Feb.   | Mar.   |          |
| <i>Broscus laevigatus</i>   | .      | .     | .     | .      | .     | .     | .     | 6(7)   | 11(19)  | .      | .      | .      | .      | 17(26)   |
| <i>Calathus cinctus</i>     | .      | .     | .     | 0(1)   | .     | .     | .     | 9(12)  | 9(17)   | 12(15) | 2(3)   | .      | .      | 32(48)   |
| <i>Calathus longicollis</i> | .      | 0(21) | 0(23) | 0(22)  | 0(3)  | 0(7)  | 5(28) | 35(40) | 8(20)   | 15(20) | 8(10)  | .      | .      | 71(194)  |
| <i>Carabus impressus</i>    | 0(1)   | 0(4)  | 0(6)  | .      | .     | .     | .     | 6(6)   | 12(22)  | 1(3)   | 0(1)   | 0(2)   | 0(1)   | 19(46)   |
| <i>Carabus sidonius</i>     | .      | 0(3)  | 0(8)  | 0(2)   | .     | .     | .     | 5(12)  | 16(26)  | 8(11)  | .      | 0(3)   | 0(3)   | 29(68)   |
| <i>Orthomus sidonicus</i>   | 6(10)  | 8(30) | 0(18) | 0(13)  | 0(7)  | 0(5)  | 0(1)  | 7(13)  | 9(24)   | 10(20) | 6(21)  | 8(21)  | 6(22)  | 60(205)  |
| <i>Trechus saulcyanus</i>   | .      | 0(2)  | 0(5)  | 0(20)  | .     | .     | .     | 1(3)   | 3(20)   | 5(12)  | 3(4)   | 3(7)   | 4(20)  | 19(93)   |
| <b>Total</b>                | 6(11)  | 8(60) | 0(60) | 0(58)  | 0(10) | 0(12) | 5(29) | 69(93) | 68(148) | 51(81) | 19(39) | 11(33) | 10(46) | 247(680) |

**Table 2:** Average number of eggs per month and species

|                             | spring |      |     | summer |     |      | autum |      |      | winter |      |      | spring |
|-----------------------------|--------|------|-----|--------|-----|------|-------|------|------|--------|------|------|--------|
|                             | Mar    | Apr. | May | Jun    | Jul | Aug. | Sep.  | Oct. | Nov. | Dec.   | Jan. | Feb. | Mar.   |
| <i>Brosicus laevigatus</i>  | .      | .    | .   | .      | .   | .    | .     | 6.8  | 3.5  | .      | .    | .    | .      |
| <i>Calathus cinctus</i>     | .      | .    | .   | .      | .   | .    | .     | 4.5  | 2.8  | 3.2    | 3.0  | .    | .      |
| <i>Calathus longicollis</i> | .      | .    | .   | .      | .   | .    | 1     | 2.7  | 4.1  | 4.1    | 5.3  | .    | .      |
| <i>Carabus impressus</i>    | .      | .    | .   | .      | .   | .    | .     | 6.0  | 3.4  | 3      | .    | .    | .      |
| <i>Carabus sidonius</i>     | .      | .    | .   | .      | .   | .    | .     | 5.6  | 3.7  | 2.9    | .    | .    | .      |
| <i>Orthomus sidonicus</i>   | 2.0    | 2.8  | .   | .      | .   | .    | .     | 1.6  | 2.1  | 4.3    | 1.8  | 2.3  | 2.2    |
| <i>Trechus saulcyanus</i>   | .      | .    | .   | .      | .   | .    | .     | 1.0  | 1.5  | 1.9    | 3.0  | 2.3  | 2.3    |

**Table 3:** Maximum number of eggs per month and species found in the ovaries of a single female

|                             | spring |      |     | summer |     |      | autum |      |      | winter |      |      | spring |
|-----------------------------|--------|------|-----|--------|-----|------|-------|------|------|--------|------|------|--------|
|                             | Mar    | Apr. | May | Jun    | Jul | Aug. | Sep.  | Oct. | Nov. | Dec.   | Jan. | Feb. | Mar.   |
| <i>Brosicus laevigatus</i>  | .      | .    | .   | .      | .   | .    | .     | 9    | 9    | .      | .    | .    | .      |
| <i>Calathus cinctus</i>     | .      | .    | .   | .      | .   | .    | .     | 6    | 6    | 8      | 3    | .    | .      |
| <i>Calathus longicollis</i> | .      | .    | .   | .      | .   | .    | 8     | 12   | 13   | 10     | 10   | .    | .      |
| <i>Carabus impressus</i>    | .      | .    | .   | .      | .   | .    | .     | 5    | 9    | 3      | .    | .    | .      |
| <i>Carabus sidonius</i>     | .      | .    | .   | .      | .   | .    | .     | 10   | 14   | 6      | .    | .    | .      |
| <i>Orthomus sidonicus</i>   | 3      | 7    | .   | .      | .   | .    | .     | 4    | 4    | 7      | 4    | 7    | 4      |
| <i>Trechus saulcyanus</i>   | .      | .    | .   | .      | .   | .    | .     | 1    | 2    | 3      | 4    | 3    | 4      |

### 3.2. Activity

Ten of the 34 species had their maximum in spring, three in summer, seven in autumn and ten in winter. Four species did not have a clear maximum but occurred with nearly the same number of specimens in at least 2 seasons (cf. Table 4).

The highest number of specimens was caught in winter and spring. 67% of all the specimens were caught between September and February and only 33% of the specimens were caught between March and August. The highest number of specimens was found in November (1235 specimens) and the lowest number in August (64 specimens). The specimens caught in July and August belonged to the species *Calathus longicollis*, *Cymindis spec.*, *Eucarterus sparsutus*, *Leistus caucasicus*, *Microlestes maurus*, *Odontocarus asiaticus*, *Orthomus sidonicus*, *Pseudaristus punctatissimus* and *Scarites saxicola*. *Eucarterus sparsutus* and *Pseudaristus*

*punctatissimus* were only caught in the summer. *Amara aenea*, *Platyderus spec.* and *Trechus quadristriatus* were caught only during spring.

40% of the total catch of *Calathus longicollis* was caught in autumn and 64% of *Orthomus sidonicus* was caught in winter. Only a few *Broscus laevigatus* specimens were caught at the end of October and the beginning of December; 86% of all specimens of this species were caught in November. During the period between October and December 78% of all of *Carabus impressus* specimens and 74% of all *Carabus sidonius* specimens were caught.

### 3.3. Reproduction

In all of the dissected species, with the exception of *Orthomus sidonicus* (Fig.8) and *Trechus saulcyanus*, (Fig.9), females with eggs were found only between the end of September and the beginning of January.

The highest number of eggs in the ovaries of a single female differed greatly among the species (Table 3), ranging from a maximum of 14 eggs in *Carabus sidonicus* to a maximum of four eggs in *Trechus saulcyanus*. The maximum number of eggs per female was 13 for *Calathus longicollis*, eight for *Calathus cinctus*, nine each for *Broscus laevigatus* and *Carabus impressus* respectively and seven for *Orthomus sidonicus*.

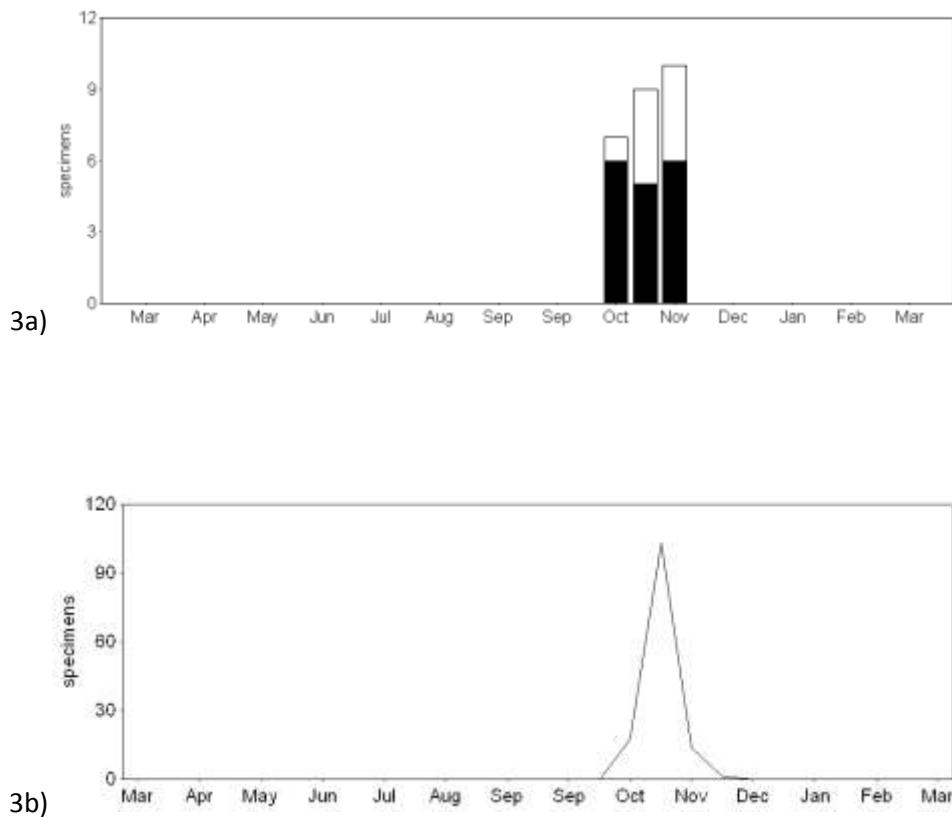
In summer (May-August) none of the dissected females had eggs in their ovaries. In October the highest number of females with eggs (74% of the dissected females had eggs in their ovaries; Table 1) was found. *Calathus longicollis* (Fig.5) was the first species with eggs in the ovaries after the summer months. In this species, the first eggs were already found in September, whereas for all the other species, the first specimens with eggs did not occur until October. In spring (March to April) the only species with eggs in the ovaries were *Orthomus sidonicus* and *Trechus saulcyanus*.

Table 4: Catching rate for all species per month with analysis of reproduction type (RT)

|   | RT                                    | Spring <sup>1</sup> |       |       | Summer <sup>1</sup> |      |      | Autum <sup>1</sup> |       |       | Winter <sup>1</sup> |      | Spring <sup>1</sup> |      | Total  |
|---|---------------------------------------|---------------------|-------|-------|---------------------|------|------|--------------------|-------|-------|---------------------|------|---------------------|------|--------|
|   |                                       | Mar.                | Apr.  | May   | Jun.                | Jul. | Aug. | Sep.               | Oct.  | Nov.  | Dec.                | Jan. | Feb.                | Mar. |        |
| <i>Amara aenea</i> DeGeer, 1774                                 | spring breeder <sup>2</sup>           | .                   | .     | .     | .                   | .    | .    | .                  | .     | .     | .                   | .    | .                   | 3.8  | 3.8    |
| <i>Bembidion liliputanum</i> (Sahlberg, 1908)                   | .                                     | .                   | 2.1   | 1.5   | .                   | .    | .    | .                  | .     | 2.6   | .                   | 1    | 1                   | .    | 8.2    |
| <i>Bembidion leucoscelis</i> Chaudoir, 1850                     | .                                     | .                   | .     | .     | .                   | .    | .    | .                  | .     | 2.0   | 2.1                 | 4.5  | 1.1                 | 1.2  | 10.9   |
| <i>Bembidion phoeniceum</i> Huber & Marggi, 1997                | .                                     | 3.0                 | .     | .     | 2.0                 | .    | .    | .                  | .     | 2.6.0 | 1.1                 | 1.8  | 1.2                 | 1.2  | 12.9   |
| <i>Broscus laevigatus</i> Dejean, 1828                          | winter breeder <sup>3,4</sup>         | .                   | .     | .     | .                   | .    | .    | .                  | 17.6  | 116.9 | 1.1                 | .    | .                   | .    | 135.6  |
| <i>Broscus nobilis</i> Dejean, 1828                             | .                                     | .                   | .     | .     | .                   | .    | .    | .                  | .     | 12.9  | 3.2                 | .    | .                   | .    | 16.1   |
| <i>Calathus cinctus</i> Motschulsky, 1850                       | autum breeder <sup>5</sup>            | .                   | .     | .     | 1.4                 | .    | .    | .                  | 30.9  | 71.7  | 48.3                | 8.0  | .                   | .    | 160.3  |
| <i>Calathus longicollis</i> Motschulsky, 1864                   | winter breeder <sup>6</sup>           | .                   | 156.5 | 186.0 | 159.2               | 9.0  | 25.7 | 107.3              | 348.5 | 287.3 | 137.7               | 14.6 | .                   | .    | 1431.8 |
| <i>Carabus impressus</i> Klug, 1832                             | .                                     | 1.0                 | 9.3   | 12.1  | 6.9                 | .    | .    | .                  | 31.3  | 94.2  | 8.4                 | 2.0  | .                   | 6.0  | 171.2  |
| <i>Carabus phoenix</i> Lapouge, 1925                            | .                                     | 4.0                 | 3.3   | 16.8  | 17.4                | .    | .    | .                  | 2.4   | 6.0   | .                   | 4.6  | 1.3                 | .    | 55.8   |
| <i>Carabus piochardi</i> Géhin, 1884                            | .                                     | .                   | 9.4   | 1.1   | .                   | .    | .    | .                  | 9.6   | 40.9  | 4.1                 | .    | 1.0                 | 1.0  | 67.1   |
| <i>Carabus sidonicus</i> Lapouge, 1907                          | .                                     | 2.0                 | 9.3   | 37.0  | 4.4                 | .    | .    | .                  | 27.9  | 126.8 | 26.7                | 1.8  | 5.8                 | 4.6  | 246.3  |
| <i>Carabus syrus</i> Roeschke 1898                              | .                                     | .                   | 4.1   | 12.7  | 11.3                | .    | .    | .                  | 21.6  | 38.0  | 4.0                 | .    | .                   | 3.0  | 94.7   |
| <i>Cymindis pallida</i> Reiche, 1855                            | .                                     | 1.0                 | .     | .     | .                   | .    | .    | .                  | 2.1   | 9.4   | 3.2                 | 8.3  | 2.6                 | 1.3  | 27.9   |
| <i>Cymindis spec.</i>   | .                                     | 2.0                 | 6.8   | 3.3   | .                   | 2.0  | .    | .                  | .     | .     | .                   | .    | .                   | 4.1  | 18.2   |
| <i>Harpalus caphius</i> Reiche & Saulcy, 1855                   | .                                     | .                   | 1.0   | .     | .                   | .    | .    | .                  | .     | .     | .                   | 1.3  | 1.0                 | .    | 3.3    |
| <i>Laemostenus cf. libanensis</i> Piochard de la Brûlerie, 1876 | .                                     | .                   | .     | .     | .                   | .    | .    | .                  | .     | .     | .                   | .    | 1.0                 | .    | 1.0    |
| <i>Laemostenus quadricollis</i> Redtenbacher 1843               | .                                     | 1.0                 | 2.0   | .     | 4.4                 | .    | .    | .                  | 7.5   | 38.0  | 30.8                | 22.8 | 5.8                 | 6.6  | 118.9  |
| <i>Leistus caucasicus</i> Chaudoir, 1867                        | .                                     | .                   | 13.1  | 14.9  | 2.0                 | .    | 1.4  | .                  | 1.0   | 36.8  | 22.1                | 21.2 | 8.3                 | 13.1 | 133.9  |
| <i>Microlestes maurus</i> (Sturm, 1827)                         | .                                     | .                   | 5.3   | 2.5   | 22.4                | 5.0  | .    | .                  | 3.0   | 4.1   | 1.1                 | .    | .                   | 51.9 | 95.3   |
| <i>Nebria hemprichi</i> Klug, 1832                              | Autum and winter breeder <sup>7</sup> | .                   | 11.3  | 36.8  | .                   | .    | .    | .                  | .     | 9.4   | 10.6                | 6.4  | 1.0                 | 1.1  | 76.6   |
| <i>Notiophilus danieli</i> Reitter, 1897                        | .                                     | 3.0                 | .     | 6.0   | .                   | .    | .    | .                  | 2.8   | 9.9   | 2.2                 | 1.0  | .                   | .    | 24.9   |
| <i>Ocys quinquestriatus</i> (Gyllenhal, 1810)                   | winter breeder <sup>8</sup>           | .                   | .     | .     | .                   | .    | .    | .                  | .     | .     | .                   | 2.3  | 1.1                 | .    | 3.4    |



The average number of eggs for the species differed among months. In the two Carabus species (Fig.6 and Fig.7), in *Broscus laevigatus* (Fig.3) and in *Calathus cinctus* (Fig.4), the average number of eggs was highest in October. For *Calathus longicollis* and for *Trechus saulcyanus*, the average number of eggs was highest in January and for *Orthomus sidonicus* it was highest in December (cf. Table 2).



**Figure 3:** a) Number of females **with eggs (black)** and **without eggs (white)** per month for *Broscus laevigatus*; b) Number of *Broscus laevigatus* specimens found per month in the pitfall traps



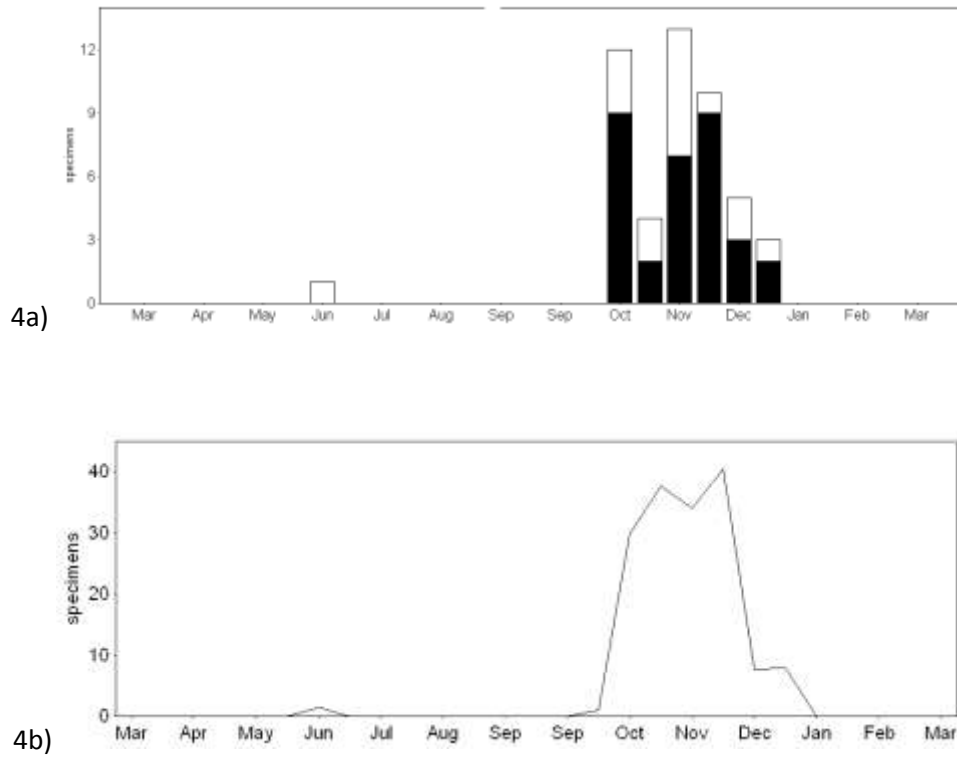


Figure 4: a) Number of females **with eggs (black)** and **without eggs (white)** per month for *Calathus cinctus*; b) Number of *Calathus cinctus* specimens found per month in the pitfall traps

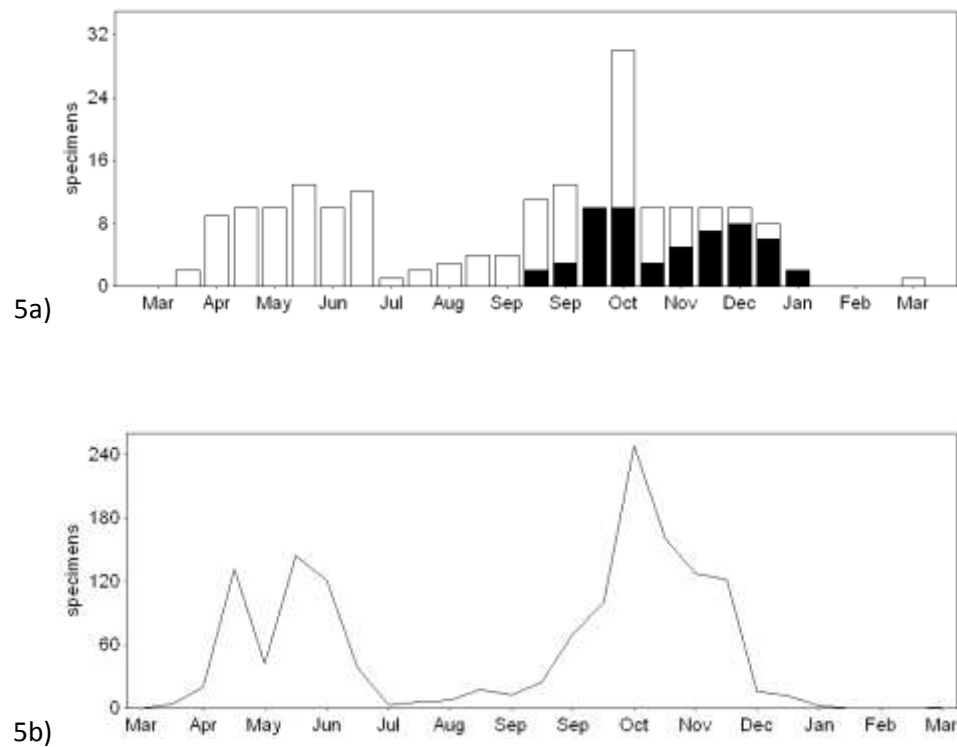
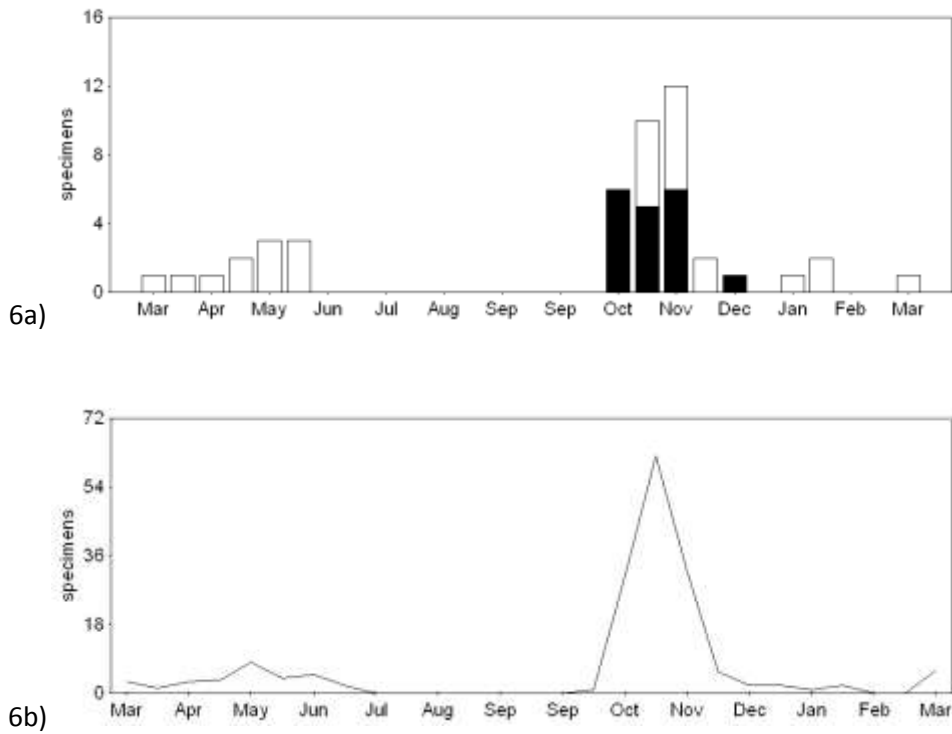
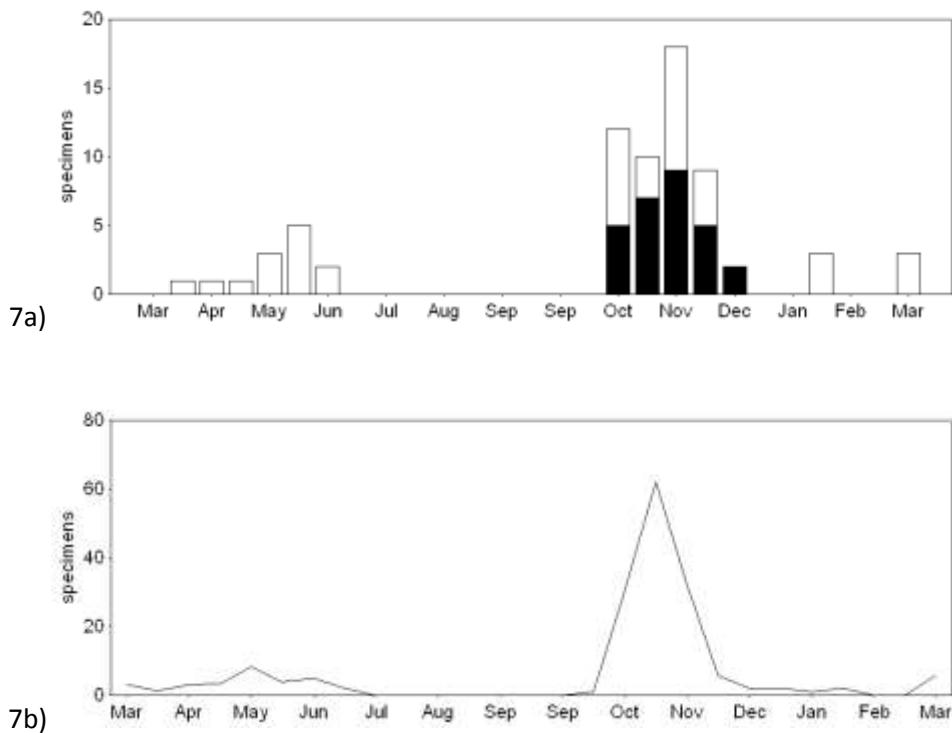


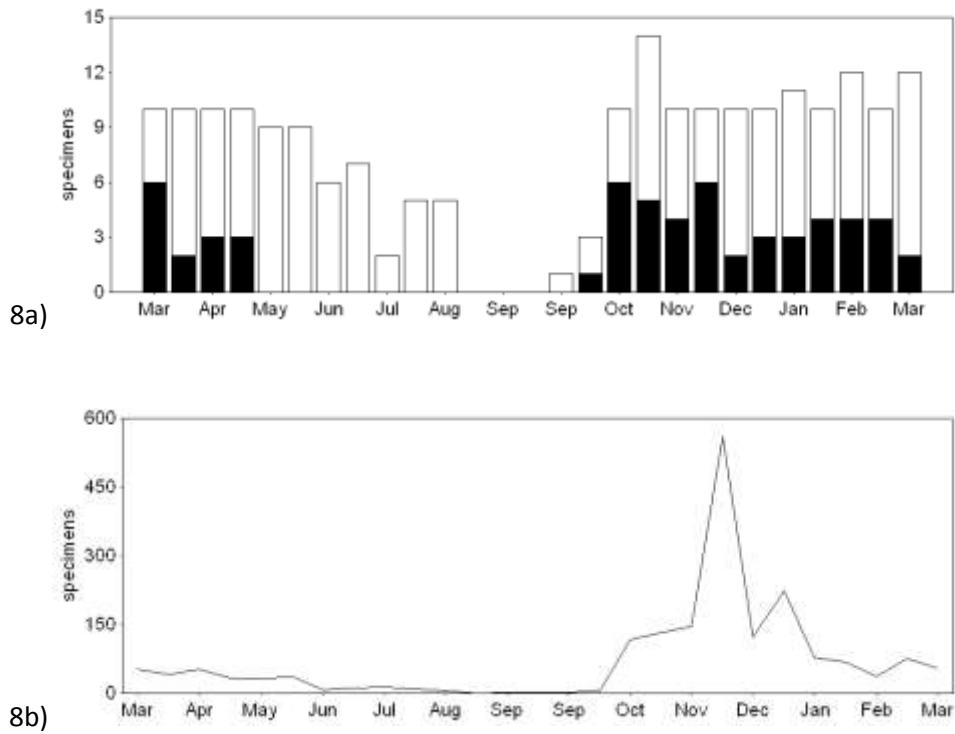
Figure 5: a) Number of females **with eggs (black)** and **without eggs (white)** per month for *Calathus longicollis*; b) Number of *Calathus longicollis* specimens found per month in the pitfall traps



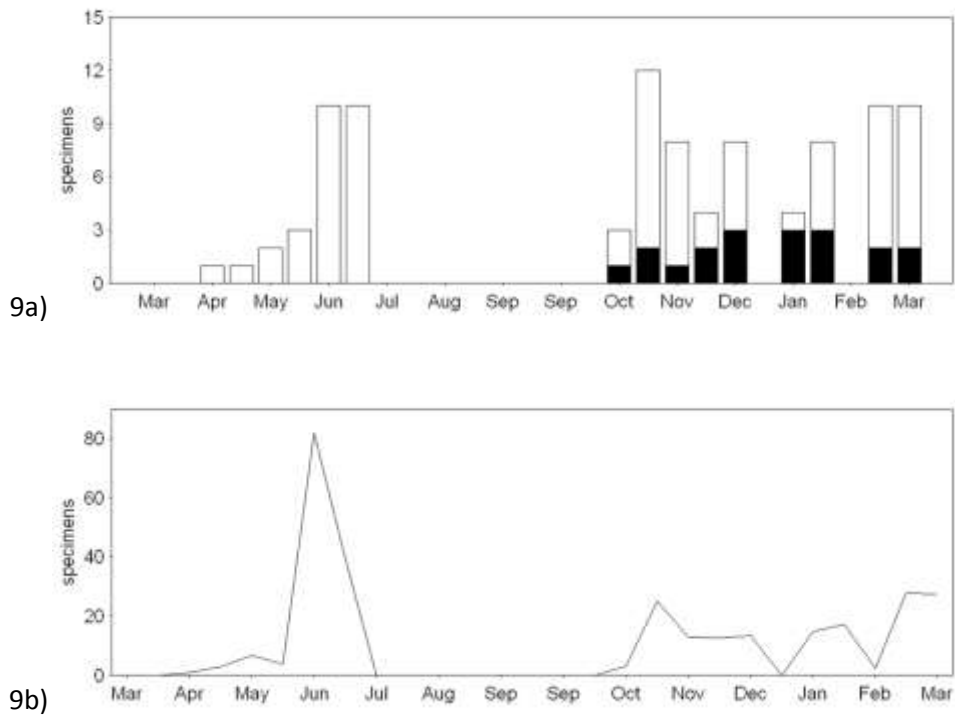
**Figure 6:** a) Number of females **with eggs (black)** and **without eggs (white)** per month for *Carabus impressus*; b) Number of *Carabus impressus* specimens found per month in the pitfall traps



**Figure 7:** a) Number of females **with eggs (black)** and **without eggs (white)** per month for *Carabus sidonius* b) Number of *Carabus sidonius* specimens found per month in the pitfall traps



**Figure 8:** a) Number of females with eggs (black) and without eggs (white) per month for *Orthomus sidonicus*; b) Number of *Orthomus sidonicus* specimens found per month in the pitfall traps



**Figure 9:** a) Number of females with eggs (black) and without eggs (white) per month for *Trechus saulcyanus*; b) Number of *Trechus saulcyanus* specimens found per month in the pitfall traps

## 4. Discussion

### 4.1. Activity patterns

In his work on “propagation rhythms of subtropical and tropical Carabidae” PAARMANN (1977) describes that winter breeding is the main propagation type in areas with winter rain. He stated that carabid beetles overcome the hot and dry season in the form of aestivation dormancy. Their high level of activity in winter indicates that this is their reproductive period. Changes in photoperiod and in temperature seem to be the main factors for gonad maturation. In his 1970 study, PAARMANN asserted that in the studied species the development of gonads began in October and oviposition took place in the months of November and December. Juvenile beetles were caught in the months March to April. In our study, most of the species studied also had chorionized eggs in the ovaries during the months November to December. Only *Orthomus sidonicus* had chorionized eggs in spring (March-April). PAARMANN (1970) reasoned that the winter breeding of carabid beetles in North Africa is due to the dry soils in summer and showed that larvae development is not possible in the North African summer months.

### 4.2. Seasonality of oogenesis

Winter breeding seems to be the most important type in the Mediterranean. However, there are also summer and spring breeders (*Orthomus sidonicus*, *Eucarterus sparsutus*, *Odotoncarus asiaticus*).

*Eucarterus sparsutus* and *Odotoncarus asiaticus* were found only during the summer months. This is also true for other studies, such as WRASE (1999). Nearly all specimens of the studied species of the genus *Oedesis* were found during the summer months (May-August). BRANDMAYR, et al. (1994) also characterized *Carterus calydonius*, as a spring-summer breeder that needs the hot summer soil to develop.

The highest activity level of *Orthomus sidonicus* was, as for all the other studied species, in autumn. Therefore, it seems that *O. sidonicus* is also an autumn species. The major difference between this and the other studied species is that there were eggs in the ovaries of *O. sidonicus* until April, and not only from October to December. PAARMANN (1977) described species which also reproduce between

October and March, such as *Pristonychus picicornis*. He assigned this species to the group of winter breeders. The question arises as to whether *Orthomus sidonicus* is able to breed during two seasons, as described for *Trechus quadristriatus* by MITCHELL (1963) or for *Pterostichus lucublandus* and *Harpalus pensylvanicus* (cf. FADL and PURVIS 1998). The ability to reproduce in more than one season could be advantageous for *Orthomus sidonicus*. It would be able to breed even if the rainy season starts only very late in the year (December or January).

Comparing our *Calathus longicollis* data with the data for *Calathus* in the study by AVGIN (2006) in Turkey, we see that in both cases the maximum number of individuals caught is in spring and in winter time. In our case, the autumn maximum is much higher than the spring maximum. In AVGIN 's data (2006) both maxima seem to have a similar height or rather the spring maximum seems to be higher than the autumn maximum.

In Palestine, BODENHEIMER (1934) caught only very few specimens of *Carabus impressus*, *Broscus laevigatus* and *Calathus fuscipes* with pitfall traps. The maximum was the same as in our case. For all three species, the graph reaches its maximum in autumn, both in our study and in the study by BODENHEIMER (1934). The main difference between BODENHEIMER 's data (1934) and our study is the fact that in the former study *Broscus laevigatus* was found in December and April, while we found no *Broscus laevigatus* specimens during these two months. BODENHEIMER (1934) stated that the high seasonal appearance of ground beetles is between September and January. This is confirmed by our data.

In his study, PAARMANN (1970) compared *Calathus fuscipes* and *Calathus mollis* in Europe and Libya. He came to the conclusion that there is a relation between the autumn breeders of Europe and the winter breeders of the Mediterranean. Our data also shows *Calathus fuscipes* as a winter breeder. This supports Paarmann's conclusion. PAARMANN (1970) explains the summer inactivity of ground beetles in the Cyrenaica with the low soil moisture during this period. In later studies (PAARMANN 1974, 1976) he showed that the larvae of ground beetles are very susceptible to dehydration. He stated in the same studies that the activity of ground beetles increases with the beginning of the rainy season and, thus, the breeding season begins. As a result, he concludes that there is a connection between the

beginning of the rainy season and the breeding season. The same is true for our results, as shown in figures 1-7. Therefore, the results of our study support Paarmann's theory and might represent an adaptation to the climate. In this case, the larvae develop during the season with the highest rainfall and therefore the highest soil moisture. In order to substantiate this theory, it is necessary to study both the annual cycle and the annual precipitation over several years in this area. We did not measure the soil moisture in our study but took the weather data of the sampled area. In summer time, there was no rain in the area, so we can conclude that the soil was also very dry. After the first rain started in September, the number of specimens increased significantly. The larvae of Carabidae are mostly very hygrophilous and susceptible to dehydration (cf. PAARMANN 1966, 1970; THIELE 1964). This might be the reason why Carabids in this area mainly reproduce during winter. The question arises as to how the larvae of the *Carterus* species are able to survive in the Mediterranean open landscapes during the summer.

PAARMANN (1970) stated that the development of ovaries begins for *Calathus fuscipes* in October and the eggs are laid between November and December. This corresponds with our findings of eggs in the ovaries of *Calathus longicollis* for the time span between the end of September and the end of January. The higher catching rate of this species during spring might be caused by the freshly hatched ground beetles. TURIN, et al. (2003) also stated that different *Carabus* species of southern Europe such as *C. dufouri* and *C. alysidotus* are winter breeders; all of the *Carabus* species found in our study were also winter breeders. CÁRDENAS (1994) stated for *Calathus granatensis*, found in the Iberian Peninsula, that the optimal time for reproduction is mainly in October; the same is true for the *Calathus* species of our study. His data set for *Calathus granatensis* and our data set for *Calathus fuscipes* are in agreement as regards the activity of these species.

*Trechus quadristriatus* is described by MITCHELL (1963) as an autumn breeder with the ability also to breed during spring. This species seems to be very adaptive in its maturation cycle. In the dissected specimens of *Trechus saulcyanus*, we found coronized eggs only during the autumn and winter months. The species is, as expected, an autumn breeder in Israel. The maximum number of eggs found in *Trechus saulcyanus* was four in our case and thus nearly the same as for *Trechus*

*quadristriatus* (4.4 eggs) dissected by FADL and PURVIS (1998). These findings were much lower than the results of MITCHELL (1963) who found up to 16 eggs per female.

#### 4.3. Activity

While PAARMANN (1970) found no ground beetles in July, in our study we found various species during this month (e.g. *Calathus longicollis*, *Microlestes maurus*, *Orthomus sidonicus*, *Eucarterus sparsutus*, *Odontocarus asiaticus*, *Pseudaristus punctatissimus*). The catching rate for ground beetles was also very low in the summer months of our study. Nevertheless, we were able to catch ground beetles in all months of the year. The lowest number of ground beetles caught in our study was in the month of August. The highest numbers of ground beetles reported by PAARMANN (1970) were caught in the months of April and May, while in our study the highest number was found during the period October to December. In our study, the number of ground beetles also increased strongly during April and May, but was lower than in autumn. Paarmann reasoned that high numbers of ground beetles in spring were juvenile swarming beetles; these are either not caught or only few are caught in pitfall traps. Therefore, these juvenile beetles might be underrepresented in our study.

#### 4.4. Conclusions for monitoring and studies on ground beetle diversity in East Mediterranean climate regions

In Europe, but also in North America, beetles are receiving an increasing amount of attention in conservation biology. The Convention on the Conservation of European Wildlife and Natural Habitats of the European Union (e.g. GUENTHER and ASSMANN 2004; MATERN, et al. 2007; SSYMANEK 1998) or the Endangered Species Act of the United States of America (e.g. MELLO 2005; TALLEY, et al. 2007) for instance, explicitly protect habitats where ground beetle species are found. Ground beetles are very important for the description of changes in habitats (BUTTERFIELD, et al. 1995; PEARCE and VENIER 2006; RAINIO and NIEMELÄ 2003; SSYMANEK 1994), because they appear in almost all terrestrial habitats and show some remarkable trends in their population-dynamic development (LINDROTH 1972). Methods for obtaining comprehensive knowledge on the existing fauna are a prerequisite for nature conservation strategies. Such knowledge is crucial for identifying changes and threats. Knowledge

of the detectability and the seasonality of ground beetle species in Mediterranean habitats and of the most suitable collecting methods and seasons are important for studying the significance of this animal group in landscape planning and biological conservation research. Therefore, it is not only necessary to use different sampling methods as shown in TIMM, et al. (2008) but also to sample throughout the entire year in order to obtain a detailed spectrum of species for these habitats.



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## **IV** Saproxylic beetle assemblages of three managed oak woodlands in the Eastern Mediterranean

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**Abstract.** Oak woodlands belong to the natural vegetation in most Mediterranean regions but have suffered from a long history of woodland devastation and overgrazing. The remaining woodlands have been managed in different ways, and we expected this to have effects on the fauna associated with trees. We investigated three different sites in the East Mediterranean with flight-interception traps to analyse the impact of woodland management on dead wood and tree structures and the relevance for saproxylic beetle assemblages. Our results show significant differences in trunk diameter, stem density and dead wood diversity between the three sites. Old oaks in the semi-open woodland are characterised by diverse stages of dead wood and harboured most saproxylic species (74 species of 98 in total) and most individuals. With regard to rarefied species richness we found that the coppice woodland with a high stem density and medium-sized trees has the most diverse beetle assemblage (19.7 species per 100 individuals). Species richness was in general strongly associated with the diameter of the oaks, but also was surprisingly of the same level as species numbers reported from studies in Central Europe. The large number of singletons which made 40 % of the entire sample may indicate a considerable proportion of unseen species. We discuss the impact of different management options on tree shape and woodland structure, issues which are also important for the saproxylic beetle assemblage associated with Mediterranean oaks. We conclude that oak woodlands in the Middle East – and especially those woodlands that have been used and managed in a sustainable way – represent a valuable resource for insect diversity.

**Key words.** *Quercus calliprinos*, Palestine Oak, Middle East, Israel, dead wood; woodland structure; biodiversity.

## 1. Introduction

Historical documents indicate that woodlands in the Mediterranean basin have been overexploited by man since Roman and Byzantine times, resulting in degraded forms of woodlands and widespread regions cleared of mature woody vegetation (GROVE and RACKHAM 2003; KANIEWSKI et al., 2007; NAVEH and DAN 1973). Anthropogenic disturbances such as grazing, fire management and agricultural

techniques are the factors which have influenced the external shape and type of these woodlands (RUNDEL 1998). Traditional land-use with goats, sheep and other livestock meant that it was not possible for the woodlands to recover until modern economic pressure lowered the number of livestock and thus the grazing pressure on the landscape. Nevertheless, historical paintings indicate the persistence of single trees and groups of trees in pasture landscapes. (e.g. SCHULER 1999). Moreover, a few sacred oak trees have survived the hazards of historical land use. The graves of holy men in the shade of these trees furthers the Moslems' belief that a curse will fall on anyone who cuts down the trees; this idea afforded such trees efficient protection for centuries. Thus, both ancient and younger trees have survived in the Israeli landscape (DANIN 1988). Due to land-use changes in the last 50 years a natural recovery of the oak woodlands in Mediterranean-type ecosystems of Israel can be observed (cf. DUFOUR-DROR 2005). The genus *Quercus* dominates this maquis vegetation and is represented in Israel by several native species. Today the evergreen Palestine Oak (*Quercus calliprinos*) is the most common tree species of the Israeli Mediterranean region (SHMIDA 2006). This species, then, would appear to be potentially important for saproxylic insects because of its frequent distribution and its evolutionary significance as a native tree species. It is likely that major parts of the Israeli landscape in the Mediterranean-climate region would consist of oak-dominated woodlands under natural conditions.

Studies from temperate and boreal regions on saproxylic insect diversity have shown a positive relationship between tree diameter and species richness (GROVE 2002; JONSELL et al., 1998; RANIUS and JANSSON 2000). There are two main reasons for increased species richness of beetles in mature old trees: a larger number of microhabitats and the occurrence of specialists dependent on late-successional tree stages, e.g. *Osmoderma eremita* (SCOPOLI, 1763), a European species which lives in tree-hollows (RANIUS and NILSSON 1997), *Cerambyx cerdo* LINNAEUS, 1758, a species predominantly occurring on oaks bigger than 60 cm in diameter (BUSE et al., 2007; BUSE et al., 2008). Large trees also offer more stable microclimatic conditions, such as temperature and moisture. Different management strategies can also be expected to have a considerable impact on patterns of saproxylic beetle species richness and community structure in Mediterranean woodlands. At present, we have information on how human impact affects plant diversity of woodlands (e.g. COWLING et al., 1996;

SCHMITZ et al., 2007) or birds (e.g. VALLECILLO et al., 2008) in Mediterranean regions, but we know very little about how invertebrates respond to different management practices. Grazing either by cattle or goats and sheep and afforestations are considered to be the main human impacts on flora and fauna in the Mediterranean region (ALRABABAH et al., 2007; HENKIN et al., 2007; MAESTRE et al., 2003). Studies from Northern and Central Europe have shown the relevance of ecological continuity and forest history for woodland structures that are important determinants of invertebrate richness associated with dead wood (cf. ALEXANDER 1998; JONSSON et al., 2005). However, similar investigations in the Mediterranean are still lacking and ecological research on Mediterranean woodlands is as yet underrepresented (MARAÑÓN et al., 1999). For nature conservation strategies and decision making in landscape planning in the Mediterranean it is essential to incorporate basics of dead wood ecology and their associated saproxylic insect fauna. The region with a Mediterranean climate in Israel was particularly strongly affected by the high rates of land consumption in recent decades (ISRAEL MINISTRY OF THE ENVIRONMENT 2005). In terms of overall species richness the Mediterranean Basin is considered to be one of the top regions in the world (MÉDAIL and QUÉZEL 1999; MYERS et al., 2000). The East Mediterranean in particular (e.g. Cyprus, Levantine countries, Turkey) shows an enormous diversity of plants and animals compared with other regions in the Mediterranean (DANIN 1988) and often habitats and distribution are poorly known, particularly for many insect taxa (ASSMANN et al., 2008; MAKRIS et al., 2008). Several saproxylic beetles have been described from the East Mediterranean in recent years (e.g. *Crossotus katbeh* Sama, 2000 (Cerambycidae); *Cryphaeus laticeps* Lillig, 2006 (Tenebrionidae); three new Staphylinidae from Turkey by SCHILLHAMMER et al., 2007). Research on occurrence and ecology of these insects is essential to study the distribution of diversity in this region and to develop conservation strategies with a long-term perspective.



**Table 1:** Differences between maquis, oak woodland and the old oak stand in some parameters; dead wood: class 1 = hard wood and all remaining bark, class 2 = hard wood, partially rotten, class 3 = log well decayed, soft wood; analysis of variance: n.s. not significant, \*\*  $p < 0.01$ , \*\*\*  $p < 0.001$ ; SD=Standard deviation.

| Parameter   | F-value | p    | Site 1            | Site 2            | Site 3          |
|---|---------|------|-------------------|-------------------|-----------------|
| Number of traps per site                          |         |      | 4                 | 4                 | 4               |
| Number of saproxylic species                      |         |      | 74                | 47                | 31              |
| Average of species                                |         |      | 32.75             | 22.00             | 14.75           |
| Total number of specimens                         |         |      | 1712              | 549               | 493             |
| Rarefied species richness for 100 individ.        |         |      | 17.36             | 19.74             | 14.69           |
| Total species richness and SD (chao-1 estimation) |         |      | 135.5<br>(±21.92) | 84.78<br>(±16.44) | 45.4<br>(±8.77) |
| <b>Tree characteristics:</b>                      |         |      |                   |                   |                 |
| Diameter at breast height                         | 57.21   | ***  | 0.73              | 0.28              | 0.13            |
| Occurrence of dead tree branches                  | 21.82   | ***  | All >5 cm         | 75% >5 cm         | All <5 cm       |
| Average tree height in m                          | 80.00   | ***  | 8                 | 6                 | 4               |
| Average number of cavities/holes                  | 12.29   | **   | 67.50             | 1.75              | 0               |
| Average deadwood diversity                        | 117.91  | ***  | 4.25              | 2.50              | 1.0             |
| Average distance to other tree species in m       | 134.04  | ***  | 30                | 100               | 7.5             |
| <b>Plot characteristics</b>                       |         |      |                   |                   |                 |
| Average amount of dead wood – class 1             | 1.00    | n.s. | 50.25             | 0                 | 0               |
| Average amount of dead wood – class 2             | 2.45    | n.s. | 0                 | 7.5               | 0               |
| Average amount of dead wood – class 3             | 1.00    | n.s. | 0                 | 5.0               | 0               |
| Average amount of dead wood – total               | 0.81    | n.s. | 50.25             | 12.5              | 0               |
| Number of stems per hectar                        | 93.05   | ***  | 160               | 2500              | 825             |
| Fraction of <i>Pinus</i>                          | 18.00   | **   | 0                 | 0                 | ~10 %           |

The purposes of this paper are (1) to analyse dead wood structures in differently managed Mediterranean woodlands, (2) to research saproxylic beetle diversity in this context, (3) to study general patterns of biodiversity and (4) to give recommendations for the conservation of insect diversity in the woodlands of the Middle East.

## 2. Material and methods

### 2.1. Study area

We studied three different plots in the north of Israel to survey the beetle fauna of Palestine Oaks (*Quercus calliprinos*) under different management conditions. Each plot has been managed in different ways in the past. “Site 1” in the nature reserve “The Fourties” (Carmel Mountains, 32°45’N, 35°01’E, 420 m a.s.l.) is characterised by mature old oaks representing a semi-open pasture landscape without any regrowth of juvenile oaks. The other two research plots are located in the Meron Mountains. The second plot “Site 2” is Bar’am Forest (33°02’N, 35°25’E, 620 m a.s.l.), a woodland which used to be managed by Christian monks and has been wooded for

almost 150-200 years (cf. SHARON et al., 2001). This woodland is characterised by oaks with several stems from the same root, a result of coppice management in the past. The third plot "Site 3" represents earlier stages of the Mediterranean maquis (33°01'N, 35°23'E, 900 m a.s.l.). All plots are grazed either by cattle or by goats and sheep throughout the year. *Quercus calliprinos* is the dominant tree species at all three sites.

## 2.2. Woodland and tree characteristics

The richness and abundance of saproxylic beetles may be influenced by a couple of variables. We surveyed our plots for both tree and woodland characteristics. Oak trees were evaluated for their height and diameter at breast height as well as the amount of dead branches (diameter >5 or < 5 cm) and the number of holes or cavities in the trunk (entrance >1 cm). As other tree species in direct neighbourhood may influence species composition of the studied assemblages, we measured the distance to other tree species (mainly *Pinus halepensis* or *P. brutia*). We counted the number and analysed the quality of fallen dead wood (logs) bigger than 5 cm in diameter on our plots. Thus, we classified the dead wood into three categories, ranging from hard wood with all the bark remaining to soft-decayed wood (cf. LORENZ 2005). We also surveyed the number of dead wood qualities in a 10 m radius around the traps as well as on the tree itself, e.g. fungi infections, snags, freshly broken branches, holes, stumps etc. Finally, we estimated the number of stems (>10 cm in diameter) per hectare by counting the stems over an area of 50 x 50 metres (0.25 ha) and extrapolating the number to one hectare.

## 2.3. Insect trapping and identification

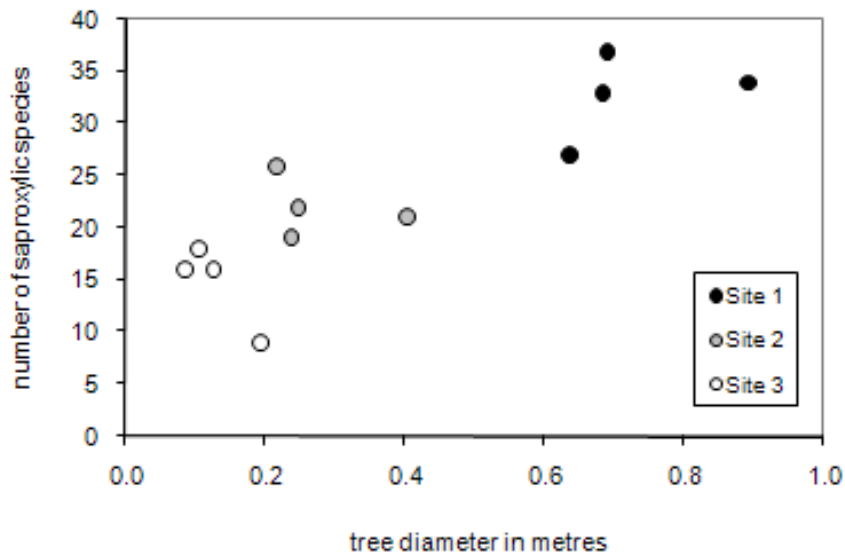
We used flight-interception traps with crossed panels of plexiglass (50 x 30 cm) to survey the flight-active beetle fauna of the plots (see HYVÄRINEN et al., 2006). Pitfall traps located in the bottom of tree cavities are another useful method when studying hollow trees (RANIUS and JANSSON 2002), but trees in our study were too small for placing pitfall traps inside the trunk except those at Site 1. In each of the plots, four traps were placed in the canopy of oak trees at a height of 2-4 m above ground level. The flight-interception traps were located between 1-3 m away from the trunk. The exact height and distance to the trunk was dependent on the shape of the trees. We

tried to hold a minimum distance between traps of 20 metres. Single study trees were selected with respect to their diameter and representativeness for the plot, means we searched for the largest trees available on each study plot. While studied trees at Site 1 have been selected from a pool of 25-30 old hollow oaks, no such oaks have been found in direct neighbourhood at the other two plots. Catches were made from May 16<sup>th</sup> to July 20<sup>th</sup> 2007. We know that some early and late active species were not be caught during this period, but the majority of species is active during our study period. We used a mixture employed by RENNER (1980) to preserve the catches and we emptied the traps at two-week intervals.

All individuals were sorted into morphospecies (cf. OLIVER and BEATTIE 1996) and all species classified at least to family level. The first specimen of each new species encountered was mounted for later comparisons. All specimens of Cerambycidae, Staphylinidae, Buprestidae, Elateridae and Tenebrionidae were identified to species level (Table 3). We included individuals from families with a high proportion of species known to be saproxylic (e.g. PALM 1959; SPEIGHT 1989), e.g. Cerambycidae or Scolytidae. Specimens from some other families such as Cantharidae or Chrysomelidae have been excluded from this study because their members are not usually dependent on wood. Many rove beetle species in Central Europe are closely related to dead wood structures but we included only such rove beetle species which were known from Europe to be saproxylic. If we had species unknown from Europe, we looked for their genus and included species from genera with saproxylic members.

#### 2.4. Statistics

We calculated analysis of variance (ANOVA) to test for differences between the plots in the characteristics measured. We placed four traps in each plot; therefore the ANOVA uses a four-times replication of the data. Rarefaction was calculated for the number of species grouped for each of the three locations (cf. KREBS 1999). Thus, we were able to compare rarefied species richness for an equal number of 100 specimens per location. We carried out statistical analyses with R 2.2.0 (R CORE DEVELOPMENT TEAM 2005). Rarefaction was performed using the Calculator from BRZUSTOWSKI available online ([www2.biology.ualberta.ca/jbrzusto/rarefact.php](http://www2.biology.ualberta.ca/jbrzusto/rarefact.php)), which is based on the program RAREFACT.FOR written by Charles J. KREBS.



**Figure 1:** Correlation between species richness and the diameter of investigated oak trees. Pearson's correlation coefficient  $r=0.861$ ,  $p<0.001$ . Raw species numbers were used

### 3. Results

#### 3.1. Woodland characteristics

Tree height and trunk diameter as well as the amount and quality of dead wood on the oaks varied between trees and to a greater extent between plots. In general, the tree individuals from Site 1 harbour much more dead wood in different qualities as the other two plots. The oaks from all plots researched ranged in their diameter from 0.11 to 0.89 metres. Young oaks on Site 3 only had dead branches smaller than 5 cm in diameter (Table 1). None of the surveyed trees on Site 3 showed any large hole or a tree hollow. The oak individuals from Site 1 were extremely rich in different qualities of dead wood. We found that they had dead branches thicker than 5 cm with and without bark, some of them with fungi infections. They usually showed a number of cavities and holes made by some large longhorn beetles (e.g. *Cerambyx*) (Table 1). We found no statistical significant differences in the amount of dead logs between our researched plots. Site 2 in Bar'am Forest has by far the highest density of stems per hectare. There was no significant difference in the amount of dead wood of any kind among the plots. Site 3 is influenced by some young pines scattered between the broadleaved trees.

### 3.2. Diversity of saproxylic beetles in the differently managed woodlands

Altogether, we found 2754 individuals belonging to 98 saproxylic beetle species. Singletons made up 40 % (40 species) of the total sample. Because of the large number of singletons, we calculated CHAO 1, which is based on the number of singletons and doubletons in a specific sample, to get a measure of estimated species richness including unseen species. The CHAO 1-estimation revealed almost twice as much species for each plot as we obtained from our catches (Table 1).

**Table 2:** Species richness and abundance of beetle families sampled in differently managed oak woodlands.

| Family        | No. species | No. specimens | Familij (cont.) | No. species | No. specimens |
|---------------|-------------|---------------|-----------------|-------------|---------------|
| Aderidae      | 1           | 14            | Laemophloeidae  | 1           | 1             |
| Alleculidae   | 2           | 66            | Malachidae      | 5           | 13            |
| Anobiidae     | 9           | 90            | Melandryidae    | 2           | 2             |
| Anthribidae   | 1           | 5             | Melyridae       | 7           | 172           |
| Bostrychidae  | 1           | 6             | Mordellidae     | 3           | 20            |
| Buprestidae   | 5           | 75            | Mycetophagidae  | 2           | 50            |
| Cantharidae   | 1           | 1             | Nitidulidae     | 4           | 6             |
| Cerambycidae  | 13          | 24            | Ptinidae        | 5           | 14            |
| Cleridae      | 2           | 6             | Scarabaeidae    | 3           | 35            |
| Cucujidae     | 1           | 1             | Scolytidae      | 8           | 1960          |
| Curculionidae | 1           | 1             | Serropalpidae   | 1           | 1             |
| Dermestidae   | 3           | 6             | Staphylinidae   | 5           | 156           |
| Elateridae    | 5           | 14            | Tenebrionidae   | 1           | 2             |
| Histeridae    | 3           | 5             | Unidentified    | 3           | 8             |

Recorded species belong to 27 families of Coleoptera. We recorded more species of longhorn beetles (Cerambycidae) than from any other family, but of the individuals caught in the traps the largest number belonged to the family Scolytidae (Table 2). There are significant differences in species richness between our study plots (Table 1). The highest number of saproxylic species was identified from Site 1, which is characterised by its old tree individuals. Site 2 harboured fewer species than Site 1, but more than the young maquis at Site 3. From Site 1 we identified at least more than double the number of saproxylic beetle species identified from Site 3. In terms of rarefied species richness, Site 2 (Bar'am) harbours the most diverse community of saproxylic beetles. At this site we counted 70 % of the species number reported from Site 1, with only one-third of the number of individuals.

We found 2 morphospecies with more than 2 specimens exclusively at Site 3, 2 species at Site 2 and 16 exclusive species at Site 1. They belonged to several families, most of them within one species. Three longhorn beetle species (Cerambycidae), in

particular, were recorded only from the Site 1. When also considering the singletons, we found that more than 50 % of the assemblage from Site 1 are unique species for this location, whereas Site 2 has 36 % and Site 3 only 16 % unique beetle species.

### *3.3. Relationships between tree characteristics and saproxylic beetle assemblages*

The overall raw number of saproxylic beetle species is strongly correlated with the diameter of the investigated oak trees (Fig. 1; Pearson's correlation coefficient  $r=0.861$ ,  $p<0.001$ ). The number of saproxylic beetle species ranged from 9 to 37 per oak tree. The number of individuals caught ranged from 74 to 569 saproxylic beetle specimens per tree and is also strongly correlated with the diameter of the trees (Pearson's correlation coefficient  $r=0.928$ ,  $p<0.001$ ). Tree characteristics such as the amount and diversity of dead wood or the number of cavities are related to tree diameter (Spearman rank or Pearson's correlation coefficient  $r>0.8$ ).

## **4. Discussion**

Natural broad-leaved woodlands belong to the group of endangered habitats in the Mediterranean region (BALLETO and CASALE 1991). However, in spite of their threatened status we do not know much about dead wood and associated diversity in these woodlands.

### *4.1. Dead wood structures in differently managed Mediterranean woodlands.*

The Mediterranean woodlands analysed in this study consist of native tree species and acquired their present shape and structure as a result of extensive human activity. It can be assumed that they differ in their tree architecture and dead wood structure from natural woodlands in this region, because of a variety of different uses by local people; activities such as charcoal production and firewood removal, for example, still influence the trees' shape and therefore the woodland structure and are the reasons for the scarcity of dead logs and snags in all surveyed woodlands. We found no statistical significant differences between the woodlands observed. One goal of this study was to show the impact of different management options on wood structures and the associated beetle assemblage. We know from historical records that Site 2 in Bar'am used to be managed by monks for firewood

and construction timber. By means of selective cutting and coppicing they managed the woodland in a sustainable way, aiming at a long-term preservation of the trees. The results can still be seen today. There are significant differences in the stem density between the woodlands analysed.

**Table 3:** Identified species from five beetle families. Species names and their catch rates in the three studied plots are given. <sup>1</sup> species recently described from Turkey (SCHILLHAMMER et al. 2007). <sup>2</sup> The status of this species is not clear yet, but is closely related to *Placusa adscita*. <sup>3</sup> n.sp. undescribed.

| Family   | Species  | Site 1<br>(Fourties) | Site 2<br>(Bar'am) | Site 3<br>(Maquis) |
|--|--|----------------------|--------------------|--------------------|
| <b>Buprestidae</b>                                 | <i>Anthaxia spona</i> Kiesenwetter, 1857                         |                      | 1                  |                    |
|  | <i>Anthaxia perrini</i> Obenberger, 1918                         | 9                    |                    |                    |
|  | <i>Agrilus hastulifer</i> Ratzeburg, 1839                        | 1                    |                    |                    |
|  | <i>Agrilus relegatus</i> Curletti, 1990                          | 59                   | 1                  | 1                  |
|  | <i>Agrilus tenuissimus</i> Abeille de Perrin, 1891               | 2                    | 1                  |                    |
| <b>Cerambycidae</b>                                | <i>Arhopalus fesus</i> (Mulsant, 1839)                           | 1                    |                    |                    |
|  | <i>Axinopalpis gracilis</i> (Krynicky, 1832)                     | 1                    |                    |                    |
|  | <i>Cerambyx cerdo</i> Linnaeus, 1758                             | 1                    |                    |                    |
|  | <i>Cerambyx welensii</i> (Küster, 1845)                          | 1                    |                    |                    |
|  | <i>Clytus rhamni</i> Germar, 1817                                | 1                    |                    | 1                  |
|  | <i>Chlorophorus gratiosus</i> (Marseul, 1869)                    | 1                    |                    |                    |
|  | <i>Chlorophorus varius</i> (Müller, 1766)                        |                      |                    | 1                  |
|  | <i>Chlorophorus yachovi</i> Sama, 1996                           |                      |                    | 2                  |
|  | <i>Niphona picticornis</i> Mulsant, 1839                         | 2                    | 1                  |                    |
|  | <i>Penichroa fasciata</i> (Stephens, 1831)                       | 3                    |                    |                    |
|  | <i>Stromatium unicolor</i> (Olivier, 1795)                       | 3                    |                    |                    |
| <i>Trichoferus fasciculatus</i> (Faldermann, 1837) | 1  |                      |                    |                    |
| <i>Xylotrechus stebbingi</i> Gahan, 1906           | 4  |                      |                    |                    |
| <b>Staphylinidae</b>                               | <i>Hesperus auricomus</i> <sup>1</sup> Schillhammer et al., 2007 |                      | 1                  |                    |
|  | <i>Paraphloeostiba gayndahensis</i> (MacLeay, 1873)              | 40                   | 28                 | 39                 |
|  | <i>Placusa adscita</i> Erichson, 1839                            | 1                    | 12                 | 11                 |
|  | <i>Placusa tachyporoides</i> (Waltl, 1838)                       | 1                    |                    |                    |
|  | <i>Placusa spec.</i> <sup>2</sup>                                | 3                    |                    | 20                 |
| <b>Elateridae</b>                                  | <i>Adelocera pygmaea</i> (Baudi, 1871)                           | 1                    |                    |                    |
|  | <i>Cardiophorus sacratus</i> Erichson, 1840                      | 1                    | 4                  |                    |
|  | <i>Melanotus fusciceps</i> (Gyllenhal, 1817)                     | 2                    |                    |                    |
|  | <i>Melanotus spec.</i> <sup>3</sup>                              | 3                    |                    | 1                  |
|  | <i>Mulsanteus quillebelli</i> (Mulsant & Godart, 1853)           |                      | 3                  |                    |
| <b>Tenebrionidae</b>                               | <i>Strongylium saracenum</i> (Reiche & Saulcy, 1857)             | 2                    |                    |                    |

The largest number of stems per area was observed in the coppice woodland of Bar'am. The even-aged trees are typical for Bar'am, where many stems often grow from the same roots. Similar woodland structures were also common in the past in many European regions (cf. POTT and HÜPPE 1991; RACKHAM 1995; TACK and HERMY 1998). But after traditional woodland management was abandoned in most European regions, the coppice woodlands disappeared. Traditional coppice woodlands are also poor in dead wood. The amount and diversity of dead wood on the oaks differed between the different managed sites we studied. Old oaks in the semi-open stand showed more dead branches and diverse dead wood qualities than the others. Studies from Europe have shown that unmanaged woodlands accumulate much more dead wood than their managed relatives (JÖNSSON and JÖNSSON 2007; KIRBY et al., 1998). Comparable studies on dead wood in Mediterranean woodlands are still lacking. We presumed that the woodland management might have an impact on saproxylic beetle abundance and diversity.

#### *4.2. Saproxylic beetle richness dependent on site management.*

First attempts to analyse saproxylic beetle richness in Mediterranean woodlands were made by TRAVÉ (2003) and especially BRIN and BRUSTEL (2006). The latter studied saproxylic beetles on cork oaks in Southern France and they found the highest cumulative species richness in a closed cork oak stand with mature trees. We found most species and most individuals on the old oaks in the semi-open woodland, but highest rarefied species richness in the coppice woodland. We thus hypothesised that tree stem density together with the diameter of the oaks is perhaps important for species richness, meaning that at least some of the saproxylic beetle species would benefit from habitat continuity as a result of coppice management over several decades or perhaps centuries. It has been shown that habitat continuity is essential for several European woodland-inhabiting species and taxa (e.g. for lichens: ROSE 1976, for plants: WULF 2004, for ground beetles: ASSMANN 1999). TABOADA et al., (2006) tested Dehesa, mature closed, mature open, young stands for overall ground beetle richness and for indicator species and found no statistical significant differences. However, they showed that the structure of the carabid assemblage is significantly affected by several physical woodland parameters such as tree height and distance between oak trees.



Nevertheless, there is evidence from our findings that many saproxylic beetle species seem to be adapted to old oaks, because we found 16 exclusive species (with 2 specimens and more) on oak trees with a diameter larger than 60 cm. Early stages of the maquis harboured only a portion of the saproxylic species pool in later successional stages and had only few exclusive species. This pattern has also been observed in boreal spruce forests (ØKLAND et al., 1996) and on Swedish oaks (RANIUS and JANSSON 2000). Although the mature oaks studied here are richer in saproxylic beetles than younger trees, there are perhaps beetle species which prefer young and thinned maquis; for instance, we found *Chlorophorus yachovi* Sama, 1996 and *C. varius* (Müller, 1766) (both Cerambycidae) only on the young maquis oaks.

Several factors may influence the species richness patterns we found in our study. Within our catches we had a large proportion of singletons that indicates that there are probably more species than we found with our limited number of traps. Particularly for the hollow oaks at Site 1 we calculated an estimate of overall species richness that is almost twice the number of species we were able to record. We suppose that there are several unrecorded species living within the large cavities of the oaks at Site 1. Those species are better recorded with pitfall traps because many species living in hollow oaks are seldom flying (RANIUS and JANSSON 2002). One further parameter that may influence our results is the degree of elevation followed by different climatic conditions. We found in our study the most species-rich assemblage at 400 m a.s.l., whereas the lowest number of species is recorded from 900 m a.s.l. Because of the lack of replication, we are not able to discuss altitudinal patterns that might be obtained from our results, although this has been studied in e.g. butterflies (GUTIÉRREZ 1997) and is perhaps a challenge for future studies with saproxylic beetles.

#### 4.3. Management recommendations for Mediterranean woodlands.

There are many examples which show that grazing increases heterogeneity and establishes a moderate disturbance regime (e.g. HENKIN et al. 2007; PECO et al., 2006). Higher levels of spatial and temporal heterogeneity should be related to increasing levels of biodiversity according to a more abundant supply of different niches (e.g. for Mediterranean grasslands: PUERTO et al., 1990). This is perhaps also true for Mediterranean woodlands because grazing by cattle or sheep/goats has an impact

on tree shape and patch structure and therefore influences woodland heterogeneity. As many saproxylic beetle species are very specific in their habitat requirements, moderate grazing should be continued to maintain a diverse woodland structure with open and shaded habitats.

On the other hand, *Quercus calliprinos* woodlands can be managed through thinning and shrub removal to gain larger and thicker trees (PEREVOLOTSKY and HAIMOV 1992). As we have shown in our study, old oaks harbour more beetle species, and perhaps some late successional species, than younger trees. Therefore, some parts of the Mediterranean woodlands should be managed to allow natural ageing of the oaks. So, selective cutting may be an appropriate management measure for Mediterranean woodlands because it promotes a combination of sustainable use and a high shrub and tree species richness (cf. TORRAS and SAURA 2008). Pollarding by cutting the branches in 2-6 m above ground might be another suitable management of Mediterranean woodlands. However, traditional coppice management with selective cutting seems to be the most sustainable way to use wood resources and should also contribute to conservation issues. Because coppice management is necessarily a long-term approach to woodland use it includes important ecological features for saproxylic beetles such as habitat continuity, spatial and temporal heterogeneity.

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## **V Saproxylic beetle assemblages in the Mediterranean region: Impact of forest management on richness and structure**

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## Abstract

Forests cover almost 30% of the Mediterranean region today, yet forest management activities have influenced structure and composition of both natural and planted forests. To date no study has been conducted to evaluate the impact of forest management on saproxylic beetle assemblages, although it is known that the Mediterranean is a biodiversity hotspot with a long-lasting human pressure on natural habitats. We provide an overview of saproxylic beetle assemblages of three forest types (mature *Pinus halepensis* forests, mature *P. brutia* forests, young *Quercus calliprinos* forests) in the East Mediterranean region using a one-year sample from 12 forest plots located in the north of Israel.

The studied forest types differed in forest structure, but we found no significant difference in saproxylic beetle species richness. Aleppo pine forests showed the largest number of saproxylic beetle species. Forests dominated by *P. brutia*, a non-native tree species in Israel, show the lowest species number of all three forest types. Species composition differs substantially between oak and pine forests. A third of the species found either in *P. halepensis* or in *Q. calliprinos* forests being unique to these habitats, while a smaller proportion of unique beetle species is found in *P. brutia* forests. Several beetle species that were found both in oak and pine plots in our study develop exclusively on broadleaved shrubs or trees. This may be explained by the small distances between the studied pine trees and oaks in their proximity.

Biodiversity in pine forests can be increased when these are mixed with broad-leaved trees, e.g. oaks in the understorey layer, as can be observed the natural regrowth in most of the planted pine stands in our research area. There is some evidence from other studies that older successional stages of oak forests are likely to host more species overall than the mature pine forests studied here. In order to enhance structural diversity foresters should allow for aging of single trees or stands, regardless of the tree species.

**Keywords:** Mediterranean oaks, pines, beetle diversity, community ecology, Israel

## 1. Introduction

The Mediterranean region is known for its large number of woody species compared to Central or Northern Europe (BLONDEL and ARONSON 1999). Sclerophyllous forests consisting mainly of evergreen oaks are the characteristic vegetation type in the Mediterranean climate zone (LIPHSCHITZ and BIGER 1990; QUÉZEL 2004; ZOHARY 1960). The whole Mediterranean region, but particularly the eastern part, is among the regions where human pressure on the landscape was exceedingly high in the past (NAVEH and DAN 1973). This long process of intensive land-use over thousands of years has led to a large-scale degradation of forests. All remnants of forests that survived are now grazed, but differ in size as well as in structure and shape, depending on the current land-use management (cf. DI PASQUALE et al., 2004; GROVE and RACKHAM 2003; WESTPHAL et al., 2009).

In the 20<sup>th</sup> century, former open land was planted with coniferous, often non-native tree species in many Mediterranean regions (BONNEH 2000; PAUSAS et al., 2004). This applies particularly to Israel where foresters planted almost 100 000 ha of former open land with coniferous trees for several purposes (GINSBERG 2006; OSEM et al., 2008). Aleppo pines (*Pinus halepensis*) and Calabrian pines (*Pinus brutia*) are the most frequently planted tree species in Israel and elsewhere in the East Mediterranean, although the latter species is not native to Israel (BIGER and LIPHSCHITZ 1991) and the former constituted only a small percentage of the native arboreal vegetation before plantations took place in the 20<sup>th</sup> century (LIPHSCHITZ and BIGER 2001). Almost simultaneously with the afforestation, socio-economic conditions changed in Israel, resulting in lower grazing pressure on the landscape. Thus, former shrublands with overgrazed and cut trees regenerated and developed into semi-natural, oak-dominated forests.

Because of its high human population density, Israel suffers severely from a loss of open space. This alarming development is in contrast with the overall importance of the region as a biodiversity hotspot (YOM-TOV and TCHERNOV 1988). Open spaces are important habitats for Israel's biodiversity (FILSER and PRASSE 2008; TIMM et al., 2009). In order to find effective solutions to conserve a maximum of biodiversity in the region, more research and a management strategy for the remaining open space is urgently needed. This is currently of major practical importance as many pine

stands have reached age classes which will require forestry management decisions in the near future, e.g. should natural development be allowed or should young pine trees be planted again (OSEM et al. 2008).

In this study we use saproxylic (=wood-dependent) beetles as model organisms. Saproxylic beetles include a large number of taxa with many that play a key role in the decomposition of woody material in forest ecosystems (cf. BUSE et al., 2009; GROVE 2002). We address the following questions:

(1) What is the impact of current forest management on saproxylic beetle assemblages in Israel?

(2) Does assemblage similarity and species richness differ between the studied forest types?

This study contributes to the broad topic of sustainable land-use under discussion in the entire Mediterranean region, because a similar land-use history took place in other countries, such as Spain, Italy, Greece and Turkey (GROVE and RACKHAM 2003).

## 2. Material and Methods

### 2.1. Research area

The study region is located in Upper Galilee in the north of Israel (Mt. Meron and surroundings). This region reaches altitudes of 800-1200 m and is characterised by a moderate Mediterranean climate with 593 mm mean annual precipitation (Israel Meteorological Service, 2008 for Station Har Kenaan near Zefat). Our study plots are between 600 and 900 m a.s.l. and are grazed either by cattle or by goats and sheep throughout the year.

Large areas of former pastures in the study region were planted with pine trees some 50 years ago for the protection of public land, providing employment, and improvement of the landscape to encourage settlement (OSEM et al. 2008). Of the two pine species mainly used for afforestation, *Pinus brutia* is not a native species, while *P. halepensis* is native, although the seeds used for plantations in Israel were imported from different locations all around the Mediterranean (BIGER and LIPHSCHITZ 1991; GRUNWALD et al., 1986; LIPHSCHITZ and BIGER 2001). In our study

plots *P. halepensis* and *P. brutia* stand either in monoculture or in a mix of both species, and sometimes the understorey layer is spotted with *Quercus calliprinos* trees. The main semi-natural vegetation in the study area is a Mediterranean sclerophyllous forest dominated by *Quercus calliprinos*, *Quercus boissieri* and *Pistacia palaestina* (ZOHARY 1960). The forests in this region are developed not as shrubland but as a true forest, with a maximum tree height of 10 m (cf. DANIN 1988).

## 2.2. Study design

Our study was designed to analyse differences in species richness of saproxylic beetles (and possible relationships with environmental parameters) under different forest management practices. We thus investigated the three main forest types in our study region: *Pinus halepensis*, *Pinus brutia* forests and *Quercus calliprinos* forests. We set up a total of 12 study plots at different locations per forest type. Five were in *P. halepensis* forests, 3 in *P. brutia* forests, and 4 in *Quercus* forests. One of the *P. halepensis* plots was originally thought to be a *P. brutia* plot, but later designated a *P. halepensis* plot since this is the dominant tree species there. This resulted in an unequal sample size. At each location we set four flight-interception traps located 15-100 m apart from each other. The traps were placed in relatively homogenous forest stands at a minimum distance of 10 m from the forest margins.

## 2.3. Insect and plot data

We used 48 flight-interception traps with crossed panels of plexiglass (50x30 cm) to survey the flight-active beetle fauna of the different woodlands (see HYVÄRINEN et al., 2006). The traps were placed in the lower canopy ca. 2-5 metres above ground from May 14<sup>th</sup> to July 20<sup>th</sup> 2007 during the main flight period of saproxylic insects. We used a preservation mixture (ethanol, water, glycerine, acetic acid; after RENNER 1980) and we emptied the traps at three-week intervals. Some of the chemicals used in the preservative mixture are known to attract beetle species (cf. JONSELL et al., 2003; SCHROEDER and LINDELÖW 1989); this can be used to enhance the probability of detecting saproxylic beetles (BOUGET et al., 2009). Individuals were sorted and counted by morphospecies, also recording the family to which they belong. This approach has been tested successfully for invertebrate species as a surrogate for true species, particularly to answer questions about species richness (OLIVER and

BEATTIE 1996). We separated saproxylic from non-saproxylic species on a taxonomical basis. Only putative saproxylic species were considered, because there is to date no list of saproxylic beetles in any Mediterranean country. Some of the taxa in our study have been identified by taxonomic experts (see Acknowledgements). All specimens will be deposited in The National Collections of Natural History of the Tel Aviv University (Israel), the Zoological State Collection Munich, and the Zoological Museum of the University of Hamburg (Germany).

We measured the following tree-dependent variables on the tree where the trap was placed: tree diameter, tree height, distance to the next different tree species, and amount of dead wood on the tree (Table 1). We also looked for characteristics in our study plots such as the number of trunks and the proportion of tree species other than the dominant ones. We estimated the total number of trunks per hectare by counting the trunks of 100 (10x10 m) m<sup>2</sup> in the *Quercus calliprinos* woodland plots and 2500 (50x50 m) m<sup>2</sup> in the pine plots. Counts within 100 m<sup>2</sup> were made around each trap location. We used a larger area for counting in the pine plots because of the greater distances between individual trees. The results were then extrapolated to one hectare.

## 2.4. Statistics

### 2.4.1. Calculating species richness

We grouped the species data from each forest type to minimise the factor levels in the analysis. Many of the species typically appear in single individuals within saproxylic beetle assemblage catches. To estimate total species richness we used  $S_{CHA01}$ , which incorporates a calculation of the number of unseen species that is based on the number of singletons and doubletons in a sample (CHAO 1984):

$$S_{CHA01} = S_{obs} + (\alpha^2 / 2\beta)$$

where  $S_{obs}$  is the observed number of species in a sample,  $\alpha$  is the number of observed species that are represented by a single individual (i.e. singletons) and  $\beta$  is the number of observed species represented by two individuals (i.e. doubletons) in the sample.  $S_{CHA01}$  was calculated with EstimateS (Version 8.0.0, COLWELL 2008).

We applied analysis of variance (ANOVA) to test for differences in the number of raw morphospecies between the forest types using species numbers pooled for each of the 12 study plots.

**Table 1:** Characteristics of the saproxylic beetle assemblages and research plots in 3 different forest types. Selected environmental variables and their values for the forest types are shown. We measured further environmental variables that are not shown here, but were used for the PCA: number of trunks/ha, relative proportion of pines and oaks, number of old and young stumps, elevation a.s.l.

SD=Standard deviation; significance level: \*\*\*  $p < 0.001$ , \*\*  $p < 0.01$ , \*  $p < 0.05$ , n.s.=not significant.

| Assemblage parameters   | Oak forest<br>(n=4) | <i>Pinus<br/>halepensis</i><br>forest (n=5) | <i>Pinus brutia</i><br>forest (n=3) | $F_{ANOVA}$            |
|---|---------------------|---|-------------------------------------|------------------------|
| Mean number of saproxylic beetle species per plot   | 32.0<br>(SD=8.5)    | 36.8<br>(SD=5.2)                            | 31.0<br>(SD=6.2)                    | $F_{2,9}=0.909$ n.s.   |
| Mean number of individuals per plot   | 595<br>(SD=146.3)   | 1003<br>(SD=198.0)                          | 544<br>(SD=211.2)                   | $F_{2,9}=7.891^*$      |
| Mean abundance of the most abundant species <i>Scobicia chevrieri</i> (Bostrychidae) per plot | 427.5<br>(SD=170.7) | 636<br>(SD=269.9)                           | 395.3<br>(SD=245.5)                 | $F_{2,9}=1.315$ n.s.   |
| Mean number of bark beetle species (Scolytidae)   | 2<br>(SD=0)         | 5<br>(SD=0.8)                               | 8<br>(SD=1)                         | $F_{2,9}=28.938^{***}$ |
| Mean number of bark beetle individuals per plot   | 26.5<br>(SD=13.2)   | 261.2<br>(SD=167.7)                         | 44.7<br>(SD=12.7)                   | $F_{2,9}=5.987^*$      |
| <b>Plot parameters</b>  |                     |   |                                     |                        |
| Mean tree diameter at breast height in metres   | 0.19<br>(SD=0.06)   | 0.37<br>(SD=0.05)                           | 0.42<br>(SD=0.006)                  | $F_{2,9}=26.259^{***}$ |
| Mean number of trunks per hectare   | 1319<br>(SD=834)    | 323<br>(SD=174)                             | 330<br>(SD=161)                     | $F_{2,9}=5.234^*$      |
| Mean tree height in metres per plot   | 4.5<br>(SD=0.54)    | 13.75<br>(SD=1.10)                          | 15<br>(SD=1.25)                     | $F_{2,9}=129.20^{***}$ |
| Mean distance to the next different tree species (oak or pine) in metres                      | 65<br>(SD=44.18)]   | 27<br>(SD=41.07)                            | 39<br>(SD=52.68)                    | $F_{2,9}=0.846$ n.s.   |
| Occurrence of large dead branches on the tree [1 = < 5 cm; 2 = > 5 cm]                        | 1=15<br>2=1         | 1=18<br>2=2                                 | 1=7<br>2=5                          | Fisher's test<br>n.s.  |

#### 2.4.2. Calculating community similarity

Despite their popularity, classic indices of community similarity, e.g. Jaccard or Sørensen, are sensitive to sample size and perform poorly when applied to species-rich communities with a large fraction of rare species (PLOTKIN and MÜLLER-LANDAU

2002). To calculate community similarity for raw abundance data, we used Chao's Sørensen index (an improved version of the classical Sørensen index), which takes different sample sizes and the relative abundance of each species into account (CHAO et al., 2005). One important advantage of this index is that the number of singletons and doubletons is part of the calculation. The incorporation of unseen shared species makes it a powerful and more accurate tool than most other indices when assessing communities with a large proportion of singletons, as in our study. We calculated community similarities between all possible sample pairs and analysed the means of similarity for the three forest types. In the settings, rare species are defined as species with no more than 2 individuals (i.e. we considered as rare singletons and doubletons) in the entire sample. Standard deviations (SD) for each similarity measure were calculated with 200 iterations. We also analysed the number of shared species between two samples. Both calculations (community similarity and number of shared species) were performed with EstimateS (Version 8.0.0, COLWELL 2008).

Host plant preferences of species in selected families were obtained from the literature and by personal communication with experts (BENSE 1995; HALPERIN and HOLZSCHUH 1984 for Scolytidae; HALPERIN and HOLZSCHUH 1993; MÜHLE et al., 2000 for Buprestidae SAMA pers. comm. for Cerambycidae, SCHEDL 1978).

#### 2.4.3. Relationship between species numbers and environmental variables

As several of the environmental variables were correlated in the dataset, we used a principal components analysis (PCA) to analyse differences in environmental variables between the forest types (Table 1) using environmental data from each of the 48 trap locations. The PCA-axes 1 and 2 were used for a correlation analysis with environmental variables to identify the most important variables affecting differences between forest types (Pearson correlations,  $r > 0.7$ ). Finally, both PCA-axes were related to the number of morphospecies in each trap to identify environmental parameters that determine species richness of saproxylic beetles in the investigated forest types.



### 3. Results

#### 3.1. Plot characteristics

Three of the *Q. calliprinos* plots consisted exclusively of broadleaved trees, whereas one was mixed with pines (10% of the total trunks). Four of the five *P. halepensis* plots had a proportion of young oak individuals in the understorey (between 10% and 30% of the total). Two of the three *P. brutia* plots were also mixed with *Q. calliprinos* in the understorey (less than 10% and 25%, respectively).

There were marked differences between and within the forest types regarding the number of trunks per hectare (Table 1). The largest number of trunks (400 to 2500 trunks per hectare) was found in the *Q. calliprinos* forests. Both pine forests show between 100 and 500 trunks per hectare. The diameter at breast height (dbh) of the trees in our study plots ranged from 0.29 to 0.54 metres for *Pinus brutia*, 0.22 to 0.51 metres for Aleppo pines and 0.09 to 0.37 metres for the oak individuals studied.

The PCA showed that the studied oak forests can be ecologically distinguished from both pine forest types (Figure 2). The first PCA-axis represents differences in forest structure and composition (Pearson correlation,  $r > 0.7$ ,  $p < 0.05$ : dbh, number of trunks, tree height, relative proportions of pines and oaks) while the second PCA-axis represents spatial differences such as the distance to other tree species and elevation above sea level. Only variables that are correlated to the first axis can be used to explain differences between forest types.

#### 3.2. Species richness

We trapped a total of 9,026 individuals from 138 saproxylic beetle morphospecies. *Pinus halepensis* forests showed an average of 1000 individuals per study plot. This is much more than the other forest types because of a larger number of bark beetles (Scolytidae and Bostrychidae) in the samples, with *Scobicia chevrieri* (Bostrychidae) individuals representing more than 67% of the entire saproxylic sample. We identified individuals from 28 beetle families (Table 2).

**Table 2:** Number of morphospecies and individuals caught from different beetle families. Sample sizes for the three forest types are unequal: 4 *Q. calliprinos* forests (16 traps), 5 *P. halepensis* forests (20 traps), 3 *P. brutia* forests (12 traps). Shown are the standardised mean sample sizes per plot for each forest type.

| Family         | Number of morphospecies | Number of individuals | <i>Quercus calliprinos</i> forest | <i>Pinus halepensis</i> forest | <i>Pinus brutia</i> forest |
|----------------|-------------------------|-----------------------|-----------------------------------|--------------------------------|----------------------------|
| Aderidae       | 2                       | 2                     | 0.3                               | 0.2                            | 0                          |
| Alleculidae    | 6                       | 44                    | 8.0                               | 2.2                            | 0.3                        |
| Anobiidae      | 12                      | 468                   | 67.3                              | 18.8                           | 35.0                       |
| Anthribidae    | 1                       | 4                     | 0.5                               | 0.4                            | 0                          |
| Buprestidae    | 7                       | 53                    | 4.3                               | 5.4                            | 3.0                        |
| Bostrychidae   | 2                       | 6077                  | 427.5                             | 636.0                          | 395.7                      |
| Bothrideridae  | 1                       | 1                     | 0                                 | 0.2                            | 0                          |
| Cantharidae    | 1                       | 1                     | 0.3                               | 0.0                            | 0                          |
| Catopidae      | 1                       | 5                     | 0.3                               | 0.8                            | 0                          |
| Cerambycidae   | 11                      | 45                    | 4.5                               | 3.8                            | 2.7                        |
| Cleridae       | 2                       | 29                    | 4.0                               | 2.0                            | 1.0                        |
| Corylophidae   | 1                       | 1                     | 0                                 | 0.2                            | 0                          |
| Curculionidae  | 4                       | 52                    | 0                                 | 4.2                            | 10.3                       |
| Dermestidae    | 8                       | 15                    | 0.8                               | 1.4                            | 1.7                        |
| Elateridae     | 9                       | 48                    | 3.3                               | 5.0                            | 3.3                        |
| Histeridae     | 4                       | 22                    | 0                                 | 2.6                            | 3.0                        |
| Laemophloeidae | 3                       | 5                     | 0                                 | 1.0                            | 0                          |
| Malachidae     | 4                       | 10                    | 2.3                               | 0                              | 0.3                        |
| Melandryidae   | 2                       | 5                     | 1.0                               | 0                              | 0.3                        |
| Melyridae      | 11                      | 135                   | 10.5                              | 10.0                           | 7.3                        |
| Mordellidae    | 6                       | 16                    | 2.0                               | 1.4                            | 0.3                        |
| Mycetophagidae | 2                       | 236                   | 9.0                               | 25.6                           | 24.0                       |
| Nitidulidae    | 6                       | 68                    | 11.3                              | 4.2                            | 0.7                        |
| Ptinidae       | 7                       | 105                   | 6.0                               | 11.8                           | 7.3                        |
| Scarabaeidae   | 4                       | 44                    | 5.5                               | 3.4                            | 1.7                        |
| Scolytidae     | 9                       | 1546                  | 26.5                              | 261.2                          | 44.7                       |
| Silvanidae     | 1                       | 1                     | 0                                 | 0.2                            | 0                          |
| Tenebrionidae  | 4                       | 7                     | 0                                 | 0.8                            | 1.0                        |
| Other          | 2                       | 2                     | 0                                 | 0.4                            | 0                          |

The most important families in terms of recorded species numbers in our study are Anobiidae, Cerambycidae, and Melyridae. Morphospecies from the Cerambycidae, Scolytidae, Elateridae, Buprestidae, Bostrychidae, Ptinidae and Bothrideridae families were identified by experts to the species level. Their occurrence in the three

investigated woodland types is shown in Table 3. The majority of the bark beetles are found exclusively in pine stands, some of them in large numbers.

Species with one individual only (singletons) made up 35.5 % of all morphospecies. The number of morphospecies per plot (4 traps each) ranged from 25 to 44, but was not significantly different between the studied forest types (Table 1, ANOVA,  $F=0.909$ ,  $p=0.437$ ). Species numbers per trap ranged from 6 to 25. Species accumulation curves for estimated species richness reached an asymptote in all three forest types, indicating that the majority of the species were recorded (Fig. 1).  $S_{CHAO1}$  values of estimated species richness were highest in *P. halepensis* forests, ranging between 102 and 129 species (mean=110) for 10 traps. This was followed by the oak forests with a mean estimated species number of 84. The species richness in oak forests showed a large variability, ranging from 64 to 146 for 10 traps. The lowest species numbers were estimated for the *P. brutia* forests ranging between 63 and 100 species (mean=73) for 10 traps.

The PCA revealed structural differences between the forest types, but these differences did not significantly affect the species richness of saproxylic beetles (Figure 2).

### 3.3. Assemblage similarity

We compared the CHAO's Sørensen values between all possible treatment combinations. The lowest values for assemblage similarity within the forest types were obtained in the *Q. calliprinos* forests, where data ranged between 0.74 and 0.94 (mean=0.802). Both *Pinus* forest types reached relatively high similarity values within their treatment. Similarity between different forest types, was lowest between *Q. calliprinos* forests and *P. halepensis* forests, ranging from 0.25 to 0.64 (mean=0.396; Figure 3). Almost no difference in the assemblage was found between the two *Pinus* forest types. *P. brutia*-forests had a higher Sørensen similarity to *Q. calliprinos* forests than *P. halepensis* forests, but did not share more species. On average, more than 14 species were shared between both *Pinus* forest types. This was also true within *P. halepensis* forests and within *Q. calliprinos* forests. On the other hand, on average only 10-11 species were shared between the oak forest and each of the *Pinus* forest types.

Figure 4 shows the proportion of species unique to the forest types and the proportion of beetle species shared in the assemblages between the forest types. Only 18% of the recorded beetle species occurred in all of the studied forest types. More than 34% in the Aleppo pine forests and 31% in the oak forests were unique species occurring only in one of these two forest types. Only 15% of the beetle species recorded in *Pinus brutia* forests were unique there.

Host plant preferences can be obtained from the literature for species that have been identified. We looked for such information for species from typical wood-feeding beetle families (e.g. Buprestidae, Cerambycidae, Scolytidae) and found that, according to the literature (see Material and Methods), four of the species that we found exclusively on oaks (*Clytus rhamni*, *Chlorophorus varius*, *Chlorophorus trifasciatus*, *Anthaxia millefolii*) develop in broadleaved shrubs or trees. On the other hand, 9 of 11 species that were found exclusively on pines during this study feed on coniferous trees during larval development. However, 7 of the 9 species that were found both in oak and pine plots in our study (Table 3) develop exclusively on broadleaved shrubs or trees. This may be explained by the small distances between the studied pine trees and oaks in their proximity as we found e.g. a negative correlation between abundance of *Xyleborinus saxesenii*, a species inhabiting broadleaved trees, and the distance between pines and oaks in their proximity (Pearson correlation,  $r=-0.426$ ,  $p=0.015$ ). Another species, *Agrilus relegatus alexeevi*, was found with one specimen each in three different traps on pines. All three pines were maximum 20 m from the next oak.

**Table 3:** Number of individuals of identified beetle species in the three investigated forest types. <sup>1</sup> n.sp. undescribed. The families and species are listed in alphabetical order. Sample sizes for the three forest types are unequal: 4 *Q. calliprinos* forests (16 traps), 5 *P. halepensis* forests (20 traps), 3 *P. brutia* forests (12 traps).

| Family   | Species  | <i>Quercus</i><br>forest | <i>calliprinos</i> | <i>Pinus</i><br>forest | <i>halepensis</i> | <i>Pinus</i><br>forest | <i>brutia</i> |
|--|--|--------------------------|--------------------|------------------------|-------------------|------------------------|---------------|
| Bostrychidae                                   | <i>Scobicia chevrieri</i> (Villa & Villa, 1835)              | 1710                     |                    | 3180                   |                   | 1186                   |               |
| Bothrideridae                                  | <i>Ogmoderes angusticollis</i> (Brisout de Barneville, 1861) | 0                        |                    | 1                      |                   | 0                      |               |
| Buprestidae                                    | <i>Agrilus relegatus alexeevi</i> Bellamy 1998               | 1                        |                    | 2                      |                   | 1                      |               |
|  | <i>Anthaxia laticeps navratili</i> Bílý, 1984                | 0                        |                    | 6                      |                   | 3                      |               |
|  | <i>Anthaxia mundula</i> Kiesenwetter, 1857                   | 8                        |                    | 14                     |                   | 4                      |               |
|  | <i>Anthaxia millefolii</i> Fabricius, 1801                   | 8                        |                    | 0                      |                   | 0                      |               |
|  | <i>Anthaxia olympica astoreth</i> Obenberger, 1937           | 0                        |                    | 1                      |                   | 0                      |               |
|  | <i>Anthaxia sponsa</i> Kiesenwetter, 1857                    | 0                        |                    | 1                      |                   | 0                      |               |
|  | <i>Chrysobothris solieri</i> Gory & Laporte, 1837            | 0                        |                    | 3                      |                   | 1                      |               |
|  | <i>Chrysobothris solieri</i> Gory & Laporte, 1837            | 0                        |                    | 3                      |                   | 1                      |               |
| Cerambycidae                                   | <i>Cerambyx cerdo</i> (Linnaeus, 1758)                       | 1                        |                    | 1                      |                   | 0                      |               |
|  | <i>Chlorophorus trifasciatus</i> (Fabricius, 1781)           | 1                        |                    | 0                      |                   | 0                      |               |
|  | <i>Chlorophorus varius</i> (Müller, 1766)                    | 1                        |                    | 0                      |                   | 0                      |               |
|  | <i>Chlorophorus yachovi</i> Sama, 1996                       | 4                        |                    | 1                      |                   | 0                      |               |
|  | <i>Clytus rhamni</i> (Germar, 1817)                          | 1                        |                    | 0                      |                   | 0                      |               |
|  | <i>Hylotrupes bajulus</i> (Linnaeus, 1758)                   | 0                        |                    | 1                      |                   | 2                      |               |
|  | <i>Nathrius brevipennis</i> (Mulsant, 1839)                  | 5                        |                    | 11                     |                   | 2                      |               |
|  | <i>Niphona picticornis</i> Mulsant, 1839                     | 0                        |                    | 2                      |                   | 1                      |               |
|  | <i>Pedostrangalia riccardoi carmelita</i> Sama, 1996         | 0                        |                    | 2                      |                   | 1                      |               |
|  | <i>Phymatodes testaceus</i> (Linnaeus, 1758)                 | 1                        |                    | 1                      |                   | 0                      |               |
| Cleridae                                       | <i>Xylotrechus smeii</i> (Castelnau & Gory, 1841)            | 4                        |                    | 0                      |                   | 2                      |               |
|  | <i>Denops albofasciatus</i> (Charpentier, 1825)              | 1                        |                    | 3                      |                   | 1                      |               |
| Elateridae                                     | <i>Opilo taeniatus</i> (Klug, 1842)                          | 15                       |                    | 7                      |                   | 2                      |               |
|  | <i>Cardiophorus sacratus</i> Erichson, 1840                  | 0                        |                    | 11                     |                   | 4                      |               |
| Elateridae                                     | <i>Lacon punctatus</i> (Herbst, 1779)                        | 0                        |                    | 1                      |                   | 0                      |               |
|  | <i>Melanotus fusciceps</i> (Gyllenhal, 1817)                 | 2                        |                    | 3                      |                   | 1                      |               |
|  | <i>Melanotus spec.</i> <sup>1</sup>                          | 7                        |                    | 5                      |                   | 5                      |               |
|  | <i>Mulsanteus quillebelli</i> (Mulsant & Godart, 1853)       | 1                        |                    | 0                      |                   | 0                      |               |
|  | <i>Peripontius terminatus</i> (Erichson, 1841)               | 0                        |                    | 1                      |                   | 0                      |               |
|  | <i>Pittonotus theseus simoni</i> (Germar, 1817)              | 1                        |                    | 3                      |                   | 0                      |               |
| Ptinidae                                       | <i>Dignomus frivaldszkyi</i> (Reitter, 1884)                 | 3                        |                    | 4                      |                   | 2                      |               |
|  | <i>Ptinus variegatus</i> Rossi, 1794                         | 1                        |                    | 0                      |                   | 0                      |               |
| Scolytidae                                     | <i>Carphoborus henscheli</i> Reitter, 1887                   | 0                        |                    | 0                      |                   | 1                      |               |
|  | <i>Crypturgus numidicus</i> Ferrari, 1867                    | 0                        |                    | 0                      |                   | 1                      |               |
|  | <i>Hylurgus miklitzii</i> Wachtl, 1881                       | 0                        |                    | 83                     |                   | 17                     |               |
|  | <i>Orthotomicus erosus</i> (Wollaston, 1857)                 | 0                        |                    | 254                    |                   | 40                     |               |
|  | <i>Pityogenes calcaratus</i> (Eichhoff, 1878)                | 0                        |                    | 826                    |                   | 41                     |               |
|  | <i>Pityophtorus spec.</i>                                    | 0                        |                    | 0                      |                   | 1                      |               |
|  | <i>Xyleborinus saxesenii</i> (Ratzeburg, 1837)               | 83                       |                    | 113                    |                   | 30                     |               |
| <i>Xyleborus monographus</i> (Fabricius, 1792) | 23   |                          | 9                  |                        | 2                 |                        |               |

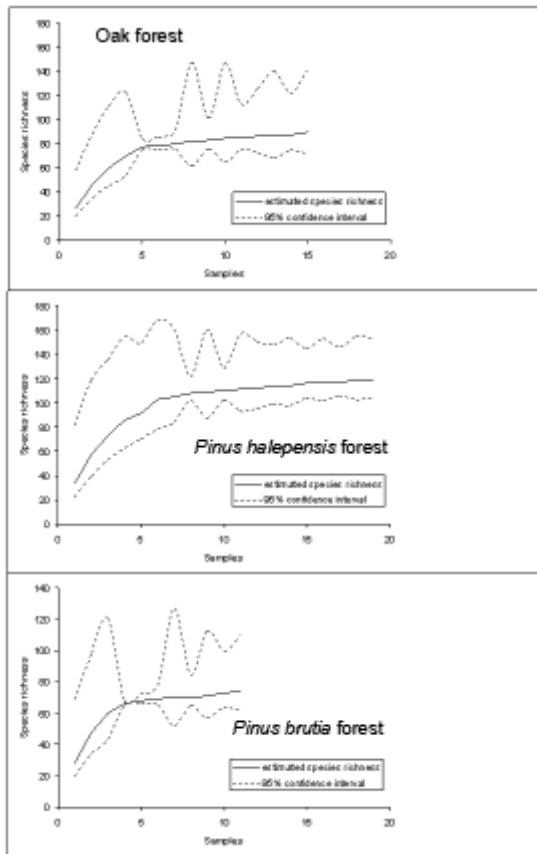
#### 4. Discussion

On average, 29% of the total land area in the Mediterranean region is covered by forests (FAO 2005 for 21 Mediterranean countries). The two pine species *Pinus halepensis* and *P. brutia* together cover 25% of the forested area in the Mediterranean region and are thus the two major forest tree species there (QUEZEL, 2000). Nevertheless, evergreen oaks are also of particular importance in the region as they cover large areas of the landscape with a natural or semi-natural vegetation type (e.g. 25% of the forested area in Spain, RODA et al., 1999). In Israel more than 12% (256.000 ha) of the total land area is covered by forests and other woodlands. Aleppo pine alone represents as much as 40% of the area covered by forests in Israel. However, there is a distinct lack of systematic studies on saproxylic insect assemblages inhabiting Mediterranean forests. Also information about saproxylic beetles other than common pest species in Mediterranean pine forests is very rare (cf. BATTISTI 2005).

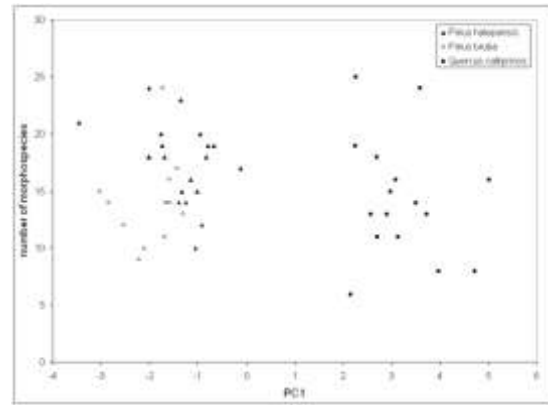
##### 4.1 Species richness in Mediterranean forests

Biodiversity criteria are today expected to play an important role in the land-use policies of many Mediterranean countries (PEREVOLOTSKY 2005; SCARASCIA-MUGNOZZA et al., 2000). Although the Mediterranean region is considered to be a biodiversity hotspot (MÉDAIL and QUÉZEL 1999; MYERS et al., 2000), only a few systematic studies report on the biodiversity of beetles in Mediterranean tree habitats (e.g. BRIN and BRUSTEL 2006; BUSE et al., 2008a; DA SILVA et al., 2009; SIRAMI et al., 2008; TABOADA et al., 2006).

There is evidence that coniferous forests have negative effects on species richness and community composition of some taxa, e.g. for woodland specialist birds (GIL-TENA et al., 2007) or plant communities (NAVEH and WHITTAKER 1979). Both faunal diversity and composition seem to be different in coniferous plantations compared with other forest types of the same region (AMO et al., 2007; GIL-TENA et al. 2007; VAN HALDER et al., 2008). Pine plantations are also known to spread into neighbouring habitats (LAVI et al., 2005) and may thus threaten adjacent natural ecosystems.



**Figure 1:** Estimated species richness ( $S_{CHA01}$ ) for the three forest types studied.



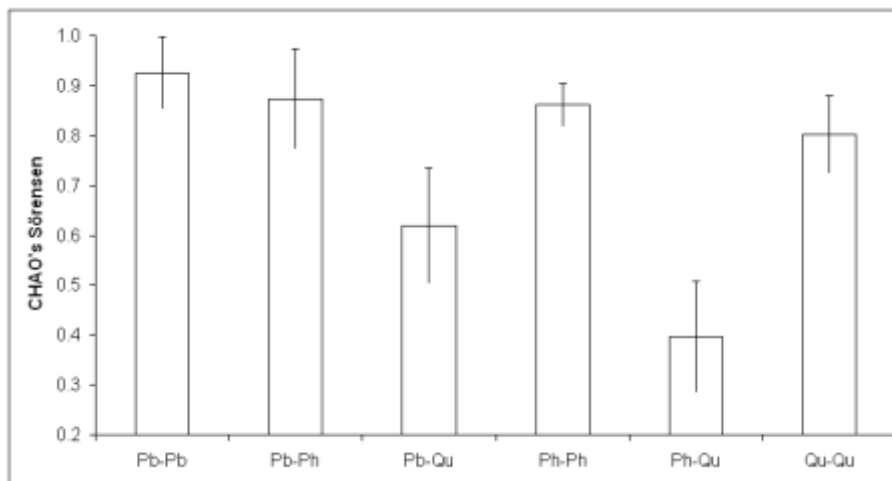
**Figure 2:** Results of the principal component analysis (PCA) for all 48 trap locations and environmental parameters. Axis 1 and its relation to the number of saproxylic beetle species are shown. The studied oak forests are ecologically distinct from the pine forests, but this is not reflected in the species numbers (Pearson correlation,  $r=-0.206$ ,  $p=0.160$ ).

Effects of Aleppo pine afforestations on faunal communities are only known from studies on birds, which show that pine plantations can reduce bird species diversity (cf. MAESTRE and CORTINA 2004). However, there is a clear lack of information on the impacts of these plantations on animal groups other than birds.

Our results show that pine afforestations in Israel do not affect species richness per se. However, we found that the saproxylic beetle assemblages living in pine and oak forests are different in terms of assemblage similarity. A relatively large number of species is unique for each forest type, although many species also appeared in all three forest types because of single scattered oaks in the studied pine stands.

Beetles, particularly bark beetles (Scolytidae), form the largest group of xylophagous insects living on the two studied pine species. Very few insect species (less than 4% of the total 113 species listed by MENDEL (2000)) seem to be exclusively dependent on *P. halepensis* and *P. brutia* during their larval development or for adult feeding purposes (MENDEL 2000). The majority of the species are able to develop in several

different pine species. In terms of the number of individuals, bark beetles are the dominant group in our samples, together with the polyphagous bostrychid beetle *Scobicia chevrieri*. In our samples *Pityogenes calcaratus* and *Orthotomicus erosus* are the most important bark beetle species in terms of individual numbers. Both species are among the bark beetle species which inhabit pines in Israel (HALPERIN and HOLZSCHUH 1984; SCHEDL 1978). Three other bark beetle species (*Carphoborus henscheli*, *Crypturgus numidicus*, *Hylurgus miklitzii*) were exclusively found in pine stands, as also reported by SCHEDL (1978) and HALPERIN and HOLZSCHUH (1984). *Xyleborinus saxesenii* and *Xyleborus monographus* are more widespread bark beetle species inhabiting broadleaved trees and were recorded in our study from both pine and oak stands. In contrast to the bark beetles (Scolytidae) 10 of the 11 longhorn beetles (Cerambycidae) that we found develop in broadleaved trees or shrubs. At least three of these species are mainly or exclusively dependent on oaks during their larval development: *Phymatodes testaceus*, *Pedostrangalia riccardoi carmelita* and *Cerambyx cerdo*. Only *Hylotrupes bajulus*, a widely distributed pest, is dependent on pines. Some longhorn beetle species dependent on broadleaved trees or shrubs, were also found in the pine stands, indicating the mixed character of the investigated stands or the species' ability to cover relatively large distances by flight.



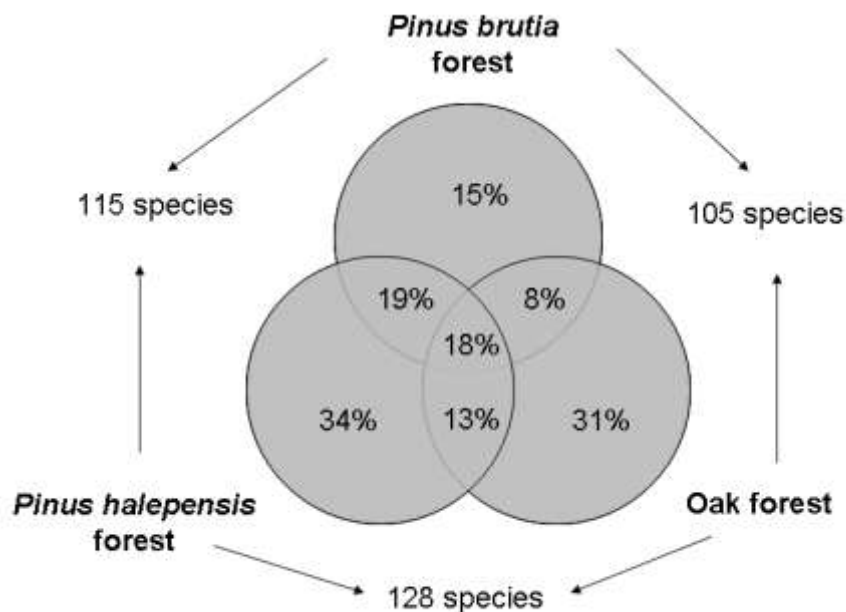
**Figure 3:** Mean values of Chao's Sørensen index for comparisons between the three forest types (Ph=*Pinus halepensis* forests, Pb=*Pinus brutia* forests, Qu=oak forests). There is a significant difference between the means of Qu-Qu and Qu-Ph (Wilcoxon rank-sum test,  $p < 0.001$ ), Qu-Qu and Qu-Pb (Wilcoxon rank-sum test,  $p = 0.003$ ), and between Pb-Qu and Ph-Qu (Wilcoxon rank-sum test,  $p < 0.001$ ). Community similarity is much lower between oak and pine stands than within the oak only or pine only stands.



Our results show that the studied oak forests can be distinguished from both pine forest types by means of structural variables such as the number of stems, dbh, and tree height. Although there are structural differences, the number of saproxylic beetle species did not differ between forest types. Scattered oaks in the studied pine forests are likely to increase species richness as some beetle species which develop in broadleaved trees were found in pine forests with scattered oaks. The scattered oaks in the pine forests as well as the oaks studied in the *Quercus calliprinos* forests were relatively young trees inhabited only by a few species. A far larger number of saproxylic beetle species can be expected in old-growth oak stands in the same region: BUSE et al. (2008a) recorded 74 saproxylic beetle species in the old oak stand “The Fourties”, Mt. Carmel, whereas the maximum species number found here in all forest types with a larger investigative effort was 44 species per forest stand. Old oak trees are of particular importance for the total number of saproxylic beetle species in Mediterranean oak forests because they provide special habitat features such as hollows and various kinds of fungi-infested wood (BUSE et al. 2008a). Forest and individual tree architecture is, however, a direct response to forest management methods (cf. DI PASQUALE et al. 2004). Moreover, some of the large-bodied longhorn beetles which are restricted to oaks seem to have the potential to be ecosystem engineers (BUSE et al., 2008b).

#### 4.2. Similarity and uniqueness of the saproxylic beetle assemblages

Aleppo pine stands and oak forests are the main forest types in the northern mountainous Mediterranean region of Israel. We show that they host different saproxylic beetle assemblages. One third of the respective assemblages are restricted to the particular forest type. We would expect to have a much higher separation of the fauna inhabiting pine and oak forests based on studies in Europe (cf. FINCH 2005). Only 10% of the saproxylic beetles in Central Europe occur in coniferous and broadleaved forests. The vast majority show clear preferences either for coniferous or for broadleaved forests (cf. KÖHLER 2000). One explanation is that in our study area most pine stands were mixed with young oaks in the understory layer.



**Figure 4:** Venn diagram showing the proportion of exclusive and shared species for each forest type using the species numbers shown in Table 1 for the forest types. The respective pooled species numbers for two assemblages are also shown. The percentages for exclusive species were then calculated using the species number of the respective forest type and not of the overall number reported from all forest types. The percentages of shared species were calculated using either the combined samples of two forest types or of all three forest types for the number of species shared between the three forest types.

Also, distances to other tree species were relatively low in all of the studied plots. *P. brutia* forests showed the lowest number of unique species, probably due to the fact that *P. brutia* is a non-native tree species in Israel. About 18% of the recorded species were found in all three forest types.

However, there is less than 40% similarity in assemblage composition between Aleppo pine and semi-natural oak forests. Most beetle species, with the exception of the majority of bark beetles and a few longhorn beetles, are facultative inhabitants in pine forests. Several beetle species that are typical inhabitants of broad-leaved trees were caught in pine forests. Some of these may have emerged from the young oak regrowth, but most of them are unable to develop in pines (e.g. *Cerambyx cerdo*) and were caught by chance as they were flying through the pine stands.

Variability of species composition within oak forests was much higher than within the pine forests. This indicates that the species living in oak forests may be more

specialised and restricted to local conditions than saproxylic beetle species living in pine forests. However, this is only a suggestion and needs to be verified by further studies.

## **5. Conclusions - Recommendations for forest management in the Mediterranean region**

In many Mediterranean countries pines are the dominant trees growing in woodlands today, although the natural woody vegetation would be evergreen broadleaved trees. Foresters have the opportunity to decide which tree species composition has to be established and for what purpose. Issues of forest management are primarily led by the objectives and potential uses of the forests. In times of global change, the potential future climatic situation and the ecosystem services provided by different woodlands also have to be considered when planning forest management (cf. also DUFOR-DROR 2005 for Israel). The Middle East is among the world's most water-scarce and driest regions and is particularly vulnerable to climate change (IPCC 1997). Forest management is therefore also a matter of regional development and must thus also incorporate social demands and conservation actions. In a recent paper OSEM et al. (2008) propose forest management with different objectives, e.g. forests as a provider of ecosystem services such as water infiltration, carbon sequestration and biodiversity.

Monotone pine forests in particular will very likely be affected by an increase in temperature and a decrease in annual precipitation or by an unbalanced seasonal variation of precipitation. SABATÉ et al., (2002) modelled the effects of climate change on selected tree species in the Mediterranean region and found positive effects of higher temperatures on growth if rainfall increases in the future. However, in the case of lower future rainfall severe negative effects on growth can be expected. Current climatic trends for the Middle East show a significant increase in different temperature indices over the last two decades, accompanied by almost stable precipitation conditions (ZHANG et al., 2005). Climatic changes may drive pest outbreaks (HODAR et al., 2003) as they may bring better breeding conditions for certain beetle species, but greater drought stress for trees, thus affecting their defence mechanisms. Outbreak events of the two main bark beetle species in Israel,

*Pityogenes calcaratus* and *Orthotomicus erosus*, have increased during the last three decades in Israel, especially after severe droughts and prolonged summers (BONNEH 2000). Such conditions also mean that some beetle species are able to produce several generations per year. More frequent outbreaks are probably due to climatic changes within the same period (cf. ZHANG et al. 2005). There is no doubt that more bark beetle species inhabit pines than oaks. Many of these are considered to be pest species. Establishing oak individuals as a woody understorey component in pine stands should be regarded as a means to increase forest diversity, to strengthen resistance and resilience against pest outbreaks, and to ensure better ecosystem functioning and soil stabilisation (cf. GINSBERG 2006; OSEM et al. 2008; PAUSAS et al. 2004).

Furthermore, foresters should allow single trees to grow old, as we know that older development stages or trees harbour unique communities of saproxylic beetles (BUSE et al. 2008a) richer than those studied here. Beetle assemblages of later successional stages also differ in species composition from assemblages found in young stands. This is particularly true in oak woodlands, as *Quercus calliprinos*-dominated woodlands are very likely the true ancient vegetation in the Mediterranean parts of Israel (LIPHSCHITZ and BIGER 1990). *Quercus calliprinos* individuals can become 10-15 m tall, indicating that 5-6 m tall trees as studied here are certainly not the maximum (WESTPHAL et al. 2009; ZOHARY 1960). A large number of saproxylic beetles can be found on the early successional stages of these oaks, and this number is only slightly lower than the species numbers found on older pines in the same region. If aging is a forestry goal for certain stands, thinning should be applied to mitigate the risk of wild fires.

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**Additional chapter:**

## **VI** The *Carabus* fauna of Israel – updated identification key, faunistics, and habitats (Coleoptera: Carabidae)

THORSTEN ASSMANN, JÖRN BUSE, CLAUDIA DREES, ARIEL-LEIB-LEONID FRIEDMAN, TAL LEVANONY, ANDREA MATERN, ANIKA TIMM & DAVID W. WRASE (2008) *ZooKeys* 1:9-22

## Abstract

This key to the *Carabus* species of Israel is an updated identification key with notes on the distribution and habitats of the species. Substantial additions, corrections and taxonomic changes on the *Carabus* fauna of the Middle East generated the need of an update of the knowledge of the genus *Carabus* in Israel. The classification and the identification of sibling taxa of the subgenus *Lamprostus* are still a problem: A zone of sympatry supports the species status of both *C. sidonius* and *C. hemprichi*. The lack of any evidence of sympatry for the taxa in species rank of the *C. syrus* group and their variability of the exoskeleton (mentum tooth, tip of aedeagus) requires further systematic and taxonomic studies.

## Keywords

*Carabus*, *Lamprostus*, identification key, faunistical records, habitat characteristics, Israel, **1. Introduction** Despite the fact that Israel is a small country (about 22,000 km<sup>2</sup>), it displays an enormous ecological diversity originating from its peculiar biogeographic location in south-western Asia and its great physical variety (FURTH 1975; POR 1975; YOM-TOV and TCHERNOV 1988): It links the desert Sahara-Arabia belt, the Mediterranean region and the high Asian mountains. The ground beetle genus *Carabus* with its preference for humid habitats reaches its southern distribution limit in Israel, and only some species are distributed there (cf. BOUSQUET et al., 2003).

The *Carabus* fauna of Israel was first described in a fundamental work by SCHWEIGER (1970). Substantial additions, corrections and taxonomic changes were made by KLEINFELD and RAPUZZI (2004) and DEUVE (2004b; 2005) in the last years. Additional records of some species demonstrate the need of an update of our knowledge on the genus *Carabus* in Israel. Moreover the increasing interest in the conservation biology, ecology, evolutionary biology and faunistics of ground beetles in Israel (BAR 1978; CHIKATUNOV et al., 2006; CHIKATUNOV et al., 1999, 2004; FINKEL et al., 2002; MIENIS 1978a, 1978b, 1978c, 1988; PAVLIČEK and NEVO 1996) demands a new identification key and a short synopsis of the present day knowledge of the distribution, faunistics and habitats of Israeli *Carabus* species. The taxonomic confusion in this group prevents us from presenting a final identification key.

However, we hope that this short overview stimulates further studies to solve some systematic problems of the *Carabus* fauna of the Middle East.

## 2. Material and methods

The *Carabus* collection of The National Collections of Natural History of the Tel Aviv University and material from Upper and Lower Galilee, Carmel Ridge, Samaria (incl. Gilboa Mountains), Judea, Negev, Golan Heights and Mount Hermon collected by Anika Timm (Lüneburg), David W. Wrase (Berlin), Peer Schnitter (Halle) and Thorsten Assmann (Bleckede) were studied (altogether about 800 specimens). The relevant literature on *Carabus* species from Israel and neighbouring countries was evaluated (ALFIERI 1976; BOUSQUET et al. 2003; DEUVE 2004a; DEUVE 2005; KLEINFELD and RAPUZZI 2004; SCHWEIGER 1970).

Nomenclature of vegetation types for a characterisation of the habitats follows DANIN (1988).

Total body length (BL) is measured from the tip of the mandibles to the apex of the elytra as the maximum linear distance.

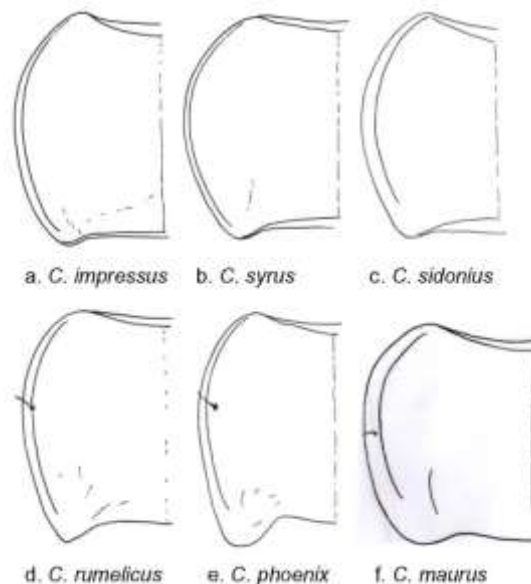
Line drawings were prepared using a drawing tube attached to a Leica MZ 95 stereobinocular microscope. Dissections were made with standard techniques; genitalia were preserved in euparal or in polyvinylpyrrolidon containing mixture on acetate labels (LOMPE 1989) or without embedding in dried condition.

The aim of this study is not a revision of the subspecific taxa. The classifications given by various authors are strikingly different (e.g. BREŽINA 1999; DEUVE 2004b; KLEINFELD and RAPUZZI 2004). The listed subspecies follow the Palaearctic Catalogue (BOUSQUET et al. 2003) and DEUVE (2004a; 2004b; 2005).

### 3. Identification key with notes on distribution and habitats of the species

The members of the genus *Carabus* are easily recognizable by lack of a typical antennal cleaner, posterior coxae contiguous in midline of body, mandibles not transversally furrowed, and third antennal segment without keel. Moreover, the species living in Israel are characterized by their body size (BL > 15 mm) and entirely black colour (without any spots or markings or metallic luster). For a general characterisation of ground beetles see TRAUTNER and GEIGENMÜLLER (1987) and BALL (2001).

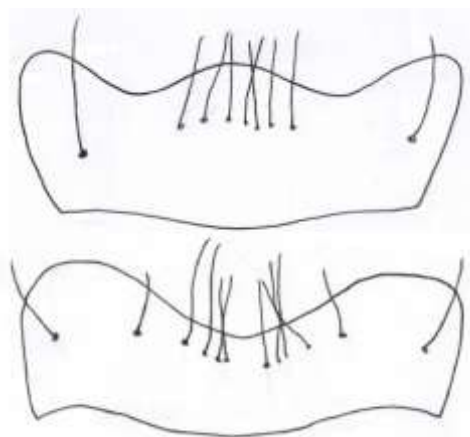
- 1 (15) Pronotum without marginal setiferous pores (Fig. 1a, b, c).....2
- 2 (3) Labrum divided into three lobes (Fig. 2). Elytra with or without punctuation and granulation, habitus variable. BL: 25-36 mm. An eurytopic species in woodlands(Fig. 15), forests, batha (open and semi-open habitats, Fig.16), arable land, dunes(Fig. 17), steppe and desert-like, overgrazed, semi-arid habitats of northern Negev(Fig. 18), up to 1200 m above sea level. In northern and central Israel southwards to the northern Negev south of Be'er Sheva' (e.g. Noqdim Plateau).<sup>4</sup> Figs 1a and 7a.....*C. (Procrustes) impressus* Klug, 1832;  
in Israel: ssp. *carmelitus* Lapouge, 1907  
ssp. *palaestinus* Lapouge, 1907  
ssp. *hybridus* Ganglbauer, 1887  
ssp. *negevensis* Schweiger, 1970



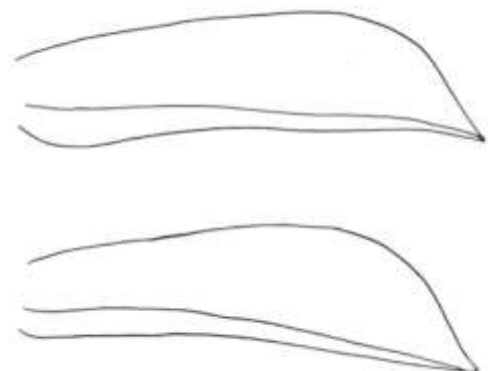
**Figure 1:** Pronotum without (a, b, c) and with (d, e, f) marginal setiferous pores.

<sup>4</sup> All records of *Carabus* specimens from the Sinai Peninsula may refer to this species (cf. ALFIERI 1976; cf. SCHWEIGER 1970).

- 3 (2) Labrum divided into two lobes (Fig. 2).....4
- 4 (5) Large (BL: 37-44mm). Head and pronotum rugously wrinkled. Protarsus in male not dilated. Last segment of maxillary palpi triangular or axe-shaped. In open and semi-open habitats (up to 1600 m above sea level). Exclusively in the north (Mount Hermon, Golan Heights, Upper Galilee) and very rare. Fig. 7b and 9.....*C. (Procerus) syriacus* Kollar, 1843  
in Israel only ssp. *galilaeus* Schweiger, 1970
- 5 (4) Smaller (BL: < 37 mm), if larger then at least head and pronotum smooth, not rugously wrinkled. Three segments of protarsus in male dilated. Last segment of maxillary palpus not triangular or axe-shaped.....6
- 6 (7) Elytral sculpture with punctures and striae. Slender species. BL: 25-36 mm. In woodlands, forests, and batha, not in arable land (~500 to 2000 m above sea level, Fig. 19). In the north (Mount Hermon, Golan Heights, Upper and Lower Galilee). Fig. 7c and 10.....*C. (Chaetomelas) piochardi* Géhin, 1884  
in Israel: ssp. *labrulerieri* Géhin, 1884  
ssp. *pinguis* Lapouge, 1914
- 7 (6) Elytron without punctures or striae, smooth. Wider species. ....8
- 8 (9) Elytron less rounded in lateral view (Fig. 3). Pronotum wider (Fig. 1b).....11
- 9 (10) Elytron more rounded in lateral view (Fig. 3). Pronotum slender (Fig. 1c)....13
- 11 (12) Tooth of mentum broad, the tip truncate (Fig. 4a). Median lobe of aedeagus rounded at apex (Fig. 7d). BL: 32-39 mm. Mainly in open and semi-open habitats (especially batha, Fig. 16), rarely in woodlands or forests (from 200 m below sea level to 1400 m above sea level, Fig. 15). From Mount Hermon and Golan Heights to Upper Galilee (Mt. Meron, first finding in 2005). Fig. 1b, 2, 3 and 11.....*C. (Lamprostus) syrus* Roeschke, 1898  
in Israel only ssp. *cheikensis* Deuve, 1992



**Figure 2:** Labrum divided into three lobes (above: *C. impressus*) and two lobes (below: *C. syrus*).



**Figure 3:** Elytron in lateral view, less rounded (above: *C. syrus*) and more rounded (below: *C. sidonius*).

- 12 (11) Tooth of mentum sharpened (Fig. 4b). Median lobe of aedeagus sharpened at apex (Fig. 7e). BL: 32-37 mm. Distribution area still poorly known, described from Lebanon. Listed by Schweiger & Rapuzzi (2004) from north-eastern Israel. ....*C. (Lamprostus) lecordieri* Deuve, 1992

**Note:** *C. lecordieri* was degraded as a subspecies of *C. syrus* by Kleinfeld & Rapuzzi (2004), but the species status was re-established by Deuve (2005). Deuve (2004b) treated the taxon as a subspecies of *C. syrus*. Some specimens from Israel cannot be classified as one of the species due to variability of the mentum tooth and small differences of the aedeagus.

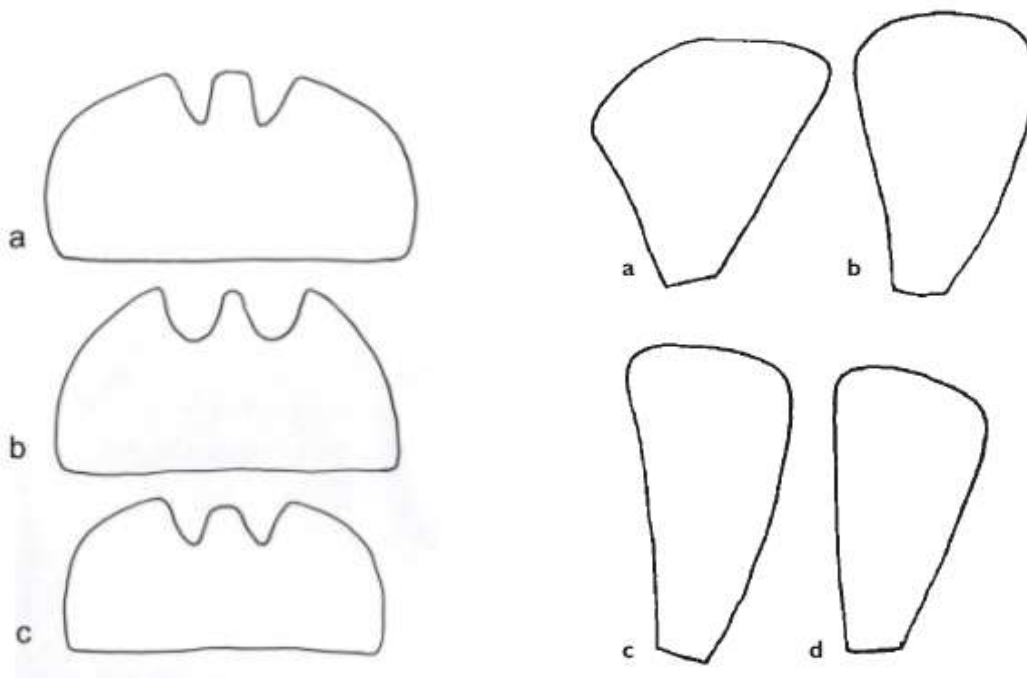
- 13 (14) Hind angles of pronotum rounded, a little bit more pronounced, very similar to its sister species (*C. hemprichi*). Apical part of aedeagus deflexed, narrow and more distinctly set off (Fig. 7f). BL: 31-35 mm. In woodlands (Fig. 15), forests, and batha (up to 1200 m above sea level, Fig. 16). Northern and central Israel, south-wards up to Jerusalem. Fig. 1c, 3, 4c and 12.....*C. (Lamprostus) sidonius* Lapouge, 1907

in Israel: ssp. *elonensis* Schweiger, 1970

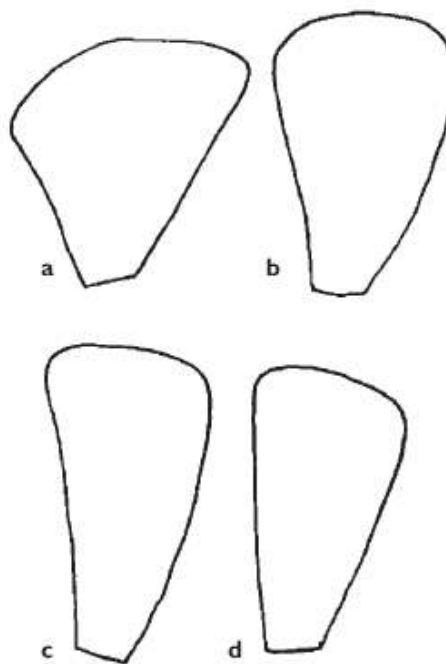
ssp. *cheikhermonensis* Deuve, 1992

- (14) (13) Hind angles of pronotum rounded, only slightly prolongate. Apical part of aedeagus not distinctly deflexed, wider and not distinctly set off (Fig. 7g). BL: 31-37 mm. In woodlands, batha and arable fields. In north-eastern Israel (Mount Hermon and Golan Heights).*C. (Lamprostus) hemprichi* Dejean, 1826

in Israel only *damascenus* Lapouge, 1924

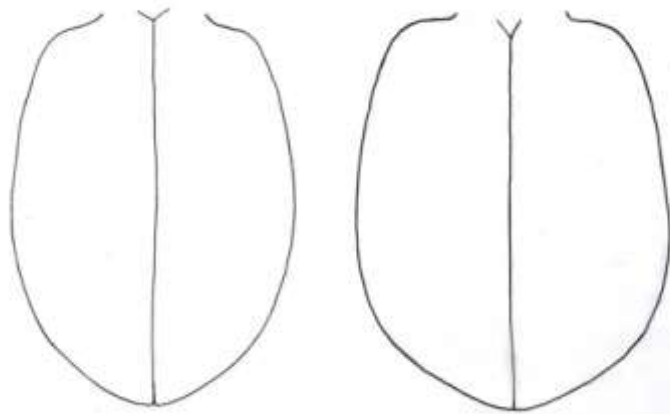


**Figure 4:** Mentum of *Lamprostus* species (a: *C. syrus*; b: *C. lecordieri*; c: *C. sidonius*).

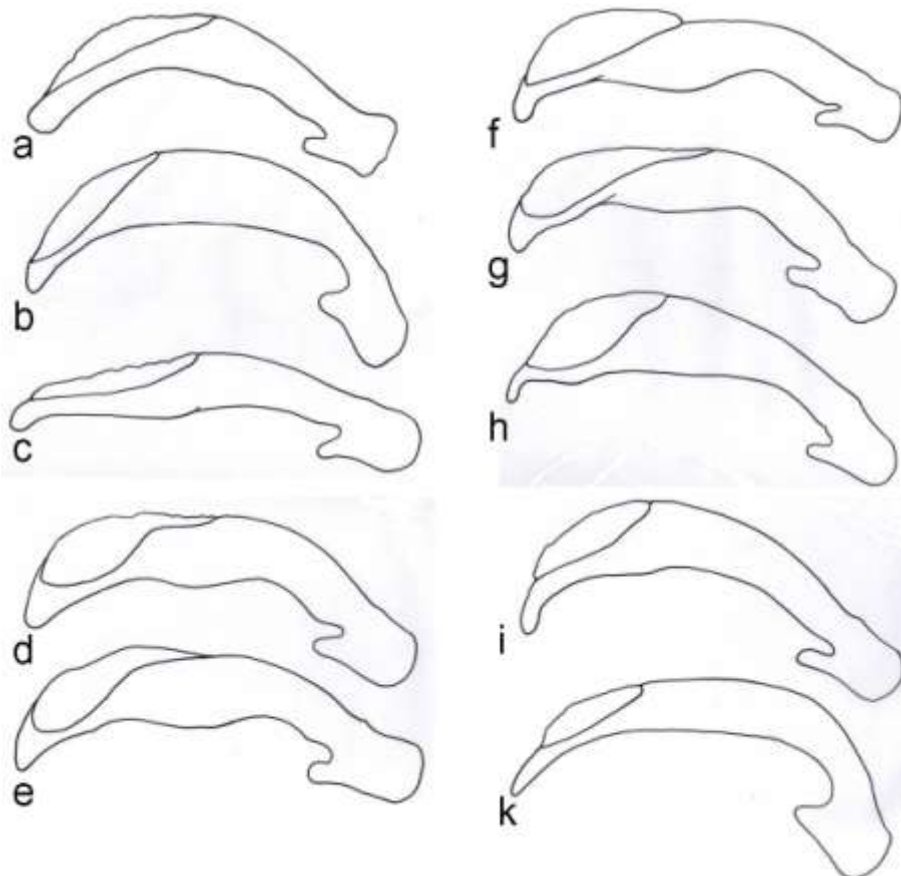


**Figure 5:** Last segment of maxillary palpi (a, b: *C. rumelicus*; c, d: *C. maurus*; a, c: male; b, d: female).





**Figure 6:** Shoulder of elytron rounded (left: *C. phoenix*) and angulate (right: *C. maurus*).



**Figure 7:** Aedeagus of *C. impressus* (a), *C. syriacus* (b), *C. piochardi* (c), *C. syrus* (d), *C. lacordieri* (e), *C. sidonius* (f), *C. hemprichi* (g), *C. rumelicus* (h), *C. phoenix* (k).

- Note:** A zone of sympatry between *C. hemprichi* and *C. sidonius* in Lebanon led DEUVE (2004) to consider both taxa as valid species. In previous publications these taxa were ranked as subspecies of *C. hemprichi*. The distinction of both species is extremely difficult. Moreover, in the last years two additional sibling species of the subgenus *Lamprostus* were described from Lebanon.
- 15 (1) Pronotum with marginal setiferous pores (if seta broken, the pupillate insertion is visible) (Fig. 1d, e, f).....16
- 16 (17) Last segment of maxillary palpus in males triangular or axe-shaped (Fig. 5a). BL: 17-20 mm. In montane and subalpine altitudes of Mount Hermon (semi-open woodlands with *Quercus libani* and tragacanth vegetation, pastures, Fig. 19). Figs 1d, 5b, 7h and 13.....*C. (Tomocarabus) rumelicus* Chaudoir, 1867  
in Israel only ssp. *syriensis* Breuning, 1943
- 17 (16) Last segment of maxillary palpus in males more elongate, slightly dilated (Fig. 5c).....18
- 18 (19) Submentum thickened. Hind angles of pronotum prolongate (Fig. 1e). Shoulder of elytra rounded (Fig. 6a). BL: 17-25 mm. In Israel exclusively known from Upper Galilee (Mt. Meron), in woodlands. (Fig. 15). Fig.13.....*C. (Archicarabus) phoenix* Lapouge, 1924
- 19 (20) Submentum not thickened. Hind angles of pronotum more rounded (Fig. 1f). Shoulder of elytra angulate (Fig. 6b). BL: 15-20 mm. In montane and subalpine altitudes of Mount Hermon (semi-open woodlands with *Quercus libani* and tragacanth vegetation). Figs 5c, 5 d and 7k.....*C. (Mimocarabus) maurus* Adams, 1817  
in Israel only ssp. *hermonensis* Schweiger, 1970



**Figure 8:** *Carabus impressus* (Negev)



**Figure 9:** *Carabus syriacus* (Mount Meron)



**Figure 10:** *Carabus piochardi* (Mount



**Figure 11:** *Carabus syrus* (Mount Meron)



**Figure 12:** *Carabus sidonius* (Mount Meron)



**Figure 13:** *Carabus rumelicus* (Mount Hermon)



**Figure 14:** *Carabus phoenix* (Mount Meron)



**Figure 15:** *Quercus calliprinos* dominated woodland (Ya'ar Bar'am). Habitat of *C. impressus*, *C. piochardi*, *C. syrus*, *C. sidonius*, and *C. phoenix*



**Figure 16:** Batha (Mount Meron). Habitat of *C. impressus*, *C. piochardi*, *C. syrus* and *C. sidonius*



**Figure 17:** Dune habitat (south of Ashdod). Habitat of *C. impressus*.



**Figure 18:** Steppe habitat (west of Be'er Sheva). Habitat of *C. impressus*.



**Figure 19:** Montane to subalpine pasture (Mount Hermon). Habitat of *C. piochardi* and *C. rumelicus*.

#### 4. Discussion

Ten species of the genus *Carabus* are known from Israel. The presence of *C. phoenix* in Israel – first records known from the surrounding of Sasa in Upper Galilee (KLEINFELD and RAPUZZI 2004) – can be confirmed by several records from the Meron area (Upper Galilee, cf. TIMM et al., 2008)<sup>5</sup>. At several locations in Galilee (including a site close to the Sea of Galilee, about 200 m below sea level) we detected *Carabus syrus* populations. The previously known distribution area in Israel covers the Golan Heights, parts of the Mount Hermon and the Upper Jordan Valley close to Qiryat Shemona (Schweiger & RAPUZZI, 1970). We believe that larger parts of Galilee (including Lower Galilee), Golan Heights and Judean Foothills are still under-represented in faunistical studies. Therefore it seems most likely that additional populations and perhaps species can be detected. From Jordan and Lebanon new species of the subgenus *Lamprostus* were already described in the last years (*C. pseudopinguis* Heinz, 2000; *C. lecordieri* Deuve, 1992; *C. rostandianus* Deuve, 2005; cf. Deuve, 2005; Heinz & Staven, 2000).

Despite the still incomplete faunistic inventory of Israel, the records of *C. syriacus* seem to decline, especially in the last decades. Coleopterists, also those collecting mainly in the northern parts of Israel, have not found this largest *Carabus* species in the Middle East for many years (e.g. RITTNER, personal communication). Urbanization, habitat fragmentation and large-scale changes of land use (especially the transformation of natural and semi-natural habitats, e.g. sclerophyllous woodlands and batha, to pine stands and arable fields) might be a reason for this decline. Species of the subgenus *Procerus* show a remarkable decline not only at the southern limit of their distribution area but also in Europe: *C. gigas* Creutzer, 1799 was once distributed in Styria and Carinthia. At present the species is extinct in Austria (PAILL, personal communication), in Slovenia the species is still occurring, but clearly declining (DROVENIK, personal communication; TURIN et al., 2003). A similar decline seems to occur in some places in Italy (BRANDMAYR and CASALE, personal communication). – If one or several populations are rediscovered, an action

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<sup>5</sup> Records from Sasa are not considered in the distribution map of *C. phoenix* given by KLEINFELD and RAPUZZI (2004).

plan to conserve the relict populations at the most southern limit of this species (and subgenus) will have to be developed.

A clear problem for identification are the sibling taxa of two *Lamprostus* groups: The characters given in the literature to separate *C. hemprichi* from *C. sidonius* and *C. syrus* from *C. lacordieri* show a remarkable variability within and between populations; this is true for both the mentum tooth and the apex of the median lobe of aedeagus. Sometimes it is impossible to classify some specimens exclusively from the exoskeleton. While a zone of sympatry is known for *C. hemprichi* und *C. sidonius* in Lebanon, any evidence of sympatry is still lacking for the members of the *C. syrus* group (including *C. lacordieri*, *C. pseudopinguis* and *C. rostandianus*).

The results of PAVLÍČEK and NEVO 1996(1996) on *C. sidonius* demonstrated a small-scaled genetic differentiation, similar to some other *Carabus* species (ASSMANN 2003; ASSMANN and WEBER 1997). The morphological differentiation (from eye inspection) reflects this strong geographic differentiation on another level and should encourage us to study the species complexes morphometrically in order to solve the taxonomic problems (but for this approach still more material is necessary than is available at the moment).

In general one has to keep in mind that differences in the aedeagus, especially those of the apex (and not of the internal sac) of this organ, do not seem to be useful to classify taxa at the species level (see for a detailed discussion: ASSMANN et al., 2008). The taxa *C. violaceus violaceus* Linné, 1758 and *C. v. purpurascens* Fabricius, 1787 of the subgenus *Megodontus* can be easily distinguished by different forms of the aedeagus tip (and by lack or presence of striae on the elytra). But both taxa form several broad hybrid zones in north-western Central Europe (ASSMANN and SCHNAUDER 1998). An excessive gene flow is documented also by molecular techniques (allozymes and mtDNA haplotypes; EISENACHER et al., in prep.). In the light of these results the species rank of some taxa of the *C. syrus* group should be critically reconsidered.

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## Presentations

- TIMM, A., DREES, C., LEVANONY, T. and Assmann, T. (2007). Habitat Selection of Ground Beetles in Woodlands and Open Fields in Upper Galilee, Israel. XIII European Carabidologists Meeting, Blagoevgrad/Bulgaria, 20.-24.8.2007 – Vortrag
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