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Carabidae (Insecta: Coleoptera) as Bioindicators of Biodiversity and Predators of Insect Pests

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Abstract: This family Carabidae is diverse and abundant in agroecosystems and beetles stand out as natural enemies of other insects, considered pests of crops and forestry plantations. Carabids have been used as indicators in environmental pollution assessments, habitat classification for ecological conservation, soil characterization concerning nutrients, and biodiversity indicators. Carabids have also been suggested for indicators in biodiversity survey programs because they present great morphological and behavioral variability and are sensitive to environmental changes. This survey aimed to identify species that can be used as bioindicators and obtain data on their population dynamics that can be correlated with evaluating success in reforestation programs. The predatory attributes of several species of carabids have been used and studied in agricultural habitats with different approaches. This study aims to describe the importance of Carabidae as functionally important bioindicators in ecosystems, in environmental conservation, as indicators of biodiversity, in the ability of this group to absorb metals, and as predators in the biological control of insect pests for agriculture. Concerned with establishing a public profile of quality research in the area, we sought to answer these questions based on a literature review in the main journals in the area national and international classified by the Coordination for the Improvement of Higher Education Personnel (CAPES). Complement this analysis with other documents such as books, chapters, documents, and digital platforms.

Keywords: Agriculture, Environmental Conservation, Biodiversity Indicators, Biological Control, Insect Pests, Predator.

RESEARCH PAPER

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1. INTRODUCTION

The order Coleoptera is home to insects popularly known as beetles. They are considered important agents of entomofauna richness as they comprise approximately 40% of the species within the Insecta class and 30% of the Animalia kingdom. They have around 360,000 described species and can be found in various habitats and ecological niches (Ball and Shpeley, 2000; Martinez, 2005; Bouchard *et al*., 2017).

The Carabidae family belongs to the order Coleoptera and suborder Adephaga, formed by beetles with a cursorial and predatory habit, generally found in sandy terrain, under rocks and litter, however, some groups are found in trees and shrubs. The occurrence of carabids can determine important characteristics of planting, in addition to contributing to the biological control of insect pests. The Carabidae are one of the most numerous families with almost 40 thousand described species. They are distributed throughout the world with a higher specific richness in tropical regions (Figure 1) (Ball and Shpeley, 2000; Bouchard *et al.*, 2017; Cerón-Gómez and Márquez, 2023).

Figure 1: Adults of the native carabid beetle *Lebia grandis* Hentz, 1830, are voracious predators of Colorado potato beetle eggs and larvae
Source: ARS photo d1518-1 by Peggy Greb

1.1. OBJECTIVE

This study aims to describe the importance of Carabidae as functionally important bioindicators in ecosystems, in environmental conservation, as indicators of biodiversity, in the ability of this group to absorb metals, and as predators in the biological control of insect pests for agriculture.

2.0. METHODS

Concerned with establishing a public profile of quality research in the area, we sought to answer these questions based on a literature review in the main journals in the area national and international classified by the Coordination for the Improvement of Higher Education Personnel (CAPES). Complement this analysis with other documents such as books, chapters, documents, and digital platforms.

3.0. SELECTED STUDIES

3.1. Morphology

The Carabidae are land beetles, belonging to the Suborder Adephaga Carabids come in a variety of sizes, colors, and shapes, making them a popular group. Despite this morphological variety, they present distinctive characteristics that are important for their recognition. The head is always narrower than the pronotum part of the body that accompanies the head, in the shape of a disc and where the first pair of legs is located ventrally, and the base of the elytra's first pair of wings modified in the way that protects the second pair of wings and abdomen; the eyes are generally prominent; The antennae are inserted between the eyes and the jaws, and have 11 toes that are part of the articulated appendages, mainly antennae and legs lastly, the jaws are large, sharp, and strong (Figure 2) (Ball and Shpeley, 2000; Lawrence, 2013; Bouchard *et al*., 2017; Shpeley and Devender, 2022; Cerón-Gómez and Márquez, 2023).

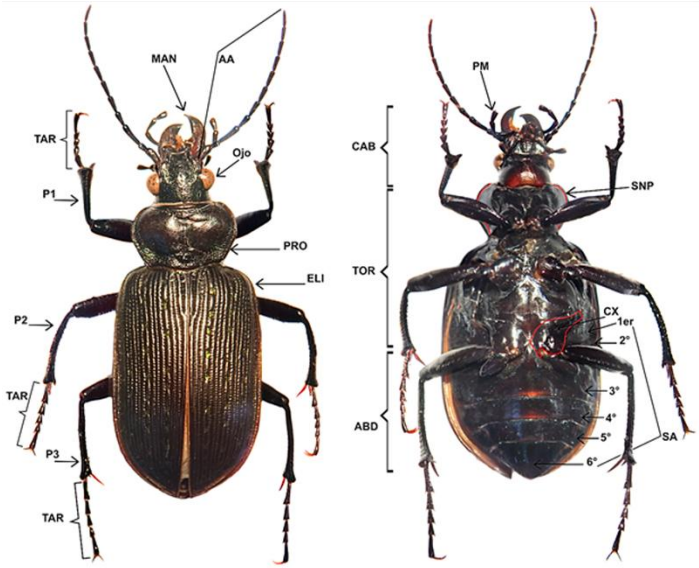

Figure 2: *Calosoma alternans* (Fabricius 1792), showing the most relevant characteristics of Carabidae. AA: antennal joints, ABD: abdomen, CAB: head, CX: coxa (retouched in red), ELI: elytra, MAN: mandible, PM: maxillary palps, PRO: pronotum, P1: anterior legs, P2: legs stockings, P3: hind legs, SA: abdominal segments, SNP: notopleural suture (retouched in red), TAR: tarsomeres, TOR: thorax
Sources: Doi: http://doi.org/10.22201/cuaieed.16076079e.2023.24.4.11 and Credit: Asian J.

In the ventral view, a clearly defined printed line called “notopleural suture” can be seen, as it runs parallel to the external margin of the pronotum. The elytra completely cover the abdomen many species are brachypterous, which means that the second pair of wings, which are membranous, is reduced and this prevents them from flying. The three pairs of legs are long and thin, their last joint is called the tarsus and is divided into five parts, which are called tarsomeres (Ball and Shpeley, 2000; Lawrence, 2013; Bouchard *et al.*, 2017).

When observing a carabid in ventral view, it can be seen that the first abdominal segment is divided by the first joint of the posterior legs last pair of legs called the coxa, and the second joint, the trochanter, is larger compared to other families of beetles. Most species have dark and opaque colorations, but there are also many species with iridescent and metallic colorations (Figure 3) (Magura and Lövei, 2020; Wagner *et al.*, 2021; Cerón-Gómez and Márquez; 2023).

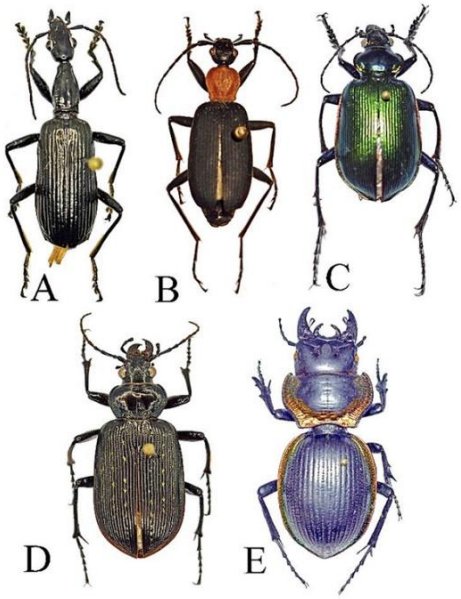

Figure 3: Figure 3: Adult specimens of the family Carabidae. A) *Agra* sp. B) *Galerita (Progaleritina) mexicana* Chaudoir, 1872. C) *Calosoma (Calosoma) aurocinctum* Chaudoir, 1850. D) *Calosoma (Castrida) alternans* (Fabricius 1792). E) *Mouhotia batesi*, Lewis 1879
Source: Credit: Own elaboration

3.2. Bioecology

They are important agents that modulate invertebrate biodiversity, as they are predatory. Its most common prey is invertebrates, but it can also prey on small vertebrates, such as amphibians. They are generally solitary and many species have specialized habits, such as cave carabids and myrmecophiles. They can be found in diverse habitats, from freshwater coastal environments in highlands to lowlands, underground and treetops, beaches, to cracks in rocks and under tree bark (Figure 4) (Ball and Shpeley, 2000; Martinez, 2005; Erwin, 2007; Erwin, 2008; Erwin, 2011; Bouchard *et al.*, 2017; Fenoglio *et al.*, 2019).

Figure 4: Ground beetles (Family Carabidae) Larva(e) 21mm long
Sources: Image Number: 5535795 and Photographer: Joseph Berger

Individuals from the Carabidae family are frequently found under rocks, trunks, leaves, tree bark, and debris, where a large part of the species, both adult individuals and larvae, are predators of other arthropods, however, few species are ectoparasites, detritivores or herbivores. This family is diverse and abundant in agroecosystems and beetles stand out as natural enemies of other insects, considered pests of crops and forestry plantations (Figure 5) (Lövei and Sunderland, 1996; Ball and Shpeley, 2000; Hayashi and Sugiura, 2021).

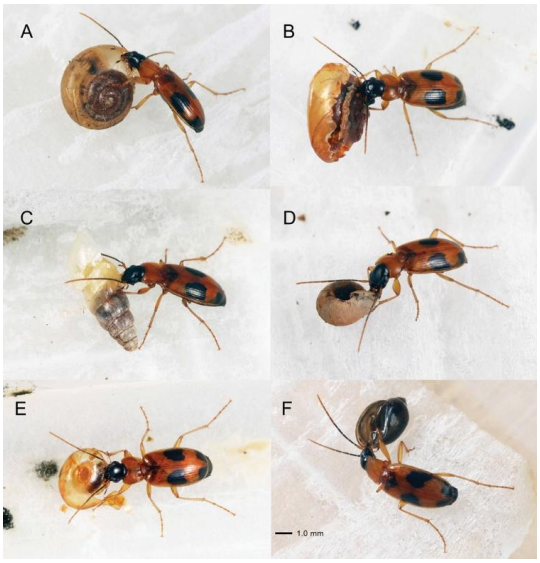

Figure 5: *Badister pictus* Bates, 1873 (Coleoptera: Carabidae), adults (A) adult biting the outer lip of *Zonitoides arboreus* (Say, 1816) (Mollusca) S (B) adult feeding on the soft body after opening the shell of *Z. arboreus* (C) adult breaking the shell of *Opeas pyrgula* Schmacker & Boettger, 1891, (Mollusca) (D) adult biting the outer lip of *Metalycaeus hirasei* (Pilsbry, 1900) (Mollusca) (E) adult feeding on the soft body of the broken shell of *Hippeutis cantori* (Benson, 1850) (Mollusca) (F) adult biting the basal lip of the sinistral snail *Physa acuta* Draparnaud, 1805 (Mollusca)

Source: https://zookeys.pensoft.net/article/62293/element/4/434//

3.3. Environmental conservation and biodiversity indicators

Carabids have been used as indicator organisms in environmental pollution assessments, habitat classification for environmental conservation, soil characterization concerning nutrients, or biodiversity indicators. The Carabidae is a bioindicator group, as it has a large proportion of species with high ecological fidelity, is quite taxonomically and ecologically diverse, is easy to collect in large samples, and is functionally important in ecosystems (Figure 6) (Brown, 1991; Ball and Shpeley, 2000; Bouchard *et al*., 2011; Dar *et al.*, 2012; Quinteiro *et al.*, 2012; Bouchard *et al*., 2017; Xueqin *et al.*, 2021).

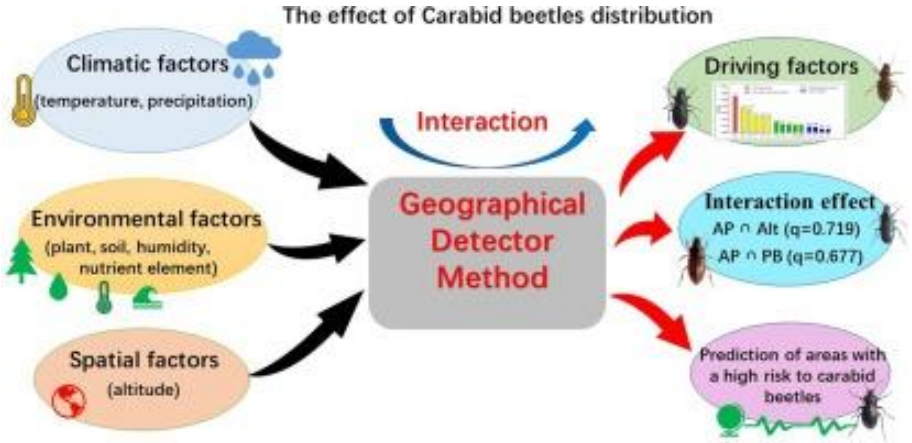

Figure 6: The geographic detector approach analyzes the driving forces of carabid beetle distribution and also offers a new method to understand the interactions between different drivers of other animal distributions more broadly. Carabid beetles are indicator species in the steppes of northwest China. Previous studies have focused on the main drivers of carabid beetle occurrence separately, ignoring the interactions between drivers

Source: https://doi.org/10.1016/j.ecolind.2021.108393

They also form relatively taxonomically well-known and identifiable groups, in addition to being closely associated with other species and resources. Carabids have also been suggested for use as indicators in biodiversity survey programs because they present great morphological and behavioral variability and are sensitive to environmental changes (Figure 7) (Ball and Shpeley, 2000; Jaskuła and Soszyńska-Maj, 2011; Bouchard *et al*., 2017; Makwela *et al*., 2023).

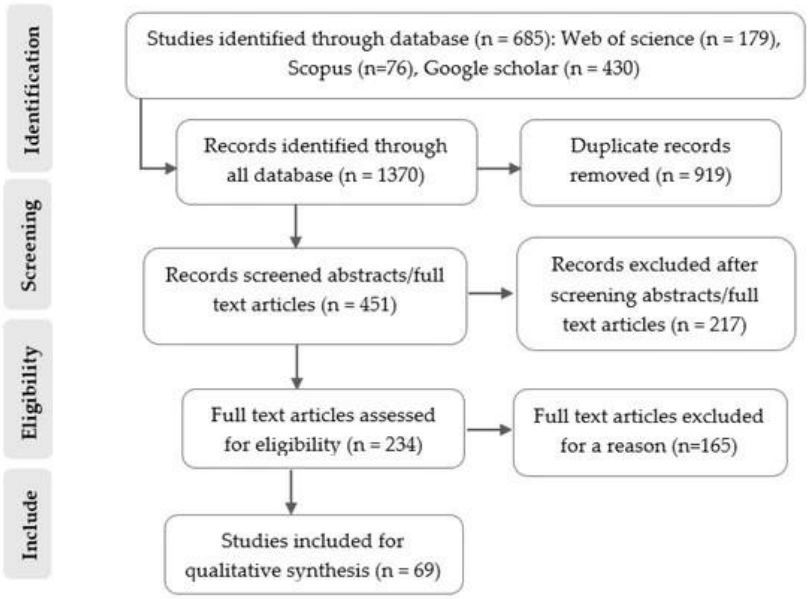

Figure 7: A flow diagram showing the systematic review process. Studies showing the response of carabid beetles to different management practices in agroecosystems were used for the qualitative synthesis. The search, screening, and inclusion of studies are schematically summarized in the flow chart below
Sources: Adapted from PRISMA guidelines and https://doi.org/10.3390/su15053936

Studies emphasizing predatory beetle communities in fragment and reforestation areas are scarce. This survey aimed to identify species that can be used as bioindicators and obtain data on their population dynamics that can be correlated with the process of evaluating success in reforestation programs. The hypothesis was established that in forest fragments a greater diversity of species from the Carabidae family and a lower abundance of individuals when compared to reforestation environments (Figure 8) (Ball and Shpeley, 2000; Niemelä and Kotze, 2000; Siqueira *et al.*, 2015; Bouchard *et al*., 2017; Jung and Lee, 2020).

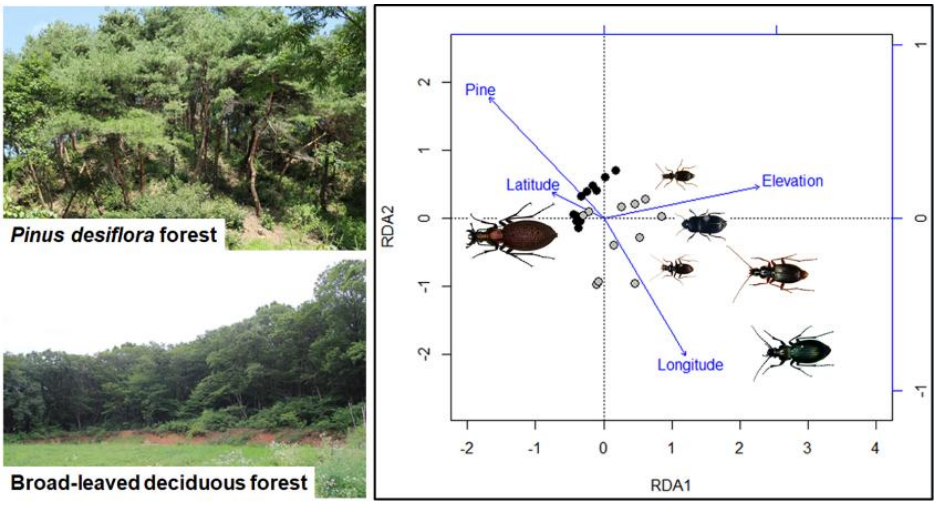

Figure 8: Korean red pine *Pinus densiflora* Siebold & Zuccarini (Pinaceae) coniferous forests in Korea. Carabid beetle assemblages in central Korea are distinctly divided by forest type based on ecological and biological characteristics. However, the possible variation in the response of beetle communities to the growth of *P. densiflora* forests needs to be considered for forest management based on biodiversity conservation in temperate regions, because the conifer plantations in this study are still young
Source: Doi:10.3390/d12070275

3.4. Habitat and Entomology Forensic

Individuals belonging to Carabidae occur in different habitats, including caves, associated with living or decomposing vegetation. It has a primary predatory habit, however, there are omnivorous, herbivorous, and carnivorous species. Both larvae and adults are usually nocturnal, a fact that would justify their small sample size in studies with carcasses. Carabidae is associated with the active decomposition stage (Figures 9-11) (Ball and Shpeley, 2000; Gennard, 2007; Casari and Ide, 2012; Bouchard *et al.,* 2017).

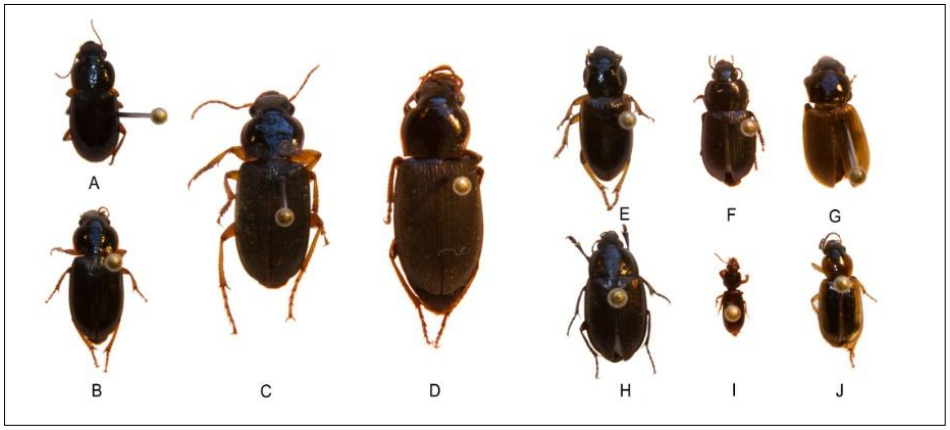

Figure 9: Granivores A-B) *Harpalus* spp.; C) *Harpalus rufipes* (DeGeer, 1774); D) *Harpalus* sp. (sp. refers to an unidentified species); E-G) *Anisodactylus* spp.; H) *Amara* sp.; I) *Clivinia* sp.; J) *Stenolophus* sp. These ground beetles are omnivores that primarily prey upon seeds

Source: Cooperative Extension: Maine wild blueberries beneficial insect series 2: Carabidae (ground beetles) on Maine farms

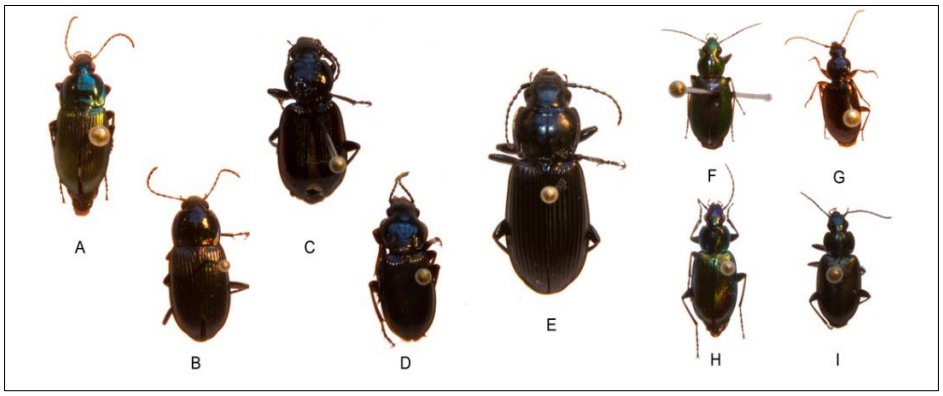

Figure 10: Omnivores A-B) *Poecilus lucublandus* (Say, 1823); C-E) *Pterostichus* spp.; F-I) *Agonum* spp. This group eats a variety of foods including other insects, alive or dead, and seeds

Source: Cooperative Extension: Maine wild blueberries beneficial insect series 2: Carabidae (ground beetles) on Maine farms

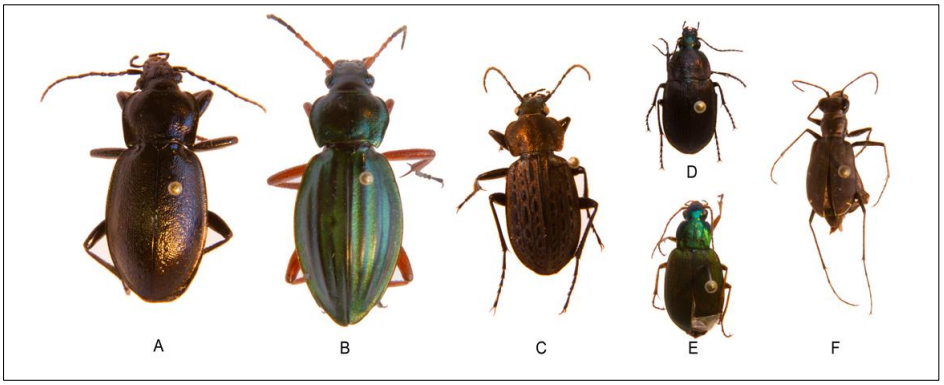

Figure 11: Generalist Carnivores A) *Carabus nemoralis* Müller, 1764; B) *Carabus maeander* Fischer von Waldheim, 1820; C) *C. meander*; D) *Chlaenius tomentosus* (Say, 1823); E) *Chlaenius sericeus* (Forster, 1771); F) *Cicindela* sp. These ground beetles consume a wide range of insect prey, including other ground beetles

Source: Cooperative Extension: Maine wild blueberries beneficial insect series 2: Carabidae (ground beetles) on Maine farms

3.5. Importance in the agricultural

Agriculture is one of the essential activities within human society since it plays a crucial role in the economy at different local or regional levels. The predatory attributes of several species of carabids have been used and studied in agricultural habitats with various approaches. One of the aspects addressed is knowing which prey are consumed by carabids in farming habitats and if organisms are considered pests among them. Other studies compare the prey they consume, in agricultural fields, with those they feed on in non-cultivated areas, in this way, it has been evaluated how effective carabids can be as pest controllers in crops (Figure 12) (Allen, 1979; Bouchard *et al.*, 2017; Silva, 2018; Fenoglio *et al*., 2019; Naccarato *et al.*, 2020; Cerón-Gómez and Almayyahi, 2023).

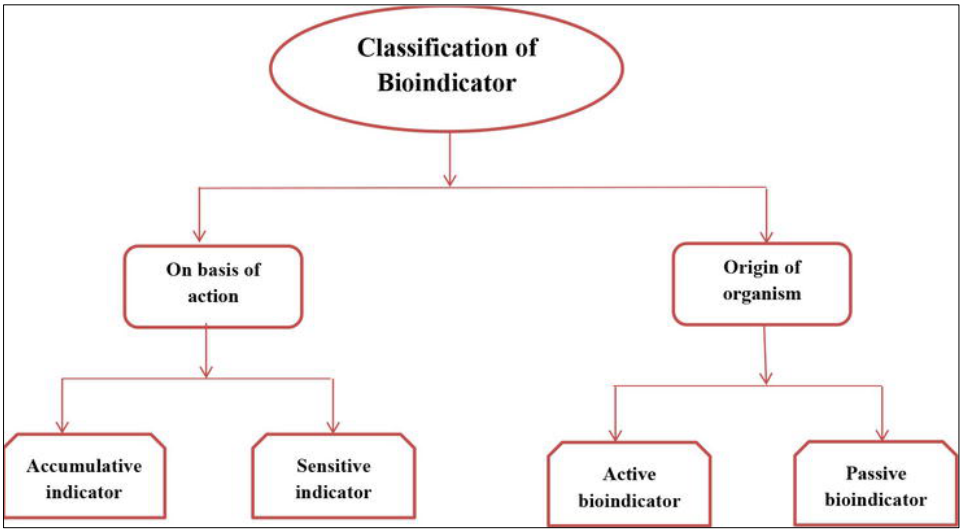

Figure 12: Schematic illustration of the classification of bioindicators. Classification of bioindicators based on mode of action and origin of the organism

One of the most debatable topics is the application of agrochemicals as pesticides, and the risks involved in their use due to the possible contamination of agricultural soil, crops, and damage to human health due to their consumption. An example of this is the measurement of concentrations of heavy metals or harmful substances, which was done in wheat fields in Italy as a consequence of the use of pesticides, using the species *Harpalus rufipes* (De Geer, 1774), a generalist predatory carabid (Figure 13) (Ball and Shpeley, 2000; Larochelle and Larivière, 2003; Bouchard *et al.*, 2017; Fenoglio *et al*., 2019; Almayyahi, 2023; Márquez, 2023).

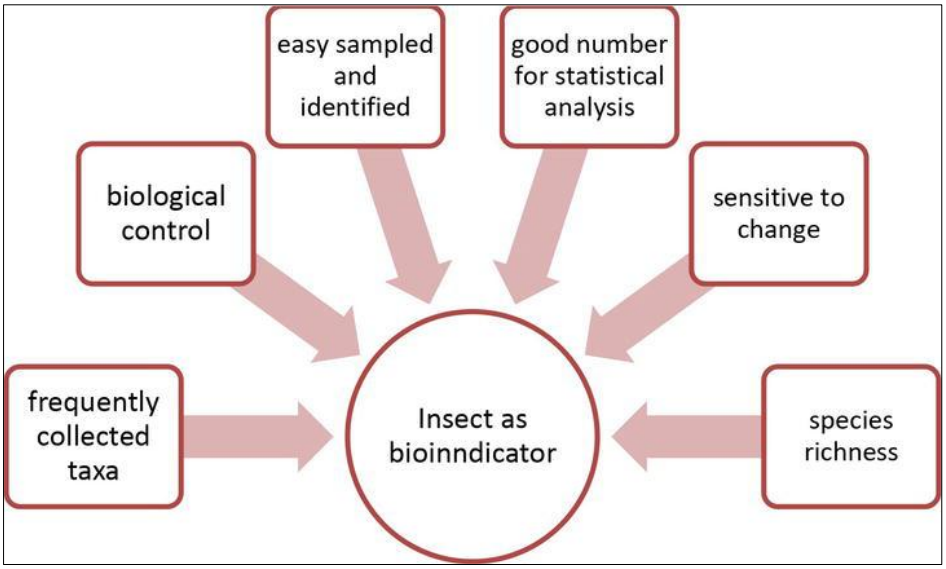

Figure 13: Researchers commonly use ground beetles as efficient bioindicators because they show a response to ecological variation as a consequence of anthropogenic activities including overgrazing, and soil and land pollution. Previously, it was the significant bioaccumulation factor range of mercury and arsenic in research by *Carabus lefebvre* Dejean, 1826, indicating that beetles were favorable for assessing mercury and arsenic in the environment
Source: Doi: 10.5772/intechopen.110212

Different concentration patterns were found in the collected individuals. Still, they determined the presence of significant amounts of heavy metals accumulated in the carabids, which highlights the regulatory capacity of this species for absorbing said metals, in which a higher concentration was found of copper, magnesium, zinc, and cadmium, they are providing reference data where the possible risks that agrochemicals have towards croplands are evident (Figure 14) (Allen, 1979; Ball and Shpeley, 2000; Bouchard *et al.*, 2017; Naccarato *et al.*, 2020; Almayyahi, 2023).

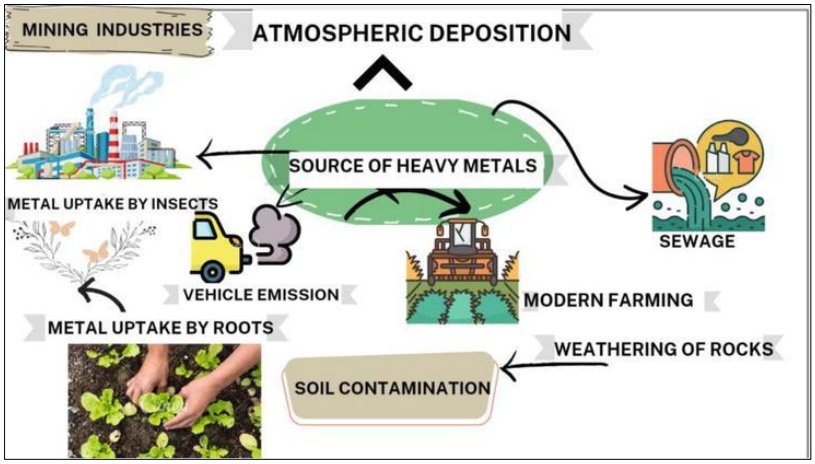

Figure 14: Various means of heavy metal pollution and their transfer to insects. Pollutant toxicity has impacted the biological processes as well as biotic interaction among living organisms such as ecological structure, parasitism, and predator-prey relationship
Source: Doi: 10.5772/intechopen.110212

3.6. Classification

3.6.1. Subfamilies

Carabidae is divided into the suborder Adephaga. It includes the subfamilies Nebriinae Laporte, 1834; Cicindinae Csiki, 1927; Cicindelinae Latreille, 1802; Loricerinae Bonelli, 1810; Omophroninae Bonelli, 1810; Elaphrinae Latreille, 1802; Migadopinae Chaudoir, 1861; Broscinae Hope, 1838; Apotominae Leconte, 1853; Siagoninae Bonelli, 1813; Melaeninae Csiki, 1933; Gehringiinae Darlington, 1933; Patrobinae Kirby, 1837; Psydrinae Leconte, 1853; Nototylinae Bänninger, 1927; Hiletinae Schiodte, 1848; Scaritinae Bonelli, 1810; Trechinae Bonelli, 1810; Brachininae Bonelli, 1810; Harpalinae Bonelli, 1810; Paussinae Latreille, 1806; and Carabinae Latreille, 1802 (Bouchard *et al*., 2011). As a result of the above observations, some records have been obtained from Brazil (Figure 15) (Ball and Shpeley, 2000; Bousquet, 2012; Casari and Ide, 2012; Dar *et al.*, 2012; Baca *et al*., 2021; Ortuño *et al.*, 2023).

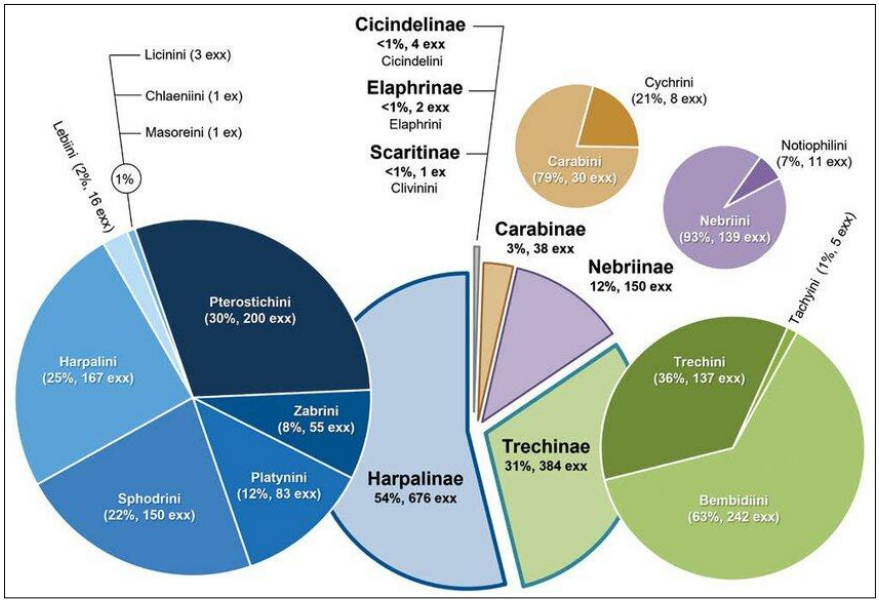

Figure 15: Quantitative analysis of the specimens collected in the Salientes Valley, grouped by subfamilies and tribes
Source: Doi: https://doi.org/10.3989/graellsia.2023.v79.364

3.6.2. Species of Carabidae

Brachinus sp., *Leptotrachelus* sp.; *Notiobia* sp.; *Aephnidius* sp.; *Tichonilla festiva* (Chaudoir, 1869), *Trichognatus marginipennis* Latreille, 1825, *Callida metallica* Dejean, 1825; *Callida amethystina* (Fabricius, 1787); *Lebia* sp.; *Lia nigropicta* (Chaudoir, 1871); *Dromius negrei* Mateu, 1973; *Colliuris* sp.; *Scarites* sp.; *Dyschirius* sp.; *Pentagonica* sp.; *Oodes* sp.; *Coptia armed* Laporte, 1832; *Brachygnathus oxygonus*, Perty, 1830; *Cnemalobus* sp.; *Ozaena* sp. *Odontocheila* sp., *Megacephala fulgida* Klug, 1834, (Reichardt, 1977; Martinez, (2005; Zhang, 2013; Zaragoza-Caballero, 2016).

4. CONCLUSION

Individuals belonging to Carabidae occur in different habitats, including caves, associated with living or decomposing vegetation. It has a primary predatory habit, however, there are omnivorous, herbivorous, and carnivorous species. Both larvae and adults are usually nocturnal, a fact that would justify their small sample size in studies with carcasses. Carabidae is associated with the active decomposition stage. Agriculture is one of the essential activities within human society since it plays a crucial role in the economy at different local or regional levels. The predatory attributes of several species of carabids have been used and studied in agricultural habitats with various approaches. One of the aspects addressed is knowing which prey are consumed by carabids in farming habitats and if organisms are considered pests among them.

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