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Structure and spatial–phenological dynamics of maize (*Zea mays* l.) pests and their natural enemies across five agroecological zones in Senegal

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Abstract
This study assesses the abundance and composition of maize pest and natural enemy communities across five agroecological zones in Senegal, representing major production areas and a range of climatic and agronomic conditions. A standardized entomological survey was conducted using the diagonal sampling method to compare the distribution of pests and beneficial insects across agroecological zones and maize phenological stages. The study areas included the Senegal River Valley (SRV), Lower and Middle Casamance (LMC), Upper Casamance and Eastern Senegal (UCES), the Southern Groundnut Basin (SGB), and the Northern Groundnut Basin (NGB). Two ecological parameters were analyzed: abundance and distribution. Of the 2,766 specimens collected, Heteroptera, *Coleoptera*, and *Lepidoptera* were the most abundant orders across all zones. The SRV, NGB, SGB, and UCES zones exhibit high pest pressure; the LMC zone supports a greater number of beneficial insects. Phenological variations showed dominance of *Coleoptera*, *Lepidoptera*, and Homoptera during the vegetative stage, whereas Heteroptera and Homoptera become more prevalent during the flowering, along with Nematoda and Dermaptera, which may act as regulators of *Lepidoptera* populations. These results indicate that maize insect communities' structure is strongly influenced by agroecological zone, crop phenology, and interactions between pests and beneficial insects. They highlight the importance of integrating beneficial insects into integrated pest management and agroecological practices to enhance ecosystem balance, reduce pesticide use, and promote sustainable maize production systems.

Keywords: Abundance, distribution, pest, beneficial insect, maize, agroecological zones, Senegal

Introduction

Maize (*Zea mays* Linnaeus, 1753) is the world's second most widely produced cereal after rice and has a wide range of food and feed uses (Coulibaly *et al*., 2021; Shandilya *et al*., 2025; Wu *et al*., 2025) [8, 38, 44]. Global maize production, which continues to increase, exceeded 1,230 million tons in 2023/2024 (Kouakou *et al*., 2024) [26]. In Senegal the main production areas are located in eastern Senegal, the Sine-Saloum, Casamance, and the Senegal River Valley, where maize is primarily grown for grain (Ndiaye *et al*., 2005; Ka *et al*., 2024) [31, 22]. This crop plays a key role in sustainable development through its contribution to food security (Thiaw, 2019) [43]. However, maize is affected by numerous pests throughout its growth cycle, impacting all its organs and potentially leading to disease and reduced crop quality (Ouali-N'Goran *et al*., 2017; Ndiaye *et al*., 2023) [34, 32]. It is therefore essential to inventory maize-associated insect fauna and their natural enemies to understand the spatial variation in pest pressure and the presence of beneficial insects. The five selected agroecological zones represent the main maize-producing regions in Senegal (Ndiaye *et al*., 2005) [31]. This selection allows evaluation of the combined effect of environmental conditions and agricultural practices on the structure of maize-associated entomological communities.

Insect communities vary with location, crop phenology, and agricultural practices (Ouali-N'Goran *et al*., 2017; Abid *et al*., 2024) [34, 2],

allowing identification of areas most exposed to pest pressure. Beneficial insects, particularly Hymenoptera, Diptera, Araneae, and Nematoda, play a crucial role in biological regulation, supporting leveraged pest management strategies and the reduction of pesticide use (Djidjonri *et al*., 2021; Bibi *et al*., 2025) [11, 6]. This study analyzes the effect of spatial variation on the abundance and distribution of maize pests and their natural enemies across five agroecological zones in Senegal.

Materials and Methods

Study area

Located in the tropics, Senegal extends between latitudes 12°00' and 16°30' North and longitudes 11°30' and 17°30' West, covering an area of 196,722 km² (Fall, 2008; Sarr, 2019) [12, 37]. The study was conducted in five major agroecological zones of the country: The Northern Groundnut Basin (NGB), the Southern Groundnut Basin (SGB), the Senegal River Valley (SRV), Lower and Middle Casamance (LMC), and Upper Casamance and Eastern Senegal (UCES). These zones are among the most productive of the seven agroecological regions of Senegal (Fig. 1). The climate is South Sudanian in the LMC and part of the UCES, North Sudanian in the remaining UCES and in the SGB, and Sahelian in the NGB and SRV. Average annual rainfall ranges from approximately 1,250 mm in southern areas to just over 200 mm in northern regions (Faye *et al*., 2017) [14].

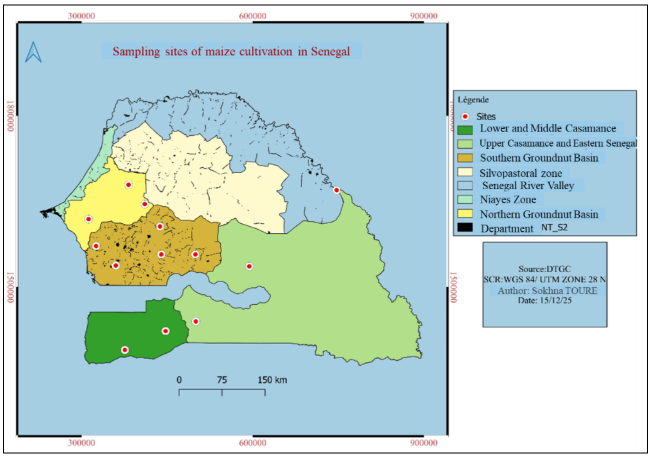

Fig 1: Seven agro-ecological zones of Senegal.

Sampling

Sampling was conducted along the diagonal method on plots measuring 26 m × 26 m, selected randomly, during the rainy season, in 12 locations from the SGB in July 2022, NGB in August 2022, UCES in September 2023, and LMC in September 2023. During the dry season, sampling was also carried out in the locality of Dembancane (SRV) in 2021 and 2023. In each locality, collections were performed before sunrise and at sunset to maximize the capture of diurnal and crepuscular species, in accordance with standard recommendations in tropical entomology.

Collection and identification

Insects were collected from different parts of the maize plant or in its vicinity using insect tweezers or netting. Collection was supplemented by the use of passive traps (buried and aerial) to capture epigeic and aerial arthropods, thus ensuring better representativeness of the entomological community. Except for Orthoptera caterpillars and larvae, which were reared to maintain their life cycle, the species were preserved in 70% alcohol. Identification was carried out in the laboratory using reference collections from the Fundamental Institute of Black Africa (IFAN-CAD) and specialized identification keys (Mestre, 1988; Bordat and Arvanitakis, 2004; Aberlenc *et al*., 2020) [29, 7, 1].

Ecological parameters

Several ecological parameters were studied, including insect distribution within agroecological zones, abundance, relative frequency, and relative abundance.

Absolute abundance (Aa) is the total number of individuals of a species captured. Relative abundance allows for the assessment of the importance of a species, family, class, or order relative to the sample as a whole. This abundance was calculated according to the inventoried orders and families (Faurie *et al*., 2003) [13]. and was calculated as:

$f = ni*100 / N$ or $Ar\,\% = Aa*100/At$,

where ni is the number of individuals of a given species and N is the total number of individuals of all species combined (Djidjonri *et al*., 2019; N'guessan *et al*., 2020) [11, 30]. According to Faurie *et al*. (2003) [13], species are classified according to their abundance: very rare (Ar% < 5%), rare (5% < Ar% < 25%), common (25% < Ar% < 50%), abundant (50% < Ar% < 75%), and very abundant (Ar% > 75%). Furthermore, the frequency of occurrence was established, representing the ratio between the number of records where species i is present and the total number of records multiplied by one hundred.

$Fo\% = Pi*100/P$,

where Pi is the number of records where species i is present and P is the total number of records. The frequency of occurrence allows us to classify the collected insect species into different groups: rare species (Fo < 5%), accidental (5% < Fo < 25%), accessory (25% < Fo < 50%), regular (50% < Fo < 75%), constant (75% < Fo < 100) and omnipresent (Fo = 100%) (Faurie *et al*., 2003) [13].

Data Analysis

The data were entered into Excel 2016 and processed using R software version 4.4.1 (R Core Team, 2024) [35] for graphing and statistical testing. The Shapiro-Wilk test was used to verify the normality of the distributions. The chi-square test was performed to test the hypothesis that the taxonomic composition (orders, families, and species) and functional structure of arthropod communities are influenced by agroecological zones, phenology, and the ecological status of the species, reflecting an ecological structuring of maize agroecosystems. A correspondence analysis (CA) was applied to the abundance matrices to explore the ecological structuring of the insect communities and to highlight the composition gradients associated with agroecological zones and maize phenological stages. The Kruskal-Wallis test was performed to assess the differences in relative abundance of families according to agroecological zones. Dunn's test is applied to those that presented at least one difference.

Results

Inventory and distribution of species associated with maize

A total of 2,766 specimens were inventoried, representing 246 morpho-species, 77 identified families, and 14 insect orders, including *Coleoptera*, Diptera, Heteroptera, Hymenoptera, Orthoptera, *Lepidoptera*, Homoptera, Thysanoptera, Mantodea, Dermaptera, Odonata, Neuroptera, Isoptera, and Embioptera. In addition to these insect orders, three families belonging to the order Araneae and one family from the order Nematoda were also included. The distribution of all specimens according to agro-ecological zones shows a clear dominance of the Senegal River Valley with 45.01% of individuals, followed by the Southern Groundnut Basin (17.76%), Lower and Middle Casamance (14.71%), Northern Groundnut Basin (12.51%), and finally Upper Casamance and Eastern Senegal (10.01%) (Table 1). The LMC (Lower and Middle Casamance) contains 407 individuals, 43 identified families, and 12 orders. The UCES (Upper Casamance and Eastern Senegal) has 277 specimens, 35 identified families, and 10 orders. The SGB (Southern Groundnut Basin) comprises 491 specimens, 39 identified families, and 11 orders. The NGB (Northern Groundnut Basin) has 346 specimens, 29 identified families, and 10 orders. The SRV (Senegal River Valley) contains 1,245 individuals, 33 identified families, and 9 orders. The most represented orders are Heteroptera (26.17%), *Coleoptera* (19.63%) and *Lepidoptera* (14.82%) (Fig. 2).

Table 1: Inventory of pest insects and their natural enemies, as well as their abundance, in the study areas

Order/Family/Subfamily		Agroecological zones				
	Species	LMC	UCES	SGB	NGB	SRV
Araneae/Araneidae	Indet	4	2	3	2	2
Araneae/Lycosidae	Indet	1	0	1	0	2
Araneae/Salticidae	Indet	8	6	3	0	8
Araneae	Indet	0	0	0	0	2
Coleoptera/Anthicidae	*Anthicus crinitus*	0	0	0	1	0
Coleoptera/Anthicidae	*Anthicus* sp.	0	0	0	0	15
Coleoptera/Anthicidae	*Anthicus velatus*	0	0	0	0	1
Coleoptera/Anthicidae	*Formicomus* sp.	0	0	1	0	0
Coleoptera/Anthicidae	*Omonadus bifasciatus*	0	0	0	0	29
Coleoptera/Bostrichidae	*Sinoxylon senegalense*	0	0	0	0	1
Coleoptera/Bostrichidae	Indet	0	0	0	0	2
Coleoptera/Carabidae	*Calleida praestans*	0	0	2	0	0
Coleoptera/Carabidae	*Cicindela senegalensis*	3	0	1	0	0
Coleoptera/Carabidae	*Drypta ruficollis*	0	0	1	0	0
Coleoptera/Carabidae	*Egadroma fugax*	2	1	0	0	0
Coleoptera/Carabidae	*Hexagonia* sp.	0	0	1	1	0
Coleoptera/Carabidae	*Hyparpalus holosericeus*	0	4	0	0	0
Coleoptera/Carabidae	*Platymetopus obscuripes*	0	0	1	0	0
Coleoptera/Carabidae	*Platymetopus* sp.	0	0	1	0	0
Coleoptera/Carabidae	Indet	1	2	0	0	0
Coleoptera/Chrysomelidae	*Callispa* sp.	1	0	0	0	0
Coleoptera/Chrysomelidae	*Callosobruchus maculatus*	0	0	1	0	0
Coleoptera/Chrysomelidae	*Caryedon serratus*	0	0	6	0	2
Coleoptera/Chrysomelidae	*Caryedon* sp.	0	0	3	2	6
Coleoptera/Chrysomelidae	*Chaetocnema* sp.	1	0	0	0	1
Coleoptera/Chrysomelidae	*Clytra* sp.	0	0	0	0	1
Coleoptera/Chrysomelidae	*Decispella* sp.	0	0	0	0	5
Coleoptera/Chrysomelidae	*Dorcathispa alternata*	3	0	0	0	0
Coleoptera/Chrysomelidae	*Eryxia* sp.	0	0	55	0	0
Coleoptera/Chrysomelidae	*Gabonia* sp.	2	0	0	0	0
Coleoptera/Chrysomelidae	*Hapsidolema melanophthalma*	0	0	1	0	0
Coleoptera/Chrysomelidae	*Lamprocopa* sp.	0	0	0	0	5
Coleoptera/Chrysomelidae	*Lema quadripartita*	1	0	0	0	0
Coleoptera/Chrysomelidae	*Lema risbeci*	0	0	7	1	0
Coleoptera/Chrysomelidae	*Lema* sp.	0	0	3	1	3
Coleoptera/Chrysomelidae	*Microsyagrus notatus*	0	0	1	0	0
Coleoptera/Chrysomelidae	*Microsyagrus* sp.	1	0	0	0	0
Coleoptera/Chrysomelidae	*Monolepta bigauti senegalensis*	0	2	0	0	0
Coleoptera/Chrysomelidae	*Podagrica* sp.	1	0	0	0	0
Coleoptera/Chrysomelidae	*Rhaphidopalpa* sp.	0	0	0	0	38
Coleoptera/Chrysomelidae	*Spermophagus* sp.	1	0	0	0	2
Coleoptera/Chrysomelidae	Indet	2	0	0	0	5
Coleoptera/Coccinellidae	*Cheilomenes sulphurea*	0	0	0	0	1
Coleoptera/Coccinellidae	*Cydonia vicina*	0	1	0	2	0
Coleoptera/Coccinellidae	*Epilachna* sp.	0	0	0	0	12
Coleoptera/Coccinellidae	*Exochomus foudrasi*	0	0	0	0	1
Coleoptera/Coccinellidae	*Exochomus* sp.	0	1	0	0	0
Coleoptera/Coccinellidae	*Harmonia* sp.	0	0	0	4	0
Coleoptera/Coccinellidae	*Scymnus senegalensis*	0	0	0	6	1
Coleoptera/Coccinellidae	*Scymnus* sp.	0	4	3	16	0
Coleoptera/Coccinellidae	Indet	2	2	0	17	0
Coleoptera/Curculionidae	*Asemus* sp.	0	0	3	0	0
Coleoptera/Curculionidae	*Gasteroclisus rhomboidalis*	0	0	1	0	0
Coleoptera/Curculionidae	*Ischnotrachelus dorsalis*	0	0	39	0	0
Coleoptera/Curculionidae	*Isomyllocerus decorsei*	0	0	1	0	0
Coleoptera/Curculionidae	*Nanophyes* sp.	0	0	0	0	3
Coleoptera/Curculionidae	*Siderodactylus sagittarius*	11	0	2	0	0
Coleoptera/Curculionidae	Indet	2	0	12	0	0
Coleoptera/Cydnidae	Indet	0	0	0	0	1
Coleoptera/Dermestidae	*Telopes* sp.	0	0	0	2	0
Coleoptera/Elateridae	*Anchastus ambiguus*	0	0	2	0	0
Coleoptera/Elateridae	*Cardiophorus holosericeus*	0	0	4	0	0
Coleoptera/Elateridae	*Heteroderes* sp.	0	5	3	2	15

Coleoptera/Elateridae	Indet	1	0	0	0	2
Coleoptera/Indet	Indet	0	0	8	2	5
Coleoptera/Meloidae	*Epicauta canesceus*	0	1	0	0	0
Coleoptera/Meloidae	*Mylabris palipis*	0	6	0	0	0
Coleoptera/Meloidae	*Mylabris* sp.	0	4	0	1	0
Coleoptera/Meloidae	*Psalydolytta fusca*	0	1	0	0	0
Coleoptera/Meloidae	*Psalydolytta vestita*	0	0	0	1	0
Coleoptera/Meloidae	Indet	0	0	0	1	0
Coleoptera/Nitidulidae	*Brachypeplus* sp.	0	12	0	0	1
Coleoptera/Nitidulidae	*Carpophilus hemipterus*	3	3	0	0	1
Coleoptera/Nitidulidae	*Carpophilus* sp.1	12	6	0	0	0
Coleoptera/Nitidulidae	*Carpophilus* sp.2	0	4	0	0	0
Coleoptera/Nitidulidae	*Carpophilus* sp.3	2	0	0	0	0
Coleoptera/Nitidulidae	*Haptoncus* sp.	0	2	0	0	0
Coleoptera/Nitidulidae	*Lasiodactylus subproductus*	1	0	1	0	0
Coleoptera/Nitidulidae	*Pocadius* sp.	0	0	1	0	0
Coleoptera/Nitidulidae	Indet	3	3	0	0	3
Coleoptera/Rhipiphoridae	*Macrosiagon* sp.	0	0	1	0	0
Coleoptera/Scarabaeidae	*Euorodalus parvulus*	0	0	1	0	0
Coleoptera/Scarabaeidae	Indet	0	1	0	0	0
Coleoptera/Scarabaeidae	*Metacatharsius peleus*	0	7	0	0	0
Coleoptera/Scarabaeidae	*Onthophagus* sp.	1	0	0	0	0
Coleoptera/Scarabaeidae	*Rhyssemus ritsemae*	0	0	0	0	1
Coleoptera/Scarabaeidae	*Rhyssemus* sp.	0	0	2	0	0
Coleoptera/Staphylinidae	*Atheta sordida*	0	5	0	0	0
Coleoptera/Staphylinidae	*Bledius* sp.	2	0	0	0	0
Coleoptera/Staphylinidae	*Paederus* sp.	0	4	0	0	2
Coleoptera/Staphylinidae	*Philonthus* sp.	1	0	0	0	0
Coleoptera/Staphylinidae	*Zyras* sp.	1	0	0	0	0
Coleoptera/Staphylinidae	Indet	2	0	0	0	0
Coleoptera/Tenebrionidae	*Oncosoma hirsutum*	0	0	2	0	0
Coleoptera/Tenebrionidae	*Leichenum canaliculatum*	0	0	1	0	0
Coleoptera/Tenebrionidae	*Tribolium castaneum*	0	0	0	0	2
Dermaptera/Forficulidae	*Forficula senegalensis*	0	0	90	25	0
Dermaptera/Labiduridae	*Labidura riparia*	8	0	0	0	2
Diptera/Asilidae	*Hoplistomerus* sp.	1	0	0	0	0
Diptera/Asilidae	*Hoplistomerus serripes*	0	0	0	1	0
Diptera/Asilidae	Indet	0	0	0	2	0
Diptera/Bombyliidae	*Chasmoneura senegalensis*	0	0	0	1	0
Diptera/Bombyliidae	Indet	0	0	1	0	0
Diptera/Calliphoridae	*Lucilia* sp.	0	0	0	1	0
Diptera/Calliphoridae	*Lucilia caesar*	0	0	0	3	0
Diptera/Calliphoridae	*Chrysomyia chloropyga*	0	0	0	2	0
Diptera/Calliphoridae	Indet	1	1	0	3	0
Diptera/Canacidae	Indet	0	1	0	0	0
Diptera/Chamaemyiidae	Indet	3	1	0	0	0
Diptera/Diopsidae	Diopsis tenuipes	0	0	0	1	0
Diptera/Diopsidae	*Diopsis* sp.	3	1	0	0	0
Diptera/Dolichopodidae	*Chrysosoma* sp.	4	0	0	0	0
Diptera/Dolichopodidae	Indet	17	32	0	0	0
Diptera/Drosophilidae	Indet	1	6	0	0	0
Diptera/Fanniidae	*Fania* sp.	3	4	0	0	0
Diptera/Fanniidae	*Piezura* sp.	8	3	0	0	0
Diptera/Muscidae	*Musca* sp.	1	0	0	2	0
Diptera/Platystomatidae	*Lamprophthalma* sp.	0	0	4	0	0
Diptera/Platystomatidae	*Engistoneura* sp.	0	0	0	2	0
Diptera/Rhiniidae	*Rhinia apicalis*	0	0	1	0	0
Diptera/Sarcophagidae	*Sarcophaga* sp.1	1	3	0	3	0
Diptera/Sarcophagidae	*Sarcophaga* sp.2	0	1	0	0	0
Diptera/Sarcophagidae	*Sarcophaga* sp.3	1	0	0	0	0
Diptera/Sarcophagidae	Indet	3	0	0	0	0
Diptera/Sphaeroceridae	Indet	0	10	0	0	0
Diptera/Stratiomyidae	*Sternobrinthes* sp.	0	0	1	0	0
Diptera/Syrphidae	*Mesembrius* sp.	1	0	0	0	0
Diptera/Syrphidae	*Syrphus* sp.1	7	0	0	0	0
Diptera/Syrphidae	*Syrphus* sp.2	2	0	0	0	0

Diptera/Syrphidae	*Syrphus* sp.3	0	0	0	4	0
Diptera/Syrphidae	Indet	4	1	0	1	0
Diptera/Tachinidae	*Pollenia* sp.	0	0	1	0	0
Diptera/Tachinidae	Indet	0	1	11	4	0
Embioptera	Indet	0	0	1	0	0
Heteroptera/Alydidae	*Leptocorisa elegans*	3	9	0	0	0
Heteroptera/Blissidae	*Blissus leucopterus*	0	0	0	0	76
Heteroptera/Coreidae	*Acanthomia curvipes*	0	0	0	0	1
Heteroptera/Coreidae	*Cletus* sp.	0	0	0	0	1
Heteroptera/Cydnidae	*Aethus macrophtalmus*	0	0	1	0	0
Heteroptera/Geocoridae	*Geocoris amabilis*	0	1	0	0	129
Heteroptera/Lygaeidae	*Dimorphopterus* sp.	0	0	0	0	11
Heteroptera/Lygaeidae	*Elasmolomus* sp.	0	0	0	0	1
Heteroptera/Lygaeidae	*Graptostethus servus*	2	5	1	0	0
Heteroptera/Lygaeidae	*Naphius* sp.	0	0	0	0	2
Heteroptera/Lygaeidae	*Pachybrachius* sp.	0	0	0	0	1
Heteroptera/Lygaeidae	Indet	0	0	0	0	4
Heteroptera/Miridae	*Creontiades pallidus*	0	0	4	1	7
Heteroptera/Miridae	*Megacoelum* sp.	0	0	0	2	0
Heteroptera/Nabidae	*Nabis capsiformis*	0	0	0	0	1
Heteroptera/Scutelleridae	*Calidea nana*	1	0	0	0	19
Heteroptera/Pentatomidae	*Carbula protalis*	0	0	4	0	0
Heteroptera/Pentatomidae	*Eysarcoris inconspicuus*	0	0	0	0	74
Heteroptera/Pentatomidae	*Myrochea aculeata*	0	0	1	0	0
Heteroptera/Pentatomidae	*Piezodorus* sp.	0	0	0	0	342
Heteroptera/Pentatomidae	Indet	0	0	0	0	2
Heteroptera/Plataspidae	Indet	2	0	0	0	0
Heteroptera/Pyrrhocoridae	*Dysdercus supersittosus*	0	0	2	0	0
Heteroptera/Reduviidae	Indet	0	0	0	0	2
Heteroptera/Rhopalidae	*Leptocoris* sp.	0	0	0	0	6
Heteroptera/Rhopalidae	Indet	0	0	0	0	1
Heteroptera	Indet	2	0	1	0	2
Homoptera/Aphididae	*Rhopalosiphum* sp.	11	45	0	125	0
Homoptera/Aphididae	Indet	5	0	0	0	0
Homoptera/Cercopidae	*Locris rubra*	16	2	0	0	0
Homoptera/Cercopidae	*Poophilus* sp.	2	1	0	0	0
Homoptera/Cicadellidae	Indet	2	2	0	0	0
Homoptera/Jassidae	Indet	21	2	0	0	0
Homoptera	Indet	0	6	0	2	10
Hymenoptera/Apidae	*Apis mellifera*	5	5	0	0	0
Hymenoptera/Braconidae	Indet	0	0	0	1	0
Hymenoptera/Crabronidae	*Bembix flavescens*	0	0	1	0	0
Hymenoptera/Crabronidae	*Cerceris* sp.	1	0	0	0	0
Hymenoptera/Crabronidae	Indet	0	0	1	1	0
Hymenoptera/Crabronidae/Pemphredoninae	Indet	3	0	0	0	0
Hymenoptera/Formicidae	*Camponotus abjectus*	0	0	17	0	0
Hymenoptera/Formicidae	*Camponotus aegyptiacus*	4	0	0	0	0
Hymenoptera/Formicidae	*Camponotus guttatus*	6	0	0	0	0
Hymenoptera/Formicidae	*Camponotus oasium*	1	0	0	0	0
Hymenoptera/Formicidae	*Camponotus* sp.	0	0	2	0	0
Hymenoptera/Formicidae	*Camponotus tanaemyrmex fellah*	23	1	2	0	0
Hymenoptera/Formicidae	*Cardiocondyla* sp.	3	0	0	0	0
Hymenoptera/Formicidae	*Lepisiota laevis*	0	1	0	0	0
Hymenoptera/Formicidae	*Myrmica* sp.	2	0	0	0	0
Hymenoptera/Formicidae	*Myrmicaria distincta*	8	0	0	0	0
Hymenoptera/Formicidae	*Pachycondyla sennaarensis*	18	0	0	0	0
Hymenoptera/Formicidae	*Tetramorium* sp.	4	0	0	0	0
Hymenoptera/Formicidae	Indet	0	0	2	0	0
Hymenoptera/Formicidae/Formicinae	Indet	1	0	0	0	0
Hymenoptera/Larridae	Indet	0	0	4	0	0
Hymenoptera/Mutillidae	*Mutilla mikado*	0	0	1	0	0
Hymenoptera/Mutillidae	Indet	0	0	3	0	0
Hymenoptera/Pompilidae	*Pompilus* sp.1	1	0	0	0	0
Hymenoptera/Pompilidae	*Pompilus* sp.2	1	0	0	0	0
Hymenoptera/Pompilidae	*Pompilus* sp.3	1	0	0	0	0
Hymenoptera/Scoliidae	*Campsomeris coelebs*	0	0	1	0	0

Hymenoptera/Scoliidae	*Campsoscolia* sp.	0	0	0	5	0
Hymenoptera/Sphecidae	*Ammophila* sp.1	0	1	0	0	0
Hymenoptera/Sphecidae	*Ammophila* sp.2	0	2	0	0	0
Hymenoptera/Sphecidae	*Ammophila* sp.3	0	0	1	0	0
Hymenoptera/Sphecidae/Ammophilinae	Indet	2	0	0	0	0
Hymenoptera/Sphecidae	Indet	0	0	1	1	0
Hymenoptera/Tiphiidae	Indet	0	0	1	0	0
Isoptera/Termitidae	*Macrotermes* sp.	0	0	2	0	0
Lepidoptera/Erebidae	*Spilosoma maenas*	0	0	5	0	0
Lepidoptera/Hesperiidae	Indet	0	0	1	0	0
Lepidoptera/Noctuidae	*Helicoverpa armigera*	0	0	0	3	23
Lepidoptera/Noctuidae	*Leucania loreyi*	0	0	0	3	57
Lepidoptera/Noctuidae	*Sesamia calamistis*	0	0	0	0	12
Lepidoptera/Noctuidae	*Spodoptera frugiperda*	20	14	46	48	140
Lepidoptera/Noctuidae	*Spodoptera littoralis*	0	0	0	1	0
Lepidoptera/Noctuidae	Indet	3	5	0	0	6
Lepidoptera/Pieridae	*Belenois aurota*	0	0	0	7	0
Lepidoptera	Indet	0	0	7	8	1
Mantodea/Mantidae	*Miomantis* sp.	1	0	0	0	0
Mantodea/Hymenopodidae	*Pseudocreobotra* sp.	1	0	0	0	0
Nematoda/Mermithidae	*Hexamermis* spp.	45	7	61	7	0
Neuroptera/Mantispidae	*Pseudoclimaciella* sp.	0	0	0	0	1
Odonata/Libellulidae	*Pantala flavescens*	6	0	0	0	0
Orthoptera/Acrididae	*Acrida bicolor*	0	0	1	1	1
Orthoptera/Acrididae	*Acrida* sp.	1	0	0	0	0
Orthoptera/Acrididae	*Acrida turrita*	1	0	0	0	0
Orthoptera/Acrididae	*Acrotylus patrueilis*	0	0	0	1	6
Orthoptera/Acrididae	*Aiolopus thalassinus thalassinus*	0	0	0	0	3
Orthoptera/Acrididae	Anacridium wernerellum	1	0	0	0	0
Orthoptera/Acrididae	*Catantops stramineus*	0	1	0	0	0
Orthoptera/Acrididae	*Cryptocatantops haemorrhoidalis*	3	0	1	0	0
Orthoptera/Acrididae	*Epistaurus* sp.	2	0	0	0	0
Orthoptera/Acrididae	*Eyprepocnemis plorans*	0	1	0	0	1
Orthoptera/Acrididae	*Morphacris fasciata*	0	0	0	0	1
Orthoptera/Acrididae	*Orthochtha* sp.	0	0	1	0	0
Orthoptera/Acrididae	*Trilophidia conturbata*	0	0	0	0	4
Orthoptera/Acrididae/Oedipodinae	Indet	2	0	0	0	0
Orthoptera/Acrididae	Indet	5	6	2	4	2
Orthoptera/Gryllidae	*Gryllus bimaculatus*	0	0	0	0	1
Orthoptera/Gryllidae	*Oecanthus pellucens*	0	0	3	0	24
Orthoptera/Gryllidae	Indet	2	0	0	0	0
Orthoptera/Phaneropteridae	*Phaneroptera nana*	0	0	0	0	6
Orthoptera/Pyrgomorphidae	*Chrotogonus senegalensis*	1	1	1	3	1
Orthoptera/Pyrgomorphidae	*Pyrgomorpha cognata*	0	0	2	0	33
Orthoptera/Pyrgomorphidae	*Pyrgomorpha vignaudii*	9	3	0	0	1
Orthoptera/Pyrgomorphidae	*Zonocerus variegatus*	2	0	16	5	0
Orthoptera/Pyrgomorphidae	Indet	6	1	1	0	0
Orthoptera/Tettigoniidae	*Ruspolia* sp.	0	0	0	0	1
Orthoptera/Tettigoniidae	*Conocephalus* sp.	0	0	0	0	1
Thysanoptera	Indet	0	0	1	0	0
Thysanoptera/Thripidae	*Thrips* sp.	0	1	0	0	44
Abondance absolue		407	277	491	346	1245
Abondance relative		14,71	10,01	17,75	12,51	45,01

Note: Indet = Indeterminate

The distribution of individuals by order reveals a strong dominance of Heteroptera (26.17%), followed by *Coleoptera* (19.63%) and *Lepidoptera* (14.82%), which account for more than half of the individuals inventoried. The orders Homoptera, Orthoptera, Diptera, Hymenoptera, Dermaptera and Nematoda are of intermediate abundance, while the other orders, including Thysanoptera, Araneae, Odonata, Mantoptera, Isoptera, Neuroptera and Embioptera, are poorly represented, reflecting an unbalanced community structure (Fig. 2).

The correspondence analysis biplot (Fig. 3) reveals a clear structuring of insect assemblages according to the VFS agroecological zone, distinct from the other zones. This structuring explains 82.2% of the total variability (Axis 1: 59.7%; Axis 2: 22.5%). A marked association is observed between the SRV zone and the orders Heteroptera, *Lepidoptera*, Orthoptera, Thysanoptera, and Neuroptera, in contrast to the other zones, whose assemblages form a relatively homogeneous group.

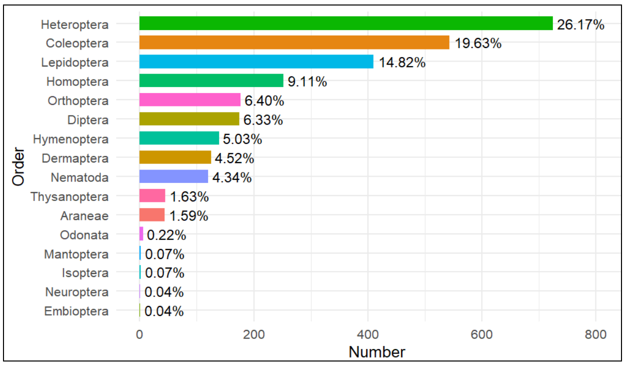

Fig 2: Abundance of orders of arthropods and nematodes associated with maize

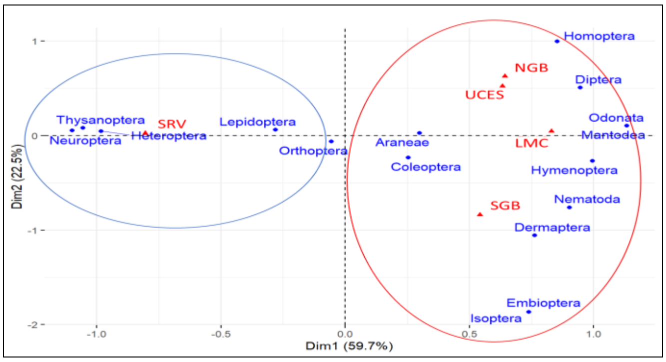

Fig 3: Correspondence analysis of orders according to agroecological zones

Distribution of maize pests and their natural enemies across agroecological zones

The heat map (Fig. 4) illustrates marked variation in the composition and relative abundance of insect orders across agroecological zones. This spatial structuring is confirmed by the chi-square test of independence, highlighting a significant association between insect orders and agroecological zones (P = 0.0005). The most abundant orders across all zones are *Coleoptera*, Heteroptera, Diptera, Homoptera, and *Lepidoptera*. The order *Coleoptera*, present in all zones, stands out with a high abundance in the SGB (35.03%) and the UCES (29.24%). Diptera show high proportions in the LMC (14.99%) and the UCES (23.47%). Homoptera are particularly well represented in the LMC (14%), UCES (20.94%), and especially NGB (36.71%) zones. Heteroptera are clearly dominant in the SRV (56.8%). Hymenoptera reach 20.64% in the LMC. Finally, *Lepidoptera* are mainly abundant in the SBA (12.02%), NGB (20.23%), and SRV (19.20%).

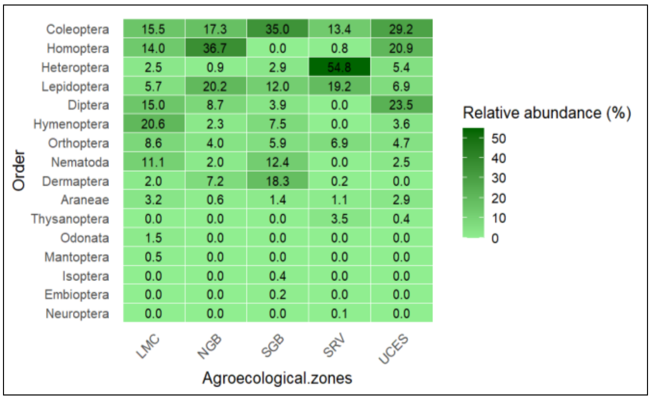

Fig 4: Relative abundance of orders according to zones

Distribution of the insect community and their natural enemies according to phenological stages

The arthropod community also varies during the phenology of maize (Fig. 5). At the vegetative stage (VS), *Coleoptera* dominate (20.7%), followed by Homoptera (15.7%), *Lepidoptera* (13.8%), and Hymenoptera (12.7%). At flowering (EFS and FS), *Coleoptera* remain abundant, but a relative increase in Heteroptera (20.5%) and Dermaptera (18.5%) is observed. During EMS and MS maturation, *Coleoptera*, Heteroptera, and *Lepidoptera* populations remain well represented. Empty cells indicate the absence of individuals belonging to certain orders at these stages.

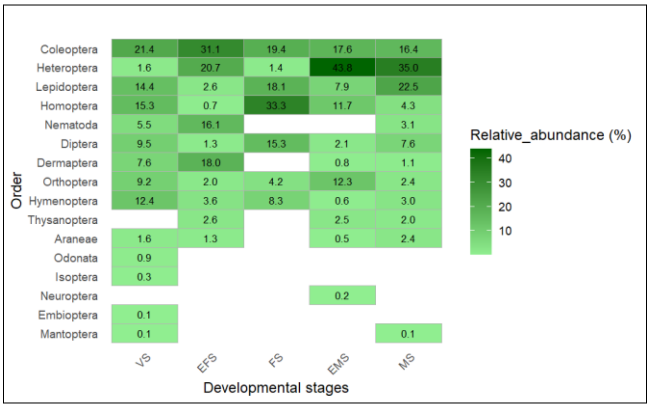

Fig 5: Relative abundance of orders associated with maize according to phenological stage

Relative abundance of families classified into intervals according to zones

Of the 81 families identified, 14 are classified as "rare" and "common," while the remaining 67 families are considered "very rare" and are grouped under the name "Other" (Fig. 6). This classification of families is not significantly influenced by the area (p-value = 0.9434). However, analysis of the relative abundance of families by order shows that the structure of the insect fauna varies considerably according to the agroecological zones (p-value = 0.019). In the LMC, the community is dominated by Formicidae (17%), followed by Mermithidae (11%). In the UCES, Aphididae predominate at 17%, alongside Dolichopodidae (12%) and Nitidulidae (11%). In the NGB, Aphididae are clearly dominant (37%), followed by *Noctuidae* (16%) and Coccinellidae (13%), which are also well represented. The SGB is marked by the dominance of Forficulidae (19%), Chrysomelidae (16%), Mermithidae (13%), and Curculionidae (12%). Finally, in SRV Pentatomidae (36%) are by far the most prevalent, followed by *Noctuidae* (19%) and Geocoridae (11%).

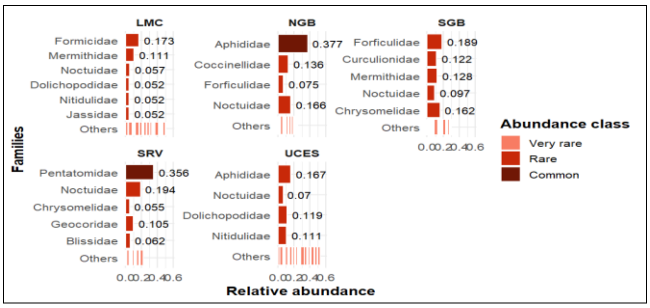

Fig 6: Relative abundance and classification of abundant families according to zones

Ecological structure of species associated with maize

Overall, the entomological community associated with maize is distributed across two trophic networks (Fig. 7). This pest-beneficial insect complex is present in all agroecological zones, with varying frequency rates depending on the zone (p-value = 1e-4). Pests dominate in the SRV (82.6%), NGB (66.9%), SGB (60.5%), and UCES (54.8%) zones, while beneficial insects are more abundant in the LMC zone (55.9%).

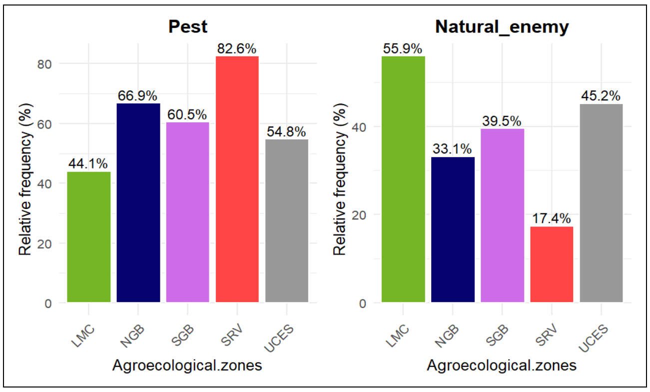

Fig 7: Population distribution according to status and agroecological zone

Functional structuring of maize pests and their natural enemies across agroecological zones in Senegal

The taxonomic composition of arthropods associated with maize and entomopathogenic nematodes varies according to their ecological status and distribution in agroecological zones (Fig. 8). The orders *Coleoptera*, Heteroptera, Diptera, and Dermaptera include both pests and beneficial insects. Conversely, the orders *Lepidoptera*, Homoptera, Orthoptera, and Thysanoptera are composed exclusively of pests, with particularly high frequencies in the NGB, SGB, and SRV zones. Among beneficial insects, *Coleoptera*, Diptera, Hymenoptera, and Heteroptera dominate in the LMC and UCES zones. In contrast, Araneae and Nematoda are present at low frequencies (10%).

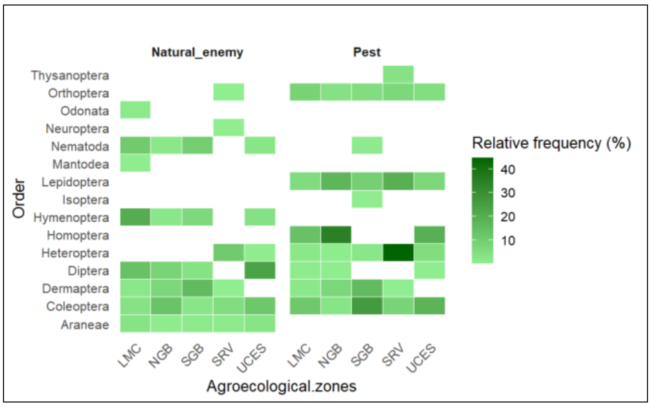

Fig 8: Distribution of pests and beneficial insects according to order and zone

Discussion

The results demonstrate that maize-associated insect communities are dominated by Heteroptera, *Coleoptera*, and *Lepidoptera*, confirming the predominant role of these groups in tropical cereal agroecosystems. This dominance, previously reported in in West Africa cropping systems (Goergen *et al*., 2016; Kane *et al*., 2023) [17, 25], is explained by the high ecological plasticity of these orders, their trophic diversity, and their ability to exploit the resources offered by crops (Basset *et al*., 2012; Delvare, 2020; Gullan and Cranston, 2020; Bibi *et al*., 2025) [4, 10, 18, 6]. However, this general structure masks significant spatial variations linked to agroecological contexts and local farming practices.

The results of the correspondence analysis (CA) confirm the existence of a spatial structure in the insect communities, highlighting a clear variation between agroecological zones according to the composition and relative abundance of the main taxonomic groups. This organization is confirmed by the results of the chi-square test, which show a significant variation in the distribution of taxonomic and functional groups across agroecological zones, indicating the influence of climate, cropping systems, and landscape complexity (Gueye *et al*., 2024) [19]. Although *Coleoptera* are abundant throughout the zones, certain orders exhibit specific dominance. Thus, the predominance of Homoptera and *Lepidoptera* in the Northern Groundnut Basin (NGB) can be associated with the frequent practice of maize monoculture, which can promote the accumulation of specialized phytophagous pests and increase biotic pressure on the crop. Conversely, the dominance of Hymenoptera in LMC and the increased presence of Dermaptera and Nematoda in SGB suggest the existence of more diversified agricultural systems, offering a mosaic of habitats favorable to the maintenance of natural enemies and more effective biological regulation (Djidjonri *et al*., 2021) [11].

These results are consistent with a conceptual model in which the complexity of cropping systems and the surrounding landscape influences the balance between pests and beneficial organisms. Areas characterized by greater plant diversity and less intensive agroecological practices (LMC and UCES) exhibit a higher proportion of beneficial organisms, reflecting better functioning of natural regulation mechanisms. Conversely, in areas with more intensive or simplified agriculture, such as the NGB and certain plots in the SGB, the use of chemical inputs and low floristic diversity can reduce the richness and effectiveness of beneficial organisms, leading to a dominance of phytophagous pests (Mballo *et al*., 2019; Sarr, 2019) [28, 37].

Beyond spatial variations, the dynamics of insect communities are closely linked to maize phenology. The dominance of *Coleoptera* at the vegetative stage (VS), observed throughout the cycle, reflects their ability to exploit all vegetative layers of the plant (Aberlenc *et al*., 2020) [1]. *Lepidoptera* and Homoptera, associated with young leaf tissues (Altieri, 1999; Ouali-N'Goran *et al*., 2017; Kamal & Ali, 2022) [3, 34, 23], are more abundant at early stages, while Heteroptera become predominant from flowering onwards, due to their affinity for sap-rich tissues (Streito *et al*., 2020) [40]. The presence of Dermaptera at these advanced stages, particularly in the horns, suggests a potential role in regulating *Spodoptera frugiperda*, despite their sometimes-ambiguous status as pests (Shylesha *et al*., 2018) [39]. Thus, the structuring of the maize entomological community results from the combined effect of agroecological conditions, cultivation practices, and crop phenology, which simultaneously modulate resource availability, habitats, and trophic relationships.

The analysis of trophic groups reveals a strong dominance of pests in certain areas, particularly in the Senegal River Valley (SRV), the NGB, and the SGB, reflecting increased vulnerability of maize to phytophagous attacks, consistent with observations reported by Goebel (1995) [16]; Jean and Boisclair (2001) [21]; Ouali-N'Goran *et al*. (2017) [34] and Laminou *et al*. (2022) [27]. This situation may result from a combination of factors, including low crop diversity, challenging climatic conditions, and intensive farming practices (Mballo *et al*., 2019; Sarr, 2019) [28, 37]. Conversely, the LMC and UCES areas exhibit a better balance between pests and beneficial insects, suggesting more functional biological regulation, likely linked to floristic complexity and traditional agroforestry systems (N'woueni and Gaoue, 2022; Bérubé-Girouard *et al*., 2024) [33, 5].

Although the overall taxonomic composition of the families is relatively homogeneous across the areas, variations in relative abundance reflect the influence of local environmental conditions. The strong dominance of Formicidae in LMC, associated with high generic diversity, illustrates the key role of these insects in pest regulation, particularly grass borers (Goebel *et al*., 2008) [15]. Similarly, the presence of nematodes of the family Mermithidae parasitizing *Spodoptera frugiperda* could help explain the low abundance of *Noctuidae* in certain areas.

Despite the promising results, some limitations must be noted. While standardized, the sampling method remains dependent on climatic conditions and the collection period, which can influence the detection of certain arthropod groups. Furthermore, taxonomic identification was limited for some parasitoids and other taxa within the family, potentially obscuring significant specific variations within functional groups. Finally, the lack of direct quantitative measurements of crop damage prevents establishing a strict link between pest abundance and agronomic impact, thus opening avenues for future studies incorporating yield and pest pressure indicators.

Overall, this study highlights the need to integrate agroecological practices and the management of arthropod functional diversity into sustainable maize protection strategies in Senegal.

Conclusion

This study highlights the central role of beneficial insects in certain agroecological zones, suggesting that the conservation of functional biodiversity is a key lever for the sustainable management of maize pests in Senegal. The maize insect fauna is dominated by the orders Heteroptera, *Coleoptera*, and *Lepidoptera*. The SRV, NGB, SGB, and UCES zones are dominated by pests, while the LMC zone harbors more beneficial insects. The entomological dynamics of maize reflect a succession of functional orders linked to the plant's phenology, from *Coleoptera*, *Lepidoptera*, and Homoptera (phytophagous insects of the vegetative stage) to Heteroptera and Homoptera (flower-visiting groups), as well as Dermaptera (potential regulators of *Lepidoptera* predators). Furthermore, the dynamics of Nematoda (parasites of *Lepidoptera*) are also evident. These results show that the composition and succession of maize insects are regulated by phenology and interactions between pests and beneficial insects, contributing to the ecological balance of fields. This study has some limitations, notably the absence of all developmental stages in certain areas. Future directions include further investigation of pest-beneficial insect interactions to better assess the impact of agricultural practices on insect dynamics and to develop integrated pest management strategies that promote ecological balance in maize crops.

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Data Availability: All the data is available in the article.

Ethics Statement: This study did not require the involvement of the local community or any particular ethnic group, as it focuses exclusively on the inventory and analysis of insects associated with crops, without recourse to human data or traditional knowledge.

Author's Contribution: MDK: initiated the scientific reflection, conducted the research and developed the methodological approach, analysed the data and drafted the initial version of the document. AGRJS: supervised the sampling, ensured the availability of resources in the field, validated the results and participated in the revision of the manuscript. TD: coordinated the project and contributed to the revision and editing of the document. ST: contributed to the creation of the map of Senegal's agroecological zones. MS: provided overall supervision of the project, allocated resources, and contributed to the revision and editing of the document.

Generative AI statement: The authors declare that no Gen AI/Deep Seek was used in the writing/creation of this manuscript.

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