Advances in Entomology, 2022, 10, 287-299
https://www.scirp.org/journal/ae
ISSN Online: 2331-2017
ISSN Print: 2331-1991

Natural Enemies and Pest Control in Field-Grown Crop in Southern Senegal

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How to cite this paper: Tendeng, E., Labou, B., Sylla, E.H.S., Baldé, A., Diatte, M., Seydi, O., Ndiaye, I.A., Diop, P., Sène, S.O., Djiba, S. and Diarra, K. (2022) Natural Enemies and Pest Control in Field-Grown Crop in Southern Senegal. *Advances in Entomology*, **10**, 287-299.
https://doi.org/10.4236/ae.2022.104021

Received: July 27, 2022
Accepted: August 27, 2022
Published: August 30, 2022

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Abstract

Crop pests are a permanent threat to horticultural production. Several control methods are recommended for their control, including biological control. This method based on the use of natural enemies is not well established. The objective of this study was to assess the diversity and abundance of natural enemies of crop pests. A survey of crops associated with pests was carried out on 144 fields in southern Senegal to measure the diversity and abundance of natural enemies of various crop pests, determine the native parasitoid complex and assess parasitism rates. Ecological indices were calculated to assess the diversity of natural enemies. A total of 25 natural enemy species were identified, including 15 parasitoids and 10 predators. Predatory Hemiptera and Parasitoid Hymenoptera were high biodiversity. The parasitism rates vary between 0 and 50% depending on the abundance of pests and parasitoid species. Knowledge of the diversity of natural enemies and the understanding of trophic interactions with pests are important in the development of biological crop protection in order to preserve resilience in agroecosystems.

Keywords

Biodiversity, Agroecosystem, Crop Protection, Pests, Market Gardening, Biological Control

1. Introduction

In Senegal, market gardening is mainly developed in the Niayes agro-ecological zone where pests cause a significant loss of crops [1] [2]. In Senegal's agro-ecological zones, vegetable production is subject to various constraints, including the pressure of insect pests. These pests are a permanent threat to horticultural production. The use of natural enemies such as predators or parasitoids for pest control is more economically viable and environmentally safer than currently recommended synthetic insecticides. Chemical control is the main strategy used to control pests as consequence of the role of natural enemies in the biological control of pests is very poorly understood by vegetable farmers in Senegal. Indeed, chemical control causes environmental pollution [3] and pesticide resistance to insects [4]. Chemical control contributes significantly to the loss of ecosystem services such as biological pest control and favours pest damage to crops. Biological control aims to keep pest populations low through natural enemies in order to restore ecosystem services and build resilience in agro-ecosystems. Natural enemies are considered to be important in agricultural ecosystems [5]. However, biological control service provided by natural enemies sometimes was very poorly known by farmers in Senegal. This method aims to enhance pest control in the field [6]. Native natural enemies regulate pest populations through predation or parasitism [7]. In Casamance, the implementation of numerous agricultural programs and projects has favoured the development of new market garden production areas which contribute to economic development and the fight against unemployment [8]. Pests are a constraint in these vegetable production basins because few research studies have been carried out on the natural enemies. The objective of this study is to assess the species richness and abundance of natural enemies of pests associated with vegetable crops.

2. Materials and Methods

2.1. Study Area

This study was conducted in three localities in the southern region of Senegal from May 2017 to June 2019 (**Figure 1**). The localities surveyed were Bignona, Oussouye, and Ziguinchor. These three departments represent together the region of Ziguinchor known as "Basse Casamance". The climate in this area is sub-Guinean and is characterized by one rainy season (June-October) and one dry season (November-May). These localities were randomly selected among others based on the crop present in the area (**Figure 1**). "Basse Casamance" region is located at 12˚33' North latitude and 16˚16' West longitude, magnetic declination 13˚05. Its altitude is 19.30 m in the southwestern part of Senegal. It covers an area of 7.339 km^2 or 3.73% of the national territory [9].

2.2. Sample Processing and Identification of Natural Enemies

The inventory of natural enemies of pests associated with crops was carried out at the vegetable fields of the agricultural holdings. Overall, 144 crop fields were surveyed in three localities. In each locality, 48 fields were visited. The surveys of the vegetable fields were carried out each week during their availability period. Predators were captured using a mouth-suction aspirator or a flexible forceps.

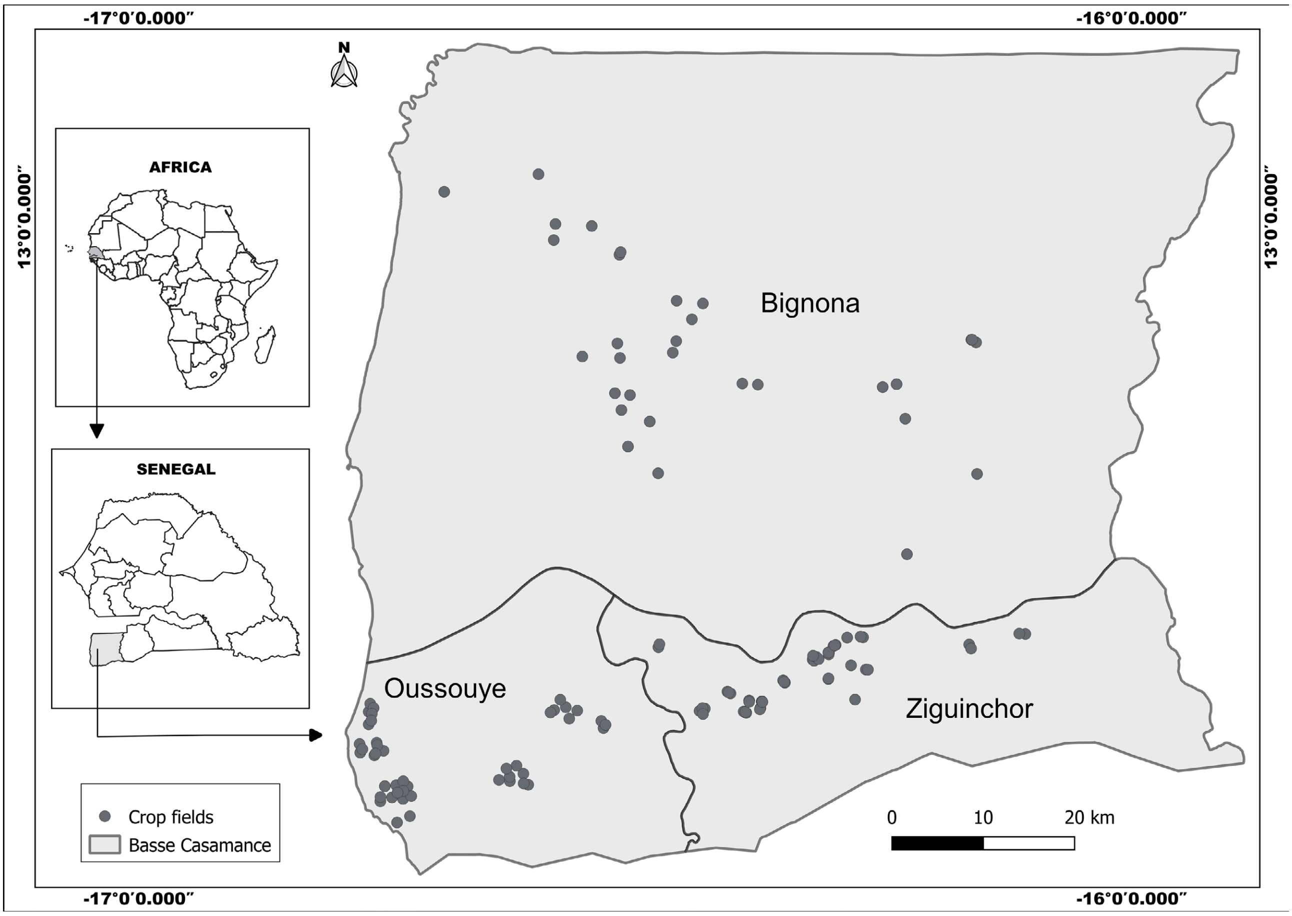

Figure 1. Distribution of crop fields visited in "Basse Casamance" agro-ecological zone in southern Senegal.

Predators are placed in a plastic jar containing absorbent paper and ethyl acetate in order to kill them and to facilitate conservation and identification. The collected samples are kept in tubes containing 70% alcohol for identification. The larvae of pests were collected and monitored in the laboratory. They were fed with fresh leaves from their host plants, which were renewed every day. The parasitoids were obtained after their emergence on the larvae monitored. For identification, the insects were observed with the "Dinolite" magnifying glass version 2.0. All adult insects obtained during this study were morphologically identified by using identification keys of Delvare and Aberlenc (1989) [10] and Bordat & Arvanitakis, (2004) [11].

2.3. Assessment of Natural Enemy Diversity

Ecological indices have been used to assess the diversity of natural enemies associated with crop pests. Statistical analyses were performed using PAST software, version 4.03 and XLSTAT 2016 software were used to compare abundance between localities using the chi-square (χ^2) test and all probabilities were appreciated at 0.05 threshold level. The diversity at each locality was analyzed through the Shannon index to measure the species evenness, the Simpson' dominance index to evaluate whether certain taxa dominate in the insect community, and the species richness with the Margalef index. The Shannon diversity index was calculated to assess the parasitoid diversity. We selected this index to take into account both richness and evenness of the parasitoid communities. Simpson's diversity index is a measure of diversity which takes into account the number of species present, as well as the relative abundance of each species. Simpson's index of diversity (1-D) was calculated to verify if there was any difference in natural enemies' diversity across localities. This index represents the probability that two randomly chosen individuals in a given sampled site will belong to distinct species. The use of such indices permits comparisons between different localities, taxa (species), functional groups, or trophic levels.

Pests attacked by predators are identified to show the number of target or prey pest species. The host range of the parasitoids was determined to show the parasite complex associated with each pest. Parasitism rates were calculated by dividing the number of parasitized larvae by the total number of larvae collected in field. Parasitism rate of the different species of parasitoids was calculated for each locality as the percentage of parasitized larvae collected from crop fields. Parasitism by gregarious parasitoid species was not an issue as larvae were kept individually. The structure of parasitoid assemblages was described by species richness (number of species), abundance (number of individuals). Emerging unidentified species parasitoids were individually conserved (in 1.5 ml microtubes with ethanol 70%) for further identification (with the help of G. Delvare, CIRAD-UMR CBGP, Montpellier, France).

3. Results

Natural enemies' species are classified according to their functional groups (predators and parasitoids). Ecological indices were used to assess the diversity of natural enemies associated with pests

3.1. Evaluation of the Diversity of Natural Enemies of Pests

Natural enemies were associated with pests. In order to evaluate these natural enemies, the diversity and abundance of pests were shown according to localities (Table 1). Abundance of pests and the number of host plants found are more important in Ziguinchor than in Bignona and Oussouye. On the other hand, the number of pest species is lower in Oussouye followed by Ziguinchor and Oussouye

Identification of the main groups of natural enemies is carried out to show their trophic relationships with the pests to understand interactions between diversity at different trophic levels.

Pest associated with host plants were more abundant in the locality of Ziguinchor compared to the other two localities (χ^2 =1226.843, df = 2, $p < 0.0001$) (Figure 2). The locality of Oussouye, which has the greatest biodiversity, has a lower abundance of pest associated with host plants.

Predators diversity

Pests attacked by predators are identified to show the number of target or prey

Table 1. Abundance and diversity of pests associated with vegetable crops according to locality.

Localities	Pest species		Number of host plants[a]
	Abundance	Number of species	
Bignona	1335	56	15
Oussouye	998	63	15
Ziguinchor	2549	57	17

[a] *Solanum aethiopicum*, *Solanum melongena*, *Solanum lycopersicum*, *Cucurbita pepo*, *Abelmoschus esculentus*, *Brassica oleracea*, *Ipomoea batatas*, *Citrullus lanatus*, *Hibiscus sabdariffa*, *Cucumis sativus*, *Cucumis melo*, *Capsicum annuum*, *Capsicum frutescens*, *Phaseolus vulgaris*, *Zea mays*, *Lactuca sativa* and *Cloeme viscosa*.

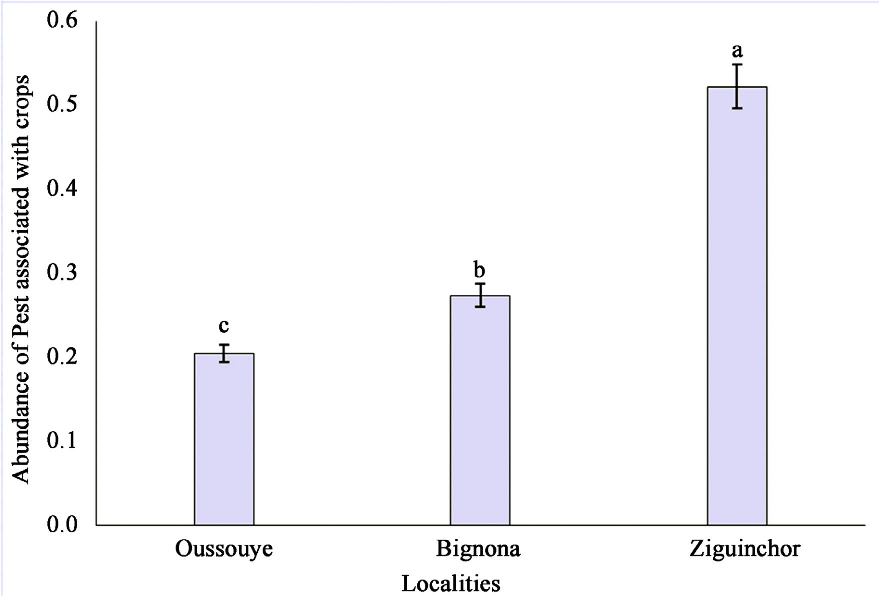

Figure 2. Abundance of pests according to locality in Casamance agro-ecological zones. (Histograms with the same letters are not significantly different, Chi^2 test $p < 0.05$)

pest species. A total of 10 predator species belonging to four orders were associated with 13 pest species in Casamance agro-ecological zone (Table 2). Among these predators, species belonging to the Hemiptera were more abundant and their target pests were more diversified.

Parasitoids diversity

The host range of the parasitoids is determined to show the parasite complex associated with each pest.

A number of 14 parasitoid species were associated with a host range of 8 pest species in Casamance agro ecological zone (Table 3). Among these parasitoids, Hymenoptera is the most representative with 10 species found.

Natural enemies' diversity indices

Ecological indices are used to assess the diversity of natural enemies associated with pests in different localities (Table 4). The species richness of natural

Table 2. Predators associated with pests in Casamance agro-ecological zone.

Order	Predators species	Target pest species
Coleoptera	*Cheilomenes propinqua* (Mulsant)	*Aphis gossypii*
	Exochomus laeviusculus Weise	*Myzus persicae*
		Lipaphis pseudobrassicae
		Aphis gossypii
	Hippodamia variegata (Goeze)	*Myzus persicae*
		Lipaphis pseudobrassicae
Diptera	*Ischiodon aegyptius* Wiedmann	*Myzus persicae*
		Lipaphis pseudobrassicae
Hemiptera	*Cosmolestes pictus* (Klug)	*Podagrixena decolorata*
		Phyllotreta cheiranthi
		Leptaulaca fissicolis
	Hediocoris fasciatus Reuter	*Podagrixena decolorata*
		Nisotra dilecta
	Nesidiocoris tenuis Reuter	*Helicoverpa armigera*
		Bemisia tabaci
	Sphedanolestes picturellus Schouteden	*Podagrixena decolorata*
		Nisotra dilecta
	Solenopsis invicta Buren	*Eublemma admota*
		Phycita melongenae
Orthoptera	*Mantis religiosa* (L.)	*Dysdercus sp.*
		Zonocerus variegatus

Table 3. Parasitoids associated with crop pests in Casamance agroecological zone.

Order	Parasitoids species	Hosts species
Hymenoptera	*Brachymeria feae* Masi	*Chrysodeixis chalcites*
	Brachymeria sp.	*Chrysodeixis chalcites*
	Campoletis sp.	*Spodoptera frugiperda*
	Charops flavipes (Kriechbaumer)	*Spodoptera littoralis*
	Chelonus sp.	*Spodoptera frugiperda*
	Copidosoma floridanum (Ashmead)	*Chrysodeixis chalcites*
	Diadegma insulare (Cresson)	*Plutella xylostella*
	Euplectrus laphygmae	*Chrysodeixis chalcites*
	Pristomerus pallidus (Brullé)	*Hellula undalis*
	Schoenlandella testacea (Kriechbaumer)	*Diaphania indica*

Continued

Diptera	Tachinidae Sp 1?	*Amsacta moloneyi*
		Helicoverpa armigera
	Tachinidae Sp 2?	*Helicoverpa armigera,*
		Chrysodeixis chalcites
	Tachinidae Sp 3?	*Helicoverpa armigera*
Nematoda	*Hexamermis* sp.	*Spodoptera frugiperda*

Table 4. Diversity indices of natural enemies calculated for the different localities in Casamance agroecological zone.

Diversity indices	Localities		
	Bignona	**Oussouye**	**Ziguinchor**
Taxa_S	17	21	24
Individuals	1259	1905	3115
Dominance_D	0.7966	0.8292	0.8243
Simpson_1-D	0.2034	0.1708	0.1757
Shannon_H	0.6203	0.5365	0.5654
Margalef	2.242	2.648	2.859
Equitability_J	0.2189	0.1762	0.1779

Richness (Taxa_S): The absolute number of species present in the population of interest is referred to as its richness; Abundance (Individuals): The abundances are measured by counting individuals; Dominance index accounts for the bias induced by the abundance of certain species; Simpson's Index of Diversity represents the probability that two individuals taken at random from the community of interest (with replacement) represent the same species. It varies from 0 to 1. A value near 1 indicates high diversity; The Shannon index varies from 0 in the case where the community is composed of only one species to 4.5 or 5 bits/individual for the most diverse communities; Margalef index is used to estimate the diversity of a community based on the numerical distribution of individuals of the species in relation to the number of existing individuals. Values below 2 are considered to be associated with areas of low biodiversity and values above 6 are considered to be indicators of high biodiversity; Equitability index is used to compare the diversity of stands with different specific or taxonomic richness. This index varies from 0 (dominance of a single species) to 1 (equidistribution of individuals in the stands)

enemies (Taxa_S) and their abundance (Individuals) are higher in Ziguinchor. The low values of the Dominance_D index in Bignona (0.7966) and the lower values of the Equitability Index (J) in Ziguinchor (0.1779) and Oussouye (0.1762) reflect the dominance of some natural enemy species in these two localities compared to Bignona. The Shanonn_H (2.62; 2.59; 2.75) and Simpson_1-D (0.9166; 0.91; 0.9223) indices for Bignona, Oussouye and Ziguinchor respectively show that natural enemy biodiversity is high in all three locations, and is highest in Ziguinchor. The highest values of Margalef index were obtained in Ziguinchor, suggesting that this locality has a significantly larger number of species than the other two localities (Table 4). The word "data" is plural, not singular.

3.2. Abundance of Natural Enemies of Pests

The abundance of natural enemies (predators and parasitoids) was compared between localities (Table 5). The polyembryonic ovo-larval parasitoid, *Copidosoma floridanum* produces large numbers of individuals. Similarly, the larval parasitoid *Euplectrus laphygmae* is a gregarious ectoparasitoid that produces numerous individuals. The results show a significantly higher abundance of natural enemies in the localities of Ziguinchor and Bignona than in the locality of Oussouye ($\chi^2 = 384.218$; df = 2; $p < 0.0001$) (Table 5).

Table 5. Abundance of natural enemies according to locality in Casamance agro ecological zone.

Functional groups	Natural enemies species	Localities			Total
		Bignona	Oussouye	Ziguinchor	
Predators	*Cosmolestes pictus* (Klug)	11	11	16	38
	Cheilomenes propinqua (Mulsant)	17	24	32	73
	Exochomus laeviusculus Weise	14	22	9	45
	Hippodamia variegata (Goeze)	20	24	25	69
	Hediocoris fasciatus Reuter	3	12	8	23
	Ischiodon aegyptius Wiedmann	5	3	15	23
	Mantis religiosa (L.)	9	13	12	34
	Nesidiocoris tenuis Reuter	11	6	13	30
	Solenopsis invicta Buren	5	1	1	7
	Sphedanolestes picturellus Schouteden	12	9	7	28
	Total	**107**	**125**	**138**	**370**
Parasitoids	*Brachymeria feae* Masi	0	1	6	7
	Brachymeria sp.	3	1	3	7
	Charops flavipes (Kriechbaumer)	1	5	2	8
	Copidosoma floridanum (Ashmead)	1123	1734	2827	5684
	Campoletis sp.	0	0	3	3
	Chelonus sp.	0	0	28	28
	Diadegma insulare (Cresson)	1	2	2	5
	Euplectrus laphygmae (Ferrière)	0	10	29	39
	Hexamermis sp.	0	0	35	35
	Pristomerus pallidus (Brullé)	3	0	0	3
	Schoenlandella testacea (Kriechbaumer)	5	2	2	9
	*Tachinidae	4	5	8	17
	Total	**1140**	**1760**	**2945**	**5845**

*Tachinidae: 3 unidentified species.

3.3. Determination of the Parasitism Rate

Natural pest control is determined by calculating the percentage of parasitism. The parasitism rate of insect pests associated with crops is calculated according to the localities. The parasitism rate was calculated by dividing the number of parasitized larvae (determined by parasitoid emergence, excluding dead larvae without parasitoid emergence) by the number of larvae collected, expressed as a percentage. The percentage of regulation varies between 0 and 50% depending on the abundance of the pests and on the parasitoid species (Table 6).

Table 6. Parasitism rate of crop pest according to locality in Casamance agro ecological zone.

Parasitoids species	Localities								
	Bignona			Oussouye			Ziguinchor		
	Larvae	P-Larvae	% P	Larvae	P-Larvae	% P	Larvae	P-Larvae	% P
Brachymeria feae Masi	17	0	0	8	1	13	56	6	11
Brachymeria sp.	17	3	18	8	1	13	56	3	5
Charops flavipes (Kriechbaumer)	25	1	4	10	5	50	55	2	3.6
Copidosoma floridanum (Ashmead)	17	3	17.6	8	2	25	56	3	5.4
Campoletis sp.	0	0	0	0	0	0	290	3	1.2
Chelonus sp.	0	0	0	0	0	0	290	28	10.9
Diadegma insulare (Cresson)	15	1	0	5	2	40	23	2	9
Euplectrus laphygmae (Ferrière)	17	0	0	8	2	25	56	5	8.9
Hexamermis sp.	0	0	0	0	0	0	290	35	13.7
Pristomerus pallidus (Brullé)	58	3	5.1	8	0	0	15	0	0
Schoenlandella testacea (Kriechbaumer)	15	5	33.3	8	2	25	12	2	16.7
*Tachinidae	29	4	13.7	35	5	14.3	121	8	6.6

Larvae = Number of collected larvae; P-Larvae = Number of parasitized larvae; % P = Parasitism rate. The parasitism rate was calculated by dividing the number of parasitized larvae (determined by parasitoid emergence, excluding dead larvae without parasitoid emergence) by the number of larvae collected, expressed as a percentage.

4. Discussion

The abundance of pests and the number of host plants found are more important in Ziguinchor than in Bignona and Oussouye. On the other hand, the number of pest species is lower in Oussouye followed by Ziguinchor and Oussouye. The presence of host plants as food resources for these pests influences their abundance. The specific richness of host plants favours pest abundance. This result is confirmed by [12] who show that the species diversity of host plants influences pest abundance. In an agrosystem, the quality and quantity of available food resources favour the abundance of certain pest species.

A number of 25 natural enemies' species were identified, including 15 parasitoids with one unidentified parasitoid species and 10 predators. The importance of the specific richness of natural enemies can be explained by the plant biodiversity in the landscape, which acts as a top-down effect. Indeed, Casamance is considered as an area with a high concentration of plant biodiversity [13]. This provides a very complex landscape with composition and configuration that allows the availability and accessibility of resources for entomofauna. In top-down effect; plant biodiversity favours the establishment of natural enemies by providing pollen or nectar as food resources and by providing a favourable habitat with alternative prey or hosts [14]. Nectar is a sweet resource that increases the longevity and oviposition period of a female parasitoid. The biodiversity of natural enemies is high in all three locations and is greatest in Ziguinchor. The presence of a high diversity of species shows an ecosystemic balance in the agroecosystems of Casamance. This balance is reflected in the high entomological diversity found. In fact, the agrosystems preserve the ecosystemic balance by maintaining the diversity of arthropods in the environment [15]. Among these arthropods, insects are important parts of the agrosystem alimentary chain [16] [17].

The abundance of natural enemies is greater in Ziguinchor. The percentage of regulation varies between 0 and 50% depending on the abundance of pests and the species of the parasitoid. This abundance can be explained by the crops grown. Indeed, Ziguinchor is the only locality where maize was found. This explains the unique occurrence of the maize pest *Spodoptera frugiperda* and its parasitoids *Hexamermis* sp., *Chelonus s*p., and *Campoletis* sp., which are the most abundant of those listed and only present in Ziguinchor. In addition, a gregarious parasitoid species *Euplectrus laphygmae*, and a polyembryonic species *Copidosoma floridanum* were found in Ziguinchor. This shows that the high abundance and diversity of natural enemies in Ziguinchor are due in part to the phenomenon of host fidelity and in part to the biology of the parasitoids. The phenomenon of host fidelity shows the influence of maize on natural enemies by the preferential choice of female parasitoids of the species *Chelonus insularis* and *Campoletis sonorensis* to prefer to stay and reproduce there [18]. This means that the presence of natural enemies depends partly on the crops grown. Indeed, crops are the first factor that alerts natural enemies through the volatile substances they secrete. When a plant is attacked by a pest, it releases volatile substances that attract the pest's natural enemies [19]. This result shows the existence of a tri-tropic interaction between plants, pests, and natural enemies. In an agroecosystem, the presence of a host plant favours the presence of the associated pest [12] [20] [21] and the presence of the pest favours natural enemies. Indeed, the host plant constitutes an indispensable food resource to maintain the pest in the environment. Similarly, pests are essential in a host-parasitoid relationship for the immature phase of the parasitoid, which is dependent on the host pest [22]. The Host plant is essential for the pests as the pests are indispensable for the natural enemies. According to the biology of the parasitoids found in Casamance, the abundance of natural enemies varies according to locality. The species *Euplectrus laphygmae*, found only in Ziguinchor and Oussouye, is a gregarious ectoparasitoid that can produce up to five eggs per parasitized larva [23]. In addition, the parasitoid *Copidosoma floridanum* is one of the most extreme cases of polyembryony, producing up to 2.000 embryos from a single laid egg [24]. However, it was in Ziguinchor and Bignona that pest larvae parasitized by *Copidosoma floridanum* were more numerous than in Oussouye. This result explains the significantly higher abundance of natural enemies observed in Ziguinchor and Bignona compared to Oussouye.

Predator Hemiptera and Parasitoid Hymenoptera have higher species richness. The presence of many species of predatory Hemiptera is explained by the availability of plant and animal food resources. Indeed, many Hemipteran predatory are zoo phytophagous. They are not only entomophagous [25] but also phytophagous [26]. The food resources of the predators including lepidopteran eggs and larvae, and plant species are very diversified and widely distributed in Casamance. This widens the range of food for these predators in the environment. Generally, predators are generalists as they feed on several insect pests. Their generalist function could partly explain their great success as a key biocontrol agent [27]. The presence of a very diverse flora in Casamance favours predatory Hemiptera. Parasitoid Hymenoptera is more specific in their relationship with their hosts than predators are with their prey. Indeed, parasitoids need a host to ensure their survival [22]. In parasitic Hymenoptera, the development of immature individuals depends at least once and necessarily on a host. The host constitutes a food resource and/or a protective shelter for immature individuals. Furthermore, Hymenoptera is known to be very successful parasitoids due to the presence of a piercing ovipositor [28].

In this work, a total of 25 species of natural enemies including 15 parasitoids and 10 predators contribute to the natural control of 13 pest species in the Casamance agroecological zone. Predatory Hemiptera and parasitoid Hymenoptera have higher species richness. Natural enemies are more abundant in Ziguinchor and Bignona than in Oussouye. The preservation of these natural enemies must be achieved through knowledge of their diversity and an understanding of trophic interactions with pests in order to develop biological control programs against crop pests and preserve the resilience of agro-ecosystems.

Acknowledgements

We express our sincere gratitude for G. Delvare and D. Bordat (CIRAD, Montpellier, France) for identification of parasitoid species. We also thank all the farmers from "Casamance Agroecological Zone" who participated in this study.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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