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Population Dynamics of Arthropods in New Caledonian Citrus Orchards

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Authors' contributions

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

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ABSTRACT

Aims: Agroecological infrastructures are central to the preservation of arthropod populations and ecosystem services associated. There is little data on the population dynamics of New Caledonian citrus orchards. Thus, this study focuses on the response of arthropods to four management methods in the orchard: conventional management, inter-row vegetated, row mulching and edge windbreaks.

Place and Duration of Study: This study was conducted in the village of La Foa in New Caledonia. It took place over three months, from the end of February to the end of May 2022.

Methodology: To collect the greatest possible diversity of insects, four complementary trapping methods were used: pitfall traps, yellow plates, Malaise traps and sweeping nets. Once collected, the trapped insects are then sorted and identified. The sorting is done with a binocular magnifying glass. Insects are identified using specific determination keys, documentation, or with the help of the Reference Collection of Terrestrial Invertebrates of New Caledonia - Xavier Montrouzier (CXMNC). When identification is not immediately possible, a morphotype number is assigned. For each species and morphospecies, a photograph is taken. Alpha and beta diversity was studied using rarefactions, Shannon index and Generalized Linear Models.

Results: A positive effect of agroecological infrastructures on insects' abundance and diversity was recorded. In contrast, low arthropod abundances and diversities were presented in the orchard under conventional management (P < 0.001). Mulching management was the parameter showing

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the much higher insects' abundance. Moreover, populations dynamics were generally correlated with the related infrastructures. Thus, windbreaks acted as ecological corridors and the inter-row vegetation as refuge habitats for beneficial insects.

Conclusion: These results demonstrate the damage of conventional agriculture on arthropod diversity in New Caledonian orchards. They also show that agroecological infrastructures can bring back insect biodiversity, especially with the mulching management.

Keywords: Entomological inventory; agroecological infrastructure; management methods; trophic guild; biological control; citrus; New Caledonian orchards.

1. INTRODUCTION

New Caledonia is particularly vulnerable to the current mass extinction crisis of biodiversity affecting arthropod populations [1-3]. Although this decline is multifactorial, conventional agriculture plays a significant role [4]. This is caused by the homogenization of landscapes leading to the loss of semi-natural habitats, pesticide toxicity and mechanization of agricultural practices that reduce the diversity and abundance of plants on which insects directly depend [5,6]. The decline of arthropods threatens the very functioning of agroecosystems. Indeed, their functions as detritivores, phytophagous, predators or parasitoids and, pollinators provide ecosystem services that directly affect crop production. These include pollination, pest regulation and recycling of organic matter, especially [7]. Their loss is therefore expected to have serious economic consequences in addition to ecological ones [8].

To limit as much as possible, the loss of biomass and diversity of arthropods and their related services, the development of agroecology and its biodiversity conservation practices are becoming a major issue [9]. These practices include agroecological infrastructures (AEIs) that allow the development of natural or semi-natural habitats that function as refuges for insect biodiversity [10]. These include plant cover [7], windbreaks [11] and mulching [12]. Diversifying landscape heterogeneity in agricultural environments allows arthropods to access more diverse resources and habitats often accompanied by a general trend towards increasing arthropods abundance and diversity [13].

However, there are still few studies on the impact of management practices on insect communities in New Caledonia, despite the fact that New Caledonian ecosystems are known for their important level of biodiversity [14]. Thus, the integration of AEIs in tropical agroecosystems represents an important lever for biodiversity conservation. The objective of this study is to compare management methods in New Caledonian citrus orchards through the prism of arthropods abundance and diversity and bio-indicators. To this end, this study presents the response of arthropods through taxonomic and functional approaches to four management modes in fruit arboriculture. These practices correspond to conventional management, inter-row grassing, row mulching and windbreaks.

2. METHODOLOGY

2.1 Study Sites and Design

This study was conducted in the village of La Foa on the west coast of Grande Terre, 115 km northwest of Nouméa, New Caledonia. Data collection took place over three months from the end of February to the end of May 2022. This period was particularly marked by heavy rainfall episodes caused by La Niña climate event and very high temperatures compared to seasonal norms.

Trapping was carried out weekly on four citrus orchards (Fig. 1). Two of them are located at the Pocquereux Fruit Research Station of the New Caledonian Agronomic Institute (IAC). These are the experimental orchards of "Tazar" and "Dormeur" with various citrus cultivars and mandarin trees respectively. The other two orchards are grower-owned Navel orange orchards. The citrus trees in each orchard produced fruit throughout the entomofauna trapping period.

To standardize the sampling effort, an area of approximately 2,500 m² was delimited in each surveyed orchard.

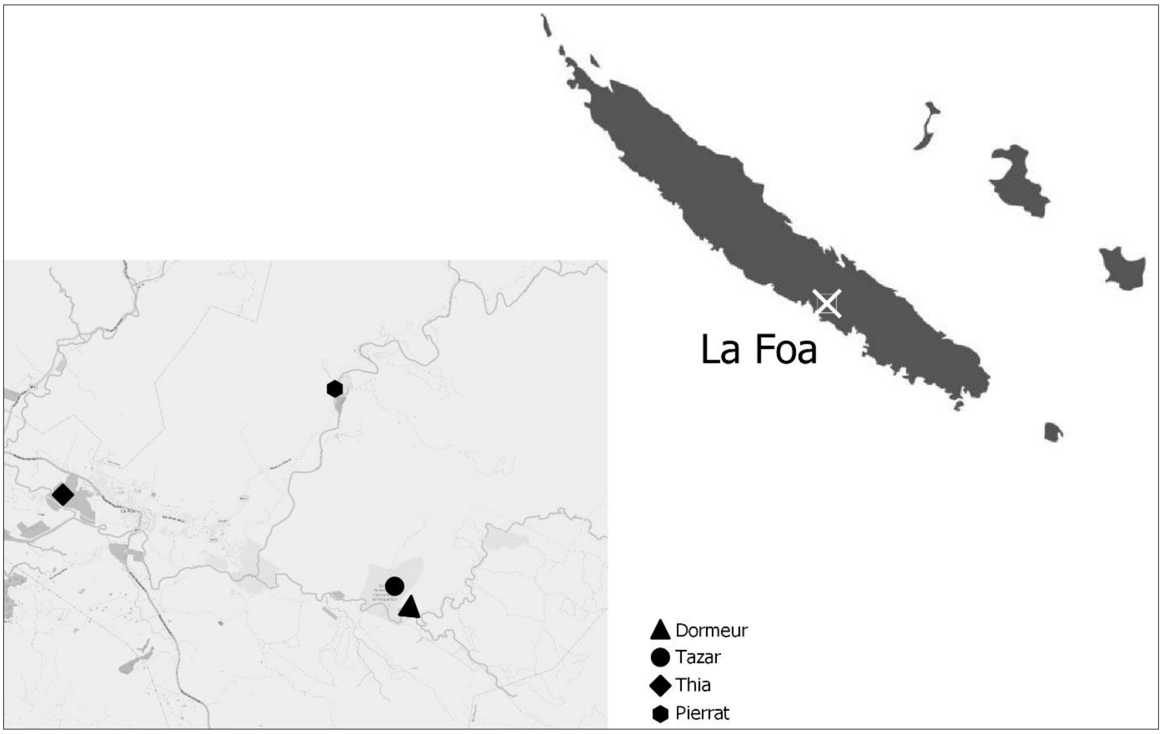

Fig. 1. Location of the orchards

2.2 Characterization of Orchards and Bio-indicators

2.2.1 Orchards

Each orchard has its own specific characteristics (Fig. 2).

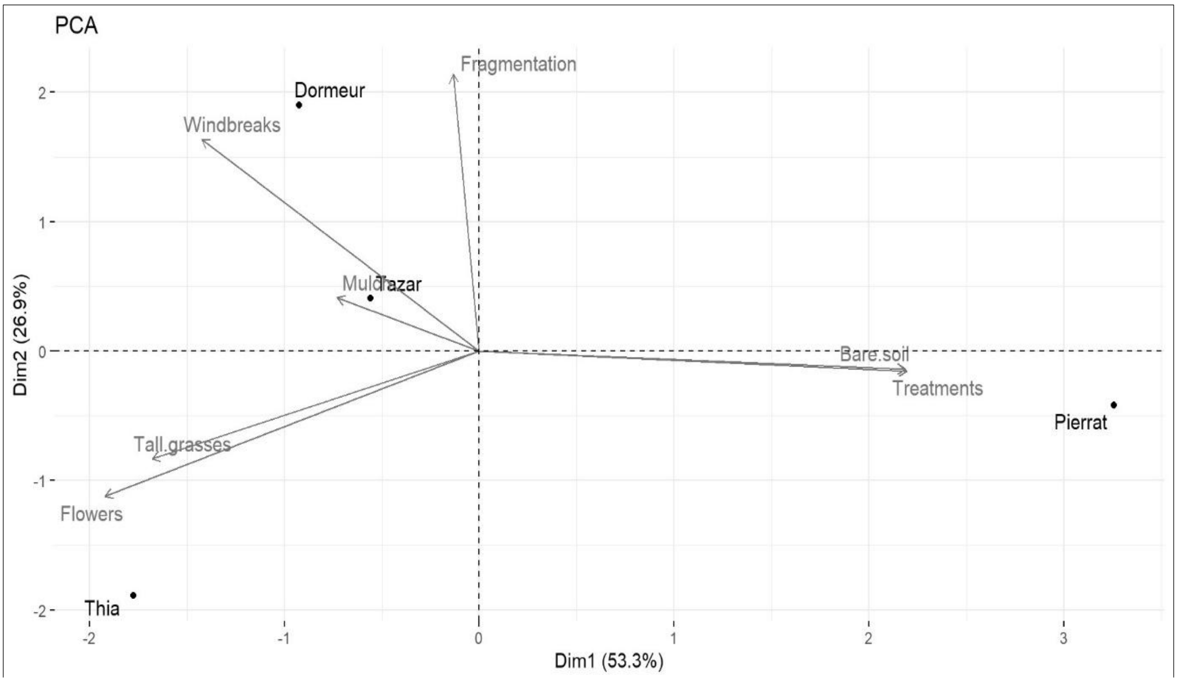

Fig. 2. PCA of the different orchards and their environmental characteristics

"Pierrat" is the orchard run under conventional agriculture. It has no AEI, just seven windbreaks per hectare and a high percentage of bare soil. In this orchard, six insecticide applications and five herbicide applications are conducted every year, as well as one Summer oil application every month, against scale insects.

"Dormeur" has AEIs of *Casuarina collina* hedges with approximately 231 trees per hectare. No insecticides are used in this orchard, but three herbicide treatments are conducted each year.

"Tazar" is the only orchard with an extremely high percentage of mulch. There are about 105 trees of *Casuarina collina* per hectare. There is no insecticide in this orchard and only one adjuvant herbicide treatment per year is applied.

"Thia" has been untreated for two years and has many flowers and tall grasses. There are 83 *Casuarina collina* per hectare acting as windbreaks.

All the orchards except Pierrat are grassed in the inter-rows.

2.2.2 Bio-indicators choice

2.2.2.1 Spiders

Spiders, through their functional diversity, cover the diverse levels of the trophic chain. Indeed, spiders are among the largest groups of generalist predators feeding on pests [15]. Their density is related to the structural complexity of the environment [16]. They are therefore of great interest to indicate the quality of habitats, especially at the plot level [17].

2.2.2.2 Mites

Mites have often been used as indicators of habitat diversity and quality, particularly in soils [18-20]. However, it should be borne in mind that mites have an extremely high diversity and are taxonomically poorly recognized, which makes their identification difficult. Indeed, mites have different behaviors, ranging from predatory to parasitic to phytophagous [21].

2.2.2.3 Orthopterans

Orthopterans such as crickets are also known to be indicators of undisturbed [22,23] and unpolluted environments [24,25].

2.2.2.4 Beetles

Beetles can be considered as representative of insects in general due to their high taxonomic and ecological diversity [26].

At the family level, the Nitidulidae, Tenebrionidae and Chrysomelidae can be useful indicators, as their diversity is correlated with that of other taxa such as scorpions, millipedes, and some butterflies [27].

2.3 Trapping Methods

In an aim to collect as much insect diversity as possible, three complementary trapping methods were used.

2.3.1 Pitfall traps

To intercept epigeous invertebrates that move on the ground, pitfall traps were set up. This trapping method consists of burying pots on the surface of the soil. These pots are filled with approximately 100 ml of coolant, which limits the decomposition of the trapped insects while avoiding evaporation of the liquid during the trapping period. Each pot is protected from the weather by a lid, which is made from a plate and nails.

As the orchards had a homogeneous structure, the placement of the pitfall traps was standardized as follows: three pitfall traps were randomly distributed in the borders, three in the rows and three in the inter-rows. No pitfall traps were placed in the inter-rows of the Pierrat plot because of the regular passage of agricultural machinery. This arrangement of traps is intended to differentiate the fluctuation of arthropods according to the layout of the plots.

The pitfall traps were collected every seven days.

2.3.2 Yellow plates

To attract floricultural flying insects such as pollinators, yellow plates were used for their color. Each trap color brings a different species range and variation in abundance and diversity. Yellow is known to collect many Diptera, Hymenoptera and some Coleoptera.

Once a week, eight yellow plates are placed for two hours in the morning. Four are placed randomly in the inter-rows and four in the borders.

The insects are trapped in soapy water containing 5 mL of washing-up liquid per 1 L of water.

2.3.3 Grass sweeping

The fauna sampling was completed by means of a sweeping net. Sweeping allows the collection of all types of insects present on the paths or in the tall grass.

Each week, four sweepings per orchard were carried out randomly in non-fixed quadrats of 1 m^2. Then, a few randomized diagonal transects were swept to collect other insects in an opportunistic way.

2.4 Sorting and Identification

The trapped insects through the different techniques described above are then sorted and identified. Sorting is conducted with a binocular magnifying glass. The insects are identified using specific determination keys, documentation, or with the help of the Reference Collection of Terrestrial Invertebrates of New Caledonia - Xavier Montrouzier (CXMNC), which is hosted in the IAC laboratory.

When identification is not possible immediately, a morphotype number is assigned. For each species and morphospecies, a photograph is taken.

2.5 Statistical Analysis

All statistical tests and fitting of the models presented were performed with RStudio software (desktop version).

2.5.1 Rarefactions

The rarefaction curves correspond to the number of species observed (species richness) as a function of the number of individuals sampled. These curves are constructed by a series of random draws of a given number of individuals from the inventory. They were produced using the devtools, iNEXT and ggplot2 packages. They allow for easy visualization of alpha diversity while providing an extrapolation that helps predict true diversity given the expected number of species not detected by the sampling effort.

2.5.2 Shannon index

The Shannon index, generated with vegan package, is used to study the specific diversity of a population of individuals. That is, the number of species present in a stand. If the Shannon index is made up of a single species, then the index will be equal to 0. Note that this index is sensitive to variations in the importance of the rarest species.

2.5.3 Generalized linear models

As the abundance data are count data, the distribution of the data is not normal, so the statistical tests used are non-parametric. Theoretically, count-type responses follow a Poisson distribution with a Lambda parameter. Thus, generalized linear models (GLM) are performed with Poisson regression. However, many results from GLMs show over-dispersion. In this case, the quasi-Poisson error structure was added to the regression model.

For data with a normal distribution such as climate data, simple linear regressions (LR) were performed.

Each model is followed by Tukey's multiple mean comparison test where the multcomp package was used.

Thus, the aim of the linear regressions is to define a significant difference, which is statistical evidence that there is a difference between two model values.

3. RESULTS AND DISCUSSION

Table 1. Abundance of orders from different orchards

	Dormeur	**Pierrat**	**Tazar**	**Thia**
Diptera	535[ab]	832[b]	719[ab]	423[a]
Acari	206[b]	29[a]	1614[c]	320[b]
Hymenoptera	297[a]	660[b]	661[b]	549[ab]
Hemiptera	535[b]	832[a]	719[c]	423[b]
Aranea	515[b]	228[a]	273[a]	272[a]
Orthoptera	687[b]	193[a]	271[a]	197[a]
Julida	273[b]	24[a]	312[b]	400[b]
Coleoptera	255[b]	90[a]	394[b]	219[b]
Total	**3315[a]**	**2205[a]**	**5520[b]**	**2845[a]**

The numbers in the lines followed by the same letter are not significantly different, P < 0.05; only orders with a relative abundance above 5% are represented

3.1 The Management Method in Conventional Farming

This study is related to many other studies that mention the massive destruction of insect biodiversity by conventional agriculture [28-30]. Indeed, in Pierrat's conventional orchard with numerous treatments and almost bare soil, the low presence of biodiversity (Table 2), especially of beetles ($P < 0.001$) which are a representative bio-indicator of biodiversity, confirmed the hypothesis that the application of broad-spectrum insecticides leaded to a decrease in the diversity and density of insects on the land surface (Table 1).

In this orchard, Diptera ($P < 0.001$) were highly abundant, including Phoridae ($P < 0.001$), a family of small flies resembling Drosophila (Table 2). They are found in a wide range of habitats and have varied feeding habits. Most species consume decaying organic matter. Others specialise in eating slug eggs or as parasites of many insects [31]. These Phoridae have a high potential for resistance to insecticides [32]. This would explain their numerous presences in this orchard under conventional agriculture.

Moreover, it is interesting to note that, in terms of hemipterans, the conventional orchard was the only one where Lygaeidae did not dominate, but where Aphididae were found on the contrary (Table 3).

Aphididae or aphids are phytophagous pests causing directly damages by sucking plant tissues, or indirectly by infesting the plant with viruses [33]. Their presence can be related to the high abundance of ants which are known to favour aphids (as scale insects) through mutualistic interactions (exchange of honeydew for protection) [34].

3.2 The Management Method with Grassing in the Inter-Rows

The presence of very diversified and flower-rich mixtures is highly beneficial for insect's presence [35]. Moreover, several studies have demonstrated the positive effect of inter-row vegetation on insect communities with a general trend towards increased abundance and diversity [9,36,37].

In two of the three grassed orchards, there were significantly more ants known to be favoured by the presence of vegetation cover [10].

Table 2. Shannon index of the four orchards

	Dormeur	Pierrat	Tazar	Thia
Shannon	3.047908	2.825924	3.042488	3.327141

Table 3. Abundance of Diptera families in different orchards

	Dormeur	Pierrat	Tazar	Thia
Phoridae	247^{a}	592^{c}	324^{b}	203^{a}
Dolichopodidae	67^{ab}	59^{a}	92^{b}	61^{ab}
Muscidae	51^{a}	49^{a}	120^{b}	51^{a}
Drosophilidae	75^{c}	56^{bc}	23^{a}	35^{ab}
Others	45^{a}	56^{a}	99^{b}	53^{a}
Total	**485^{b}**	**812^{d}**	**658^{c}**	**403^{a}**

The numbers in the lines followed by the same letter are not significantly different, P < 0.05; only families with a relative abundance above 5% are represented

Table 4. Abundance of different orchards in hemipteran families

	Lygaeidae	Aphididae	Miridae	Alydidae	Others
Dormeur	416^{c}	33^{b}	45^{b}	11^{a}	42^{b}
Pierrat	23^{b}	89^{c}	15^{ab}	1^{a}	22^{b}
Tazar	772^{d}	197^{c}	137^{b}	20^{a}	148^{bc}
Thia	192^{b}	45^{a}	31^{a}	145^{b}	52^{a}

The numbers in the lines followed by the same letter are not significantly different, P < 0.05; only families with a relative abundance above 5% are represented

In addition, spiders of the Lycosidae family, bio-indicators of habitat quality, were significantly more abundant in the inter-rows (*P* = 0.025), as were orthopterans, indicators of undisturbed environments. In fact, the orchard with the highest number of orthopterans of the family Gryllidae is managed under conservation agriculture and has a high floristic diversity (Table 1).

3.3 The Management Method with Mulching

Of the four orchards studied, the Tazar orchard with row mulch had significantly higher insect abundance, particularly of beneficial insects (*P* < 0.001) (Table 5). Numerous studies have shown that the presence of mulch in orchards can have a beneficial impact on pests [12,38,39].

Mulch coverage was strongly correlated with the presence of saprophagous, particularly Oribatidae (*P* < 0.001) (Table 6). These are frugivorous and detritivores mites which feed on substrates and organic matter. They play a significant role in the decomposition process by consuming microbial populations or by fragmenting organic matter [40]. They are also recognised as indicators of soil diversity and quality.

In the mulched orchard, there are many ants (*P* < 0.001) that are widely recognised as natural biological control agents that regulate pest populations in tropical regions [41]. In the mulched orchard, there are many ants (*P* < 0.001) that are widely recognized as natural biological control agents that regulate pest populations in tropical regions [41]. However, ants encountered in New Caledonian agrosystems are mostly exotic or invasive ones that are mutualistic with sap-sucking pest insects (H. Jourdan, IRD-IMBE, France, personal communication). So ants' benefits need to be investigated more closely in respect to predation *versus* sap-sucking insects tending and its potential interference with their biocontrol. Moreover, many bugs of the family Lygaeidae (*P* < 0.001) considered phytophagous and referred to as seed-bugs are also present (Table 6), but some of them are also omnivorous and even predators by eating other insects.

Insects were more abundant in the inter-rows (Fig. 3). This can be linked to the importance of the inter-row grass cover (*P* < 0.001). Thus, the movement of individuals between the mulched rows may justify this result.

3.4 The Management Method with Windbreaks

In landscape dynamics, ecological corridors such as windbreaks play a key role in increasing landscape heterogeneity. Indeed, the presence of uncultivated habitats in the landscape is favourable to predators and parasitoids [42,43]. In the study plots, present windbreaks are composed of *Casuarina collina*. They are large trees, thriving on a wide range of mineral-deficient soils. *Casuarina collina* is an endemic species of New Caledonia and is dominant in disturbed land due to its rapid growth, suckering ability, and fire resistance, thus having a high potential for rehabilitation of degraded sites [44]. However, *Casuarina collina* windbreaks are not known for their abundant biodiversity.

Therefore, little population difference existed between edges and orchards. It would seem that the host conditions were equivalent between these two locations. However, it should be noted that beneficial insects (*P* < 0.001) were more present in the borders of the Dormeur orchard, which has many windbreaks per hectare. In fact, two bio-indicators of habitat quality, saprophagous mites (*P* < 0.001) and predatory spiders (*P* < 0.001), were significantly more abundant in the borders of this orchard (Table 7).

Table 5. Abundance of beneficial insects in different orchards

	Dormeur	Pierrat	Tazar	Thia
Beneficials	1669^{a}	1057^{a}	3466^{b}	1737^{a}

The numbers in the lines followed by the same letter are not significantly different, P < 0.05

Table 6. Abundance of Oribatidae, Formicidae and Lygaeidae in different orchards

	Dormeur	Pierrat	Tazar	Thia
Oribatidae	170^{b}	27^{a}	1479^{c}	251^{b}
Formicidae	132^{a}	340^{b}	316^{b}	320^{b}
Lygaeidae	416^{c}	23^{a}	772^{d}	192^{b}

The numbers in the lines followed by the same letter are not significantly different, P < 0.05

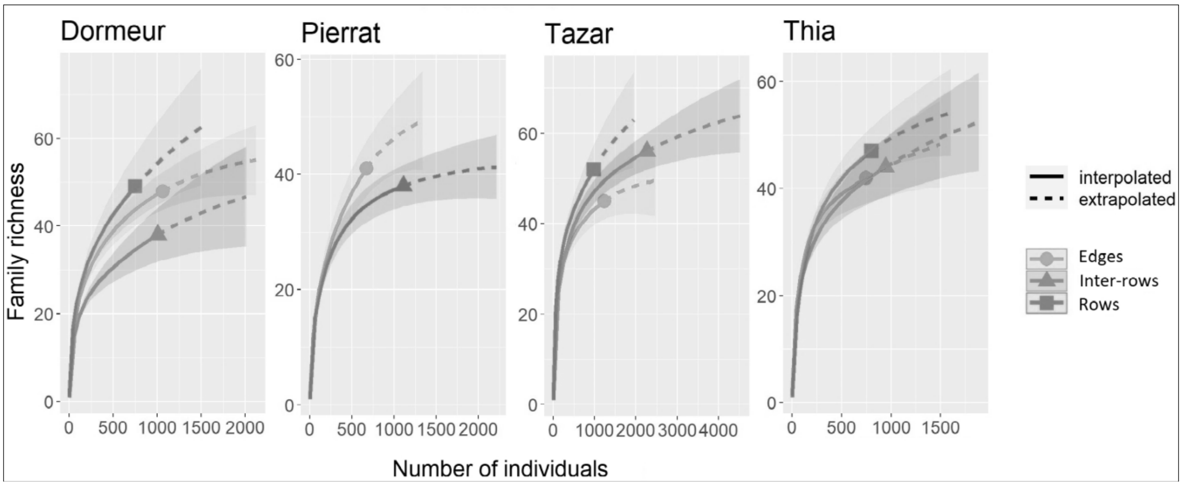

Fig. 3. Rarefactions of different orchards according to locations

Table 7. Abundance of Acari, Aranea and beneficial insects in relation to Dormeur locations

	Edges	Inter-rows	Rows
Acari	109[b]	32[a]	60[a]
Aranea	340[b]	103[a]	45[a]
Beneficials	729[b]	384[a]	285[a]

4. CONCLUSION

In the context of the significance of conserving arthropod biodiversity by integrating AEIs into New Caledonian citrus orchards, this study highlighted differences in insect abundance and diversity in each management mode.

Indeed, low arthropod abundances and diversity in the orchard under conventional management were revealed. In comparison, the orchards with agroecological infrastructures, such as inter-row grassing, windbreaks at the edges or mulching on the rows, showed more diverse and abundant vegetation and entomofauna.

A much higher abundance of insects was observed in the mulched orchard. Population dynamics were generally correlated with the corresponding infrastructure. For example, windbreaks acted as ecological corridors and inter-row cover as refuge habitats for beneficial agents.

Thus, agroecological management methods allowed the implementation of habitats that are essential for biodiversity. In a context of vulnerability of the New Caledonian biodiversity, these conservation measures should be enforced to preserve the diversity of arthropods and associated ecosystem services, as has already been done in other both continental [45,46] and insular contexts [47,48].

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Hallmann CA, Sorg M, Jongejans E, Siepel H, Hofland N, Schwan H et al. More than 75 percent decline over 27 years in total flying insect biomass in protected areas. PLOS ONE. 2017;12(10):e0185809.
2. Lister BC, Garcia A. Climate-driven declines in arthropod abundance restructure a rainforest food web. Proc Natl Acad Sci U S A. 2018;115(44):e10397-e10406.

3. Violette Z. La biodiversité de la Nouvelle-Calédonie. Paris, France: Maison de la Nouvelle-Calédonie. 2016;23. French.
4. Cardoso P, Barton PS, Birkhofer K, Chichorro F, Deacon C, Fartmann T et al. Scientists' warning to humanity on insect extinctions. Biol Conserv. 2020;242:108426.
5. Brühl CA, Zaller JG. Biodiversity decline as a consequence of an inappropriate environmental risk assessment of pesticides. Front Environ Sci. 2019;7.
6. Habel JC, Samways MJ, Schmitt T. Mitigating the precipitous decline of terrestrial European insects: requirements for a new strategy. Biodivers Conserv. 2019;28(6):1343-60.
7. Garcia L, Celette F, Gary C, Ripoche A, Valdés-Gómez H, Metay A. Management of service crops for the provision of ecosystem services in vineyards: a review. Agric Ecosyst Environ. 2018;251:158-70.
8. Franin K, Barić B, Kuštera G. The role of ecological infrastructure on beneficial arthropods in vineyards. Span J Agric Res. 2016;14(1):e0303-e0303.
9. Judt C, Guzmán G, Gómez JA, Cabezas JM, Entrenas JA, Winter S et al. Diverging effects of landscape factors and inter-row management on the abundance of beneficial and herbivorous arthropods in Andalusian vineyards (Spain). Insects. 2019;10(10):320.
10. Blaise C, Mazzia C, Bischoff A, Millon A, Ponel P, Blight O. The key role of inter-row vegetation and ants on predation in Mediterranean organic vineyards. Agric Ecosyst Environ. 2021;311.
11. Laurent P, Aubertot JN, Deguine JP, Ratnadass A, Gloanec C. Protection agroécologique des cultures. Quae. 2016. French.
12. Brown MW, Tworkoski T. Enhancing biocontrol in orchards by increasing food web biodiversity. J Fruit Ornamental Plant Res. 2006;14:19.
13. Shapira I, Gavish-Regev E, Sharon R, Harari AR, Kishinevsky M, Keasar T. Habitat use by crop pests and natural enemies in a Mediterranean vineyard agroecosystem. Agric Ecosyst Environ. 2018;267:109-18.
14. Morat P, Jaffré T, Tronchet F, Munzinger J, Pillon Y, Veillon JM et al. Le référentiel taxonomique Florical et les caractéristiques de la flore vasculaire indigène de la Nouvelle-Calédonie. Adansonia. 2011;34(2):179-221.
15. Pfingstmann A, Paredes D, Buchholz J, Querner P, Bauer T, Strauss P et al. Contrasting effects of tillage and landscape structure on spiders and springtails in vineyards. Sustainability. 2019;11(7):2095.
16. Silva EB, Franco JC, Vasconcelos T, Branco M. Effect of ground cover vegetation on the abundance and diversity of beneficial arthropods in citrus orchards. Bull Entomol Res. 2010;100(4):489-99.
17. Sarthou JP, Choisis JP, Amossé A, Arndorfer M, Bailey D, Balázs K et al. Indicateurs de biodiversité dans les exploitations agricoles biologiques et conventionnelles des vallées et coteaux de Gascogne, cas d'étude français du projet européen BIOBIO. Innov Agron. 2013;32:333. French.
18. Mites GME (Acari) as indicators of soil biodiversity and land use monitoring: a review. Pol J Ecol. 2007;55(3):415.
19. O'Neill KP, Godwin HW, Jiménez-Esquilín AE, Battigelli JP. Reducing the dimensionality of soil micro invertebrate community datasets using indicator species analysis: implications for ecosystem monitoring and soil management. Soil Biol Biochem. 2010;42(2):145-54.
20. Tabaglio V, Gavazzi C, Menta C. Physico-chemical indicators and microarthropod communities as influenced by no-till, conventional tillage and nitrogen fertilisation after four years of continuous maize. Soil Till Res. 2009;105(1):135-42.
21. Gerlach J, Samways M, Pryke J. Terrestrial invertebrates as bioindicators: an overview of available taxonomic groups. J Insect Conserv. 2013;17(4):831-50.
22. Saha HK, Haldar P. Acridids as indicators of disturbance in dry deciduous forest of West Bengal in India. Biodivers Conserv. 2009;18(9):2343-50.
23. Bazelet CS, Samways MJ. Identifying grasshopper bioindicators for habitat quality assessment of ecological networks. Ecol Indic. 2011;11(5):1259-69.
24. Hoffmann BD, Lowe LM, Griffiths AD. Reduction in cricket (Orthoptera: Ensifera) populations along a gradient of sulphur dioxide from mining emissions in northern Australia. Aust J Entomol. 2002;41(2):182-6.
25. Lijun L, Xuemei L, Yaping G, Enbo M. Activity of the enzymes of the antioxidative

system in cadmium-treated Oxya chinensis (Orthoptera Acridoidae). Environ Toxicol Pharmacol. 2005;20(3):412-6.
26. New TR. Butterfly conservation in Australia: the importance of community participation. J Insect Conserv. 2010;14(3):305-11.
27. Fattorini S, Dennis RLH, Cook LM. Conserving organisms over large regions requires multi-taxa indicators: one taxon's diversity-vacant area is another taxon's diversity zone. Biol Conserv. 2011;144(5):1690-701.
28. Popov V, Kostadinova E, Rancheva E, Yancheva C. Causal relationship between biodiversity of insect population and agro-management in organic and conventional apple orchard. Org Agric. 2018;8(4):355-70.
29. Tooker JF, Pearsons KA. Newer characters, same story: neonicotinoid insecticides disrupt food webs through direct and indirect effects. Curr Opin Insect Sci. 2021;46:50-6.
30. Wagner DL. Insect declines in the Anthropocene. Annu Rev Entomol. 2020;65:457-80.
31. Merritt RW, Courtney GW, Chapter KJB. Diptera: (Flies, Mosquitoes, Midges, Gnats). Encyclopedia of insects. 2nd ed. Vol. 76. Academic Press. 2009;284-97.
32. Mirzaei M. Susceptibility of two species of mushroom flies, to different insecticide groups; 2015 ([doctoral dissertation]. University of Zabol).
33. Mille C, Jourdan H, Cazères S, Maw E, Foottit R. New data on the aphid (Hemiptera, Aphididae) fauna of New Caledonia: some new biosecurity threats in a biodiversity hotspot. ZooKeys. 2020;943:53-89.
34. Mansour R, Suma P, Mazzeo G, La Pergola A, Pappalardo V, Grissa Lebdi K et al. Interactions between the ant Tapinoma nigerrimum (Hymenoptera: Formicidae) and the main natural enemies of the vine and citrus mealybugs (Hemiptera: Pseudococcidae). Biocontrol Sci Technol. 2012;22(5):527-37.
35. Blaise C, Mazzia C, Bischoff A, Millon A, Ponel P, Blight O. Vegetation increases abundances of ground and canopy arthropods in Mediterranean vineyards. Sci Rep. 2022;12(1):3680.
36. Geldenhuys M, Gaigher R, Pryke JS, Samways MJ. Diverse herbaceous cover crops promote vineyard arthropod diversity across different management regimes. Agric Ecosyst Environ. 2021; 307.
37. Sáenz-Romo MG, Veas-Bernal A, Martínez-García H, Campos-Herrera R, Ibáñez-Pascual S, Martínez-Villar E et al. Ground cover management in a Mediterranean vineyard: impact on insect abundance and diversity. Agric Ecosyst Environ. 2019;283.
38. Brown MW, Tworkoski T. Pest management benefits of compost mulch in apple orchards. Agric Ecosyst Environ. 2004;103(3):465-72.
39. Mathews CR, Bottrell DG, Brown MW. Habitat manipulation of the apple orchard floor to increase ground-dwelling predators and predation of Cydia pomonella (L.) (Lepidoptera: Tortricidae). Biol Control. 2004;30(2):265-73.
40. Coleman DC, Crossley DD, Hendrix PF. Fundamentals of soil ecology. 2nd ed. Academic Press. USA : Elsevier Science & Technology Books; 2017;408.
41. Offenberg J. REVIEW: Ants as tools in sustainable agriculture. J Appl Ecol. 2015;52(5):1197-205.
42. Jacquot M. Biodiversité et fonctionnement écologique des agroécosystèmes à base de manguiers à la Réunion. Biodiversité et ecologie [thèse de l'Université de la Réunion]. 227. French; 2016.
43. Landis DA, Wratten SD, Gurr GM. Habitat management to conserve natural enemies of arthropod pests in agriculture. Annu Rev Entomol. 2000;45(1):175-201.
44. Hodgson C, Mille C, Cazères S. A new genus and species of felt scale (Hemiptera: Coccoidea: Eriococcidae) from New Caledonia. Zootaxa. 2014;3774(2):152-64.
45. Henríquez-Piskulich PA, Schapheer C, Vereecken NJ, Villagra C. Agroecological strategies to safeguard insect pollinators in biodiversity hotspots: Chile as a case study. Sustainability. 2021;13(12): 6728.
46. Patrício-Roberto GB, Campos MJ. Aspects of landscape and pollinators—what is important to bee conservation? Diversity. 2014;6(1):158-75.
47. Fanchone A, Alexandre G, Chia E, Diman J-L, Ozier-Lafontaine H, Angeon V. A typology to understand the diversity of strategies of implementation of agroecological practices in the French

West Indies. Eur J Agron. 2020; 117:126058.
48. Deguine J-P, Jacquot M, Allibert A, Chiroleu F, Graindorge R, Laurent P et al. Agroecological protection of mango orchards in la Réunion. Sustain Agric Rev. 2018;28:249-307.

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