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## PHYTOSEIID MITE DIVERSITY (ACARI: MESOSTIGMATA) AND ASSESSMENT OF THEIR SPATIAL DISTRIBUTION IN FRENCH APPLE ORCHARDS

Marie-Stéphane TIXIER<sup>1\*</sup>, Ivson LOPES<sup>1</sup>, Guy BLANC<sup>2</sup>, Jean-Luc DEDIEU<sup>2</sup>, Serge KREITER<sup>1</sup>

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<sup>1</sup> Montpellier SupAgro, UMR CBGP INRA/IRD/CIRAD/ Montpellier SupAgro, Campus International de Baillarguet, CS 30016, 34988 Montpellier-sur-Lez cedex, France. (\*Corresponding author) [tixier@supagro.inra.fr](mailto:tixier@supagro.inra.fr), [kreiter@supagro.inra.fr](mailto:kreiter@supagro.inra.fr)

<sup>2</sup> Bayer S.A.S, Bayer CropScience, 16 rue Jean-Marie Leclair, CS 90106, 69266 Lyon cedex 09, France. [guy.blanc@bayer.com](mailto:guy.blanc@bayer.com), [jean-luc.dedieu@bayer.com](mailto:jean-luc.dedieu@bayer.com)

**ABSTRACT** — The present study reports the results of surveys carried out over two years in 173 apple orchards in France. Eleven species of Phytoseiidae were observed, among them three were dominant: *Amblyseius andersoni*, *Kampimodromus aberrans* and *Typhlodromus (Typhlodromus) pyri*. *Cydnodromus californicus* was also found but only in some orchards and nearly always in association with one of three dominant species. This observation confirms the faunal modification initiated more than ten years ago. *Amblyseius andersoni* was recorded in high densities in nearly all the regions considered. *Typhlodromus (T.) pyri* was also widespread, even if particularly frequent and abundant in the Rhône-Alpes region. *Kampimodromus aberrans* was localised in some regions; it was especially frequent and abundant in the Mediterranean region. An identification key containing the eleven reported species is provided. Taylor's law was applied in order to characterize the Phytoseiidae distribution in apple orchards. The distribution is clearly aggregative, whatever the region and the Phytoseiidae species considered. Relationships between the occupation rate and the mean number of Phytoseiidae per leaf was established and an abacus was constructed to facilitate surveys and the counting during practical assessments of Phytoseiidae fauna in apple orchards.

**KEYWORDS** — *Amblyseius andersoni*; *Kampimodromus aberrans*; *Typhlodromus pyri*; aggregative distribution; biological control

### INTRODUCTION

The mite family Phytoseiidae comprises several predator species which can effectively reduce densities of mite pests in various agrosystems (McMurtry and Croft 1997; Gerson *et al.* 2003). Most species of this family are generalist predators; they can feed on their prey (especially of the families Tetranychidae and Eriophyidae) but can also develop feeding on pollen, plant exudates, fungi and small insects (McMurtry and Croft 1997; Kreiter *et al.* 2005).

The family presently comprises more than 2,000 valid species widespread in the world (Moraes *et al.* 2004; Tixier *et al.* 2012). In France, more than one hundred species have been reported, especially in crops. However, their occurrence has not been equally studied in all agrosystems. The most well-known French acarofauna is that of vineyards (*i.e.* Kreiter *et al.* 2000, 2002; Tixier *et al.* 2002, 2005; Barbar *et al.* 2006). However, despite the economic importance of apple orchards, little is known on the French Phytoseiidae fauna in this crop. Few

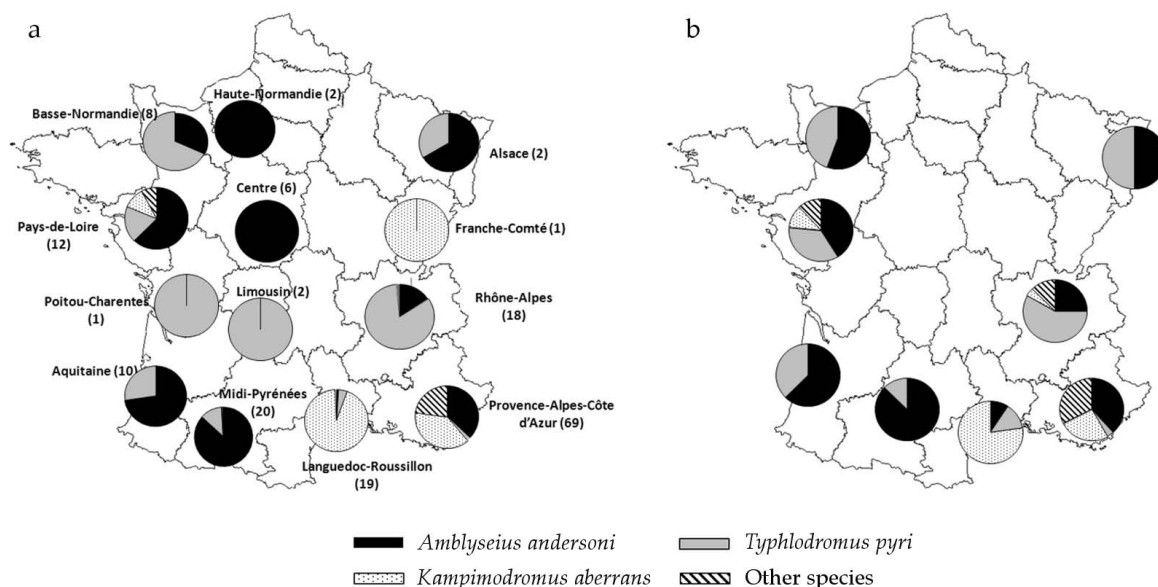


FIGURE 1: French regions sampled (with the number of orchards considered) and: a – proportions of dominant species in each region in regards to mite densities; b – proportions of dominant species in each region in regards to number of plots occupied.

studies carried out more than ten years ago (Fauvel and Gendrier 1992; Fauvel *et al.* 1993; Bourgoïn *et al.* 2002) showed the presence of *Typhlodromus* (*Typhlodromus*) *pyri* Scheuten, *Amblyseius andersoni* Chant, *Cydnodromus californicus* (McGregor) and *Kampimodromus aberrans* (Oudemans). However, these species were differently distributed depending on the regions considered. Furthermore, the augmentation of some species as *A. andersoni* in south-western France and *K. aberrans* in south-eastern was observed in the last survey in 2002. In other neighbouring countries as Italy, Spain and Switzerland, these same species are observed in apple orchards (Linder 2001; Miñarro *et al.* 2002; Iglésia *et al.* 2005; Duso *et al.* 2009).

The present work presents the results of surveys carried out in 173 apple orchards in several regions of France. The first aim of this survey was thus to determine the Phytoseiidae species encountered. For each species, a discussion on its biology, its occurrence in apple orchards sampled and the factors that could affect its presence is provided. An identification key to females is proposed to assist Phytoseiidae species diagnosis in French apple orchards.

The second aim was to determine the spatial distribution of Phytoseiidae into orchards. According to this spatial distribution, the third aim was to provide an optimal sampling method to assess their densities for practical and accurate counting.

## MATERIALS AND METHODS

### Sampling and species identification

One hundred and seventy-three apple orchards (planted with 24 different cultivars) in thirteen regions were sampled from May to September in 2011 and 2012 (Table 1, Figure 1). The number of orchards surveyed in each region was similar. Only one or two orchards have been sampled in Alsace, Centre, Haute-Normandie, Franche-Comté, Limousin and Poitou-Charentes. Thus for these regions, no conclusion would be drawn on the Phytoseiidae fauna.

Fifty leaves were collected in each plot. Each leaf was individually observed; Phytoseiidae were counted and collected for identification with a fine hair-brush. Then the females were mounted on slides in Hoyer's medium and identified under

TABLE 1: Localities (and GPS coordinates) of the 173 French apple orchards and date where and when the eleven Phytoseiidae mite species have been observed.

SPECIES	LOCALITY	REGION	LATITUDE	LONGITUDE	DATE	
<i>Amblyseius andersoni</i>	Albefeuille-Lagarde	Midi-Pyrénées	44° 3'56.59"N	1°16'41.41"E	04/07/2011	
	Alixan	Rhône-Alpes	44°58'29.83"N	5° 1'34.86"E	22/06/2011	
	Asques	Aquitaine	44°57'8.25"N	0°24'48.61"O	14/06/2011	
	Bailleul	Pays-de-Loire	50°44'11.28"N	2°44'8.09"E	13/08/2012	
	Ballots	Pays-de-Loire	47°53'43.74"N	1° 3'1.87"O	18/07/2011	
	Bouge Chambalud	Rhône-Alpes	45°19'52.11"N	4°54'5.92"E	18/07/2011	
	Caderousse	PACA	44° 6'7.61"N	4°45'23.40"E	04/05/2011	
	Campsas	Midi-Pyrénées	43°53'48.03"N	1°19'36.61"E	04/07/2011	
	Carpentras	PACA	44° 3'20.00"N	5° 2'54.68"E	25/06/2012	
	Cavaillon	PACA	43°50'13.47"N	5° 2'16.48"E	23/06/2011	
	Chouzé/Loire	Centre	47°14'10.99"N	0° 7'38.85"E	23/07/2012	
	Corbarieu	Midi-Pyrénées	43°56'40.06"N	1°22'2.30"E	16/05/2011	
	Crosnières	Pays-de-Loire	47°44'42.60"N	0° 8'59.33"O	23/07/2012	
	Curbans	PACA	44°25'39.24"N	6° 2'9.14"E	19/07/2011	
	Francheville	Rhône-Alpes	45°44'18.44"N	4°45'13.48"E	07/08/2012	
	Ile de la Barthelasse	PACA	43°58'20.27"N	4°49'54.10"E	15/06/2011	
	Isles sur la Sorgue	PACA	43°55'1.08"N	5° 3'3.17"E	09/05/2011	
	La Motte-Servolet	Rhône-Alpes	45°35'47.24"N	5°52'26.74"E	25/07/2011	
	Lamonzie St Martin	Aquitaine	44°50'31.98"N	0°22'59.27"E	04/07/2011	
	Laragne	PACA	43°50'38.33"N	6°32'28.64"E	12/09/2011	
	Le Pin	Midi-Pyrénées	44° 2'7.36"N	0°58'4.97"E	28/06/2011	
	Le Poet	PACA	44°17'31.60"N	5°53'49.96"E	12/09/2011	
	Lignières de Touraine	Centre	47°17'49.36"N	0°25'5.47"E	22/06/2011	
	Lizac	Midi-Pyrénées	44° 6'19.48"N	1°11'12.16"E	06/06/2011	
	Mallemort	PACA	43°43'53.64"N	5°10'49.93"E	23/07/2012	
	Mées	PACA	43°42'9.09"N	1° 6'29.89"O	25/07/2011	
	Mirabel	Midi-Pyrénées	44° 8'39.86"N	1°25'11.36"E	28/06/2011	
	Moissac	Midi-Pyrénées	44° 6'17.47"N	1° 5'4.85"E	21/06/2011	
	Mondragon	PACA	44°14'20.17"N	4°42'47.24"E	11/05/2011	
	Monétier-Allemont	PACA	44°23'10.77"N	5°56'37.26"E	13/09/2011	
	Montauban	Midi-Pyrénées	44° 0'57.89"N	1°21'10.69"E	16/05/2011	
	Montech	Midi-Pyrénées	43°57'30.58"N	1°13'52.04"E	05/07/2011	
	Montesquieu	Midi-Pyrénées	43°33'45.09"N	3°16'35.65"E	21/06/2011	
	Monteton	Aquitaine	44°37'19.61"N	0°15'28.63"E	21/06/2011	
	Morizès	Aquitaine	44°36'46.30"N	0° 5'21.01"O	22/06/2011	
	Mornas	PACA	44°12'11.85"N	4°43'39.66"E	21/06/2011	
	Negrepelisse	Midi-Pyrénées	44° 4'31.56"N	1°31'19.07"E	20/06/2011	
	Plan d'Orgon	PACA	43°52'1.06"N	4°44'8.00"E	28/06/2011	
	Pont-Saint-Esprit	PACA	44°15'39.09"N	4°38'53.71"E	22/06/2011	
	Prignonrioux	Aquitaine	44°51'19.55"N	0°24'7.04"E	20/06/2011	
	Rene/Sarthe	Pays-de-Loire	48°16'37.57"N	0°13'12.41"E	11/07/2011	
	Ribiers	PACA	44°13'47.91"N	5°51'27.42"E	09/05/2011	
	Saint Alexandre	Languedoc-Roussillon	44°13'40.97"N	4°37'18.68"E	22/06/2011	
	Sainte Helene sur Isère	Rhône-Alpes	45°36'45.99"N	6°19'6.37"E	22/06/2011	
	Saint Nicolas de la Grave	Midi-Pyrénées	44° 3'52.81"N	1° 1'26.19"E	29/06/2011	
	Sées	Basse-Normandie	48°36'20.94"N	0°10'21.52"E	23/07/2012	
	Seiches sur Loir	Pays-de-Loire	47°34'39.17"N	0°21'48.72"O	19/07/2012	
	Senas	PACA	43°44'43.77"N	5° 4'39.77"E	24/07/2012	
	Sigolsheim	Alsace	48° 8'0.33"N	7°18'0.96"E	29/07/2011	
	Soucelles	Pays-de-Loire	47°34'5.93"N	0°25'5.33"O	06/06/2011	
	Saint Andiol	PACA	43°50'7.79"N	4°56'40.28"E	16/06/2011	
	Saint Epain	Centre	47° 8'29.60"N	0°32'26.91"E	23/07/2011	
	Saint Julien le Faucon	Basse-Normandie	49° 4'7.37"N	0° 5'4.78"E	06/08/2012	
	Saint Martin du Bois	Pays-de-Loire	45° 1'35.09"N	0°15'56.88"O	06/09/2011	
	Saint Ouen de Mimbré	Pays-de-Loire	48°17'32.36"N	0° 3'0.02"E	11/07/2011	
	Saint Paul d'Espis	Midi-Pyrénées	44° 8'36.71"N	0°58'9.23"E	14/06/2011	
	Saint Nazaire	Midi-Pyrénées	44°12'37.96"N	1°25'53.18"E	16/05/2011	
	Toutainville	Haute-Normandie	49°21'49.13"N	0°27'42.64"E	30/07/2012	
	Upaix	PACA	44°19'4.23"N	5°52'24.84"E	12/09/2011	
	venterol	PACA	44°23'26.57"N	5° 5'52.07"E	30/05/2011	
	Verquières	PACA	43°50'15.68"N	4°55'7.98"E	16/06/2011	
	Vinzieux	Rhône-Alpes	45°19'34.94"N	4°42'5.47"E	20/08/2012	
	<i>Typhlodromus (A.) rhenanoides</i>	Ile de la Barthelasse	PACA	43°58'20.27"N	4°49'54.10"E	15/06/2011
	<i>Typhlodromus (T.) baccettii</i>	Saint Andiol	PACA	43°50'7.79"N	4°56'40.28"E	28/06/2011
	<i>Parasetulus triporus</i>	Aigues vives	Languedoc-Roussillon	43°44'20.32"N	4°10'48.77"E	27/05/2011
		Alixan	Rhône-Alpes	44°58'29.83"N	5° 1'34.86"E	22/06/2011
		Moissac	Midi-Pyrénées	44° 6'17.47"N	1° 5'4.85"E	21/06/2011
		Mondragon	PACA	44°14'20.17"N	4°42'47.24"E	11/05/2011
	<i>Phytoseius horridus</i>	Arquenay	Pays-de-Loire	47°59'10.14"N	0°34'12.61"O	18/07/2011
	<i>Euseius finlandicus</i>	Ballots	Pays-de-Loire	47°53'43.74"N	1° 3'1.87"O	18/07/2011

TABLE 1: Continued.

SPECIES	LOCALITY	REGION	LATITUDE	LONGITUDE	DATE	
<i>Kampimodromus aberrans</i>	Aigues vives	Languedoc-Roussillon	43°44'20.32"N	4°10'48.77"E	27/05/2011	
	Arquenay	Pays-de-Loire	47°59'10.14"N	0°34'12.61"O	18/07/2011	
	Beaucaire	PACA	43°48'26.89"N	4°38'38.44"E	17/05/2011	
	Béziers	Languedoc-Roussillon	43°20'40.17"N	3°12'57.36"E	17/05/2011	
	Carpentras	PACA	44° 3'20.00"N	5° 2'54.68"E	25/06/2012	
	Cavaillon	PACA	43°50'13.47"N	5° 2'16.48"E	15/06/2011	
	Chateaufort/Lsere	Rhône-Alpes	45° 0'53.17"N	4°56'23.74"E	04/07/2011	
	Dollon	Pays-de-Loire	48° 1'58.46"N	0°35'57.31"E	23/07/2012	
	Isles sur la Sorgue	PACA	43°55'1.08"N	5° 3'3.17"E	24/07/2012	
	Lamanon	PACA	43°42'4.92"N	5° 5'5.68"E	15/06/2011	
	Le Thor	PACA	43°55'46.51"N	4°59'41.15"E	19/06/2012	
	Lycée de Pouillé	Pays-de-Loire	47°27'18.66"N	1° 9'41.71"O	06/06/2011	
	Mallemort	PACA	43°43'53.64"N	5°10'49.93"E	14/06/2011	
	Mondragon	PACA	44°14'20.17"N	4°42'47.24"E	11/05/2011	
	Pont-Saint-Esprit	PACA	44°15'39.09"N	4°38'53.71"E	22/06/2011	
	Puicheric	Languedoc-Roussillon	43°13'18.96"N	2°37'4.23"E	27/05/2011	
	Sellieres	Franche-Comté	46°49'40.03"N	5°33'44.49"E	25/05/2011	
	Senas	PACA	43°44'43.66"N	5° 4'39.92"E	04/06/2012	
	<i>Cydnodromus californicus</i>	Albefeuille-Lagarde	Midi-Pyrénées	44° 3'56.64"N	1°16'41.50"E	04/07/2011
		Alixan	Rhône-Alpes	44°58'29.83"N	5° 1'34.86"E	22/06/2011
Carpentras		PACA	44° 3'20.00"N	5° 2'54.68"E	25/06/2012	
Cavaillon		PACA	43°50'13.47"N	5° 2'16.48"E	23/06/2011	
Curbans		PACA	44°25'39.24"N	6° 2'9.14"E	19/07/2011	
Ile de la Barthelasse		PACA	43°58'20.27"N	4°49'54.10"E	15/06/2011	
La Motte-Servolex		Rhône-Alpes	45°35'47.40"N	5°52'26.80"E	25/07/2011	
Lamanon		PACA	43°42'4.92"N	5° 5'5.68"E	15/06/2011	
Le Pin		Midi-Pyrénées	44° 2'7.36"N	0°58'4.97"E	28/06/2011	
Mées		PACA	43°42'9.09"N	1° 6'29.89"O	25/07/2011	
Montauban		Midi-Pyrénées	44° 0'57.89"N	1°21'10.69"E	16/05/2011	
Monteton		Aquitaine	44°37'19.61"N	0°15'28.63"E	21/06/2011	
Mornas		PACA	44°12'11.85"N	4°43'39.66"E	21/06/2011	
Ribiers		PACA	44°13'47.91"N	5°51'27.42"E	04/07/2011	
Saint Alexandre		Languedoc-Roussillon	44°13'40.97"N	4°37'18.68"E	22/06/2011	
Verquieres		PACA	43°50'15.68"N	4°55'7.98"E	16/06/2011	
Le Thor		PACA	43°55'46.51"N	4°59'41.15"E	19/06/2012	
<i>Euseius gallicus</i>		Mondragon	PACA	44°14'20.17"N	4°42'47.24"E	24/05/2011
		Montech	Midi-Pyrénées	43°57'30.58"N	1°13'52.04"E	05/07/2011
		Rognonas	PACA	43°53'54.60"N	4°48'10.88"E	14/06/2011
	Cavaillon	PACA	43°50'13.47"N	5° 2'16.48"E	06/09/2011	
<i>Euseius stipulatus</i>	Ile de la Barthelasse	PACA	43°58'20.27"N	4°49'54.10"E	15/06/2011	
	Plan D'Orgon	PACA	43°52'1.06"N	4°44'8.00"E	28/06/2011	
	Saint Andiol	PACA	43°50'7.79"N	4°56'40.28"E	28/06/2011	
<i>Typhlodromus (T.) pyri</i>	Aigues vives	Languedoc-Roussillon	43°44'20.32"N	4°10'48.77"E	27/05/2011	
	Arquenay	Pays-de-Loire	47°59'10.14"N	0°34'12.61"O	18/07/2011	
	Ballots	Pays-de-Loire	47°53'43.74"N	1° 3'1.87"O	18/07/2011	
	Bessenay	Rhône-Alpes	45°46'36.44"N	4°33'12.67"E	09/06/2011	
	Béziers	Languedoc-Roussillon	43°20'40.17"N	3°12'57.36"E	17/05/2011	
	Bouge Chamalud	Rhône-Alpes	45°19'52.09"N	4°54'5.94"E	18/07/2011	
	Carpentras	PACA	44° 3'20.00"N	5° 2'54.68"E	25/06/2012	
	Charleval	PACA	43°43'1.23"N	5°14'44.93"E	02/07/2012	
	Chateaufort/Lsere	Rhône-Alpes	45° 0'53.17"N	4°56'23.74"E	04/07/2011	
	Chazay	Rhône-Alpes	45°52'27.36"N	4°42'35.81"E	18/07/2011	
	La Motte-Servolex	Rhône-Alpes	45°35'47.40"N	5°52'26.80"E	25/07/2011	
	Le verdier haut	Limousin	45° 4'3.93"N	1°44'45.60"E	30/05/2011	
	Maclas	Rhône-Alpes	45°21'42.66"N	4°41'5.39"E	27/06/2011	
	Maussane	PACA	43°43'18.24"N	4°48'15.11"E	29/07/2011	
	Mazières	Midi-Pyrénées	45°50'11.21"N	0°34'2.47"E	13/08/2012	
	Messimy	Rhône-Alpes	45°41'51.54"N	4°40'31.65"E	16/06/2011	
	Mirabel	Midi-Pyrénées	44° 8'39.86"N	1°25'11.36"E	28/06/2011	
	Mondragon	PACA	44°14'20.17"N	4°42'47.24"E	11/05/2011	
	Monteton	Aquitaine	44°37'19.61"N	0°15'28.63"E	21/06/2011	
	Morizès	Aquitaine	44°36'46.30"N	0° 5'21.01"O	22/06/2011	
	René/Sarthe	Pays-de-Loire	48°16'37.57"N	0°13'12.41"E	11/07/2011	
	Saint Pardoux	Poitou-Charentes	46° 3'29.70"N	1°16'57.62"E	06/06/2011	
	Sarlande	Aquitaine	45°27'5.62"N	1° 6'59.73"E	01/07/2011	
	Sées	Basse-Normandie	48°36'20.94"N	0°10'21.52"E	18/07/2011	
	Sigolsheim	Alsace	48° 8'0.33"N	7°18'0.96"E	29/07/2011	
	Sommervieu	Basse-Normandie	49°17'28.85"N	0°39'3.39"O	06/08/2012	
	Sonnay	Rhône-Alpes	45°21'19.57"N	4°54'25.01"E	27/06/2011	
	Saint Germain d'Arce	Pays-de-Loire	47°37'26.74"N	0°17'23.66"E	13/08/2012	
	Saint Ouen de Mimbré	Pays-de-Loire	48°17'32.36"N	0° 3'0.02"E	11/07/2011	
	Saint Pois	Basse-Normandie	48°44'57.63"N	1° 4'4.10"O	04/09/2012	
	Vinzieux	Rhône-Alpes	45°19'34.94"N	4°42'5.47"E	18/07/2011	

a phase contrast microscope at  $400 \times$  magnification (Leica DMLB, Leica Microsystems SAS, Reuil-Malmaison, France) using specific identification keys and original descriptions and re-descriptions (Tixier *et al.* 2008a, b; Tixier 2012; Akashi *et al.* 2012). The nomenclature used was that proposed by Chant and McMurtry (2007) in the last revision of the family except for the species *Neoseiulus californicus*, recently re-associated to the genus *Cydnodromus* (Tsolakis *et al.* 2012).

All Phytoseiidae found in apple orchard are generalist predators. Conversely to specific predators, their occurrence is usually not linked to their prey and no correlation is usually observed between densities of Phytoseiidae and preys (Slone and Croft 2001). Thus, species of Tetranychidae were not identified nor counted. Furthermore, their densities were usually very low.

#### Phytoseiidae distribution in apple orchards

In order to characterize Phytoseiidae distribution at the plot level, Taylor's law has been used (Taylor 1961). This law relates the standard deviation ( $S^2$ ) to the mean ( $m$ ) according to the following relation:  $S^2 = am^b$ . When applying a log transformation, the latter relation describes a straight line ( $\log S^2 = \log(a) + b \times \log(m)$ ), where  $b$  is the slope. The  $b$  value of this relation provides information on distribution: when  $b = 1$ , the species is randomly distributed, when  $b > 1$  the distribution is aggregative and when  $b < 1$ , the distribution is regular. To establish such a relation and calculate the  $b$  value, the mean and the standard deviation of each plot have been calculated (and log transformed) and a simple correlation test has been applied (Statsoft 2008).

Characterisation of the sample size for optimal sampling

In order to define the number of leaves to be sampled in further surveys for characterising the number of Phytoseiidae in apple orchards ( $N$ ), the following relation (Nachmann 1984) was applied:  $N = am^{(b-2)}/E^2$  where  $a$  and  $b$  are Taylor's law variables,  $m$  the mean, and  $E^2$  the accepted error around the mean. We herein tested two errors: 10% and 20% of variation around the mean, *i.e.* for a mean of 0.5 Phytoseiidae/leaf that means that the samplings

can provide estimation intervals of 0.45 – 0.55 and 0.4 – 0.6 Phytoseiidae/leaf, respectively.

## RESULTS AND DISCUSSION

### Species of Phytoseiidae in French apple orchards

One thousand, nine hundred and eighty-five specimens have been identified. Eleven species of Phytoseiidae have been observed. The list of species, localities and regions is provided in Table 1. Three species were particularly abundant and frequently observed: *A. andersoni*, *K. aberrans* and *T. (T.) pyri* (Table 2). *Cydnodromus californicus* was observed in several regions in medium densities, whereas the other seven species were observed in some plots but usually in low densities and in association with the three dominant species (Tables 2, 3). Apart from the three dominant species, only two (*Euseius gallicus* Kreiter and Tixier and *Euseius stipulatus* [Athias-Henriot]) have been found alone (not occurring with other Phytoseiidae species) in one and three plots, respectively (Tables 1 and 2). In most of orchards, the three dominant species were not found in association with each other (Table 3). The highest co-occurrence was found between *T. (T.) pyri* and *A. andersoni* co-found in 11 plots among the 173 sampled (Table 3). *Cydnodromus californicus* was always found with one of the three dominant species and highest co-occurrence was observed with *A. andersoni* (in 17 plots among the 20 in which *C. californicus* was found). Duso *et al.* (2009) reported the dominance of four species of Phytoseiidae in European orchards: *A. andersoni*, *K. aberrans*, *T. (T.) pyri* as in the present survey. However, they also reported the dominance of another species, *Euseius finlandicus* (Oudemans), rather rare in the apple orchards considered in our study.

Table 4 shows the cultivars on which the three dominant species have been found. No clear relationship between apple cultivar and Phytoseiidae species appears as the three dominant species have been found on the most common cultivars.

The list of the eleven species found is provided below with some information on their occurrence and biology.

TABLE 2: Densities and number of plots occupied for eleven Phytoseiidae species recorded in the 173 French apple orchards sampled.

	Densities (%)	Number of plots occupied
<i>Amblyseius andersoni</i>	748 (37.7)	86
<i>Kampimodromus aberrans</i>	627 (31.6)	43
<i>Typhlodromus (Typhlodromus) pyri</i>	421 (21.2)	40
<i>Cydnodromus californicus</i>	109 (5.5)	20
<i>Euseius stipulatus</i>	42 (2.1)	8
<i>Euseius gallicus</i>	13 (0.6)	4
<i>Phytoseius horridus</i>	11 (0.5)	1
<i>Paraseiulus triporus</i>	7 (0.3)	5
<i>Typhlodromus (Anthoseius) rhenanoides</i>	3 (0.1)	1
<i>Typhlodromus baccettii</i>	3 (0.1)	1
<i>Euseius finlandicus</i>	1 (0.05)	1

TABLE 3: Number of plots where two of the dominant species co-occured in the 173 French apple orchards sampled.

	<i>Amblyseius andersoni</i>	<i>Kampimodromus aberrans</i>	<i>Typhlodromus (T.) pyri</i>	<i>Cydnodromus californicus</i>
<i>Amblyseius andersoni</i>	-			
<i>Kampimodromus aberrans</i>	3 plots	-		
<i>Typhlodromus(T.) pyri</i>	11 plots	5 plots	-	
<i>Cydnodromus californicus</i>	17 plots	3 plots	2 plots	-

*Amblyseius andersoni* was the most frequent and abundant species. It was observed in more than half of the orchards sampled, on 27 apple cultivars (among 34 sampled) and in nearly all the French regions sampled (Figure 1a, b). *Amblyseius andersoni* was dominant in seven of the regions sampled. We can thus question the occurrence of this species in such regions if the number of plots would have been higher. This species is quite common in agrosystems, especially in vineyards and apple orchards in Europe (*i.e.* Spain, Turkey, Switzerland,

Slovenia and Italy) (Moraes *et al.* 1986). It is reported to feed and develop on tetranychid mites and to ensure efficient biological control of these mites (Duso and Camporese 1991; Genini *et al.* 1991; Koveos and Broufas 2000; Fischer and Mourrut-Salesse 2005; Houten *et al.* 2005; Lorenzon *et al.* 2012). Some studies have also shown its ability to develop resistance to pesticides (*i.e.* Duso *et al.* 1992; Pozzebon *et al.* 2002; James 2002, 2003).

*Euseius finlandicus* has been observed in only

TABLE 4: Percentage of the four most important Phytoseiidae species occurring on the 28 apple cultivars in the 173 French orchards sampled in 2011 and 2012.

	<i>A. andersoni</i>	<i>T. (T.) pyri</i>	<i>K. aberrans</i>	<i>C. californicus</i>
Akane	67.7		32.3	
Ariane	94.1			5.9
Avrolles		100		
Blackburn	100			
Braeburn	54.8	15.4	28.8	1
Brookfield		50.7	49.3	
Canada	13.9	86.1		
Chanteclerc			100	
Douce Moen	90	10		
Early Red One	55.8		34.9	9.3
Fuji	66.1	9.2	22.9	1.8
Gala	37.4	26.9	29.7	5.9
Galaxy	41	8.4	43.4	7.2
Golden	45.5	21.9	7	25.7
Goldrusk	33.3	66.7		
Granny Smith	29.9	11.5	56.3	2.3
Hillwell	100			
Idared	75	22.2		3
Juliette			100	
Judor	50	50		
Kermerrien	66.7	17.5	15.9	
Melrose		100		
Mondial Gala	100			
Petit jaune	58.8	41.2		
Pink lady	41	47.5	11.5	
Prim Gold	100			
Redfield	48.9		51.1	
Reine des Reinettes	23.5	44.1	32.4	
Rosy Glow	83.3		16.7	
Royal Gala	87.9	3		9.1
Scarlett Rouge	95			5
Smoothee	100			
Starkimson	14	86		
Sundourner		100		

one orchard in North West France (Table 1). One specimen has been observed in this study, but this species is quite common in France, especially on uncultivated shrubs and trees but rarely in crops (Moraes *et al.* 1986, 2004). It is reported as a frequent species of apple orchards in Europe by Duso *et al.* (2009).

*Euseius gallicus* has been observed in four orchards located in the South-East of France (Table 1) on three apple cultivars. This species recently described has been reported from shrubs and trees. Nothing is known on its biology and it is morphologically close to *E. stipulatus* (Okassa *et al.* 2009; Tixier *et al.* 2010).

*Euseius stipulatus* has been found in four orchards located in the South-East France (Table 1). This species is commonly found in the southern Europe. It is a very common species in crops, especially in citrus orchards (Ferragut and Escudero 1997; Sahraoui *et al.* 2012). Several studies have shown its ability to feed on pollen but also on pests such as *Tetranychus urticae* (Koch) and *Panonychus citri* (McGregor) (*i.e.* Ferragut *et al.* 1992; Abad-Moyano *et al.* 2009; Pina *et al.* 2012). It is usually found on plants with smooth leaves. In the present study, it has been reported on four apple cultivars, but essentially on Golden Delicious, whereas in other orchards with the same cultivar, other Phytoseiidae species have co-occurred.

*Kampimodromus aberrans* was the second most abundant and frequent species; it was found in 43 orchards and 16 apple cultivars. It was however less widespread than *A. andersoni* (Figure 1a, b). Indeed, it was only present in four regions and it prevailed in Languedoc-Roussillon only. In Franche-Comté, *K. aberrans* was the unique species sampled; however only one plot was considered. This species has a Palearctic distribution; it has been observed both in natural vegetation and crops, especially apple orchards and vineyards (*i.e.* Tixier *et al.* 1998, 2000; Kreiter *et al.* 2002; Duso *et al.* 2009). However, it is more often reported in untreated apple orchards than in commercial plots (Duso *et al.* 2009). In France, this species is the prevalent species in vineyards of southern France, whereas in the North *T. (T.) pyri* prevails (Kreiter *et al.* 2000).

This southern distribution is similar to what has been presently observed in French apple orchards. Climatic conditions, especially dry conditions of Mediterranean climate might favour the presence of *K. aberrans*. However, this species has been reported from higher latitudes, as Germany, Ukraine and Slovakia in orchards (Schruft 1967, Jedlickova 1991, Kolodochka and Omeri 2007) and presently in North-East France, suggesting that other factors could explain its distribution. Duso *et al.* (2009) suggested that the occurrence of *K. aberrans* in Italian apple orchards was linked to pesticide applications and tolerance to pesticides applied. Duso *et al.* (2009) also showed the importance of apple cultivar leaf characteristics on the occurrence of this latter species. In the present study, we can note that *K. aberrans* was particularly abundant on cultivars "Reinette", known to have hairy leaves and on the cultivar Chanteclerc. However this latter cultivar has only been sampled in Languedoc-Roussillon, thus it is impossible to determine if the dominance of *K. aberrans* is due to cultivar or climatic conditions.

*Cydnodromus californicus* was observed in twenty orchards and eleven cultivars but always at low densities (Table 4). It was mainly observed in Provence-Alpes-Côte d'Azur and Midi-Pyrénées (Table 1). It was the prevailing species in apple orchards in surveys carried out more than ten years ago (Bourgouin *et al.* 2002). This species tends thus to disappear in apple crops. This evolution is similar to what has been observed in vineyards (Kreiter *et al.* 2000). *Cydnodromus californicus* has been often reported as a species usually present in highly treated plots because of its ability to develop resistance to pesticides (*i.e.* Fauvel and Bourgouin 1993; Castagnoli *et al.* 2005; Cloyd *et al.* 2006). The fact that this species has disappeared from French orchards and vineyards could be explained by the development of Integrated Pest Management practices and the decreasing of toxic pesticide applications. Duso *et al.* (2009) observed that *K. aberrans* increased its densities in apple orchards when pesticides less toxic to Phytoseiids are used; it would be more competitive than other species. However, additional studies should be carried out to confirm

this hypothesis.

*Paraseiulus triporus* (Chant and Yoshida-Shaul) was found on five cultivars in five orchards located in South of France (Table 1). The densities were always low. This species is rather common in the entire West Palearctic region; it has been reported from apples in Sweden, Italy and The Netherlands (Moraes *et al.* 2004). Nothing is known on its biology.

*Typhlodromus (Anthoseius) rhenanoides* Athias-Henriot was found in one apple (cultivar Golden Delicious) orchard in South of France, only (Table 2). It has been observed on apples in Spain and Portugal and on vines in France (Kreiter *et al.* 2000). However, this species is rarely reported from crops.

*Typhlodromus (Typhlodromus) baccettii* Lombardini was found in one apple orchard (cultivar Red Winter) in South of France. It has been reported from apples only from Norway (Edland and Evans 1998). Nothing is known on its biology. It is a quite rare species only reported from Europe. It is the second record of this species in France (Tixier *et al.* 2006).

*Typhlodromus (Typhlodromus) pyri* was found in nearly all the regions, 40 orchards and 21 apple cultivars (Figure 1a, b). However, even if present in many regions, it was observed only in some plots. It is interesting to note the dominance of this species in the regions Rhône-Alpes and Basse-Normandie. This species is quite common in apple orchards and vineyards all over the world (Hardman *et al.* 1991; Moraes *et al.* 1986, 2004; Roda *et al.* 2003). Several studies have shown its ability to control mite pests and to resist somewhat to pesticide applications (*i.e.* Genini *et al.* 1991; Bonafos *et al.* 2007). Roda *et al.* (2003) showed that apple leaf pubescence could affect the densities of *T. (T.) pyri* because of pollen and fungi spore retention. In the present study, no clear effect of apple cultivar on its occurrence has been observed (Table 4).

*Phytoseius horridus* Ribaga was found in one apple orchard (11 specimens identified on the cultivar Karmerrien) in North West of France (Table 1). It is the first report of this species in France. It has also been observed on apples in Spain (Miñarro *et*

*al.* 2002). Nothing is known on the biology of this west Palearctic species.

In order to assist the identification of the females of the Phytoseiidae species reported in apple orchards in France, an identification key is provided below.

#### Identification keys of eleven Phytoseiidae species reported in French orchards

1. Podonotal region of the dorsal shield, anterior to *R1*, with 4 pairs of lateral setae (*j3*, *z2*, *z4* and *s4*); *z3* and *s6* are absent . . . . . Sub-family Amblyseiinae 3  
— Podonotal region of the dorsal shield , anterior to *R1* with 5 or 6 pairs of lateral setae (*j3*, *z2*, *z4* and *s4* always present); *z3* and/or *s6* are present . . . . . 2
2. Posterior "lateral" dorsal shield setae *Z1*, *S2*, *S4* and *S5* absent. Setae *J2* and *R1* absent. Setae *Z4* much longer than 100  $\mu\text{m}$  (108  $\mu\text{m}$ ); setae *s4* much longer than 100  $\mu\text{m}$  (148  $\mu\text{m}$ ). . . . . Sub-family Phytoseiinae: *Phytoseius horridus* Ribaga  
— At least one of the setae *Z1*, *S2*, *S4* or *S5* is present. . . . . Sub-family Typhlodrominae 8
3. Sternal shield with median posterior projection, some forward "migration" of preanal setae *JV2* and *ZV2*. . . . . 4  
— Sternal shield without posterior projection, without forward "migration" of preanal setae *JV2* and *ZV2*. . . . . 6
4. Peritreme short, extending to *z4*. Spermatheca with a short calyx and a globular atrium. . . . . *Euseius finlandicus* (Oudemans)  
— Peritreme long, extending at least to setae *z2*. Spermatheca with a long calyx . . . . . 5
5. Dorsal shield reticulated, calyx of spermatheca tubular, elongated, vase-shaped. . . . .  
. . . . . *Euseius gallicus* Kreiter and Tixier  
— Dorsal shield not so reticulated, calyx of spermatheca tubular, elongated, calyx with parallel sides. . . . . *Euseius stipulatus* (Athias-Henriot)

- 6. Setae *S4* absent.....  
 .....*Kampimodromus aberrans* (Oudemans)  
 — Setae *S4* present.....7
  
- 7. Ratio setae *s4*:  $Z1 < 3.0:1.0$ ; *s4*, *Z4*, and *Z5* not greatly longer than other setae, never with wide sternal shield; *J2* always present. Macrosetae are absent on genu II and III.....  
 ..... *Cydnodromus californicus* (McGregor)  
 — Ratio setae *s4*:  $Z1 > 3.0:1.0$ ; wide sternal shield. *s4*, *Z4*, and *Z5* markedly longer than other dorsal setae. *J2* present. Macrosetae are present on genu II and III. Ratio of setae *S2* (25  $\mu\text{m}$ ) / *J2* (8  $\mu\text{m}$ ) is about 3. Calyx of spermatheca bell-shaped with nodular atrium. Three Macrosetae on leg IV, genu, tibia and tarsus, the longest (78  $\mu\text{m}$ ) on the Genu.....  
 ..... *Amblyseius andersoni* (Chant)
  
- 8. Setae *z6* present, setae *JV2* absent, ventrianal shield larger than wide with two pairs of preanal setae. Three solenostomes on the dorsal shield (*gd2-gd6-gd9*).....  
 ..... *Paraseiulus triporus* (Chant & Yoshida-Shaul)  
 — Setae *z6* absent, setae *JV2* present.....9
  
- 9. Setae *S5* absent.....10
  
- 10. Eight setae on the Genu II, peritreme extending at level *z2*, *Z5* ranging between 50 and 70  $\mu\text{m}$ .....  
 .....*Typhlodromus (T.) pyri* Scheuten  
 — Seven setae on the Genu II, peritreme extending at level *j3*, *Z5* ranging between 32 and 48  $\mu\text{m}$ .....  
 ..... *Typhlodromus (T.) baccetti* Lombardini

**Phytoseiidae distribution in apple orchards**

A high and significant correlation was observed between  $\log(m)$  and  $\log(S^2)$  ( $R^2 = 0.96$ ,  $P < 0.0001$ ), allowing to use the indices of Taylor’s law to characterise Phytoseiidae distribution. The slope value was 1.26 (Standard Error = 0.02), showing an aggregative distribution. Table 5 shows the parameters of the regression for different regions (where the number of plots was sufficient to carry out the analysis). In all the regions considered, the slope value was significantly higher than 1 (except in Aquitaine), showing an aggregated distribution. However, sometimes two species were co-occurring in a same plot. It is thus impossible to determine if the distributions of the two species are differ-

TABLE 5: Slope *b* (and associated Standard Error : SE)and  $R^2$  (and *P*) values of the regression relations (Taylor’s law) obtained in seven regions and for the three dominant Phytoseiidae species in the 173 French apple orchards sampled.

REGIONS	Number of plots	Mean (phytoseiidae/leaf)	$R^2$	<i>P</i>	<i>b</i>	SE
Provence-Alpes-Côte d'Azur	69	1.23	0.96	$P < 0.0001$	1.27	0.03
Midi-Pyrénées	20	0.78	0.95	$P < 0.0001$	1.32	0.07
Aquitaine	10	1.15	0.88	$P < 0.0001$	1.09	0.15
Basse-Normandie	8	0.04	0.97	$P < 0.0001$	1.37	0.05
Languedoc-Roussillon	19	2.54	0.92	$P < 0.0001$	1.39	0.09
Pays-de-Loire	12	1.07	0.99	$P < 0.0001$	1.21	0.03
Rhône-Alpes	18	1.01	0.92	$P < 0.0001$	1.26	0.09
SPECIES	Number of plots	Mean (phytoseiidae/leaf)	$R^2$	<i>P</i>	<i>b</i>	SE
<i>Amblyseius andersoni</i>	70	0.91	0.95	$P < 0.0001$	1.27	0.03
<i>Typhlodromus pyri</i>	34	1.06	0.92	$P < 0.0001$	1.23	0.06
<i>Kampimodromus aberrans</i>	38	2	0.96	$P < 0.0001$	1.31	0.04

ent. In order to assess the distribution of the three dominant species, only plots where one of these latter species represented 80 % of the densities were considered and then the Taylor's law was applied. The slope values obtained were significantly higher than 1 for the three species, showing a clear aggregated distribution for all of them (Table 5).

TABLE 6: Abacus relating the average number of Phytoseiidae per leaf and the occupation rate (at least one Phytoseiidae per leaf) obtained in seven regions in the 173 French apple orchards sampled.

Occupation rate	Average number of Phytoseiidae / leaf
5-10 %	0.1
15-20 %	0.2
25%	0.3
30%	0.4
35%	0.5
40%	0.6
45%	0.7
50%	1
55%	1.2
60%	1.6
> 65 %	> 2
> 80 %	> 4

#### Characterisation of the sample size for optimal sampling

As Phytoseiidae distribution is aggregated the number of leaves to be sampled should be important. To estimate the average densities of Phytoseiidae per leaf with an error of 10 % around the mean, 260 leaves per orchard would have to be sampled. For practical work and producers, this is clearly not possible as too time consuming. However, with an error of 20 % around the mean, the average number of apple leaves to be sampled would be 40. Below 40 leaves, the precision around the mean might be too low to estimate sufficiently accurately the densities of these predators. In order to simplify sam-

plings, the relation between the average number of Phytoseiidae per leaf and the rate of leaves occupied by at least one mite has been assessed (Figure 3). The good correlation obtained ( $R^2 = 0.88$ ) enables to establish an abacus to determine the average densities of Phytoseiidae when only their presence/absence of the leaves is assessed (Table 6).

## CONCLUSION

This paper is the first one presenting such a great survey in apple orchards in France. It shows the importance of three species and their relative abundance. *Amblyseius andersoni* was clearly the dominant species whereas the samplings carried out ten years ago demonstrated the dominance of *C. californicus*. This survey confirms thus the fauna modification seemingly initiated ten years ago.

The prevalence of *A. andersoni* does not apply in all the regions. *Kampimodromus aberrans* is dominant in Languedoc-Roussillon and Franche-Comté whereas *T. (T.) pyri* prevails in Rhône-Alpes, Limousin, Poitou-Charentes and Basse-Normandie. However, in these three latter regions as well in Franche-Comté, the number of orchards sampled is too low to consider this distribution representative. However, it is clear that *K. aberrans* predominates in Mediterranean climates whereas *T. (T.) pyri* prevails in Rhône-Alpes. Cultural practices and climatic conditions could certainly explain such different localisations. *Kampimodromus aberrans* seems to be less affected by low relative hygrometry than the other two species (*K. aberrans*,  $RH_{50} = 56\%$ , *T. (T.) pyri*  $RH_{50} = 58\%$ , *A. andersoni*  $RH_{50} = 62\%$ ) (Duso and Camporese 1991; Genini *et al.* 1991; Gambaro 1994). This could explain why *K. aberrans* has been mainly recorded in orchards of Languedoc-Roussillon (the driest region considered) and *A. andersoni* in more humid regions. However, as *K. aberrans* has also been found in North of France, as well as in North and central Europe (Moraes *et al.* 2004) and *A. andersoni* in Provence where humidity is quite low, other factors probably affect Phytoseiidae occurrence. For instance irrigation type but probably essentially pesticide applications could be involved. Kreiter *et al.* (2000) and Duso *et al.* (2009)

have indeed shown the importance of pesticide application to explain the distribution of Phytoseiidae in French vineyards and Italian apple orchards, respectively.

Furthermore, *K. aberrans* is usually observed on plants with hairy leaves (Kreiter *et al.* 2002), suggesting that apple cultivar could also affect the diversity of Phytoseiidae. Duso *et al.* (2009) also emphasized the influence of apple cultivar on Phytoseiidae densities, especially for the species *K. aberrans*. However, in the present case, cultivar does not seem to affect Phytoseiidae mite species occurrence. Other factors, such as cover-crop type, not much studied until now in French apple orchards could affect the Phytoseiidae diversity. Some studies in apple orchards but also in citrus orchards indeed showed exchange between plants in the inter-rows and trees (Alston 1994; Coli *et al.* 1994; Nyrop *et al.* 1994; Tuovinen 1994; Stanyard *et al.* 1997; Fitzgerald and Solomon 2004; Pereira *et al.* 2006; Aguilar *et al.* 2008, 2011; Mailloux *et al.* 2010). Nothing is known on the occurrence in inter-rows of the main Phytoseiidae species found on apple trees. *Kampimodromus aberrans* and *T. (T.) pyri* are essentially recorded on trees and shrubs but are little known from herbaceous plants. *Amblyseius andersoni* has been more frequently observed on herbaceous plants. The occurrence of such species in inter-rows should thus be studied especially to develop weeding practices for biological control improvement and natural enemy efficiency. Finally, this study shows the aggregative distribution of Phytoseiidae in apple orchards and provides useful information for improving samplings and more accurately determining Phytoseiidae densities on apple trees. In further surveys, it could be interesting to determine the relation between Tetranychidae and Phytoseiidae mites in order to propose decision rule for managing pesticide application.

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