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Influence of fire prevention management strategies on the diversity of butterfly fauna in the eastern Pyrenees

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Abstract Fire prevention management is becoming a necessity in many Mediterranean locations to regulate fire of natural or human origin. However, very few studies have determined the real effects of the strategies adopted on local fauna. Butterflies are sensitive to local changes and they can thus serve as indicators of environmental changes. Three different types of fire prevention management approaches in three different localities in the Eastern Pyrenees (France) were performed and the butterfly community composition was investigated. We show that of the 80 species of butterflies observed, 36 % can be considered as biological markers. An original objective treatment of data using hierarchical distance analysis combined with a neural network analysis (Self-Organizing Maps) was applied in this study. Our conclusions are that the overall number of species is maintained independently of the fire prevention type but that some important changes are observed among butterfly communities, with a clear reduction of the numbers of endemic/specialized species in favour of generalist ones for the two most drastic fire prevention management approaches studied here. The influence of such approaches is discussed on the basis of the conservation of Mediterranean species of Lepidoptera.

Keywords Lepidoptera · Biological indicators · Fire cuts management · Pyrenees

Introduction

A major risk for Mediterranean forests is fires of human origin. On average, 30,000 ha/year burn in the Mediterranean region of France. For instance, 45,600 ha have burned during the last 30 years in the *Département* of *Pyrenées Orientales* alone (0.8 % of the total surface area; from Promethee database: www.promethee.com).

Many management policies have been applied to protect endangered biota from fire, among which partial or undergrowth clearing is currently the preferred technique, and is chosen for most slope orientations, and prevailing winds, etc. Depending on how drastic the clearing is, such policies result in changes in flora and the thus in the associated fauna, but have been proved to reduce the risk of complete destruction of vast areas (Ricouart 2005; Quartau 2009).

Many insects have already been used as ecological indicators (Kimberling et al. 2001; Paoletti 1999) including Coleoptera (Bohac 1999), ants (King et al. 1998; Lobry de Bruyn 1999), grasshoppers (Andersen et al. 2001; Zschokke et al. 2000), Diptera (Frouz 1999) and Syrphidae (Sommaggio 1999; Speight et al. 2002). Resilience of the various insects to fire events (whether natural or provoked) is notably variable, but most can rebuild their initial population levels a few years after a total burn of the area (Braby 2010; Warren et al. 1987). In some specific cases, fires can even be a necessity to maintain populations of endangered species by

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renewing the host-plant population (Warren et al. 1987). Anyway, most of time, the effects are deleterious for the specialized species but neutral to beneficial for generalists (Powell et al. 2007; Swengel and Schicht 2011).

Lepidoptera were not included among the insects first used as indicators. It was generally considered, as a first approximation, that due to their ability to fly, they are not sufficiently specific to act as indicators of perturbations. However, many field studies (Erhardt 1985; Oostermeijer and van Swaay 1998; Thomas and Hanski 1997; Thomas and Harrison 1992) oppose this view, showing a high specificity of these insects for certain micro-habitats or anthropogenically disturbed areas (Luque et al. 2007, 2009; Van Halder et al. 2011). Furthermore, butterflies and moths have one of the highest sensitivities to rapidly changing environmental conditions (New 1997). Anyway as recently demonstrated by Rosin et al. (2011), this sensitivity and specificity is highly variable among Lepidoptera species even belonging to the same genus.

In order to provide a critical appraisal of the use of adult Lepidoptera as biological indicators in the special context of fire prevention management in the Eastern Pyrenees, we used a novel strategy. First, we determined whether, among the species encountered in this region, some possess a specificity to a certain type of habitat. An original approach based on a hierarchical distance analysis was tested. Then, we checked the specificity of distribution among the study sites and for different types of fire prevention managements on the Lepidoptera. To do this, a neural network model was applied. Finally, we determined whether Lepidoptera species groupings occurred, depending on the type of fire prevention management. Distance treatment was used for this step. Based on these three conditions, we discuss the relevance of the use of adult butterflies as markers of anthropogenically disturbed areas to evaluate the effects of fire prevention management strategies on the Lepidopteran fauna. In conclusion, we measured the balance between fire prevention management and the impact on the diversity of Lepidoptera.

Materials and methods

Localities studied

The three study sites were situated in the *Département* of *Pyrénées Orientales* (Southern France; Fig. 1). The localities (Argeles-sur-mer ARG, Calmeilles CAL, Campoussy CAM) were chosen to compare different types of Mediterranean habitat (Table 1).

Argeles and Calmeilles are typically Mediterranean locations, but the former (ARG) is composed more of open field/shrubs while the latter is dominated by shrubs/maquis and therefore does not experience the same extremes of heat. The third locality (CAM) is an open field in a Mediterranean mountainous location much cooler than the other two locations.

Each locality was divided into three sub-localities depending on the type of fire protection management system adopted (Table 2). The management actions were carried out during the winter of 1999/2000. Our study then started the first year after implementation of the new management approaches. Note that for CAM, virtually no trees were present before the management strategy, meaning that no, or few differences, existed between Zone A and Zone B (Zone C was also accidentally subjected to this management strategy). Fences were placed around the study zones to avoid cattle from biasing the protocol.

Zone A: This zone class was totally cleared of vegetation with only the herbaceous level remaining. The goal of this drastic treatment was to ensure that no burnable material is present and to provide safe refuges for firemen if a fire does occur.

Zone B: The treatment of this type of zone consists mainly in removing bushes (minimum: 2/3 of the zone) while the trees are kept. As bushes represent the main source of combustible material, this treatment is assumed to limit fires in such zones.

Zone C: The treatment of type C zones consists only of placing grazing animals in the area (goats or cows, depending on the location). Zones C are thus considered as “sub natural” but with herbivory over-pressure. As livestock will eat mainly the herbaceous and shrub level, the expectation is that any fires will be slowed.

Butterfly sampling

Samples were collected 5 times a year: once a month from May to September. The study covered two successive years: 2000 and 2001. Butterflies were collected with standard Lepidoptera hand nets (Sticks 1.5 m, diameter 40 cm) in a single plot per zone and per site of 1 ha (the largest area available in all the studied zones without approaching the edge). The three locations were sampled during the same week, taking care that weather conditions were similar. Two people performed the sampling for 90 min at every location and sub-location. For each location, samples were collected on the same day, to avoid variations due to weather conditions. Except for a few species, none had a strict circadian rhythm that would make their densities and occurrences vary within the day. The insects were then released, or killed for identification using KCN jars (mainly for Lycaenidae and Hesperiidae) and/or for further molecular analysis studies. Identification was performed using various field guides (Geiger 1987; Leraut 1992; Tolman and Lewington 1999). For a

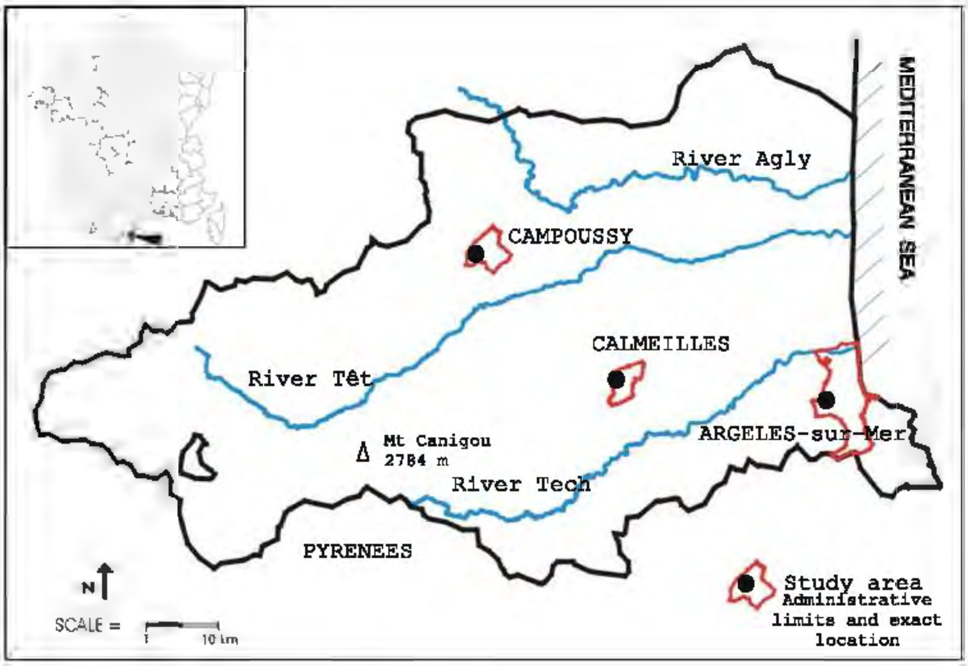


Fig. 1 Map of the studied locations including main rivers

Table 1 Geographical, climatological and ecological traits of the three study sites

	Argelès-sur-mer	Calmeilles	Campoussy
Coordinates			
Latitude	42°31′N	42°32′N	42°41′N
Longitude	3°3′E	2°42′E	2°29′E
Altitude (in m)	200–500	400–600	800–900
Geology	Granitoides, gneiss	Schist	Granites, proximity of limestone
Average annual temperature	13 °C	12 °C	10 °C
Precipitation/year (in mm)	800–900	900–1,000	1,000–1,100
Dominant trees	*Quercus suber*	*Quercus ilex*	*Prunus spinosa*
	Q. ilex	*Q. pubescens*	*Quercus pubescens*
Dominant shrubs	*Erica arborea*	*Erica arborea*	*Cistus laurifolius*
	Cistus monspeliensis	*Caluna vulgaris*	*Rubus sp*
	Ulex parviflorus	*Genista pilosa*	*Sarothamnus scoparius*

few species such as Melitaeini and *Leptidea reali*, identity was confirmed by preparing genitalia. For this last tribe, we based our nomenclature on that of Zimmermann et al. (1999). Naming follows the proposals of www.leps.it.

Data analysis

Distance method

An original approach of hierarchical classification was performed. By using the different ecological traits of each of the species found, we assimilated them to characters to achieve a network of inter-relationships between taxa. Being convinced that such rough groupings (even though we checked for the presence of a potential host-plant) are often invalid (Shreeve et al. 2001; Soberon and Townsend-Peterson 2005), this preliminary analysis should detect if, due to local conditions in our sampling zones, some species are miss-placed when analysing distribution patterns.

The species were classified according to two main ecological criteria: the openness of the terrain and humidity factors. For both these main criteria three sub-categories were defined.

For terrain openness, a hierarchical gradient was defined:

1. Grassland, open field without shrubs over 30 cm.
2. Shrub areas, up to the forest zone, where trees accounted for less than 10 % of the cover.

Table 2 Description and treatment characteristics of the three study sites

	Argèles-sur-mer	Calmeilles	Campoussy
Region	Albères	Aspres	Fenouillèdes
Management in 2000	Undergrowth clearing in Zones A (100 %) and B (75 %) + fencing in Zones A and B	Undergrowth clearing in Zones A (100 %) and B (75 %) + fencing in Zones B and C	Total clearing in Zones A (100 %) and B (95 %)
Management in 2001	Fencing in Zone C	Fencing in Zone A	No treatment
Zone A surface area (ha)	6.82	13.48	15.06
Zone B surface area (ha)	11.6	10.85	12.36
Zone C surface area (ha)	51.13	45.94	1.49
Pasture	Goats	Cows	Cows
Total surface area (ha)	70	70	28.91

See text to explain the small surface of Zone C Campoussy

3. Forest zones including edges (mainly composed of shrubs).

Humidity conditions were divided into the three following categories: xeric, mesophilic and hydrophilic.

Many species have a potential habitat covering two or more of our categories (according to various field guides and our own experience). However, most are observed to occur preferentially in one habitat type. Note that, some species which live strictly in dry habitats in Northern Europe prefer relatively cool damp conditions in Mediterranean areas. In our ecological matrix, we coded: 0 for absent or very rare, 1 for regular occurrence in a biota and 2 for a clear preference.

Distance trees were dealt with using the same principle except that we took into account the presence (1)/absence (0) of species in each location studied. Only species forming a potential population were included in the final analysis (at least two specimens sampled and the presence of a potential host plant, data not shown).

All analyses were performed using Paup* 4.0b10 software (Swofford 2002). All heuristic searches for optimal trees were carried out by TBR (tree-bisection–reconnection) branch swapping. Negative branch lengths were allowed, but set to zero for tree-score calculations. The steepest descent option was not in effect. Distance measurement used mean character difference. Starting tree(s) were obtained by neighbour joining.

As our intention was not to perform a phylogenetic classification, we decided not to include any outgroups in our data set. The distance trees obtained are represented unrooted. When multiple sub-equal trees were found, a Majority Rule (50 %) consensus tree was calculated. Bootstrap values were not calculated as no information was available from the literature to judge if such treatment was relevant using ecological characters and furthermore because we did not perform a character-state treatment (parsimony). A pattern code was attributed to each species depending on distribution type and place on the distance trees. The code was determined from the neural network results.

Considering the specificity per zone inside locations, we checked if specialized species were more represented in conserved areas (corresponding to Zones C) rather than in managed areas (Zones A and B). Species specific to one zone or mainly found in one zone are expected to be in the same clade. Species encountered in Zone C are circled.

Modelling species assemblages

Inspired by the structure and the mechanism of the human brain, Artificial Neural Networks (ANNs) provide convenient tools to maximize the information extracted from "simple" presence-absence data (Lek and Guégan 2000). The Self-Organizing Map (SOM, unsupervised neural network, Kohonen 2001) performs a topology-preserving projection of the input data onto regular two-dimensional space. In the output layer of the network the neurons act as virtual samples and approximate the probability density function of the input data. Therefore, using a binary dataset of species occurrences, the SOM calculates continuous quantitative values which vary between 0 and 1, so that the occurrence probability of any species in a given area, in the form of a connection intensity (visualized in gray shades), can be visualized on a virtual map. Additionally, the SOM algorithm averages the input dataset using weight vectors and thus removes noise. These features were relevant in our study because we analysed a binary dataset with many zeroes. The SOM Toolbox (version 2) for Matlab® developed by the Laboratory of Information and Computer Science at the Helsinki University of Technology (http://www.cis.hut.fi/projects/somtoolbox/) was used (see Vesanto et al. 1999 for practical instructions).

The structure of the SOM for our study consisted of two layers of neurons connected by weights (i.e., connection intensities): the input layer was composed of 80 neurons (one per species) connected to the 18 samples (3 sites × 3 zones × 2 years), the output layer was made up of 21 neurons (visualized as hexagonal cells) organized in an array with 7 rows and 3 columns. In the output layer, the neurons act as virtual sites and approximate the probability density function of the input data. The occurrence probability of each species in a given area in the form of the connection intensity was visualized on the SOM map in grey scale, and therefore allowed us to predict the occurrence probability of each species in the various geographic areas. The SOM algorithm is an unsupervised learning procedure which can be summarised as follows:

- The virtual sites are initialised with random samples drawn from the input data set.
- They are updated in an iterative way:
    - A sample unit is randomly chosen as an input unit.
    - The Euclidean distance between this sample unit and every virtual site is computed.
    - The virtual site closest to the input is selected and called 'best matching unit' (BMU).
    - The BMU and its neighbours are moved a bit towards the input unit.
- Training was broken down into two parts previously defined in Lek and Guégan (2000):
- Ordering phase (the 2,000 first steps): when this first phase takes place, the sites are highly modified in a wide neighbourhood of the BMU.
- Tuning phase (75,000 steps): during this phase, only the virtual sites adjacent to the BMU are slightly modified.

The network was trained with different map sizes (from 10 to 200 units), and the optimum map size was chosen based on local minimum values for quantization and topographic errors (see Céréghino and Park (2009) for practical considerations). Quantization error (QE) is the average distance between each data vector and its BMU and, thus, measures map resolution (Kohonen 2001). Topographic error (TE) measures map quality (i.e., to assess whether the map has been properly trained), it represents the proportion of all data vectors for which 1st and 2nd BMUs are not adjacent, and is thus used for the measurement of topology preservation. The total of 21 output neurons retained for this study fits the heuristic rule proposed by Vesanto and Alhoniemi (2000) who reported that the optimal number of map units is close to $C = 5\sqrt{n}$, where n is the number of samples. 18 samples were classified on the basis of eight environmental variables. At the end of the learning process, each sample was set in the corresponding hexagon of the SOM. Neurons that are neighbours on the grid are expected to represent neighbouring clusters of samples; consequently, samples separated by a large distance from each other, according to species assemblages, are expected to be distant in the output space.

Ward's algorithm was applied to the weight vectors of the 21 neurons in order to divide the SOM units (hexagons) into clusters.

Analysis and interpretation

The occurrence probability of each species in a given area in the form of the connection intensity was visualized on the SOM map (in gray scale), and therefore allowed us to predict the occurrence probability of each species in areas (i.e., subsets of sites, or clusters) where they were not consistently collected during the sampling. In other words, the patterns of distribution for each Lepidoptera species among the various sites become apparent by superimposing the various species maps on the clustering of sites observed in the SOM map. This treatment allowed us to determine qualitatively and quantitatively (see Fig. 3b) the specificity of distribution of each species among the three Mediterranean locations studied (Arg: dry and low elevation, Cal: cooler and low elevation, CAM: cooler and higher elevation). A completely generalist species will occupy all the Kohonen map and with an almost regular probability of presence (scale of grays), and for example a specialized species for low elevation open field Mediterranean biota (Type Argeles) will show only a few hexagons filled with a high probability (black) on the bottom right of the SOM grid. These two extreme situations never strictly occurred, but some dominant patterns are visible which allowed us to qualify the specificity of each species sampled, see Fig. 3c where a few examples of the different situations are shown.

A comparison was performed between the theoretical habitat of each species and results obtained using the SOM approach in order to test our a priori hypothesise. When congruence was found: we noted Y; when congruence was not found: N and finally, when a species is considered as generalist for one approach (theoretical or observed) and considered as specialist for the other, we noted: 0.

Results

The species of Rhopalocera (including Hesperiidae) collected in 2000 and in 2001 are presented in Table 3 with their respective occurrences by zone.

The three localities were not equivalent in numbers of species: we recorded 37 species in Argelès (ARG); 47 in Calmeilles (CAL) and 57 in Campoussy (CAM) i.e. there were large differences between the three study zones.

Using data from the literature (Geiger 1987; Lafranchis 2000) and personal observations in other regions, a first

Table 3 Samples collected at the three study sites

Species	Argelès sur mer						Calmeilles						Campoussy					
	Zone A		Zone B		Zone C		Zone A		Zone B		Zone C		Zone A		Zone B		Zone C	
	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001
Carcharodus alceae													x	x	x	x		
Hesperia comma														x		x		
Pyrgus armoricanus														x		x		
Pyrgus cirsii										x								x
Pyrgus malvoides											x							
Pyrgus serratulae														x		x		
Thymelicus acteon																	x	
Thymelicus sylvestris														x		x		x
Aricia agestis	x	x	x	x						x							x	
Callophrys avis					x													
Callophrys rubi			x		x								x		x		x	x
Celastrina argiolus	x	x		x		x				x	x	x		x		x		
Favonius quercus	x		x				x			x	x	x						
Glaucopsyche alexis											x							
Glaucopsyche melanops									x									
Lampides boeticus								x		x				x		x		
Leptotes pirithous		x			x	x		x	x	x								
Lycaena alciphron														x		x		
Lycaena phlaeas	x	x	x	x				x		x			x	x	x	x	x	x
Polyommatus bellargus									x	x				x		x		
Polyommatus coridon													x	x	x	x	x	x
Polyommatus escheri														x		x		
Polyommatus hispana													x		x			
Polyommatus icarus	x	x	x	x	x	x	x	x	x	x	x		x	x	x	x	x	x
Polyommatus thersites									x									
Satyrium acaciae														x		x		x
Satyrium esculi	x	x	x	x	x	x	x	x	x	x	x	x						
Satyrium ilicis							x	x				x	x		x			
Aglais urticae			x															
Arethusana dentata													x	x	x	x	x	x
Argynnis adippe													x	x	x	x		
Argynnis aglaja													x	x	x	x	x	x
Argynnis pandora							x										x	

Table 3 continued

Species	Argelès sur mer						Calmeilles						Campoussy					
	Zone A		Zone B		Zone C		Zone A		Zone B		Zone C		Zone A		Zone B		Zone C	
	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001
Argynnis paphia							x	x	x	x	x	x						
Brintesia circe		x						x	x		x	x	x	x	x	x	x	x
Charaxes jasius	x				x	x				x	x							
Chazara briseis														x		x		
Clossiana dia										x	x		x	x	x	x	x	x
Coenonympha arcania												x					x	x
Coenonympha dorus								x			x							
Coenonympha pamphilus										x			x	x	x	x	x	x
Cynthia cardui	x	x	x	x	x	x	x		x		x		x	x	x	x		x
Hipparchia alcyone							x				x		x	x	x	x	x	x
Hipparchia fidia					x													
Hipparchia semele					x	x		x			x	x	x	x	x	x		x
Hipparchia statilinus								x				x	x	x	x	x		x
Issoria lathonia	x												x	x	x	x	x	x
Lasiommata megera	x	x	x		x	x	x	x	x	x	x		x	x	x	x	x	x
Libythea celtis			x								x							
Limenitis reducta								x		x							x	
Maniola jurtina	x	x				x				x	x	x	x	x	x	x	x	x
Melanargia lachesis	x	x	x										x	x	x	x	x	x
Melitaea celladusa							x	x	x		x	x	x	x	x	x	x	x
Melitaea cinxia														x		x	x	x
Melitaea didyma													x	x	x	x	x	x
Melitaea parthenoides							x										x	
Melitaea phoebe													x	x	x	x		x
Nymphalis antiopa											x							
Pararge aegeria	x	x	x	x	x	x	x		x	x	x	x	x	x	x	x		
Pyronia bathseba						x			x	x								
Pyronia caecilia					x	x												
Pyronia tithonus								x			x		x	x	x	x	x	x
Satyrus actaea						x												
Satyrus ferula													x		x			
Vanessa atalanta		x		x	x	x	x	x				x						
Iphiclides feisthamelii						x	x	x	x	x	x	x	x		x		x	

Table 3 continued

Species	Argelès sur mer						Calmeilles						Campoussy					
	Zone A		Zone B		Zone C		Zone A		Zone B		Zone C		Zone A		Zone B		Zone C	
	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001	2000	2001
Papilio machaon	x	x											x	x	x	x		
Anthocharis cardamines					x								x	x	x	x	x	x
Aporia crataegi													x	x	x	x		x
Colias crocea	x	x			x	x		x	x	x			x	x	x	x	x	x
Colias hyale										x			x		x			x
Euchloe ausonia						x												
Gonepteryx cleopatra	x	x	x	x	x	x	x	x		x	x			x		x	x	x
Gonepteryx rhamni								x				x						
Leptidea reali							x			x								
Pieris brassicae	x	x	x	x	x		x	x		x	x		x	x	x	x		x
Pieris mannii		x																
Pieris napi	x	x		x			x				x		x		x			
Pieris rapae	x	x	x		x			x		x	x	x	x	x	x	x	x	
Pontia daplidice					x	x								x		x	x	
Number of species	23		18		25		30		31		31		50		50		41	

Occurrences depending on treatment zone and year

Species are presented by families: Hesperiidae, Lycaenidae, Nymphalidae, Papilionidae and Pieridae. Same presentation in Table 4

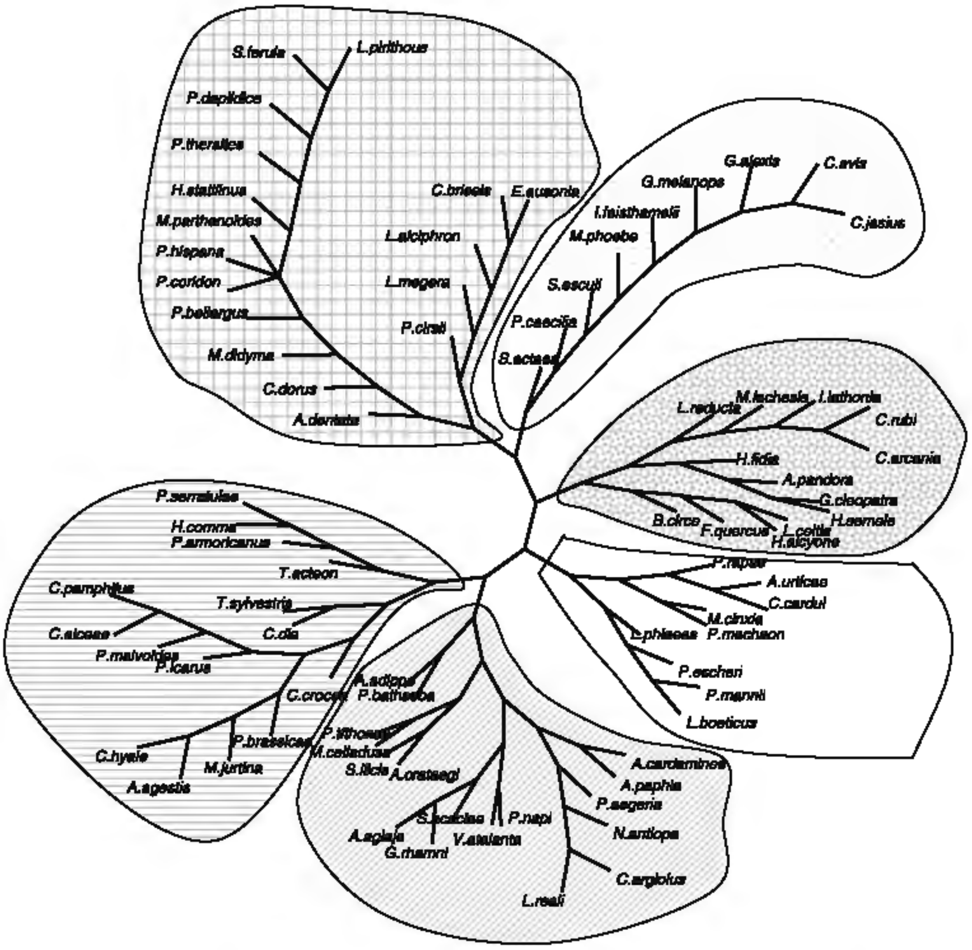


Fig. 2 Distance tree (Heuristic search): Theoretical functional groups and classification depending on preference of biota of Lepidoptera according to the literature (see text) and personal observations. ▦ xeric/open rather than shrubs, ☐ xeric/shrubs, ▒ xeric/trees and shrubs, ☐ generalist, ▨ humid/trees and shrubs, ▤ humid/open

grouping of species was performed and some functional groups were defined independently of collection locations. The 80 species collected were classified depending on their theoretical ecological constraints (Fig. 2; Table 4). Functional groups are defined and no species were found to be outside or isolated from their respective theoretical group. In particular, there is a clear separation between xeric and meso/hydrophilic species.

Study by site

Using the SOM, we checked what the groupings were for the sampling sites independently of years, on the basis of Lepidoptera species occurrences.

A first result is that main associations are by site, but not by fire prevention management treatment (Fig. 3a). The locality of Campoussy (CAM) is notably different from the two others. Moreover, except for calB01 (Calmeilles, Zone B, year 2001) the two sites Calmeilles and Argeles are not mixed. These last two sites are warmer and are also situated at lower elevations than Campoussy (Table 1). We may group CAL + CAM in terms of coolness, CAL + ARG for low elevation Mediterranean biota and CAM + ARG for being more open fields (Fig. 3a).

Except for Campoussy, but due to local conditions and because the local farmer was not applying the fire prevention procedure strictly (see "Materials and methods" section) no groupings by zones or year emerged.

Distribution specificity of Lepidoptera

The SOM treatment shows the level of specificity of each species for a type of location and/or a specific type of fire prevention management (Fig. 3b). In our study, 36 % (29 out of 80) of the butterflies encountered showed habitat specificity in the field and additively 23 % (18 out of 80) of species tended to occupy just one type of habitat. Finally, for 41 % (33 out of 80) we were unable to assign a special type of habitat in the limited context of the locations studied and considering the resolution of our treatment.

A selection of the different patterns encountered is given in Fig. 3b.

The first line of Fig. 3b represents generalist species, the first two are widespread and common in Europe (*Pieris*

Table 4 Theoretical versus observed distributions (SOM analysis) of the 80 species contacted

Species	Theoretical grouping	SOM pattern observed distributions	Probability collection (%)	Congruence Theo/Obs
Carcharodus alceae	Humid/open	Northern cool specialist	73	Y
Hesperia comma	Humid/open	Northern cool specialist	63	Y
Pyrgus armoricanus	Humid/open	Northern cool specialist	63	Y
Pyrgus cirsii	Xeric/open	Southern dry generalist	23	Y
Pyrgus malvoides	Humid/open	Northern cool generalist	34	Y
Pyrgus serratulae	Humid/open	Northern cool specialist	63	Y
Thymelicus acteon	Humid/open	Northern cool specialist	34	Y
Thymelicus sylvestris	Humid/open	Northern cool specialist	78	Y
Aricia agestis	Humid/open	Generalist	81	0
Callophrys avis	Xeric/shrubs	Strict Mediterranean	23	Y
Callophrys rubi	Xeric/trees and shrubs	Northern cool generalist	97	N
Celastrina argiolus	Humid/trees and shrubs	Generalist	77	0
Favonius quercus	Xeric/trees and shrubs	Generalist	71	0
Glaucopsyche alexis	Xeric/shrubs	Southern dry generalist	30	Y
Glaucopsyche melanops	Xeric/shrubs	Strict Mediterranean	24	Y
Lampides boeticus	Generalist	Generalist	70	Y
Leptotes pirithous	Xeric/open	Southern dry generalist	71	Y
Lycaena alciphron	Xeric/open	Mediterranean hill specialists	63	Y
Lycaena phlaeas	Generalist	Generalist	100	Y
Polyommatus bellargus	Xeric/open	Generalist	70	0
Polyommatus coridon	Xeric/open	Northern cool specialist	99	N
Polyommatus escheri	Generalist	Mediterranean hill specialists	63	0
Polyommatus hispana	Xeric/open	Mediterranean hill specialists	71	Y
Polyommatus icarus	Humid/open	Generalist	100	Y
Polyommatus thersites	Xeric/open	Strict Mediterranean	24	Y
Satyrium acaciae	Humid/trees and shrubs	Northern cool specialist	78	Y
Satyrium esculi	Xeric/shrubs	Generalist	100	0
Satyrium ilicis	Humid/trees and shrubs	Generalist	71	0
Aglais urticae	Generalist	Generalist	23	0
Arethusana dentata	Xeric/open	Mediterranean hill specialists	99	Y
Argynnis adippe	Humid/trees and shrubs	Northern cool specialist	73	Y
Argynnis aglaja	Humid/trees and shrubs	Northern cool specialist	99	Y
Argynnis pandora	Xeric/trees and shrubs	Generalist	34	0
Argynnis paphia	Humid/trees and shrubs	Generalist	90	0
Brintesia circe	Xeric/trees and shrubs	Generalist	99	0
Charaxes jasius	Xeric/shrubs	Southern dry generalist	53	Y
Chazara briseis	Xeric/open	Mediterranean hill specialists	63	Y
Clossiana dia	Humid/open	Northern cool generalist	99	Y
Coenonympha arcania	Xeric/trees and shrubs	Generalist	43	0
Coenonympha dorus	Xeric/open	Southern dry generalist	60	Y
Coenonympha pamphilus	Humid/open	Northern cool generalist	99	Y
Cynthia cardui	Generalist	Generalist	95	Y
Hipparchia alcyone	Xeric/trees and shrubs	Northern cool generalist	99	N
Hipparchia fidia	Xeric/trees and shrubs	Strict Mediterranean	23	Y
Hipparchia semele	Xeric/trees and shrubs	Generalist	95	0
Hipparchia statilinus	Xeric/open	Generalist	95	0
Issoria lathonia	Xeric/trees and shrubs	Northern cool specialist	99	N

Table 4 continued

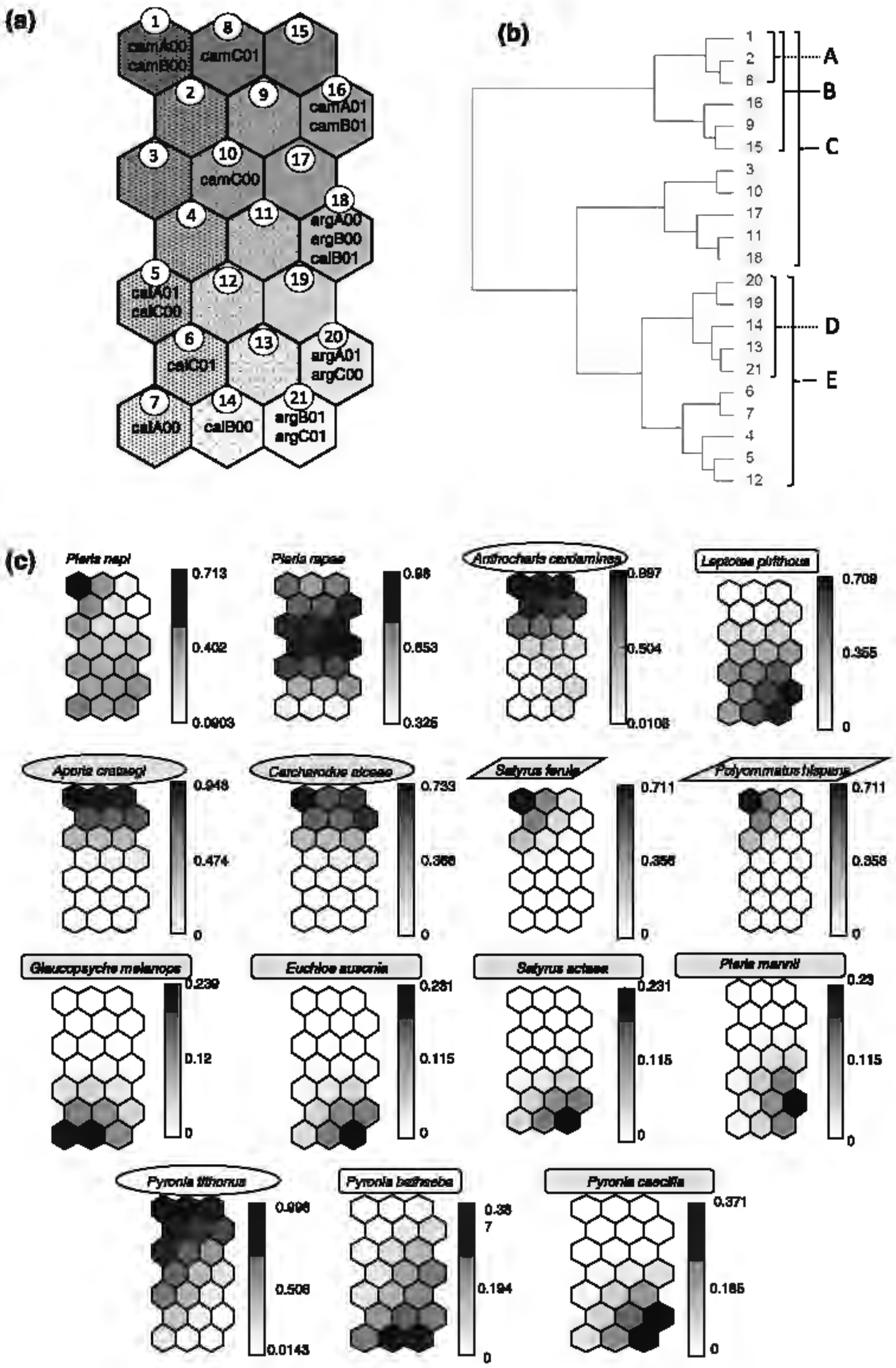
Species	Theoretical grouping	SOM pattern observed distributions	Probability collection (%)	Congruence Theo/Obs
Lasiommata megera	Xeric/open	Northern cool generalist	100	N
Libythea celtis	Xeric/trees and shrubs	Generalist	31	0
Limenitis reducta	Xeric/trees and shrubs	Generalist	49	0
Maniola jurtina	Humid/open	Generalist	100	0
Melanargia lachesis	Xeric/trees and shrubs	Northern cool generalist	100	N
Melitaea celladusa	Humid/trees and shrubs	Generalist	100	0
Melitaea cinxia	Generalist	Northern cool specialist	84	0
Melitaea didyma	Xeric/open	Northern cool specialist	94	N
Melitaea parthenoides	Xeric/open	Generalist	34	0
Melitaea phoebe	Xeric/shrubs	Northern cool specialist	95	N
Nymphalis antiopa	Humid/trees and shrubs	Generalist	30	0
Pararge aegeria	Humid/trees and shrubs	Generalist	99	0
Pyronia bathseba	Humid/trees and shrubs	Southern dry generalist	39	N
Pyronia caecilia	Xeric/shrubs	Strict Mediterranean	37	Y
Pyronia tithonus	Humid/trees and shrubs	Northern cool generalist	100	Y
Satyrus actaea	Xeric/shrubs	Strict Mediterranean	23	Y
Satyrus ferula	Xeric/open	Mediterranean hill specialists	71	Y
Vanessa atalanta	Humid/trees and shrubs	Generalist	83	0
Iphiclides feisthamelii	Xeric/shrubs	Southern dry generalist	95	Y
Papilio machaon	Generalist	Northern cool generalist	73	0
Anthocharis cardamines	Humid/trees and shrubs	Northern cool generalist	99	Y
Aporia crataegi	Humid/trees and shrubs	Northern cool specialist	95	Y
Colias crocea	Humid/open	Generalist	99	0
Colias hyale	Humid/open	Northern cool generalist	93	Y
Euchloe ausonia	Xeric/open	Strict Mediterranean	23	Y
Gonepteryx cleopatra	Xeric/trees and shrubs	Generalist	99	0
Gonepteryx rhamni	Humid/trees and shrubs	Generalist	48	0
Leptidea reali	Humid/trees and shrubs	Generalist	33	0
Pieris brassicae	Humid/open	Generalist	95	0
Pieris mannii	Generalist	Strict Mediterranean	23	0
Pieris napi	Humid/trees and shrubs	Generalist	71	0
Pieris rapae	Generalist	Generalist	98	Y
Pontia daplidice	Xeric/open	Generalist	70	0
	Bio-indicator species	29/80 = 36 %		N = 11 %

Probabilities of collection given in %. Evaluation of the congruence theoretical/observed

Evaluation of the congruence: Y (yes), N (no) 9/80 species, 0: compatible but not positive or negative (see also "Results" section)

napi and *Pieris rapae*). Note that the maximum probability of presence of collection for *P. napi* was lower than *P. rapae* (71 vs. 98 %, respectively). The third, *Anthocharis cardamines,* occurred dominantly in the cooler area which is logical knowing that this species possesses its main distribution in Northern Europe. In opposition, the fourth species *Leptotes pirithous* is a Mediterranean species which is less common in cool areas even though it is widely distributed in the region studied (partially migratory species).

The second line of Fig. 3b can be separated into two groups. Species whose main distribution is in the North of Europe (species at the southern limit of their distribution e.g. *Aporia crataegi* and *Carcharodus alceae*) and species highly specialized for hills/mountainous Mediterranean biota (*Satyrus ferula* and *Polyommatus hispana*). The pattern of the Kohonen map is of the same type in both these cases (only the upper part of the grid filled) but the specialized Mediterranean mountain species show less covering of the SOM map.



The third line of Fig. 3b is composed of strictly Mediterranean species (*Glaucopsyche melanops*, *Euchloe ausonia*, *Satyrus actea*, *Pieris mannii*). It is notable that the probability of collection was much lower than for generalist species indicative of the endangered status of these species (average = 23.3 %).

Finally the fourth line shows the specificities of the three European *Pyronia* species (*P. tithonus*, *P. bathseba* and *P. caecilia*). *Pyronia tithonus* presents an ample distribution in northern Europe and was mainly found in the coolest location. *Pyronia bathseba* is a southern species but prefers cooler humid zones. Finally *P. caecilia* is a strict

Fig. 3 **a** Kohonen (SOM) map of the three fire prevention managements for the three studied sites for 2 years depending on occurrences of Lepidoptera species and variations of abiotic conditions. Gradients: *vertical*; from white (hot) to *dark gray* (cooler), *horizontal from dotted* (fresh/humid) to *no dots* (dry). *Circled* in *white* are numbers corresponding to those indicated in **b** (see also Table 3 for more details). **b** Clustering of the 21 SOM neurons using Ward's algorithms. Numbers as in **a** (*circled in white*). Biota specificity of each butterfly species (**c**) is determined by checking occurrences in the various clusters defined here: *A*: Mediterranean hill specialist (Neurons 1, 2, 8); *B*: Northern cool specialist species (Neurons 1, 2, 8, 9, 15, 16); *C*: Northern cool generalist species (Neurons 1, 2, 8, 9, 15, 16, 3, 10, 17, 11, 18); *D*: strict Mediterranean species (Neurons 20, 19, 14, 13, 21); *E*: Southern dry generalist species (Neurons 20, 19, 14, 13, 21, 6, 7, 4, 5, 12). Generalist species are determined when SOM patterns are almost equally distributed between *C* and *E*. **c** Gradient analysis of the probability of occurrence of 15 selected butterfly species on the trained SOM, with visualization in shading scale (*dark* high probability of occurrence, *light* low probability of occurrence). Each little map is to be compared, or superimposed on the map in **a** for location. Species name above the map highlighted using symbols: *No symbols*: generalist species, *circled* + *white*: Northern cool generalist species, *rectangular* + *white*: Southern dry generalist species, *circled* + *gray*: Northern cool specialist species, *trapezoidal* + *gray*: Mediterranean hill specialists and *rectangular* + *gray*: strict Mediterranean species

Mediterranean species, which occurs only in the driest and warmest locations. This last example illustrates the specificity and the resolution level of our treatment. The probability of collection of the two most restricted species (average = 37.9 %) was notably lower than for the generalist species (99.8 %).

Complete results are given in Table 4 and an evaluation of the congruence between theoretical (results of Fig. 2) and SOM treatment (Fig. 3) was provided.

Note that probability of collection was notably different between generalist and specialized species (Table 4) 80 ± 20 versus 63 ± 35 % even though SD values are high. The values became really low when considering only the strict Mediterranean species with 25 ± 5 %.

Search for functional groups of species

In order to check if species can be grouped depending on their specificity, we built distance trees using the methodology described in "Materials and methods" section. This original approach provides a per-site image of the association of species in each location. The trees are a superimposition of ecological factors (same matrix as the one used to construct Fig. 2) and local occurrences (presence/absence by zone/year and location; Fig. 3b).

Except for very few species, separation between cool/humid areas and hot/dry areas is visible. Grouping by level of openness of the area was also observed.

Considering fire prevention management treatments, the only clear results were for the locality of Argelès, most species specialized for dry Mediterranean areas are grouped in Zone C (circled; Fig. 4a). For the locality of Calmeilles, species encountered in Zone C were mainly thermophilic preferring open or bushy areas but included species with a wide geographical distribution (Fig. 4b). Finally, even though it is the most diverse location in terms of species number, the locality of Campoussy did not give any significant results and, furthermore, most of the specialized species of mountainous Mediterranean areas (in purple) were absent from Zone C (Fig. 4c).

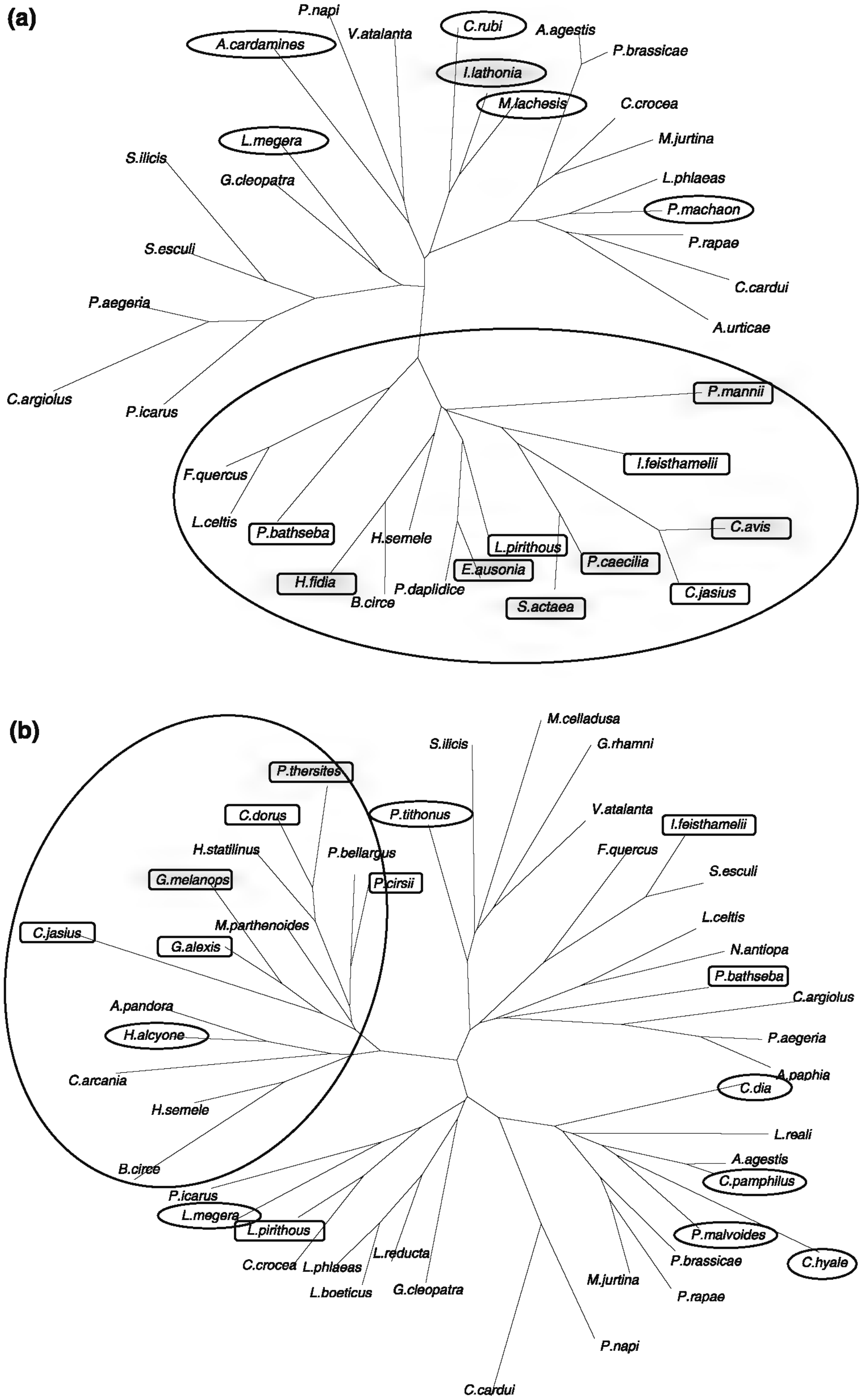
Discussion

Specificity of Lepidoptera habitat

Some Lepidoptera species have been shown to possess high habitat specificity (Geiger 1992; Luque et al. 2007). Caterpillars are much more reliable to prove the presence of a population but as one of the aims of our study was to design an approach that non-specialists would be able to follow i.e. the dynamics of butterfly communities and the influence of fire cuts, we preferred to use adults. In any case, the presence of at least one potential host plant was checked for every species (data not shown). Caterpillars possess the main disadvantage of being more difficult to find (some live in trees, others are mainly nocturnal) and are, most of time, much more difficult to identify.

Some Lepidoptera species were found in the field in full accordance with their theoretical habitat but a certain number were found to be in discordance with it, similar results were pointed out in the South West of France (Van Halder et al. 2011). This was especially true for species found strictly in or on the edge of "maquis" (dense Mediterranean scrub/woodland in granitic areas) as these species were assumed to be open-field specialists (*Glaucopsyche. melanops, Glaucopsyche alexis, Pyrgus cirsii, Euchloe ausonia,* and *Satyrus actaea*). Our interpretation is that these species are the most sensitive to the management of their biota and may survive only in the few open areas close to or in this type of Mediterranean forest. Some theoretically open-field species were also found preferentially in the "maquis" such as *Thymelicus acteon, Polyommatus thersites, Pyrgus malvoides* or even *Coenonympha arcania*, but a more plausible explanation is that these species, widely distributed in Northern Europe, prefer cool refuges in more bushy/forest areas when living in sometimes extremely hot Mediterranean locations (Stefanescu et al. 2004). When comparing species with rather similar ecological demands such as the big Satyrinae (*Chazara briseis, Satyrus ferula, Satyrus actaea* and *Hipparchia fidia*), we found that the two with the widest ranges (in France, *C. briseis* and *S. ferula* are present in many xeric locations outside the Mediterranean area (Lafranchis 2000)) are less sensitive to management.

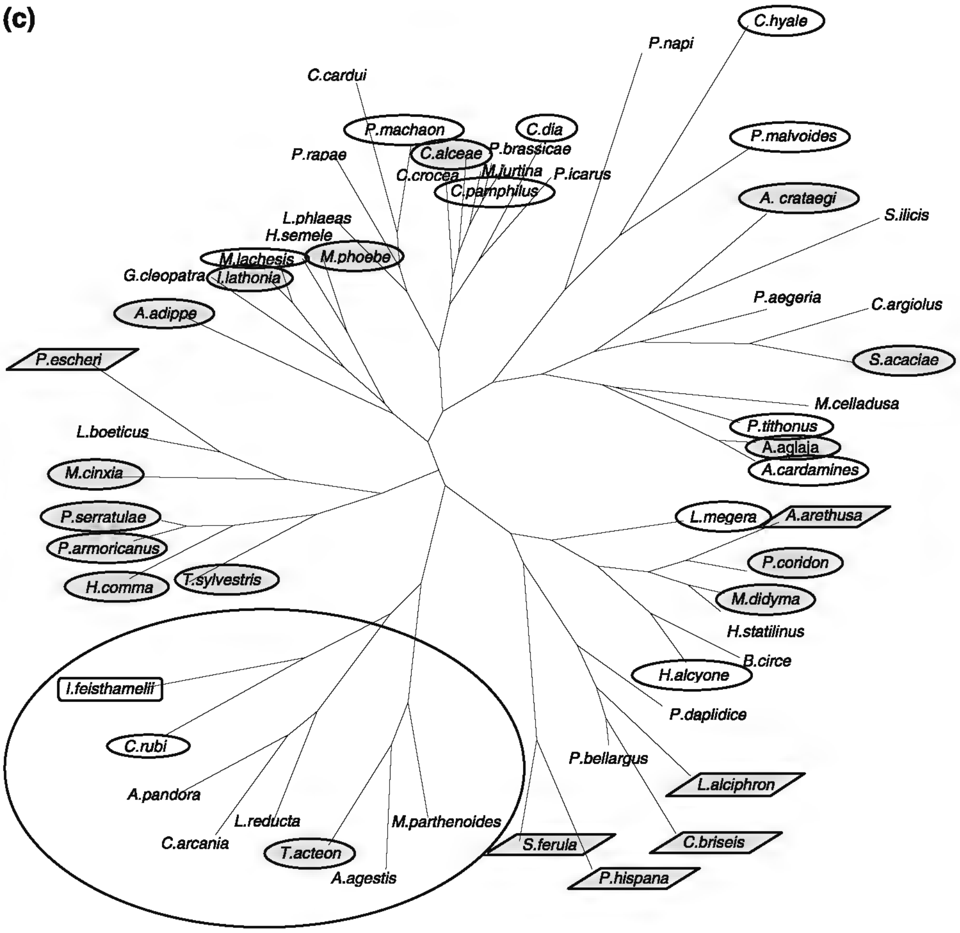
Fig. 4 Heuristic distance trees for each of the sites studied depending on occurrences of species on the three fire prevention management types. **a** Argelès, **b** Calmeilles, **c** Campoussy. *Circled* species occurring with preference in Zones "C" when relevant. Each species is *highlighted* with the corresponding pattern deduced from the SOM treatment



On the other hand, the two strictly Mediterranean species (*S. actaea* and *H. fidia*) seem to need the stability of their original biota (none or a type C fire prevention management) to maintain a population.

The total number of species collected in the various zones for each site was fairly stable. Maximum stability was found in Calmeilles where, surprisingly, for both years of collection, we found exactly 30, 31 and 31 species for

Fig. 4 continued



Zones A, B and C respectively. The endemic fauna is perturbed and new, so-called "anthropomorphic" species appear. Most are strictly open field species and live on host-plants favoured by human activity such as Urtica or Brassicaceae.

In the South West of France, Van Halder et al. (2011) found that, for a limited number of butterfly species (23) 12 showed habitat specificity (7 for edges, 5 for inner forest), while 11 were not specific. Moreover, some species which were defined as generalists in our study can become specific when changing sampling scale (a good example is *S. esculi*, which was present and common in our three locations, therefore: generalist in our study, but which could be specific if some of our sampling sites were situated outside the Mediterranean region).

Impact of fire prevention management on Lepidoptera

Our distance approach allowed us to present a possible grouping of species. These distance approaches (phenetic) are designed for phylogenetic studies and more recently have been applied to the study of populations using cuticular markers (Roux et al. 2006) but have never been used with ecological constraints. We attempted to compare our approach with more classical ACP and canonical approaches, but the resolution obtained with such methods was very poor.

Our analysis shows us that only when experimental conditions are strictly applied by field managers is it possible to reach interpretable results. In the case of Argelès, fire prevention management was strictly applied under our proposed specifications. In Calmeilles, treatment was well done but Zone B was not in direct contact with the two other zones (500 m away). Finally Zone B of Campoussy was totally cleared (Zone A type treatment) and we managed to stop field managers before Zone C was heavily damaged too. A special mention in this locality, as many specialized Mediterranean species prefer open field conditions, they are naturally absent from type C Zones.

Such management problems are finally very informative as they show the high sensitivity of our statistical treatments to define functional groups. Anyway, there is some serious support for the functional groups as our results for the locality of Argelès clearly show that specialized species prefer conserved habitats when available. In the two other locations, some specialized species were able to survive and were found flying in disturbed areas as long as some patches of host plants remain.

Fire prevention management therefore favoured some generalist species but damaged populations of specific/endemic Lepidoptera but also other insects (Fowles et al. 2004, Quartau 2009). However, it seems that the resilience of these insects is high (Fowles et al. 2004; Luque et al. 2007) as shown between our 2 years of collection (especially clear for CAM). That is why a balance must be drawn between the efficiency of complete cuts ("Zone A" type) to protect Mediterranean forest and long-term damage to populations of specialized Lepidoptera (Warren et al. 1987) even if such policies show a high level of efficiency in comparable areas (Collins and Stephens 2007). Our approach therefore clearly shows for the first time that, in choosing between the degrees of fire protection afforded by the different types of measure studied here, the degree of disturbance to native fauna should also be taken into account. Although treatments A and B, do not change people's global perception (Ricouart 2005) of the landscape, maintaining the same number of butterflies species in each type of treatment area, they significantly reduce populations of specialized and endemic insects of the zone to be protected from fires. The present results involving granitic areas are furthermore congruent with some studies done in calcareous areas where persistence of sheltered areas (our type C) favoured endemic/specialized species while opening of the forest and colonization by grasses (our types A and B) represents a negative factor which favoured generalist/migrating species (Rosin et al. 2011). Therefore, from an angle of conservation of endemic/specific species our results indicate that the type C management approach should be favoured whenever possible mainly for species naturally living in shrub/forest biota.

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