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URBAN PERMEABILITY: A MULTIDISCIPLINARY APPROACH TO STUDY TURIN BUTTERFLY MOBILITY

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1 Introduction

On a global scale, most people live in urban landscapes (55% of global population) but 70% of the world's population is expected to live in urban areas by 2050 (UNDESA, 2018). Today, Europe is the third most urbanised region in the world, with 73% of the population living in cities (after North and South America; UNDESA, 2018). The effects of this phenomenon are different and some still need to be discovered. However, some direct effects have been already recorded, in particular changes on land surface, which was considered transformed by one-third already in 1997 (Vitousek et al., 1997). Moreover, the effects on understanding, connection and perception of nature on human beings, are clear and studied at multidisciplinary level. Nowadays urban expansion is one of the global threats of biodiversity (Seto et al., 2012). Considering that conserving biodiversity is a major 21st-century challenge (EU Biodiversity Strategy for 2030), the number of studies on the urban environment is growing. Although human settlements affect the environment in different ways, recently not all effects are considered negative (Niemelä et al., 2011). Indeed, urban habitats can support different biodiversity components in relation to the availability of resources, such as for pollinators are pollen, nectar and nesting resources (Cane, 2005).

Environment loss, fragmentation and disruption of connectivity can negatively influence the persistence of populations (Hanski, 1999; Komonen et al., 2008). On the other hand, the ability to move will affect the probability of survival in fragmented landscapes, as suggested by population dynamics models (Barbaro & Van Halder, 2009; C. D. Thomas, 2000). Indeed, species with low mobility can be more subject to decline with respect to high-mobility ones. Species with high dispersal ability can more easily move and colonise new portions of habitat (Magura et al., 2015). Generally, large patches have been considered to support higher biodiversity (Wilson & Willis, 1975), however recent studies suggest that even several small patches can support species (e.g. Riva & Fahrig, 2023). Although the fragmentation level of urban landscapes is high, species-specific factors, such as mobility, need to be considered. The urban areas can work as a filter against low-mobility species (Sattler et al., 2010; Rochat et al., 2017).

Insect communities for their survival in a long-term scenario rely on habitat connectivity (Samways et al., 2020). Among them, butterflies are often the most studied and known and through their protection it is possible to maintain vital and functional ecosystems (Launer & Murphy, 1994; New, 1997; Macrì et al., 2023). For these and other reasons, they have been considered indicator species (Maes & Van Dyck, 2001; J. Thomas, 2005). Moreover, butterflies are quite easy to identify at species level. In previous studies, butterflies were already considered a good indicator in urban environments, and the pressure on the communities was already assessed (Jones et al., 2013; Ramírez-Restrepo & MacGregor-Fors, 2017).

Several species of butterflies are threatened (Bonelli et al., 2018). In total the IUCN assessed 1638 species of butterfly, more than 20% classified as threatened. From the same data, 219 European species were assessed, and 30% results threatened. Land use changes have been considered one of the main drivers of butterfly decline (J. A. Thomas, 2016; Warren et al., 2021), and urbanisation is a major driver of land cover change worldwide (Grimm et al., 2008). Indeed, cities are not planned to support butterfly biodiversity but a suitable management of existing and new green areas - based on scientific observations - could improve butterfly mobility and thus support a healthy community (Baldock, 2020). The greatest feature that distinguishes a natural environment from a human settlement is the presence of buildings, roads and any architectural structures which limit the other living beings in different ways. In particular, mobility of butterflies is affected by the presence of roads and buildings, which work as physical barriers and constraints (Dániel-Ferreira et al., 2022). Thus, a key point to sustain a resilient butterfly community within the city is the connection of suitable areas inside a permeable urban matrix.

1.1 The Multidisciplinary Approach

Biodiversity loss is considered a wicked problem (Sharman & Mlambo, 2012). A wicked problem is defined by Rittel and Webber (1973), as a term to indicate difficulties in planning solutions for specific complex problems. It is used to enlighten how simplistic and one-field approaches applied to complex challenges of social or environmental origin, are extremely limited (Xiang, 2013). Even in our case, this term describes the problem we are facing: the alteration of species communities and mobility due to human expansion, especially the urban environment, which today is essential for every society. Precisely for this reason, it requires changes that maintain the social advantage for people but on the other hand reduce the negative impacts on biodiversity. In this sense, new multidisciplinary approaches are required to attempt to enhance the current conditions, maintaining the complexity of the urban ecosystem.

Butterfly mobility is difficult and work-demanding to study (Stevens et al., 2010) but they are essential to understand population conservation status and to identify present and future threats. The future main goal of this project is to assess which environmental variables affect the mobility of butterflies within the city. Classical ecological methods and statistical models are extremely limited by data availability (Stevens et al., 2010). Thus, the result is the description of certain behaviour linked to collected data. However, data on mobility of butterflies through MRR are difficult to collect and are strictly lined to study area sizes and weather conditions (Čelik, 2012). An Artificial Intelligence neural network is like a black box: from input data, the learning model aims to reduce the error, finding the best fit, using the algorithm given from the coder. Thus, simulation results are the best fit for the initial set of data. In our project, the idea is to understand and foresee mobility changes of butterflies, as a group of independent individuals in the environment. This approach was applied in this project, using biological, and ecological knowledge and field-based data to model butterfly mobility with a Multi-Agent System (MAS).

A Multi-Agent System, a form of distributed artificial intelligence, are computerised systems composed of agents situated in an environment, where they can interact, among each other and with the environment itself, and behave independently and asynchronously (Durfee & Rosenschein, 1994). The agent is the core component of this type of modelization, which can be described as a computer system, situated in an environment, able to perform autonomous actions to meet designated objectives (Wooldridge & Jennings, 1995). In general, these models could be classified under the type of paradigm of reasoning process of the agent. To summarise, there are three types:

i. Reactive, such as a model that reproduces the "reasoning process" of a thermostat: a continuous input of information (air temperature detection) and direct response (reduction or increase of temperature). At every action, the system produces one reactive response.

ii. Deductive, the most complete one, which could be based on attitudes like "believe", "desire" and "intention". This type is used with more complex systems. As an example, we can think about a model that reproduces a stock trader, who buys/sells actions even on certain personal attitudes and sensations about the company.

iii. Hybrid, which is similar to the first one, but more than just reactive actions, has the ability to process and fulfil proactive decisions/actions.

The model's agents used for this project lay its reasoning process on the third one, thanks to its core feature: the subsumption. This is the "rule book" of every action that every agent follows. It recreates the decision process thanks to a hierarchical structure of actions. The actions are the responses that each agent performs. Every time the simulation starts, the agent interacts with the environment around it, analysing its current status. In this sense, any behaviour that a real-butterfly carries out during its life: eating, resting/basking, reproducing and egg-laying. Moreover, the agent will have some internal independent parameters that regulate the virtual life of the single butterfly-agent: life span, energy and fertility. Every point previously mentioned will be later discussed and explained.

Another important feature of the MAS is the environment, where the agents move and interact. The urban environment of the study area is described through different GIS files, and filled with any useful information. It is important to highlight that the set of the environmental data is called environmental agent, since it is an independent system of information, which can interact with the butterfly-agents. It is necessary to clarify that during the simulation, for each butterfly-agent, the environment is everything that has information and it is able to interact with. In this sense, the environment under the viewpoint of a single butterfly-agent will be called agent's environment.

1.2 Aim of this Study

In this thesis, I will present my work that will be the base for future simulations that will evaluate which and how ecological and architectural factors of urban areas might affect butterfly mobility. In order to achieve this task, a multidisciplinary team was created, thanks to the collaboration between the Department of Life Science and System Biology and the Department of Physics of the University of Turin. Specifically, the aim of this thesis is to identify biological and ecological parameters, such as abundance, dispersal of butterflies, density of nectar sources and mowing activities, in an urban context as the basis for future simulations. Moreover, those data have already been used to run a first set of simulations to estimate the energy consumption of butterflies performing different behaviors (such as feeding, flying, copulating and resting). Thus, knowledge on Pieris butterfly abundance and mobility within the city were studied in the field. Thanks to the analysis with statistical methods, the foundations for future simulations were laid, identifying energy consumption for pre-defined behaviours. Those energy consumption parameters will be useful for future simulations that will understand the mobility of butterflies within urban areas.

2 Materials and Methods

The project is interdisciplinary, including biology, ecology and physics. In order to provide data on butterfly mobility in the city of Turin, Mark Release Recapture (hereafter MRR) method was applied in the two identified areas. After butterflies were surveyed, the data was then analysed and explored to obtain information on mobility. Using information obtained through literature research and field direct observations, the multidisciplinary team started to build the architecture of the model and run a first set of simulations. In this section, every on-field and modelling methods will be explained.

2.1 Area Selection

The study area was located in Turin (Italy, 45°04’20.1"N 7°39’44.0”E). The city is one of the greatest urban areas in Italy, with a total area of 130 km^2 where more than 800 thousand people live (ISTAT, 2023). The city of Turin is already the scene of projects aimed at the enhancement of the urban habitat for butterflies, since it is one of the four cities that joined the ProGIreg project in 2018. During this international project, founded by the European Commission under the Horizon 2020 programme, in the post-industrial area of the city there were implemented different NBS, some of them (NBS 6 - Accessible Green Corridors, NBS 8 - Pollinators’ Diversity) are focused on city permeability and resilience of pollinators in urban areas.

In order to study the mobility of butterflies within the city, two areas with different ecological features were chosen (Fig. 1). The first, hereafter called “Urban area” (33.4 ha), is characterised by a dense presence of infrastructures, with small fragmented green areas. The second area (20.4 ha) is a peripheral urban area, and also includes Parco Piemonte, the park that gave the name to the site (hereafter “Parco Piemonte”), and an urban garden, held by the social enterprise “Orti Generali s.r.l.”.

2.2 Field Sampling

In order to investigate the mobility of butterflies, four species were selected. The selection was made under the next condition: i. The species need to be widespread in Europe and abundant in urban areas; ii. Only food-generalist and multivoltine species with great mobility were chosen; iii. The group of selected species (Fig. 2) needs to be uniform under ecological needs. In this sense, four species within the same genus were initially selected: *Pieris rapae*, *P. napi*, *P. mannii* and *P. brassicae*. Later in the project, the largest species, *P. brassicae*, was removed from the list, since it was sampled just twice and never recaptured.

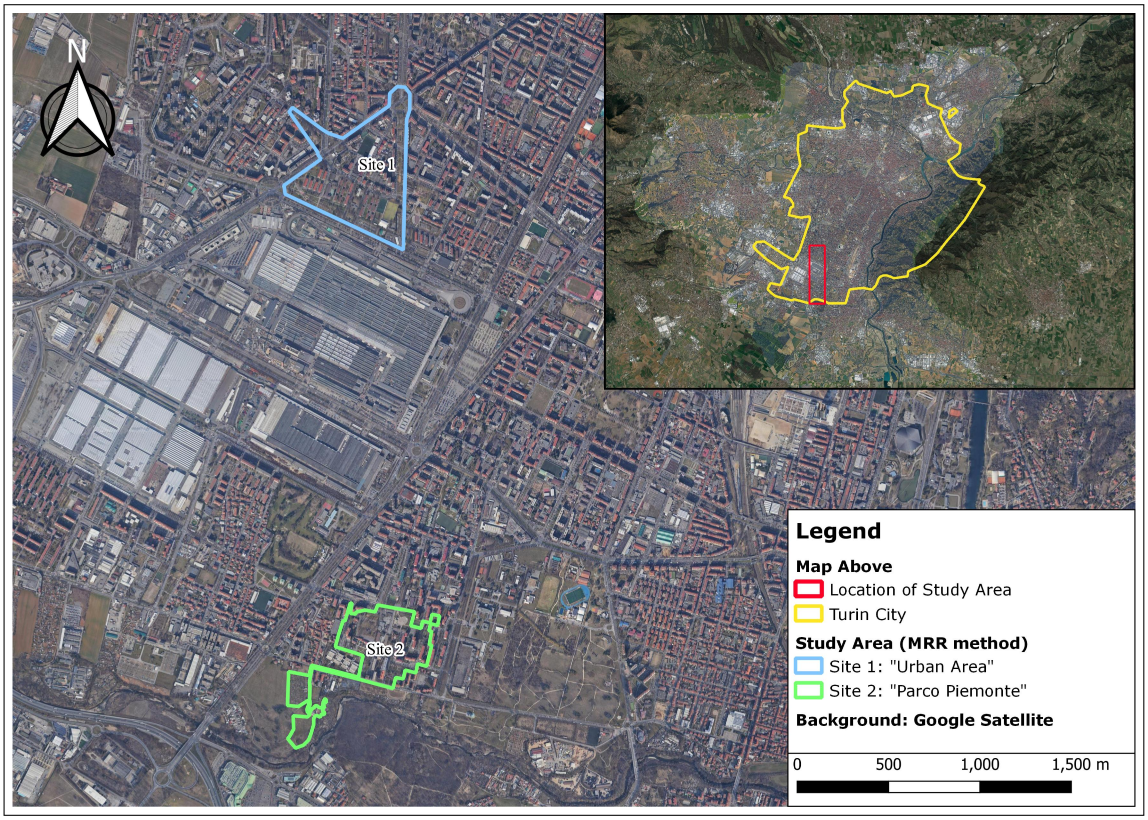


Figure 1: Map of the study area, in blue the "Urban area" (Site 1; 45°02'11.6"N 7°37'51.9"E) and in green the "Parco Piemonte" (Site 2; 45°00'34.0"N 7°37'34.7"E). In the top-right box, the position of both areas (red rectangle) is shown relatively to the borders of the city of Turin.

Figure 2: Butterfly species selected for the experiment. From left to right: *Pieris rapae*, male (photo by Marco Bonifacino); *Pieris mannii*, female (photo by Raniero Panfili); *Pieris napi*, female (photo by Paolo Mazzei). *Photos from www.leps.it*.

The method chosen to obtain quantitative data on the butterfly mobility is MRR, capturing, marking individuals, releasing and recapturing butterflies, and recording sex and GPS position

(Garmin eTrex 20, with precision 3 m) at each capture event (e.g.Parile, Piccini, & Bonelli, 2021). Moreover, the species and the variables were chosen to study the flight behaviour of urban butterflies, and allow the future MAS to have a clearer and more realistic vision of mobility within the city habitat.

I started monitoring the site “Parco Piemonte” from the 20th of July to the 10th of August, and from the 23rd of August to the 26th of the same month. On the 29th of July, I started surveying the Urban area until the 6th of August, then I monitored the same area from the 17th of August to the 3rd of September of 2021. The MRR was performed every day from 9:30 am to 4:30 pm (7 hours, non-stop). Every day with suitable weather conditions, one of the two areas was surveyed. The conditions needed to start the daily sampling were based on the flight ability of butterflies: sunny or partially cloudy days and with temperatures greater than 18° C (at 9:30 am; Swaay, Brereton, Kirkland, & Warren, 2012). In total, 21 days were spent surveying the "Urban area", and 17 in the second area, "Parco Piemonte" (Fig. 1).

Each butterfly was captured and individually marked with a consecutive number on the underside of the right hind wing using a non-toxic fine-tip permanent marker, and immediately released at the same location. The wing size does not allow me to write more than 2 numbers in a row, so I change the colour of the marker every 99 individuals. At every capture, the butterfly was gently held in the net with the finger, and marked through the net (Fig. 3). Once marked, the individual’s data were recorded in the notebook (see Supplementary Material). During the data recording, the butterflies were placed in a nearby shaded area, or the insect was covered from the sunlight with the body, to reduce the increase of temperature.

The data taken for each individual could be categorised as logistic and biological/ecological. As logistic data, the GPS position (Garmin® eTrex 20 with precision of±3 m), the time (hour, minute) and the individual ID number were recorded. The biological data noted were the species, the sex, the habitat (just in the Parco Piemonte site, which was divided as "Urban" and "Park" sub-area), the behaviour (in case of "feeding", the flower species was recorded too) and the habitus. As habitus, the physical condition of the butterfly was recorded with a four-level scale: "0" indicates a perfect physical condition, which represents a butterfly newly-emerged (i.e. young adult), while "3" represents a butterfly with large missing parts of wings (i.e. a supposed old individual; Parile et al., 2021). I recorded the date, hour and minute of the start and the end (even for early ending due to rain) of each sampling occasion, and the average temperature of the day (after the monitoring ended). After the first sampling day, I recorded recapture events. In the same way, the same data was recorded, and noted as a recapture event. To evaluate mobility and behaviour, I registered individuals that were captured more than once during the same day of activity.

Figure 3: Photo of me, in the Urban site, during one MRR session. This is a public garden, called “Giardino Zen” (45°02’14.1"N 7°37’48.2"E), which is formed by abandoned architectural structures and different grass plots. From a first on-field observation, it seems a connection spot, since it is in the middle of other greater green areas.

2.3 Estimated Number of Butterflies in the Areas

Starting from the data obtained with Mark Release Recapture, the estimation of the number of adults in the two areas was obtained. The POPAN model, within MARK 8.0 (White & Burnham, 1999) was used, considering, therefore, the existence of a metapopulation dynamic. The POPAN approach (Schwarz & Arnason, 1996) was already used for butterfly populations, in particular in open population with great changes in size, due to immigration and death of adults (Čelik, 2012; Weyer & Schmitt, 2013; Pennekamp et al., 2014; Jugovic et al., 2017). The data required by the model were derived: daily survival probability (ϕ), recruitment rates (probability of new arrivals; pent), capture probability (p), and the total population size (N) was estimated. These parameters, dependent on sex (g) or on time (t), need to be constant (.). This model also provided the daily size (Ni) and daily number of immigrants (Bi) in the population. The model selection was executed identifying the model with the lowest value of Akaike’s Information Criterion (AIC).

2.4 Mobility

To understand the mobility of the Pieris spp., the distance between consecutive captures on different days (D) was as a straight line connecting two consecutive points of butterfly capture in QGIS 3.4 (QGIS Development Team 2018). According to Jugovic et al. (2017), the mean, median and maximum distances were calculated by sex. A Generalised Linear Models (GLMs) were used to model the distance (D) in Site 1 “Urban area” and in Site 2 “Parco Piemonte”, with sex and species as explanatory variables. Since the distribution for both models was not normal (Shapiro-Wilk normality test: W1 = 0.71255, p-value1 = 4.14e-16 and W2 = 0.75865, p-value2 = 9.899e-14), the gamma distribution was used in the GLM. The fit of the model was performed with the maximum likelihood method.

The dispersal ability (Pennekamp et al., 2014), was analysed estimating the movement with respect to distance beyond those covered during the study. Therefore, the Negative-Exponential Function (NEF) was calculated, according to previous studies (Hill et al., 1996). The flight distances, divided by sex, were grouped into 50 m classes. Thus, the probability of an individual moving a certain distance (D), was calculated as: $P_{NEF} = a^{kD}$. The average flight distance (D’) was estimated according to Hill et al. (1996), like D’=1/k.

Considering that log-transformed formulas can be expressed as linear relationships (i.e. $ln(P_{NEF})$ $= ln(a) - kD$), and following Čelik (2012), the a and k parameters were estimated by LMs in R. Thus, the natural logarithms of the inverse cumulative proportions (ICP) of individuals moving certain distances (lnP) were regressed on distances (meters). Therefore, we modelled natural logarithms of ICP into a LM (Gaussian, maximum likelihood fit) where sex (as a categorical variable), meters (as continuous variables), and their interaction (sex x distance) were used as additive explanatory variables. We tested for the normality of the residuals (Shapiro–Wilk test: $p > 0.05$).

2.5 Modeling Butterfly Mobility

The principal feature of our MAS type is the parametric behavioural scheme, called ***subsumption***. Therefore, to build the subsumption the first operation needed was to categorise any type of actions that a butterfly-agent could perform, and then to connect them, to build its reasoning process.

The ***actions*** were identified as feeding, copulation, egg laying (female only), basking, intake of water and mineral salts, and wandering flight. To prioritise behaviours, they were classified from the most to the least common (Fig. 4).

To simulate the interaction between different agents and butterfly-environment, every agent needs a value of ***range of perception***. Like a real butterfly, the sight of its virtual environment is limited in terms of space. The shape of the visual field of the agent is a circle, all around the virtual insect, since actual studies observed that butterflies have almost a panoramic vision (Bergman et al., 2021). The visual field used in the simulations has 35 meters of radius (Ohsaki, 1980).

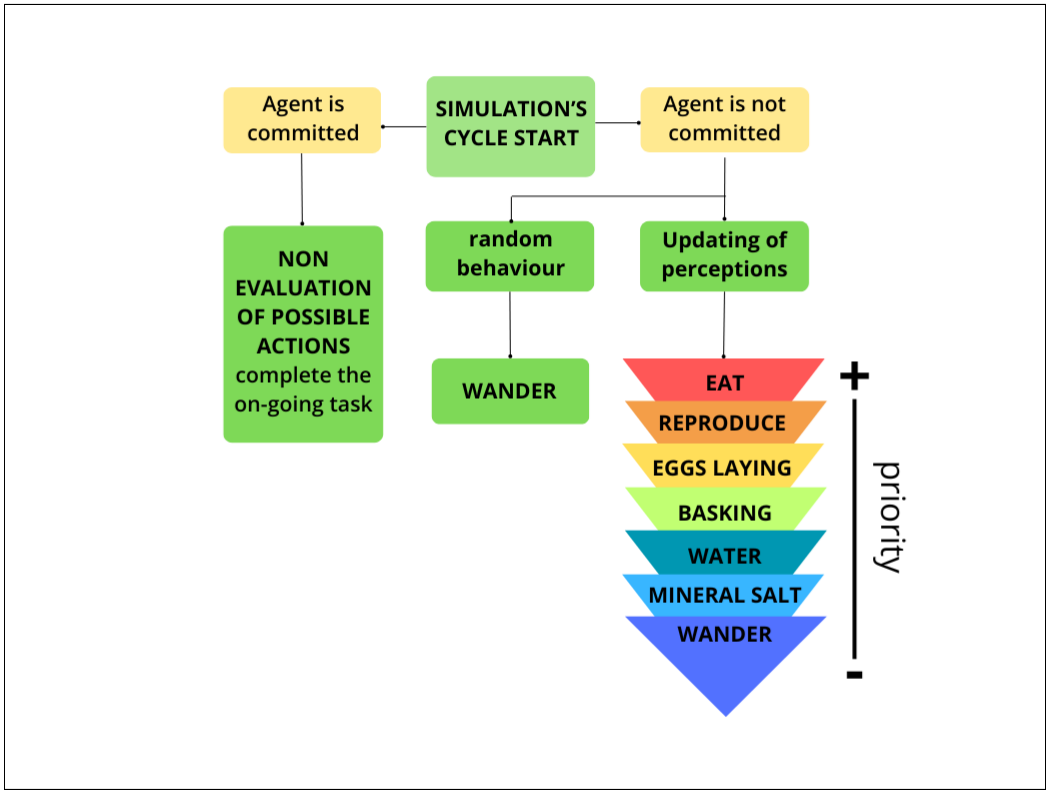


Figure 4: Schematic representation of the subsumption, the hierarchical structure that rules the reasoning process of every butterfly agent. When every cycle starts, if the agent is already committed to a task, it will continue it. If not, the analysis of the environment and its status will determine the action to perform, according to the needs of the virtual insects.

Every butterfly-agent has a determined task to complete (at the beginning of the simulation is feeding) and the model needs to consider the time and the energy spent to complete the task. The task is predetermined and does not depend on what a butterfly-agent sees but it depends on the internal needs of the butterfly-agent. If a status modification is required, such as in the case when the energy level is reaching the threshold, it is mandatory for the butterfly to fulfil the task "feeding". However, in case it is not possible to complete the task in the visual range of a butterfly-agent, it will start a random flight, called "wandering behaviour", to find a nectar source. This movement has a random direction of flight. If it perceives a nectar source, the butterfly-agent will focus to complete the new task. In case there are no tasks, the butterfly-agent performs the wandering behaviour.

In this model, the ***time*** is a virtual representation of a real-life day (with the accuracy of a second), but agent's movement, life span and agent's actions are defined by another unit: the cycle. Every simulation is divided into cycles, which can be seen as a forward step (i.e. one simulation cycle) into time. In this sense, virtual time is not a continuous variable, but a discrete array of cycles. During the simulation, the movement of each butterfly-agent visually results like a video with low frame-rate. In the first simulation, it was decided that every cycle represents 2 seconds (i.e. 0.5 fps), but it can be extended.

The decision was made in order to properly model the road crossing possibilities of the butterflies. Under this assumption, to any action a number of cycles was given (see Table YY -mettere tabella con valori numero cicli/azioni). Every time the simulation starts and the butterfly-agents are deployed, at every cycle, the agent will evaluate its conditions (e.g. "need food" or "laying eggs") and the environment it can perceive. Once recorded the information, the agent will decide the task that wants to achieve, and consequently the number cycles to perform.

Times also regulate the ***age of the butterfly-agents***. Every butterfly-agent, once it spawns into the simulation, has a prefixed life span, described as the number of cycles before death. When the maximum age is reached, it *will not be part of the simulation*. The same happens when the agent reaches a certain energy threshold (i.e. starvation) or fails crossing a road (like it was hitted by a vehicle). The age of the butterfly-agent is determined by a Gaussian curve, where the mean is the average lifespan of *P. rapae*. In the same way, different parameters are determined by a curve.

2.5.1 Environmental Data

During the field season, different data on the urban environment were taken. In order to model the city, from the point of view of a butterfly, information on biotic and abiotic components needs to be considered. I recorded the nectar source (i.e. flowers) density for every green plot of any size present in the sampling area. I recorded it as a categorical value: 0%=0; 1-25%= 1; 25-50%= 2; 50-75%=3; 75-100%=4. This data was obtained at the end of the butterflies sampling on the 4th of September. During the sampling session, three mowings were performed by the administration, in different green areas at the "Urban area". Since the removal of plants could affect butterfly presence and mobility (Aguilera et al., 2019), the date and the location of these operations were recorded.

To implement the "agent environment" for MAS, maps of Turin were needed. Environmental variables that might be behavioural drivers were therefore also taken into consideration, and constitute the input to the model, clustered in layers describing the different attributes of the environment in the MAS: buildings, roads, green areas and their attributes. All maps were geo-localised using QGIS. It was not possible to record the size and temporal changes of urban structures during field season. Therefore, the data were obtained from the "Dipartimento Urbanistica ed Edilizia Privata" (Territorial Informative System - Geoportale Piemonte Region), which provided the data, free of charge. The sum of the maps describes the entire municipality of Turin under the view of land cover and use, sizes of every building (height included) and "natural" areas (i.e. from the public park, to green traffic islands and tree position).

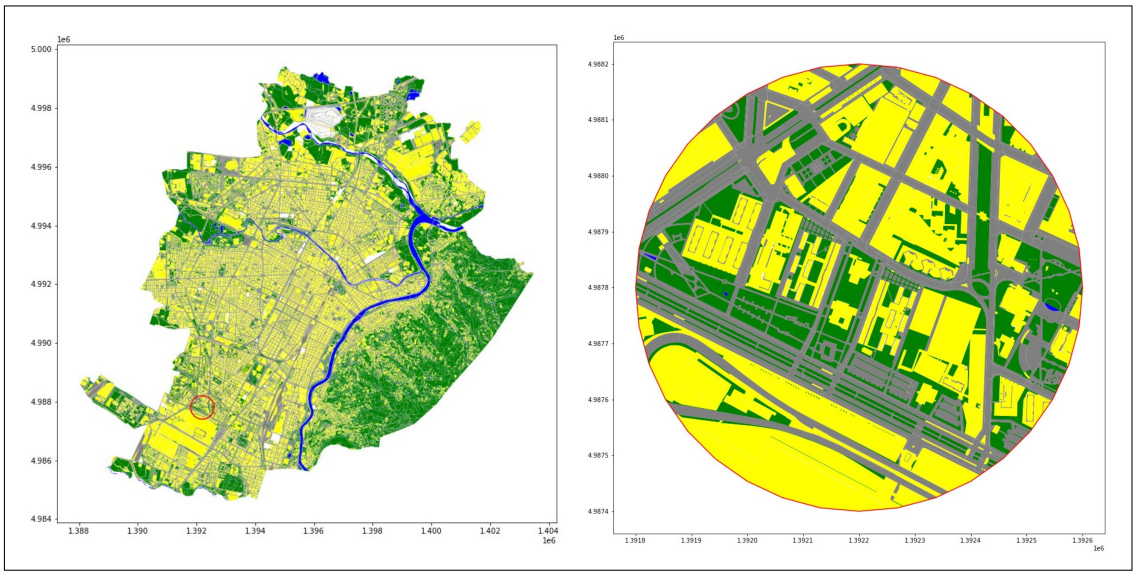


Figure 5: Representation of the city environment. Turin city map (left) and a section of the Urban area (right; 400 m radius), with colour scale based on three types of environment: infrastructures and buildings (yellow), green areas of any kind (green) and roads/pathways (grey). This is a basic, graphical categorization, each shapefile geometry includes every information needed for the simulation (e.g. height of buildings or nectar sources availability).

The environment in this simulation is represented by a group of GIS layers and data obtained in the field. The set of GIS maps of buildings and infrastructures, combined with those of the streets and associated structures (i.e. pavements and road medians), describe the abiotic components of the study area. Adding the georeferenced information on the urban green areas, such as parks, gardens, public or private, the city was described under the point of view of the butterflies (Fig. 5). This data defines a dynamic (its parameters can change), accessible (it can communicate with other agents) representation of the city: the ***environment agent***. This was possible thanks to the geo-localisation features of a GAMA (Taillandier et al., 2019) framework importing GIS.

The agents in this simulation represent each butterfly that flies in the city in a predefined-period of time.The butterfly-agent acquires all information, static and dynamic, from the environment during its virtual-life. Any information obtained from an interaction with the environment (e.g. presence/absence of nectar sources, infrastructures location and features) and data on conspecific individuals, represent a unique environment to each single butterfly-agent. Thus, any action performed by the single butterfly agent will be the result of the exchange of information from the agent's environment, and will modify, in some ways, the status of actions and the environment agent itself.

2.5.2 Virtual Energy of Butterfly-Agents

Thanks to the knowledge, the field experience and the ability to estimate the biological values, the modelling of butterflies and the urban environment was precise enough to process the first training of the model.

As first step to simulate butterfly mobility, simulations to determine butterfly virtual energy have been run. In order to perform actions the butterfly-agent needs energy. Indeed, even in real life, every organism, from bacteria to humans, requires biological energy to perform each action. The understanding of the basal metabolic rate of a butterfly, and how much any movement will be spent, is not easily available from field work or in previous studies. To simplify the concept of biological energy, we model the agent with a virtual battery: to any action, from the lighter (e.g. resting) to the most complex (e.g. copulation), a certain value of energy was given. Like a real-life animal, with feeding the energy is restored, and with any action is reduced (Fig. 6).

At each cycle of the simulation, the activity performed will reduce or increase the amount of energy. In case the agent spends all the energy available without any mid-stage intake, it will virtually die. To make it clear, a butterfly with low energy identifies a nectar source in its visual range. To obtain the resource, considering the space between the individual and its target, and the flying speed, the agent will spend the required amount of steps to reach the flower location. At every cycle, the agent will check the surroundings, but it remains committed to the main task. Once it arrives at the site, it will spend a bit of time eating the nectar, which also requires some time in terms of simulation cycles. With the same reasoning process, the agent will perform any actions (e.g. Fig. 7)

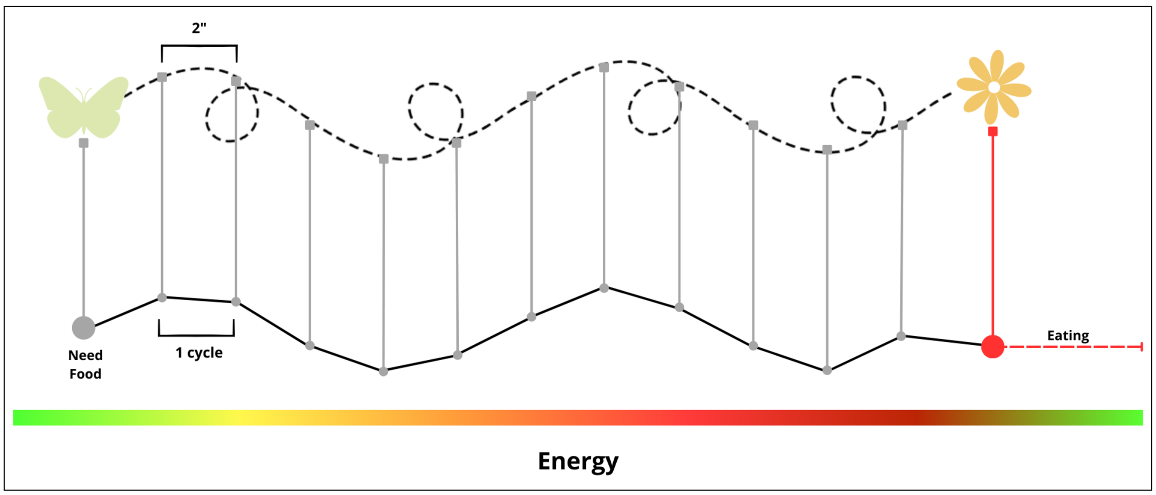


Figure 6: Schematic representation of the concepts of cycles, committed tasks and energy. Above, the flight of a butterfly (dashed line), toward the flower. The segmented black line below, represents the discrete flight of butterfly-agent. Each grey vertical line indicates the beginning of a new cycle of the simulation (2 seconds). In this graph, the agent simulates a butterfly that needs to eat, and reach a nectar source (that is within the perception range). With the bottom coloured line, the consumption of energy to fly is shown (green, high level of energy; red, low level of energy). Once reached, the butterfly-agent spends some time still, increasing the energy-level.

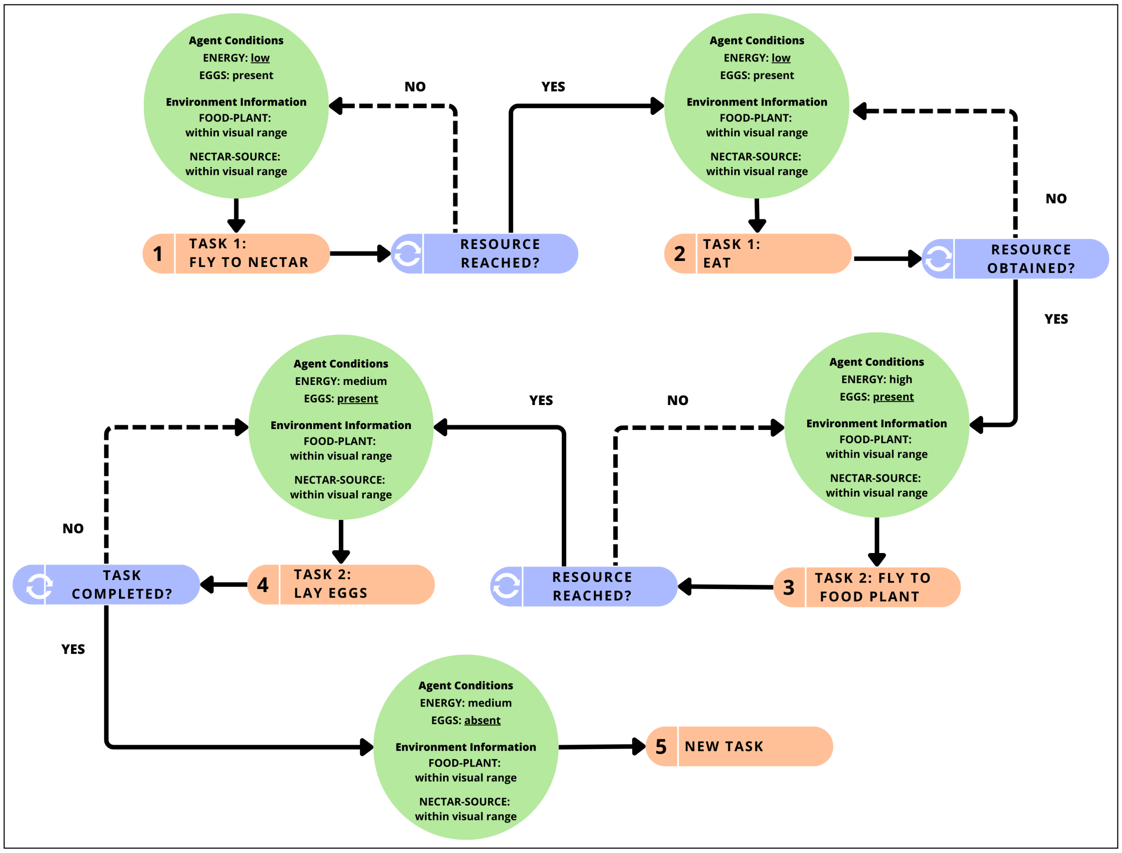


Figure 7: Example of coordination between different tasks. This figure represents the reasoning process of a female butterfly-agent, after copulation. In the first part, the agent analyses (i.e. perception, green circle) the environmental and self-status information. It is ready to lay eggs, but its energy is too low to perform the task. The task selected by priority order (see Fig. X schema subsumption) is to find and obtain nectar ("EAT"). The butterfly-agent starts flying toward the nectar source, for the needed number of cycles (which is already visible, since it is within the visual range). After reaching and obtaining it (spending another number of defined cycles), it will be ready to perform the new task: find and fly toward a food-plant, and lay eggs over it. The action will be repeated until the agent will perceive the absence of eggs to lay (i.e. it lays every egg from that copulation).

3 Results

3.1 Field Sampling

In total, 1020 were captured and marked in the two sampling areas (393 in the Urban area, and 625 in Parco Piemonte). The most sampled species was *P. rapae*, in both sites, while the less sampled species was *P. napi* (Tab. 1).

Site	**Species**	**Capture**	**Recapture Events**	**Recapture Rate**
Site 1 "Urban area"	*P. rapae*	273	196	71.79
	P. mannii	97	38	39.18
	P. napi	23	22	95.65
	Total	393	256	65.14
Site 2 "Parco Piemonte"	*P. rapae*	461	173	37.53
	P. mannii	118	25	21.19
	P. napi	46	10	21.74
	P. brassicae	2	0	0
	Total	627	208	33.17

Table 1: Summary of Mark Release Recapture data, grouped by site and species. Overall, the most common species was P. rapae. Since just two individuals of P. brassicae were captured, but non recaptured, it was not considered in the setting of MAS parameters.

Between the recorded species, there are no differences, in terms of functional traits. All of them are polyphagous, spread distributed and have multiple generations across the year (Middleton-Welling et al., 2020). Moreover, mobility did not vary between sex and between species, in both sites (Tab. 4).

In both sites, I captured more males (67.5% of the total; Tab. 2) than females. Over the total, the number of individuals recaptured at least once is 465 individuals (recapture rate 45.6%). Overall, in the first site less individuals were marked, but the recapture rate was higher (65.14%) than the one in the second site (33.17%).

Considering that there are no differences for functional traits and under an ecological point of view, data are grouped by sex and site only (Fig. 8). Thus, we train the model by considering all species together (genus *Pieris*) as a butterfly agent.

Site	Sex	Capture	Recapture Events	Recapture Rate
Site 1 "Urban area"	M	279	193	69.18
	F	114	63	55.26
	Total	393	256	65.14
Site 2 "Parco Piemonte"	M	410	145	35.37
	F	217	63	29.03
	Total	627	208	33.17

Table 2: Summary table of the data obtained from the MRR sampling. The data are here grouped by sex and site. To study the butterfly permeability with the MAS model, we decided to collect the data from three different species, but consider them as a unique set of data on the genus *Pieris*.

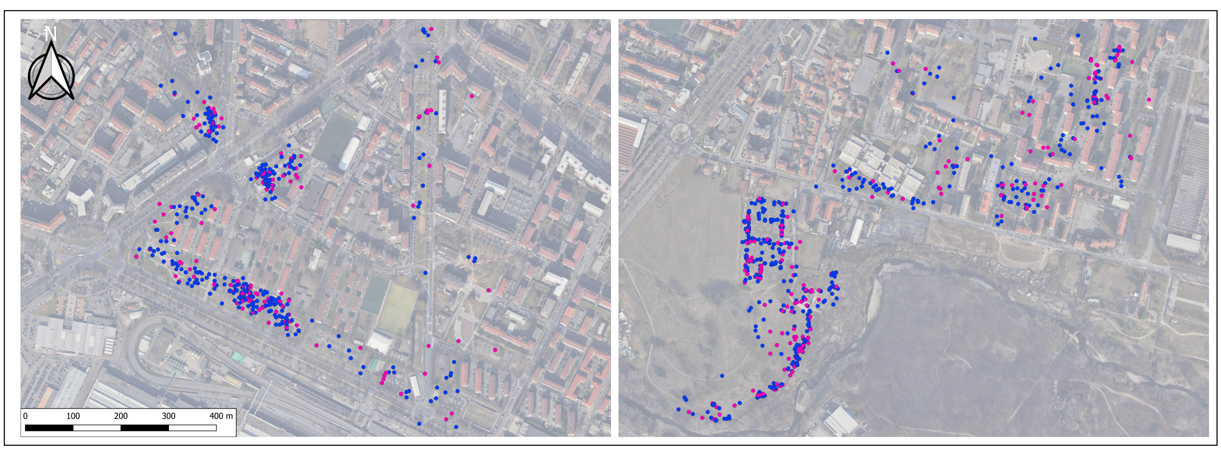


Figure 8: Maps of the two sampling sites (left: Urban area; right: Parco Piemonte) with the location of each captured and recaptured individual. The samples are here divided by sex, where blue points represent males, while females are pink.

3.2 Estimate Abundance of Individuals

With the POPAN model in MARK, the number of individuals during the period of sampling in the two areas was estimated. It was estimated that during the summer of 2021, a total 1409 of *Pieris* individuals flew within both areas. For the same reason explained above, the data presented in the subsequent table are grouped by sampling site and sex, but not by species (Tab. 3).

Site	**Sex**	**Estimate**	**St. dev.**	**CI lower**	**CI upper**
Site 1	M	397.360	21.666	361.193	446.985
"Urban area"	F	182.691	15.823	157.680	220.825
Site 2	M	460.111	39.880	391.412	548.775
"Parco Piemonte"	F	369.228	65.865	265.825	528.957

Table 3: Table with the estimated number of individuals, in each site, divided by sex. Standard deviation and confidence intervals are present too.

3.3 Mobility

Thanks to location acquired every encounter with an individual, the distance between the first capture and the last recapture was measured. In Urban and Parco Piemonte areas, the mean distance is 286.24 m and 231.61 m respectively. The longest distance a male individual flew in site 1 is 1659.64 m, and 2054.51 m in site 2, whereas for females the same record was 1939.194 m and 867.004 m, respectively.

Site 1	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	0.003	0.001	3.998	0.0001	***
Sex - Males	0.001	0.001	0.938	0.350	
Species *P. napi*	0.002	0.003	0.822	0.413	
Species *P. rapae*	0.001	0.001	-0.844	0.400	

Site 2	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	0.004	0.001	3.852	<0.001	***
Sex - Males	-0.001	0.001	-0.720	0.473	
Species *P. napi*	0.003	0.003	1.117	0.266	
Species *P. rapae*	0.001	0.001	1.141	0.256	

Table 4: Model results of analysis of flight distance and the interaction of sex and species. Distance did not vary between sex and species.

The natural logarithmic inverse cumulative proportion of moving butterflies decreased with increasing distances and was different for each sex (NEF function: Sex * Distance: t value = -3.782, p = 0.4*** in site 1, while t value = 4.859, p < 0.001*** in site 2; Table 5).

Site 1	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	-0.373	0.112	-3.317	0.002276	**
Sex - Males	0.226	0.154	1.461	0.153664	
Distance	-0.002	<0.001	-12.377	9.66e-14	***
Males x Distance	-0.001	<0.001	-3.782	0.000643	***

Site 2	Estimate	Std. Error	t value	Pr(>|t|)	
(Intercept)	0.156	0.175	0.893	0.38003	
Sex - Males	-0.614	0.216	-2.839	0.00867	**
Distance	-0.004	0.001	-12.061	3.74e-12	***
Males x Distance	0.002	<0.001	4.859	4.88e-05	***

Table 5: Results of Negative Exponential Factor model.

Fitting NEF to mobility data resulted in the following equations: Pm1 = 0.8629 $\hat{e(}$0.0027D) and Pm2 = 0.633 $\hat{e(}$0.0025D) for males, and Pf1 = 0.6886 $\hat{e(}$0.0019D) and Pf2 = 1.1692$\hat{e(}$0.0044D) for females, in site 1 and 2 respectively (where P is a probability of moving the distance D). The estimated distances (D' = 1/k; Nowicki et al. 2005) between consecutive captures were 370 m and 526 m, respectively, for males and females in Urban area. The estimate on Parco Piemonte resulted in 400 m for males and 227 m for females.

The estimated probabilities (in % of individuals) of long-distance movements (dispersal) of 500 m, 1 km and 2 km in both sites, is shown in Table 6, while in Figure 9 all the data are represented grouped by sex and site.

Urban area	Male	Female
500 m	22.18 %	26.1 %
1000 m	5.7 %	9.89 %
2000 m	0.54 %	0.1 %

Parco Piemonte	Male	Female
500 m	18.38 %	12.85 %
1000 m	5.34 %	1.41 %
2000 m	0.02 %	0.45 %

Table 6: Estimated probabilities of long-distance flight (in % of individuals). Here are shown the probability of movement reaching 500, 1000 and 2000 m, in the two sites, grouped by sex.

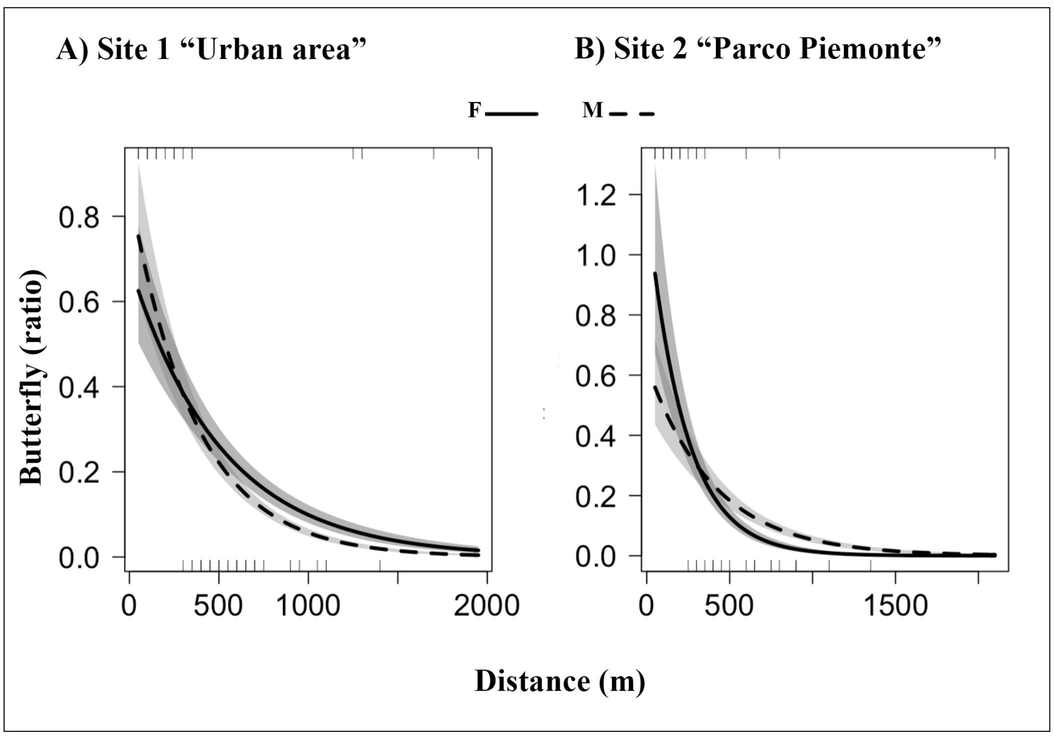


Figure 9: The figure shows dispersal probability of butterflies. The estimate is grouped by site ("Urban area" on the left; "Parco Piemonte" on the right). The solid lines represent females, while dashed lines represent males.

3.4 MAS

In order to develop future MAS simulations to understand butterfly mobility within urban areas, input parameters and simulations of virtual energy batteries have been developed.

3.4.1 Input Parameters

Thanks to the knowledge on the sampled species, a preliminary simulation was run (language GAML; Taillandier et al. (2019)). The information obtained from field-work and a bibliographic research, were merged in a unique set of data (Tab. 7, 8, 9) to obtain a more general description of the genus *Pieris*. In this way, the butterfly-agent was built.

Actions Parameters	Value	Resource and notes	
Duration of wandering (s)	20	Field observation	
Duration of basking (s)	120	Field observation	
Duration of wandering (sparetime s)	6	Assumption	
Duration of eating (s)	26		(Ohtani & Yamamoto. 1985)
Duration of depose (s)	15		(Ohtani & Yamamoto. 1985)
Duration of drinking and mineral salts (s)	120	Assumption	
Duration of coupling (s)	240	Assumption	
Duration of chasing (s)	20	Assumption	
Update perceptions (s)	4	Update information intake from environment	
Time committed to wander (s)	60	Assumption	
Crossing street probability	0.	Assumption	(Dániel-Ferreira et al. 2022)
Probability of "drink"	0.02	Field observation	
Probability of "mineral salts"	0.02	Field observation	
Probability of "basking"	0.01	Field observation	

Table 7: Parameters used in the simulations: actions of butterfly-agents. For each parameter (unit between brackets), it is shown the origin of the data and more information. Whenever a value is not available through bibliographic research, training or field data, assumptions were made.

Butterfly-agent parameters	Value	Resource and notes	
Perceptual range (m)	35	Radius of visual range	(Ohsaki, 1980)
Life span (days)	9	Life of butterfly-agents (mean value, randomized)	(Karlsson, 1998)
Speed of butterfly male (km/h)	15	Flight speed dapted from resource	(Williams et al., 1956)
Std Speed of butterfly male (km/h)	2	Flight speed Adapted from resource	(Williams et al., 1956)
Speed of butterfly female (km/h)	13	Flight speed Adapted from resource	(Williams et al., 1956)
Std Speed of butterfly female (km/h)	2	Flight speed Adapted from resource	(Williams et al., 1956)
Probability of dying crossing the street	0.001	Adapted from resource	(Skorka et al. 2013)
Max height of building crossable (m)	30	Maximum height at which butterfly fly over	Field observation
Refractory time male(h)	3	Measured in hours	(Wedell & Cook, 1999)
Refractory time female(g)	3	Measured in days	(Wedell & Cook, 1999)
Number of depositions per hour	5		(Ohtani & Yamamoto, 1985)
Number of eggs per hour	5.08		(Ohtani & Yamamoto, 1985)
Hatching time egg mean (days)	30	Fieldbase data (no new born in this sim.)	
Hatching time egg std (days)	1	Fieldbase data (no new born in this sim.)	
Start hour of the day	8	Start of butterfly-agent activity	Field data in july
End hour of the day	18	End of butterfly-agent activity	Field data in july

Table 8: Parameters used in the simulations: actions of butterfly-agents. For each parameter (unit between brackets), it is shown the origin of the data and more information. Whenever a value is not available through bibliographic research, training or field data, assumptions were made. Some data were assumed, due to lack of information, to make the model work properly, since it is a first version of it.

Simulation parameters	Value	Resource and notes
Max cycles	108100	Number of cycles
First generation butterflies number	80	Number of initial butterflies
Percentage of females	0.5	Assumption
Simulation step (s)	2	Duration of one cycle (in seconds)
Date of start	31/07/2021 17:59	Start day of the simulation

Table 9: Values of parameters at the beginning of the simulation.

3.4.2 Environmental data

The most important data the model needed is the quality of the green area, to simulate preferences in butterfly direction. In this sense, I describe the flower density coverage for each green plot: 0%=0; 1-25%= 1; 25-50%= 2; 50-75%=3; 75-100%=4. In total, the green plots where flowers were observed were 66 in site 1 "urban area", while 30 in site 2 "Parco Piemonte". However, the average level of flower coverage is not very different: 1.07 in Urban, 1.2 in Parco Piemonte.

Two mowing events were recorded during the sampling period. They happened only within site 1: 3rd of August Pitagora Square and Siracusa Street (the east side of the area), on the 25th of August the south side (known as Giardino Pietro Nenni) was mowed completely (Fig. 10). The information was recorded since it could be used as a variable in the MAS model.

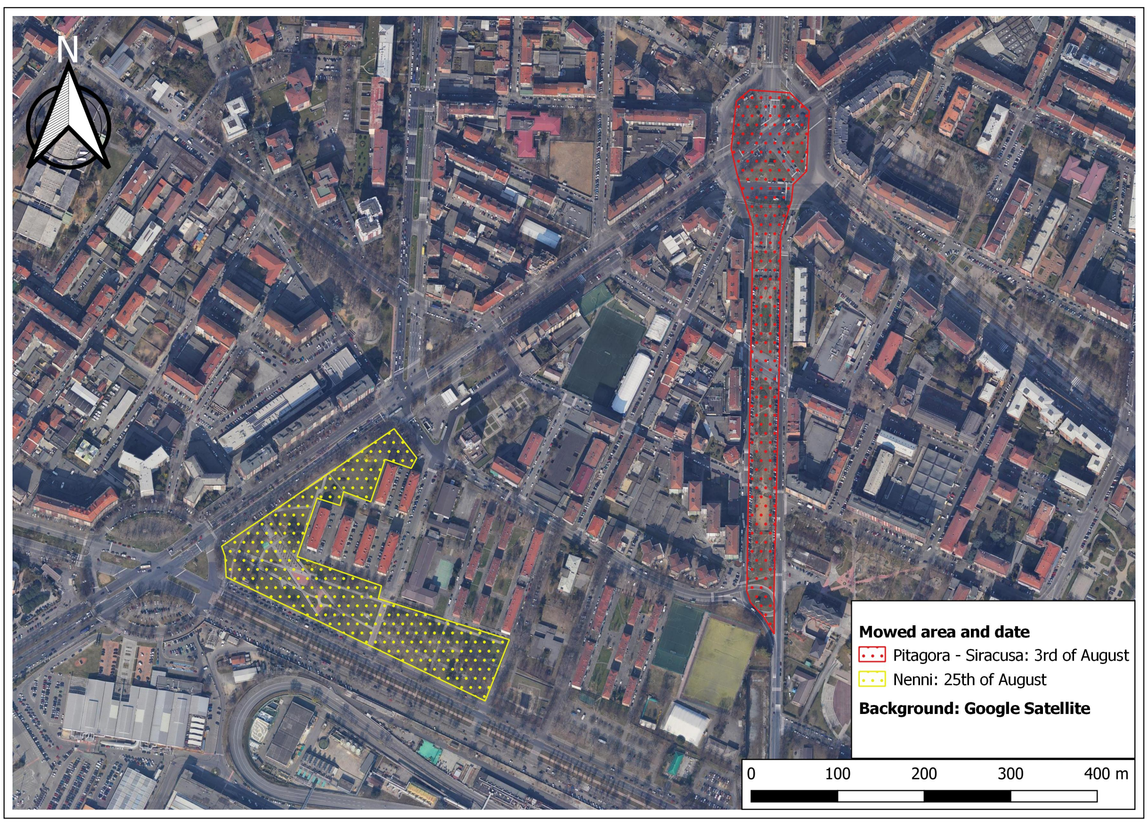


Figure 10: Map shows the location of the two areas, affected by mowing operations during the sampling period. Both of them are situated within Site 1. Colours distinguish the two events: red, 3rd of August; yellow, 25th of August.

3.4.3 Simulation Runs for Butterfly-Agent Virtual Energy

Field-based data on energy consumption of butterflies performing different behaviours are not available. However, data on time spent in different behaviours (such as eating, reproducing, flying and resting) are presented in Hirota and Obara (2000). From the data obtained from Hirota and Obara (2000) it is possible to train/set/find configurations of energy parameters. This work analyses a group of P. rapae and their daily activity, recording the frequency of each behaviour, the number of butterflies that follow a certain behaviour and the time spent committed to a certain behaviour. In order to insert energy parameters in the simulation, multiple random and independent simulations were carried out in order to understand the energy consumed in each behaviour. Outputs of each simulation run were the time spent in each behaviour. Specifically, we run those simulations hypothesising different energy intakes. The simulation output closer to the data from Hirota & Obara (2000; Fig. 11 and 12) was chosen as the best fit. In this way we choose the optimal energy parameters that make the simulation closer to the data recorded by Hirota and Obara (2000). The energy input of the best fit simulation will be used as input parameters for further simulations, to understand butterfly mobility in urban environments.

From the simulations, the optimal parameters are the following: energy consumed to fly = 0.01 energy/cycle, energy consumed to rest = 0.005 energy/cycle and energy intake from nectar sources 0.074 energy/cycle (Table 10). These values need to be considered as a proxy of a real energy measurement unit (e.g. calories). Since it is not possible to obtain it with a classical unit, an adimensional value is the result of our training. Thus, the values obtained from the simulation best fit, estimate the energy consumption by time unit (i.e. cycle), and the energy acquired during the feeding (by cycle). The flight energy consumption is estimated for an average speed of 15±2 km/h for males and 13±2 km/h for females (adapted from Williams et al. (1956). Then, these parameters will be used to simulate butterfly mobility within the city.

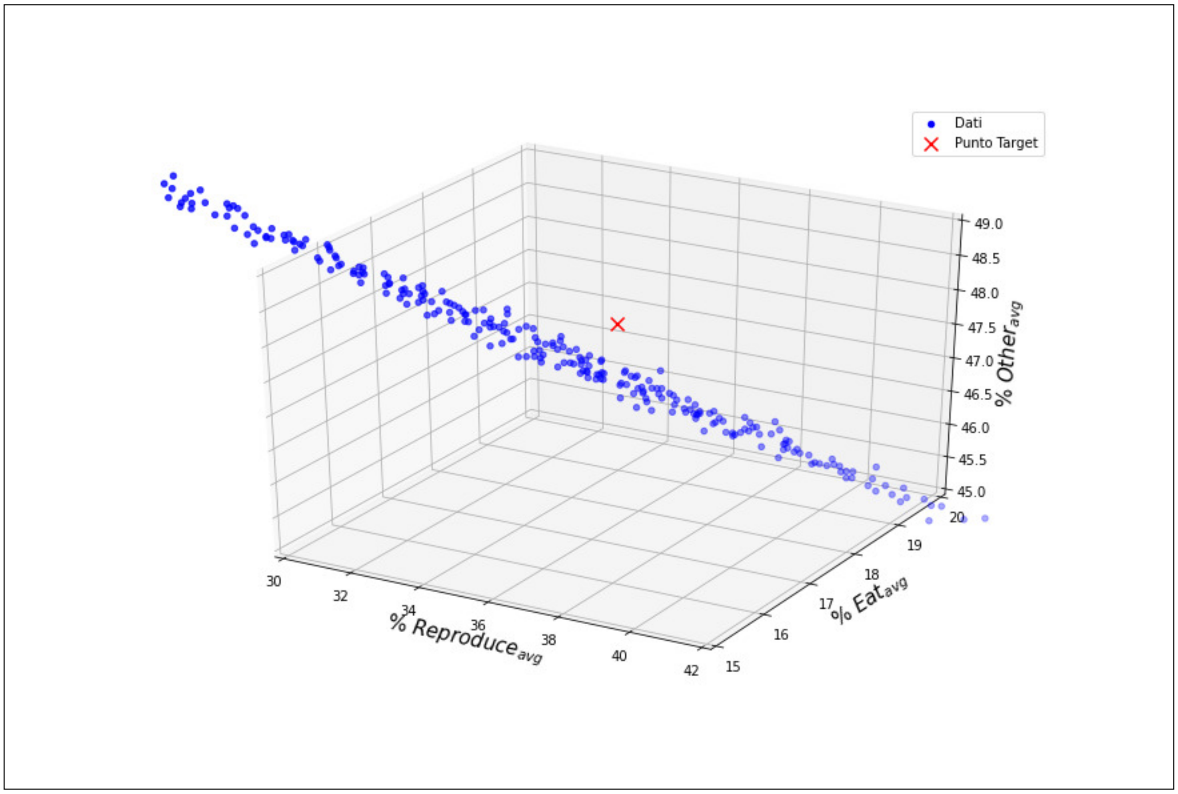


Figure 11: The plot shows the results of all simulations with different energy parameters in input. Each axis represents one energy class: energy intake (axis Y), energy spent to fly and resting (axis Z), energy spent to reproduce (axis X). Blue dots are the mean point between the three outputs of each simulation run. The red "X" represents the configuration obtained from Hirota and Obara (2000). The closest point to the target point "X" represents the optimal configuration that guarantees dynamics (output in terms of time spent in different behaviours) similar to what has been recorded in Hirota and Obara (2000). For each simulation output is possible to measure the distance and the error, which allow to calculate the loss of the model.

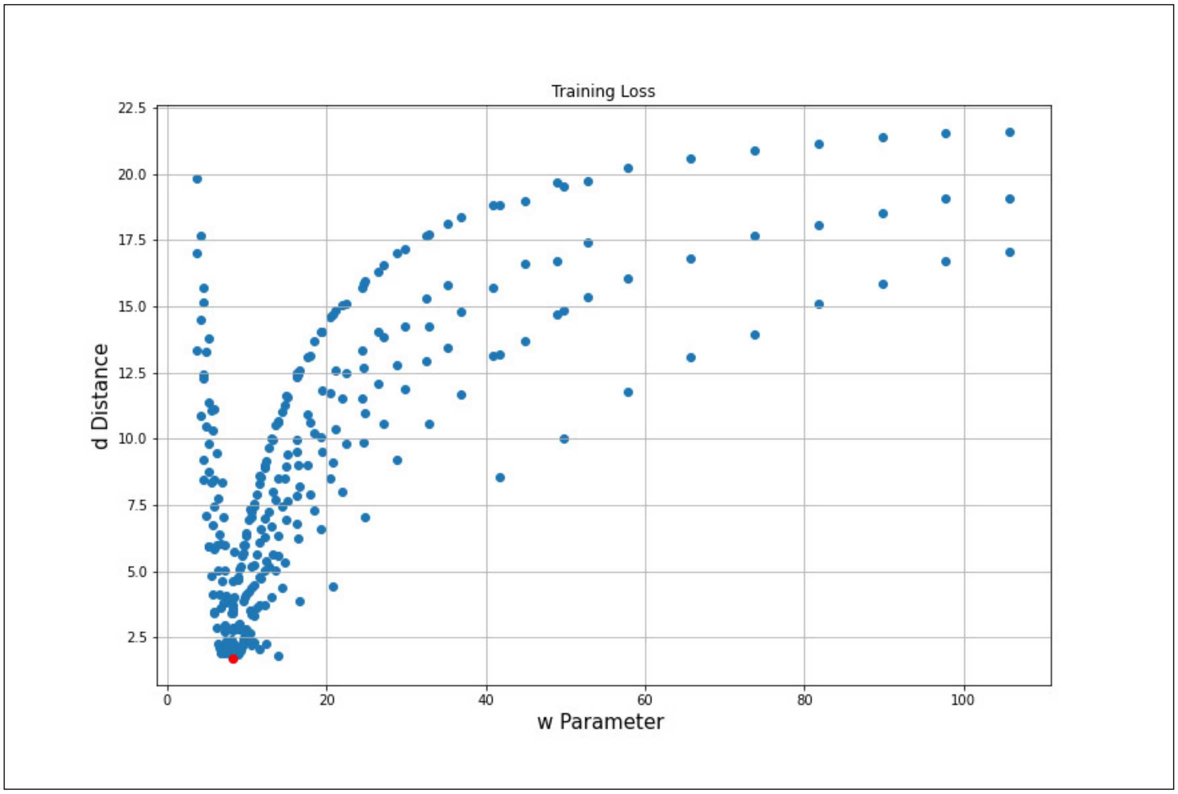


Figure 12: Loss values plot. The loss value indicates how far the simulation is from the target value, as many dots are closer to 0 as much as they are close to the target value. Each blue dot represents one of the random and independent simulation outputs. After the data were simulated, the ratio between intake and use of energy was calculated as $W = E_{in}/E_{out}$. On the y-axis, the distance between the W and the target value is shown, while on the x-axis W values are represented. As much as dots are closer to y=0, as much as they are the optimal fit. The target values are determined by Hirota and Obara (2000).

Energy parameters	Value	Resource and notes
% energy when I created	0.66	From training
energy consumed to move	0.01	From training
energy consumed to rest	0.005	From training
energy taken to eat	0.07378	From training

Table 10: Energy parameters obtained from training. These are simulations values, closer to the target value. This first output will be used as input parameters for further simulations.

The parameters of energy intake and consumption can be use to run other simulations. Those other simulations can be useful to test the performance of the MAS model (in terms of efficiency of the subsumption), and to detect limits and errors.We run some preliminary simulations to show possible results of the project. These preliminary simulations were performed in the area surrounding the sampling Urban area, with 80 butterfly-agents (sex ratio 1:1). The environment was simulated with the maps previously presented (Fig. 5), and filled with the data obtained during the field-work (such as nectar resources). During the simulation, it is possible to obtain data on the position of each butterfly, the location of laid eggs (Fig. 13) and the movements (with direction, Fig. 14). These data can be useful in further simulation, to understand which environmental variables affect abundance and mobility of butterflies and thus to plan the green areas, reducing the impact on butterfly mobility.

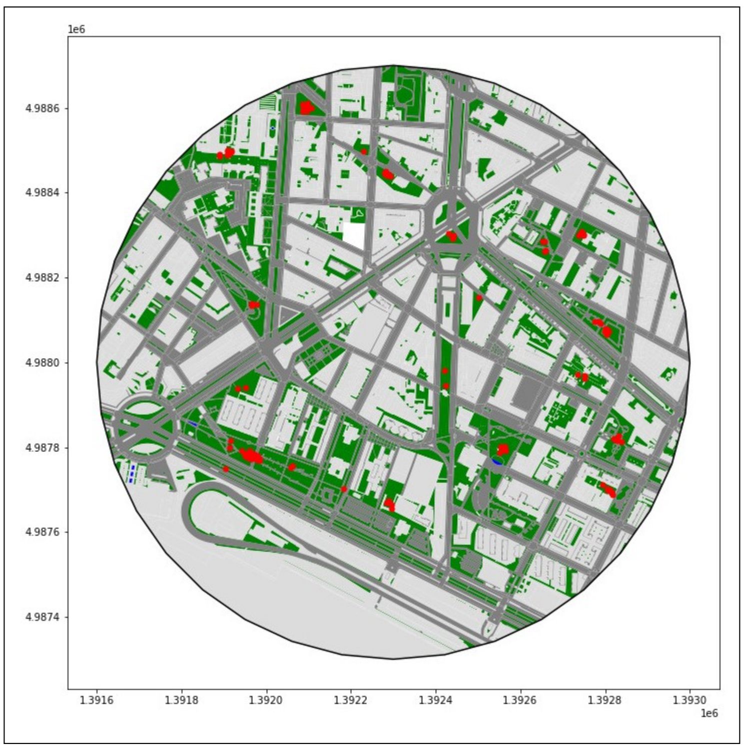
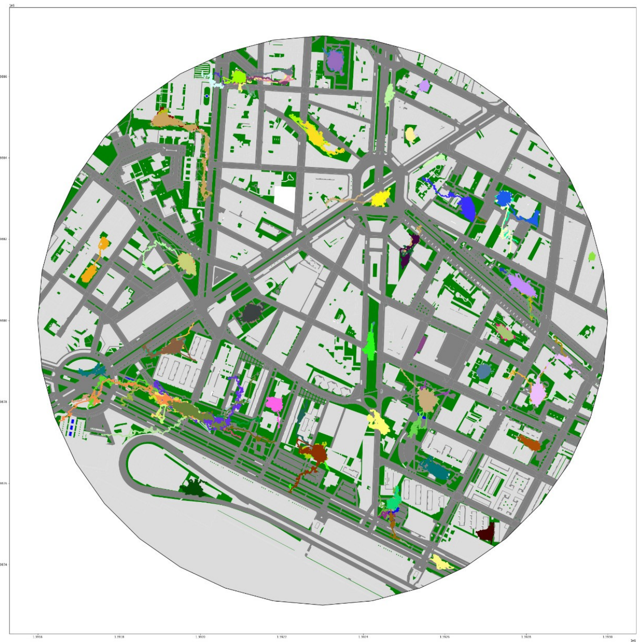
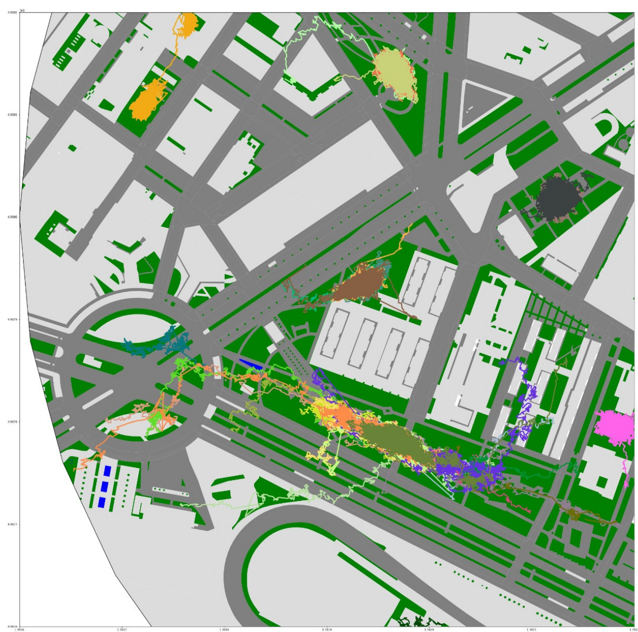


Figure 13: Figure shows possible results of a next simulation, based on the energy parameters that we obtain. Through the same simulation, another information was obtained: eggs location. The red spots represent one single egg. Only the eggs that will allow the virtual birth of a new butterfly-agent (12% survival rate from egg to new adult; Davies and Gilbert (1985)) are shown in the map.



(a)



(b)

Figure 14: Figure shows possible results of next simulations, based on the energy parameters that we obtain. The colours represent the four groups of environmental information of the model: roads (dark grey), buildings (light grey), green areas (green) and water sources (e.g. fountains; blue). This map shows the flight movements of the butterfly-agent, represented by the colourful lines (one colour each individual). a) the entire map of the simulation, which is a 800 m radius circle, in the area of site 1. b) a zoom over the south-west corner, where flight movements are more visible.

4 Discussion

From the data collected on the field, individuals of three common and generalist species were analysed together as *Pieris* genus (no significant differences among species). The mobility and local abundance of these butterflies were analysed within the study areas. A total of 1020 individuals were captured and marked, of which 61.5% in site 2 “Parco Piemonte”. In both sites, males were the most sampled (67.6% of the total). Mobility was found to not differ between sex or species and higher dispersal has been recorded in the urban areas, which likely serves as an area of passage to other more suitable areas of the city. Preliminary simulations of MAS have shown ratios between energy consumption and intake for butterflies performing different behaviours. Next steps will be to use these results and further simulations to understand which environmental variables influence abundance and mobility of butterflies within the city.

4.1 Estimation of Local Abundance

Compared to other studies of Pieris species (Ohsaki, 1980; Matteson & Langellotto, 2012), the numbers of captures and recaptures were similar (1020 and 464, respectively). The percentage of recaptures (45.49%) was comparable to other populations (46%; Parile et al., 2021). The number of marked females was lower than that of males, resulting in a sex ratio of 1:2.1. The demographic pattern with a higher male catchability is similar to other butterflies (e.g. Baguette & Schtickzelle, 2003; Fric, Hula, Klimova, Zimmermann, & Konvicka, 2010; Čelik, 2012. Indeed, males have been recaptured more frequently than females (49.1% vs. 38.1%), also in accordance with Ohsaki (1980). Less individuals were sampled in “Urban area” (393 over 1020 captured in total), but this was even the site with higher recapture rate (65.14%, while site 2 recapture rate is 33.17%). This confirms the relation between butterfly abundance and urbanisation level, shown in previous studies higher urbanisation support less butterflies (e.g. Blair & Launer, 1997; Ramírez-Restrepo & MacGregor-Fors, 2017).

We found that the number of individuals and their distribution in the two areas differ, indeed in the greener area (Site 2 Parco Piemonte) there are more individuals. Indeed, the local individuals easily obtain food resources and host plants in the wide suitable area. Thus, their movements are more stable in time and they remain in the same area. Indeed, the high presence of generalist species that present high mobility, is linked to habitat quality and resource presence (Pla-Narbona et al., 2021; Angold et al., 2006).Thus, an unsuitable area (more anthropic, fragmented and with less resources) does not tend to host a large number of individuals, or rather it is just a passage area as demonstrated by the greater mobility.

4.2 Mobility

The network of suitable habitats is more effective when large and well connected patches are present, because butterflies are most likely to move between patches that are close together (Hill et al., 1996). Patch size and connectivity can influence the population turnover (Komonen et al., 2008), to the point that several rare UK butterflies are restricted to relatively large and non-isolated habitat patches, while small patches and those that are isolated from population sources remain vacant (C. Thomas et al., 1992).

From mobility analysis, the butterflies in site 1 "Urban area" have greater mobility compared to the individuals in site 2 "Parco Piemonte". Thus, considering the lower recapture rate, demonstrate that the lower resources disposal increases the mobility of the individuals. Around "Urban area" wide green areas are absent, which increase the value of the site as a hotspot, and as a "stepping stone". Indeed, two different sites were selected for the sampling session, under the assumption that different urbanisation levels affect the mobility differently. The northern site (Site 1, "Urban area") is a residential area, characterised by widest and more frequented roads, with few, highly fragmented narrow green areas. The peri-urban site (Site 2, "Parco Piemonte") is more recent area of the city, distinguished by the presence of a greater green area (i.e. "Parco Piemonte") and urban gardens, managed by citizens, through the social enterprise "Orti Generali s.r.l.". The features that most differentiate the two sites are the type and distribution of the green areas, indeed in site 1 the green plots are mainly little and narrow, along or in the middle of main roads, while in site 2 most of the green areas (a part from the gardens and the park) are plots between houses or buildings, grouped and in pedestrian areas.

The mobility is strictly dependent on sex, habitat quality and presence of ecological barriers (Örvössy et al., 2013; Piccini et al., 2022). In urban areas, buildings, paved areas and mowing are the obstacles for butterfly mobility (Goddard et al., 2013). Thus, low mobility might also affect isolation of populations (Roland & Matter, 2007), making some green areas, such as parks, ecological traps (McFrederick & LeBuhn, 2006; Shipley et al., 2013). Indeed, our data confirms that female butterflies in Parco Piemonte disperse less than in urban areas (for distances of <1km), because in the park they found host plants to lay eggs on. Conversely, males have similar dispersal movements in both areas for distances <1km. Indeed, mating systems and asymmetry in parental investment may lead to sex biassed dispersal, with sexual conflicts which involve female-female competition for feeding or egg-laying areas and male-male competition for sexual partner access (Perrin & Mazalov, 2000; Trochet et al., 2013). Dispersal of >1km is highly dependent on scale and ecological barriers present in the sampling areas (Kuefler et al., 2010). Consequently, females in Parco Piemonte disperse more than males (Table 6), because the resources are more abundant and there are less risks (Turlure et al., 2011). Males in Urban area disperse more than females (Table 6), likely due to the general higher dispersal ability of males especially under stressful conditions, such as unsuitable habitat (Ducatez et al., 2012).

4.3 MAS: Energy Consumption and Intake Estimation

A Multi Agent System could help predict butterfly ecological preferences and mobility, but it depends on several biological and ecological input variables, such as energy consumption. Even if lepidoptera is the second order by number of species (Stork, 2018), precise and field-related data on metabolism and individual behaviours, are unknown.

Starting from data of Hirota and Obara (2000), frequency of different behaviours (eating, reproduction, flight and resting) were converted in ratio of frequencies. From this ratio, was used as the target of a set of simulations, to estimate the parameters of energy. It is known that energy intake is dependent by the amount of nectar present in each flower (that can be related to the flower species and also on how many other pollinators have fed on it; (Daniel et al., 1989)). However, for these simulations we considered as a proxy of energy intake the average time spent by butterflies on flowers (Hirota & Obara, 2000). Multiple random and independent simulations were run and analysed. The output of this training session will be used as input in further simulations, as parameters of butterfly-agent energy. Through the simulations have been possible to estimate the energy intake and consumption for each behaviour. This is really hard to be estimated in the field and only proxies of energy intake can be estimated, such as body mass or metabolic rate before performing behaviours (Niitepõld et al., 2009). In other cases when several other factors might influence data obtained in the field, such as sample size and fieldwork effort, simulations can adjust field-based estimates (Wang et al., 2022).

As a caveat, we recognize that the model can be more precise adding specific information on flower richness or frequency of mowing, which changes depending on the public administration. Future improvements of the model could be made, including further information and/or temporary changes of environmental variables. In the next future, the MAS simulation can be improved using other data from fieldwork or other models (e.g. forecast scenarios). Thus, the MAS could provide results on a determined species or city data. Moreover, by setting different parameters of the virtual environment, the model will be able to predict the outcomes of restoration operations on the urban area.

4.4 Conclusion

This interdisciplinary approach opens new possibilities in the field of urban ecology studies. Indeed, current ecological studies are based on data collection methods (e.g. MRR), which requires a great effort on fieldwork and is highly linked to the size of investigated areas (Schneider, 2003). The data analysis is then based on the data obtained and the results are data-dependent. Thus, those models are limited in time and space, to the data collection. Indeed, combining MRR, field-based data and agent-based simulations can increase the accuracy and the efficiency of estimations for both butterfly abundance (Wang et al., 2022) and mobility.

Multiple running simulations selecting input values ranging in parameters space and the comparison of the MAS output with experimental data are needed in order to test and validate this MAS model. The MAS then, would help to identify which of the architectural and ecological variables plays a major role in the butterfly dynamics and how they rule the pollinator permeability within an urban environment. From this innovative interdisciplinary approach to the urban ecology studies, policy makers and urban area managers (such as urban architects and landscaper) could integrate a new point of view in the planning operation of public green areas, about both structural and biological perspectives.

Turin can act as a case study, but the degree of customisation allowed by the selected design of the MAS would allow a greater use. Even when the model will be completed, each component will be adaptable at needs. Thus, with the same agent structure, this approach could be adapted to different butterfly species. requiring a deeper level of customisation of the agents' behaviours but not a redesign of the MAS, it could be extended to other species of pollinators. Moreover, since it is based on common GIS maps, the application of the model is not limited to the city of Turin, but could be applied to any city which can provide the same geographic information. Thanks to these characteristics, a future version of the model, could predict the mobility of pollinators in any urban settlements, accounting for specific characteristics of its environment

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Supplementary Material

Area: Operatore: Data: Ora inizio: Ora fine: GPS: Nectar sources: Rain: T:

Time	Point N°	COOR_X	COOR_Y	Cap	Recap	Habitat	Activity	Species flowers	Habitus	Sex	Species	Code	Weather	Note
							Cop: Fly: Basking: Feed: Resting:						Wind: Cloud:	
							Cop: Fly: Basking: Feed: Resting:						Wind: Cloud:	
							Cop: Fly: Basking: Feed: Resting:						Wind: Cloud:	
							Cop: Fly: Basking: Feed: Resting:						Wind: Cloud:	
							Cop: Fly: Basking: Feed: Resting:						Wind: Cloud:	
							Cop: Fly: Basking: Feed: Resting:						Wind: Cloud:	

Figure 15: Field work notes. This format contain every information I used to record during the sampling session with the MRR method

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