# AGENT-BASED MODELLING OF THE HOUSE SPARROWS

## DESIGNING A SPATIAL BEHAVIOURAL MODEL FOR THE HOUSE SPARROW IN ZAANDAM

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# Abstract

The loss of biodiversity is a global problem. As such, there has also been a significant decline in the number of house sparrows in north-western Europe including the Netherlands. It is therefore important that research is carried out into the behavior and distribution of house sparrows. Conceptual behavioral model can be used to explore the interaction between the spatial environments and the behavior of the house sparrows to develop pathways that predict the spatial distribution of House sparrows. The method was to design a conceptual behavior model by developing an agent-based model in Netlogo. From the model, pathways 1, 2, 3, 4 and standard are designed. Pathways 1 and 3 provide the best distribution of house sparrows over the buildings, while the standard pathway and pathway 4 have the poorest distribution of house sparrows. The developed model only partly corresponds to real-world observations but large standard deviations. initial birds and predators have the greatest influence on the total population. Green gardens and predators have only a very small influence on the spatial distribution of house sparrows. The suitability of the houses has the greatest influence on the spatial distribution of house sparrows. It is important to note that there is a major difference compared to the original agent-based model. The improvements in the model have led to more interaction between the spatial environments and the behavior of the house sparrows. This makes the model suitable for studying the spatial distribution of house sparrows. However, because the standard deviations are quite high and the model does not completely match reality, more research is needed.

Samenvatting – in het Nederlands

Het verlies aan biodiversiteit is een wereldwijd probleem. Zo is er ook in Noordwest-Europa, waaronder Nederland, een aanzienlijke afname van het aantal huismussen. Het is daarom belangrijk dat er onderzoek wordt gedaan naar het gedrag en de verspreiding van huismussen. Met behulp van een conceptueel gedragsmodel kan de interactie tussen de ruimtelijke omgeving en het gedrag van de huismussen worden onderzocht om zo pathways te ontwikkelen die de ruimtelijke verspreiding van huismussen voorspellen. Het ontwikkelen hiervan werd uitgevoerd door het ontwerpen van een agent-gebaseerd model in Netlogo. Vanuit het model zijn de pathways 1, 2, 3, 4 en standaard ontwikkeld. Pathway 1 en 3 zorgen voor de beste verdeling van huismussen over de gebouwen, terwijl de standaard pathway en pathway 4 de slechtste verdeling van huismussen hebben. Het ontwikkelde model komt slechts gedeeltelijk overeen met waarnemingen uit de werkelijkheid, maar de standaardafwijkingen zijn groot. initiële vogels en predatoren hebben de grootste invloed op de totale populatie. Groene tuinen en predatoren hebben slechts een zeer kleine invloed op de ruimtelijke verspreiding van huismussen. De geschiktheid van de huizen heeft de grootste invloed op de ruimtelijke spreiding van huismussen. Het is belangrijk op te merken dat er een groot verschil is ten opzichte van het oorspronkelijke agent-based model. De verbeteringen in het model hebben geleid tot meer interactie tussen de ruimtelijke omgevingen en het gedrag van de huismussen. Dit maakt het model geschikt voor het bestuderen van de ruimtelijke verspreiding van huismussen. Omdat de standaardafwijkingen echter vrij hoog zijn en het model niet volledig overeenkomt met de werkelijkheid, is meer onderzoek nodig.

## PREFACE

THIS THESIS WAS CONDUCTED TO COMPLETE MY MASTER'S DEGREE IN SUSTAINBLE DEVELOPMENT TRACK ENVIRONMENTAL CHANGE AND ECOSYSTEMS. MY RESEARCH INCLUDED DESIGNING A CONCEPUTAL MODEL OF THE HOUSE SPARROW'S BEHAVIOUR AND SPATIAL DISTRIBUTION.

IN A WORLD WITH A LOT OF CLIMATE CHANGE AND BIODIVERSITY LOSS, I AM GLAD THAT WITH MY DEGREE I CAN CONTRIBUTE A LITTLE TO A BETTER AND CLEANER WORLD. THE FACT THAT I CAN GRADUATE FROM MY STUDIES BY CONTRIBUTING RESEARCH TO THE PROTECTION OF HOUSE SPARROWS IS THEREFORE A VERY NICE BONUS. I PERSONALLY FIND IT A FASCINATING RESEARCH TOPIC BECAUSE IT IS A COMBINATION OF USING COMPUTER INTELLIGENCE AND THE BEHAVIOR OF HOUSE SPARROWS. AS THE TECHNICAL POSSIBILITIES CONTINUE TO GROW, DESIGNING CONCEPTUAL MODELS BECOMES AN INCREASINGLY LOGICAL OPTION. I WOULD ALSO LIKE TO THANK MY SUPERVISOR STEFAN DEKKER AND INTER SUPERVISOR BELINDA KATER FOR THE GOOD SUPPORT IN MY RESEARCH! ESPECIALLY THE MEETING WITH THE THREE OF US WAS VERY VALUABLE TO ME.

I SINCERELY HOPE THAT MY RESEARCH WILL CONTRIBUTE TO THE DEVELOPMENT OF THE WORLD OF SCIENCE!

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# 1. INTRODUCTION

## 1.1 LOSS OF BIODIVERSITY

The loss of biodiversity due to human activities is a global problem (Zari, 2018). Besides the loss of fauna and flora, the loss of biodiversity leads to increased pressure on ecosystems which are crucial to the supply of services and goods for humans. Hence, damaging ecosystems also reduces human-well-being (Díaz, et al, 2006; Cardinale ,2012). An ecosystem in which the interaction between humans' activities and fauna is very interconnected is in urban ecosystem (Mustafa, 2015). Certain birds' species mainly live in urban ecosystems, such as the house sparrow (*passer domesticus*) (Choudhary, et al, 2019).

The house sparrow is a bird that occurs worldwide as native in mainly Europe and Asia and as introduced bird for the Americas (BirdLife International, 2022; Choudhary, et al, 2019), see figure 1. In Europe, estimates are between 270 and 378 million, with a best estimate of 316 million birds (BirdLife International, 2021).
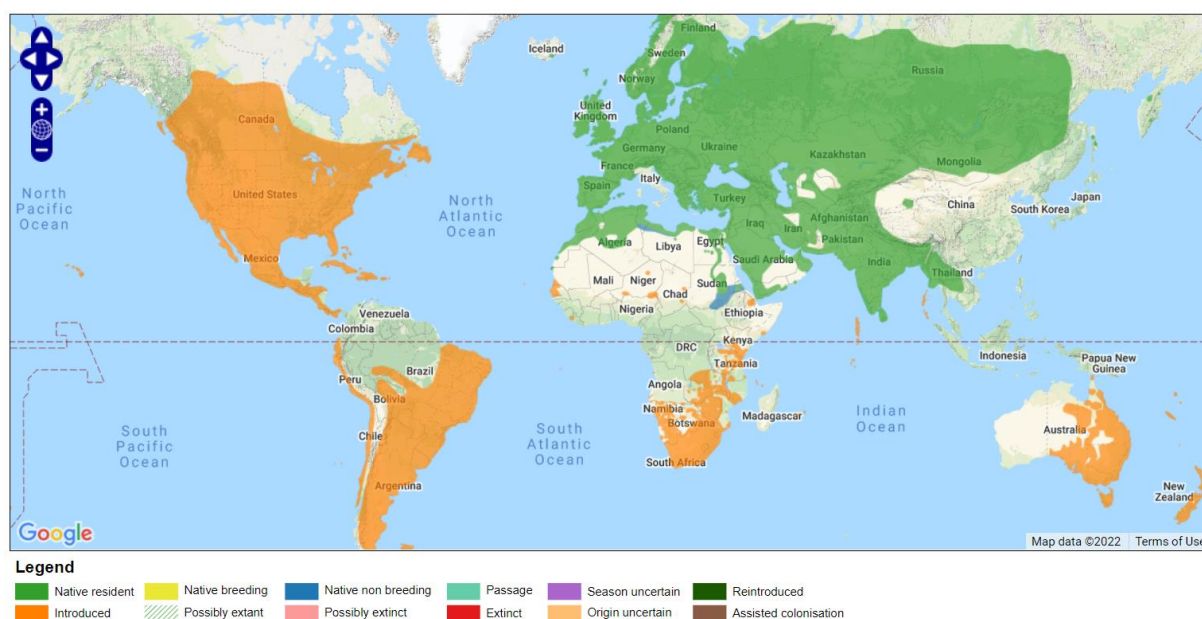


FIGURE 1. DISTRIBUTION MAP OF THE HOUSE SPARROW (BIRDLIFE INTERNATIONAL, 2022).

There are different reasons why this species is living mainly in cities. Firstly, in the urban environment there is plenty of food available that matches their diet (granivorius/omnivorus) and secondly, there are many opportunities to nest (Moudra, et al ,2018). In fact, the house sparrow is more common in urban areas than in the rural areas (Jokimäki, et al, 2021). The most common natural predators of the house sparrow include the house cat (*Felis catus*) and the sparrowhawk (*Accipiter nisus) (*Seress, et al, 2011; Fitzwater, 1994*).

According to the Red list status (BirdLife International, 2021), the number of sparrows is decreasing in Europe. The decline in house sparrows was first reported in Great Britain (Bernat-Ponce, et al, 2018; Mustafa, et al, 2015). House sparrow populations in Great Britain have declined by up to 65% over a period from 1970 to 2012, reaching 70% in some large cities. In other European countries, this pattern is being replicated, with the number of house sparrows in Valencia (Spain) also declining by 70% over a 10-year period (1998/2008) (Bernat-Ponce, et al, 2018). In the Netherlands, there has been a significant decline in the house sparrow since the 1990s (Klok, et al, 2006). Not only Europe is dealing with the disappearance of house sparrows, the loss of house sparrows seems to be a worldwide trend, for example the population is also declining in India (Mustafa, et al, 2015).

Although, it still falls into the category of least concern (LC) according to Birdlife international (2021), meaning that the house sparrow is in the lower category in terms of extinction risk. Nevertheless, there is still urgency to monitor house sparrows since there is a decline observed worldwide (Birdlife International, 2021; Berigan, et al, 2020; Choudhary, et al, 2019; Peach, Et al, 2018).

### 1.1.1 Reasons that the house sparrow is declining

It is not yet entirely known what the reason is for the declining house sparrow population in Europe. One of the reasons that has been mentioned is that there is a link between the population density of humans in urban areas and the decline in the house sparrow population. This connection may be since house sparrows prefer old houses with sloping roofs and more cracks and holes in the walls to build their nests. This type of house decreases as the rate of urbanization in an area increases. (Moudrá, et al, 2018; Jokimäki, et al, 2021). Urbanization also influences the presence of gardens and other green areas in the city. The presence or absence of green areas also has a major influence on the presence of the house sparrow.

The differences in urban areas with new built-up areas and old buildup leads to a significant difference in the amount of house sparrows present, see Figure 2 (Moudrá, et al, 2018).
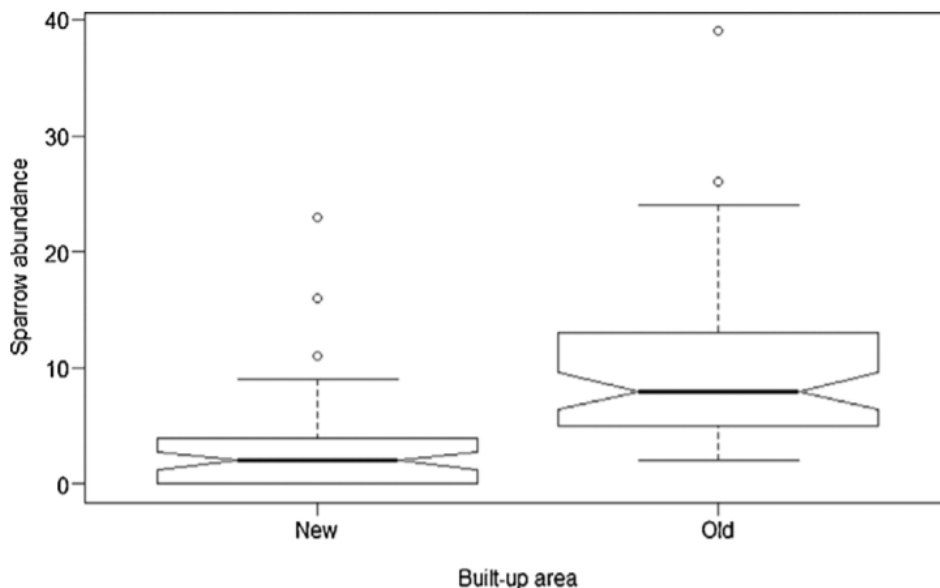


**FIGURE 2. HOUSE SPARROW MALE PER 4 HA SITE IN NEW (<1990) AND OLD (>1990) BUILT-UP AREAS (MOUDRÁ, ET AL, 2018).**

Another possible cause could be a shortage of food, and then especially in winter. The main problem with food sources is not due to lack in seeds availability but due to a shortage in invertebrate (prey of the house sparrow) (Peach, et al, 2008; Moudrá, et al, 2018). Moreover, this would mainly affect the success of reproduction and the development of chicks and less effect on the success of adult individuals (Peach, et al, 2018). The population of house sparrows does not depend on only one factor.

### 1.1.2 PROTECTING THE HOUSE SPARROWS

By applying various rules and laws, attempts are being made to counteract the loss of biodiversity in The Netherlands. This is covered by the Nature conservation Act. With which the Netherlands incorporates the European Habitat and Birds guidelines into its legislation. Due to this law both endangered as well unthreatened flora and fauna are protected (Rijksoverheid, n.d) House sparrow is a protected species in the Netherlands. Because of this 'Nature Conservation Act', there are measures that must be carried out to protect the house sparrow during some activities in built-up areas. Therefore, certain strict laws must be followed when rebuilding, re-insulating, demolishing, and renovating buildings (Van den Akker, 2018).

To carry out these projects, an exemption must be requested from the municipality. This means that you can make an exception to the laws from the Nature Protection Act (van den Akker, 2018; Rijksoverheid, n.d.). To obtain this exemption, first research must be carried out on the site of the activities. In the case of the presence of flora and fauna, the influence of the various activities on them is examined. Furthermore, measures must be designed in case the construction work affects the existing biodiversity (Van den Akker, 2018). Unfortunately, the number of house sparrows is still decreasing dramatically in north-western Europe (Shaw, et al, 2008).

## 1.2 THE IMPORTANCE OF RESEARCH

It is important to protect the house sparrow because its loss contributes to weakening the urban ecosystem (Mustafa, et al, 2015). To be able to offer the house sparrows protection there must be a clear overview of how they are distributed spatially and where they nest. In this way, we can offer appropriate measures and/or migration options. One way to study the spatial distribution of house sparrows and thus protect them is using agent-based models. By using such agent- based models, the behavior of individuals can be studied and predict. An agent-based model is based on the complex dynamic interactions in a system. Thereby, the model can investigate the complex interactions between individuals and their environment (Wilensky & Rand, 2015; Railsback & Grimm 2019). So, the use of models as a first step is necessary to give a fast and easy overview in a short period of time.

Furthermore, as van den Akker also pointed out (Van den Akker, 2018), that a model is a valid scientific tool that provides valuable support for the current way of operating. Especially the ability to predict the impact of mitigation measures is a great advantage. Fortunately, Arcadis has already developed two models that focus on the house sparrow (van den Akker, 2018; Ceelen, 2021; Kater, 2022), see table 1. Those two models by themselves provide insight and information about the behavior and distribution of the house sparrow. However, a combination of these two models would lead to an ultimate product in which the influence of different housing types on nesting as well as the individual behavior of house sparrows is shown. This new model could then be used very effectively to research and protect the house sparrow. Additional information on these two models can be found in Chapter Theory.

TABLE 1. TWO DIFFERENT MODELS DEVELOPED BY ARCADIS (VAN DEN AKKER, 2018; CEELEN, 2021; KATER, 2022).

| $1^{ste}$ model (Ceelen, 2021): | Agent-based model in which the behavior of a population of house sparrows is illustrated. The world in which this population can be found is 'not real' and the nests are located randomly in the field. |
|---|---|
| | Program used: Netlogo. |
| $2^{de}$ model (Van den Akker, 2018; Kater, 2022): | Suitability model in which different types of houses with different characteristics are shown and with which of these characteristics there is a possibility that house sparrows can nest here for Zaanstad. |
| | Program used: ArcGIS Pro |

Protecting species like the House Sparrow is also of importance in order to meet the UN's sustainable development goals. This research could therefore add to the achievement of the goals life on land (G. 15) and sustainable cities and communities (G. 11) (UN, 2016). Therefore, this research fits well as a thesis topic in the program: Sustainable Development, track environmental changes and ecosystems.

## 1.4 RESEARCH AIM & QUESTION

The goal of this study is to create a conceptual model that can simulate the spatial distribution of the house sparrow by adding the different suitability of the houses for nesting House sparrows. A conceptual model is a framework consisting of processes through which interactions between different subjects can be investigated and understood (Elangovan & Rajendran, 2015). Once this model is running, it can also be used to assess different pathways. The research aim and research gap therefore lead to the following research question:

***How can a conceptual behavioral model simulate the spatial distribution of the house sparrow to assess different pathways in Zaanstad?***

This main question is answered in this research using three sub-questions: *How can you use a conceptual model to investigate the spatial distribution of house sparrows, including the influence of spatial characteristics/ What are the different pathways for the house sparrow in Zaandam? What is the spatial distribution of the house sparrow with different mitigation actions/adaptive behavior of the house sparrow?*

It was hypothesized that the different spatial characteristics influence the spatial distribution of house sparrow which can be observed by using an agent-based model. Hereby will lead to different spatial distributions between the different pathways for Zaanstad.

First, a theoretical background is given in Chapter 2. This provides information on the two different models used as a basis for the conceptual behavioral model of the house sparrow. In Chapter 3, the methods used are described. It also gives a short explanation of each part and the codes used to design the model. Further on, the results obtained by the method are discussed in Chapter 4. Following this chapter, the conclusion and discussion are presented to answer the research question.

## 2. THEORY BACKGROUND

### 2.1 THEORY USED

The theory used is based on the papers and models from Arcadis conducted by Van Den Akker (2018), Ceeleen (2021) and Kater (2022). The following chapters contains information on the agent-based model (the original ABM) and the suitability model.

#### 2.1.2 AGENT-BASED MODEL

This chapter contains information of an agent-based model for behavior and spatial distribution of the House sparrow (Ceelen, 2021). In this paper this model will be named the original ABM. An agent-based model represents individual behavior of an agent (Wilensky & Rand, 2015; Railsback & Grimm 2019), in this case a house sparrow. So, with an ABM the spatial distribution of individual house sparrows can be observed. The agent-based model provided by Arcadis describes a couple of different relations. The first relation is between daytime activities of the house sparrows and its environment (green areas). The second relation is between nighttime activities and the nests on houses (needed features). It also provides information on the distance between the house sparrow and a nest spot.

The theory behind the original ABM is based on a couple of requirements that affect the behavior of the house sparrow (Ceelen, 2021). First, all the following requirements must be found within a certain distance of the nest. The maximum distance for house sparrows is 200 meters from his nest. Ideally, the preferred distance is around 50 meters, but 100 meters is also considered as a good distance. The environmental and population density requirements that must be present within distance are listed in the table 2 below:

**TABLE 2. THEORY BEHIND THE ORIGINAL ABM (CEELEN, 2021).**

| Requirements needed in 200 meters around the nest | | Used in the original ABM |
|---|---|---|
| **1.** | Dense Shrubs between the 3 and 4 meters | Yes |
| **2.** | Food source | Yes |
| **3.** | Sand bath | No |
| **4.** | Water Bath | No |
| **5.** | Other House sparrows<br> a. Bad <10 pairs<br> b. Good >10-<25 pairs<br> c. Best >25 pairs | No |

Requirements 3, 4 and 5 are not included in the current version of the model. The reason that requirement 3 is not included is because sand is always present for example, next to or between paving stones (Ceelen, 2021).

Additional background information relevant to requirement 5 (not included in the original ABM) is that house sparrows live in colonies. It is important that a minimum number of pairs is present to ensure a stable population. The chance of a stable population is high with 25 pairs or more. Under 25 to 10 pairs, the chance of a stable population decreases. Below 10 pairs, the population becomes too unstable, and the population does not survive. There are three factors that influence the size of a population house sparrows, which are

reproduction, death, and migration. The chance that a youngster survives in its first year is about 41%. When the youngster reaches adulthood, this percentage increases to between 45% and 65% (Ceelen, 2021).

Figure 3 shows the original ABM during running during a daytime. The white birds are individual house sparrow, and the brown spots are the nesting spots. The red squares are building, and the green squares are areas with green space, for example gardens.



FIGURE 3. ABM HOUSE SPARROW IN MEDIUM ENVIRONMENT (CEELEN, 2021).

### 2.1.3 AGEND-BASED MODEL USED

The information used from original ABM is mainly on house sparrow behavior. The first behavior is that house sparrows search for a nest at night. The second behavior is that they look for food in gardens when they are hungry during the day. The theory from requirement 1 and 2 will be used for this. The gardens themselves are not used from the model but added later by information from the suitability model, this can be found in the next chapter. Furthermore, information out of requirement 5 will be used. The model will not run if the population is lower than 20 pairs.

The original model is still missing a few features, so adjustments are therefore needed. Therefore, the population size impact (changes in population due to deaths, reproduction, and migration) needs to be added to the model. Another change that is needed is that each bird stays on its own nest in the night.

### 2.2.1 SUITABILITY MODEL

The second model that will be used in this study is the suitability model of the Zaanstad region. This model shows the suitability of each building for nesting of the house sparrow. This means to what extent a building is suitable for a nest. This model was developed by van den Akker (2021) and Kater (2022) and is called the suitability model in this report.

The suitability model is based on several suitability criteria developed by van den Akker (2021). These criteria are divided into suitability requirements for the environment and suitability requirements of buildings, see Figure 3. The requirements for the environment are an average NDVI value, within a 100 m buffer, greater than 0.25. This means that there must be green available in the area. The second environmental factor that must be met simultaneously is that there must be no more than 25% forest within 100m of the house.

The suitability model also shows what the suitability requirements of the buildings are. They must always occur and are: Buildings/properties with a height between 2.5 m and 12 m (no flats) and Construction year <2000 and Sloping tile roof/no roof insulation. If one of the characteristics is not present, there is no suitability (Van den Akker, 2021).

| House sparrow<br>*Criteria* probability of nesting | | | Building suitability requirements | |
| --- | --- | --- | --- | --- |
| | | | ▪ Buildings/properties with a height between 2.5 m and 12 m (no flats)<br>AND<br>▪ Construction year <2000<br>AND<br>▪ Sloping tile roof<br>▪ no roof insulation | |
| | | | Yes ↓ | No ↓ |
| Environmental suitability requirements | | | Building suitable | Building unsuitable |
| ▪ Average NDVI value within buffer 100m larger than 0.25*<br><br>AND<br><br>▪ No more than 25% forest within 100 m of house | Yes → | Environment suitable | ✓ High probability of nesting.<br>✓ Always nature-proof and mitigate the property. | ✓ Low likelihood of presence of nests.<br>✓ Nature clearance if actual observations present.<br>✓ Always mitigate property. |
| | No → | Environment unsuitable | ✓ Medium likelihood of presence of nests.<br>✓ Search for plus in the environment.<br>✓ Always nature-proof and mitigate the property. | ✓ Low likelihood of presence of nests.<br>✓ Search for plus in the environment.<br>✓ Always mitigate property. |

**Figure 4. CRITERIA PROBABILITYOF PRESENCE (VAN DE AKKER, 2018). *will be removed from the suitability model and be used to add green gardens.**

The suitability model used in this research bases the suitability of the houses on the same criteria as the figure above indicates. By which a probability is calculated that gives information about the probability of the presence of a house sparrow's nest per building (Kater, 2022). Meaning that each building has a suitability value in which the greater the value, the higher the probability of the presence of nests.  In this study, the Zaanstad region is studied. The outcome of this model for a part of Zaanstad is shown in Figure 5. In the suitability model, the highest probability is 0.856 (light purple/lilac) and the lowest probability is 0.22 (light blue).

Furthermore, the suitability model contains observations made during field research. These observations are divided into 15 categories or '*broedcodes*' (number 4 is skipped), see figure 6.
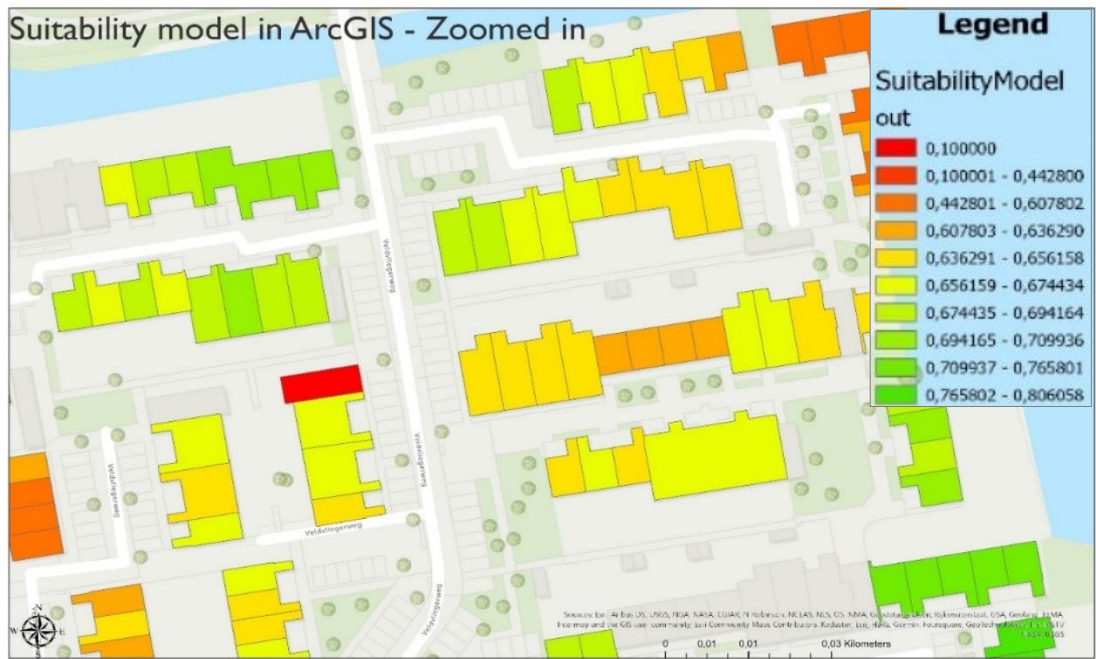
**Figure 5. Suitability model of house sparrows in Zaanstad zoomed in (Kater, 2022).**
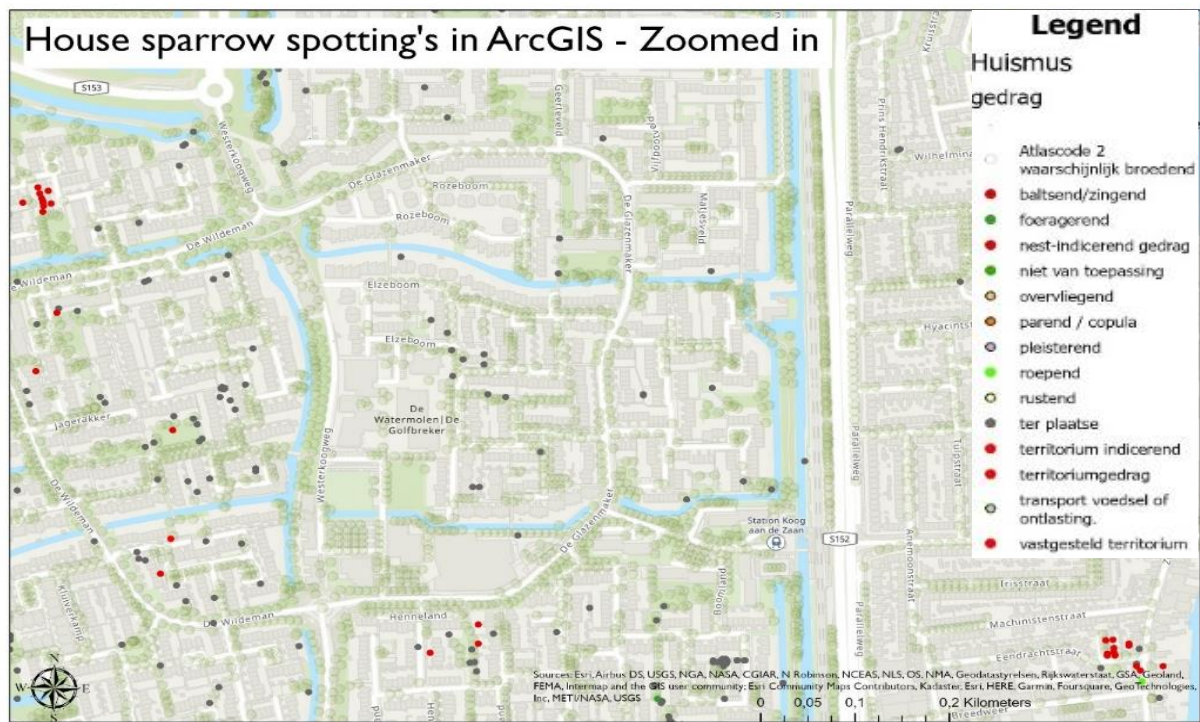


**Figure 6.** Field observations broedcodes with: overig/buiten broedbiotoop (other/outside breeding habitat),volwassen individu (adult individual), zingende of baltsend individu (singing or courtship individual), paar (bij balts/zang code 2 0f 5) (pair (wi with courtship/singing code 2 0f 5)), baltsend paar (ook paring) (mating pair (also mating)), waarschijnlijk nestplaats (probable nesting site), alarmeren, waaks gedrag (alarm, vigilant behaviour), vogel met broedvlekken (bird with breeding spots), nestbouw (nest building), afleidingsgedrag (diversion behaviour), pas gebruikt nest (recently used nest), pas uitgevlogen/ dons jongen (newly fledged/ down young), bewoond nest (bezoek ouders) (inhabited nest (visiting parents)) (kater, 2022).

### 2.2.2 SUITABILITY MODEL USED

The suitability model is used to substantiate the suitability of each building and therefore how many nests are present per building. Thus, this model will be used as based map for the new behavior model. Furthermore, will the information of the NDVI removed from the database and used to create gardens in the areas. The spotting is used to eventually compare the newly developed agenda-based model with reality.

## 2.3 THE USE AND IMPORTANCE OF THE THEORY

To be able to answer the aim and the research question, these two models will be combined to provide a model that shows where nests can be found together with the individual behavior of the house sparrows. This will give a spatial distribution of house sparrows in an area. This model can be used later to show possible future pathways. Therefore, it is important to use these two models with underlying theories. By building a new model and seeing if it matches reality, I will test the theory.

These two models and their underlying theories are very important because I create my model from them. Therefore, my hypothesis is that by combining the two models, a valid model emerges. This model is seen as a valid one because its findings correspond to reality. This ensures that the model can also be used for other areas where no field studies have been done, lack of information about the buildings.

## 2.4 AREA DESCRIPTION

As a research example, this study focuses on the area of Zaandam, and then with the specific focus on the neighborhood with the streets: Langeweide, Haalweide, Beekweide and Schaarwiede, see figure 7. It is surrounded by Houveldweg in the east and Volendamstraat in the west. To the north, the area is surrounded by a ditch. This area falls under the neighborhood Westerwatering in the municipality Zaanstad. The reason for choosing this area is that it is surrounded by water on several sides, creating a nicely framed area.
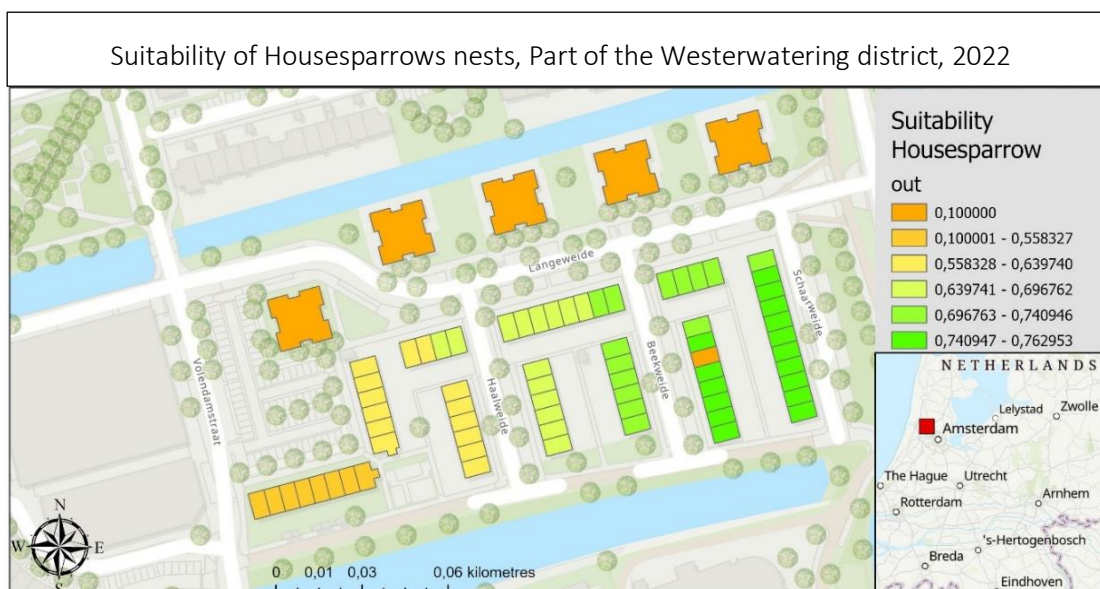


**Figure 7. Suitability for House sparrows for a part of the Westerwatering district in 2022 (Kater, 2022).**

## 3. METHOD

Flowcharts 1 below show how the research question is answered by the method, with the chapters following the flowcharts.
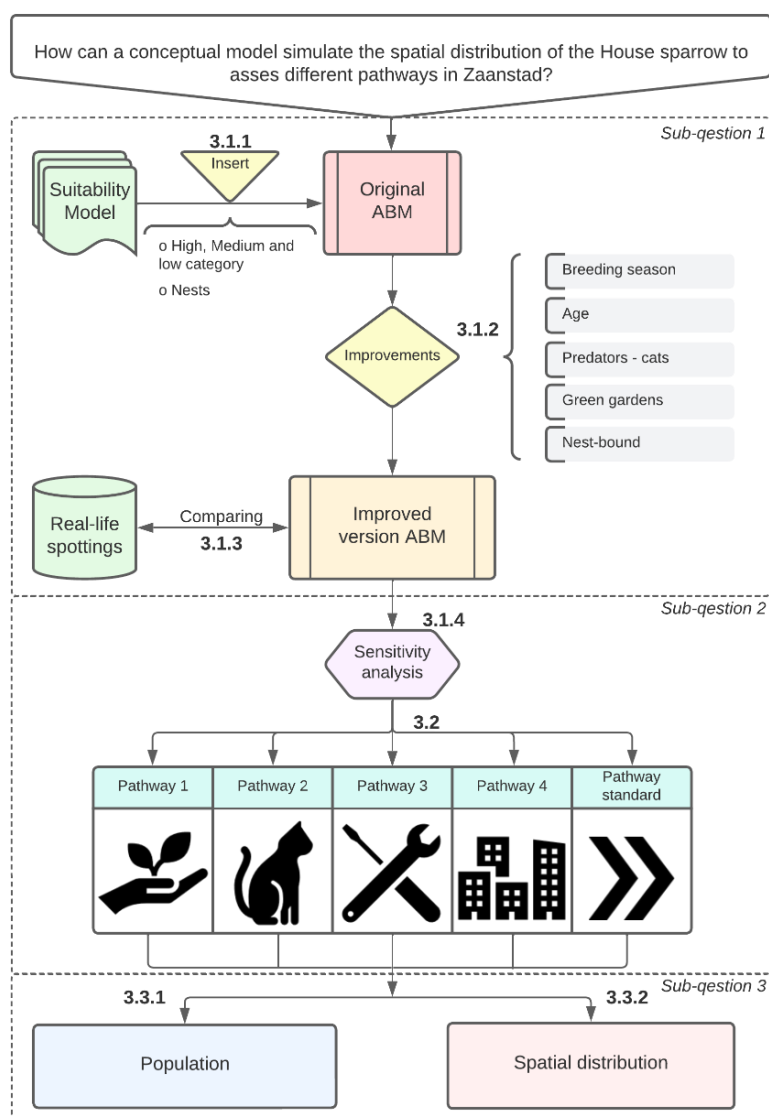
## 3.1 DEVELOPMENT OF A SPATIAL MODEL BY COMBINING CONCEPTUAL BEHAVIOR PROCESS AND A SUITABILITY MODEL

This part of this report discusses the methods used to answer the question: *How can you use a conceptual model to investigate the spatial distribution of house sparrows, including the influence of spatial characteristics?*

### 3.1.1 EXPLAINING THE CHANGES THAT ARE MADE SO THAT THE MODELS CAN BE COMBINED

#### 3.1.1.1 FROM ARCGIS TO NETLOGO

The first step is to be able to insert the suitability model outcome into the existing ABM. This is accomplished by using the extension [GIS] in Netlogo (Northwestern, n.d.; Walker & Johnson, 2019). As the extension GIS is used, the map must fulfil some conditions. First of all, the GIS extension in Netlogo doesn't recognize all the global

coordination's projection used in ArcGIS Pro (Northwestern, n.d). The original suitability model has RD new coordination format that is not recognized by Netlogo (Walker & Johnson, 2019). RD new is the national coordinate system of The Netherlands whereby Amersfoort (the tower of our dear lady) the center of the projection is (Kadaster, n.d.). Furthermore, RD new is only available for the Netherlands up to 19.3 kilometres from the coast, including the Waddensea and the Waddenislands (EPSG, n.d.). Therefore, the projection has been converted to Robinson (world).

Furthermore, the GIS extension of Netlogo does not support all types of files. It supports for vector data ESRI shapefiles (.shp) and for raster data ESRI ASCII grid files (.asc or. grd). In this research only vector data are used. Therefore, the ArcGIS map needs to be converted to have the correct extension (.shp).

**Table 3. Differences between the original suitability model and the updated suitability model.**

|  | Original ArcGIS Model | New ArcGIS model |
| --- | --- | --- |
| **global coordination's projection** | RD New ND | Robinson (world) |
| **Projection** | Double Stereographic | Double Stereographic |
| **Geometry type** | Polygon (vector) | Polygon (vector) |
| **Z value** | enabled | disabled |
| **M value** | enabled | disabled |
| **XY value** | enabled | enabled |
| **area** | - | selection |

The second step is to load the data into Netlogo. To load the dataset from ArcGIS into Netlogo the primitives Gis:load-dataset and Gis:setworld-envelope are used (Northwestern, n.d.; Walker & Johnson, 2019). The first primitive is used to load the dataset into Netlogo and the second one is used to set the Netlogo world to the size of the used dataset. Primitives are standard building blocks containing longer algorithms used for complex models in Netlogo programming containing longer algorithms (Northwestern, 2021). The table 3 shows the differences between the original suitability model in ArcGIS and the updated version.

As discussed in chapter 2 (theory), the suitability model contains information about the city of Zaandam. However, the focus in this study is on a part of a district. This decision was made because investigating the whole of Zaandam would be too large if loaded into Netlogo. The next step is to select a neighborhood from the dataset. As mentioned earlier, the choice was made for the neighborhood with the streets: Langeweide, Haalweide, Beekweide and Schaarwiede, see figure 7. Selecting a part of the data was performed using the function Select by Polygon in ArcGIS.

```
Version 0.1
 if environment-size = "zaanstad"
 [ set housemap-dataset gis:load-dataset "wiede_wijk.shp"
   gis:set-world-envelope gis:envelope-of housemap-dataset
  gis:set-drawing-color yellow
  gis:draw housemap-dataset 2
 ]
 end
```

The next step is to load the dataset in a way that the patches are filled with the corresponding data. The primitives: gis:feature-list-of housemap-dataset, gis:intersecting vector-feature, and gis:property-value vector-feature are used (Northwestern, n.d.; Walker & Johnson, 2019), see appendix A.1. With the use of those primitives the data from the suitability model will intersect with the patches in Netlogo. The colors are scale-color according to the outcomes data from the suitability model ('out').

### 3.1.1.2 BREAKDOWN OF HIGH, LOW AND AVERAGE SUITABILITY

The fourth step towards designing an improved ABM is to divide the suitability into three categories. The size of the categories is based on the division made in ArcGIS pro. The subdivision in ArcGIS consists of 3 categories, with an average of 0.6396. Regarding the frequency of occurrence of the suitability, the higher suitability levels occur more often. Furthermore, there are no buildings with unsuitability (= 0) in this specific area.

**Table 4. The six categories divided in ArcGIS Pro and used to make the 3 categories: High, medium and low.**

|  | | | | |
|---|---|---|---|---|
|  | 0.1 | - 0.558327 | Low suitability | *orange* |
|  | 0.558328 | - 0.696762 | Medium suitability | *yellow* |
|  | 0.696763 | - 0.762953 | High suitability | *lime* |

This leads to the following suitability categories: high (> 0.76), medium (0.70 till 0.56), and low (< *0.56*) refer to table 4. In the new model, these elements are implemented by using the primitive gis:find-range. See in the appendix A.1 the exact lines used to create the categories with corresponding colors.

### 3.1.1.3 DISTRIBUTION OF NESTS IN THE AREA

The final step is adding nests with different suitability in the model. The categories are presented in the previous paragraph. Per category several nests are assigned. It was decided to create 400 nests in areas with high suitability, 200 nests in areas with medium suitability and 100 nests in areas with low suitability. In effect, a house sparrow is more likely to find a nest in areas with high suitability than in areas with low suitability. The main primitives used to add the nests are *repeat* and *sprout-nests.* See in the appendix A.2 the exact lines used to create the amount of nest for areas with a high suitability.

## 3.1.2 ADJUSTMENTS TO THE NEW COMBINED MODEL

### 3.1.2.1 HOW TO ADJUST THE POPULATION GROWTH

One of the first steps to improve the ABM is to add natural population growth. The original agent-based model has no population-based system. Hence, the size of the population does not change over time, see figure 9. Therefore, the first step in improving the model is to add a population system (Olševičová, et al, 2013). The aim is designing a stable population where the population fluctuates around a certain level. The population of a house sparrow is influenced by three factors: death, births, and immigration (Ceelen, 2021). However, the decision was made to focus only on the



**Figure 8. Population in the original ABM.**

factors birth and death within this model, see figure 10. To build complexity in steps. Furthermore, a population of less than 10 pairs of house sparrows is considered a poor population (Ceelen, 2021). Therefore, a function is introduced into the model which ensures that if the population falls below 20 house sparrows, all the house sparrows die.
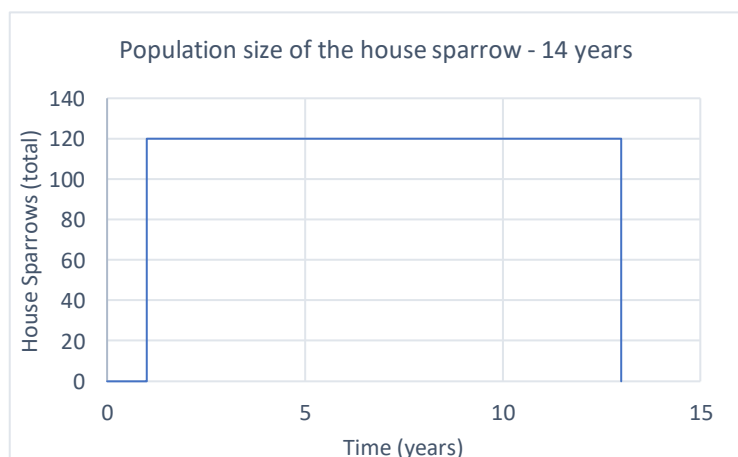
The population dynamics of the house sparrow in this model can be divided into two major parts: within the breeding season and outside the breeding season. During the breeding season, the population growth is the prominent factor, whereas outside the breeding season, mortality is the dominant factor. Factors influencing mortality are age and predators. These factors are discussed in the next two paragraphs.
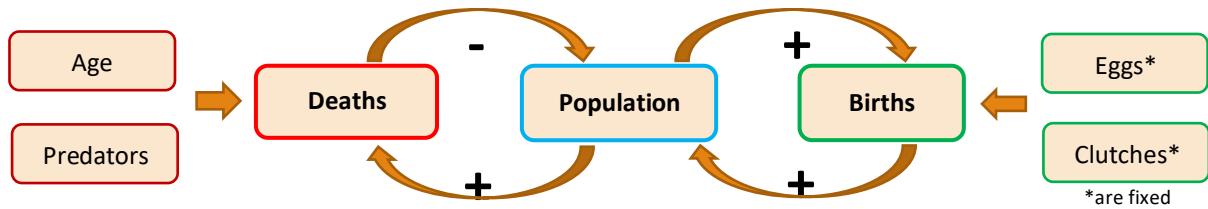


**Figure 9. Population factors in the new adjust Netlogo model.**

The breeding season of the house sparrow runs from the end of March to August. A pair lays 2 to 3 clutches with between 4 and 6 eggs per season (Ceelen, 2021). The number of eggs is multiplied by 0.30 in the calculation so only 30% of the young from the eggs will survive.

In this study, the population only grows during the breeding season since immigration is not included in the model. The population during the breeding season is growing in an exponential rate. Outside the breeding season, there is no population growth, and the exponential growth of the population stops. In figure 11 the colored areas are important during the breeding season for exponential growth.

This information is used in the new ABM Netlogo model. The most important primates used for this step are '*time:get*' and '*hatch*'. Where the first one is used to indicate that growth only happens in peak months,
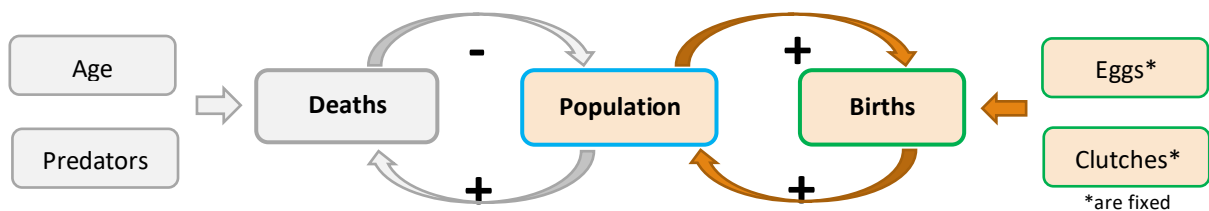


**Figure 10. Population factors essential during the breeding season.**

in this case April, May, June, July and August. The second primitive is used to create new house sparrows. Using the term, a new house sparrow is created with the same parameters as the parents.

Adding population dynamics was not successfully accomplished all at once, but through several versions. In the first version of adding a population growth model, the script below was used (version 1.1). However, in this first version the population only increased month by month causing all the house sparrows to hatch at once. Therefore, a different version has been developed.

```
Version 1.1
to check-pop
 ;if time:is-between? ("04-01")("08-01")(dd)
 if time:get "month" dt = 4 or time:get "month" dt = 5 or time:get "month" dt = 6
 [let numb-birds count housesparrows
    if numb-birds < 1000
  [
    set fertility floor new-fertility
    set fertility-remainder new-fertility – (floor new-fertility)
  ]
  ifelse (random-float 100) < (100 * fertility-remainder)
    [ hatch fertility + 1 ]
    [ hatch fertility    ]
```

```
   ]
 ;ifelse debug?
      ;print "ik kom uit"
 end
```

The final version of adding a population growth is developed as version 1.2. In this case the growth depends on the number of eggs and nests, these numbers are fixed at 5 and 2 . The numbers 5 and 2 are based on the average eggs and nest lay by house sparrows (Ceelen, 2021). Furthermore, the probability of each house sparrow hatching an egg (Hatch) is calculated for each month. It is furthermore only possible to lay eggs when the bird is over 1 year old.

Version 1.2

```
to check-pop2 ;dit gebruikt het model WEL
  let change-uit (Eggs * clutches)
  let uit-maand (change-uit / 5) ; 5 months breeding seizoen
  let uit-dag2 ((uit-maand / 30.5) * 100)  ;days
  let uit-dag3 uit-dag2 / 2 ;per housesparrow
  let uit-dag uit-dag3 * 0.30 ; 30% will survive

  if time:get "month" dt = 4 and time:get "hour" dt = 3 ;April
  [let births random 100
   if births < uit-dag and age > 1
   [hatch 1
     set age 0**
     set partner nobody*
     set own-nest nobody**
   ]]
.......
End

**Will be explained in paragraph 3.1.2.2, an 3.1.2.3 *not used
```

### 3.1.2.2 HOW TO ADD AGE GROWTH

It is essential to add an age growth rate to the model as this is used to determine which house sparrows can lay eggs and which house sparrows die due to age (Olševičová, et al, 2013), see Figure 12.
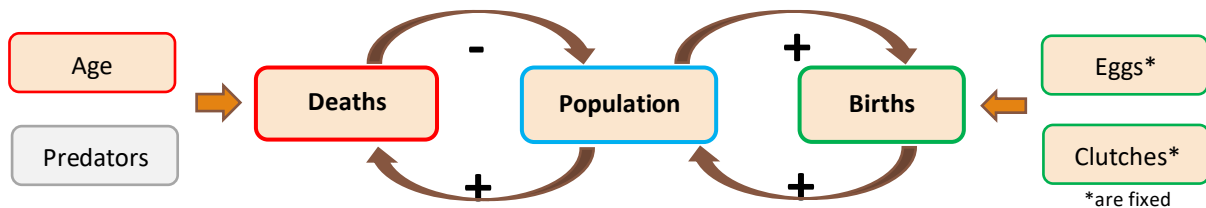
**Figure 11. Factors influences by age for the population.**

The original ABM model contained no age progression. As discussed in the introduction, the oldest house sparrow is known to have reached 13 years in the wild (Ceelen, 2021). This number is used as the maximum age in the model, when a house sparrow reaches this age, it
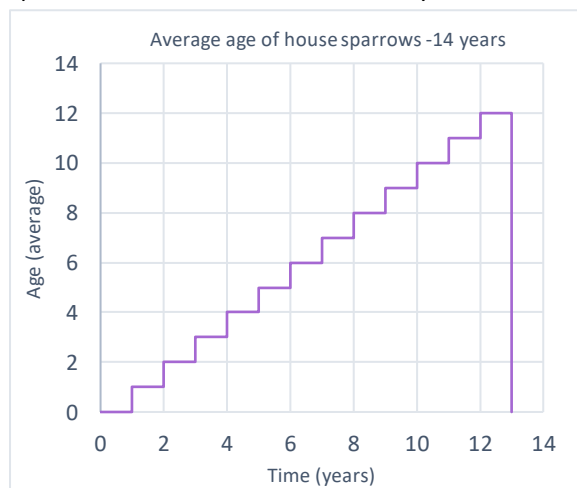
dies. In the original ABM the following code line was used: set age time:difference-between birth-date dt "year" . This causes the House sparrow to age each year, but no age difference existed. This can be seen in figure 13 which shows the mean age of the birds. It shows that each year the birds turn all the same age. After 13 years al the birds die of old age resulting in the absence of birds in the model. This was due to the fact that in the characteristic of the house sparrows the age setting was *set birth-date dt "year"* see the box X below. This did not lead to the desired population with different ages, which made change necessary

**Figure 12. Age growth in the original ABM for a period of 10 years.**

| Original version ABM |
|---|
| *set birth-date dt "year"; start counting from the year the bird hatch/made* |
| |
| to check-age ;; house sparrow procedure |
|  set age time:difference-between birth-date dt "year"   ;; set age to difference birth-date - dt |
|  if age > max-age                                                                ;; house sparrows die day 1 of their 13th year |
|    [die] |
| End |

Using the open coding method, the code lines *set age (1 + age)* and *set age random 13* were added was the best approach to running the model properly. The entire codes used in the model is shown below. It is necessary to add age to meet the research question as it helps to develop an improved version of the ABM where it t contributes to the development of a natural population size for the house sparrow.

| Version 3.2 |
|---|
| *set birth-date dt "year"; start counting from the year the bird hatch/made* |
| *set age random 13* |
| |
| *to check-age* |

```
if time:get "month" dt = 1 and time:get "day" dt = 1 and time:get "hour" dt = 1
[set age (1 + age)
  if age < max-age                 ;; housesparrows die day 1 of their 13th year
  [die]
]
end
```

### 3.1.2.3 HOW IS ADDING A PREDATOR APPLIED

Adding a predator is carried out to slow down the rate of population in a natural way. This, together with age, ensures that the population not only increases but also decreases, see figure 13. The methods used to contribute to this part of the paper is a combination of open coding and desk research.
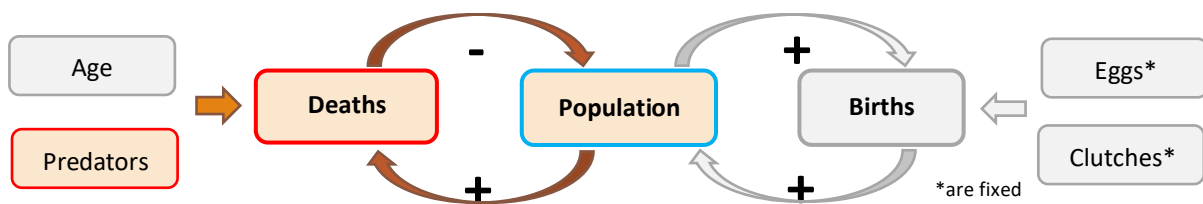


**Figure 13. Population system in the new model.**

For the predator, it was decided to add cats (*Felis Catus*) to the system. Cats are one of the main predators of the house sparrow, causing many house sparrows to be attacked and killed (Fitzwater, 1994). Other potential predators are the sparrowhawk (*Accipiter nisus) (*Seress, et al, 2011)*. However, for this model only the domestic cat has been chosen as this is the major predator. The addition of a predator is achieved by using open coding and machine learning partly based on existing models from the library of Netlogo. The primates used in the model are mainly *one-of housesparrows-here* and *breed [wolves wolf*] (Wilensky, 1997; Wilensky & Reisman, 1998; Wilensky & Reisman, 2006; Wilensky & Rand, 2015; Volterra, 1926).

After adding the predator, the predator will catch a house sparrow when they encounter one another followed by the death of the house sparrow (Wilensky, 1997; Wilensky & Reisman, 2006; Lotka, 1925). The capture and killing of the house sparrows by the cats are based on the theory that cats kill more house sparrows in densely populated areas than in areas with low density of sparrows in comparison to the number of cats (Van Heezik, et al, 2010; Churcher & Lawton, 1987). In this report, if the total number of house sparrows is above one-and-a-half times of the initial birds  the probability of killing a house sparrow is 6 out of 10. When the total number of house sparrows is below the initial birds, the probability of killing a house sparrow by a cat is 1 in 10. The numbers 1 out of 10 and 6 out of 10 are based on trial and error of the model. The aim was to ensure that the population of house sparrows would not become extinct after a few seasons. The script that was used can be found in the appendix A.3.

After there is a population system set up in the model, the model is runs 100 times with the function behaviorSpace in Netlogo. After the 100 runs, the min, mean and max of each interval are calculated in excel. By doing so, it is possible to see what the minimum and maximum number of house sparrows in the model is.

### 3.1.2.4 HOW IS ADDING A GREEN AREA APPLIED

This chapter discusses the method for developing gardens in the vicinity of houses based on NDVI data. It is important to include and explore this since it helps to improve the original ABM and therefore helps to answer the research question: *How can you use a conceptual model to investigate the spatial distribution of house sparrows, including the influence of spatial characteristics?*

The addition of gardens is carried out using open coding and trial and error. First, the data on the NDVI is analyzed in ArcGIS. The average NDVI of the district is 0.169 with a standard deviation of 0.019. Based on the values from ArcGIS, three categories are created which include many gardens, average number of gardens and few gardens. The values of the three categories are for many gardens: 0.18 - 0.20, for average gardens: 0.15-0.179 and for few gardens: 0.12- 0.149. The NDVI of the area is shown in figure 14.



**Figure 14. Map with the NDVI values made in ArcGIS.**

The gardens were added by using the *primatives gis:find-range* and *gis:intersecting*. The patches are shown which NDVI values belong to it. The gardens are placed around the houses by placing green patches in a radius around the houses. In areas with many gardens the radius is 3 patches, for average number of gardens 2 patches and in low number of gardens 1 patch. The process is done with the primitives*: in-radius*. This results in 1300 gardens around the gardens meaning that all the areas around the houses are green. However, in this research it was decided not to make the whole area green but 500 patches of the 1300.

The box below (*version 5*) shows which lines are used in the new Netlogo model for the low quantity gardens. The rest the script can be found in the appendix B – if environment-size = "zaanstad".

```
Version 5
if environment-size = "zaanstad"
[......
let ndvi_low gis:find-range housemap-dataset "mean_ndvi" 0.12 0.1499
......
ask patches gis:intersecting ndvi_low
    [ ask patches in-radius 1 [if pcolor = black [
      set pcolor green]]
    ]
.......
ask up-to-n-of (1300 - gardens) patches with [pcolor = green] [ set pcolor black ]
..........
ask patches with [pcolor = green] [ set surface-type "garden"]
....]
end
```

### 3.1.2.5 HOW IS ADDING NEST-BOUND HOUSE SPARROWS APPLIED

This part of the method explains the method used to assign house sparrows to their own nest. This contributes to the development of an improved version of the ABM model that helps to answer the subquestion; *How can you use a conceptual model to investigate the spatial distribution of house sparrows, including the influence of spatial characteristics?*

House sparrows return to the same nest continuously while incubating a nest. Once the nest with eggs has been hatched, they move to a nearby nest. This is simplified in the model by having the house sparrow always return to the same nest.

The primitive used to add this is: *own-nest*, in the box below you can see the lines that were eventually used in the new ABM. The change takes place in the process of search-sleeping-place.

```
Version 6
ifelse own-nest = nobody
[
..........
set own-nest (min-one-of nests [distance myself])
]
[
move-to own-nest
]
end
```

### 3.1.3. COMPARING WITH OBSERVATIONS AND THE RESULTS OF THE MODEL

### 3.1.3.1 MERGING OF REAL OBSERVATIONS AND THE NEW MODEL

To investigate whether the model corresponds to reality, a comparison is made between the distribution of house sparrows in the Netlogo model and house sparrow observations entered in the Nationale Databank Flora and Fauna (NDFF) (Kater, 2022). This section is important in that it contributes to answering the research question. Furthermore, the method used for this part is a combination of open coding and desk research.

The data of the Arcadis spotting events are registered in ArcGIS As discussed in the chapter theory, this consists of different activities of the house sparrow. The first step is to make a difference between with nest and non-nesting behavior. The process is accomplished by using the function select by attributes to create a new layer. Furthermore, this layer must also fulfil the same features as the suitability map discussed in paragraph method 1. Changing the coordination projection to Robison (wordl) and to converted into a shapefile (.shp)

The map with the nests is loaded into the new ABM. This is achieved by using the following GIS extensions; gis:load-dataset, gis:feature-list-of , gis:intersecting and gis:fill. After inserting the nest sightings in Netlogo, a small spatial difference can be observed between the houses layer and the nests layer. The nests are not located on the houses like they were in ArcGIS. The difference is reduced by using the primitives or gis:set-world-envelope gis:envelope-of but not solving the problem completely. Therefore, in the study, the houses closest to the nests are designated as nest spots. The justification for doing so is that house sparrows often build new nests near their old nests. The script used for this addition can be found below.

```
Version 7
to create-vergelijking
set mussen-dataset gis:load-dataset "Nesten_mussen.shp"
set geen_mussen-dataset gis:load-dataset "geen_nesten_mus.shp"
gis:set-world-envelope gis:envelope-of geen_mussen-dataset  ;; set world size to shrubmap extend
let nesten gis:find-range mussen-dataset "aantal_min" 0.0 10.0

foreach gis:feature-list-of mussen-dataset
[vector-feature ->
gis:set-drawing-color blue
gis:fill vector-feature 2.0
gis:set-drawing-color red

ask patches gis:intersecting nesten
```

```
[ ask one-of patches in-radius 4 [if pcolor = yellow or pcolor = lime [ set pcolor 16 ]]
]]
end
```

After adding the sightings, the model is run 100 times using the function behaviorSpace in Netlogo. The function can run the model multiple times with different variables. However, in this section, we choose to run the model 100 times with the same variables. The model has a certain amount of randomness in it, which causes the outcome to be slightly different each time. By running the model 100 times and analyzing the results, more information can be retrieved making it more reliable. The variables chosen for this run are; init-birds = 80, initial-number-predators = 3 and gardens =500 patches.

The results of the 100 runs are analysed in Excel. The mean, standard deviation and normal distribution are calculated. Using the functions AVERAGE (arithmetic mean), STDEV.p (standard deviation based on the entire population), and norm.dis (normal distribution). These calculations are performed for the total number of house sparrows in the area. To be able to say something about the spatial distribution, these calculations including the normal distribution are done for: the number of house sparrows per suitability area, number of house sparrows per nest for the areas with real nest spotting, and number of house sparrows per surface area of the suitability areas and areas with real nest spotting, and number of house sparrows per nest for the suitability areas and areas with real nest spotting. In the end, four figures emerge with the normal distributions.

### 3.1.4 SENSITIVITY ANALYSIS OF THE MODEL

The version developed in the first 5 (?) paragraphs of the method is used to investigate the influence of different variables which helps to answer both sub-questions: *How can you use a conceptual model to investigate the spatial distribution of house sparrows, including the influence of spatial characteristics* and *What are the different pathways for the house sparrow in Zaandam?* The main method used to conduct this information is by using open coding and Data analysis.

When investigating the influence, the tool BehaviourSpace is used, which runs the model 100 times for different variables. The parameter used in this tool are shown in Appendix C. The results of the 100 runs are analyzed in Excel. In Excel, the mean and standard deviation are calculated. This is done using the functions; AVERAGE (arithmetic mean), STDEV.p (standard deviation based on the entire population) and the use of a PivotTable. The calculations are performed for the total number of house sparrows and house sparrows per suitability area. The variables studied are initial-birds, number of gardens, and number of predators. With the period 202-03-28 till 2021-07-15. The values of the variables can be found in table 5 and Appendix D.

**Table 5. Parameters used for the sensitivity test.**

| Inital-birds | 300 | 500 | 1000 |
|---|---|---|---|
| Amount of gardens | 1 | 3 | 7 |
| Amount of predators | 30 | 80 | 130 |

## 3.2 DIFFERENT PATHWAYS

From the influence of the different variable discussed in the previous section, 5 pathways are developed to contribute to answer the sub question *What are the different pathways for the house sparrow in Zaandam?* This implies designing different roadmaps that each create a different picture of possible futures (Fazey, et al, 2016). The extreme variables that affect population and spatial distribution as a result of carrying out method 3.1.4 are used for pathways 1, 2, 3 and 4. For the rest, a standard pathway that uses the normal variable is also included.

## 3.3 THE SPATIAL DISTRIBUTION AND POPULATION OF THE HOUSE SPARROW WITH DIFFERENT PATHWAYS

### 3.3.1 INFLUENCE OF DIFFERENT PATHWAYS ON THE POPULATION GROWTH

The development of this method helps to answer the sub-question**:** *What is the spatial distribution of the house sparrow with different mitigation actions/adaptive behavior of the house sparrow?*

After developing the different pathways discussed in the previous chapter, the population sizes of the house sparrow within each pathway are examined. The behaviorSpace tool in Netlogo is used to achieve this goal. The same model with the same variables is run 100 times. The value of the variables differs per pathway and is determined by the developed pathways from chapter X.

Next, in Excel, the results of 100 running experiments of each pathway are used to calculate the average and a standard deviation. These two values can be used to calculate a normal distribution in a graph, creating 5 figures. The functions used in Excel are AVERAGE (arithmetic mean), STDEV.p (standard deviation based on the entire population), and norm.dis (normal distribution). After the calculations of the normal distribution of the population, the different pathways are compared with each other.

### 3.3.2 INFLUENCE OF DIFFERENT PATHWAYS ON THE SPATIAL DISTRIBUTION

The development of this method helps to answer the sub-question**:** *What is the spatial distribution of the house sparrow with different mitigation actions/adaptive behavior of the house sparrow?*

The spatial distribution of the house sparrows is analyzed next. Using a normal distribution based on the mean and standard deviation. Through this, it is possible to easily see in a graph the extent to which the different areas with different suitability deviate from each other. The calculation is carried out in Excel using *AVERAGE* (arithmetic mean), *STDEV.p* (standard deviation based on the entire population), and *NORM.DIS* (normal distribution).

The first normal distribution is based on the absolute number of house sparrows per area. The second normal distribution is based on the number of house sparrows per number of nests in an area. The third normal distribution is calculated based on house sparrows per square meter of patches per suitability category. These calculations are performed for each of the pathways, resulting in 15 figures. After these calculations have been made, the different pathways and their outcomes can be compared.

Finally, the difference in the number of house sparrows and the percentage of occupied patches between the three categories is calculated for each pathway. The increase or decrease between areas of high and medium suitability, between high and low suitability, and between medium and low suitability is thus considered. Then the average of the increases and decreases of the three categories per pathway is taken, which makes it possible to compare them with each other. This average shows in which pathways the greatest differences occur between the three categories.

# RESULTS

## 4.1 ANALYZE THE MERGING BETWEEN THE BASIC BEHAVIOUR MODEL AND THE SUITABILITY MODEL

### 4.1.1 THE CHANGES THAT ARE MADE SO THAT THE MODEL CAN BE COMBINED

This section discusses the results that determine the sub-question: *How can you use a conceptual model to investigate the spatial distribution of house sparrows, including the influence of spatial characteristics?*

#### 4.1.1.1 FROM ARCGIS TO NETLOGO

The results of the first step of inserting the suitability data into the original Netlogo model can be seen in 15A. It shows that the contours of the buildings from the suitability model are visible with a yellow line. Furthermore, the house sparrows are properly loaded and move across the model searching for food and nests, However, both are not yet present.
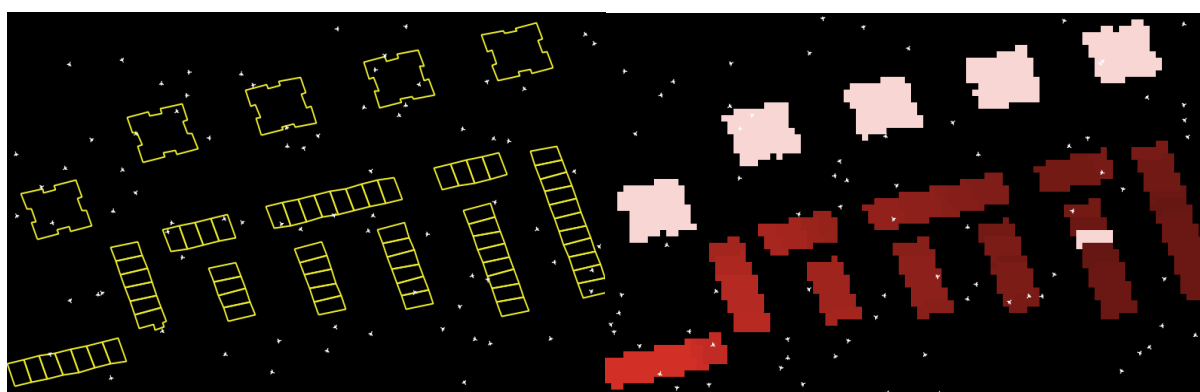


**Figure 15A. First version of adding the suitability model in Netlogo where only the contour is visible. B. Second version of adding the suitability model in the Netlogo model where light areas have low suitability and dark red areas have high suitability.**

After the contents of the suitability model are inserted with the patches in Netlogo, the program recognizes the values that belong to the buildings, see figure 15B. The patches are colored whereby a dark red color stands for high suitability values and a light pink color for low suitability values. The buildings at the top of the figure have a low suitability. The buildings in the left middle and below have the highest suitability values. In the second street from the right stands a house that has very low suitability values in comparison with its neighbors.

#### 4.1.1.2 RESULTS OF SUBDIVISION OF HIGH, LOW AND MEDIUM SUITABILITY

The result after adding 3 different suitability levels is shown in figure 16. The buildings with low suitability are in the area on top and on the left side indicated as orange. The areas with medium suitability are in the middle of the district (yellow) and with high suitability category at the right side (green). Furthermore, in the second street from the right, a house can be seen where the neighbor houses fall within the category high, and the house falls within the category low.

### 4.1.1.3 RESULTS OF NEST DISTRIBUTION

After inserting the nests into the areas, the map results as follows (Figure 17). The light brown circles on the houses are the nests. In the areas with low suitability there are fewer nests present than in the areas with medium suitability. This also applies to the areas with high suitability, where most nests are present. Furthermore, house sparrows are again flying around in the model, where they can locate the nests at night. However, they cannot find food because gardens have not yet been added in the area.



Figure 17. View of adding nest in Netlogo

### 4.1.2 RESULTS OF THE ADJUSTMENTS TO THE NEW COMBINED MODEL

### 4.1.2.1 ANALYZE ADJUSTMENTS ADDITION OF A BREEDING SEASON

If looking at the results of only the birth rate, it appears to increase only during the breeding season. Figure 18 shows the time on the x-axis in hours and the number of house sparrows on the y-axis. For this run, the population starts on 28-03-20 with 80 birds and increases within two breeding seasons (till 15-03-22) to 813 birds. The breeding season is the growing trend and outside the breeding season the trend remains stable, see figure 18. This exact number differs in each run because of randomness in the model.
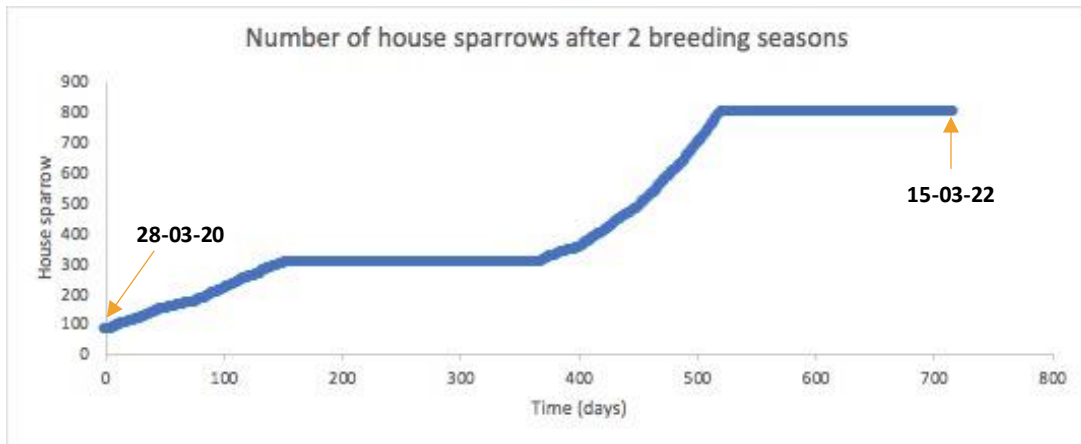
Figure 18. Population growth of House sparrows for two breeding seasons in Netlogo.

### 4.1.2.2 ANALYZE ADDING AN AGE APPLIED

The result of adding age differences in the model results in different ages of sparrows in the model. The average age varies throughout the year with the lowest average age at the end of the breeding season and the highest age at the beginning of the season, as shown in figure 19. This happens because a lot of new birds are born in this period with age = 0. Also, the ratio of old birds to new birds then changes considerably. Moreover, after the first few hours of running the model, quite a few house sparrows die of old age. If we exclude the first period, the average age of the house sparrow in the model is around 1.5 years. Furthermore, there is a decrease in population growth because a maximum age has been added.
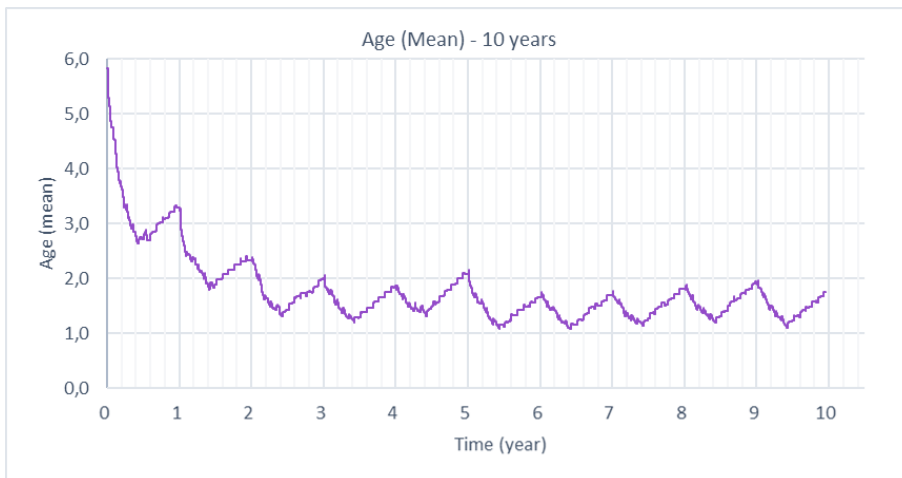


Figure 19. Mean age of the house sparrow for a period of 10 years.

Figure 20 shows a histogram of the number of sparrows per age. In the left figure you can see that the birds all have a random age up to 13 years. In the right figure you can see that the ratio changes (figure 20B). The reasons for this are that birds die at too high an age and many new young birds are born every year.
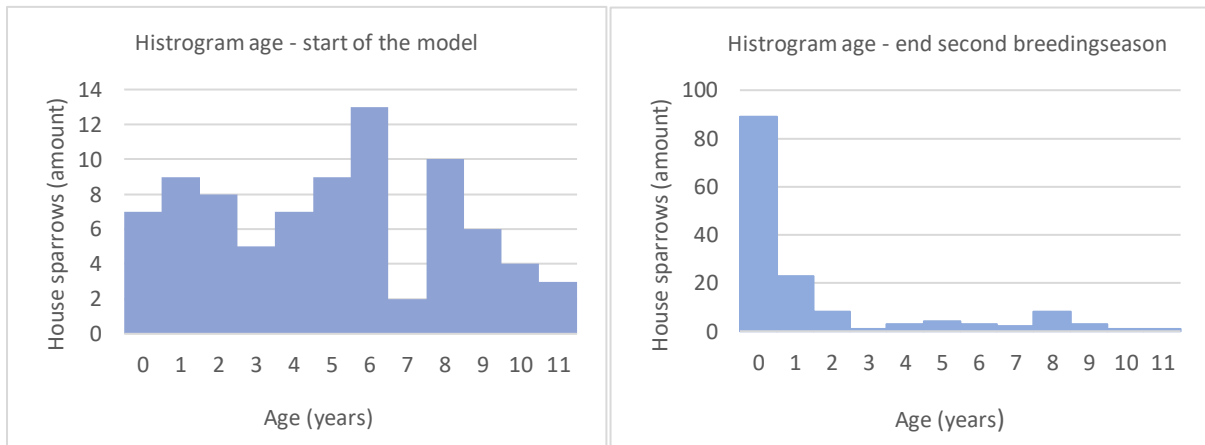


**Figure 20A. Histogram of the age at the start of the run in Netlogo. B Histogram of the age at the end of the run in Netlogo.**

### 4.1.2.3 ANALYZE ADDING AN PREDATOR

The addition of a predator results in a decrease of house sparrows in the system. Figure 21 show the difference between the model with and without a predator. In this figure there are 3 predators in the system. In the figure you can see that after 30 days the population has exceeded the 100 house sparrows with a beginning of 80 house sparrows without a predator. With a predator and after 30 days there is a total of about 80 house sparrows with the same initial number of 80.
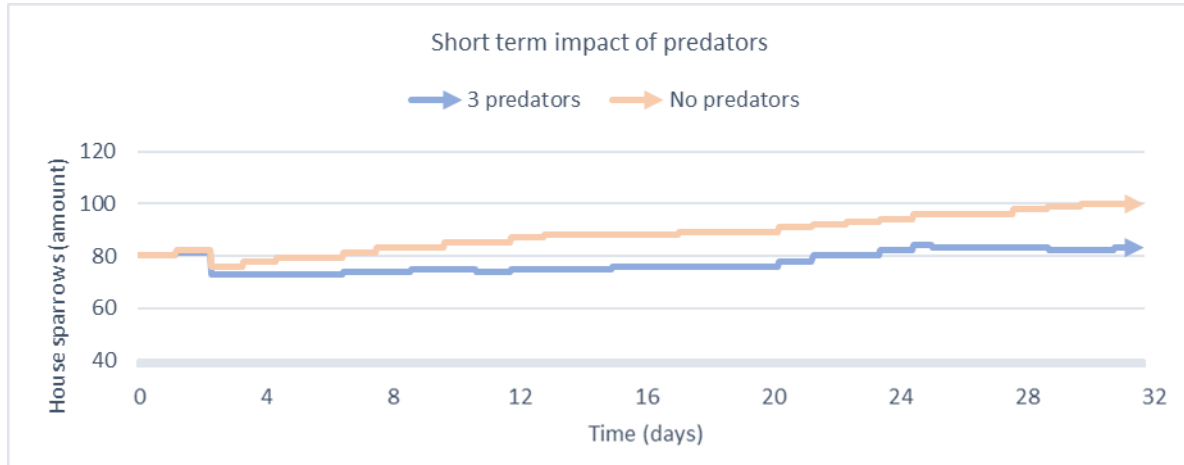


**Figure 21A. population size of the house sparrow after 30 days with predator in the model and population size of the model after 30 days hours without a predator.**

In the first results of adding a predator, there was no difference in the capture probability if the population dropped. As a result, the predator was always able to catch prey, which caused the number of house sparrows to decline and eventually die out in this area. An example of this population decline can be seen in figure 22. Figure 22 shows a population of 7 years, where the first two breeding seasons are still clearly visible at the two peaks. After this, the population declines sharply, and the breeding seasons are still vaguely recognizable where the line remains stable and does not decline. At the end of year 7, this difference is almost non-existent, and the population dies out.
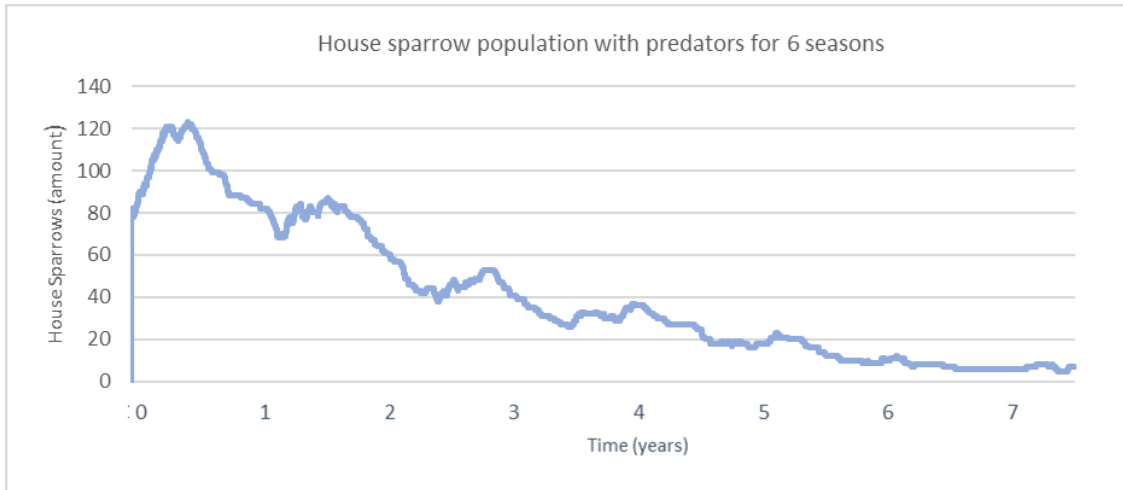
**Figure 22. Population size after adding predators for a period of 5 years.**

After adding the predator's learning system, whereby the predator kills fewer birds at a low population, this population line changes. The population no longer decreases so steeply after a few breeding seasons but follows a pattern that during the breeding season the population increases and outside the breeding season it decreases, see figure 23. The figure shows the population for a period of 10 years. All the peaks are about the same size with a small increase at year 5 years. Furthermore, there are small fluctuations in the line.
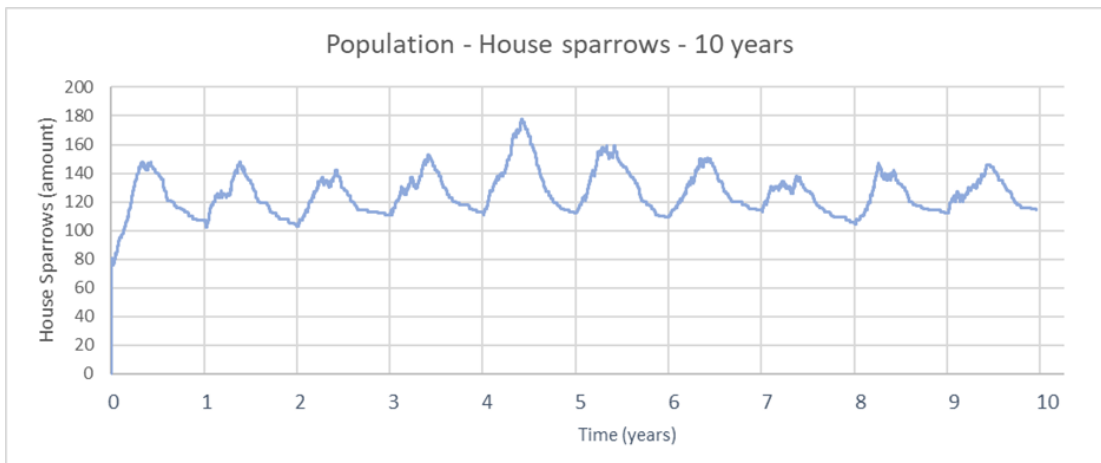


**Figure 23. Population size with age, predators, and births for 10 years. Red line serves as a reference.**

When looking at the result over the total population of house sparrows in 100 runs, it appears that the number of house sparrows does not exceed 190 house sparrows with an initial of 80 house sparrows, see figure 24. Furthermore, if the first period is not included, the minimum number of house sparrows does not exceed 100 house sparrows.
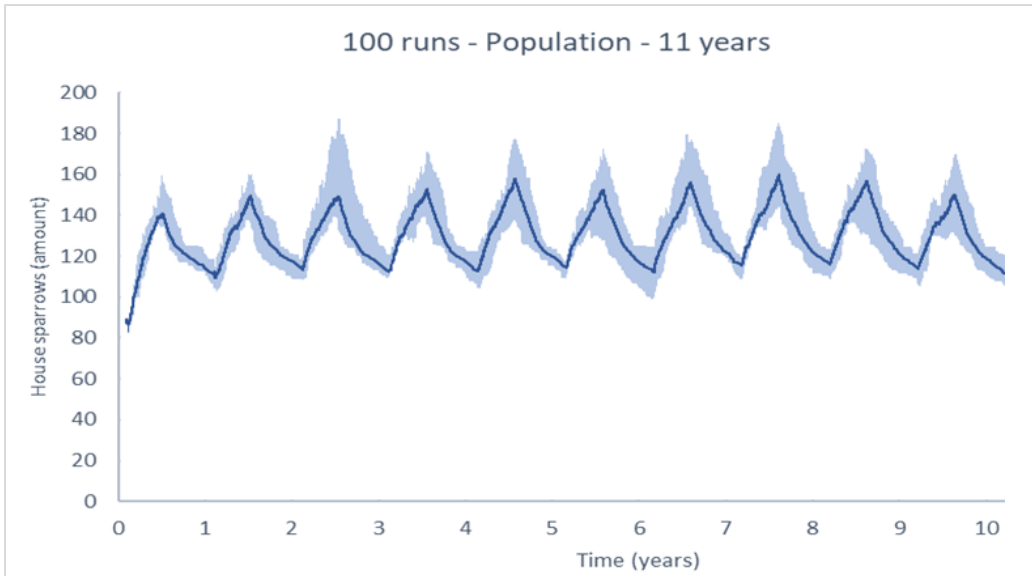
Figure 24. Outcomes of Population House sparrows for 100 runs of 10 year.

## 4.1.2.4 ANALYZE ADDING A GREEN AREA APPLIED

After adding gardens based on NDVI values, the image changes compared to previous versions, see figure 25. Green patches can be seen around the buildings. The buildings in the lower left and upper right show few gardens in the area. The buildings in the top left and middle show buildings with a medium number of gardens. And the high number of gardens are on the right-hand side of the map. The house sparrows in the model can find both nesting places and places to find food.
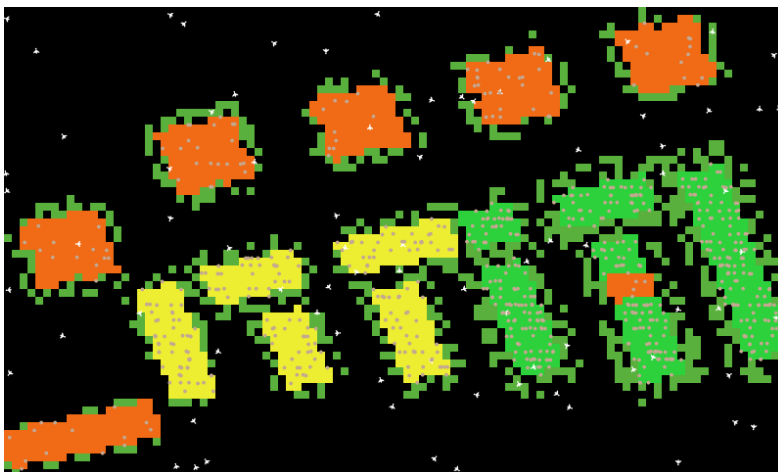


Figure 25. View of the new model in Netlogo after adding gardens around the buildings.

## 4.1.2.5 ANALYZE THE ADDITION OF NEST-BOUND BIRDS

Adding the script developed for adding an own nest for each house sparrow, it becomes evident one returns to one's own nest each night. This is visible in figure 26 where figure 26B was made the night before figure 26A.

Figure 26A. House sparrows on a building during the first night (date) B. House sparrows on a building during the second night.

### 4.2.1 ANALYZE COMPARINGS WITH THE REAL OBSERVATIONS AND THE NEW MODEL

Figure 27 shows the result of separating sightings by nest-indicating behavior and non-nesting indication behavior which is for example singing, mating, or flying around. The red triangles indicate spots where there is behavior that is indicative of nesting. The green-blue dots are points where a house sparrow has been spotted but is not displaying nest-indicating behavior.
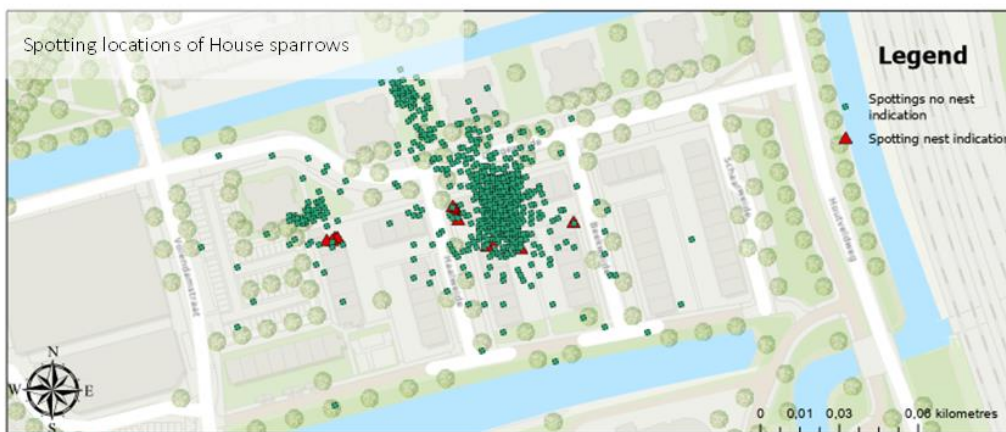


Figure 27. Locations of sightings of House sparrows, ArcGIS.
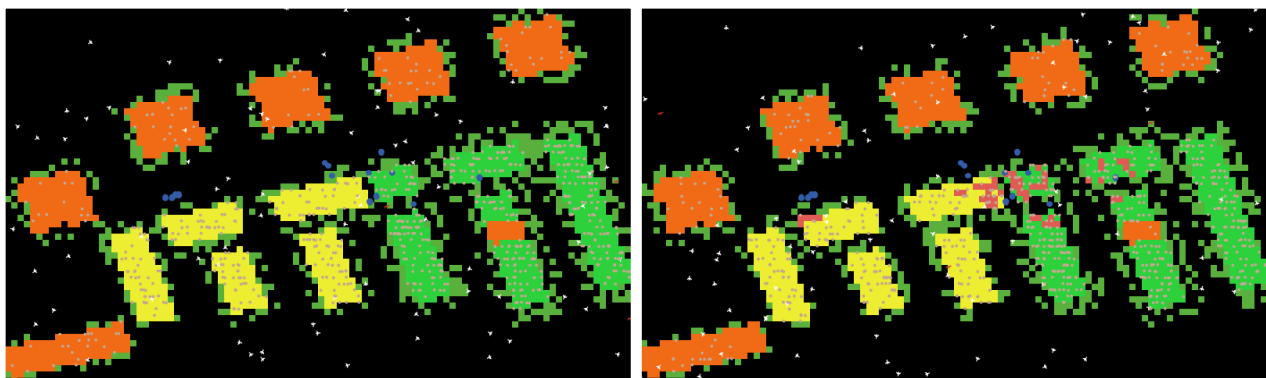


Figure 28 A and B. View of the setup from the agent-based model in Netlogo.

Figure 28 shows the outcome of the model in Netlogo where the birds are spotted. In the first step (figure 28A) only the nests are visible, these are the blue circles in the middle of the vieuw. In the last step (figure 28B) the nests are visible and the areas close to the nests are coloured darker pink. As the layers are not perfectly aligned, the areas closest to each other have been indicated. It is noticeable that the areas are only located in areas with a high and medium suitability.
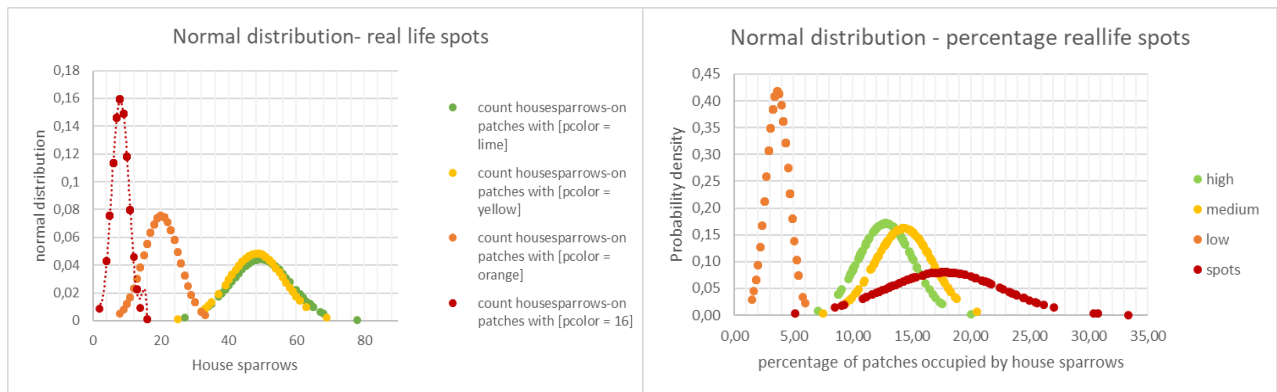
**Figure 29A & B. 100 runs in of the agent-based model in Netlogo.**

Figure 29A shows the normal distribution of 100 runs with the values initi-birds = 80, predators = 3 and gardens = 500. In this case, most house sparrows are found in areas of high suitability. The mean here is 49.39 house sparrows with a standard deviation of 9.01. The medium suitability areas followed shortly after with a mean of 48.25 and a standard deviation of 8.23. Areas with low suitability also have the lowest number of house sparrows. The mean here is 20.16 house sparrows with a standard deviation of 5.28

Figure 29B shows the normal distribution of the percentage of house sparrows occupied for the areas. Areas with low suitability is less compared to the other lines. It is always below 6 percent. The percentage occupied for average suitability is the majority between 12 and 17.5 percent. The percentage for areas with high suitability lies most of the time between 10 and 16 percent. Furthermore, the average is higher on the green line (high) compared to the yellow line (medium). The red graph looks at the areas that contain nests according to real-life sightings. If you look at this distribution, you can see that most of the percentages are between 10 and 25 percent. This graph is much wider compared to the yellow and green graph.

## 4.2.2 SENSITIVITY ANALYSE OF THE NEW MODEL

In this part of the results, the outcome of the sensitivity of the different parameters is elaborated. It concerns the parameters; "green" gardens, number of predators, and number of house sparrows at the beginning.

The initial number of house sparrows at the start of the model run affects the number of house sparrows at the end of the runs (Figure 30). The higher the initial number (first set 30, second set 80, third set 130) of house sparrows, the larger the population at the end of the runs. However, relatively the model run with initial 30 (run 1), ends with 130, meaning a fourfold increase, while model run 19 only increases less than two-fold.

Looking at the results of the sensitivity runs the results are that the number of predators has a large influence on the population. In runs 1, 3, 7, 10, 13, 16, 19, 22 and 25 the number of predators in the system is 7. In runs 2,5,8,11,14,17,20,23,26 there are 3 predators in the system. In the remaining runs there is 1 predator present. The number of gardens has no influence on the total number of house sparrows (300, 500, 1000). The standard deviation and values of the runs can be found in a table in the appendix E.
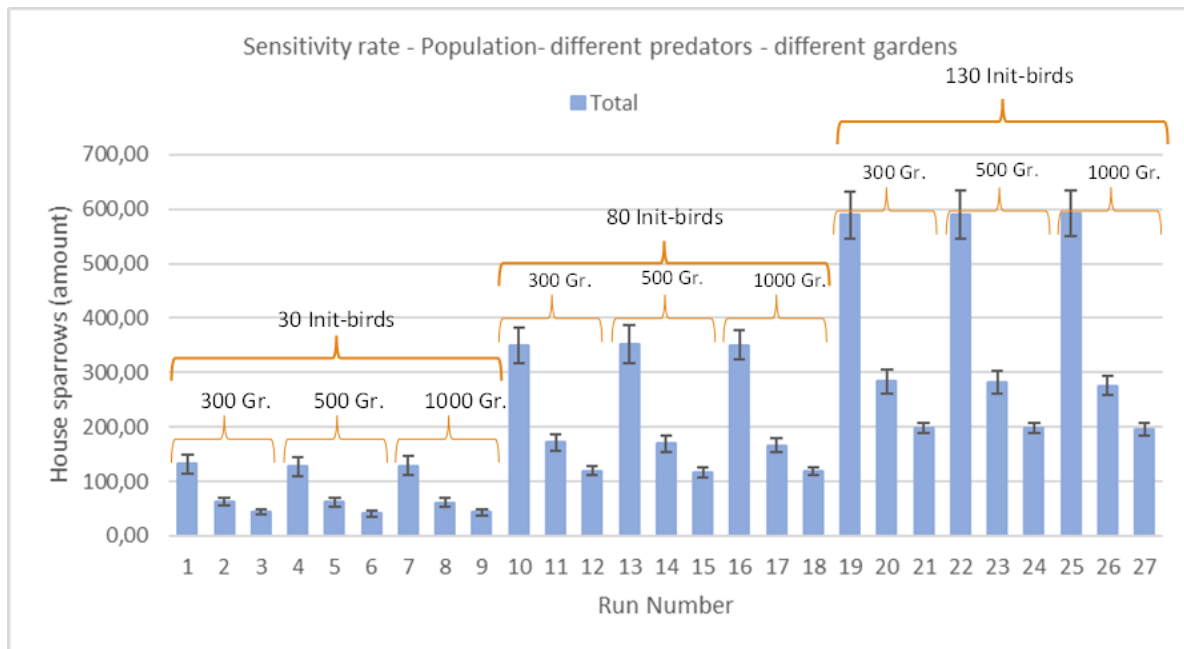
**Figure 30. Results of the sensitivity rate for the total population.**

Secondly, looking at the sensitivity rate between areas with low, medium and high suitability for runs with 30 initial birds, we see that the number of house sparrows varies between areas. In most runs, most house sparrows are found in areas of high suitability, followed by areas of medium suitability. And the least number of house sparrows is found in the low suitability areas. However, runs 8 and 9 are the exception, in these runs most house sparrows can be found in the areas with medium suitability.

When looking at the influence of the first parameter predators, one of the first results that stands out is that the number of predators has a negative influence on the total amount of house sparrows in the system has. The runs which contain 7 predators are run 3,6 and 9 and contain less house sparrows in total.

Furthermore, looking at the spatial distribution and the influence of the parameter gardens, different results can be reported. The runs with a low number of gardens (300 patches) show that if one compares the runs with 1 predator, proportionally more house sparrows are present in areas with a high suitability in runs with a low number of gardens, see also appendix E column: Average of the differences (%). The standard deviation is also higher in runs with a low number of gardens. Comparing runs with low numbers of gardens and 3/7 predators with 500 gardens, there is little difference. However, if comparing runs of 1000 gardens with 500 gardens for runs with 3/7 predators, we see that in runs with a high number of gardens, most house sparrows are found in areas with medium suitability. So, if there is a lot of garden space, suitability is less important, there is less pressure, and they find medium suitability fine.

Further, looking at the influence of predators on the distribution, it appears that at 300 and 500 gardens, the predator has almost no influence on the number of house sparrows per category. However, at 1000 gardens, it seems that the predator does have an influence, with 3 predators causing more house sparrows in areas with medium suitability, see also appendix E column: Average of the differences (%).

In general, the patterns for runs with 80 and 130 initial birds are the same as those with 30 initial birds. One of the differences is that the number of house sparrow in areas of medium suitability is higher than areas of high suitability in runs with 130 initial birds with 7 predators and 500 patches of gardens. This pattern is reversed

when we look at 130 initial birds with 3 predators and 1000 patches gardens, The areas with high suitability are also the areas with the highest number of house sparrows. These and all the values can be found in Appendix E.
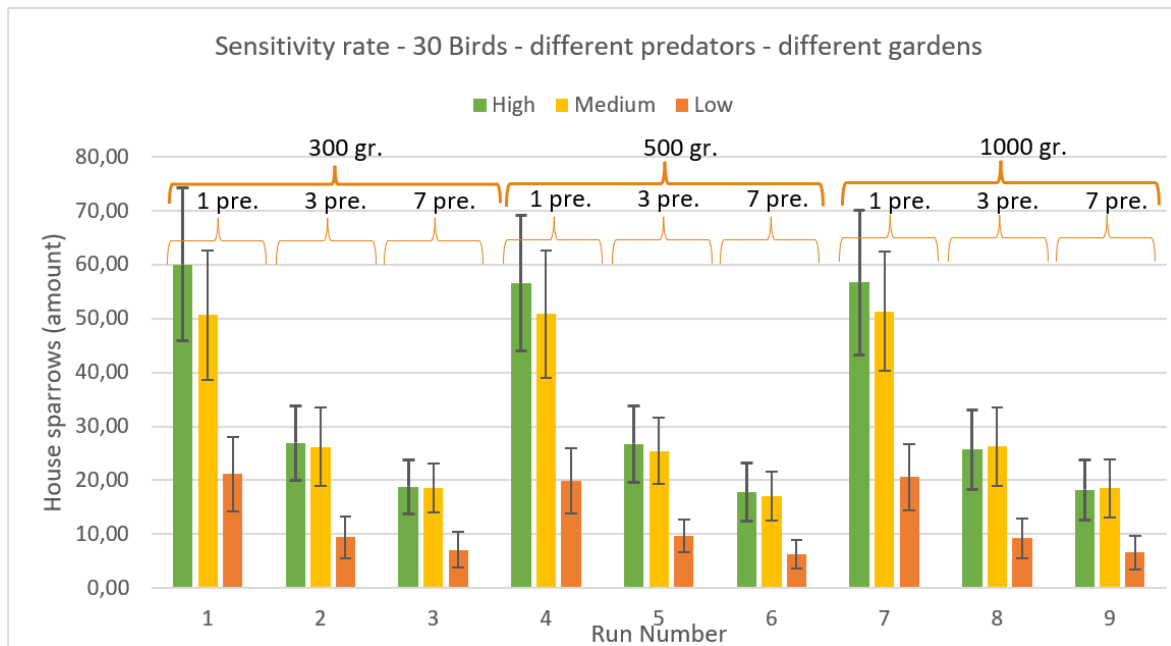


**Figure 31. Results of the sensitivity rate for the different suitability areas with 30 initial birds.**
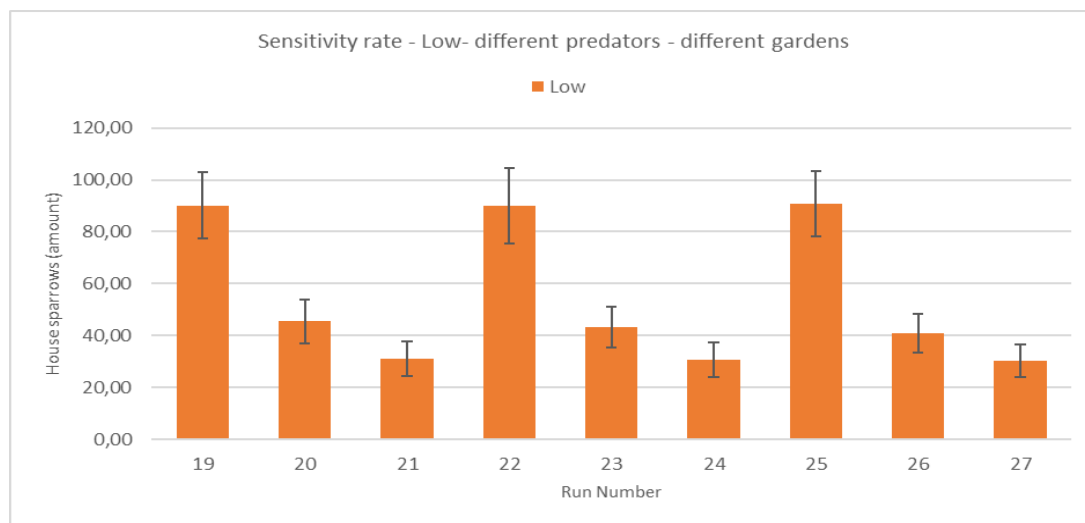


**Figure 32. Results of the sensitivity rate for low suitability areas with 130 initial birds.**

Because the differences between the low suitability areas are difficult to see in an overview figure, we now focus only on the number of sparrows in low suitability areas with 130 initial birds. Here it can be clearly seen that for areas with low suitability the influence of more gardens ends in lower sparrow numbers when we compare run 23 and 26. The rest of the runs do not differ much.

## 4.4 DIFFERENT PATHWAYS

From the results of the sensitivity analysis, different pathways were developed (see table 6 and 7). In pathway 1, there are more green gardens in the area and nest boxes are hung at locations of low suitability. In pathway 2, there are more predators present in the area and several hives are hung in areas with a low suitability. In pathway 3, a row of houses is being worked on, making the gardens and nests unavailable for a period. In the fourth pathway the houses become less suitable for nests and the gardens lose some of their greenery. The last pathway is called the standard pathway, table 7. In this case the parameters remain the same and it is therefore suitable to make comparisons more explicit.

**Table 6. Different pathways.**
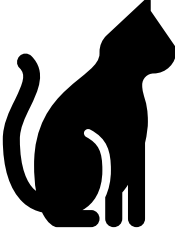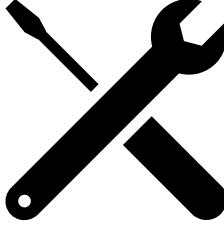
| Pathways 1 | | Pathway 2 | | Pathway 3 | | Pathway 4 | |
|---|---|---|---|---|---|---|---|
| Cities are increasingly aware of protecting and enhancing urban biodiversity. Because of this, hives are hung in areas with low suitability for house sparrows. Furthermore, gardens are becoming greener by removing terraces and adding vegetation. | | More families with cats have settled in the neighborhood. This causes a considerable increase in predators for the house sparrows. Furthermore, hives are hung in areas with low suitability for house sparrows. | | Row houses are being rebuilt so are not available for a while. The gardens belonging to them are also temporarily unavailable to the sparrows due to nuisance. | | The city is becoming more and more petrified. Due to a shortage of houses, the current houses are being extended by adding an extra floor). This leads to a reduction in the suitability of houses for sparrows.<br><br>Furthermore, some of the gardens are being tiled, which means that there is less green cover. | |
| **Predators** | 3 | **Predators** | 5 | **Predators** | 3 | **Predators** | 3 |
| **Initi-birds** | 80 | **Initi-birds** | 80 | **Initi-birds** | 80 | **Initi-birds** | 80 |
| **Gardens** | 1200 | **Gardens** | 500 | **Gardens** | 500 | **Gardens** | 120 |
| **suitability** | 50 nesting boxes with 2 nesting places. | **suitability** | 50 nesting boxes with 2 nesting places. | **suitability** | Missing | **suitability** | less |

**Table 7. Standard Pathway.**

| Standard pathway | |
|---|---|
| The neighborhood does not change over the years. everything remains as it is. | |
| **Predators** | 3 |
| **Initi-birds** | 80 |
| **Gardens** | 500 |
| **suitability** | same |

After developing the pathways, each pathway has its own view. The result of how pathway 1 looks is shown in the figure 33A. In the orange areas like the buildings above, birdhouses have been hung up. The birdhouses are the light blue squares. These birdhouses contain 2 nesting possibilities which increases the number of nests in the orange areas from 100 nests to about 200 nests. Furthermore, the gardens have become a lot greener, which causes a large part of the houses to turn completely green. There are also 1200 patches of green gardens in the area. The hypothesis for the outcome of the 100 runs in Netlogo is for pathway 1 is that the large number of gardens and the addition of nest boxes in low suitability areas ensure a more even distribution between low, medium, and high suitability areas. The percentage of occupied patches follows this pattern.

The result of pathway 2 is that bird boxes are hung in the orange areas. These boxes are the light blue spots in figure 33B. By adding different nest boxes, the number of nests is increased from 100 nests to 200 nesting possibilities. For the rest, the number of green gardens does not differ from the standard pathway. So, random green gardens are placed around the buildings. Hypothesis for pathway 2 is that due to the present of more predators the total population of house sparrows is lower compared to the rest. For the average number of green gardens in combination with the nest boxes provides a fairer distribution of house sparrows over the three categories compared to the standard pathway. However, the distribution is less equal than in pathway 1. Furthermore, the percentage of nests that are occupied is lower than in the other pathways due to the lower number of house sparrows present.

The development of pathway 3 results in two different views. At the beginning of the run period, a part of the Haalweide in the middle of the neighborhood is being renovated. As a result, the gardens are overgrown and there are no green gardens. Furthermore, the entire building is not suitable for nests. The renovation takes one year and after that the suitability is the same as in the standard pathway. After a year, the gardens have also regrown and are as green as before. Figure 33C shows the neighborhood during the renovation, indicated in brown. Figure 33D shows the district after the renovation where the state is again of medium suitability. Looking at the hypothesis of pathway 3, it is expected that in total as many house sparrows are present at the end as the pathway standard, 1, and 4. Furthermore, it is expected that the number of sparrows in the areas high and low will increase due to the conversion of the building with a medium suitability. The ratio between low, high, and medium thus increases in comparison to pathway 1 and 2, and standard. The percentage of occupied patches follows this pattern.

Pathway 4 is characterized by more areas with low suitability. There are therefore more orange patches in the yellow and green areas as shown in figure 33E. This results in an increase from 553 patches to 688 patches of medium suitability. There are also fewer green gardens, namely only 120 patches instead of 500 in the standard pathway. e hypothesis for pathway 4 is that the total population of house sparrows is lower than pathways 1,3 and standard because there are fewer nests. Furthermore, it is expected that the number of house sparrows in areas with high suitability will increase, and the number of house sparrows in low suitability areas will decrease. Meaning that the few gardens cause the ratio of house sparrows present at low, medium, and high to be more different from each other. The same pattern is observed when looking at the percentage of patches occupied. However, these percentages are lower than pathway 1,3 and standard because there are fewer house sparrows present.

The last pathway is the standard pathway characterized by standard amounts of gardens of 500 patches, see figure 33F. The initial birds start at 80, with 3 predators.

**A.    Pathway 1**

**B Pathway 2**

**C Pathway 3**

**D. Pathway 3**

**E Pathway 4**

**F standard pathway**
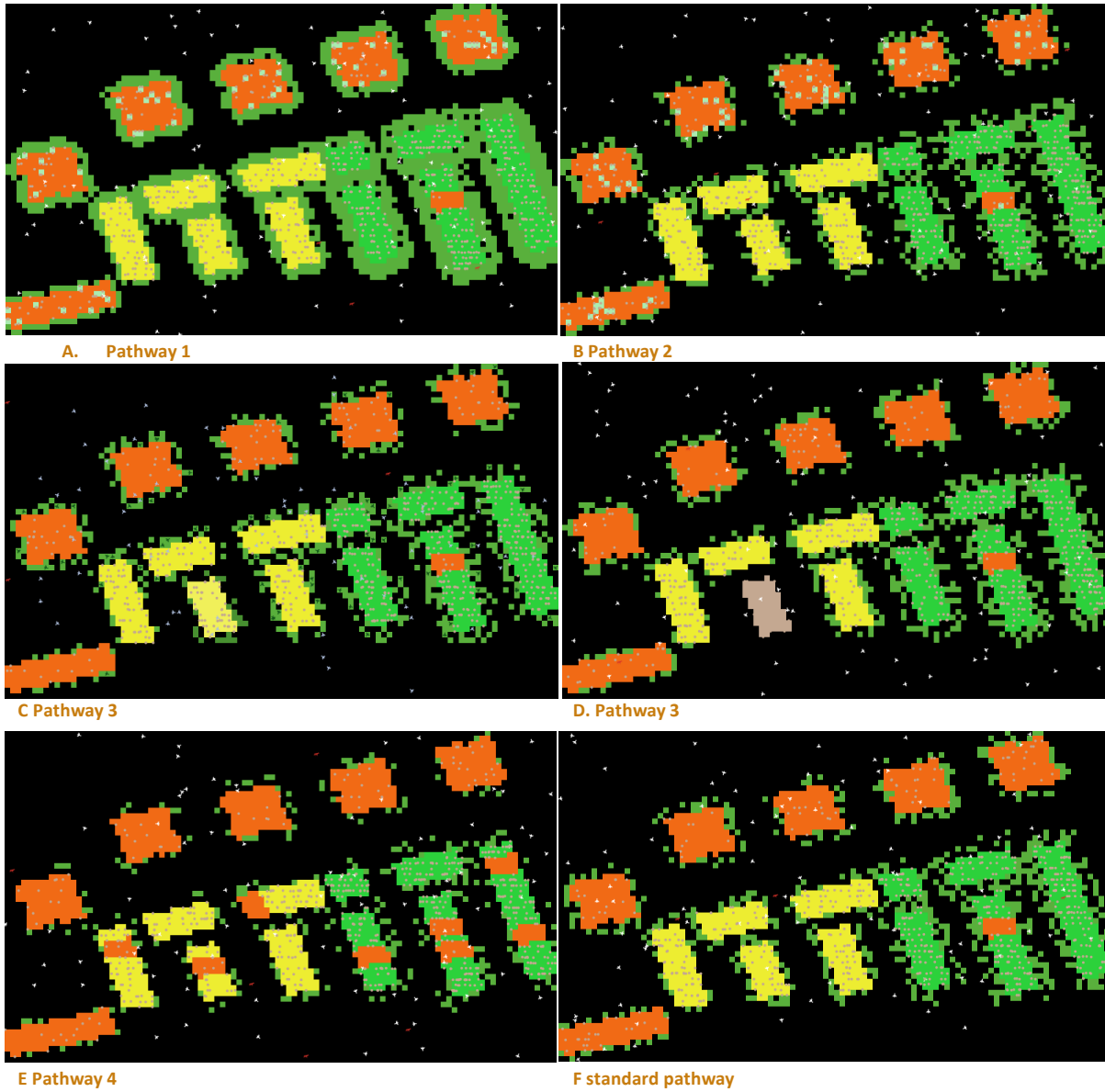
Figure 33. A. View of pathway 1 in Netlogo where the light green/blue areas represent the nesting boxes that have been hung up by the citizens. Furthermore, with parameters of green gardens: 1200 patches, 3 predators and 80 init-birds. B. Results of view of pathway 2 in Netlogo. C. Results view of pathway 3 at the start of the run. D. view of pathway 3 at the end of the running time. E. Results view of pathway 4 in Netlogo. F. Results view of pathway standard

### 4.5.1 RESULTS ON THE POPULATION

The results of the 100 runs of the different pathways are discussed in this section. The table below shows the average number of house sparrows at the end of the model and its standard deviation. The contents of this table are further elaborated below for each pathway.

**Table 8. Average amount of house sparrows of 100 runs for each pathway.**

| Impact population | How many house sparrows are present in this area during the third breeding season (start time: 28-03-2022, end time: 15-07-2022) - 100 runs | |
| --- | --- | --- |
| | *Count house sparrows* | |
| | Total Average | Total standard dev. |
| **Pathway 1** | 134.35 | 9.13 |
| **Pathway 2** | 118.98 | 6.30 |
| **Pathway 3** | 136.20 | 8.82 |
| **Pathway 4** | 138.42 | 8.70 |
| **Standard** | 134.56 | 8.01 |

The standard pathway is based on the information of the current situation. This implies the following parameters: 500 patches, 80 init-birds, and normal suitability. The total number of house sparrows in the third breeding season is in the standard pathway has an average of 134.56 house sparrows. In the majority (about 68%) of the runs the population size is between 126.55 ($\mu$-$\sigma$) and 142.57 ($\mu$+$\sigma$) house sparrows, see figure 33 and table 6.
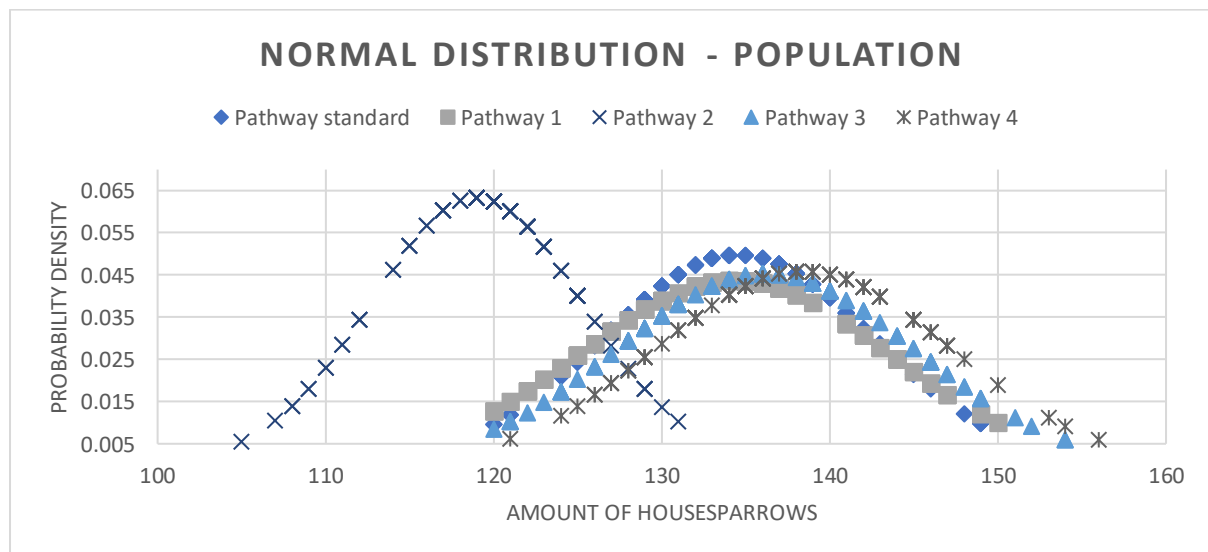


**Figure 34. Normal distribution of the population for each pathway.**

The average number of house sparrows in pathway 1 is 134.35 with a standard deviation of 9.13. For most of the 100 runs, the average number of house sparrows lies between 125.22 and 143.48, see figure 34 and table 6. In pathway 2, the average number of house sparrows is 118.98. With a standard deviation of 6.30. The outcome of the 100 runs of pathway 3 is the average number of house sparrows at the end of the breeding season is around 163.20. Also, the standard deviation is around 8.82. Both the number of house sparrows and the standard deviation are higher than those of the standard pathway. The last result of 100 runs is from Pathway 4. Here the average is 134.56 with a standard deviation of 8.01.

## 4.5.2 IMPACT ON THE SPATIAL DISTRIBUTION

The first result to be discussed is the number of house sparrows per suitability category for the different pathways.







**Figure 35. A. Comparison of the normal distribution of each pathway for areas with a high suitability. B. Comparison of the normal distribution of each pathway for areas with a medium suitability. C. Comparison of the normal distribution of each pathway for areas with a low suitability.**

Looking at the normal distribution of the total number of house sparrows on houses with high suitability, several things stand out, see figure 35A. First of all, the average number of house sparrows is highest in the standard pathway with a mean of 57.06 and a standard deviation of 9.38. Pathway 3 follows (the grey triangles) with a mean of 61.56 and a standard deviation of 11.75. The average of pathways 1 and 4 are close to each other, namely 55.56 (deviation 10.02) and 59.23 (deviation 9.90). Pathway 2 has the lowest mean of 48.15 with a standard deviation of 9.48. Pathway 2 is the highest, followed by pathways 1 and 4. That indicates that these pathways have smaller standard deviations. The average result of the runs is therefore closer to one another. In pathway 3 and standard, the graph is less high and therefore has a large standard deviation and a greater chance of extreme values.

Furthermore, the normal distributions of house sparrows on buildings with a medium suitability are examined. Looking at figure 35B, it appears that the mean number of house sparrows is highest in the standard pathway (56.86) with a standard deviation of 8.66. Close behind is Pathway 4 with a mean of 56.39 and a standard deviation of 10.00. Pathway 1 follows with a mean of 51.57 (σ = 9.50). The lowest two pathways are 2 and 3 with an average of 47.49 (σ =7.91) and 46.16 (σ = 8.86). In the height of these graphs, pathway 2 followed by pathway 3 and standard are the highest. The other pathways are flatter. This means that the outcomes of the runs of pathways 2, 3 and standard are closer to the average compared to pathways 1 and 4.

Finally, the low suitability areas are examined. Here, pathway 3 has the highest mean house sparrow count (28.48) with a standard deviation of 6.04. This is followed by pathway 1 with an average of 27.22 (σ=6.97). Further, the third highest is pathway 2 with a mean of 23.34 and a standard deviation of 5.86. Second last is pathway 4 with an average of 22.99 (σ=5.45) followed by the standard pathway with an average of 20.64 (σ= 5.09).Taking a look at the probability density of the areas with low suitability, these pathways have a higher probality density compared to high and medium. Meaning that the outcomes of the 100 runs are closer together. Pathway standard, 4 and 2 score the highest here.

**Table 9. Average House sparrows for each pathway.**

| Impact spatial distribution | How many house sparrows are present in this area during the third breeding season (start time: 28-03-2022, end time: 15-07-2022)- 100 runs | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| | *Count housesparrows- on High suitability patches* | | *Count housesparrows- on medium suitability patches* | | *Count housesparrows- on low suitability patches* | |
| | Average | *St. dev* | Average | *St. dev* | Average | *St. dev* |
| **Pathway 1** | 55.56 | *10.02* | 51.57 | *9.50* | 27.22 | *6.97* |
| **Pathway 2** | 48.15 | *9.49* | 47.49 | *7.91* | 23.34 | *5.86* |
| **Pathway 3** | 61.56 | *11.75* | 46.16 | *8.86* | 28.48 | *6.04* |
| **Pathway 4** | 59.23 | *9.90* | 56.39 | *10.00* | 22.99 | *5.45* |
| **Standard** | 57.06 | *9.38* | 56.86 | *8.66* | 20.64 | *5.09* |

When comparing the average number of house sparrows of the areas with high, medium, and low suitability, it can be noted that on average the most house sparrows are found in areas with high suitability. The average lies between 48.15 and 61.56 house sparrows. Which is more than in the area with medium suitability. Here, the average number of house sparrows lies between 46.16 and 56.86 house sparrows. In areas with low suitability, considerably fewer house sparrows can be found, namely between 20.64 and 28.48 house sparrows.

**Table 10. Ratio between the number of house sparrows in the three different categories.**

| | Pathway 1 | Pathway 2 | Pathway 3 | Pathway 4 | Pathway standard |
| --- | --- | --- | --- | --- | --- |
| **Average of the differences (%)** | 67,10 | 70,39 | 70,53 | 102,65 | 117,43 |

The greatest differences between the three categories can be found in the standard pathway. The average difference is around 117.43%. The smallest differences are found in pathway 1 with an average of 67.10%. Pathways 2 and 3 are close to each other with a percentage of 70.39% and 70.53%. The average difference of pathway 4 is 102.65%. Appendix F shows the values of the differences between high, low, and medium on which these averages are based.

COMPARISON - HIGH - PATCHES - NORMAL DISTRIBUTION

COMPARISION - MEDIUM - PATCHES - NORMAL DISTRIBUTION

COMPARISION - LOW - PATCHES - NORMAL DISTRIBUTION
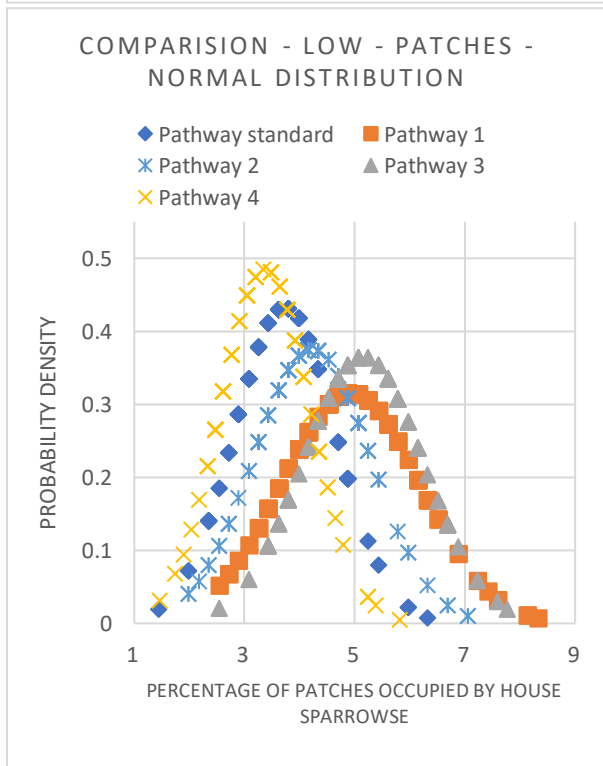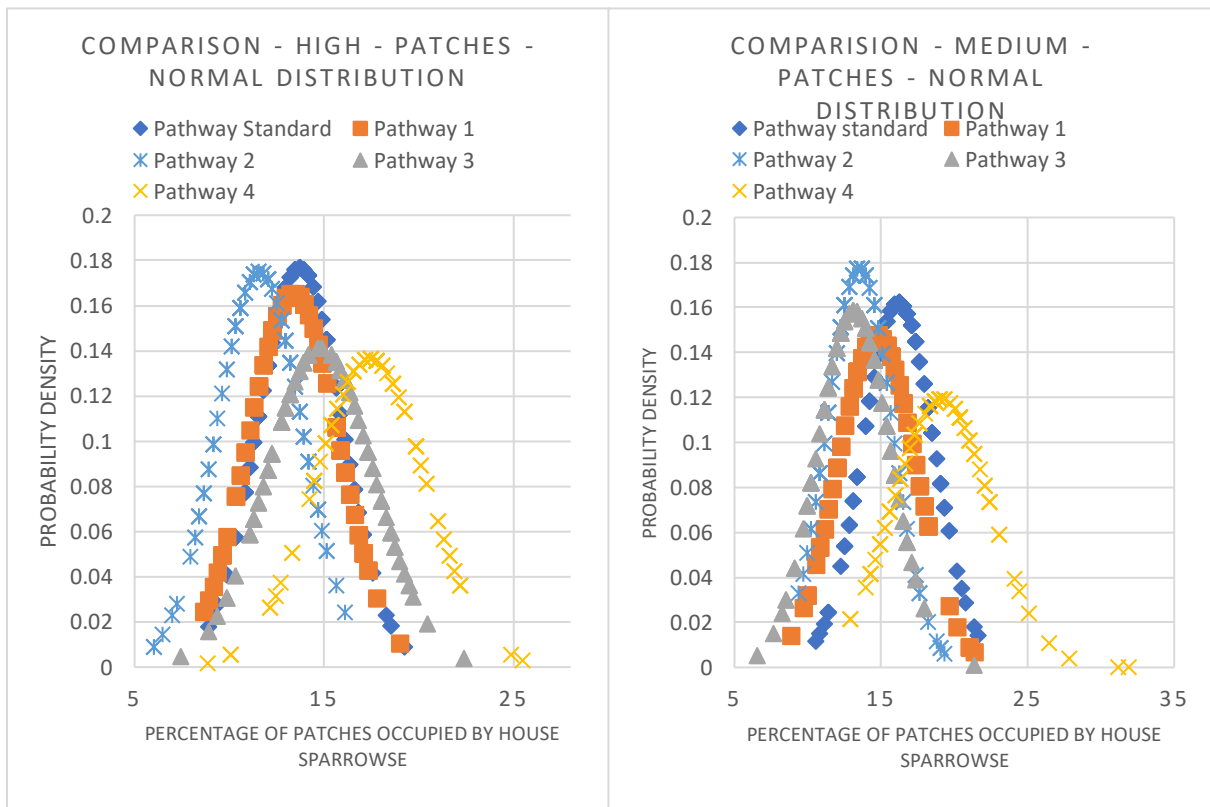
**Figure 36. A Comparison of the normal distribution of Percentage of patches occupied by house sparrows for each pathway with high suitability. B. Comparison of the normal distribution of Percentage of patches occupied by house sparrows for each pathway with medium suitability. C. Comparison of the normal distribution of Percentage of patches occupied by house sparrows for each pathway with low suitability.**

First, the results of the areas with high suitability are shown in Figure 36A and Table 9. The average percentage is between 11.75% and 17.75%. The average of the average pathways is 14.18%. The pathway with the highest average percentage of house sparrows is pathway 4 with an average of 17.43% (σ = 2.92). Followed by pathway 3 with a mean of 14.80 % and a deviation of 2.83. It is followed by the standard pathway with a mean of 13.72% (2.25). The second lowest average percentage is in pathway 1 with 13.36% and a standard deviation of 2.41. The lowest average occurs in pathway 2 with 11.57% and a standard deviation of 2.28. Considering the highest of the probability densities, the values of pathways 1, 2 and standard are the highest. Meaning that for those, the outcomes of the runs are closer to each other compared to the outcomes of pathway 3 and 4. Furthermore, the probability density of the patches is lower compared to the probility density total of areas with high suitability (Figure 36A and 35A).

Secondly, the results of the percentage of house sparrows per medium area are discussed. The average percentage lies between 19.09% and 13.11%. The average of the medium pathways is 15.30%. The highest percentage of house sparrows is found in pathway 4 (19.09%, σ = 3.34), see figure 36B. The second highest percentage is found in the standard pathway with an average percentage of 16.15 and a standard deviation of 2.46. Following is pathway 1 with an average percentage of 14.65% (σ = 2.70) and pathway 2 with an average percentage of 13.49% ( σ = 2.25). The lowest percentage is found in pathway 3 with an average of 13.11% and a standard deviation of 2.52. The probability density of pathway 2, 3 and standard is higher than that of the other pathways leading to higher graphs.

Finally, looking at areas with low suitability, said figure 36C and table 9. The average percentage is between 3.37% and 5.15%. The average of the average pathways is 4.28%. The highest average percentage of house sparrows can be found in pathway 3 with a mean of 5.15% and a standard deviation of 1.09. Pathway 1 follows with a mean of 4.92% and a standard deviation of 1.26. Pathway 2 follows with an average percentage of 4.22 and a standard deviation of 1.06. The standard pathway has the second lowest number percentage of 3.73 with a deviation of 0.92. However, the lowest average percentage is in pathway 4 with 3.37% and a standard deviation of 0.82. The Probability density of pathway 2, standard and 4 are higher compared to the rest. However, its value is higher in comparison with the areas of high and medium suitability.

**Table 11. Average percentage of patches occupied by house sparrows for each pathway.**

| Impact spatial distribution | How many house sparrows are present in this area during the third breeding season (start time: 28-03-2022, end time: 15-07-2022)? | | | | | |
| --- | --- | --- | --- | --- | --- | --- |
| | Percentage on patches - 100 runs | | | | | |
| | Count house sparrows- on High suitability patches | | Count house sparrows- on medium suitability patches | | Count house sparrows- on low suitability patches | |
| | Average | St. dev | Average | St. dev | Average | St. dev |
| Pathway 1 | 13.36 | 2.41 | 14.65 | 2.70 | 4.92 | 1.26 |
| Pathway 2 | 11.57 | 2.28 | 13,49 | 2.25 | 4.22 | 1.06 |
| Pathway 3 | 14.80 | 2.82 | 13.11 | 2.52 | 5.15 | 1.09 |
| Pathway 4 | 17.43 | 2.92 | 19.09 | 3.34 | 3.37 | 0.82 |
| Standard | 13.72 | 2.25 | 16.15 | 2.46 | 3.73 | 0.92 |

Comparing the average percentages of areas with high, medium, and low suitability, the areas with medium suitability have the highest percentage of house sparrows (between 13.11% and 19.09%). It is followed by the average percentage of high suitability areas (between 11.75% and 17.75%). Low suitability areas also have by far the lowest average percentage of patches occupied by house sparrows, between 3.37% and 5.15%.

**Table 12. Average ratio between the number of house sparrows in the three different categories.**

| | Pathway 1 | Pathway 2 | Pathway 3 | Pathway 4 | Pathway standard |
| --- | --- | --- | --- | --- | --- |
| Average of the differences (%) | 126,04 | 136,02 | 118,28 | 297,46 | 205,28 |

Considering the average difference between the three categories, the differences are greatest in pathway 4 with a percentage of 297.46%. Followed by the standard pathway with an average difference of 205.28%. The third highest differences are found in pathway 2 with a percentage of 126.04%. Followed by pathway 1 with 126.04%. The least difference is found in pathway 1. In the appendix F you can find the values of the differences between the pathways on which these averages are based.

## 6. DISCUSION

The hypothesis that the different spatial characteristics influence the spatial distribution of house sparrows with the use of an agent-based model is partly supported by the results. The different suitability areas lead to the fact that most house sparrows can be found in areas with high and medium suitability. Looking at the influence of gardens on spatial distribution, this influence is low. A small difference can be seen between medium and high number of gardens. Whereby high and low numbers of gardens ensure a fair distribution between the areas. Furthermore, the different pathways suffer from different numbers of house sparrows per area. Pathway 1 leads to the most equality between areas with different suitability when considering the number of house sparrows per area. For the percentage of occupied patches by house sparrows, the difference is the lowest in pathway 3.

The hypothesis for pathway 1 is that large number of gardens and the addition of nest boxes ensuring a more even distribution of the house sparrows between low, medium, and high suitability areas. The percentage of occupied patches by house sparrows follows this pattern. The hypothesis of pathway 1 is partly supported by the results. It is true that there is a difference between the number of house sparrows per category. Most house sparrows are found in categories with high suitability. Looking at the results of the differences between the categories, the difference between the categories is lowest in pathway 1. However, the pattern is different in the results of the number of house sparrows per patch. Here pathway 1 is the second lowest.

Hypothesis for pathway 2 was that due to the present of more predators the total population of house sparrows is lower compared to the rest. For the average number of green gardens in combination with the nest boxes provides a fairer distribution of house sparrows over the three categories compared to the standard pathway. However, the distribution is less equal than in pathway 1. Furthermore, the percentage of nests that are occupied will be lower than in the other pathways due to the lower number of house sparrows present. This hypothesis of pathway 2 is also partly supported by the results. It is entirely true that this pathway has the lowest total number of house sparrows due to the presence of multiple predators. Looking at the number of house sparrows per category, most house sparrows are found in areas of high suitability. It is also hypothesized that the equality between the different categories is higher than pathway 3,4 and standard but lower than pathway 1. However, it is not clear from the results about the number of house sparrows per patch. Here pathway 4 is lower in equality.

The hypothesis of pathway 3, is that the same total house sparrows present at the end as in pathway standard, 1, and 4. Furthermore, the number of sparrows in the areas high and low will increase due to the conversion of the building with a medium suitability. The ratio between low, high, and medium thus increases in comparison to pathway 1 and 2, and standard. The percentage of occupied patches by house sparrows follows this pattern. The results from pathway 3 suggest that this hypothesis is partly supported. It seems that the number of house sparrows in pathway 3 is higher than in pathway 1 and standard. Furthermore, it also seems that the results underline that the areas high and low have higher house sparrow numbers compared to the standard pathway. However, what is not underlined is that the ratios between the categories are on average smaller than in pathway 3,4, and standard. These patterns are followed when looking at the patches occupied by house sparrows.

The hypothesis for pathway 4 is that the total population of house sparrows is lower than pathways 1,3 and standard because there are fewer nests. Furthermore, it is expected that the number of house sparrows in areas with high suitability will increase, and the number of house sparrows in low suitability areas will decrease. The same pattern will be observed when looking at the percentage of patches occupied by house sparrows. However, these percentages will be lower than pathway 1,3 and standard. The hypothesis is again partly supported by the results. The first part of the hypothesis that the house sparrow population is lower than the rest is not supported. Furthermore, the hypothesis that the number of house sparrows increases in high suitability areas is supported. However, it does not support the hypothesis that it increases in low suitability

areas. Looking at the relationship between the categories, it is suggested that the difference is higher compared to pathway 1, 2 and 3, but not compared to pathway standard, which makes the hypothesis only partially supported. The pattern is also different if you look at the percentage of occupied patches. In this case, the medium and high percentages are the highest compared to the other pathways, which means that this part of the hypostasis is not supported. This causes the ratio between the different categories to be the most different compared to the other pathways, which in turn means that the hypostasis is not supported.

By adding the connection between the suitability model and the behavioral model, an interaction between behavior and spatial environment is created. Figure 37 shows the difference between the image of the original model and the current model. This interaction is also partly shown in this research, however, the interaction in the new adjust agent-based models is not yet optimal. As a result, the model can be used to understand the interactions and the dynamic between them but cannot be used to indicate where exactly house sparrows are present in an area.  The model is still quite basic, with a few places where there is potential for improvement. The use of this model would therefore not replace real life research into the presence and population size of house sparrows. However, it also is a good support. The use of this behavioral model could for example be used
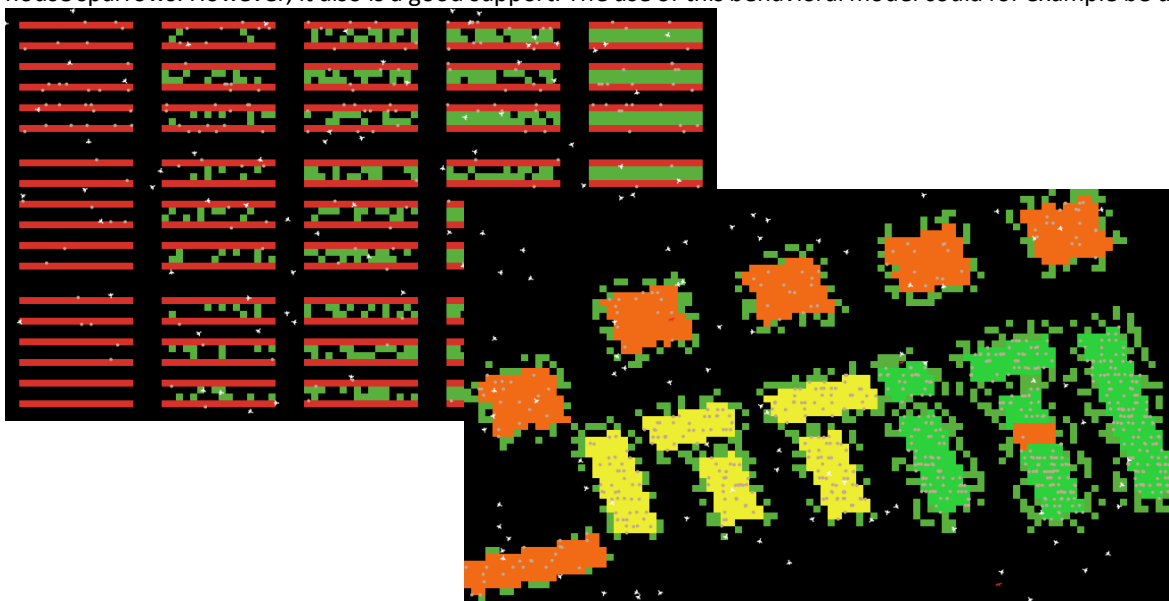


**Figure 37. Difference between the view of the original agent-based model and the updated version of the model.**

in combination with monitoring ringed house sparrows.  The study of ringed house sparrows can be used to start tracking house sparrows in the right places, and the behavioral model could then be used to predict future behavior and distribution of this original group of birds. The model can be applied to any given area as long as a suitability model has been developed in ArcGIS.

Furthermore, it is important to recognize that still this new model has a few limitations. There is very little interaction between districts in the neighborhood where other house sparrows might be present. Moreover, there is no immigration or emigration in the model. This may affect the spatial distribution of the house sparrow. If immigration is added to the model, the results of the population size in the pathways would differ. If there is a reduction of green gardens in a specific area, this might cause the number of house sparrows to decrease. They might look for areas with more green gardens rather than accept that they must nest in places that are less suitable. This also applies in reverse as more green gardens could result in the area attracting more house sparrows. The model also assumes that there are "smart" house sparrows. Meaning that the sparrows know before they choose a nest that there is enough food and other sparrows present in the vicinity.

Looking only at the model itself, there are also a few additional factors that can contribute to an even more effective model, see table 13. The addition of a division between male and female sparrows would be one

of them. It would then also be possible for a house sparrow to reproduce only after it has found a partner of the opposite sex. This function would cause changes because eggs hatched would then depend on the ratio of male to female since house sparrows a partner need (Sappington, 1977). An additional factor that might be interesting to look at in a model is the influence of the environment on the laying and hatching of eggs (Stewart & Westneat ,2013). Another factor would be to add an additional predator such as the sparrowhawks. Adding a second predator would provide an additional interaction in the system (Barnard, 1979).

**Table 13. Possible recommendations for improving the model.**

| List of recommendations - *possible additions* |
| --- |
| **1.** Adding genders (female/male) |
| **2.** Adding a permanent partner |
| **3.** Adding environmental impact on eggs |
| **4.** Adding additional predator |

Next, we will discuss the justification behind the use of some specific data and assumption used. In the method about adding a population, it is chosen to reduce the chance of a house sparrow hatching by 30%. This is done because, according to research, a large percentage of the young die within their first year and even a part of the eggs does not hatch. According to research, the chance that a young house sparrow dies is 10% higher, furthermore, the average egg mortality of house sparrows is 30% and the nestling mortality is also 30% (Pinowski, et al, 1994; Klok, et al, 2008). If you add these percentages together, the chance that a house sparrow hatches from an egg are reduced to 30%.

The first assumption made in the model is that 100 nests were chosen in areas of low suitability, 200 for medium suitability and 400 for high suitability. These values were chosen because in the original model 800 nests were present in total. In the new model there are less patches with houses present so I have chosen for a total of 700 nests. This subdivided in the categories low, medium, and high have led to the values. The number of nests is not scientifically supported so the numbers could be improved in future studies. The second assumption is the choices for the number of gardens per area. Looking at the values of the NDVI, none of the houses have an NDVI of 1, which would mean that everything around them would be green. So, the choice was made to have some of the gardens black. This choice was made by looking at the image. If we look at the numbers of patches of gardens in the three categories, the distribution is based on the ratio between the categories (0.13, 0.16 and 0.19). The number of gardens is further based on an assumption so the numbers could be improved in the future by conducting more surveys.
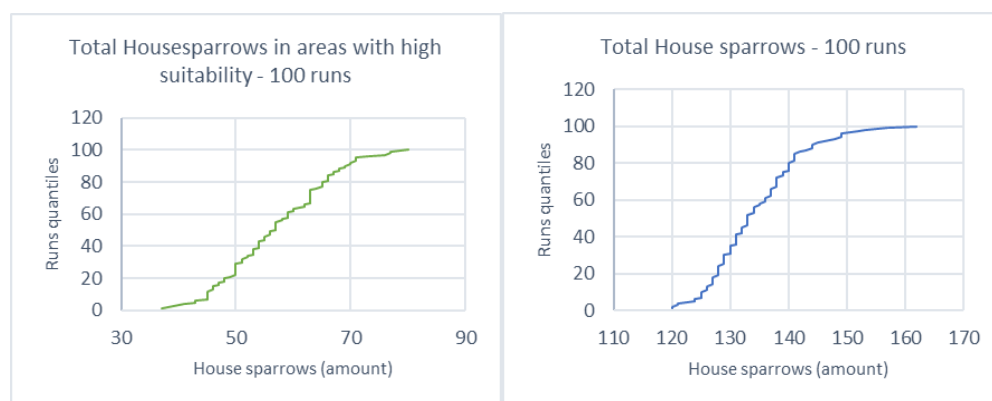


**Figure 38. A. Data after distributing it from small to large for areas high suitability in pathway normal. B. Data after distributing from small to large for total population in pathway normal.**

If we are going to look at the reasoning behind choosing a normal distribution, we start by looking at the outcome of the 100 runs sorted from small to large and plotted in a figure, the above figures emerge, see

Figure 38. The results of the sorted runs form almost an angled straight line. Meaning that the data is distributed in such a way that it is a normal distribution. In figure 38A consisting of runs on the number of house sparrows per area of high suitability, the line is very straight which means that it is a normal distribution. If the line is less straight, as shown in figure 38B with the total number of house sparrows, then it means that there is a distribution with more extreme high numbers than low numbers of house sparrows.

A practical problem of using a behavioral model in Netlogo is the running time. It is important to run the model at least 100 times with the same parameters and functions, as due to the nature of ABM there is high probability in the individual model runs.

Furthermore, we will look at differences and similarities between the results of my research and the results of other studies on the house sparrow. The first comparison, when we look specifically at the average age of 1.5 years, this corresponds reasonably well with several ring tests of the House Sparrow (Magnussen, & Jensen, 2009). In a ring survey in the Faroes Islands, the average age was around 1.3 years. Most house sparrows had an age between 0 and 10 months. The ages of the improved ABM in our own research thus follow the pattern of the research from the Faroe Islands. However, the oldest house sparrow was 10 years old, compared to 12 years in the model (Magnussen, & Jensen, 2009). The high influence of cats on the population of House sparrows is also supported by other researchers (Magnussen, & Jensen, 2009; Shaw, et al, 2008). However according to others, there is still too little information available to determine the exact rate of deaths due to cats (Klok, et al, 2006). Furthermore, adding nesting boxes for house sparrows is not supported by everyone as a beneficial substitute in places with low nesting suitability (Von Post, & Smiths, 2015).

The influence of gardens is low in this study but is more important in other research. Choudhary, et al, (2020) have found a higher influence on the distribution of house sparrows in areas with a lower suitability for nesting. They found that the influence of the environment in India found that 73% of house sparrows nest within 10 meters of the nearest vegetation patch. And another study shows that more house sparrows are present in the vicinity of gardens with a high vegetation density (Wilkinson, 2006). One reason for this difference compared to the results of my research may be that the distances to green areas in the ABM are small and preferences lie in choosing a green area that is closer.

Some results are differently than expected. One result that raised questions was the low suitability in a house on the second street from the right (Beekweide). Compared to its neighbors, this house has a worse suitability value of 0.1. This low value is since this house is the only one in the street with an extra floor and a flat roof, see image 1. This makes it clear that all the factors that influence suitability are very important. Thus, even the addition of an extra floor can have a high negative influence on the suitability for the house sparrow.



Image 1. Image of the house with low suitability in Google maps (Google, 2022)

Looking at the results of the population size of the different pathways, pathway 4 has the highest number of house sparrows. This result would not be expected if considering the factors that influence the environment.

However, as discussed earlier, there is no emigration in the model, so there is no possibility that the population changes very much. The model does not assume that birds will die if there is too little green space in the environment. There is a function in the model that sparrows die if they do not find a nest quickly enough *(if nest-search-time >= 24 [die])*. However, in pathway 4, on average fewer nests are present, so it was expected that the population was also lower. However, in the pathways the nests are found, and not enough house sparrows die to see a significant difference. The reason for this may be that either the function does not work properly or there are not enough house sparrows compared to nests. Another possible explanation for the fact that pathway 4 has a higher population is that it is due to the randomness of an agent-based model. After all, pathway 4 is very close to pathways 3, 1 and standard. The difference between them ranges from 2 to 4 house sparrows. The standard deviation of all pathways lies between 9.13 and 8.01, meaning that the majority of all four pathways, including pathway 4, have similar values. Therefore, there is no significant difference between pathway 4 and 1,3 and standard. Pathway 2 is significantly more different as the number of predators in this pathway is the only one that is larger.

Another result of pathway 4 is that the percentage of occupied house sparrows in high suitability areas is very high. The reason is that many areas that were originally high suitability areas are now low suitability areas. Therefore, the ratio of high suitability patches and number of house sparrows is proportionally higher than the rest. In pathways 1 and 2, the number of bird hives is included in the number of patches for low suitability areas. Therefore, the percentage of occupied patches for low suitability areas in these pathways does not show a high difference compared to the other pathways. The other results are in reasonable agreement with the expectations arising from the parameters associated with the pathways.

An additional result to be discussed is from the sensitivity analysis. In areas with a medium number of gardens (500), there are areas with little green and areas with enough green. The house sparrow is then more likely to nest in areas with both many gardens and high suitability. The conclusion of the standard deviation is that the standard deviation is greater in areas with fewer than 130 gardens than when 500 or 1000 gardens are present. This is because with few gardens, the garden must be in just the right place to attract house sparrows.

After all, it is certainly the case that the house sparrow is declining in the urban area (Klok, et al, 2006). It is therefore important to develop various methods, including behavior models, to better understand the house sparrow. By better understanding the interaction between house sparrows and their environment, a better picture can be created of how best to protect or support house sparrows. The disappearance of bird species such as the house sparrow damages the urban ecosystem, making it lose its balance. Thus, research on the house sparrow is important so that we can not only improve the status of the house sparrow but contribute to strengthening the urban ecosystem (Mustafa, et al, 2015). By offering more research and eventually applying the results of these research, together we ensure that we strengthen the ecosystems.

## 5. CONCLUSION

As the number of house sparrows worldwide continues to decline, research is needed into the behavior and distribution of house sparrows. In order to investigate the spread of the population, this research investigates whether a conceptual behavioral model can be used to explore the interaction between the spatial environments and the behavior of the house sparrows to develop pathways that predict the spatial distribution of House sparrows.

With an Agent Based Model I have developed a model that simulates the population, nesting options and age growth in a reasonable way for the situation in Zaanstad. I have found that the average age of the house sparrows lays around the 1,5 years. When looking at the maximum number of house sparrows, the population will not exceed 190 and will not fall below 100 house sparrows with 80 initial birds when running with the standard model. Furthermore, adding a house sparrow's own nest ensures that the house sparrows return to their own nest. Overall, the new adjust agent-based model runs correctly, with house sparrows searching for a nest at night and searching for food during the day. Overall, the average houses sparrows present in area with

real life observations are higher than in comparison with high, medium, and low suitability areas but not during every run due to the large standard deviation.

The overall conclusion of the sensitivity analysis is that the number of gardens only has limited impact on the spatial distribution of House sparrows in areas with low, high, and medium suitability. If there are no gardens in the area, the choice of where to nest depends only on the suitability of the house. This principle also applies the other way around if you look at the presence of many green gardens, the spatial distribution of house sparrows depends on the suitability of houses. An average number of gardens does seem to have an influence on the spatial distribution of house sparrows. However, these influences are very low, which leads to the conclusion that the overall impact of the gardens is not high. Further predators also have only a small influence on the spatial distribution of house sparrows in areas of low, medium, or high suitability.

Therefore, the pathways are designed by making differences in the suitability of the houses, for example nest boxes or renovations. Combined with differences in the number of green gardens and predators, as a combination might lead to these factors influencing the spatial distribution of house sparrows. Leading to the subject of five different pathways, pathway 1 being a combination of hanging nest boxes in areas of low suitability and many green gardens. Pathway 2 is a combination of nest boxes and multiple predators present. The third pathway (3) consists of a one-year rebuilding period in an area of medium suitability. The fourth pathway (4) consists of a combination of adding areas of low suitability in combination with few green gardens. The final pathway (standard) consists of the current situation with no changes.

I conclude that with the influence of the different pathways on the total population house sparrows, the number of predators and the number of initial house sparrows of the model have the greatest influence on the total number of house sparrows. The more predators, the lower the population. And the larger the initial birds, the larger the population.

Looking at the spatial distribution of house sparrows per category per pathway, I conclude that the combination of nesting boxes and many gardens provides the best distribution of house sparrows (Pathway 1). Followed by the combination of placing nest boxes and adding a predator (Pathway 2). Having a conversion in an area of medium suitability including gardens leads to the third best dispersal (Pathway 3). A combination of few green gardens and a reduction in suitability in areas of high suitability leads to the second worst distribution (pathway 4). The current situation in the model leads to the worst distribution with the lowest number of house sparrows in areas with low suitability (pathway standard). The conclusion of the spatial distribution of Houses sparrows looking at the occupancy per patch per area. Consequently, having a renovation in an area with medium suitability including gardens leads to the best distribution (pathway 3). Followed by the combination of nest boxes in low suitability areas with many gardens (pathway 1). Followed by the combination of placing nest boxes and adding a predator (pathway 3). Then a combination of few green gardens and reduced suitability in high suitability areas (pathway 4). And finally, with the poorer distribution, the situation as it is now in the model (standard pathway).

It is important to note that there is a major difference compared to the original agent-based model. The improvements in the model have led to more interaction between the spatial environments and the behavior of the house sparrows for Zaanstad. Overall, the research show that a conceptual behavioral model can used to assess different pathway and shows that the spatial distribution of house sparrows is Influenced by the different pathways. However, the influence of the number of gardens and number of predators on the distribution of the house sparrow is low according to this model. The predator mainly influences the total size of the population. Furthermore, the standard deviation in the pathways is also large. furthermore, the results only partly correspond to the field sightings of House sparrows and besides that, the standard deviation of each run is high. It is therefore important to develop this model further in the future, with more interactions to create a model that corresponds even better to reality. Also, more research is needed into the use of conceptual behavioral models to better predict the spatial distribution of house sparrows.

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## ACKNOWLEDGEMENTS

## APPENDIX

### APPENDIX A

#### APPENDIX A.1

```
Version 0.3
if environment-size = "zaanstad"
  [
    set housemap-dataset gis:load-dataset "wiede_wijk.shp"     ;creat environment with zaanstad as base
    gis:set-world-envelope gis:envelope-of housemap-dataset    ;set world size to shrubmap extend

    let suith gis:find-range housemap-dataset "out"   0.696763 1
    .......

    foreach gis:feature-list-of housemap-dataset
    [vector-feature ->

      ask patches gis:intersecting suith
      [set surface-type "house"
        set pcolor lime
      ]
      .........
    ]

    define-nestsh
    .........

    ask patches with [pcolor = black] [set surface-type "paved"]
    ask patches with [pcolor = green] [ set surface-type "garden"]
  ]
  end
```

#### APPENDIX A.2

```
Version 0.4
to define-nestsh ;for areas with high suitability

    repeat 400  ;n-nests
  [
    ask one-of patches with [ pcolor = lime]
      [sprout-nests 1
        [set color 37
          set size 0.5
          set shape "circle"
          set xcor (xcor + (random-float 0.8 - 0.4)) ; give nests a random spot close to the edge of a roof
          set ycor (ycor + one-of [0.45 -0.45])     ; not exaclty on the edge, so the nest is still on the calling patch
        ] ; end sprout-nests
      ] ; end ask patches
    ]
end ; end define-nests
```

#### APPENDIX A.3

```
Version 4.1
breed[wolves wolf]

to eat-birds
```

```
  let prey one-of housesparrows-here            ; grab a random bird
  if prey != nobody  [                ; did we get one? if so,
   Let surf random-float 101
    if surf > 70 [
      ask prey [ die ] ; kill it, and...
    ]


  ]
end
```

<table>
<tr><td><strong>Version 4.2 (Wilensky, 1997)</strong></td></tr>
</table>

```
to eat-birds-learning       ;de kat leert erg goed want veel vogels dus de kans op dood gaan is hoger
  let amount-change count housesparrows
  let learn-change (init-birds + (init-birds / 2))

  ifelse amount-change > learn-change
  [
   let prey one-of housesparrows-here         ; grab a random bird
  if prey != nobody  [               ; did we get one? if so,
   Let surf-a random-float 101              ; dus 10 telt ook mee
     if surf-a > 49 [                ;'slagings' kans is 1/10
       ask prey [ die ]             ; kill it, and...
   ] ]
  [ let prey one-of housesparrows-here            ; grab a random bird
  if prey != nobody  [               ; did we get one? if so,
   Let surf-b random-float 101
     if surf-b > 86 [               ;kans op dood gaan in 6/10
     ask prey
       [ die ] ; kill it, and...
   ] ] ]
end
```

## APPENDIX B

<table>
<tr><td><strong>Codes</strong></td></tr>
</table>

```
;;;;;;; activate extensions  ;;;;;;;
extensions [time gis vid]  ;; Created by Colin Sheppard, Steve Railsback and Jacob Kelter

;;;;;; set breeds and variables ;;;;;;
breed[housesparrows housesparrow ]
breed[nests nest]
breed[wolves wolf]

globals[ dt  cur-day-length  start-daytime  end-daytime    max-age  change-to-die housemap-dataset mussen-dataset geen_mussen-dataset]

nests-own
[vol]

housesparrows-own
[
 ;; Model variables
 age
 overflow
 birth-date
 sleeping?
 tired?
 cur-activity
 activity-time
 food-patches-today
 houses-searched-today
 last-nest
 own-nest ;new nesten
 distance-from-nest
 partner
 ;;population
 birth-rate
 ;; reporting variables
```

```
    nest-search-time
    extra-time-awake
    time-spent-sleeping
    time-spent-eating
    time-spent-washing
    food-search-time
]

patches-own[ surface-type row column block suitability]

links-own[ weight ]

;;;;;;; setup and go procedures ;;;;;

to setup
  ;; Clear & reset environment
  clear-all
  reset-ticks

  ;; if min-max activity time is incorrect, send message in pop-up
  if min-activity-time >= max-activity-time
  [
  user-message (word "WARNING: Min-activity-time should be less than Max-activity time")
  ]

  if time:is-after? model-start-time model-end-time
  [
  user-message (word "WARNING: Model-end-time should be after model-start-time")
  ]

  ;; Set initial values globals
  set dt time:create model-start-time
  print time:show dt "HH:mm:ss yyyy-MM-dd"
  update-daytime
  set max-age 12

  ;; create model, initial values set in corresponding procedure
  create-environment
  create-birds
  create-predators
end ;; end setup

to go
  if time:get "hour" dt = 3 and time:get "minute" dt = 0
  [
    update-daytime
  ]
  ask wolves
  [
    move
      eat-birds-learning
  ]
  ask housesparrows
  [
    check-age
    update-age

    check-pop2
    look-for-partner

    ifelse tired?
    [
      ;; you are tired
      ifelse sleeping?
      [
        ;; you are sleeping and still tired
        if debug?[
          write "housesparrow " print who
          write "tired? " print tired?
          write "sleeping? " print sleeping?]
        ;; keep on sleeping in this spot
        set time-spent-sleeping time-spent-sleeping + 1
        ;; check time to wake? -> change tired?

        if time-to-wake?
        [
          set tired? FALSE
          set color white
          set nest-search-time 0
          set cur-activity "none"
          set activity-time 0
```

```
        set food-patches-today patch-set []
        set houses-searched-today patch-set []
        set distance-from-nest 0

        if debug?[
          print "Time to wake up"]
      ]    ;; end time to wake?
    ]    ;; end tired and sleeping
    [
      ;; you are tired but not sleeping
      if debug?[
        write "housesparrow " print who
        write "tired? " print tired?
        write "sleeping? " print sleeping?
        print "searching for sleeping place"]
      ;; search for a sleeping place
      ;search-partner ;finding a partner for nesting
      search-sleeping-place
      ;find-nest ; werkt niet...
      set nest-search-time nest-search-time + 1

      if nest-search-time >= 100
      [die]
      ;if nest-search-time = FALSE

      if time-to-wake?
      [
        set tired? FALSE
        set color white
        set nest-search-time 0
        set cur-activity "none"
        set activity-time 0
        set food-patches-today patch-set []
        set houses-searched-today patch-set []
      ]
    ]    ;; end tired, not sleeping
  ]    ;; end tired
  [
    ;; you are not tired
    ifelse sleeping?
    [
      ;; you are not tired, but still sleeping
      if debug?[
        write "housesparrow " print who
        write "tired? " print tired?
        write "sleeping? " print sleeping?
        print "I woke up"]
      set time-spent-sleeping time-spent-sleeping + 1
      ;; wake up
      set sleeping? FALSE
    ]    ;; end not tired, still sleeping
    [
      ;; you are not tired and not sleeping
      if debug?[
        write "housesparrow " print who
        write "tired? " print tired?
        write "sleeping? " print sleeping?]
      ;; daytime activities
      daytime-activity
      ;; check time to sleep? -> change tired?
      if time-to-sleep?
      [
        set tired? TRUE
        set color blue
        set extra-time-awake ((time:get "hour" dt + (time:get "minute" dt) / 60) - end-daytime) * 60

        if debug?[
          print "its time to sleep"]
      ]    ;; end time to sleep?
    ]    ;; end not tired, not sleeping
  ]    ;; end not tired

  ;; Check distance from last nest for home-range indicator
  check-distance-from-nest
]   ;; end ask housesparrows

ifelse plot-every-tick
[
  update-plots
]
[
```

```
      if time:get "hour" dt = 3 and time:get "minute" dt = 0
    [
      update-plots
    ]
  ]


  set dt time:plus dt min-per-timestep "minutes"

  if count housesparrows < 20 [stop]        ;; stop the model if there are no more housesparrows

  if time:is-after? dt time:create model-end-time [stop] ;; stop the model if given end date is reached
  if vid:recorder-status = "recording" [ vid:record-view ]
end ;; end go

to create-vergelijking
  set mussen-dataset gis:load-dataset "Nesten_mussen.shp"
  set geen_mussen-dataset gis:load-dataset "geen_nesten_mus.shp"
  gis:set-world-envelope gis:envelope-of geen_mussen-dataset   ;; set world size to shrubmap extend

  let nesten gis:find-range mussen-dataset "aantal_min" 0.0 7.1

  foreach gis:feature-list-of mussen-dataset
  [vector-feature ->
     ask patches gis:intersecting nesten
     [ ask one-of patches in-radius 4 [if pcolor = yellow or pcolor = lime
     [set pcolor 16]]
    ]
  ]

end


to move  ; predator procedure
  if (xcor > max-pxcor) or     ;; check if close to the edge
     (ycor > max-pycor) or
     (xcor < min-pxcor) or
     (ycor < min-pycor)
   [right 50

   ]                     ;; turn around if close to edge
   right (random 21) - 10
   fd 3                 ;; always do this movement
end
;;;;;;; Internal procedures  ;;;;;;;

to eat-birds-learning
  let amount-change count housesparrows
  let learn-change (init-birds + (init-birds / 2))

  ifelse amount-change > learn-change
  [ ;de kat leert erg goed want veel vogels dus de kans op dood gaan is hoger
   let prey one-of housesparrows-here        ; grab a random bird
  if prey != nobody  [                   ; did we get one? if so,
   Let surf-a random-float 101                 ; dus 10 telt ook mee
     if surf-a > 49 [                    ;'slagings' kans is 1/10
      ask prey [ die ]              ; kill it, and...
    ] ]
  ]
  [ ;dus kat leert minder goed dus de kans op dood gaan is lager
   let prey one-of housesparrows-here             ; grab a random bird
  if prey != nobody  [                    ; did we get one? if so,
   Let surf-b random-float 101
     if surf-b > 86 [               ;kans op dood gaan in 6/10
     ask prey
       [ die ] ; kill it, and...
    ]
  ]
  ]
end

to verbouwing
  if time:get "month" dt = 4 and time:get  "hour" dt = 8 and time:get "day" dt = 1
  [
   let verbouwd gis:find-range housemap-dataset "out" 0.63973 0.63975
   let verbouwd2 gis:find-range housemap-dataset "out" 0.635653 0.635655
   let verbouwd3 gis:find-range housemap-dataset "out" 0.639667 0.639669
   let verbouwd4 gis:find-range housemap-dataset "out" 0.624595 0.624597
     ask patches gis:intersecting verbouwd
     [set surface-type "verbouwing"
      set pcolor 36]
```

```
      ask patches gis:intersecting verbouwd2
      [set surface-type "verbouwing"
        set pcolor 36]
      ask patches gis:intersecting verbouwd3
      [set surface-type "verbouwing"
        set pcolor 36]
      ask patches gis:intersecting verbouwd4
      [set surface-type "verbouwing"
        set pcolor 36]

    ask nests-on patches with [pcolor = 36]
    [die]]
end

to nestkast
  if time:get "month" dt = 4 and time:get "hour" dt = 9 and time:get "day" dt = 1
  [ask patches with [pcolor = pink]
    [
      sprout-nests 4
        [set color 37
          set size 0.5
          set shape "circle"
          set xcor (xcor + (random-float 0.8 - 0.4)) ; give nests a random spot close to the edge of a roof
          set ycor (ycor + one-of [0.45 -0.45])     ; not exaclty on the edge, so the nest is still on the calling patch
        ] ; end sprout-nests
    ]
  ]

end


;; Time ;;
to update-daytime
  set cur-day-length seasonal-cycle 12 4 -10 (time:get "dayofyear" dt) 365
  set start-daytime 12 - cur-day-length / 2
  set end-daytime 12 + cur-day-length / 2
end
to-report seasonal-cycle [avg amp lag dayno-loc daysperyear]
  let frac_year (dayno-loc - lag) / daysperyear
  report avg + amp * sin(frac_year * 360 - 90)
end


;; Population ;; (Wilensky, 1997)

to check-pop2
  let change-uit (legsels * eggs)
  let uit-maand (change-uit / 5) ;5 maanden broeidseizoen
  let uit-dag2 ((uit-maand / 30.5) * 100)
  let uit-dag3 uit-dag2 / 2
  let uit-dag uit-dag3 * 0.30

  if time:get "month" dt = 4 and time:get "hour" dt = 3 ;April
  [let births random 100
    if births < uit-dag and age > 1
    [hatch 1
      set age 0
      set partner nobody
      set own-nest nobody
   ;set age time:difference-between birth-date dt "year"
    ]
  ]

  if time:get "month" dt = 5 and time:get "hour" dt = 3 ;mei
  [let births random 100
    if births < uit-dag and age > 1
    [hatch 1
      set age 0
      set partner nobody
      set own-nest nobody
    ]
  ]

  if time:get "month" dt = 6 and time:get "hour" dt = 3 ;juni
  [let births random 100
    if births < uit-dag and age > 1
    [hatch 1
      set age 0
      set partner nobody
      set own-nest nobody
    ]
```

```
  ]
  if time:get "month" dt = 7 and time:get "hour" dt = 3 ;juli
[let births random 100
  if births < uit-dag and age > 1
  [hatch 1
    set age 0
    set partner nobody
    set own-nest nobody
  ]
]
  if time:get "month" dt = 8 and time:get "hour" dt = 3 ;augustus
[let births random 100
  if births < uit-dag and age > 1
  [hatch 1
    set age 0
    set partner nobody
    set own-nest nobody
  ]
]

end

;; For setup: environment and agents ;;
to create-environment

if environment-size = "zaanstad"
  [ ;;creat environment with zaanstad as base
    set housemap-dataset gis:load-dataset "wiede_wijk.shp" ;dit geeft nu geen error meer
    gis:set-world-envelope gis:envelope-of housemap-dataset


  let suith gis:find-range housemap-dataset "out"   0.696763 1
  let suitm gis:find-range housemap-dataset "out"   0.558328 0.696762
  let suitl gis:find-range housemap-dataset "out"   0.0 0.558327

    let ndvi_low gis:find-range housemap-dataset "mean_ndvi" 0.12 0.1499
    let ndvi_mid gis:find-range housemap-dataset "mean_ndvi" 0.15 0.179
    let ndvi_high  gis:find-range housemap-dataset "mean_ndvi" 0.180 0.20

    foreach gis:feature-list-of housemap-dataset
    [vector-feature ->
      ask patches gis:intersecting ndvi_low
    [ ask patches in-radius 1 [if pcolor = black [
      set pcolor green
      ]]]

      ask patches gis:intersecting ndvi_mid
    [ ask patches in-radius 2 [if pcolor = black [
      set pcolor green
      ]]    ]

      ask patches gis:intersecting ndvi_high
    [ ask patches in-radius 3 [if pcolor = black [
      set pcolor green
      ]]
    ]

      ask patches gis:intersecting suith
    [set surface-type "house"
        set pcolor lime
    ]
      ask patches gis:intersecting suitm
    [set surface-type "house"
      set pcolor yellow
    ]

      ask patches gis:intersecting suitl
    [set surface-type "house"
      set pcolor orange
    ]
    ]

    define-nestsh
    define-nestsm
    define-nestsl
  ask up-to-n-of (1300 - gardens) patches with [pcolor = green] [ set pcolor black ]
  ask patches with [pcolor = black] [set surface-type "paved"]
  ask patches with [pcolor = green] [ set surface-type "garden"]
  ]
if environment-size = "large"
  [ ;; create large 100X60 environment with 15 blocks of 20X20
```

```
resize-world 0 99 0 59
set-patch-size 8

(foreach [0 1 2 3 4] [0 24 48 72 96]
  [ [ columns green-proportion ] ->

   (foreach [0 1 2] [1.10 1.50 5.00]
   [ [ rows nestspots ] ->
   ask patches with[pxcor >= columns * 20 and
            pxcor <= columns * 20 + 19]
      [set column columns + 1]

   ask patches with [pycor >= rows * 20 and
            pycor <= rows * 20 + 19]
      [set row rows + 1]
   let houses patch-set patches with [pycor = 2 + (20 * rows) or
            pycor = 5  + (20 * rows) or
            pycor = 8  + (20 * rows) or
            pycor = 11  + (20 * rows) or
            pycor = 14  + (20 * rows) or
            pycor = 17  + (20 * rows) and
            pxcor > 1 + (20 * columns) and
            pxcor < 18 + (20 * columns)]

     ask houses
     [set pcolor red]

     repeat nestspots * init-birds / 15
     [ask one-of houses
       [sprout-nests 1
        [set color 37
          set size 0.5
          set shape "circle"
          set xcor (xcor + (random-float 0.8 - 0.4)) ; give nests a random spot close to the edge of a roof
          set ycor (ycor + one-of [0.45 -0.45])      ; not exaclty on the edge, so the nest is still on the calling patch
         ] ; end sprout-nests
       ]
      ]

    ask n-of green-proportion patches with [pycor = 9 + (20 * rows) or
                pycor = 10  + (20 * rows) or
                pycor = 15 + (20 * rows) or
                pycor = 16 + (20 * rows) or
                pycor = 3  + (20 * rows) or
                pycor = 4 + (20 * rows) and
                pxcor > 1 + (20 * columns) and
                pxcor < 18 + (20 * columns) ]
          [set pcolor green]

     ])])
  ]
if environment-size = "medium" ;;Check which environment is asked
[   ;; start creating medium 20X20 environment
  resize-world 0 19 0 19
  set-patch-size 20
  ask patches with [pycor = 2 or
            pycor = 5 or
            pycor = 8 or
            pycor = 11 or
            pycor = 14 or
            pycor = 17 and
            pxcor > 1 and
            pxcor < 18]
            [set pcolor red]
  ask n-of 16 patches with [pycor = 9 or
                pycor = 10 and
                pxcor > 1 and
                pxcor < 18]
                [set pcolor green]
  ask patches with[pycor = 15 or
          pycor = 16 and
          pxcor > 1 and
          pxcor < 18]
          [set pcolor green]

   ;; set surface-type to corresponding color
ask patches with [pcolor = red] [set surface-type "house"]
ask patches with [pcolor = green] [ set surface-type "garden"]
ask patches with [pcolor = black] [ set surface-type "paved"]

ask patches with [pycor >= 12][set block 1]
```

```
   ask patches with [pycor <= 11 and pycor >= 6][set block 2]
   ask patches with [pycor <= 6][set block 3]

define-nests
  ] ;; end creating large 20X20 environment
  if environment-size = "small"
  [ ;; start creating small 10X10 environment
    resize-world 0 9 0 9
    set-patch-size 40

  ask patches with [pycor = 8 or
             pycor = 6 or
             pycor = 3 and
             pxcor > 0 and
             pxcor < 9]
             [set pcolor red]
  ask patches with [pycor = 7 and
             pxcor > 0 and
             pxcor < 9]
             [set pcolor green]
  ask patch 1 2 [set pcolor red]
  ask patch 1 1 [set pcolor red]
  ask patches with [pycor = 1 and
             pxcor > 2 and
             pxcor < 9]
             [set pcolor red]
  ] ;; End creating small 10X10 environment

  ;; set surface-type to corresponding color
  ask patches with [pcolor = red] [set surface-type "house"]
  ask patches with [pcolor = green] [ set surface-type "garden"]
  ask patches with [pcolor = black] [ set surface-type "paved"]


end ;; end create-environment
to create-birds
  create-housesparrows init-birds [   ;; set on interface
    ;set label who
    set xcor random-xcor
    set ycor random-ycor
    set shape "housesparrow"
    set color white
    set size 1
    set birth-date dt
    set partner nobody
    set own-nest nobody

    set sleeping? FALSE
    set tired? FALSE
    set cur-activity "None"
    set food-patches-today patch-set []
    set houses-searched-today patch-set []
    set distance-from-nest 0
    ;set birth-rate 1
    set age random 13
    ;set change-to-die 0.070
    set carrying-capacity 100

    if debug?
    [pen-down]
    ]
end ;; end create-birds
to create-predators ;Copyright 2005 Uri Wilensky

  create-wolves initial-number-predators [
    set xcor random-xcor
    set ycor random-ycor
    set shape "wolf"
    set size 1
    set color red]
end

to define-nests

    repeat 800 ;n-nests
  [
    ask one-of patches with [surface-type = "house"
    ]
      [sprout-nests 1
        [set color 37
          set size 0.5
```

```
            set shape "circle"
            set xcor (xcor + (random-float 0.8 - 0.4)) ; give nests a random spot close to the edge of a roof
            set ycor (ycor + one-of [0.45 -0.45])     ; not exaclty on the edge, so the nest is still on the calling patch
          ] ; end sprout-nests
        ] ; end ask patches
    ]


end ; end define-nests

to define-nestkasten
 repeat 2
 [
 ask patches with [pcolor = 68]
 [sprout-nests 1
       [set color 37
         set size 0.5
         set shape "circle"
         set xcor (xcor + (random-float 0.8 - 0.4)) ; give nests a random spot close to the edge of a roof
         set ycor (ycor + one-of [0.45 -0.45])     ; not exaclty on the edge, so the nest is still on the calling patch
       ] ; end sprout-nests
   ] ; end ask patches
 ]
end

to define-nestskast

    repeat 8 ;n-nests
 [;ask one-of patches with [surface-type = "house" ;and neighbors with [surface-type = "paved"]
  ask one-of patches with [pcolor = pink
   ]
      [sprout-nests 1
       [set color 37
         set size 0.5
         set shape "circle"
         set xcor (xcor + (random-float 0.8 - 0.4)) ; give nests a random spot close to the edge of a roof
         set ycor (ycor + one-of [0.45 -0.45])     ; not exaclty on the edge, so the nest is still on the calling patch
       ] ; end sprout-nests
     ] ; end ask patches
   ]


end ; end define-nests

to define-nestsh

    repeat 400 ;n-nests
 [;ask one-of patches with [surface-type = "house" ;and neighbors with [surface-type = "paved"]
  ask one-of patches with [ pcolor = lime
   ]
      [sprout-nests 1
       [set color 37
         set size 0.5
         set shape "circle"
         set xcor (xcor + (random-float 0.8 - 0.4)) ; give nests a random spot close to the edge of a roof
         set ycor (ycor + one-of [0.45 -0.45])     ; not exaclty on the edge, so the nest is still on the calling patch
       ] ; end sprout-nests
     ] ; end ask patches
   ]


end ; end define-nests

to define-nestsm

    repeat 200 ;n-nests
 [
  ask one-of patches with [ pcolor = yellow
   ]
      [sprout-nests 1
       [set color 37
         set size 0.5
         set shape "circle"
         set xcor (xcor + (random-float 0.8 - 0.4)) ; give nests a random spot close to the edge of a roof
         set ycor (ycor + one-of [0.45 -0.45])     ; not exaclty on the edge, so the nest is still on the calling patch
       ] ; end sprout-nests
     ] ; end ask patches
   ]


end ; end define-nests
```

```
to define-nestsl

   repeat 100 ;n-nests
 [;ask one-of patches with [surface-type = "house" ;and neighbors with [surface-type = "paved"]
   ask one-of patches with [ pcolor = orange
   ]
     [sprout-nests 1
       [set color 37
         set size 0.5
         set shape "circle"
         set xcor (xcor + (random-float 0.8 - 0.4)) ; give nests a random spot close to the edge of a roof
         set ycor (ycor + one-of [0.45 -0.45])     ; not exaclty on the edge, so the nest is still on the calling patch
       ] ; end sprout-nests
     ] ; end ask patches
   ]
end ; end define-nests

;; Behavior// Time and state checks //
to check-age ;; housesparrow procedure
   if age > max-age                          ;; housesparrows die day 1 of their 13th year
   [die]
end

to update-age ;; housesparrow procedure
 if time:get "day" dt = 3 and time:get "hour" dt = 3
 ;if time:get "hour" dt = 3
 [
 set age (0.0832258065 + age)
 ]
End

to-report time-to-sleep?
 let t-hour time:get "hour" dt + (time:get "minute" dt) / 60
 report (t-hour >= end-daytime - random-float 1 or t-hour < start-daytime)
end ;;  end bool-reporter daytime?
to-report time-to-wake?
 let t-hour time:get "hour" dt + (time:get "minute" dt) / 60
 report (t-hour >= start-daytime + random-float 1)  and (t-hour < end-daytime - 1)
end
to check-distance-from-nest
 if last-nest != 0
 [
   let current-distance distance last-nest
   if current-distance > distance-from-nest
   [set distance-from-nest current-distance]
 ]
end

;; Behavior// Search procedures ;;
to bird-move ;; housesparrow procedure
 repeat min-per-timestep       ;; do the move activity as often as there are minutes in a timestep
 [
   if (xcor > max-pxcor) or     ;; check if close to the edge
     (ycor > max-pycor) or
     (xcor < min-pxcor) or
     (ycor < min-pycor)
   [right 100

   ]                   ;; turn around if close to edge
   right (random 21) - 10
   fd 0.5              ;; always do this movement
 ]
end ;; bird-move

;; Behavior// Search procedure // nest// partner ;;
to find-partner
 let singles housesparrows with [partner = nobody]
 if not any? singles [ stop ]

 ask singles [
   lt random 50
   rt random 50
   fd 1
 ]

 ask housesparrows [
   if (partner = nobody) and (any? other housesparrows-here with [partner = nobody]) [
     set partner one-of other housesparrows-here with [partner = nobody]
     ask partner [
```

```
          set partner myself
        ]
      ]
   ]
end

to look-for-partner
  if partner = nobody
  [ ;;heeft geen partner
    let close-housesparrow min-one-of housesparrows in-radius search-radius with [partner = nobody] [distance myself]
    set partner close-housesparrow
    ask partner
    [set partner myself
     set color red]
    ; [distance myself]
  ]

end

to find-nest ;;dit deed het niet dus gebruik ik niet!

  let nest-zoeken housesparrows with [own-nest = nobody]
  if not any? nest-zoeken [ stop ]

  ask nest-zoeken [ ;dit aanpassen naar hoe ze normaal lopen
    lt random 50
    rt random 50
    fd 1
  ]

  ask housesparrows [
    if (own-nest = nobody) and (any? other nests-here with [vol = nobody]) [
      set own-nest one-of other nests-here with [vol = nobody]
      ask own-nest [
        set own-nest myself
      ]
    ]
  ]
end

to search-sleeping-place  ;;

  ifelse own-nest = nobody  ;toe gevoegd van opzoek gaan naar hetzelfde nest

  [ ;;heeft geen nog geen nest
   ifelse surface-type != "house"
   [
     ;; You are not on a house patch
     let x a-close-house-patch-2
     ifelse any? patch-set x
       [move-to x]
       [bird-move]

     if debug?[
       print "MOVING TO HOUSE-PATCH"]
   ]
   [
     ;; You are on a house patch
     ifelse (xcor = pxcor and ycor = pycor)    ;; if located on center of patch, search for nests, if not, move to another house patch
     [
       ;; you are on the center of a patch
       ifelse count nests-here > 0         ;; check if there are any nests here
       [
         ;; there are nests on this house
         move-to one-of nests-here           ;; move to one of those nests
         ifelse nest-in-use? = FALSE
         [

           set sleeping? TRUE
           set last-nest (min-one-of nests [distance myself])
            set own-nest (min-one-of nests [distance myself])

           if debug?
           [ print "NEST FOUND"
            show min-one-of nests [distance myself]]
         ]
         [
           ;; this nest is not free
           ;nest-competition    ;; currently does nothing, first bird always wins

           if debug?
```

```
        [ print "NEST COMPETITION"]
      ]
    ]  ;; end nest in use?
    [
      ;; there are no nests on this house patches so move to another house patche
      let m other-close-house-patch
      ifelse any? patch-set m
      [move-to m]
      [bird-move]
      ;; there are no nests on this house

      if debug?[
        print "NO NESTS HERE"]

    ]  ;; end nests here?
    set houses-searched-today (patch-set houses-searched-today patch-here)
  ] ;; end  you are on the center of a patch
  [
    ;; you are not on the center of a patch
    let x a-close-house-patch-2
    ifelse any? patch-set x
    [move-to x]
    [bird-move]

    if debug?[
      print "ALREADY SEARCHED HERE, MOVING ON"]
  ] ;; end if on center of patch?
  ] ;; end if on a house patch
  ]

  [

    ;; you do have a nest
   move-to own-nest
    ;;ad wat te do if your nest is gone?

  ]
end ;; end birds-sleep


to-report nest-in-use?
  let closest-other-housesparrow min-one-of other housesparrows [distance myself]
  ifelse distance closest-other-housesparrow = 1
  [report TRUE]
  [report FALSE]
end

to-report a-close-house-patch ;; chooses 1 of 5 closest patches ;MISSCHIEN HIER DINGEN AANPASSEN
  let current-patch patch-here
  let some-close-houses [min-n-of 5 (other patches with [surface-type = "house"]) [distance myself]] of current-patch
  report one-of some-close-houses
end
to-report a-close-house-patch-2 ;; chooses 1 patch within search radius
  let current-patch patch-here
  let some-close-houses [ other patches in-radius search-radius with [surface-type = "house"]] of current-patch
  let new-close-houses some-close-houses with [not member? self [houses-searched-today] of myself]
  report one-of new-close-houses
end

to-report other-close-house-patch ;chooses 1 of 5 closest other patches with type "house"
  let current-patch patch-here

  let some-close-houses  [ other patches in-radius search-radius with [surface-type = "house"]] of current-patch
  let other-close-houses some-close-houses with [not member? self [houses-searched-today] of myself]
  report one-of other-close-houses
end

to nest-competition
;; empty procedure. Option to create different behavior when nest is allready in use.
end


;; Behavior// Search procedure // food ;;
to find-food-spot
  let close-gardens patches in-radius search-radius with [surface-type = "garden"]
  let food-options close-gardens with [not member? self [food-patches-today] of myself]

  ifelse any? food-options
  [
    ;; there are options here
    ;print "IM IN FOOD"
```

```
    move-to one-of food-options
    set cur-activity "eating"
    set color 62
    reset-activity-time
    set food-patches-today (patch-set food-patches-today patch-here)
    set time-spent-eating time-spent-eating + 1

    if debug?
    [print "IVE FOUND A NEW EATING SPOT"]
  ]
  [
   ;; there are no options here
   bird-move
   set color white
   set food-search-time food-search-time + 1

   if debug?
   [print "I COULDNT FIND A NEW EATING SPOT"]
  ]
end

;; Behavior// Search procedure // washing ;;
to find-washing-spot
 ;print "IM IN WASHING"
 move-to one-of patches in-radius search-radius
 set cur-activity "washing"
 set color blue + 3
 reset-activity-time
 set time-spent-washing time-spent-washing + 1

 if debug?
 [print "IVE FOUND A WASHING SPOT"]
end


;; Behavior// Daytime activities
to daytime-activity

 ifelse activity-time > 0
 [
  ;; you are still busy with your current activity
  set activity-time activity-time - min-per-timestep

   (ifelse
    cur-activity = "washing"
    [set time-spent-washing time-spent-washing + 1]
    cur-activity = "eating"
    [set time-spent-eating time-spent-eating + 1]
   )
   if debug?
   [
    write "KEEP DOING" print cur-activity
   ]
 ]
 [
  ;; you are done with your current activity, choose a new one
  if debug?
  [write "IM DONE" print cur-activity]

  choose-new-activity
 ]
end
to choose-new-activity
 (ifelse
   ;; you were washing, switch to eating
   cur-activity = "washing"
   [
    if debug?
    [ print "MY LAST ACTIVITY WAS WASHING"]

    find-food-spot
   ]

   ;; you were eating, switch to washing
   cur-activity = "eating"
   [
    if debug?
    [print "MY LAST ACTIVITY WAS EATING"]

    find-washing-spot
   ]
```

```
    ;; you were not doing any of the above
    [
      set cur-activity one-of ["washing" "eating"]

      if debug?
      [write "I WAS DOING NOTHING, I WILL DO" print cur-activity]

      (ifelse
        cur-activity = "eating"
        [find-food-spot]
        cur-activity = "washing"
        [find-washing-spot]
        [])


    ]
  )
end

;;time
to reset-activity-time
  set activity-time (min-activity-time + random (max-activity-time - min-activity-time + 1))
end
```

## APPENDIX C

*count housesparrows-on patches with [pcolor = lime]*
*count housesparrows-on patches with [pcolor = yellow]*
*count housesparrows-on patches with [pcolor = orange]*
*count housesparrows-on patches with [pcolor = green]*
*count housesparrows-on patches with [pcolor = 16]*
*count housesparrows-on patches with [ pcolor = 16 and any? neighbors with [ pcolor = yellow ] ]*
*count housesparrows*

*count nests-on patches with [pcolor = 16]*
*count nests-on patches with [pcolor = lime]*
*count nests-on patches with [pcolor = yellow]*

*count patches with [ pcolor = 16 and any? neighbors with [ pcolor = yellow ] ]*
*count patches with [ pcolor = 16 and any? neighbors with [ pcolor = lime ] ]*
*count patches with [pcolor = 16]*
*count patches with [pcolor = lime]*
*count patches with [pcolor = yellow]*

## APPENDIX D

**Table 14. Parameters of the various runs from the sensitivity check in Netlogo.**

| Number | Birds | Gardens | Cats |
|--------|-------|---------|------|
| **1** | 30 | 300 | 1 |
| **2** | 30 | 300 | 3 |
| **3** | 30 | 300 | 7 |
| **4** | 30 | 500 | 1 |
| **5** | 30 | 500 | 3 |
| **6** | 30 | 500 | 7 |
| **7** | 30 | 1000 | 1 |
| **8** | 30 | 1000 | 3 |

| | | | |
|---|---|---|---|
| **9** | 30 | 1000 | 7 |
| **10** | 80 | 300 | 1 |
| **11** | 80 | 300 | 3 |
| **12** | 80 | 300 | 7 |
| **13** | 80 | 500 | 1 |
| **14** | 80 | 500 | 3 |
| **15** | 80 | 500 | 7 |
| **16** | 80 | 1000 | 1 |
| **17** | 80 | 1000 | 3 |
| **18** | 80 | 1000 | 7 |
| **19** | 130 | 300 | 1 |
| **20** | 130 | 300 | 3 |
| **21** | 130 | 300 | 7 |
| **22** | 130 | 500 | 1 |
| **23** | 130 | 500 | 3 |
| **24** | 130 | 500 | 7 |
| **25** | 130 | 1000 | 1 |
| **26** | 130 | 1000 | 3 |
| **27** | 130 | 1000 | 7 |

## APPENDIX E

**Table 15. Results of the various runs from the sensitivity check in Netlogo.**

| Number | Birds | Gardens | Cats | High | *StdDev high* | Medium | *StdDev Medium* | Low | *StdDev Low* | *Average of the differences (%)* |
|---|---|---|---|---|---|---|---|---|---|---|
| **1** | 30 | 300 | 1 | 60,05 | *14,24* | 50,68 | *11,99* | 21,15 | *6,96* | 114,01 |
| **2** | 30 | 300 | 3 | 26,92 | *6,9* | 26,19 | *7,31* | 9,47 | *3,86* | 121,2 |
| **3** | 30 | 300 | 7 | 18,76 | *5,05* | 18,55 | *4,48* | 7,1 | *3,3* | 108,88 |
| **4** | 30 | 500 | 1 | 56,54 | *12,56* | 50,84 | *11,76* | 19,89 | *6,05* | 117,03 |
| **5** | 30 | 500 | 3 | 26,71 | *7,01* | 25,4 | *6,14* | 9,61 | *3,03* | 115,8 |
| **6** | 30 | 500 | 7 | 17,8 | *5,42* | 17,1 | *4,49* | 6,3 | *2,64* | 119,35 |
| **7** | 30 | 1000 | 1 | 56,73 | *13,42* | 51,38 | *10,98* | 20,55 | *6,1* | 112,17 |
| **8** | 30 | 1000 | 3 | 25,66 | *7,31* | 26,23 | *7,37* | 9,21 | *3,65* | 121,86 |
| **9** | 30 | 1000 | 7 | 18,2 | *5,61* | 18,48 | *5,34* | 6,56 | *3,14* | 120,22 |
| **10** | 80 | 300 | 1 | 155,85 | *23,05* | 139,55 | *21,4* | 53,81 | *9,48* | 120,22 |
| **11** | 80 | 300 | 3 | 73,09 | *12,5* | 72,44 | *13,55* | 26,3 | *6,32* | 118,08 |
| **12** | 80 | 300 | 7 | 49,44 | *9,45* | 51,44 | *9,81* | 18,69 | *5,18* | 114,55 |
| **13** | 80 | 500 | 1 | 160,36 | *23,45* | 138,15 | *20,98* | 53,82 | *8,75* | 123,57 |
| **14** | 80 | 500 | 3 | 73,05 | *12,66* | 69,35 | *10,96* | 26,9 | *6,38* | 111,57 |
| **15** | 80 | 500 | 7 | 50,88 | *8,97* | 48,18 | *9,04* | 18,01 | *4,85* | 118,54 |

| 16 | 80 | 1000 | 1 | 157,4 | 20,52 | 137,21 | 19,81 | 55,65 | 10,17 | 114,7 |
|----|----|------|---|-------|-------|--------|-------|-------|-------|-------|
| 17 | 80 | 1000 | 3 | 70,27 | 11,94 | 70,12 | 10,57 | 25,79 | 6,29 | 114,86 |
| 18 | 80 | 1000 | 7 | 50,35 | 8,89 | 50,07 | 8,91 | 18,14 | 4,91 | 118,05 |
| 19 | 130 | 300 | 1 | 263,09 | 32,54 | 235,98 | 27,46 | 90,19 | 12,7 | 121,61 |
| 20 | 130 | 300 | 3 | 121,96 | 17,57 | 116,44 | 16,84 | 45,41 | 8,3 | 109,91 |
| 21 | 130 | 300 | 7 | 83,67 | 12,24 | 82,82 | 12,4 | 31,11 | 6,72 | 112,06 |
| 22 | 130 | 500 | 1 | 265,06 | 30,71 | 235,31 | 26,51 | 89,98 | 14,58 | 122,91 |
| 23 | 130 | 500 | 3 | 120,32 | 17,41 | 118,25 | 17,53 | 43,31 | 7,97 | 117,53 |
| 24 | 130 | 500 | 7 | 80,5 | 12,74 | 85,9 | 12,86 | 30,63 | 6,66 | 116,51 |
| 25 | 130 | 1000 | 1 | 265,09 | 28,74 | 235,91 | 26,38 | 90,76 | 12,72 | 121,46 |
| 26 | 130 | 1000 | 3 | 120,48 | 17,7 | 114,56 | 16 | 40,95 | 7,59 | 126,38 |
| 27 | 130 | 1000 | 7 | 82,48 | 11,5 | 82,34 | 12,28 | 30,24 | 6,42 | 115,07 |
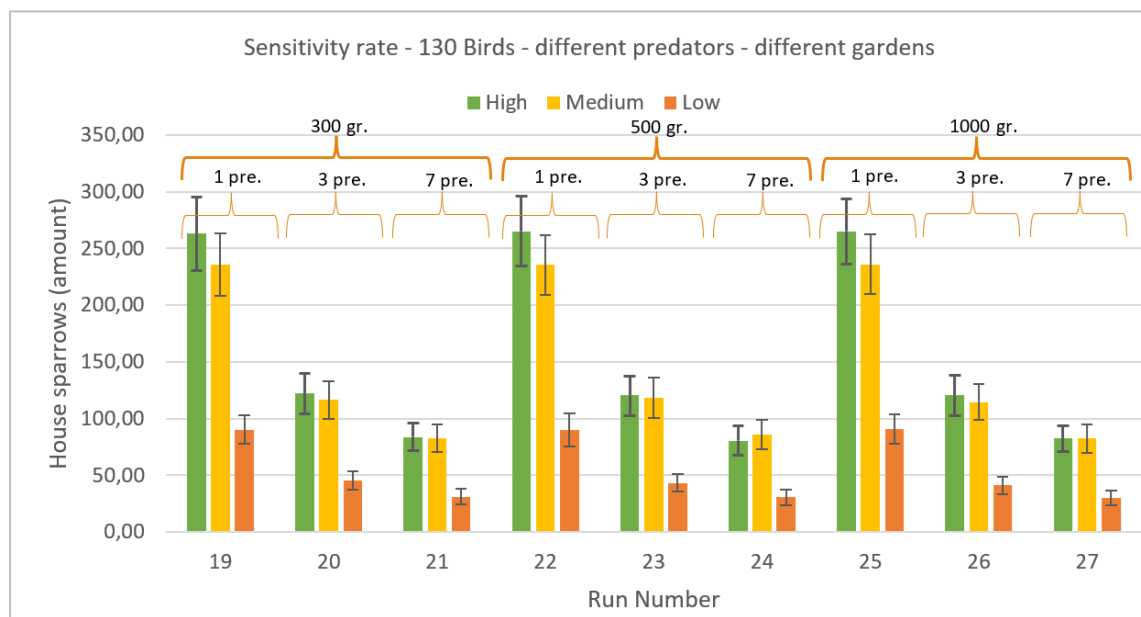


**Figure 39. Results of the sensitivity rate for the different suitability areas with 130 initial birds.**

APPENDIX F.

**Table 16. Results of the comparison between the number of house sparrows per category.**

| | Difference between high and medium (%) | Difference between high and low (%) | Difference between medium and low (%) | Average of the differences (%) |
|---|---|---|---|---|
| **Pathway 1** | 7,737056 | 104,1146 | 89,45628 | 67,10265 |
| **Pathway 2** | 1,389766 | 106,2982 | 103,4704 | 70,38613 |
| **Pathway 3** | 33,36222 | 116,1517 | 62,07865 | 70,53085 |
| **Pathway 4** | 5,036354 | 157,6338 | 145,2806 | 102,6502 |
| **Pathway standard** | 0,351741 | 176,4535 | 175,4845 | 117,4299 |

**Table 17. Results of the comparison between the number of patches occupied by house sparrows per category.**

|  | Difference between high and medium (%) | Difference between high and low (%) | Difference between medium and low (%) | Average of the differences (%) |
|---|---|---|---|---|
| **Pathway 1** | -8,80546 | 171,5447 | 197,7642 | 126,0381 |
| **Pathway 2** | -14,2328 | 174,1706 | 219,6682 | 136,0239 |
| **Pathway 3** | 12,89092 | 187,3786 | 154,5631 | 118,2776 |
| **Pathway 4** | -8,69565 | 417,2107 | 466,4688 | 297,4584 |
| **Pathway standard** | -15,0464 | 267,8284 | 332,9759 | 205,2836 |