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A honey bee requirements design study based on multi-objective optimization

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Abstract. The honeybee is a major pollinating insect and plays a vital role in the ecological chain. Therefore, the correct prediction of honeybee population size and optimal beehive configuration is beneficial for developing long-term or phased management plans for bee colonies to obtain high yields of bee products. Through literature analysis, this paper chooses economic benefits and environmental effects as the multiple objectives of the model. The model is also constrained by the maximum number of bees pollinating and the minimum daily pollen consumption of bees to calculate the optimal number of beehives for a given area. In this paper, we adopt the multi-objective equal-weight processing and transform it into a single-objective approach, which is solved using the artificial bee colony algorithm. According to the final calculation, the optimal number of beehives for this area is 54.

Keywords: Honeybee population prediction; Optimal allocation of the number of bee- hives; mathematical model; Multi-objective programming; Artificial bee colony algorithm.

1. Introduction

1.1 Problem Background

Beekeeping plays a vital role in the healthy development of agriculture and in improving the ecological environment. Therefore, the correct prediction of changes in the number of bee colonies in the beehive is essential for the sustainable development of beekeeping. The factors influencing changes in honeybee populations are diverse and interact with each other. Some of these facts have been revealed, including weather, humidity, and food source. In order to anticipate the future change in the beehive pack, those factors are inevitable to count in. For beekeepers, the selection of a beekeeping location and the weather factors resulting from its surrounding geography are one of the conditions that must be considered. The geographic features and natural environment, including temperature, humidity, vegetation cover, and the number of plant and animal species, vary from one beekeeping location to another. Therefore, predicting future bee populations for two or more beekeeping sites may vary de- pending on many factors. Therefore, a static method for predicting the number of bees within a colony will be designed based on multiple identical beekeeping sites in a group, or bee- keeping sites (groups) with widely varying geographic environments can be selected for comparison among different types of groups.

1.2 Problem Restatement

Difficulties in studying future changes in bee populations within colonies at a single beekeeping site or a group of similar sites include: (1) The influence of the geography surrounding the beekeeping site relative to its climatic characteristics is a necessary consideration, and therefore the association between different geographic features and different weather and the influence between the two needs to be investigated. (2) Excluding good weather conditions, the effect of experiencing lousy weather for a short or long period on the colony and its queen will be a necessary consideration, so real-time monitoring of weather and conditions within the colony is needed. (3) Considering the distribution of plant and animal species around different beekeeping sites, too few flowering bushes will directly affect the food source of the whole colony. If the nectar source near a beekeeping site is not concentrated enough, the slow intake of pollen will directly lead to the reproduction rate. If the reproduction rate cannot keep up with the death rate of adult bees, it will lead to a serious "ageing" situation in the beehive, which means that the number of new bees born is too low to make up for the death of old bees, and this phenomenon will directly affect the number of beehives.

In summary, the environmental factors (differences) around the beekeeping site will have a significant impact on the overall colony (inter)population (differences). Making a set of scientific and practical prediction methods will be of great help in predicting the future colony numbers of similar and dissimilar colonies, thus forming an effective comparison and unilateral prediction and comparison of the differences between different beekeeping sites (and their geographical environment) and their different future colony population changes.

Based on the above analysis, the specific idea of this paper is as follows.

To address the requirement of Question 1 to establish a prediction model for the change of honeybee population size over time, this paper first analyzes the important influencing indicators of honeybee population size. Subsequently, a mathematical model of honeybee population size is constructed considering the key indicators analyzed above. Finally, the accurate prediction of honeybee population size is achieved. In response to the requirement of Question 2 to conduct sensitivity analysis on the es- tablished model, this paper selects key indicators to conduct sensitivity analysis on them. The effects of different indicators on honeybee population size are also discussed.For Question 3, which requires the allocation of beehive numbers to a specific size area, this paper solves the problem by constructing a model for optimal allocation of beehive numbers. Starting from both economic and ecological effects, the required number of bee- hives is constructed and solved by considering the number of flowers pollinated and the pol- len quantity constraint required for the survival of honeybees.

2. Assumptions of the Models

(1) The initial population size of adult honeybees is accurate.

(2) The daily spawning rate is accurate, or the value can be corrected by factors.

(3) Drone is similar enough or small enough to be considered equivalent to worker without introducing errors in the population estimation.

(4) Queen bee egg laying is seasonal in nature.

(5) The maximum number of eggs laid depends mainly on the age of the queen.

(6) The life cycle of bees is mostly seasonally fixed.

(7) Despite this seasonality, the longevity and survival of honeybees depends largely on colony conditions.

(8) Population conditions may change over time due to changes in environmental conditions.

3. Mathematical Model of the Population Prediction of the Honeybee Colonies

3.1 Analysis of the Honeybee Population Indicators

3.1.1 Honeybee Population Density

Population density is divided into maximum, minimum and optimum densities, and honeybee population density can be studied at individual and colony levels. Individual honeybee population density is expressed as the number of individual bees per unit space, while the honeybee population density is expressed as the number of honeybee colonies per unit space. Honeybee population

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density varies continuously with time and space, so the study of honeybee population density should be defined for a specific time and space.

3.1.2 Honeybee Population Birth Rate

The birth rate refers broadly to the ability of any organism to produce new individuals and is sometimes expressed as the number of new individuals born in a population per unit of time [3]. It is expressed as the ratio of the number of individuals born per unit of time to the population of individuals in the population. The birth rate of a population has its meaning in either way, and it is a different way to describe the population. It is a different way of de scribing the change in population size. Honeybees are fully metamorphic insects that undergo four stages of development: egg, larva, capper, and adult [4]. Each stage is accompanied by a certain degree of mortality; only the egg is the most accurate indicator of the population's ability to produce new individuals. Therefore, the birth rate of individual honeybee populations can be expressed in terms of the daily egg production of the queen; the birth rate of honeybee populations can be defined as the number of newly separated eggs. The birth rate of honeybee colonies can be defined as the percentage of newly separated colonies to the total number of initial colonies and is mainly related to natural and artificial bee splitting. It is mainly related to natural and artificial splitting.

3.1.3 Honeybee Population Mortality

Insect population ecology defines mortality as "the number of individuals that die per unit of time in a population" and is calculated as the total number of individuals that die at the beginning of the wave [4]. It is expressed as the number of dead individuals at the tide's be- ginning. Mortality can be divided into physiological mortality and ecological mortality. The former refers to the population in optimal environmental conditions. Through the above analysis, this paper mainly selects the daily queen egg production, the daily temperature, the number of adult bees in the honeybee population, the total proportion of unfertilized eggs, the proportion of naturally unfertilized eggs, the proportion of un- fertilized eggs due to light and foraging population, the proportion of spermatozoa that have been used, the foraging population size as the primary influence indicators of the honeybee population.

3.2 Development of the Mathematical Model of the Honeybee Population Prediction

The birth rate of individual honeybee populations can be expressed in terms of daily queen egg production, so the daily queen egg production Ht should be calculated first.

$Ht = Gmax + [a(d)2 + F(d)] Ht$

Where Gmax is the maximum daily egg production of the queen and d is the number of days the queen lays eggs. α and β are correlation functions. The range of α can be obtained by collecting information between [-0.003, -0.0025] and β is between [0. 100, 0.45], which is determined by the species of bees.

It is empirically known that the egg production of queen bee is related to the age, temperature, light and population size of queen bee, and the correction equation of queen bee egg production was constructed by referring to related literature.

$Gt = PP \times Jt \times Mt \times Ht$

$Jt = d2(Jt)3 + F2(Jt)2 + C2Jt + 20.6$

Where Jt represents the sunshine hours per day.

$Mt = [\log(mt \times 0.001) + 1] \times 0.736$

where mt represents the number of adult bees in the honeybee population.

The proportion of fertilized eggs that can develop into drone and worker then needs to be calculated [9]. Here we start with the proportion of unfertilized eggs and divide it into the proportion of naturally unfertilized eggs and the proportion of unfertilized eggs due to light and foraging population, as shown in Equation.

$0t = Kt + Et$

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Where 0t represents the total proportion of unfertilized eggs, Kt represents the proportion of naturally unfertilized eggs, and Et represents the proportion of unfertilized eggs due to light and foraging population.

Kt = 1 + 7.655kt3 + 6.782kt2 − 3.2kt + 2. 1

Where kt is the proportion of spermatozoa that have been used.

Et = Rt St

Rt = [log(Jt × 0. 1)] × 0.37

St = [log(st × 0.003)] × 0.821

where Jt represents the sunlight hours per day and st represents the foraging population size.

3.3 Prediction Result of the Proposed Mathematical Model

This paper uses MATLAB programming to perform honeybee population prediction, and the calculation results are shown in Figure 1. According to the calculation results, the honeybee population rose and then fell, reaching a peak of 39,250 in October.

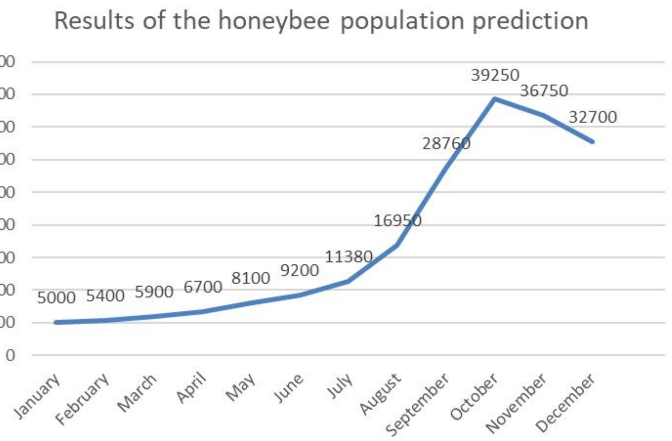

Figure 1 Results of the honeybee population prediction

4. Sensitivity Analysis of the Proposed Honeybee Population Prediction Model

4.1 Sensitivity Analysis of Critical Indicators of the Honeybee Popula- tions

We analyze the effect of initial values on the peak honeybee population size. According to the analysis results, it is clear that the peak of the honeybee population size increases with the daily sunlight hours, as shown in Figure 2.

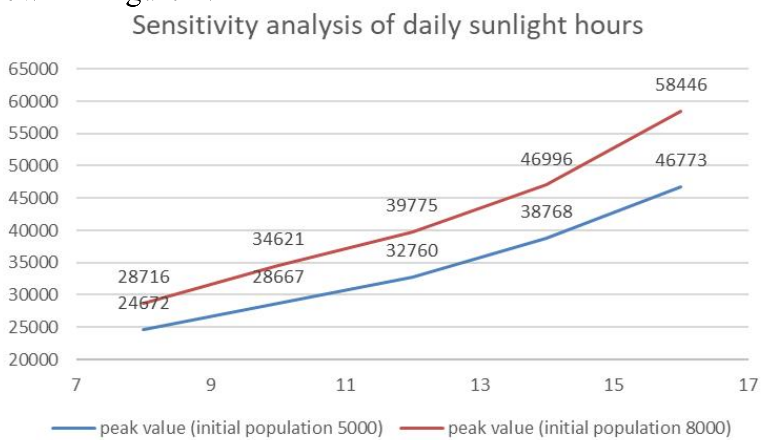

Figure 2 Sensitivity analysis of daily sunlight hours

According to Figure 3, the peak of the honeybee population size increased with the in- crease in daily egg production.

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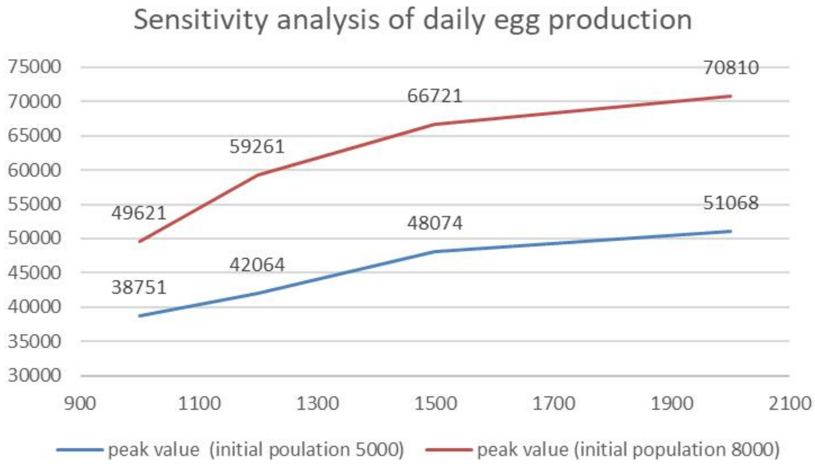

Figure 3 Sensitivity analysis of daily egg production

According to Figure 4, the peak of the honeybee population size increased with the in- crease in the total proportion of unfertilized eggs.

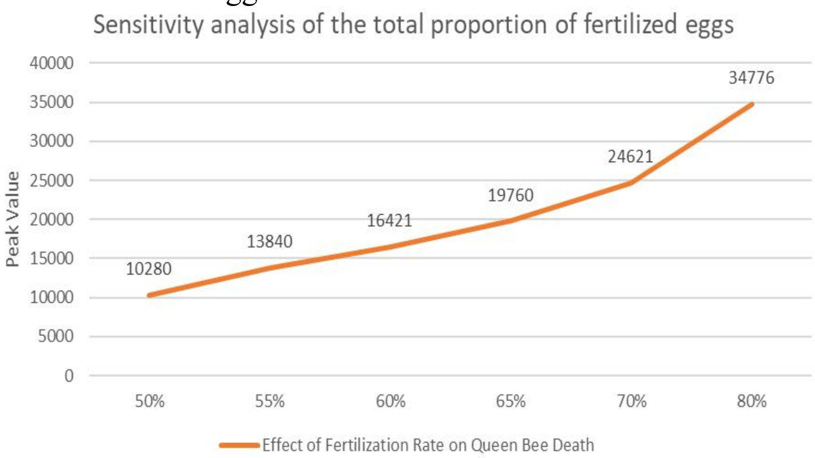

Figure 4 Sensitivity analysis of the total proportion of fertilized eggs

The above analysis allows a qualitative understanding of the trends of the different indicators for the honeybee population. Subsequently, this paper analyzes the key influencing factors through a cross-sectional comparison between different indicators, as shown in Table 2.

Table 1Comparison of sensitivity analysis between different indicators

Sensitivity analysis	-20%	- 10%	-5%	0%	5%	10%	20%
Ht	- 11.45%	-6.63%	-3.34%	0	4. 11%	8. 15%	13.53%
Gmax	- 14.64%	-7.87%	-3.54%	0	4.68%	8.33%	14.65%
dd	-26.85%	- 15.42%	3.35%	0	4.49%	17.24%	- 14.22%
mt	-2.73%	-2.62%	-1. 13%	0	0.76%	1. 13%	1.92%
Et	-38.58%	- 13.87%	-8.36%	0	9.34%	12.85%	28.68%
kt	-23.38%	-8.57%	-4.20%	0	3.87%	8.05%	20.81%
Sensitivity analysis	-20%	- 10%	-5%	0%	5%	10%	20%

Based on the results of the analysis, it can be seen that the proportion of unfertilized eggs due to light and foraging population (Et), the daily temperature (dd) and the proportion of spermatozoa that have been used (kt) are the most critical factors affecting the honeybee population size in the model proposed in this paper.

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4.2 Discussion of Predicted Honeybee Population Results

We studied the population dynamics of individual experimental honeybee populations in a region of the United States. The results showed that the population dynamics coordinated with changes in the region's environmental factors, such as climate and nectar sources, showing a clear trend of seasonal changes. Honeybee populations control the number of eggs laid by the queen according to environmental regulations such as nectar sources. The amount of eggs laid by the queen is influenced by the supply of royal jelly, which is assumed by worker bees. Therefore, the reason for the change in honeybee population size, i.e., the mechanism by which worker bees regulate the supply of royal jelly, is unclear.

The dynamic change curves of the number of egg and larvae age classes in individual honeybee populations were consistent, with an increasing trend in honeybee populations in spring and autumn and a significant decreasing trend in summer and winter. However, adult bees presented a less pronounced pattern and were inconsistent with the changes in other age classes. The increase in the number of bee seeds did not precisely cause a significant increase in adult bees after 20 d. This paper suggests that the possible reason for this is that the bee population dynamics are coordinated with the natural environmental conditions in the area, especially the changes in temperature and nectar sources. Two aspects influence the adult bee population dynamics: the increase or decrease in the number of bees directly affects the number of adult bees, and there is a specific mortality rate for bees and adult bees. In spring and autumn, when there are good sources of pollen, the worker bees' labour intensity in- creases and their life span shortens, while in summer and winter, when there is a lack of pollen sources, the worker bees' nursing intensity decreases and their life span increases.

The factors influencing the population dynamics of honeybee populations can be divided into two main categories, exogenous and endogenous, namely the natural environment and he small intra-colony environment. The influence of the natural environment (climate, pollen sources, predation, competition, etc.) on honeybee population dynamics should be indirect. The influence of the natural environment (climate, pollen sources, predation, competition, etc.) on the population dynamics of honeybees should be indirect because when the natural environment changes, the colony will behave accordingly. The natural environment's effect on honeybee populations' population dynamics should be indirect. In contrast, the influence of the microenvironment (microclimate, nectar and pollen storage, queen quality, colony potential, etc.) on the population dynamics should be indirect. The effect of the microenvironment (microclimate, nectar storage, queen quality, colony potential, etc.) on population dynamics needs to be quantified and analyzed to understand the effect of the environment on honeybee population dynamics. The effect of the environment on population dynamics needs to be quantified to understand better the impact of the environment on honeybee population dynamics.

5. An Optimal Beehive Configuration Model Based on Artificial Bee Colony Algorithm

Since there are only 81000 square meters, assuming the land is rectangular, the length is 400m. The width is 202.5m, which is entirely within the range of 6km, so there is no need to consider the impact of the bees' range of activities. That is, there is no need to consider the location of the beehive arrangement, but in order to reduce the overlap of the bees' paths when collecting honey, which causes some flowers to be repeatedly collected many times and reduces the efficiency, so when arranging the beehive, the beehives should be spread out as much as possible and placed at the midpoint of the four sides through analysis. Since the peak pollination season is in the summer, it is only necessary to satisfy the summer season. Based on the model we built in Question 1, we can conclude that the number of bees per beehive in the summer is approximately a. By collecting data, we can get that there are approximately x flowers per acre to be pollinated in the area we thought to choose, and the pollen available is approximately y. Then, based on the data above, we

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can build a target planning equation with the goal of the maximum number of bees that can be raised in the summer while ensuring that the pollination of the flowers is completed.

Based on the above analysis, we construct a multi-objective optimization model for optimal configuration of the number of beehives. The model takes the maximum economic and ecological effects as the objective function, as shown in Equation where J represents economic benefits and S represents ecological effects.

$$J=m\times b\times(1-d)+20k\times p$$

$$P=100mx$$

Where m represents the number of bees, b represents the amount of pollen each bee can collect in a day, d represents the percentage that can be converted into edible nectar, k represents the value of the plant per acre, and p represents the amount of pollination. The formula for calculating p is shown.

The ecological value is mainly divided into the ecological value generated by bees' pollination and nectar production and the ecological value possessed by the bees themselves, which is calculated as shown in Equation. where y denotes the actual number of pollen that can be collected per flower and q is the ecological value of silver.

$$J=(d*20y)/m+20k\times q$$

The constraints in this paper are mainly divided into a maximum pollination constraint and a bee survival limit constraint. Based on the information in the question, each bee can only collect flowers within a maximum of 20 km per day, resulting in the maximum pollination constraint, as shown in Equation. Where z is the minimum amount of pollen required per bee per day. With the above analysis, the final multi-objective optimization model for optimal con- figuration of the number of beehives is established.

$$m\times b\times(1-d)\leq 20y$$

$$(1-Q)\times 20ym\geq z$$

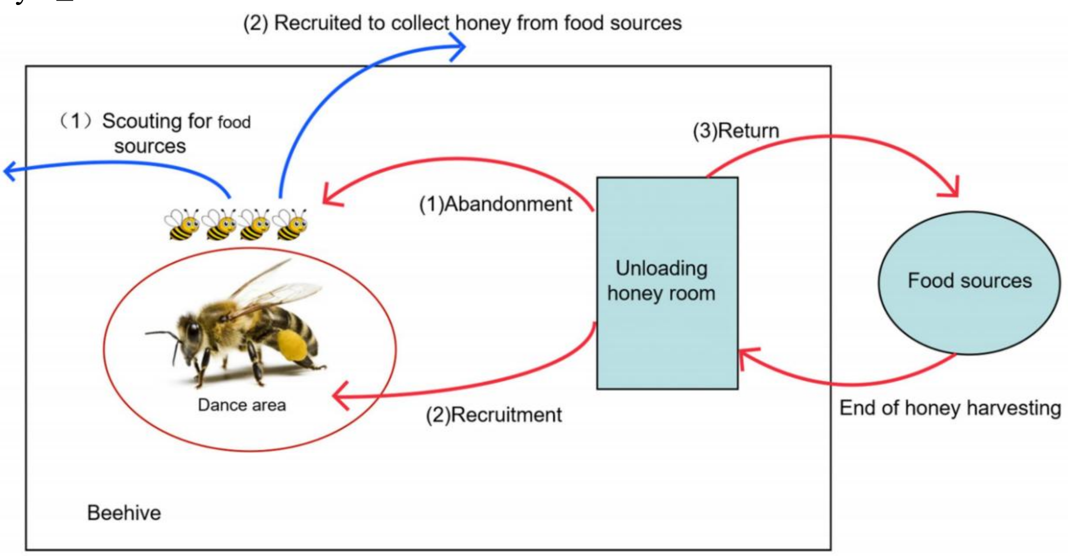

Figure 5 Honey harvesting mechanism diagram of artificial bee colony algorithm

For the model set up in this paper, the initial set parameters of the artificial bee colony algorithm contain the total number of bees, the search count limit and the maximum number of iterations. The selection of the control parameters, which significantly impact its performance, may lead to entirely inconsistent results with different parameter settings. The parameters selected in this paper are used to determine the final results by varying the value of a particular parameter and performing a dynamic optimization search process. In seeking the optimal parameter settings, the following are the points that need to be paid attention to.

(1) Total number of honeybees

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Too large a total number of bees can make the search space larger and the resulting solution closer to the optimal solution, but it makes the solution more computationally intensive; The total number of bees is too small, which can make the model converge to the best quickly,

but the solution may be local best, but not the global best.

(2) Search number limit

The number of searches is too small to perform an excellent local search, and the number of searches is too large to increase the computational effort and has no improvement in the results.

(3) Maximum number of iterations

If the number of iterations is too small, the algorithm will not get the optimal solution. Too many iterations may make the algorithm converge to the optimal solution in advance, and nothing will be improved afterwards. It will make the operation time longer. By reviewing the relevant literature, this paper identifies the constants d = 0.63, q = 78, m = 26589, b = 5.3, X = 76450 [14]. In this paper, the multi-objective optimization is assigned equal weights and transformed into a single-objective optimization [15].

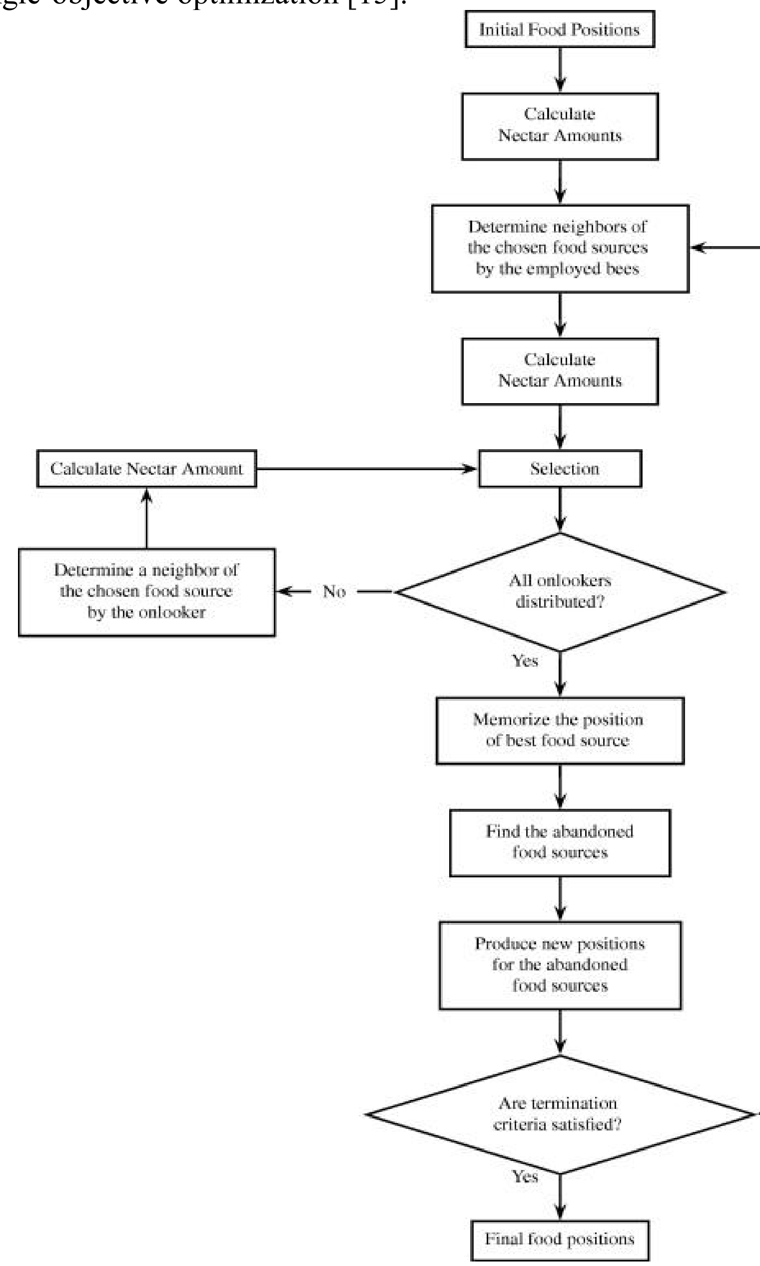

Figure 6 Algorithm flow chart of artificial bee colony algorithm

The specific parameters of the artificial bee colony algorithm applied in this paper must be determined after several experiments. In this paper, by setting several different groups of

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parameters and conducting a comparative analysis, the final selected algorithm parameters are listed as follows.

Table 3 The selected parameters of the artificial bee colony algorithm

Parameter	Value
The number of dimensions D	7
The total number of bees N_s	40
The size of the honey picker population N_e	Ne=20
The size of the following bee population N_u	Nu=20
The maximum number of iterations T_{max}	3000
The limit of search number Limit	280

This study is guided by the coordinated ecological and economic development, while considering the practicality and operability of the study. According to the calculation steps of multi-objective linear programming, the multi-objective weighting method is used, which makes the problem of optimizing multiple objective functions, be transformed into a sin- gle-objective optimization problem, for the determination of the weights of the two functions of ecological and economic benefits, this paper differs according to their respective focuses.

By reviewing the relevant literature, this paper identifies the constants d = 0.63, q= 78, m = 26589, b = 5.3, X = 76450 [14]. In this paper, the multi-objective optimization is assigned equal weights and transformed into a single-objective optimization [15]. The final result of the number of beehives calculated by MATLAB solving is 54 beehives.

6. Model Evaluation

6.1 Strengths

The mathematical model of the honeybee population prediction developed in this paper fully considered honeybee population density, birth rate, mortality rate and environmental factors and extracted eight key indicators as critical variables in all aspects. The mathematical model has a solid theoretical foundation and can reflect the interactions between key indicators of honeybee population size. The method is easy to operate and can analyze the influence of critical indicators on honeybee population size through sensitivity analysis.

This paper uses an artificial bee colony algorithm to solve the optimal configuration of the number of honeycombs. The method has the following advantages: (1) Multi-role division of labor mechanism. The bees use different methods to search according to their color and spontaneously adjust their roles according to the quality of the nectar obtained from the solution. (2) Collaborative working mechanism. When choosing a path, the bees decide whether to use the information left by previous bees and how to use it based on their roles. (2) Cooperative working mechanism. When choosing a path, the bees decide whether to use the information left by previous bees and how to use it based on their roles, and can find the optimal solution to the optimization problem with a high probability; (3) Robustness—using probabilistic rules rather than (3) Robustness. Using probabilistic rules rather than deterministic rules to guide the search, without having to guide other a priori information, has excel- lent robustness and broad applicability; (4) Robustness. Even if an individual (4) Robustness. Even if an individual fails, the whole group can still complete the task; (5) Easy to combine with other methods. It is easy to combine various heuristics to improve the algorithm's performance.

6.2 Weaknesses

The population prediction of the honeybee colonies mathematical model developed in this paper does not consider the effects of human activities such as bee parasites, pesticides and insecticides. In addition, the model has more assumptions that need to be verified from actual production in the future. Moreover, the artificial bee colony algorithm still has disadvantages: (1) it is limited to

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locally optimal solutions. Regarding the nature of the algorithm's solution, the bee colony algorithm is looking for a better local optimal solution rather than forcing a globally optimal solution; (2) the intermediate stagnation problem of the working process. In the working process of the algorithm, after a certain number of iterations, the bees may stagnate in the neighborhood of some or some local optimal solutions. (3) Longer search time is required. However, improving computer computing speed and optimizing the swarm algorithm can alleviate this problem to some extent for large-scale optimization problems or significant obstacles.

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