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4.1.3.16. Искусственный интеллект и цифровые технологии в агрохимии, агропочвоведении, защите и карантине растений (биологические науки)

АВТОМАТИЗИРОВАННЫЙ СИСТЕМНО-КОГНИТИВНЫЙ АНАЛИЗ ВЛИЯНИЯ ТЕМПЕРАТУРЫ И ВЛАЖНОСТИ НА РАЗВИТИЕ ФИТОФАГИИ У ЖУЖЕЛИЦ РОДА HARPALUS: H. AFFINIS И H. DISTINGUENDUS В АГРОЦЕНОЗАХ КРАСНОДАРСКОГО КРАЯ

Сердюк Владислав Юрьевич
научный сотрудник
РИНЦ SPIN-код: 8779-4695
vladislav-serdyuk@yandex.ru
КНИЦ «Дикая природа Кавказа»

Замотайлов Александр Сергеевич
д.б.н., профессор
РИНЦ SPIN-код: 9780-8686
a_zamotajlov@mail.ru
Кубанский государственный аграрный университет имени И.Т. Трубилина, Краснодар, Россия

В данной статье рассматривается применение автоматизированного системно-когнитивного анализа и системы Эйдос в защите растений. Обсуждаются основные принципы и методы системно-когнитивного анализа, а также возможности и перспективы использования системы Эйдос для выявления закономерности появления фитофагии у жужелиц рода Harpalus: H. affinis и H. distinguendus в зависимости от температуры и влажности

Ключевые слова: АСК-АНАЛИЗ, АВТОМАТИЗИРОВАННЫЙ СИСТЕМНО-КОГНИТИВНЫЙ АНАЛИЗ, ИНТЕЛЛЕКТУАЛЬНАЯ СИСТЕМА «ЭЙДОС», ЖУКИ-ЖУЖЕЛИЦЫ, ЭНТОМОФАГИ, АГРОЦЕНОЗЫ, КРАСНОДАРСКИЙ КРАЙ

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4.1.3.16. Artificial intelligence and digital technologies in agrochemistry, agrosoil science, plant protection and quarantine (biological sciences)

AUTOMATED SYSTEM-COGNITIVE ANALYSIS OF THE INFLUENCE OF TEMPERATURE AND HUMIDITY ON THE PROGRESS OF PHYTOPHAGY IN THE GROUND BEETLE GENUS HARPALUS: H. AFFINIS AND H. DISTINGUENDUS IN AGROCENOSES OF KRASNODAR KRAI

Serdyuk Vladislav Yurevich
research assistant
RSCI SPIN-code: 8779-4695
vladislav-serdyuk@yandex.ru
KNIC "Wildlife of the Caucasus"

Zamotajlov Alexandr Sergeevich
Dr.Sci.Biol., professor
RSCI SPIN-code: 9780-8686
a_zamotajlov@mail.ru
Kuban State Agrarian University named after I.T.Trubilin, Krasnodar, Russia

This article deals with the application of automated system-cognitive analysis and Eidos system in plant protection. The basic principles and methods of system-cognitive analysis are discussed, as well as the possibilities and prospects of using the Eidos system to identify the regularity of phytophagy progress in beetles of the genus Harpalus: H. affinis and H. distinguendus depending on temperature and humidity

Keywords: ASC-ANALYSIS, AUTOMATED SYSTEM-COGNITIVE ANALYSIS, INTELLIGENT SYSTEM "EIDOS", GROUND BEETLES, ENTOMOPHAGES, AGROCENOSES, KRASNODAR REGION

Introduction.

In recent years, the use of machine learning and neural networks has become increasingly popular in various fields of science. For example, in biological and agricultural sciences, AI (artificial intelligence) helps optimize various processes, such as yield forecasting, spectrum diagnostics of plant diseases, resource management, etc. The resulting models can analyze data on climate, soil, and plant health, allowing agronomists to make informed decisions to protect crops.

Agrocenoses of Krasnodar Krai exhibit a variety of pest complexes affecting agricultural crops. The taxonomic composition and number of these groups are subject to change depending on the geographical features of the study area, phenological stages of plant development, and agrotechnical cultivation conditions (including varietal composition, preceding crops, mineral nutrition levels, and other factors) [14]. The most significant transformations of the pest complex occur during crop vegetation. Among the harmful invertebrates that directly affect crop yields and quality are representatives of the Coleoptera order.

Among the beetles in the agrocenoses of the south of Russia, ground beetles (Coleoptera, Carabidae) occupy a special place. Many domestic and foreign researchers point out their ability to suppress a number of pests [2, 4, 10, 11, 13, 16]. In most cases, the role of ground beetles in agrocenoses is positive due to the ability of predatory beetles of the Carabidae family to regulate the number of many insects, terrestrial mollusks and other invertebrates, including a number of dangerous pests of agriculture and forestry. However, some species of ground beetles, which are phytophages and mixophytophages, cause significant damage to agricultural crops, and sometimes to pastures and forest crops [1, 15].

At present, the causes and factors influencing the occurrence and intensity of phytophagy in a number of ground beetle species are not entirely clear, as they can vary significantly depending on the region.

Well-known factors influencing phytophagy and mixophytophagy in ground beetles include:

Availability of food. During periods of low numbers of potential prey, carabids are forced to switch to plant food sources, demonstrating trophic plasticity. This may be caused by the mass death of invertebrates that serve as food for ground beetles due to viral, bacterial and zooparasitic diseases [2].

Migration The inertia of migration processes in ground beetles relative to the movements of their prey also leads to the need to search for alternative food sources, including plant components.

Phases of victim development. Variation in the life cycles of potential prey of ground beetles, leading to the transition of some individuals to states inaccessible to these predators (e.g., flying stages or pupae), reduces the amount of available food. This transformation in nutritional resources may stimulate modification of the diet of ground beetles and their adaptation to changed conditions.

*Competition*The presence of a large number of competitors consuming the same prey may stimulate ground beetles to exploit alternative food resources, including plants. This reduces interspecific competition and increases their chances of survival.

Anthropogenic factors Various changes in the ecosystem, such as habitat destruction and other forms of anthropogenic impact, can lead to a decrease in the availability of traditional food and force ground beetles to seek alternative food sources.

Physiological needs. In some cases, plant foods can provide essential nutrients for ground beetles that cannot be obtained from animal food. Thus, certain species of beetles may consume plant foods to accumulate the energy needed for reproduction. The sex of the ground beetles also affects seed consumption: females consume more than males. Probably because they require more energy for reproduction.

Abiotic factors (temperature and humidity). Ground beetles are unable to drink water, and in dry and hot weather they can obtain moisture from plant material.

These factors can act both individually and in combination, promoting the emergence and development of phytophagy in a number of ground beetle species. In general, ground beetles have the ability to adapt to changes in the environment, which allows them to switch to alternative food sources when their usual food is in short supply.

The influence of temperature and humidity on the occurrence of phytophagy in ground beetles (Coleoptera, Carabidae) requires clarification.

As a result, we decided to apply a new artificial intelligence method, Automated System-Cognitive Analysis (ASC-analysis and its toolkit, the Eidos system), to study the effect of temperature and humidity on the development of phytophagy in ground beetles Harpalus affinis Schrank, 1781 and Harpalus distinguendus Duftschmid, 1812. This method has proven itself in other subject areas [6-9, 12]. It is a unique approach, as it is one of the few methods that allow for multiparameter typing and comparative system identification of complex systems based on both quantitative and textual characteristics that can be measured in various units.

Target. Using automated system-cognitive analysis and its tools of the Eidos system, to determine the effect of temperature and humidity on damage by ground beetles Harpalus affinis and H. distinguendus to winter barley and winter wheat.

All of the above determined the direction of our research.

Research methodology.

The material was collected over 5 years in the Slavyansky District of the Krasnodar Territory. The objects of the study were beetles of the genus Harpalus: H. affinis and H. distinguendus, collected using Barber-Heidemann traps. These beetles are among the dominant species in the agrocenoses of the estuary-flooded zone of southern Russia.

The data were processed on a personal computer using the software tools of the Eidos system. These species of beetles were not chosen without reason.

Many literary sources indicate their role as entomophages. Nevertheless, these species can harm a number of agricultural crops.

Brief biology of the studied species.

*Harpalus affinis*Schrank, 1781. Mixophage. Quite common. Polytopic mesophile, inhabiting a wide range of plain and mountain zonal communities. Found in agrocenoses. Flies to light. Recorded as damaging a number of agricultural crops. Damages cereals (wheat, corn, barley), legumes (peas, soybeans), industrial (beet, flax, mustard), vegetables (cucumbers, lettuce), fodder (alfalfa) [13].

The beetle is 9-12 mm long. The top is bright metallic, bronze or copper. The bottom, and sometimes the femurs, are pitch-black. The head is naked on top, with one setiferous pore at the inner edge of the eyes. The chin tooth is pronounced [2].

In addition to plants, the diet of this species includes about 20 species of invertebrates (Colorado potato beetle, weevils, click beetles, etc.).

Harpalus distinguendus Duftschmid, 1812. Mixophage. Mass eurytopic species, prefers open spaces, common in agrocenoses. It is noted as damaging a number of agricultural crops. It damages cereals (oats, wheat, rye, millet, barley), legumes (beans, peas), industrial crops (mustard, potatoes, sunflower, beets), vegetables (tomatoes, lettuce), and fodder crops (clover, alfalfa) [13].

The beetle is 9-11 mm long. Metallic green, copper, sometimes blue-black towards the top. The antennae are reddish-brown with a red first segment and darkened bases of the second and third segments. The underside of the body and legs are pitch-black, the tarsi are brown. The pronotum between the posterior angles and the main pits is not flattened, its lateral edge is narrow everywhere. The outer spaces of the elytra are without small dots and hairs [2].

More than 50 species of invertebrates (click beetles, Colorado potato beetles, leaf beetles, noctuid caterpillars, etc.) have been noted in the food composition.

Characteristics of the initial data.

Below is a table with the initial data on temperature and humidity in the Slavyansky district of the Krasnodar region (Chernoerkovskaya village and Semisvodny farm) for the period from 2018 to 2022. The average values of temperature (t0) and absolute humidity (AH) for 12 months are calculated.

Text and numerical values were written in an Excel file and placed in the AID_DATA – Inp_data folder. After that, the Eidos system itself was launched (_START_AIDOS-X).

Table 1. Initial data for analogues (temperature and humidity)

Year	**Jan**		**Feb**		**Mar**		**Apr**		**May**		**June**		**Jul**		**Aug**		**Sep**		**Oct**		**Nov**		**Dec**		**Wednesday**	
	t0	AH	t0	AH	t0	AH	t0	AH	t0	AH	t0	AH	t0	AH	t0	AH	t0	AH	t0	AH	t0	AH	t0	AH	t0	AH
2018	1.3	81	2.2	79	5.4	69	13.5	52	19.3	62	23.1	51	25.5	43	25.4	31	19.3	59	14.1	54	3.6	79	2.6	86	12.9	62
2019	2.8	82	2.8	77	5.9	64	11.4	51	18.4	52	24.4	38	22.2	41	23.3	31	18.1	44	13.0	65	6.7	61	4.4	86	12.8	57
2020	2.7	88	3.9	84	8.8	76	9.2	72	15.8	81	22.4	80	25.3	74	23.8	66	21.0	69	15.9	82	5.8	90	1.5	89	13.0	79
2021	2.7	86	1.4	82	4.3	87	10.4	91	17.2	86	21.3	88	25.9	74	24.8	88	16.7	85	10.1	85	7.6	90	5.0	88	12.3	86
2022	1.8	90	4.9	87	2.6	83	12.5	85	14.9	81	22.6	75	23.2	79	25.9	75	18.2	82	13.0	88	7.6	92	3.9	88	12.6	84

Legend: t° - temperature, AH - humidity

Stages of system-cognitive analysis and transformation of data into information, and it into knowledge in the Eidos system.

Systemic cognitive analysis includes the following stages, which are fully automated in the Eidos system, with the exception of the first:

1. Cognitive structuring of the subject area.

2. Formalization of the subject area:

2.1. Development of classification and descriptive scales and gradations.

2.2. Development of a training sample, i.e. description of the initial data using gradation codes of classification and descriptive scales.

3. Synthesis and verification of models.

4. Selecting the most reliable model.

5. Solving problems of identification, forecasting, decision-making and research of the modeled subject area using the most reliable model.

Results and their discussion.

During the studies, depending on the year, in the agrocenoses of the Slavyansky district of the Krasnodar region, the ground beetles Harpalus affinis Schrank, 1781 and Harpalus distinguendus Duftschmid, 1812 caused a number of damages in the fields of winter barley and winter wheat (Table 2).

Table 2. The level of damage caused by ground beetles H. affinis and H. distinguendus in agrocenoses by year

Year	**Culture**	
	Winter barley	**Winter wheat**
2018	ZP	SRP
2019	SRP	ZP
2020	ZP	ZP
2021	BY	BY
2022	BY	BY

Legend: PO – no damage, SRP – moderate damage, ZP – significant damage

Phytophagy in these species of beetles is determined by a complex of factors, including, first of all, the availability and quality of food resources. However, humidity and temperature of the environment also influenced the occurrence of phytophagy, as indicated by the results of the ASC analysis and the Eidos system.

The Eidos system allows us to identify the strength and direction of the influence of various factor values (table 1) on the modeling object (table 2). To prepare the initial data for input into the Eidos system in API-2.3.2.2, we will combine the data on the factors from table 1 with the data on the results of their influence on the modeling object from table 2:

Год	Повреждения озимый ячмень	Повреждения озимая пшеница	янв t°	янв АН	фев t°	фев АН	мар t°	мар АН	апр t°	апр АН	май t°	май АН	июн t°	июн АН	июл t°	июл АН	авг t°	авг АН	сен t°	сен АН	окт t°	окт АН	ноя t°	ноя АН	дек t°	дек АН	средняя за год, t°	средняя за год, АН
2018	3/3 - значительные	2/3 - средние	1,3	81,0	2,2	79,0	5,4	69,0	13,5	52,0	19,3	62,0	23,1	51,0	25,5	43,0	25,4	31,0	19,3	59,0	14,1	54,0	3,6	79,0	2,6	86,0	12,9	62,0
2019	2/3 - средние	3/3 - значительные	2,8	82,0	2,8	77,0	5,9	64,0	11,4	51,0	18,4	52,0	24,4	38,0	22,2	41,0	23,3	31,0	18,1	44,0	13,0	65,0	6,7	61,0	4,4	86,0	12,8	57,0
2020	3/3 - значительные	3/3 - значительные	2,7	88,0	3,9	84,0	8,8	76,0	9,2	72,0	15,8	81,0	22,4	80,0	25,3	74,0	23,8	66,0	21,0	69,0	15,9	82,0	5,8	90,0	1,5	89,0	13,0	79,0
2021	1/3 - отсутствуют	1/3 - отсутствуют	2,7	86,0	1,4	82,0	4,3	87,0	10,4	91,0	17,2	86,0	21,3	88,0	25,9	74,0	24,8	88,0	16,7	85,0	10,1	85,0	7,6	90,0	5,0	88,0	12,3	86,0
2022	1/3 - отсутствуют	1/3 - отсутствуют	1,8	90,0	4,9	87,0	2,6	83,0	12,5	85,0	14,9	81,0	22,6	75,0	23,2	79,0	25,9	75,0	18,2	82,0	13,0	88,0	7,6	92,0	3,9	88,0	12,6	84,0

ASC-analysis allows you to form a SWOT matrix (model) for a certain class, indicating the level of influence of both facilitating and restraining factors. This analysis is based on empirical data, which makes it a valuable tool for automated quantitative SWOT analysis (within the direct task of SWOT analysis).

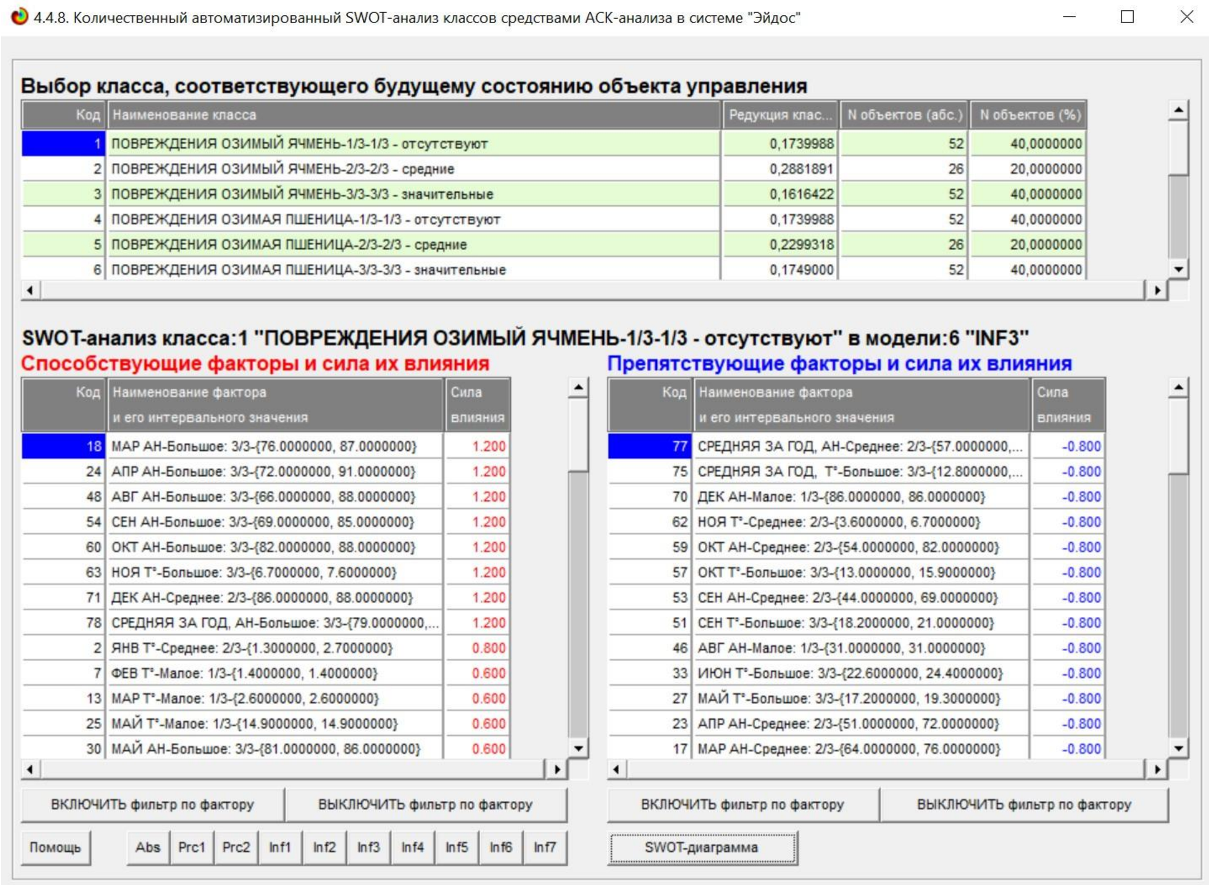

Figure 2. Screen form for selecting the output of the solution results for the direct task of SWOT analysis in text form

In this screen form, the user can select any expected state of the modeling object and any model, and will also be able to see quantitative indicators of the factors that contribute to or hinder the transition of the object to the selected state, and determine the degree of their influence.

In our case, in the SWOT analysis, when selecting a class (for example, damage to winter barley 1/3 – absent), we see how the selected class corresponds to the future state of the object, i.e. the strength of the influence of each abiotic factor (t0 and AH) on the class itself.

A graphical representation of the corresponding SWOT diagram is shown in Figure 3.

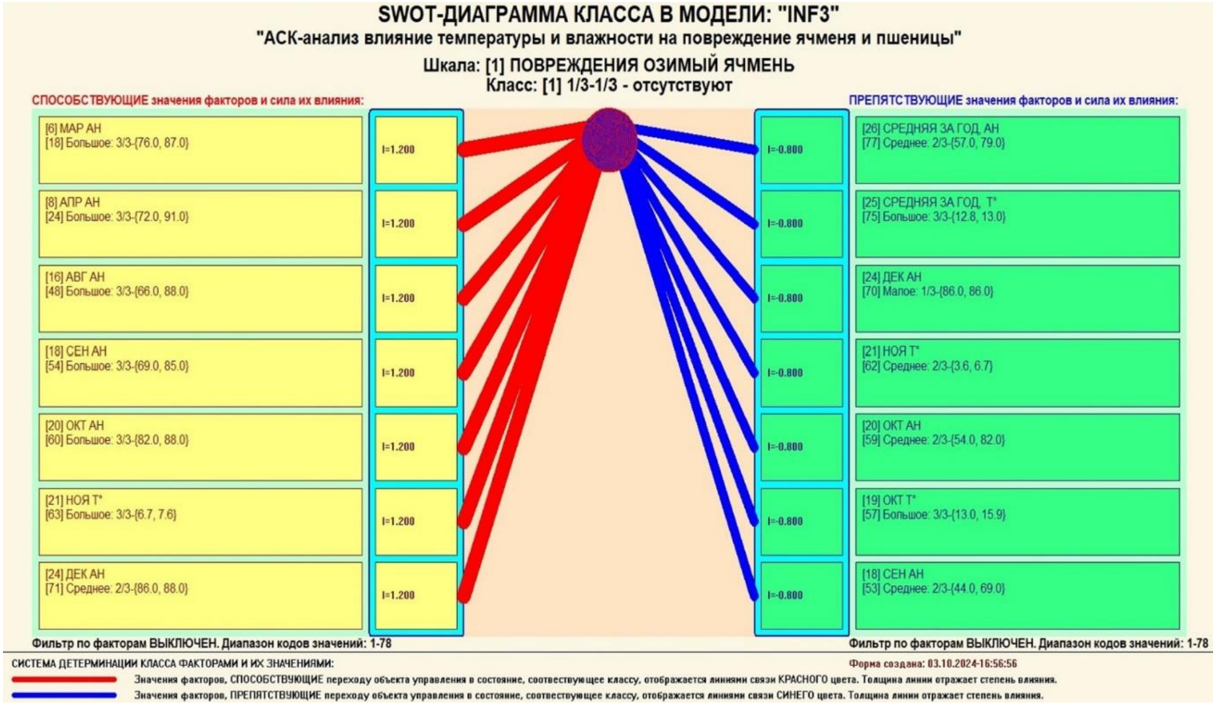

Figure 3. SWOT diagram generated in mode 4.4.8 of the Eidos-X++ system

In the process of direct SWOT analysis, we observe the influence of factor values on achieving the selected state of the modeling object. The thickness of each line reflects the degree of influence. Thus, in Figure 3, we see what force of influence temperature and humidity had on damage to winter barley in a specific month (significant damage, average or none). But when solving the inverse problem, we, on the contrary, observe how a given factor value influences the achievement of various states of the modeling object, the achievement of which this factor value promotes, which it hinders and to what extent.

The inverse task of SWOT analysis is solved in mode 4.4.9 of the Eidos-X system. On the screen form similar to that shown in Figure 2, the user can select any value of the factor and see how it affects the achievement of various future states of the modeling object: which states it supports, which it hinders and to what extent. So, for example, with the value of the factor t0 for the month of April with average damage), using SWOT analysis, you can see the state of the crop (damage level).

A graphical representation of the corresponding SWOT diagram is shown in Figure 4.

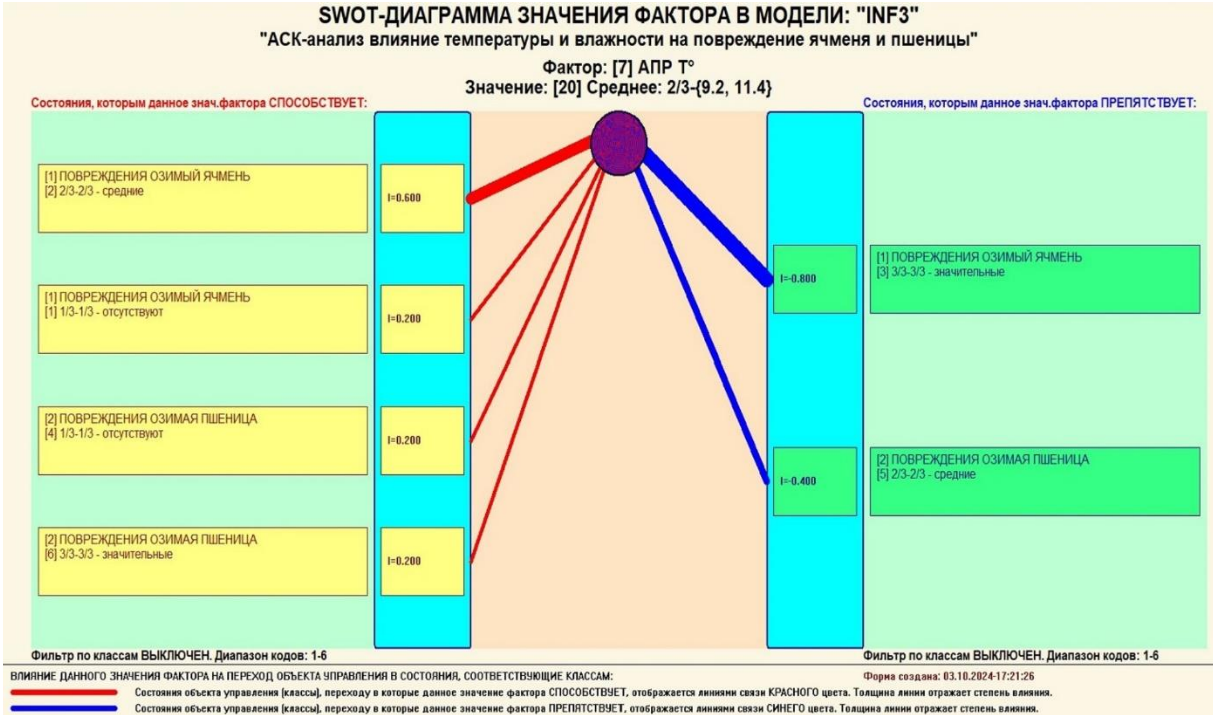

Figure 4. SWOT diagram generated in mode 4.4.9 of the Eidos-X++ system

Using cluster-constructive analysis of factor and class values in the ASC analysis and the Eidos system, we investigated the relationships between factors (Fig. 5). During the study, similarities and differences between classes were analyzed based on their characteristics. Similarities between classes are visualized using red connection lines, where the thickness of each line, indicated in the circle in the center, serves as an indicator of the degree of similarity. This allows us to visually assess how close the classes are to each other in their characteristics.

At the same time, the differences between classes are represented by blue connection lines. The thickness of these lines is also indicated in circles and indicates the degree of difference. This approach provides a clear visual representation of how classes differ from each other, which can be useful for further analysis and interpretation of the data.

Thus, this study not only demonstrates the relationship between classes, but also highlights their unique features, which allows for a deeper understanding of the structure and dynamics of the objects under study.

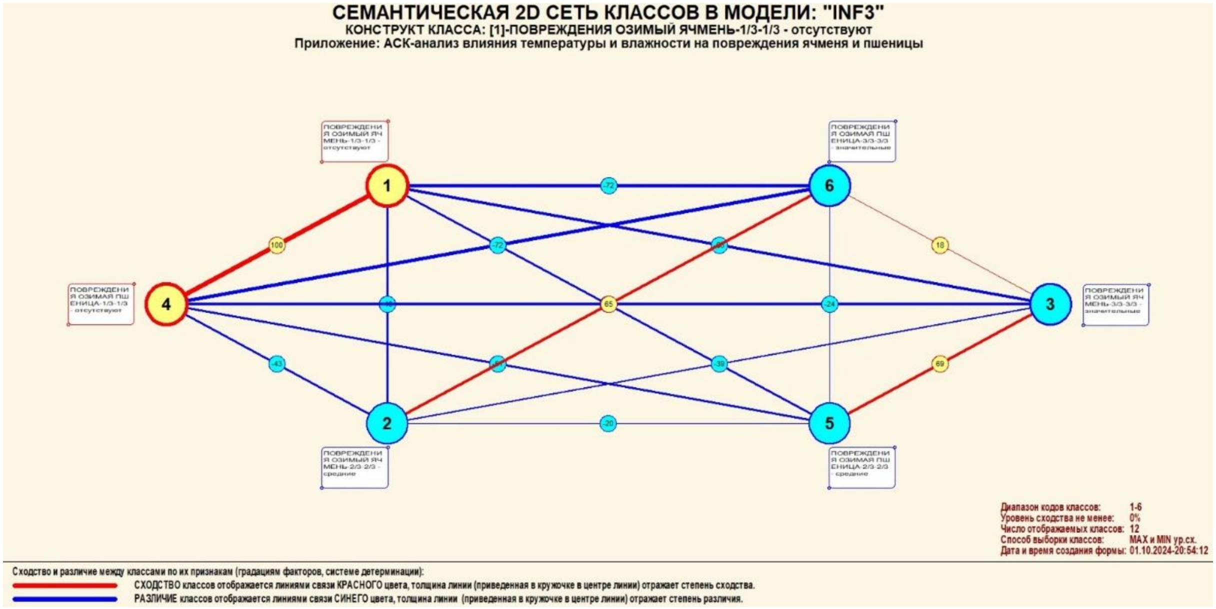

Figure 5. An example of a semantic network of factor values (features), reflecting their similarities and differences in their influence on the modeled object

Moisture deficiency and high temperatures in 2018-2020 contributed to the fact that the ground beetles H. affinis and H. distinguendus switched to phytophagy. In this case, agricultural crops (winter wheat and winter barley) became an alternative food for them, allowing them to survive unfavorable environmental conditions for the species. The importance of moisture deficiency as one of the factors in the transition of ground beetles to plant food was noted by A.G. Koval when studying the genera Carabus and Calosoma [5]. This suggests that even such predators switch to an unusual diet for themselves in order to survive.

In contrast, 2021 and 2022 had higher air humidity and lower temperatures compared to other years. These climatic conditions may have influenced the feeding behavior of ground beetles during this period. Higher humidity and lower temperatures may have encouraged ground beetles to feed more on animal food rather than plant food.

Conclusions. Distribution of faunal complexes of harmful beetles in various cultural and natural biotopes and stations is of great practical importance for taking timely and correct measures to combat these pests. Trophic connections of numerous groups of beetles, characterized by their heterophagous nature, often complicate the clarification of faunal complexes inhabiting individual groups of cultivated plants [3].

As a result of the conducted research, we found out that, along with known factors such as: food availability, migration, prey development phases, competition, environmental conditions and physiological needs – humidity and temperature are of great importance for the occurrence of phytophagy in the ground beetles Harpalus affinis Schrank, 1781 and Harpalus distinguendus Duftschmid, 1812.

Thus, in 2018-2020, due to a lack of moisture and high temperatures in the village of Chernoerkovskaya and the village of Semisvodny in the Slavyansky district of the Krasnodar Territory, phytophagy was observed in the studied species of carabids in the field of winter barley and winter wheat.

High humidity and low temperatures in 2021 and 2022 allowed Carabidae to feed on animal food and not cause any harm to crops.

Using the ASC-analysis method and the Eidos system, we confirmed our hypothesis that temperature and humidity, along with other factors, have a direct relationship to the occurrence of phytophagy in the ground beetles Harpalus affinis and H. distinguendus.

It is worth noting that damage to agricultural crops by these types of beetles in the agrocenoses of the Krasnodar Territory is mostly “superficial”, moreover, this group of arthropods in their entirety is capable of destroying more than 70 types of harmful organisms.

The article proposes a solution to a problem that is relevant for agronomists – forecasting the occurrence of phytophagy in a number of species of beetles, which allows taking timely steps. This artificial intelligence system can be applied in various fields of science. The described technology is automated, universal and is in full open free access at the link (http://lc.kubagro.ru/aidos/index.htm).

The integration of artificial intelligence (AI) into crop protection processes is a key element in the development of modern agriculture. “AI” allows for more accurate and timely detection of threats to cultivated plants by using machine learning algorithms to analyze data and provide recommendations for crop protection.

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