Problem Chosen	2025	Team Control Number
E	MCM/ICM	2527078

Summary Sheet

Our team, The Consideration of Mature Agricultural Processes (COMAP), have been tasked to find the impacts of natural processes and human decision on economic efficiency and ecosystem of a forest to farm environment. We have programmed a food web model after retrieving data through research that depicts an ecosystem of a Kentucky cornfield recently transformed from a forest.

After we created the food web model, we were able to apply various effects onto the system in the form of events and regular monthly occurrences. The first aspect we considered is the agricultural cycle. Specifically, we looked into how different animal species and insects can impact corn production and how different monthly factors impact the species populations.

We then were able to model how herbicides and pesticides can affect the food web while considering farming needs. According to our model and the data we found to inform it, although herbicides and pesticides can reduce insect populations (effectively increasing crop yield), their cost and effect on the quality of corn outweighs their benefits, especially when compared to alternative methods. As such, we also simulated how the farm would operate with organic methods, and they provided much of the same benefits as herbicides and pesticides without much harm to the ecosystem or to the corn.

We also modeled the re-introduction of deer and rabbits into the ecosystem and the introduction of bats specifically added by the farmer for pest control purposes. The re-introduction of deer and rabbits surprisingly increased corn yield and ecosystem stability due to a chain of causations expounded upon later in this report. The introduction of bats also proved a potent and healthy alternative to chemical methods.

Much of the necessary data was inaccessible, inconsistent, or, to our knowledge, nonexistent. As such, much of the data we use may not be exactly accurate to a real-world context. However, since no model can accurately represent the exact numerical data of a real ecosystem, our model attempts to evaluate casual relationships through numerical data instead, as we felt that this was the most important and feasible objective.

Table of Contents

Mathematical Model

A forest has been deforested and transformed into a cornfield. Our team at Consideration of Agricultural practices has evaluated the impact of this transformation regarding the ecosystem. We specifically analyzed how natural processes such as the agricultural cycle, reemergence of species, and human decisions such as chemical uses, and implementation of bats can impact the population of animals in the environment. We represented transformation by creating a coded model of a food web and the various impacts on corn production through various stages.

We began with deciding on a specific type of ecosystem and crop. We landed on Kentucky oak-hickory forests and corn due to their commonality. In order to create a working food web, we wanted a primary producer, primary consumer, secondary consumer, tertiary consumers, and decomposer that also highlighted specific animals you might find in an ecosystem in farmland Kentucky. According to the Kentucky Department of Fish and Wildlife, we were able to choose the animals and insects. In the end we chose grasshoppers, beetles, (primary consumers), birds, squirrels (secondary consumer), foxes, coyotes (tertiary consumers), and earthworms (decomposer). However, due to time and coding constraints, we decided to condense the insects into a single data point, and we simplified the decomposer considerations to a general soil quality index. We decided to model our farm as one square mile and used data giving estimations for a relative population of each species in the area. We created a spreadsheet and collated information for reproduction, survival rate, life expectancy, average weight of animal, and average weight of food eaten a day (Table 1). The data we found was not specific to our model and left us to estimate based off general averages for each species. Consequently, due to time and coding restraints, the following data was mostly used to inform the data that was coded in as opposed to being the exact values used.

Table 1

Animal	Population	Reproduction	Life Expectancy	Age of Maturity	Weight	Corn Consumed	Corn Destruction
Coyote	2	8 pups in May	7 years	2 years	30 lbs.	½ lb./day	10 lbs./month
Fox	3	5 pups in March	3 years	1 year	12 lbs.	½ lb./day	10 lbs./year
Bird	1000	4 eggs in March	3 years	1 year	1 lb.	1/32 lb./day	no destruction
Squirrel	6400	3 babies in March	1.5 years	9 months	1 lb.	¾ lb./day	2 lbs./day
Grasshopper	12000	500 babies in June	6 months	10 weeks	1/100 lb.	1/200 lb./day	1 lb./month
Beetle	2000	500 babies in June	1 year	30 days	1/16 lb.	1/8 lb./day	1 lb./month
Earthworms	1000000	9 worms per week	5 years	3 months	1/32 lb.	Do not eat	no destruction
Deer	25	3 babies in May	8 years	6 years	375 lbs.	8 lbs./day	4 lbs./day
Rabbit	10	28 babies in March-Sept	1 year	4 months	3 lbs.	¼ lb./day	1 lb./day
Bat	300	1 pup in June	20 years	8 months	2 lbs.	Do not eat	no destruction

To model this information, we created a program that updates the population after scenarios such as predation, reproduction, aging, death, starvation and farming methods. An organism's food needs are based on an energy system where each organism requires a certain amount of energy per month and each organism contains a certain amount of energy to feed predator populations. Predators have preset diet ratios for how much of each prey population they consume (which are dynamically affected by prey populations and competing predator populations). Each prey organism has a base evasion rate that determines the amount of prey available to the predators to account for failed hunting.

```
class Fox{
public:
    deque<int> pop = {0, 12, 0};
    int totPop = 12;
    int energyConsump = 4500;
    int cornConsump = 1500;
    int repAge = 1;
    int child = 5;
    int repMonth = 2;
    double genMort = 1;
    double evadRate = 0.2;
    int energy = 1200;
    vector<int> prey = {3, 4, 7};
    vector<int> pred = {0};
    vector<double> diet = { .33, .33, .34 };
    int devour(int);
    void birth(int);
    void age(int);
    void starvation(int);
    void consume(Fox&, Deer&, Bird&, Squirrel&, Insect&, Bat&, Rabbit&);
};
```

To simulate aging and death, each organism has a queue that updates every relevant cycle that determines the amount of its population that exists in each age range. When updated (update interval varies based on organism), all values in a previous age range advance to the next, with the population in the last age range dying. For reproduction, each organism had a set age at which it becomes capable of reproduction. Each organism has a specific month in which it reproduces, and a specific number of offspring produced per member each time that month has passed based on the data collated. Since predation ratios are being updated every month based on prey populations and competition for those populations, if there is not enough prey to even satisfy the adjusted ratio for a predator, members of the predator organism population starve (die) until consumption needs are satisfied.

```
void Fox::birth(int month) {
    if (repMonth != month) return;
    int tot = 0;
    int curr;
    for (int i = repAge; i < pop.size(); i++) {
        tot += pop[i];
    }
    pop[0] = (child * (tot / 2));
    totPop += pop[0];
    return;
}

void Fox::age(int month) {
    if (repMonth != month) return;
    totPop -= pop.back();
    pop.pop_back();
    pop.push_front(0);
    return;
}

void Fox::starvation(int deficit) {
    int death = ceil((double)deficit / (double)energyConsump);
    int deathCount = 0, i = 1;
    int subtract;
    while (deathCount < death) {
        subtract = ceil(((double)pop[pop.size() - i] / (double)totPop) * 1.1 * death);
        if (subtract > pop[pop.size() - i]) {
            subtract = pop[pop.size() - i];
        }
        deathCount += subtract;
        if (deathCount > death) {
            subtract -= deathCount - death;
        }
        pop[pop.size() - i] -= subtract;
        i++;
    }
    totPop -= death;
    return;
}
```

We also wanted to evaluate how the ecosystem impacts the production of corn. For each animal, we found data for how they might impact the growth of corn or how much they may consume. We subtracting the resulting values from our estimated original corn production. A typical corn farm in Kentucky, we assumed, produces 113,200 bushels of corn a year and profits of about $5 per bushel by default (the programmed model applies certain effects to profit per bushel relative to quality). The total value of the harvest is determined by a combination of these values, subtracting basal operating costs along with any costly initiatives the farmer chooses to introduce.

Through our code, we wanted to simulate the different stages that would impact our ecosystem and corn production. All variations to the system that are not typical to the system's normal functioning and can be represented as mathematical modification to certain variables are treated as such. Herbicide and Pesticide addition may add a monthly mortality rate to insects that was not originally a factor. Events are toggled as prompted, and come into effect on predetermined months. This accounts for many of the human decisions along with the re-emergence of species. Table 2 shows the results from our code before any specific events were added.

Table 2

Month	Coyote	Deer	Fox	Bird	Squirrel	Insect	Bat	Rabbit	Corn
1	2	0	12	1529	1555	1270650	0	0	0
2	2	0	12	1242	1126	928850	0	0	0
3	2	0	42	2803	1795	676000	0	0	0
4	2	0	23	1655	1198	248250	0	0	0
5	7	0	14	428	776	64225	0	0	115200
6	3	0	4	274	314	920600	0	0	112283
7	2	0	3	183	166	895750	0	0	93009
8	1	0	2	118	84	881550	0	0	74562
Profit:	283055	Harvest:	56611						

The agricultural cycle was modeled by first showing the planting, seeding, and growth process. Insects such as grasshoppers and beetles have been known to feast on seeds after they are planted. This behavior would mean they may be consuming small seeds, but the impact is entire corn stalks are unable to grow. We modeled this by allowing certain species to consume corn earlier than others. Unfortunately, we did not have the time to add further functionality in this arena. In addition, some animals such as foxes or coyotes may destroy the land by trampling during the growth phase. We estimated how much destruction each animal may commit through a combined numerical value, and this was multiplied by the population to show how it would impact corn produced.

There are many ways farmers control pests and weed damage including differing methods of herbicides and pesticides. If either are done incorrectly or obsessively, corn plants can be damaged. In our model, we assumed the farmer implemented these methods correctly. There are different types of control a farmer may use, but for our model we generalized a typical effect that each chemical would have. For example, pesticides can kill 90% of grasshoppers, so our population will dramatically be impacted after this was applied to the code through adding a constant rate of decline to insect populations. We also intended to incorporate negative impacts into the ecosystem such as the herbicides killing birds, but unfortunately did not have the time. However, the decline in insect populations does negatively affect the bird population in this model, as they can begin to starve if insect populations get too low. Regardless of the influences on the ecosystem, we wanted to present the economic benefits of using these methods. A typical farm without herbicides, for example, would lose an average of 23% of corn crops to weed damage. This way we can effectively understand the benefits or drawbacks to using pest and weed control. The code shows pesticides and herbicides effectively kills off insects thus increasing yield but lowers projected profit due to lower yield quality along with extra costs of chemicals. Herbicide/pesticide hurt at least short-term profits in this scenario and sent the ecosystem towards collapse (Table 3).

Table 3

Month	Coyote	Deer	Fox	Bird	Squirrel	Insect	Bat	Rabbit	Corn
1	2	0	12	1529	1555	1315150	0	0	0
2	2	0	12	1242	1126	1016250	0	0	0
3	2	0	42	2803	1795	804200	0	0	0
4	2	0	23	2172	1198	358600	0	0	0
5	7	0	16	695	783	104290	0	0	115200
6	4	0	6	445	384	209910	0	0	110941
7	2	0	5	285	190	144178	0	0	105468
8	1	0	2	182	93	101593	0	0	101824
Profit:	233752	Harvest:	99335						

There are many ways to control pests and weeds besides using chemicals. One of these methods that is found in Organic Farming is known as cover crops. This is the practice of planting crops that have the purpose of smothering the weeds, deterring pests, and enriching the soil. This method of pest and weed control involves little to no chemicals, effectively avoiding killing off such a large part of our animal populations at once. This was represented in our model as a linear modification to certain values that controlled pest populations and managed soil health. Another method to pest control is crop rotation. While this method does not get rid of the pests, it does disrupt the feeding habits of many pests that are reliant on specific crops, and also enriches the soil. This was another factor that we intended to implement in more detail, but ultimately did not have the time to do so. One of the down sides to the organic methods as a whole is that it costs a lot to convert to these methods and yields less product than other farming methods. This was a consideration that was difficult to model, as it relied heavily on specific values that we could not acquire. However, in theory, the model should reflect more accurate results if provided with more accurate data. Table 4 shows the food web using organic compost, while Table 5 shows the effects of cover crops. With Organic Compost, the harvest is somewhat higher due to randomness, profit is slightly proportionally higher despite the cost of organic compost (due to quality of yield). The compost was beneficial in this simulation. In this simulation (and seemingly in this model as a whole), cover crops are greatly beneficial as they increase yield quality while disrupting the reproductive capability of hostile insects.

Table 4

Month	Coyote	Deer	Fox	Bird	Squirrel	Insect	Bat	Rabbit	Corn
1	2	0	12	1528	1555	1274500	0	0	0
2	2	0	12	1241	1127	932600	0	0	0
3	2	0	36	2802	1801	674350	0	0	0
4	2	0	20	1714	1172	219975	0	0	0
5	7	0	10	530	549	54993	0	0	115200
6	2	0	5	339	269	752100	0	0	112491
7	1	0	3	217	132	728550	0	0	96502
8	0	0	2	139	64	714500	0	0	81365
Profit:	336398	Harvest:	66733						

Table 5

Month	Coyote	Deer	Fox	Bird	Squirrel	Insect	Bat	Rabbit	Corn
1	2	0	12	1529	1555	1241000	0	0	0
2	2	0	12	1242	1126	866750	0	0	0
3	2	0	42	2803	1795	577950	0	0	0
4	2	0	17	1484	1011	144487	0	0	0
5	7	0	4	352	253	36121	0	0	115200
6	1	0	2	226	124	241750	0	0	113520
7	0	0	2	153	67	225850	0	0	108109
8	0	0	1	122	47	214850	0	0	103219
Profit:	539910	Harvest:	98631						

As the environment changes over time and readjusts after deforestation, edge habitats start to redevelop, and native animals are reintroduced into the ecosystem. For our model, we reintroduced deer and rabbits and evaluated their impacts to the existing ecosystem as well as corn production. Deer can provide a benefit to the existing ecosystem as another primary consumer that also provide additional prey for animals like coyotes. Deer, however, can cause damage to the corn when it first sprouts as they pull it up when they eat it. They can knock over corn stalks and eat along the edge of the pasture. Rabbits offer similar benefits to the ecosystem, but they can also create a lot of damage to the plants. They can graze in corn fields and are known to gnaw on the stems of young corn stalks creating a noticeable diagonal cut. The impacts these animals make are added to the code under the regular corn consumption events. In Table 6, although you would expect the re-entry of species that eat corn to harm the corn yield, interestingly, in this simulation, the re-entry of deer and rabbits diverts the eating habits of coyotes and foxes away from the birds and squirrels, allowing for higher insect-eater populations, decreasing the insect consumption of crops. The re-introduction of deer and rabbits also seems to somewhat stabilize the ecosystem (the most of any of the tested methods).

Table 6

Month	Coyote	Deer	Fox	Bird	Squirrel	Insect	Bat	Rabbit	Corn
1	2	9	12	1602	1672	1259700	0	77	0
2	2	8	12	1396	1350	883100	0	57	0
3	2	7	42	3540	2596	571100	0	39	0
4	2	6	33	1038	1793	155750	0	23	0
5	7	5	10	259	535	38937	0	13	115200
6	3	4	3	189	237	500900	0	90	113329
7	2	3	3	167	197	480700	0	69	102426
8	2	2	3	146	161	463550	0	52	92074
Profit:	410970	Harvest:	82194						

Bats are known to help stabilize the ecosystem by eating hundreds of insects every night. They act as a natural pest controller, which can help the economic production of a corn field. We modeled bats by adding them as a separate event in which a farmer may release bats into the environment to help the farm. Another animal known to positively impact a corn field ecosystem is owls. Owls can also help control rodent populations and are especially beneficial because of their ability to hunt at night when many nocturnal rodents are active. We decided not to include owls in our model due to time constraints. We can predict they would help control rabbit populations as they are reintroduced based on the effect of the bats in the model. According to our code, bats are a good alternative to pesticides, as they seem to keep insect populations in check relatively well, increasing crop yield.

Table 7

Month	Coyote	Deer	Fox	Bird	Squirrel	Insect	Bat	Rabbit	Corn
1	2	0	12	1529	1555	1258000	97	0	0
2	2	0	12	1242	1126	943095	94	0	0
3	2	0	36	2803	1800	669285	91	0	0

4	2	0	23	1580	1181	237135	88	0	0
5	7	0	9	342	763	49547	85	0	115200
6	2	0	2	78	242	309600	108	0	112762
7	0	0	2	54	135	282330	104	0	106172
8	0	0	1	43	94	257770	100	0	100282
Profit:	474730	Harvest:	94946						

There are many different factors that impact the production of a corn field and the surrounding ecosystem. When humans make the decision to deforest land to change it to a farm or otherwise, many species are impacted. Through our model we were able to create a program depicting a working food web. The data we collected, and our coded food web, allowed us to draw conclusions about the impact of different human decisions and natural processes. The agricultural cycle is greatly affected by the different animal species in the food web. When re-introducing animals to the edge habitats, the ecosystem somewhat stabilized, allowing for more effective and consistent predation of pest populations. In the end our team was not surprised by most of our model's outcomes, as it reflected the effects that we anticipated that different farming methods and natural occurrences would have based on our research.

Given more time, and better data, this model could be used as a potent skeleton for evaluating the effects of certain actions on an ecosystem as a whole. Even without the accurate numerical data, this model provides insights into the interconnectivity of different factors, which allowed us to observe effects that would have been incredibly difficult to notice with the human mind alone. Shifts in one aspect of this model can cause seemingly unrelated values to change in unexpected ways as can be seen in Table 6. This interconnectivity of causation is so complex, that, as is shown on many of the previous tables, we couldn’t manage to keep the ecosystem from collapsing despite extensive efforts to do so. This is a great example of how complicated and delicate ecosystems can be, even only considering a few factors in the near infinite independent variables that exist within a real ecosystem. Given the necessary time to bring this model to stability and increase the complexity of certain factors, even more obscured relationships could be discovered, leading to profound insights into agricultural ecosystem dynamics.

Dear Farmer,

My colleagues and I at the Consideration of Mature Agricultural Practices (COMAP) have been made aware of your thoughts about different farming methods. While there are many great methods out there, each one comes with their own trade-offs. We will also be looking into the sustainability of these methods in the economy today.

From our research, we found the two main methods used in farming are Conventional Farming and Organic Farming. Conventional Farming implement chemicals as a way to keep pests and weeds away. If done properly, this method can be very beneficial to you as it is the most effective method to produce a large yield of crops. However, this method does have some major drawbacks as it can cause major destruction to the ecosystem, which can have drawbacks on soil health and crop quality.

The other main method is Organic Farming which implements cover crops and crop rotation to keep pests and weeds at bay. This works because crop rotation disrupts pest populations that rely on singular food sources. Cover Crops also work as pest control as it benefits predators, effectively killing off more pests. Cover crops also smother all of the weeds which helps the health of the corn and contributes to the general health of the soil. Because of the lack of chemicals, this method is considered to be more environmentally friendly. This conclusion was supported by our model, that found that chemicals can disrupt an ecosystem by throwing certain interconnected populations out of balance. In addition, you are able to charge more for your crop as organic foods are in high demand in today's economy as luxury/health products. A particular drawback of this method, however, is that it will cost you more in the beginning as you will potentially need lots of new equipment and/or workers. This method also yields less crops than any other method.

While both of these methods are considered to be sustainable, many would push that Organic Farming is the best method as it does not drastically harm the environment. While that is up to the individual to decide for themselves based on various factors, we think that the economy will push many farmers to go organic as we have seen the sales of organic food rise to $61.7 billion in the United States.

Sincerely,

COMAP

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Appendix

- Code Link: https://github.com/jnaughton42/Agricultural-Ecosystem-Model