Risk Analysis of Japanese Beetle in Utah

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Abstract

The Japanese Beetle (JB) is an invasive species first introduced to the United States in 1916. It has since spread to more than 30 States. JB causes damage to agriculture products in its early stages of life as a grub by feeding on over 300 host plants ranging from nursery stock and ornamental plants to fruit, grain, and vegetable bearing plants as an adult and feeding on turf as a grub. The potential damages to agriculture commodities and horticulture if Utah becomes infested with JB has led the Utah Department of Agriculture and Food (UDAF) to maintain a statewide quarantine for nine years and undertake an eradication effort nationally unprecedented in size upon discovery of an established JB population in Orem Utah in 2006.

Keywords: cost-benefit analysis, CBA, risk-analysis, economics, econometrics, invasive species, Popillia Japonica, Japanese beetle, Cobb-Douglas production function

Risk Analysis of Japanese Beetle in Utah

Popillia japonica, commonly known as the Japanese beetle (JB), is native to northern Japan. It is a non-native organism to the United States, introduced accidentally or deliberately through trade, migration, etc. (Fleming, 1972). JB was introduced to New Jersey in 1916 (*USDA APHIS | Japanese Beetle*, n.d.). After JB's introduction to the U.S. and establishment (a sustainable population to continue existence that disrupts the ecosystem it colonizes; Crooks & Rilov, 2009) in the Eastern states, JB began its migration westward, transported in nursery stock, soil from tools/ machinery, airplanes, cars, and trucks (Oregon Department of Agriculture, 2017).

The first record of JB in Utah was found in 2006 by an Orem homeowner (Utah Department of Agriculture and Food, 2012). The U.S. has policies in place to reduce the introduction of non-native species. However, it is nearly impossible to completely prevent the introduction of a non-native species (Aukema et al., 2011; Cranshaw, 2018). Especially in the modern world, with ease of international travel and trade. Also, quantifying the damages of invasive species brings challenges in accounting for invasive species in trade policies (Bradshaw et al., 2016; Wright, 1995). Pimentel et al.,(Pimentel et al., 2005) estimate the total cost of invasive species to the U.S. is about $13.5 billion per year. Sather-Smith (2014)noted the US spends about $450 million per year to control beetle populations. Japanese beetles are one of the most aggressive invasive species in the U.S., suggesting the establishment of JB in Utah could create substantial economic and ecological costs.

The Japanese Beetle, an Invasive Species

Not all non-native species are invasive. Nonindigenous species become invasive when they dominate an entire ecosystem (Bradshaw et al., 2016; Crooks & Rilov, 2009). Species can accomplish this when there are few resources or environmental conditions (limiting resources) that limit the growth of JB population. A limiting resource can be biotic like competition over resources (e.g., food, mates, etc.) or abiotic (e.g., soil temperature, soil moisture, space available for JB, climate conditions, etc.) (Bragard, 2018; Crooks & Rilov, 2009). Limiting resources are often expressed as a lack of a resource. Limiting resources explain why JB is unsuccessful in Japan. In Japan, natural predators and unsuitable terrain conditions (little available turfgrass) control the JB population since there is more competition over limiting resources (Bragard, 2018). In the U.S., JB has less competition over resources since resources are of more abundance, allowing JB to establish successfully.

Darwin's Theory of Natural Selection

Darwin applies Malthus' theory of population to the success of an invasive species in his theory of Natural Selection. JB in Malthus' theory would predict that increases in subsistence (wages) will result in increases in population. Applied to JB, replacing subsistence for their limiting resources implies that increases in the availability of limiting resources, the population will increase. Under Darwin's theory of natural selection, populations are controlled by checks. If there is a lack of food resources then food becomes a limiting resource, this acts as a check, increasing competition requiring the fittest to survive.

Biocontrol is a method of controlling invasive species by releasing one species (JB predators) to control another species population. Some JB natural predators include wild birds (cardinals, robins, etc.), opossums, raccoons, skunks, moles, and shrews all eat beetle grubs. It should be noted these mammals damage the turf or crops during the process of eating JB. Biological control thus wouldn't help control JB in the agricultural industry as it would reduce crop yields and damage the plant. Biological control will not completely wipe out an invasive species, it controls population to reduce their damage but not eliminate it. UDAF is very efficient in controlling JB population through trapping and insecticides. In previous years when JB populations exponentially rose (2006) the UDAF was able to reduce populations relatively close to zero beetles the following summer of 2007 (Caputo & Watson, 2020). Since mechanical and chemical control methods are sufficient and relatively low-cost options to keep JB populations low, then biological control is unnecessary.

The Lifecycle of the Japanese Beetle

JB emerges from the soil between mid-June to early July with a peak population in Utah occurring July to August according to data collected by the Utah Department of Agriculture and Food (UDAF) (Caputo & Watson, 2020; Cranshaw, 2018). Females typically surface first and release a pheromone, attracting males out of the ground to mate on nearby host plants (Fleming, 1972). Females will return into the ground to lay eggs (a process called oviposition), after which; she returns to the plant leaves to feed. The cycle will be repeated multiple more times throughout their life above ground, distributing, on average, a total of 40-60 eggs over her lifespan (Bragard, 2018; Fleming, 1972). The overall length of the adult JB lifecycle is about one year (Fleming, 1972). Their lifecycle tends to be longer, closer to two years, in cooler temperatures, and shorter in relatively higher climates (Fleming, 1968).

Larvae Stage. The JB larvae's survival depends on the female's oviposition site and three key abiotic factors; (1) land topography, (2) soil temperature, and (3) soil moisture (Fleming, 1972). Larvae have limited mobility and feed on surrounding plant roots. Therefore, a major survival factor for JB is a nearby food source (plant roots) (Cranshaw, 2018; Fleming, 1972; Utah Department of Agriculture and Food, 2012). Early signs of turf damage from JB are similar to drought-stressed turf, often leaving damage unnoticed until the turf has completely detached from its roots (Fleming, 1972).

JB larvae are also extremely sensitive to extreme temperatures and lack of soil moisture (Fleming, 1972). The survival rate of a JB is at the highest risk during their first and second stages as a larva (Fleming, 1972). If survival rates are low, JB cannot develop a sustainable population to overtake an ecosystem, and JB will not become invasive. Therefore, the damage of JB is highly dependent upon the oviposition of the larva to increase survival chances.

Temperature. Fleming (1976) found optimal larva survival occurs between $15°C - 31°C$ and at prolonged temperatures below $15°C$, for low to no chance of survival. When exposed to prolonged (seven days) extreme temperatures above $34°C$, zero eggs hatched (Fleming, 1972). Below $0°C$, larvae displayed a 100% mortality rate. Average temperatures during larvae stages in June-August within the range of $15°C - 31°C$ range are suitable for JB survival. Adults also tend to be most active (feeding, flying, and mating) on warm sunny days, which also increases reproduction rates and population growth.

Soil Moisture. Soil moisture is crucial to the survival of the larvae and the establishment of JB. JB larva cannot retain water, requiring high soil moisture content, and a minimum annual average of 250 mm of precipitation (Bragard, 2018). JB contains around 80% of its weight (at maximum weight) in water (Fleming, 1972). Human-created climates, through the introduction of irrigation and other technology have allowed for farming and JB larvae to survive in areas that historically had arid soil terrain that were unsustainable for both.

Land Topography. In addition to moist soil, JB larva must be positioned near plant roots (Cranshaw, 2018; Fleming, 1972). The larvae's limited mobility means that the damage to plants depends on how far the larvae are positioned from the plant. Waltz et al., (2010) noted larvae eat plant roots in their general area, causing the turf to die and "roll up like a carpet" (Waltz et al., 2010). Larvae also affects plant durability and the plant's water and nutrient intake from the soil

(Shanovich et al., 2019). By laying eggs underground, JB larvae are very difficult to detect and often remain unnoticed until there is extreme damage leaving areas of turf dead. If an area does not meet these three requirements, the female will find a more suitable area to lay her eggs.

Adult Stage. The adult JB tends to aggregate in a localized area to feed and mate, which can cause extreme damage to areas of host plants (Hodgson et al., 2011). Meanwhile, leaving nearby areas of host plants undamaged (Hodgson et al., 2011). They skeletonize the plant leaves leaving little remaining, while also feeding on the plant's crop production (i.e., fruit, berries). Adults fly on warm and sunny days or when disturbed. Typically flying short distances, most within a 50-meter radius and estimated rate of spread of about 7.7 km per year (Allsopp, 1996).

Host Plants. JB feeds on over 300 plant species in 79 families across the U.S (Hodgson et al., 2011, p. 2012; Shanovich et al., 2019; Utah Department of Agriculture and Food, 2012). An abundance of host plants increases the availability of survival resources and reduces population checks ultimately decreasing competition for JB. With the ability to consume over 300 different plant species (high abundance of resources) and little competition over resources, the longevity and reproduction rates dramatically increase. General categories in JB diet includes; shrubs, trees, fruits, berries, field crops, vegetables, ornamentals, nursery plants, and damage to turf including private lawns, golf courses, and pastures(Cranshaw, 2018; Utah Department of Agriculture and Food, 2012). Shanocich et al. (Shanovich et al., 2019) noted JB prefers host plants with a high sugar concentration. Since the canopy receives the most sunlight, JB tends to defoliate plants from the top down to consume the parts of the plant with higher sugar concentrations (Bragard, 2018).

Cost-Benefit Analysis.

JB has the potential to generate major economic costs for the State of Utah's horticultural and agricultural markets. By damaging host plants, the state of Utah risks decreasing crop production, increasing production costs, and losing market share to other states. The proposed cost-benefit analysis (CBA) will help Utah decision-makers to make more informed and rational decisions regarding expenditures for JB.

CBA helps to create a clear net social benefit, in monetary terms, of the decision to maintain quarantine against JB in Utah. The opportunity cost of doing nothing is the costs incurred by the private sector; therefore, the benefits of the state controlling the population mainly accumulate within the private sector. Essentially, by controlling JB population, provided as a public good, the state is subsidizing the private sector for this positive externality. The state of Utah should continue to control JB population if the benefit to cost (B-C) ratio is greater than one, such that that for every $1 spent there is more than a $1 benefit, making the overall net social benefit positive. If the net social benefit is negative, it indicates Utah spending is more than the benefit provides, indicating Utah should stop controlling JB population.

Disadvantages of Cost-Benefit Analysis

Researchers would like to identify, assign monetary values, and aggregate all possible costs and benefits (tangible and intangible), to determine the B-C ratio. Value judgments enter as individuals assign subjective values to costs and benefits without an exact monetary value. It is difficult to infer an individual's values, tastes, and preferences and extrapolate the outcome of the decision.

Another shortcoming is that all individuals do not equally value income. The marginal utility $1 brings to a person with less money is likely greater than the marginal utility an additional dollar brings to a rich person. Individuals using CBA results to make a decision should consider its shortcomings when evaluating the results. The effect of JB destruction will differ for various groups in Utah. For example, if destroyed turf is not replaced or redesigned (i.e., a rock garden), the homeowner's property value may decline. Homeowners in lower-income brackets will likely prioritize investing in their lawn lower than a wealthier homeowner. Income is a scare resource to the low-income homeowner and must be allocated efficiently, meaning that yard up-keep is likely not their top priority. These lower-income households could experience a decline in their property value, furthering a wealth inequality gap between the two groups.

International Trade and Invasive Species within CBA

Bradshaw (2016) argues that climate change and international trade are the two leading factors of increased introductions and expanding distribution of non-native species. International trade can have net positive effects on society. However, it also increases the risk of transportation of non-native species to the native area, which can have serious economic and social costs. Human migration, movement of traded goods, and growing populations all increase the likelihood of a non-indigenous species establishing and becoming invasive, which can become extremely costly to the US as a whole.

New invasive species are often not identified until they have caused significant economic damage and have an uncontrollable population established, making the costs to eradicate significantly larger than the benefits (Courtois et al., 2017; Holmes et al., 2009). Climate change has also allowed for non-native species to live in new locations they historically could not survive in (Allsopp, 1996). Across the globe, we are engaging in more international trade than ever, increasing our exposure to unintentional introductions of species from other countries.

The introduction of an invasive species poses significant costs for the US (including control costs, loss in agricultural and horticultural production, and destruction of natural resources) (Bradshaw et al., 2016; Courtois et al., 2017). The allocation of resources for invasive species, in theory, would be spent more efficiently in the production of a good or service in which it has a comparative advantage. However, due to the introduction and establishment of the invasive species, resources must now be allocated (while the costs are relatively lower) to prevent further growth in population, future damages and inefficient resource allocation.

Cost-Effective Approaches

Early and effective prevention from allowing an invasive species to establish is the lowest cost option to restrict establishment and mitigate spread (Bradshaw et al., 2016; Courtois et al., 2017; Kaiser & Burnett, 2010). Without management and control of JB, as populations rise exponentially (due to abundance of limiting resources), so will the costs associated with controlling the population (Bradshaw et al., 2016). The underestimation of costs associated with the damage from JB will intensify over time since costs to control will rise exponentially as JB populations rise. Rejmánek and Pitcairn (2002) stress the importance of early prevention methods as the lowest cost option. For some invasive species, the population can grow so considerable that eradication becomes impossible when the costs exceed the benefits that population control provides.

Positive externalities can be provided by public or private parties. If the control of JB is made private, a private party might be subsidized to be encouraged to take more efforts in privately controlling JB. In effect, by providing JB population control publicly, the state is subsidizing these private parties. However, providing the subsidy this way is more effective in controlling JB.

When an investment has a personal cost but a common benefit, economic agents will tend to underinvest, the private market will then under supply these goods. Leaving the control of JB population up to private parties become vulnerable to the free-rider problem. If certain individuals take action to control JB population on their property, others are more likely to choose to do nothing if they feel enough other people are taking action. This will lead to market failure in that the positive externality of controlling JB populations will be underproduced. Indicating populations would be more effectively controlled if quarantine was treated as a public good.

Achieving the most efficient control of JB population is only possible if eradication or control is treated as a public good and covered by the Utah state government and possibly assisted by private groups with a vested interest (i.e., corn farmers). If control of JB is left to individuals and the private sector, only some households and firms will actively take efforts to quarantine and others will do nothing. The lack of effort by some parties will not properly control the population and will allow JB to establish, counteracting other individual's efforts to control the population. The lack of control efforts by some parties is known as the free-rider problem. Those who do not control JB population will benefit (temporarily) from parties who actively control JB population. These parties are thus underpaying for the benefit, while others are paying more.

Human-assistance through irrigation of turfgrass and agriculture has created an environment for JB to establish west of the Mississippi River, where it previously could not survive (Shanovich et al., 2019). Invasive species can have severe economic and environmental costs if improperly managed and controlled. JB damages agricultural commodities by destroying ornamental plants, crops (i.e., corn, fruits and berries) and Utah's natural resources and biodiversity. These damages make Utah less competitive in these commodity markets as it becomes increasingly costly to produce the commodities. Do the social benefits of maintaining a quarantine against JB, specifically in Utah's agricultural corn industry and urban turfgrass, exceed the cost for Utah to maintain quarantine?

Method

Procedure

Researchers developed a cost-benefit analysis on maintaining JB quarantine. The CBA weighs costs incurred by the UDAF to maintain a quarantine against the foregone losses to the Utah Agricultural economy that could result from the infestation of JB. Researchers used foregone losses in agricultural commodities (losses as a result of allowing JB to invade) as the benefit in the CBA. To establish the value of the losses, researchers developed a model to apply to agricultural commodities that are vulnerable to JB damage. Due to a lack of complete data available and resource constraints, researchers restricted the current foregone loss estimate to the value of corn production and the value of turfgrass. Turfgrass is also limited to areas considered as "urban turf".

Cost of JB Population Control Incurred by Utah State

The cost for the state to control JB population is based on the aggregate costs if they continue to quarantine until 2027. Inflation rates were not accounted into cost calculations since researchers assumed constant market prices for corn and turf. The costs also remain constant as this is currently Utah's budget for JB; therefore, we expect the cost to remain the same over years if Utah can continue to keep JB populations low. Researchers used the maximum value of the

UDAF budget as the costs for JB control. This will overestimate costs to produce more conservative results.

Japanese Beetle Population Predictions

Utah is currently JB free. Thus, researchers forecasted the value of potential losses eight years in the future (2019-2027). Eight years would allow for adequate time for a significant JB population to establish in Utah. Researchers built a model to estimate JB pollution growth based on the following assumptions; 1) the average female JB lays 50 eggs within a year, and 2) 35% of those eggs reach adulthood. Based on these assumptions, forecasted populations started at 1.29 beetles in 2019.

Corn Yield Predictions

Data for corn forecasting was analyzed using the program RStudio (*RStudio*, 2020). Data structure and availability allowed for the yield of corn in Utah to be forecasted through the population growth period of 2027. Researchers forecasted corn yields using two methods; 1) statistical regression analysis, and 2) a weighted historical growth model.

Statistical Regression. Statistical regression methods consisted of constructing an unrestricted Cobb-Douglas function. Researchers chose an unrestricted Cobb-Douglas function for its ease of manipulations and interpretation, and its good fit to the data (Griliches, 1963). A panel data construction was used since only nine of the 29 counties in Utah consistently produce corn. A sample size of nine is too small to perform practical statistical regression and could yield unreliable and invalid results. To solve this, researchers constructed a panel of data using three years of data from the nine counties. Researchers obtained data from the UDSA Census of Agriculture. This census is released every five years, which dictated the years included to 2007, 2012, and 2017, and helped determine the year researchers chose to forecast out to (2027). Collected data consisted of corn used for grain yield in bushels and several labor and capital cost variables as directed by the Cobb-Douglas production function method. See Appendix A Table A1 for a full list and description of possible variables of interest for the statistical regression forecasting for corn.

Model Specification. Researchers ran initial regressions using two-way fixed effects, which assumes the influence of variables is constant across all observations. See Appendix A Table A2 for complete regression results. Our main variables of interest for our statistical regression were; $cornyld$ (total corn yield in bushels), $util$ (total cost of agricultural utilities), $fert$ (total cost of fertilizers applied), $labor$ (total cost of hired and contracted labor), $rent$ (total cost of rent), and $treatins$ (number of acres treated to control insects). After testing different variable combinations, researchers used the following variables to synthesize the equation used for forecasting purposes;

$$\log(cornyld) = 1.172 \log(util) + 2.209 \log(fert) - 2.114 \log(labor) - 1.123 \log(rent) + 0.985 \log(treatins)$$ [1].

All variables were significant at the 5% level, with the exception of the $treatins$ variable, which was significant only at the 10% level. Researchers generated OLS and random effects versions of this equation and conducted testing to determine which model is most accurate.

F-Tests. After generating an OLS [2] version of this equation, an F-test was conducted to test for individual effects. This test is based on a null hypothesis that OLS is a better fit than a fixed effects model.

F-Test Results:

[1] Appears as fix48 in the regression reporting table, Appendix A Table A2
[2] Appears as ols48 in the regression reporting table, Appendix A Table A2

$F = 5.39, df1 = 8, df2 = 13, p - value = 0.003846$

$H_0: no\ effect$

$H_1: significant\ effects$

The p-value is less than the 0.05 benchmark; therefore, we reject the null hypothesis that the OLS is a better fit, in favor of a fixed-effects model.

Hausman Test. Researchers also generated a random-effects version [3] of this equation. Then subjected both equations to a Hausman Test to determine which proved a better fit. This test is based upon the null hypothesis that a random-effects equation is a better fit.

Hausman Test Results:

$chisq = 14.063, df = 3, p - value = 0.00282$

$H_0: random - effects\ model\ is\ consistent$

$H_1: random - effects\ model\ is\ inconsistent$

The p-value is less than the 0.05 benchmark, indicating the null hypothesis (random-effects is the best fit model) should be rejected and instead, researchers should use a fixed-effect model. After determining the fixed effect model is the best fit, researchers used the coefficients of variables within the final regression to forecast the 2027 corn yield in Utah. All variables in the final equation are expressed as a double-log to normalize the data. Double-log equations are interpreted as elasticities such that "for every one percent change in the independent variable, the model estimates a $\widehat{\beta_1}$% change in corn yield". Researchers forecasted yield by estimating the change in all independent variables over the forecasting period to get the growth rates. Then multiplied the growth rates by the equation coefficients. Finally, both were added together to obtain the growth in the dependent variable.

[3] Appears as rand48 in the regression reporting table, Appendix A Table A2

Weighting Growth Rates. To estimate the change in all independent variables, researchers collected six periods of data in 5-year intervals from 1987 to 2017, as dictated by the scheduled releases of the Census of Agriculture, for all variables except for the $util$ (utilities) variable since only the four most recent years were available. Researchers derived growth rates from data according to two different methods to estimate future changes; 1) a simple average from the observation to observation growth rates from all years, and 2) a weighted average of observation to observation growth rates over all years according to the weighing scale in Table 1.

Table 1

Weighing Scale for Variable Growth from 1992-2017

Variable Growth Weighting						
Year	1992	1997	2002	2007	2012	2017
Weight	5.00%	8.00%	11.00%	17.00%	27.00%	32.00%

Note. Weighing scale applied to individual period growth of independent variables to calculated weighted growth used for forecasting.

Table 2

Weighing Scale for $Util$ Variable from 2007-2017

Util Growth Weighting			
Year	2007	2012	2017
Weight	20.00%	30.00%	50.00%

Note. Weighting scale applied to period to period growth of the $util$ variable to calculate the weighted growth used for forecasting.

See Appendix A Table A3 for a complete report of all variable growth. Note in Appendix A Table A3; there is one estimated observation within the growth variable. Estimation was necessary because one county was missing a $clabor$ (contract labor) input for 2007. In order to account for the missing value, researchers estimated the labor value for 2007 using two methods. 1) a simple average of all years with available data, and 2) a weighted average of all years with available data according to the weighing scale in Table 3.

Table 3

Weighing Scale for Labor Variable from 1987-2017

Labor Weighting Scale						
Year	1987	1992	1997	2002	2012	2017
Weight	3.00%	7.00%	20.00%	30.00%	30.00%	10.00%

Note. Weighing scale used to calculate missing Juab county 2007 $clabor$ variable.

See Appendix A Table A3 for simple and weighted average results. Researchers then applied both growth rate aggregation methods to all variables and summed the results accordingly to determine the expected percent change in the corn yield variable according to the two methods.

Table 4

Expected Percent Change in Corn Yield

Total cornyld % Growth	
Total SA - cornyld % Change	Total WA - cornyld % Change
32.30%	34.45%

Note. Total expected 5-year percent growth in Utah corn yield according to a simple average (SA) and weighted average (WA).

These growth rates represent the expected 5-year growth in corn yield based upon the historical growth rates of all the independent variables. According to the Census of Agriculture, Utah corn yield used for grain totaled 5,050,322 bushels.

In order to forecast Utah crop yield for 2027 from this number, it must be grown through two periods using the growth rates above. Growing the actual yield number through two periods gives the final forecast of Utah corn yield.

Weighted Growth Model. To forecast using the weighted historical growth model, researchers analyzed and extracted growth rates and ratios from 25 years of historical corn data ranging from 1994 to 2018, obtained from annual statistical reports from the UDAF. Variables of interest include; growth rates of acres harvested, yield per acre, and yield per acre as a ratio. Researchers aggregated the growth of these variables across the 25 years of data using the weighting scale in Table 5.

Table 5

Aggregated Growth Rates of Acres Harvested and Yield Per Acre Ratios

1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006
0.25%	0.50%	0.75%	1.00%	1.25%	1.50%	1.75%	2.00%	2.25%	2.50%	2.75%	3.00%	3.25%
2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	
3.50%	3.75%	4.00%	4.25%	4.50%	4.75%	5.00%	7.00%	8.00%	9.00%	10.00%	13.50%	

Note. Weighting scale applied in the calculation of acres harvested growth rate, yield per acre growth rate, and yield per acre ratio. This weighting scale places more than 50%[4] of the weighted on the first six years of data.

Table 6

Aggregation Results

Aggregation Results	
Variable	Rate
Acres Harvested	4.27%
Yield per Acre (Growth)	-1.34%
Yield per Acre (Ratio)	0.79%

[4] 52.5%

Note. Aggregation Results according to the weighing scale.

Researches constructed two different models from the annual aggregate values. The first model contained both acres harvested and yield per acre projected for each year of the forecasting periods from 2018 through 2027 using the growth rates above. Researchers then multiplied together to reach a total yield figure for each year. The second model contained projected acres harvested for each year in the forecasting period from 2018 through 2027, with the growth rate above. The yield per acre is calculated by taking the forecasted acres harvested results for each year and multiplying it by the yield per acre ratio. Researchers then multiplied results together to reach a total yield figure for each year. The 2027 results from both models are as shown in Table 7. See Appendix A Table A4 for comprehensive results containing the forecasted values for each year.

Table 7

Weighted Growth Model Yields

Weighted Growth Model Yields		
Method	2018	2027
Acres & Yield Growth	4,004,000	5,164,016
Acres & Yield Ratio	4,004,000	8,132,953

Note. Corn yield forecasting results for 2027 according to both methods applied from 2018 actual values.

Turfgrass Estimations

Researchers estimated total foregone loss to turfgrass by aggregating total turf JB larvae could survive in Utah multiplied by the cost to replace turf, estimated at $0.69. Researchers gathered a list of important survival requirements for JB based on Fleming's (1972) extensive research on JB biology. This prior research was used to calculate the total Sq. Ft. of turf in Utah where JB larvae could survive. Larvae development is the most critical stage of JB survival and is the most sensitive stage to changes in the surrounding climate. The survival factors of larvae provide a good indicator of JB's ability to establish. JBs tend to remain in areas suitable for their eggs, suggesting areas proper for larvae survival are areas that will likely experience higher damage rates. JB research has determined three main factors essential for survival; 1) land topography, 2) soil moisture, and 3) soil temperature. See Appendix B for Japanese Beetle Survival Requirements.

Data Elimination of Unfit Survival Areas. Researchers used an ArcGIS datasheet from the Utah Water Resources Open Data Group (2018) to calculate the total square feet of turf available for JB to invade and destroy. The data contains 337,229 data points and specifies total square meters of different water-related land use for each county in Utah. After cleaning the data in Excel (*Microsoft Excel*, 2020) by eliminating urban turf areas JB larvae could not survive in (the three factors stated above), the data contained 5,213 data entries. See Appendix B for JB survival requirements based on Fleming's (1972) research. While this data set contains extensive varieties of crops in Utah, it only includes total square meters the crop occupies and does not include crop yields to allow for forecasting on other crops.

Cleaning the Data. The data included other states, so researchers eliminated other states, so only Utah turf would be included in the benefit estimates. Next, researchers eliminated data fields classified as $Agriculture$ under the variable $Landuse$, leaving $Urban$ remaining. A majority of the agricultural land use in the data is designated for other crop categories, such as $corn$, $barren$, $barley$, $wheat$, etc. Though many of these crop areas may also have turf areas for JB to survive and lay eggs, researchers removed these areas to reduce any risk of double counting damages if additional crops are calculated into the foregone losses in the future. Researchers also focused on turf classified as $urban$ since there is a higher likelihood this turf will be replaced upon destruction than turf used for agricultural purposes. Urban turf will also create more realistic costs for what would be spent by private and public institutions.

The irrigation methods variable allowed researchers to determine areas with sufficient soil moisture. Researchers selected "sprinkler" under the IRR_{method}(irrigation method) in order to remove all data classified as having no irrigation. Essential moisture for JB survival requires an average of $250mm$ of annual precipitation. Due to Utah's somewhat arid climate, areas that use sprinklers likely meet this minimum, whereas areas without sprinklers likely do not receive enough water for JB larvae to survive. Researchers eliminated categories under $Class_{Name}$, leaving the following entries; $Cherries$, $Deciduous\ Forest$, $Developed/\ High\ Intensity$, $Developed/\ Low\ Intensity$, $Developed/\ Med\ Intensity$, $Developed/\ Open\ Space$, $Evergreen\ Forest$, $Grass/Pasture$, $Mixed\ Forest$, $None$, $Other\ Hay/Alfalfa$, $Peaches$, and $Shrubland$. The calculation of turf in the categories of cherries and peaches is separate from a foregone loss specific to cherry and peach production in Utah. First, the peaches and cherries are classified as urban turf, and therefore is not commercial. Also, the calculation is based on turf surrounding the tree and not the production of the tree's fruits. Irrigation is one of the main reasons JB is able to survive in Utah. Otherwise, the Utah terrain and ecosystem would be unsuitable for JB larvae.

Calculation of Damage Rate. Researchers gathered average temperatures for June, July, and August in each Utah county. For average temperatures outside the survival range of $59\ °F - 88°F$, researchers calculated a discount rate so counties with temperatures further outside the range utilize a smaller percentage of the total Sq. meters of turf. This indicates less damage to turf in areas JB does not survive well in. Researchers then applied a damage rate to every county of 80% for our best-case scenario. Meaning researchers expect about 20% of the turf (after accounting for temperatures in various counties) to be damaged, or JB will occupy 20 % of the total turf. Researchers added the discount rate (counties with temperatures outside the range) and the damage rate together to find the total percentage to be discounted from each data point's Sq. Ft area.

Discount Rate for Temperatures. Researchers gathered minimum and maximum temperatures for June, July, and August for each Utah county (*Utah State - USA.Com™*, 2010) and averaged the maximum and the minimum temperature averages for the three months to calculate the overall minimum and maximum temperature averages for each county over the three months.

The percentage of the average temperature each county is under the minimum is calculated by $\left(-\frac{(Average\ Min.Temp\ for\ the\ County - Required\ Min.Temp\ for\ Survival)}{(Average\ Min.Temp\ for\ the\ County)}\right)$. For the minimum percentage difference, we use the additive inverse of all percentages so it could be added to the damage rate to find the overall percentage of acres each data point will be discounted by. The percentage the average temp is above the maximum is calculated for each county by $\left(\frac{(Average\ Max.Temp\ for\ the\ County - Required\ Max.Temp\ for\ Survival)}{(Average\ Max.Temp\ for\ the\ County)}\right)$.

An if statement was computed to determine the total percentage above the maximum and below the minimum for each Utah county. If the percentage below the minimum is positive, then take the $percentage\ below\ the\ minimum + (1 - \ damage\ rate)$, if the percentage below the minimum is less than zero put $(1 - damage\ rate)$. Remember, researchers used the additive inverse, so a positive percentage means the overall minimum average for that county was below the required minimum, and a negative percentage indicates the overall minimum average for that county is within the survival range. For the maximum, if the percentage above the maximum is greater than zero, then take the $percentage\ above\ the\ maximum + (1 - \ damage\ rate)$, if the percentage above the maximum is less than zero puts $(1 - damage\ rate)$. Researchers then averaged the minimum and maximum percentages together to determine the overall weighted damage for each county. These average weighted damages for each county represent the amount of turf in that county JB will not destroy, and the reciprocal would indicate the percentage of turf in that county JB would damage/ occupy. This allows researchers to identify different possible scenarios.

Total Estimated Turf Destroyed. Next, within the Urban Turf data, researchers adjusted the variable $Shape_{Area}$. This variable represents the total Sq. Meters of urban turf in that area. This variable needed to be adjusted to account for the calculated overall average weighted discount rate. Researchers used a $vlookup$ function to find the average weighted discount rate that corresponds to the county the $Shape_{Area}$ data refers to. For example, if the shape area in a specific data point belongs to the county Millard, then the average weighted discount rate previously calculated for Millard will be used against that $Shape_{Area}$. Researchers used the equation $\left[Shape\ Area_{X\ Data\ Point} - \left(Shape\ Area_{X\ Data\ Point} * Average\ Weighted\ Discount\ Rate_{For\ X\ County}\right)\right]$ to calculate the $Discounted_{Shape\ Area}$. From here, researchers aggregated the $Discounted_{Shape\ Area}$ for each data point in the Urban Turf data to calculate the total urban turf JB is likely to damage based on the specified damage rate.

$Shape_{Area}$ is calculated in Sq. Meters, so values were converted to Sq. Ft to match the cost of replacement turf measured in Sq. ft. Researchers then took

$\text{Total Urban Turf JB is Likely to Damage Based on the Specified Damage Rate (sq ft)} \times$ $\text{Cost to Replace Turf (per sq ft)}$, to find the benefit of turf by maintaining quarantine. The replacement cost of turf is based on labor, sod, and delivery costs to install turf per Sq. Ft.

Results

The purpose of this research is to identify the B-C ratio of continuing to control JB population. Researchers predict that the benefits of controlling JB population will be significantly greater than the costs for UDAF to continue to quarantine. The results of the cost-benefit model will inform whether or not the potential losses to the Utah agricultural economy due to JB infestation merit the expenses incurred by the UDAF in maintaining a quarantine against JB. If the value of foregone losses is greater than costs incurred, this indicates the UDAF should maintain its quarantine against JB. If the value of the foregone losses are less than the costs, then the UDAF should stop allocating resources to control JB population.

Cost of Quarantine Estimates

Based on information from UDAF regarding their annual budget to control JB, we estimated the cost at $60,000 per year for a total of $480,000 cumulative cost by 2027. The estimated cost per year is the higher end of the budget, which will increase our estimated costs to control.

Population Estimates

Based on our assumptions of JB population growth rates, our model estimated that JB population could grow to over 6.3 billion by 2027. Researchers consider this population size to be large enough to cause significant damage to the Utah agricultural economy, allowing researchers to apply damages more accurately.

Corn Yield Results

Statistical Regression Results

The econometric form of the model including all variables can be written as;

$$\log(\widehat{cornyld}) = 1.172\log(util) + 2.209\log(fert) - 2.114\log(labor) - 1.123\log(rent) + 0.985\log(treatins)$$ [5].

Table 8

Statistical Regression of Corn Yield Forecasts for 2022 and 2027

Statistical Regression Corn Yield Forecast			
		2022	**2027**
SA % Change		SA Yield	SA Yield
32.30%	2017 Yield	6,668,114	8,821,609
	5,040,322		
WA % Change		WA Yield	SA Yield
34.45%		6,776,813	9,111,559

Note. Results after a single growth period to 2022 and through the second period to 2027.

Table 8 contains the results of forecasting using statistical regression using both the simple average and weighted aggregation of percent change in explanatory variables. Results are shown through one period to 2022 and a second period to 2027.

Weighted Growth Model Results

Table 9

Weighted Growth Model Yields

[5] Appears as fix48 in the regression reporting table, Appendix A Table A2

Weighted Growth Model Yields		
Method	2018	2027
Acres & Yield Growth	4,004,000	5,164,016
Acres & Yield Ratio	4,004,000	8,132,953

Note. Corn yield forecasting results for 2027 according to both methods applied from 2018 actual values.

Aggregation

To keep final corn yield estimates conservative, researchers weighted the most conservative results from both the statistical regression and the weighted growth model methods of estimation together equally to reach our final yield estimate of 6,992,812. Using the most recent price of $4.50 per bushel, as constant, from the UDAF's 2019 Utah Agricultural Statistics and Annual Summary Report, this estimated yield equates to a value of $31,467,996.

Estimated Losses to Corn

Gould (1963) estimates losses to corn from JB infestation at 10 bushels per acre. Researchers used this prior finding of 10 bushels per acre damage to estimate as the worst-case-scenario for losses to the Utah corn industry in 2027. Researchers also generated a most likely case and best-case scenario at eight and six bushels lost per acre. To determine the total acreage the forecasted 2027 yield represents, researchers derived simple and weighted average values of yield per acre from the same eight years of data used to calculate the growth of all independent variables used in statistical regression. The weighing scale, as well as results, are contained in Table 10.

Table 10

Yield to Acer Variable Growth

Yield to Acres Variable Growth								
Year	1987	1992	1997	2002	2007	2012	2017	
Yield	2,559,872	2,392,540	2,642,441	2,134,158	3,249,594	5,379,627	6,225,791	Simple Average
Acres	18,930	19,142	17,924	14,999	21,367	33,879	36,219	148
Yield/Acre	135.23	124.99	147.42	142.29	152.08	158.79	171.89	Weighted Average
Weight	3.0%	6.0%	9.0%	10.0%	20.0%	25.0%	27.0%	156
Weighted Y/A	4	7	13	14	30	40	46	

Note. Simple and weighted average yield per acre results as well as weighing scale used in weighted average calculations.

Table 11

Scenarios of Corn Loss Predictions for 2027

Corn Losses			
Acres	Loss per Acre	Bushels Lost	Value
	10	449,470	2,022,615
44,947	8	359,576	1,618,092
	6	269,682	1,213,569

Note. Number and value of corn bushels lost at 44,947 acres for worst-case (10), most-likely (8), and best-case (6) scenarios.

Forecasted yield was divided by the weighted average yield per acre of 156 bushels per acre to estimate a conservative total acreage estimate at 44,947 acres. The most likely case-scenario presents losses of 359,576 bushels equating to a value of $1,618,092.

Turfgrass Results

Researchers used various discount rates to estimate a best-case, most likely and worst-case scenarios of JB larvae damage to urban turfgrass. A constant market price of $0.69 per Sq. Ft. was used based on estimates from UDAF on the replacement cost of turf. If the cost to replace turf increases the benefit of foregone losses of turf will also increase. Researchers based the benefit of turf calculation on the best-case scenario, which indicates less damage caused by the JB larvae to turf. This ensures that the benefit is underestimated and not overestimated.

Therefore, if the results show that the benefit is greater than the costs, with underestimated benefits, the decision is more than justified to continue to control JB population. If the foregone losses are actually larger than estimated, then the benefits of quarantine would increase.

Table 8

Scenarios of Turf Loss Predictions for 2027

Turf Replacement Costs			
Sq. Ft of Turf	Turf Damaged	Sq. Ft Damaged	Replacement Cost
	50%	502,105,070	(345,197,236)
1,069,542,470	35%	341,673,699	(234,900,668)
	20%	181,242,329	(124,604,101)

Note. The table shows the estimated Sq. Ft of turf damaged and the cost to replace the damaged turf, based on a market price of $0.69 per Sq. Ft for the best-case, worst-case, and most likely scenarios based on various damage rates.

Researchers based best-case scenario on a 20% damage rate, which indicates that of the available turf for JB to survive in, only about 20% of that turf will be damaged. This 20% was used as a starting point since JB tends to aggregate in confined areas and tends to lay her eggs near feeding areas , indicating most larvae are relatively in close proximity to each other. Indicating damage would be confined to a relatively small area out of the entire turf in that area. The damage rates for the most-likely case and worst-case scenarios were estimated at 35% and 50%, respectively.

Aggregate Foregone Losses

Our findings suggest the aggregate foregone losses to Utah by continuing to maintain quarantine (corn and turf benefit to Utah's agriculture) is forecasted at a total of $126,222,199 in 2027.

Discussion

The purpose of this research is to identify the B-C ratio of UDAF continuing to control JB population in Utah. Researchers predict that as of 2019 data, the benefits will be significantly greater than the current costs for the state to control the beetle. We predict that for every $1 UDAF spends on control, the state as a whole will benefit by more than $1. Meaning that Utah should continue to provide the public good of JB quarantine.

The main benefit of this research is to provide the state with evidence in monetary terms if their efforts to control are warranted or not. This will allow the state to determine if resources (funds) are being allocated efficiently. The CBA will assist in making rational decisions on the allocation of scarce resources. By using monetary values, individuals can see the major costs and benefits of a decision. This research will also provide a framework for other states to calculate CBA on JB or another invasive species for their state. In addition, the framework can be utilized by UDAF to continue to reevaluate the B-C ratio of maintaining quarantine to ensure they maximize the efficiency of resource allocation.

If the results indicate the benefits are greater than the costs, we suggest Utah should continue to control JB population and should reject the decision of stopping control. The CBA will also indicate if the state is efficiently allocating resources. If the CBA deems that the costs outweigh the benefits, Utah should stop controlling JB population and leave it up to private economic agents. If the state continues to spend money on the control when the costs are greater than the benefits. This would be an inefficient use of resources, the state would be spending money to lose money, and the resources currently going toward this program would be more efficiently spent in a project that yields an efficient B-C ratio.

Limitations

The most significant limitations were data and resource constraints. Due to a lack of complete data that contained all variables required for each crop. Often data was incomplete, with missing Utah counties and other variables. Researchers were unable to find consistent data with similar variable measures for multiple different crops to allow for forecasting of a variety of crop yields.

Our models suggest the benefit (foregone losses) from maintaining quarantine is greater than the cost to quarantine the Japanese beetle at an estimated cumulative B-C ratio of $\$126{,}222{,}199 - \$480{,}000$ in 2027. The forecasted projections suggest that the accumulated costs of maintaining the quarantine are less than 1% of the potential losses to Utah Agriculture. The cost to benefit ratio can be interpreted as for every $\$0.0038$ spent on JB control, Utah benefits by gaining $1. The benefit to cost ratio can be interpreted as for every $1 spent on JB control, Utah benefits by gaining an estimated $263. Based on our findings, as of 2019 current JB populations in Utah, we recommend that the Utah Department of Agriculture and Food continues to maintain the quarantine against the Japanese Beetle. See Appendix C for complete summary of CBA on the JB for the State of Utah.

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Appendix A

Table A1

Variables Used for Statistical Regression Forecasting Method for Corn

Regression Varaibles	
cornyld - Total corn yield in bushes used for grain	labor - Summation of the hlabor and clabor variables
fert - Total cost of fertilizers applied measured in $1,000	proll - Total Farm payrolls measured in $,1000
chem - Total cost of chemicals applied measured in $1,000	workers - Number of workers
seeds - Total cost of seeds purchased measured in $1,000	rent - Total cost of all rents paid measured in $1,000
fuel - Total cost of fuels used measured in $1,000	mach - Total cost of machinery measured in $1,000
util - Total cost of agricultural utilities measured in $1,000	treatins - Number of acre treated for control of insects
hlabor - Total cost of hired labor measured in $1,000	treatcropl - Acres of cropland treated
clabor - Total cost of labor under contract measured in $1,000	
othexp - Total farm expenses incurred less the summation of all variables measured in $1,000 except proll	

Table A2

Regres-sion #	X1- Fert	X2-Chem	X3-Seeds	X4- Fuel	X5-Util	X6-La-bor	X7-HLabor	X8-CLabor	X9-Rent	X10-Mach	X11-Treatins	X12-Treat-Cropl	X13-Other-Exp	X14-Workers	X15-HLabor/Workers	X16-Labor/Workers	X17-Chem/Treatins	X18-Proll	X19-Proll/Workers	E-Cornyld	R^2
2 Way Fixed Effect Equations																					
fix1	217.804	-200.770	41.214																		0.370
fix2	1.227	0.252	-0.470																		0.294
fix3	200.202*						-60.975	-81.467													0.443
fix4	1.658**						-0.740	-0.143													0.486
fix5	0.673	1.315		0.093			-1.213	-0.161													0.560
fix6	1.428**		0.132		1.603*		-2.169**	0.016													0.733
fix7	1.616**		-0.422		1.471*		-1.837*														0.548
fix8	1.305**				1.414*		-1.944*			0.110											0.593
fix9	1.263**				1.407*		-2.229**						1.274*								0.694
fix10	0.603	0.919			1.233*		-2.440**						1.336*								0.727
fix11		1.488**			1.170*		-2.477***						1.400**								0.709
fix12	1.440**			-0.711	1.430*		-2.270**						1.260*								0.714
fix13	2.892**				1.261*		-1.940**		-1.542*				-0.074								0.795
fix14	2.630**				1.247*	-1.853**			-1.278				-0.113								0.773
fix15	2.209***				1.172**	-2.114***			-1.123**		0.985										0.828
fix16	2.522*					-1.325			-1.246*		1.166	-0.311									0.707
fix17	703957*				311525	-312693			-326205		-69260									Not Logged	0.465
fix18	0.273				0.458						1.293			-1.578							0.424
fix19	1.031*													-0.716							0.308
fix20	0.478										1.361			-1.285							0.399
fix21						-0.583					2.271**			-1.070							0.340
fix22					0.574						1.533			-1.727*							0.415
fix23					1.447*	-2.170**					1.851*										0.512
fix24					1.181	-1.589				0.010	1.347										0.340
fix25				0.281	1.430*	-2.181**					1.821*										0.515
fix26				0.193	0.168						1.033					-0.120					0.178
fix27				0.136	0.063						1.019				0.117						0.176

Regression #	X1- Fert	X2- Chem	X3- Seeds	X4- Fuel	X5-Util	X6-Labor	X7- HLabor	X8- CLabor	X9- Rent	X10- Mach	X11- Treatins	X12- Treat-Cropl	X13- Other-Exp	X14- Workers	X15- HLabor/ Workers	X16- Labor/ Workers	X17- Chem/ Treatins	X18- Proll	X19- Proll/ Workers	E- Cornyld	R^2
Two Way Fixed Effect Equations																					
fix28	1.217				0.109										-0.792						0.281
fix29	1.530	-0.371			0.242										-0.842						0.287
fix30	1.503*		-0.726		0.629										-0.265						0.338
fix31					0.070						1.036				0.129						0.175
fix32					0.898							3.810**			-0.432						0.495
fix33	3.274***				0.279				-1.822**						-1.450*						0.654
fix34					0.404										-0.034		0.475				0.109
fix35					0.477											-0.314	0.577				0.116
fix36	1.384*				0.196											-1.181					0.330
fix37	1.160				0.156														-0.615		0.308
fix38	1.008				0.761									-0.497				-0.713			0.428
fix39																		-0.053			0.001
fix40					1.133													-0.677			0.196
fix41														-.0623				0.170			0.030
fix42	0.928				0.011																0.244
fix43	1.443**				1.437	-2.236**															0.610
fix44	1.529**				1.418*	-2.419**								0.283							0.614
fix45	2.533***				1.260*	-1.876**			-1.190**												0.773
fix46	2.410				1.227*	-2.066*			-1.088	0.158											0.605
fix47	1.958**	0.796			1.113*	-2.058**			-1.178**												0.797
fix48	2.209***				1.172**	-2.114***			-1.123**		0.985										0.827
One Way Fixed Effect Equations																					
fix49	2.209***				1.172**	-2.114***			-1.123**		0.985										0.827
Random Effects Equations																					
rand36	1.227**				0.069											-0.3374					0.508
rand48	2.051***				0.989*	-1.285***			-0.707		0.257										.806

Table A3

Historical values of independent variables. Simple and weighted average results. Weighing scale applied for weighted results.

util Variable Growth							
Year	1997	2007	2012	2017	Simple Average		cornyld % Change
Value	15,792	23,677	30,095	36,154	32.39%	Equation Ceofficient	37.949%
Growth		49.9%	27.1%	20.1%	Weighted Average	1.17163	cornyld % Change
Weight		20.0%	30.0%	50.0%	28.18%		33.022%
Weighted Growth		10.0%	8.1%	10.1%			

labor - SA Variable Growth										
Year	1987	1992	1997	2002	2007	2012	2017	Simple Average		cornyld % Change
Value	31,657	45,874	50,258	62,815	85,390	103,294	128,890	26.86%	Equation Ceofficient	-56.782%
Growth		44.9%	9.6%	25.0%	35.9%	21.0%	24.8%	Weighted Average	-2.11431	cornyld % Change
Weight		5.0%	8.0%	11.0%	17.0%	27.0%	32.0%	25.46%		-53.828%
Weighted Growth		2.2%	0.8%	2.7%	6.1%	5.7%	7.9%			

labor- WA Variable Growth										
Year	1987	1992	1997	2002	2007	2012	2017	Simple Average		cornyld % Change
Value	31,657	45,874	50,258	62,815	85,255	103,294	128,890	26.85%	Equation Ceofficient	-56.774%
Growth		44.9%	9.6%	25.0%	35.7%	21.2%	24.8%	Weighted Average	-2.11431	cornyld % Change
Weight		5.0%	8.0%	11.0%	17.0%	27.0%	32.0%	25.47%		-53.860%
Weighted Growth		2.2%	0.8%	2.7%	6.1%	5.7%	7.9%			

fert Variable Growth										
Year	1987	1992	1997	2002	2007	2012	2017	Simple Average		cornyld % Change
Value	9,317	12,563	17,077	16,458	24,792	43,973	42,225	31.86%	Equation Ceofficient	70.381%
Growth		34.8%	35.9%	-3.6%	50.6%	77.4%	-4.0%	Weighted Average	2.20887	cornyld % Change
Weight		5.0%	8.0%	11.0%	17.0%	27.0%	32.0%	32.44%		71.663%
Weighted Growth		1.7%	2.9%	-0.4%	8.6%	20.9%	-1.3%			

treatins Variable Growth										
Year	1987	1992	1997	2002	2007	2012	2017	Simple Average		cornyld % Change
Value	163,472	160,755	131,531	137,608	162,006	193,510	223,499	6.24%	Equation Ceofficient	6.149%
Growth		-1.7%	-18.2%	4.6%	17.7%	19.4%	15.5%	Weighted Average	0.98511	cornyld % Change
Weight		5.0%	8.0%	11.0%	17.0%	27.0%	32.0%	12.19%		12.013%
Weighted Growth		-0.1%	-1.5%	0.5%	3.0%	5.3%	5.0%			

rent Variable Growth										
Year	1987	1992	1997	2002	2007	2012	2017	Simple Average		cornyld % Change
Value	9,726	10,405	11,698	14,540	19,160	32,219	29,717	22.64%	Equation Ceofficient	-25.401%
Growth		7.0%	12.4%	24.3%	31.8%	68.2%	-7.8%	Weighted Average	-1.12171	cornyld % Change
Weight		5.0%	8.0%	11.0%	17.0%	27.0%	32.0%	25.33%		-28.418%
Weighted Growth		0.3%	1.0%	2.7%	5.4%	18.4%	-2.5%			

Table A4

Year to year forecast results for method using solely growth rates titled "Growth Forecast" and results for method using growth rate and ratio titled "Ratio Forecast"

Weighted Growths	
Bearing Acreage	4.27%
Yield per Acre (growth)	-1.34%
Yield per Acre (ratio)	0.79%

Growth Forecast									
Year	2019	2020	2021	2022	2023	2024	2025	2026	2027
Acres Harvested	22,939	23,918	24,938	26,003	27,112	28,269	29,476	30,733	32,045
Yield per Acre	182	189	198	206	215	224	233	243	254
Total Yield	4,167,451	4,530,725	4,925,665	5,355,033	5,821,828	6,329,313	6,881,036	7,480,852	8,132,953
Price	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Value of Utilized	18,753,527	20,388,261	22,165,494	24,097,648	26,198,226	28,481,910	30,964,662	33,663,833	36,598,290

Ratio Forecast									
Year	2019	2020	2021	2022	2023	2024	2025	2026	2027
Acres Harvested	22,939	23,918	24,938	26,003	27,112	28,269	29,476	30,733	32,045
Yield per Acre	180	177	175	172	170	168	166	163	161
Total Yield	4,118,804	4,236,900	4,358,381	4,483,346	4,611,894	4,744,128	4,880,153	5,020,078	5,164,016
Price	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5
Value of Utilized	18,534,618	19,066,048	19,612,716	20,175,058	20,753,524	21,348,575	21,960,688	22,590,352	23,238,070

Appendix B

Japanese Beetle Survival Factors for ArcGIS Map

- Land Topography:
    - Turf. All grass/turf in Utah, including areas like pastures, lawns, golf courses, etc.
    - Vegetation type. Near fields of fruits (i.e., apples, apricots, sweet cherries, tart cherries, peaches) of rye, clover, corn, beans, tomatoes, and nursery stock. JB tends to lay eggs in close proximity (within 100 ft) to host plants.
    - Prefers to lay eggs in tall over low brush
    - Also likes moist sandy areas: including sandy loams and loams
    - Moderate soil texture
- Temperature:
    - June-August average temps between 15 °C - 31°C
- Mean Soil Temperature:
    - June- August between 17.5°C and 27.5°C
    - Soil temperature during winter is above -9.4°C (below 9.4 no survival).
    - Low moisture environments not as suitable for survival
- Soil Moisture: moderate to high soil moisture, loose and moist soil
    - Drought: will not lay eggs in area that are hard and dry and will find another place
    - Irrigation
- Average Precipitation at least 250 mm during the summer (below 250mm JB larvae can-not survive)
    - Infrequent summer drought
    - Irrigated areas

Appendix C



ECONOMIC RISK ANALYSIS

UTAH AND THE JAPANESE BEETLE ON TURF AND CORN

By Sarah Jane Grundon and Hudson Schmucker

Benefit of Corn

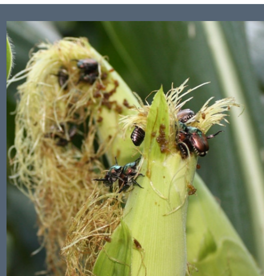
Estimated Damages for 2027		
Best Case Scenario 6 Bushels	Most Likely Scenario 8 Bushels	Worst Case Scenario 10 Bushels*
269,683 bushels	359,577 bushels	449,472 bushels
$1,213,574	$1,618,098	$2,022,623

*Base of 10 bushels per acre (Gould, 1963)

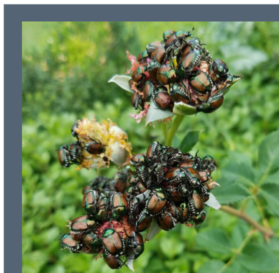
Benefit of Turf

Estimated Damages for 2027		
Best Case Scenario 20% Damage	Most Likely Scenario 35% Damage	Worst Case Scenario 50% Damage
181,242,329 Sq. Ft	341,673,699 Sq. Ft	502,105,070 Sq. Ft
$124,604,101	$234,900,668	$345,197,235

Aggregate Cost-Benefit Analysis of Japanese Beetle on Turf and Corn in Utah



Benefit	2027
Corn Yield / Revenues Saved	$1,618,098.04
Savings of replacement for turf based on total possible turf in Urban areas in Utah (Based on 20% damage)	$124,604,101.12
TOTAL	$126,222,199.17



Cost	2019	2027
Overall Estimated Cost to Quarantine (Government cost to trap beetles, Government cost of insecticides, etc.)	$60,000.00	$480,000.00
TOTAL		$(480,000.00)

Forecasted Projections

Our forecasted projections suggest the accumulated costs of maintaining the quarantine is less than 1% of the potential losses to Utah Agriculture. Based on our findings, we recommend that the Utah Department of Agriculture and Food continues to maintain the quarantine against the Japanese Beetle.

Our findings suggest the benefit to Utah's agriculture by maintaining quarantine is greater than the cost to quarantine the Japanese beetle at an estimated cost-benefit of $480,000-$126,222,199 in 2027.

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Appendix D

Economic Terminology

Opportunity Cost: The opportunity cost of a decision made is the foregone benefits (loss of potential gains) of an alternative decision. It is the lost value of the next best alternative of allocating recourses (funds) when a decision is made.

Cost-Benefit Analysis (CBA): a methodology for estimating all costs and potential benefits of a decision measured in monetary terms to determine the net social benefit to society. Allows for more efficient resource allocation by making rational decisions.

Benefit-Cost Ratio (B-C): The benefit to cost ratio states for every $1 spent the benefit will be equal to $\$\frac{benefit}{cost}$. Shows the relationship between the benefits and costs of a decision, expressed in monetary terms.

Free-Rider Problem: A market failure that occurs when some individuals benefit from using resources and public goods, but do not pay for them. Whoever pays for the resource's gains, but those who do not pay also gain.

Public Good: Goods that are non-rival, consumption of the good by one individual does not prevent others from consuming and non-excludable, non-paying consumers cannot be excluded from using the good.

Economic Efficiency: When scarce resources are optimally allocated in a way the minimizes waste (inefficiency). The economy is pareto optimal (any change would leave some individuals worse off). It also occurs when a good or service is produced at the lowest possible cost.

Economic Costs/ Damages/ Social Costs: the social cost includes the tangible monetary costs to quarantine (i.e., cost of pesticides, labor, etc.) and external costs to society that would occur from not providing the public good.

Social Benefits: these are the benefit to society that are positive externalities (meaning the market fails because the good or service is underproduced) providing the public good.