Colony Collapse Disorder and an Analysis of Honey Bee Colony Numbers - High School Sample Classroom Task

Introduction

Colony Collapse Disorder (CCD) refers to the drastic loss of honey bees and honey bee colonies, such as what has been observed around the world in recent decades. Because many of the causes that are thought to be associated with CCD do not represent changes within a stable population, the changes in honey bee populations over time can be used to investigate factors affecting the bee populations during periods of stability as well as instability (including the potential causes of CCD). In this task, students use data from domestic honey bee populations as a model within which to study the dynamics of CCD. Students mathematically model changes in the bee colony numbers from the United States and from two individual states, California and South Dakota. Students then use their constructed mathematical models to describe factors affecting the bee colony populations. The students choose function(s) that best fit the data, both the whole dataset and a subdivided data set. Based on trends identified by the models, students also consider how changes in bee colony numbers might affect the overall stability and biodiversity of ecosystems in which the honey bees participate. Finally, students evaluate a proposed solution for CCD using a set of criteria and constraints.

This task was inspired by the 2010 United Nations Environment Programme (UNEP) Emerging Issues report "Global Honey Bee Colony Disorders and Other Threats to Insect Pollinators." Available at: (http://www.unep.org/dewa/Portals/67/pdf/Global_Bee_Colony_Disorder_and_Threats_insect_pollinators.pdf)

Standards Bundle

(Standards completely highlighted in bold are fully addressed by the task; where all parts of the standard are not addressed by the task, bolding represents the parts addressed.)

CCSS-M

MP.2 **Reason abstractly and quantitatively.**

MP.3 **Construct viable arguments and critique the reasoning of others.**

MP.4 **Model with mathematics.**

HSF.LE.1 **Distinguish between situations that can be modeled with linear functions and with exponential functions.**

HSF.LE.2 **Construct linear and exponential functions,** including arithmetic and geometric sequences, **given a graph, a description of a relationship, or two input-output pairs (include reading these from a table).**

HSF.LE.5 **Interpret the parameters in a linear or exponential function in terms of a context.**

HSS.ID.6 **Represent data on two quantitative variables on a scatter plot, and describe how the variables are related.**

HSS.IC.6 **Evaluate reports based on data.**

NGSS

HS-LS2-2 **Use mathematical representations to support and revise explanations based on evidence about factors affecting biodiversity and populations in ecosystems of different scales.**

HS-LS2-6 Evaluate the claims, evidence, and reasoning that **the complex interactions in ecosystems maintain relatively consistent numbers and types of organisms in stable conditions**, but changing conditions may result in a new ecosystem.

HS-ETS1-3 **Evaluate a solution to complex real-world problem based on prioritized criteria and trade-offs that account for a range of constraints, including cost, safety, reliability, and aesthetics, as well as possible social, cultural, and environmental impacts.**

CCSS-ELA/Literacy

RST.11-12.2 **Determine the central ideas or information of a primary or secondary source; provide an accurate summary that makes clear the relationships among the key details and ideas.**

RI.11-12.7 **Integrate and evaluate multiple sources of information presented in different media or formats (e.g., visually, quantitatively) as well as in words in order to address a question or solve a problem.**

RST.11-12.7 **Integrate and evaluate multiple sources of information presented in diverse formats and media (e.g. visually, quantitatively, as well as in words) in order to address a question or solve a problem.**

RST.11-12.9 **Synthesize information from a range of sources (e.g., texts, experiments, simulations) into a coherent understanding of a process, phenomenon, or concept, resolving conflicting information when possible.**

W.11-12.7, & WHST.11-12.7

Conduct short as well as more sustained research projects **to answer a question (including as self-generated question) or solve a problem; narrow or broaden**

inquiry when appropriate; synthesize multiple sources on the subject, demonstrating understanding of the subject under investigation.

W.11-12.9 & WHST.11-12.9

Draw evidence from informational texts to support analysis, reflection, and research.

Information for Classroom Use

Connections to Instruction

This task is aimed at students in 10th or 11th grade, in Biology 1, a comparable course, or an integrated science course that includes the ecosystem dynamics, and who have successfully completed the requirements of a rigorous Algebra I course. This task would be used after students have studied interdependent relationships in ecosystems and energy transfer in ecosystems, and during or after students have explored the dynamic interactions involved in ecosystems. The task should be completed after students have had experience with modeling contextual situations using linear equations and, ideally, after students have studied a variety of function families, for each of which they could compare the characteristics in determining the best function for the data presented. Fitting a line or curve to data can be done based on the students' prior experience with families of functions. If the task is done within an Algebra 1 course, students could be limited to using linear and quadratic function models. The entire task is intended as a means of checking for students understanding of mathematical and science concepts related to modeling ecosystem dynamics, particularly within an integrated math/science course. Because the plotting required in Task Components A, B and C is used as evidence for the discussion in those task components and the ones that follow, students could be allowed to revisit the plots before completing the remained of the task components.

This task includes interdisciplinary connections to ELA/ Literacy in both reading and research (writing). Here the informational texts students research and/or read are represented both in words and graphically and come from both primary and secondary sources, including informational texts students locate via research and informational texts students compose in words and/or graphically throughout the various components of the task; however, in this task, the reading students do is assessed via writing, which in this task most closely aligns with writing in relation to short research projects. Students can be formatively assessed on the reading standards and on drawing evidence from informational texts through writing for Task Components A through F and assessed on the reading and research standards formatively in Task Components G and H.

This task has been aligned to the ELA/Literacy reading and research standards for the 11–12 grade band. Teachers using this task in 9th or 10th grade should refer to the comparable CCSS for the 9–10 grade band.

Approximate Duration for the Task

The entire task could take from 3 to 8 class periods (45-50 minutes each) spread out over the course of an instructional unit, with the divisions listed below:

Task Components A, B and C: 1-3 class periods total, depending on whether parts are done outside of class.

Task Components D, E and F: 1-3 class periods total, depending on whether parts are done outside of class.

Task Component G: up to 1 class period, depending on whether parts are done outside of class.

Task Component H: 1-2 class periods, depending on whether parts are done outside of class.

Note that this timeline only refers to the approximate time a student may spend engaging in the task components, and does not reflect any instructional time that may be interwoven with this task.

Assumptions

- Teachers must be familiar with regression models for mathematical modeling, which can be determined using a graphing calculator or a software program such as Excel.
- Students successfully completing this task will need to have studied interdependent relationships and energy transfer in ecosystems and be comfortable with function families and using plotting programs to fit a line or curve to the data.

Materials Needed

- It is assumed that students have access to graphing calculators and/or a computer plotting or spreadsheet program that allows students to input data and conduct regressions.
- Students will need to research honey bees and CCD. Access to the Internet or a set of articles for students to use are necessary.

Supplementary Resources

- Honey Bees and Colony Collapse Disorder, from U.S. Department of Agriculture Agricultural Research Service with information on CCD: www.ars.usda.gov/News/docs.htm?docid=15572
- Optional video for introductory purposes: www.youtube.com/watch?v=eB4HdG8he4g
- U.S. Historical Population Data: www.census.gov/popest/data/historical/
- USDA National Agriculture Statistics Service's reports: http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1191

Accommodations for Classroom Tasks

To accurately measure three dimensional learning of the NGSS along with CCSS for mathematics, modifications and/or accommodations should be provided during instruction and assessment for students with disabilities, English language learners, and students who are speakers of social or regional varieties of English that are generally referred to as "non-Standard English".

Classroom Task

Context

It is said that one out of every three bites of food that we eat comes from a plant that was pollinated by a bee. Honey bees transfer pollen as they move among many different flowers in their search for food/pollen, and account for 80% of all pollination by insects. Because of their huge pollination contribution, humans have come to rely on honey bees. For example, we depend on honey bees to pollinate crops, such as fruits, vegetables, and tree nuts. Indeed, honey bee-driven pollination is needed for high fruit and vegetable yields, resulting in an estimated $15 billion increase in crop value each year. Additionally, we use products that honey bees create, such as honey and beeswax, to make things the people want and need. For example, we use honey bee venom to make arthritis medicine.

Many honey bee colonies have experienced a significant drop in numbers of bees. This phenomenon is referred to as Colony Collapse Disorder (CCD). Overall, CCD is expected to have an economic impact on agricultural food production that will significantly affect humans. As a result, government agencies and scientists from around the world are researching CCD. Part of that research involves identifying bee colonies that are affected and documenting changes in bee colony numbers in different geographic areas. Another important part of their research is studying the potential causes of CCD. Currently, scientists have identified at least three potential causes: parasites, pesticides, and poor nutrition of the bees. It is not yet clear if just one of these, or some combination of these, is causing CCD. In this task, you will use domestic honey bee populations (i.e., cultivated in the United States) as a model for honeybee ecosystem dynamics across the world. You will (1) investigate bee colony population numbers, (2) consider factors that are affecting these numbers, and (3) develop and evaluate potential solutions to decrease bee colony loss due to CCD.

Task Components

A. Use the provided data on honey bee populations (Attachment 1) to graph the change in U.S. (not California- or South Dakota-specific data) bee colony numbers over time on a scatterplot. You may use a graphing or spreadsheet program to create your plot. Choose a mathematical function (linear, exponential, logarithmic, etc.) that could be used to model the change in bee populations over time for the entire time range of the dataset (1939-2013). Write an equation for the function that you think best fits the entire dataset. Using only the function you created, describe the changes in bee colony numbers in the United States over time. In your description, make a prediction based on your function and equation for how bee colony numbers will change in the future.

   I. For datasets that have a lot of variability, the mathematical function serves as a simplified explanation of how the variables are related, identifying a general trend within “noisy” data. Because of this, it is important to evaluate how well the function actually represents the changes in the data set. Consider the fit of your function to the data set, and describe how well your chosen function represents the dataset. Describe (1) specific characteristics of the fit of the equation to the data, and (2) limitations or inadequacies of the fit of the equation to the data. Use specific examples from your scatter plot as evidence in your description.

B. Reconsider the scatterplot of U.S. bee colony numbers as follows: Subdivide the dataset and choose at least two different functions to describe the change in bee colonies over time. Write an equation for each of your functions. Use the functions you created to describe the changes in the bee colony numbers over time. In your description, make a prediction based on your functions for how bee colony numbers will change in the future.

I. Describe how the changes over time in the bee colony numbers, and your predictions for the future, changed based on how the dataset was mathematically modeled. Describe why you may want to model different portions of the data with different functions, and describe what this might mean for how the bee colony data are interpreted.

C. Use the provided data on honey bee populations (Attachment 1) to graph the change in bee colony numbers over time in California and South Dakota on a scatterplot(s). You may use a graphing or spreadsheet program to create your plots. Choose a mathematical function or functions (linear, exponential, logarithmic, etc.) that could be used to model the change in bee populations over time in each state. Write an equation(s) for the function(s) that you think best fits the entire dataset.

I. Compare the U.S., California, and South Dakota datasets. Cite specific similarities and/or differences among the scatterplots and the functions and equations that model the data. Can the smaller scale of state data be used to understand/make predictions about the larger scale model for the United States? Which state would you chose to use if you wanted to conduct a smaller scale experiment on bee colonies that could be used as a way to test solutions for the changes affecting bee colony numbers in the entire U.S.? Are there any additional factors you would need to consider? Describe the reasoning behind your answer.

D. Which parts of the U.S. honey bee colony data (1939–2013) that you mathematically modeled in Task Components A and B do you think represent the population fluctuations of a stable bee population? Which parts of the data do you think represent an unstable change in the population? Using what you know about the limiting factors that affect populations in an ecosystem (predation, competition for food, competition for living space, disease, etc.), identify (a) what factors you think limited the bee population and determined or defined the carrying capacity of the bee population, keeping it stable, and (b) what factors you think caused the drastic change in the bee populations. Based on the functions that you defined in Task Components A and B, at what point do you think these factors affecting the bee population changed? Describe the reasoning behind your choices. Cite the U.S. or state bee colony numbers, plots, functions, and/or equations as evidence as appropriate. Also, consider the pressures and influences of larger-scale ecosystems that honey bees are a part of and/or interact with, including the human ecosystem. See Attachments 2 and 3 for a chart and scatter plots of human population data for the U.S., California, and South Dakota to reference when you are constructing your answer.

E. Review the suspected causes of colony collapse disorder (see the USDA-Agricultural Research Services “Honey Bees and Colony Collapse Disorder” webpage or any other external references you may find helpful). Consider the evidence that connects each suspected cause to CCD and any information on when these cause agents may have become an issue or problem, such as when an invasive species may have been introduced. Based on your research and the data and plots produced in previous task components, revise your discussion for (a) what factors you think limited the bee populations and determined or defined the carrying capacity of the bee population, keeping it stable, and (b) what factors you think caused the drastic change in the bee populations. Based on the functions that you defined in Task Components A and B and the data plots, at what point do you think these factors affecting the bee populations changed, and how does this timing relate to what is known about the timing of the suspected cause agents?

F. Reconsider your comparison of the U.S., California, and South Dakota bee colony number datasets as follows: Based on what you have learned about the suspected causes of CCD and through your evaluation of the U.S. bee colony numbers dataset, revise your explanation for how the smaller scales of state data can be used to understand/make predictions about the larger scale model for the United States. Include in your revision a description of what you think the data suggest about whether each of the smaller-scale state bee ecosystems are affected by the same causes/stressors as is the larger U.S. bee ecosystem.

G. Construct an argument of how continued trends related to changes in bee colony numbers might be impacting the stability and biodiversity of ecosystems and agricultural systems in which the bees participate. Cite your data plots, functions, and equations as evidence for your argument and describe why they can be used as evidence. You may also review and cite scientifically relevant external references and examples as evidence. Describe effects on ecosystems outside of the human agricultural system as well as effects on the human ecosystem, specifically related to food production. Clearly state the boundaries and scale of the human and non-human ecosystems that you are describing.

H. Based on external research, construct a list of suggested solutions for CCD. In your list, include solutions that require or use new forms of technology as well as those that are associated with changes in beekeeping practices. Choose one of these solutions, and evaluate the solution using your understanding of population changes and ecosystem stability and any evidence or data you may uncover in your research of the solution. Describe how this solution is intended to work to decrease the effects of CCD, determine how well the solution meets the criteria and constraints that are listed below, and define trade-offs in instances of competing criteria:

- The solution is effective in decreasing the effects of CCD on bee populations
- It is low in cost
- It isn't too complex (doesn't require a large number of different types of changes)
- It is safe for beekeepers to use or administer
- It has minimal effect on other species in the ecosystems in which the bees participate
- It addresses as many suspected causes of CCD as possible
- It is reliable through repeated use
- It addresses any cultural, social, or aesthetic concerns of the human community in

which the solution is being used
- If it involves technology, it is an accessible solution for beekeepers with a range of technological knowledge and capabilities

Based on your evaluation, do you feel that the solution is a viable solution for CCD given the constraints? Describe your reasoning.

Alignment and Connections of Task Components to the Standards Bundle

Task Components A, B, and C ask students to use data on honey bee colony numbers in the United States and in individual states (California and South Dakota) to determine which mathematical function(s) can be used to model bee populations and then answer questions related to the fit of the data to the functions and what the functions imply about changes in bee populations over time at different scales. This partially addresses the NGSS performance expectation of **HS-LS2-2** and part (an individual bullet from Appendix F) of the associated practice of **Using Mathematics and Computational Thinking** and part of the crosscutting concept of **Scale, Proportion, and Quantity**. This also partially addresses part of the NGSS crosscutting concept of **Patterns**. By choosing which functions and equations to use that will best model the datasets and by discussing the fit and implications of the function to the dataset, students can demonstrate their understanding of parts of the CCSS-M content standards of **HSF.LE.1** (addresses only the stem statement, the subparts of this standard are not addressed), **HSF.LE.2** (the task does not address arithmetic and geometric sequences), and **HSF.LE.5** (the task does not explicitly require that the parameters of the functions will be specifically addressed). More fully addressed are the CCSS-M content standard **HSS.ID.6** and the CCSS-M practices of **MP.2** and **MP.4**. The understanding of the change in bee populations in these task components is enhanced by the modeling of the datasets, particularly the parts where the future changes in the populations may be different depending on the function chosen, while the need to consider multiple models for the science dataset provides an opportunity to check for a student's ability to decide what type of function to use, to discuss the importance of the fit of the data, and to describe the modeled relationships, given a realistic context. In order to describe, explain, compare and contrast, evaluate, and make predictions based on these data, students address parts of ELA/Literacy standards **RST.11-12.2**, **RI.11-12.7**, **RST.11-12.7**, and **RST.11-12.9**, reading informational text and on **W.11-12.9** and **WHST.11-12.9**, drawing evidence from informational texts to support writing.

Task Components D, E, and F ask students to consider factors affecting bee populations (stable and unstable changes), following the modeled relationships of bee population changes over time, to consider potential cause factors of CCD, and then to revise their explanation of factors affecting the bees based on the new information and how it matches the modeled relationships. This partially assesses the NGSS performance expectation of **HS-LS2-2** and parts of the associated core ideas of **LS2.A: Interdependent Relationships in Ecosystems** and **LS2.C: Ecosystem Dynamics, Functioning, and Resilience (as they relate to HS-LS2-2, HS-LS2-6, and HS-LS2-7)**, parts of the practices of **Obtaining, Evaluating, and Communicating Information** and **Using Mathematics and Computational Thinking**, and part of the crosscutting concept of **Scale, Proportion, and Quantity**. This also partially assesses part of the NGSS crosscutting concepts of **Patterns**, **Cause and Effect** and **Stability and Change (as it relates to HS-LS2-6)**. By using modeled relationships to consider and discuss the connection between the data and causes for population changes, students are partially assessed on the CCSS-M content standard **HS-S-IC.6**, and the CCSS-M practices of **MP.2** and **MP.3**, which further enhances assessment of the science standards. When students must review suspected causes of CCD, they are partially addressing part of the NGSS practice of **Obtaining, Evaluating, and Communicating Information**. By reviewing both primary and secondary source information and considering evidence to evaluate and support cause/effect claims, students are partially addressing the CCSS- ELA/Literacy standards **RST.11-12.2**, **RI.11-12.7**, **RST.11-12.7**, and **RST.11-12.9**, reading informational text; and by reviewing web resources or other relevant external references students are partially addressing **W.11-12.9** and **WHST.11-12.9**, drawing evidence from informational texts to support writing.

Task Component G asks students to consider and describe how changes in bee populations will affect the ecosystems in which bees participate. This partially addresses the NGSS performance expectation of **HS-LS2-2** and part of the associated core idea of **LS2.C: Ecosystem Dynamics, Functioning, and Resilience**. This also partially addresses part of the NGSS practice of **Engaging in Argument from Evidence**; part of the crosscutting concepts of **Stability and Change**, **Cause and Effect,** and **Systems and Systems Models**; and part of the core idea of **LS4.D: Biodiversity and Humans**, particularly when students discuss the effect of bee population changes on the human ecosystem. By reviewing and citing both primary and secondary source information, students demonstrate the understanding of parts of the ELA/Literacy standards **RST.11-12.2**, **RI.11-12.7**, **RST.11-12.7**, and **RST.11-12.9**, reading informational text and on **W.11-12.9** and **WHST.11-12.9**, drawing evidence from informational texts to support writing. By reviewing and citing scientifically relevant external references, students are also partially addressing **W.11-12.7** and **WHST.11-12.7**, conducting short research projects.

Task Component H asks students to research solutions to the CCD issues, to evaluate one of the possible solutions using the provided criteria (including technological solutions and potential tradeoffs), and to comment on the viability of the solution for CCD. This addresses several parts of the NGSS performance expectation of **HS-ETS1-3** through an integration of part of the core idea of **ETS1.B: Developing Possible Solutions**; part of the practice of **Constructing Explanations and Designing Solutions**, and part of the connection to engineering, technology, and applications of science of **Influence of Science, Engineering, and Technology on Society and the Natural World**. This also partially addresses part of the NGSS core idea of **LS4.D: Biodiversity and Humans**. By conducting external research to construct a list of suggested solutions, students partially address **W.11-12.7** and **WHST.11-12.7**, conducting short research projects; on **RST.11-12.2**, **RI.11-12.7**, **RST.11-12.7**, and **RST.11-12.9**, reading informational text; and on **W.11-12.9** and **WHST.11-12.9**, drawing evidence from informational texts to support writing.

Together, **Task Components A, B, C, D, E, F, and G** address all parts the NGSS performance expectation of **HS-LS2-2** in this context. The task components address and integrate parts of the core ideas of **LS2.A: Interdependent Relationships in Ecosystems** and **LS2.C: Ecosystem Dynamics, Functioning, and Resilience (as they relate to HS-LS2-2, HS-LS2-6, and HS-LS2-7)**; part of the practice of **Using Mathematics and Computational Thinking**, and part of the crosscutting concept of **Scale, Proportion, and Quantity** by using functions of bee population data at two different scales (United States and individual states) to describe how population changes associated with normal population stressors and potential causes of CCD affected the ecosystem of a bee colony and the ecosystems in which bees participate.

Evidence Statements:

Task Component A

- Students identify the mathematical function family that best fits the entire dataset, and write an equation to represent the data that fits within that function family.
- Students describe the data in terms of the equation they produced (e.g., decreasing linearly with a slope of...), and predict future changes in bee colony numbers that reflect the numbers identified by extending the equation line beyond year 2013.
- I. Students make a statement about how well the function represents the data set.
- I. Students describe any of the following as evidence:
  - places where the pattern of the equation matches the pattern of the data (e.g., both increasing linearly)
  - places where the pattern of the equation does not match the pattern of the data
  - places where the data are located far from the equation line (a poor fit)
  - places where the data are located near or along the equation line (a good fit)
- I. Students connect the evidence to their statement of how well the function represents the dataset, explicitly describing some of the following reasoning:
  - Because the pattern does not match all or part of the data, the equation does not represent the dataset well.
  - Because the data points are located far from the equation line in part of or all of the plot, the equation does not represent the dataset well.
  - Because the pattern matches all or a large portion of the data, the equation represents the dataset well.
  - Because the data points are located near or along the equation line in parts or all of the plot, the equation represents the dataset well.

Task Component B

- Students identify the mathematical function families that best fit the subdivided dataset, and write equations that fit within those function families to represent each subset of the data.
- Students describe the data following the equation they produced for the part of the dataset that includes 2013, and they predict future changes in bee colony numbers that reflect the numbers identified by the extension of that equation line beyond year 2013.
- I. Students describe how the number of colonies changed over time was different when different parts of the dataset could be modeled using different functions (the degree of difference will depend on the student's choice of functions and equations).
- I. Students include one of the following ideas in their description of the changes:
  - The prediction for the future was similar or the same (e.g., both decreasing).
  - The prediction for the future was different (e.g., one continuing to decrease and the other leveling off to relatively unchanging numbers).
- I. Students identify and describe evidence from the scatterplots. Examples include the following:
  - Where the dataset is modeled with two different equations, the mathematical relationship describing the change in bee colonies is different.

  - When modeled with two equations, there is better fit between the equations and the data.
  - Part of the datasets are described by the same type of function, but the equations are not exactly the same.
- I. Students describe their reasoning about how changes to the functions describing the dataset are related to the following:
  - A change in the interpretation of the how the bee colonies changed over time.
  - How the prediction for the future stayed nearly the same or different.
  - How a section of the dataset may be better modeled if the dataset is subdivided, even if the prediction for the future is not that different (e.g., better fit in earlier decades).

Task Component C

- Students identify the mathematical function family/families that best fit(s) each state dataset, and write equations that fit within those function families to represent the datasets
- I. In their comparison, students include a statement that the California dataset (plots, functions, and/or equations) is similar to the U.S. dataset, while the South Dakota dataset is different.
- I. Students identify and describe, as evidence, a comparison of observations between the U.S. dataset and each of the state datasets. Examples include the following:
  - Both the U.S. and California datasets show a decreasing trend (linear, etc.) in more recent years.
  - While the U.S. dataset shows a decreasing trend in the more recent years, the South Dakota dataset shows an increasing trend.

- I. Students explicitly describe their reasoning that the usefulness of the state scale for understanding, predicting or testing changes to the bee populations at the United States scale is dependent on how similar the changes in bee populations are between the state scale and the United States scale, and how similar the variation in the data sets are. Examples include the following:
  - Because the California dataset is most similar to the U.S. dataset, the factors affecting the population are probably similar, so it may be used as a smaller scale model of the U.S. ecosystem to make predictions of the future of bee populations or to test solutions for CCD.
  - Because the South Dakota dataset is different from the U.S. dataset, the factors affecting the population are probably different, so it should not be used as a smaller scale model of the U.S. ecosystem to make predictions of the future of bee populations or to test solutions for CCD.
- I. In their reasoning, students include that although smaller-scale studies might be done in a single state, the variation in the U.S. data has contributions from a number of states, so factors that affect the data trends in multiple states are important contributors. Students reason that comparisons of the state-level data sets, and determining the factors contributing to CCD at those levels, may help parse the relative contributions of those factors to CCD at the U.S. scale.

Task Component D

- Students identify time spans between 1939 and 2013 that represent fluctuations of a stable population (e.g., 1945–1965) and fluctuations of an unstable population (e.g., 1965–2013).
- Students connect the identified years of stable and unstable population changes to the features of the plot, function(s), and/or equations.
- Students include reasoning for why the cited features on the graph represent stable/unstable changes in the population. For example:
    - The linear function that describes the change in population between 1945 and 1965 has a small, relatively flat slope, which indicates that there was little change in the population over that time period, so it was most likely stable.
    - The liner function that describes the change in population between 1965 and 2013 has a decreasing slope; in this time period, human populations were increasing, but the bee populations were decreasing in what was probably an unstable change.
- Students identify factors (predation, competition for food, competition for living space, disease, etc.) that limited the bee population during times of population stability, defining its carrying capacity.
- Students identify factors that are causing unstable changes during the times of instability.
- Students describe their reasoning behind the choices for why a specific factor was chosen to be the cause of stable population changes versus unstable population changes. For example:
    - Predation and disease are causes of unstable population changes if the predation is from a new predator or a new disease is introduced.
    - Competition for food and living space are causes of stable population changes because the number of bees would only be as high as is possible given the food and hive space that there is available.
- Students identify a time period(s) during which the factors affecting the bee populations changed, and cite the changes in the functions that model the dataset as evidence for the choice of dates.

Task Component E

- Students obtain information from at least two sources, and evaluate both the information and sources for credibility.
- In the revision, students identify and describe a connection between one of the suspected causes of CCD and the causes of the unstable population change from the original explanation.
- Students describe why a specific factor was chosen to be a cause of a stable or unstable population change, including reasoning associated with the addition of suspected causes of CCD.
- Students describe the possible relationship between the timing of suspected causes and the modeled functions and/or the interpretation of which parts of the dataset represent stable and unstable changes, including describing a specific relationship between the introduction of a suspected cause of CCD in the bee ecosystem and the cited timing of the change in bee populations from stable to unstable (e.g., the introduction of the *Varroa* mite in the 1980s or the growing use of *neonicotinoid* pesticides in the 1990s).

Task Component F

- Students update or revise their comparison to include a comparison of the timing of the transition from stable to unstable population change between United States and state datasets, including whether the timing of specific causes of CCD can also be linked to the state datasets.
- In their revised comparison, students include the reasoning that:
  - Decreasing colony numbers in California are more likely to reflect the effects of CCD (similar to the U.S. population), so the state could be used as a smaller scale representative of the U.S. population, although the California data does not look exactly like the US population data.
  - Increasing colony numbers in South Dakota are more likely to show that CCD may not be affecting those colonies, so the state would not be a good smaller scale representative of the U.S. population.

Task Component G

- Students make the claim that the decreasing trend in bee colony numbers may lead to a corresponding decrease in the stability and biodiversity of the ecosystems in which they participate.
- Students identify the boundaries and scale of the human and non-human ecosystems discussed as examples.
- Students identify evidence that shows or connects decreasing bee numbers with a corresponding decrease or loss of species in another ecosystem (dominantly non-human) in which they participate (e.g., one result of fewer bees would be decreased pollination, which may lead to fewer plant seeds and an overall decrease or loss in the plant populations).
- Students identify evidence that shows or connects decreasing bee numbers with a corresponding change in the amount, types, or cost of fruit/produce within a dominantly human ecosystem (e.g., fewer bee colonies are available for rent, so the cost of bee hive rental increases and the cost of fruit goes up).
- Students evaluate the evidence for relevance and sufficiency to support the claim, and identify any weaknesses in the evidence.
- Students use the evidence and their evaluation to describe reasoning that because species numbers decrease or are lost, the biodiversity may decrease and the ecosystem in which the bees participate may become unstable.

Task Component H

- Students construct a list of suggested solutions for CCD, and identify one solution as the solution to be evaluated.
- Students evaluate the identified solution, including a description of how the solution works to decrease the effects of CCD.
- In their evaluation of the solution, students identify how well the solution meets each of the listed criteria and constraints and describe logical reasoning for why the solution meets those criteria and constraints.
- In their evaluation of the solution, students identify trade-offs between competing criteria and constraints, and describe reasoning for why one criterion or constraint is met over another.

- Students cite and describe externally sourced data or scientific knowledge as evidence in support for why a criterion or constraint is or is not met.
- Students provide a single final statement on the viability of the solution for CCD given all of the criteria and constraints and any reasoning or examples.

Attachment 1. Number of Honey Bee Colonies in the United States, California, South Dakota Reported from Producers with Greater than Five Colonies (1939-2013)

Number of Bee Colonies (in thousands)			
Year	California	South Dakota	United States
1939	380	13	4422
1940	380	14	4350
1941	395	14	4477
1942	435	17	4893
1943	448	18	4887
1944	470	18	5217
1945	470	16	5460
1946	461	18	5787
1947	470	18	5916
1948	442	17	5724
1949	438	16	5591
1950	451	15	5612
1951	487	17	5559
1952	521	19	5493
1953	537	23	5520
1954	537	24	5451
1955	537	35	5300
1956	548	36	5296
1957	559	40	5365
1958	559	49	5381
1959	570	59	5402
1960	564	67	5396
1961	581	74	5507
1962	587	83	5498
1963	599	89	5530
1964	599	96	5600
1965	605	92	5556
1966	559	95	4766
1967	559	101	4815
1968	565	104	4770
1969	559	110	4762
1973	500	131	4103
1974	500	148	4195
1975	500	158	4163
(continued)			
1977	525	165	4346
1978	504	171	4081
1979	504	204	4155
1980	504	220	4141
1981	500	180	4213
1986	520	201	3205
1987	500	250	3190
1988	520	245	3186
1989	535	230	3311
1990	480	245	3188
1991	520	225	3200
1992	470	240	3030
1993	500	245	2876
1994	400	260	2770
1995	420	240	2647
1996	390	240	2566
1997	400	240	2579
1998	450	225	2633
1999	505	224	2688
2000	440	235	2634
2001	425	235	2513
2002	440	225	2524
2003	480	200	2590
2004	390	215	2556
2005	400	220	2410
2006	380	225	2932
2007	340	255	2442
2008	360	225	2301
2009	355	270	2462
2010	410	265	2684
2011	370	250	2491
2012	340	270	2624
2013	330	265	2640

Data are compiled from the United States Department of Agriculture National Agriculture Statistics Service's "Honey Production" (1940's-1980's) and "Honey" (1970's-2010's) reports:
http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1191
http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1670

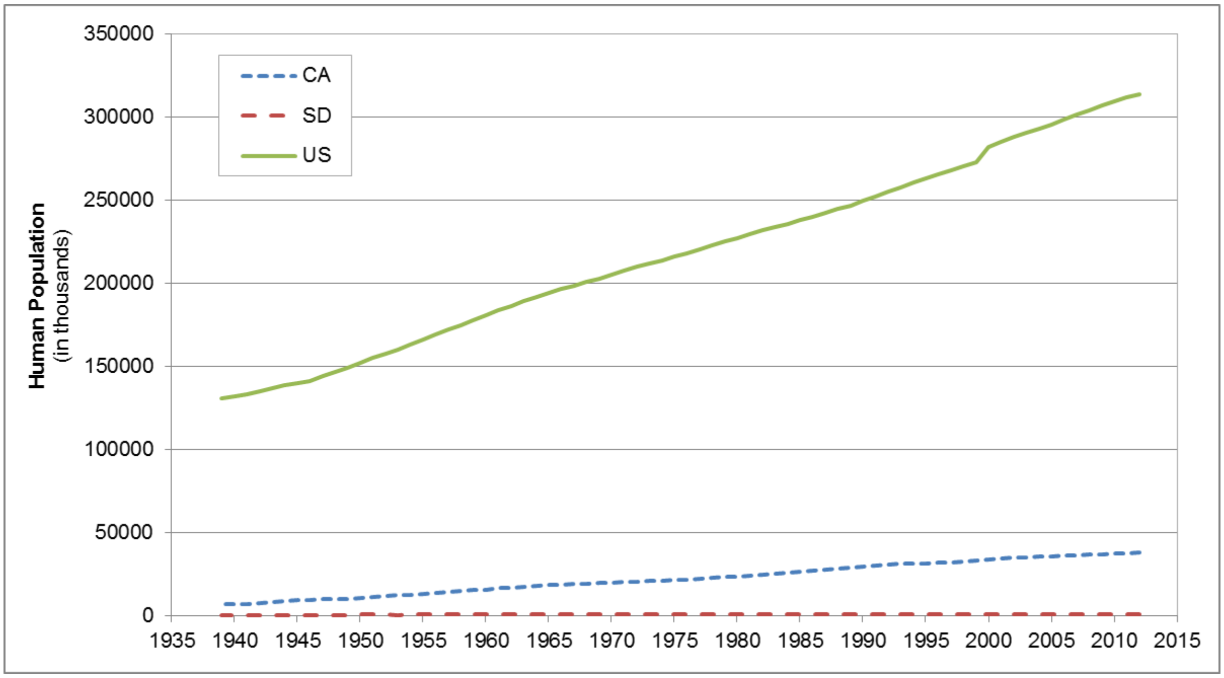
Attachment 2. Human Population for the United States, California, and South Dakota (1939-2012)

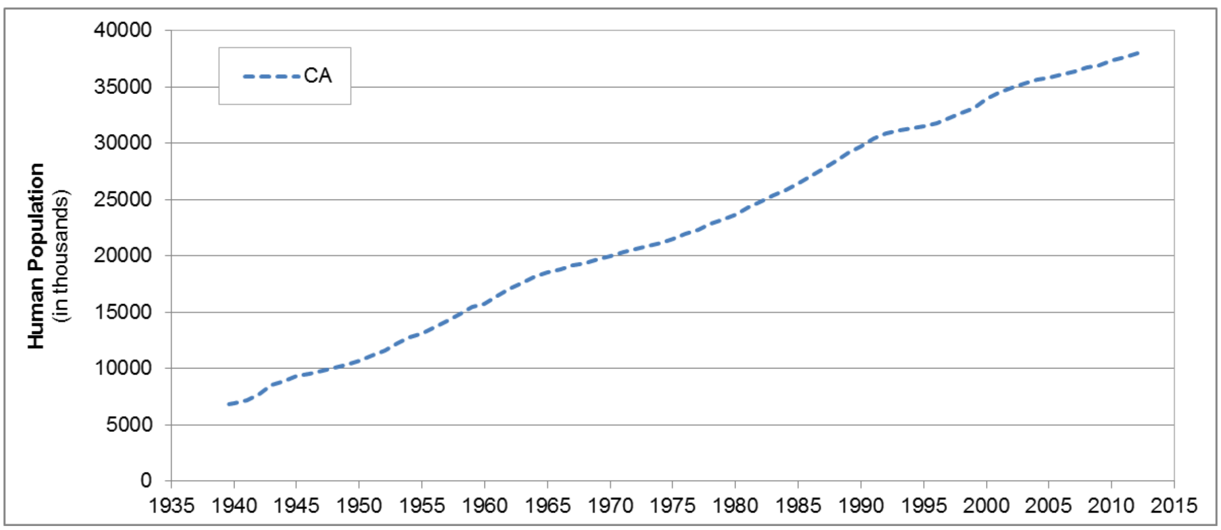
Human Population (in thousands)			
Year	California	South Dakota	United States
1939	6785	645	130880
1940	6950	641	132122
1941	7237	613	133402
1942	7735	589	134860
1943	8506	587	136739
1944	8945	565	138397
1945	9344	579	139928
1946	9559	588	141389
1947	9832	601	144126
1948	10064	612	146631
1949	10337	631	149188
1950	10677	653	152271
1951	11134	655	154878
1952	11635	651	157553
1953	12251	648	160184
1954	12746	655	163026
1955	13133	663	165931
1956	13713	670	168903
1957	14264	666	171984
1958	14880	656	174882
1959	15467	667	177830
1960	15717	681	180671
1961	16497	693	183691
1962	17072	705	186538
1963	17668	708	189242
1964	18151	701	191889
1965	18585	692	194303
1966	18858	683	196560
1967	19176	671	198712
1968	19394	669	200706
1969	19711	668	202677
1970	19953	666	205052
1971	20346	671	207661
1972	20585	677	209896
1973	20869	679	211909
1974	21174	680	213854
1975	21538	681	215973
1976	21936	686	218035

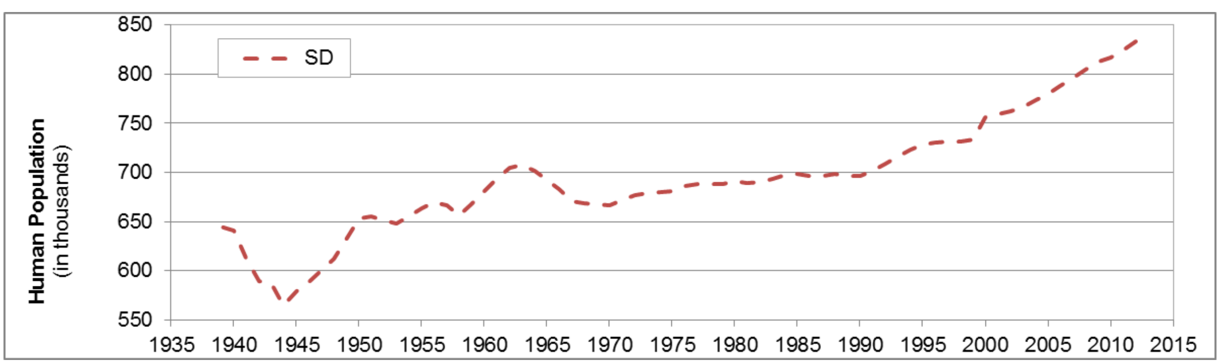
Human Population (in thousands)			
Year	California	South Dakota	United States
(continued)			
1977	22352	688	220239
1978	22836	689	222585
1979	23257	688	225055
1980	23668	691	227225
1981	24286	690	229466
1982	24820	691	231664
1983	25360	693	233792
1984	25844	697	235825
1985	26441	698	237924
1986	27102	696	240133
1987	27777	696	242289
1988	28464	698	244499
1989	29218	697	246819
1990	29760	696	249464
1991	30414	701	252153
1992	30876	709	255030
1993	31147	716	257783
1994	31317	723	260327
1995	31494	728	262803
1996	31781	731	265229
1997	32218	731	267784
1998	32683	731	270248
1999	33145	733	272691
2000	33999	756	282172
2001	34507	759	285040
2002	34916	762	287727
2003	35307	766	290211
2004	35630	774	292892
2005	35885	779	295561
2006	36121	787	298363
2007	36378	796	301290
2008	36757	804	304060
2009	36962	812	307007
2010	37334	816	309330
2011	37684	824	311592
2012	38041	833	313914

US Historical Population Data was compiled from: https://www.census.gov/popest/data/historical/

Attachment 3. Human Population Graphs: United States, California, and South Dakota (1939-2012)

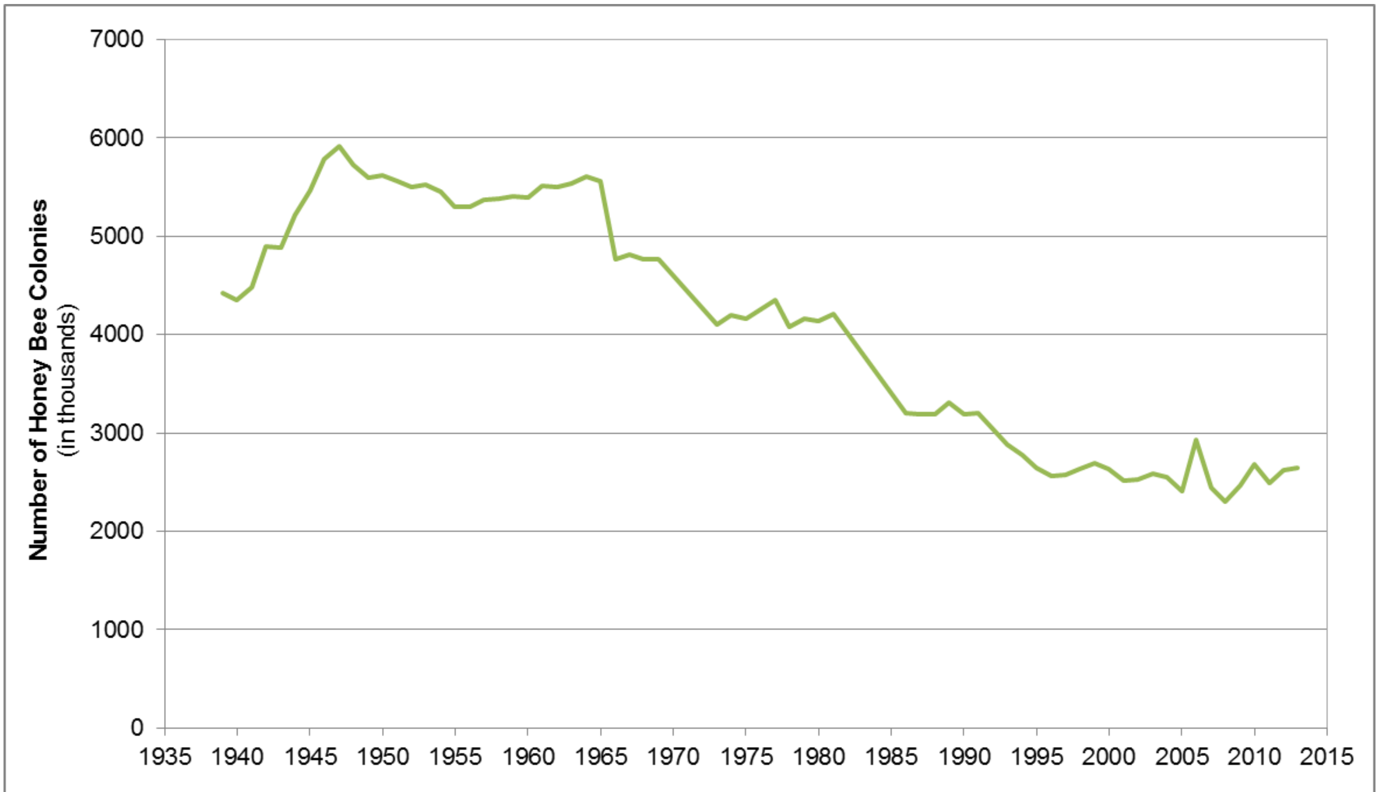


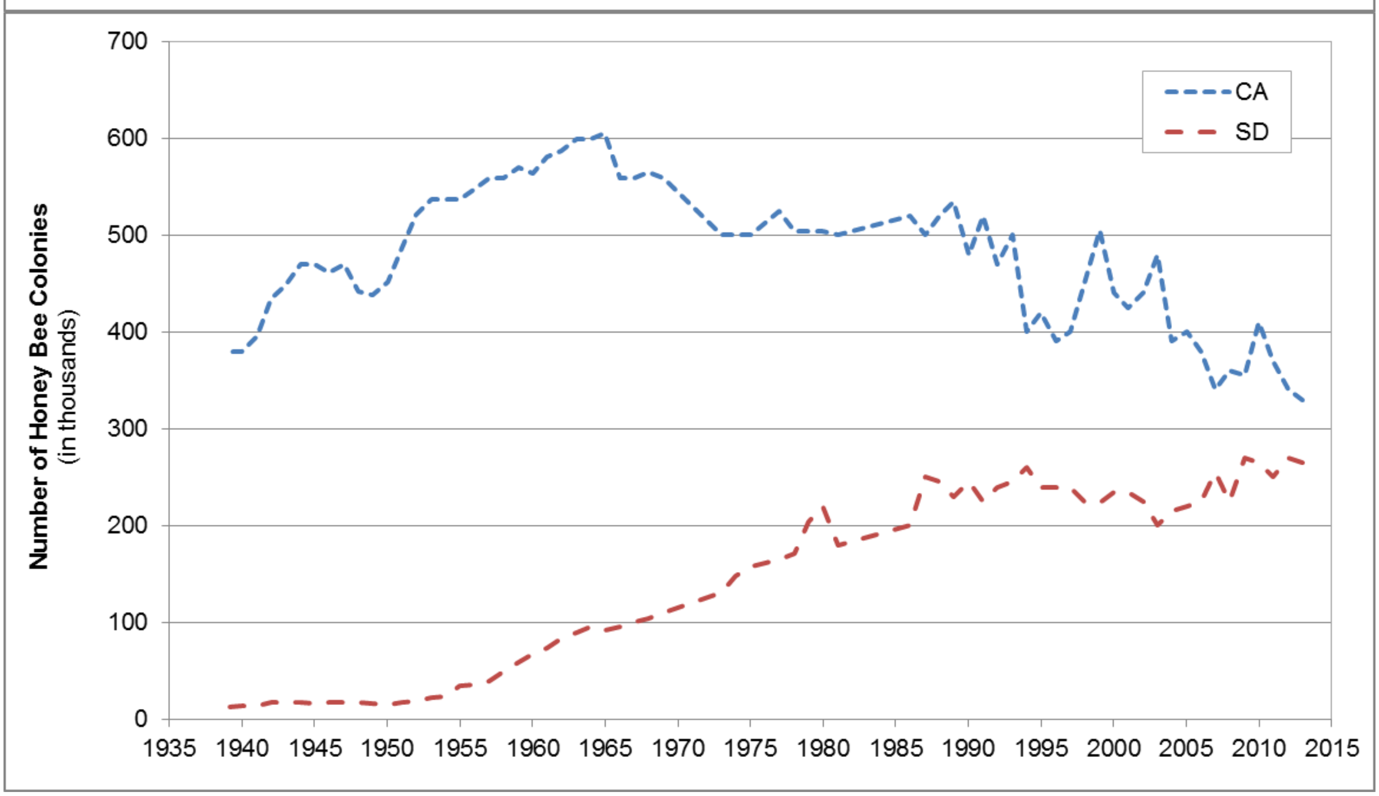


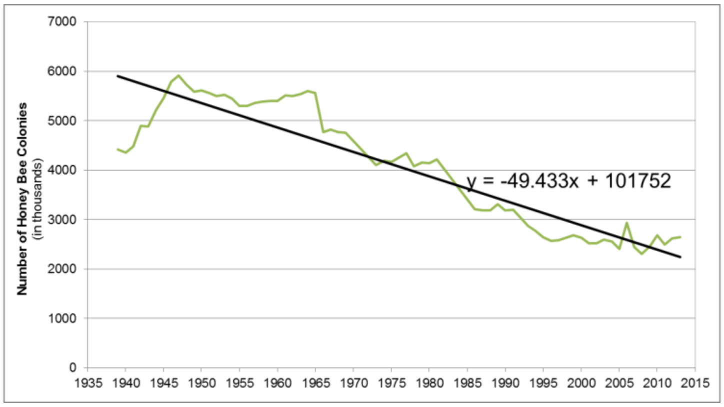


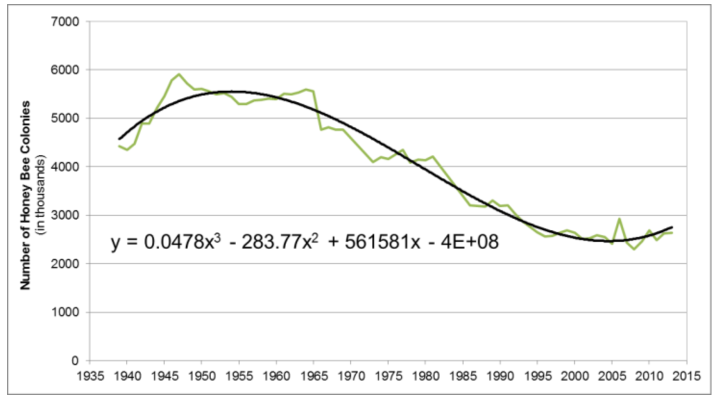
Sample Answer Plots

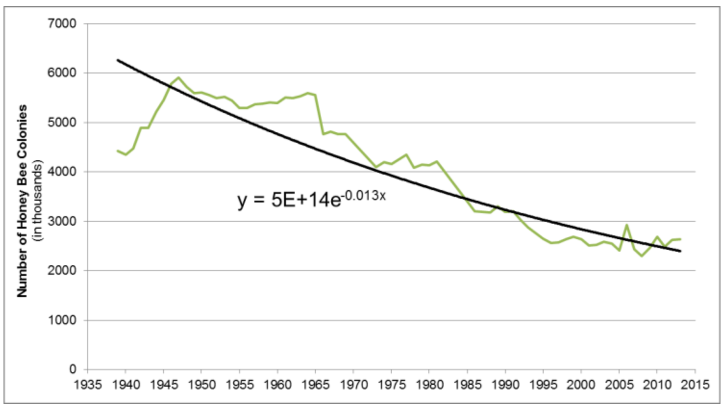
Number of Honey Bee Colonies Graphs: United States, California and South Dakota (1939-2013)

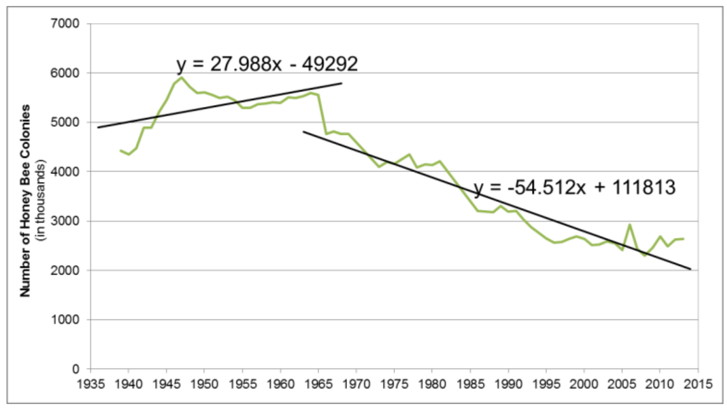


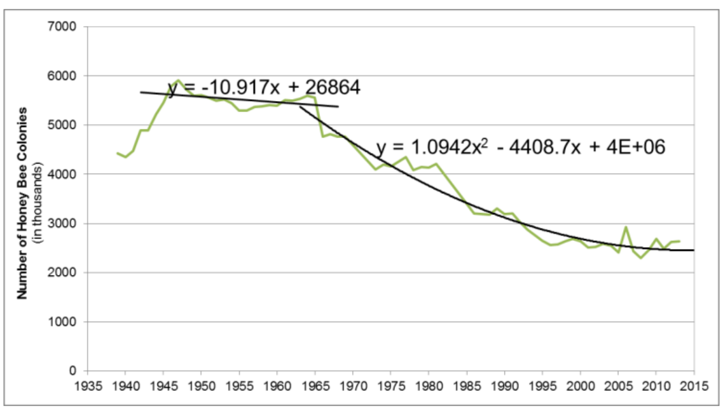


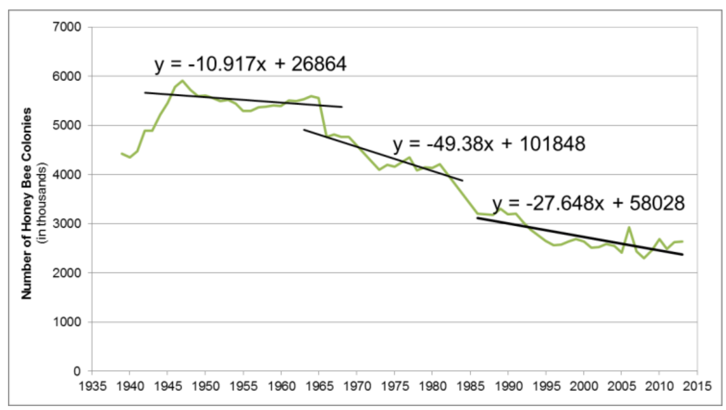

Number of Honey Bee Colonies (in thousands)
y = -49.433x + 101752

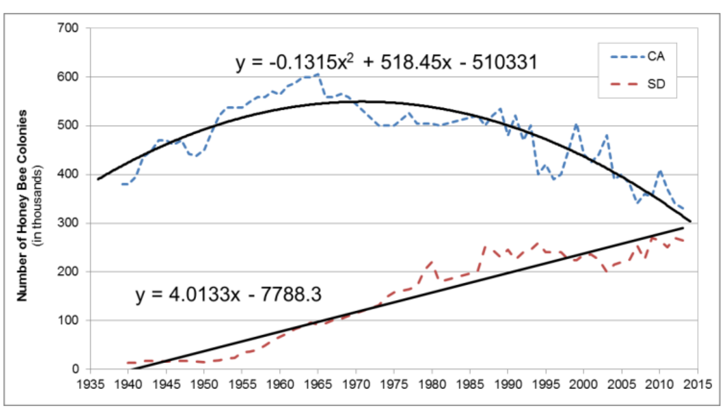

Number of Honey Bee Colonies (in thousands)
y = 0.0478x³ - 283.77x² + 561581x - 4E+08

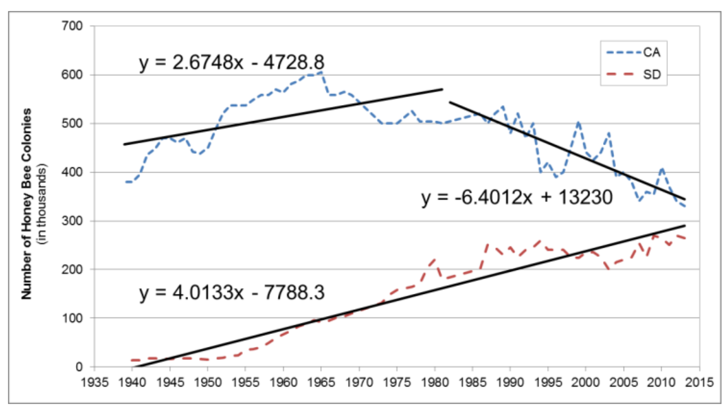

Number of Honey Bee Colonies (in thousands)
y = 5E+14e^-0.013x


Number of Honey Bee Colonies (in thousands)
y = 27.988x - 49292
y = -54.512x + 111813


Number of Honey Bee Colonies (in thousands)
y = -10.917x + 26864
y = 1.0942x² - 4408.7x + 4E+06


Number of Honey Bee Colonies (in thousands)
y = -10.917x + 26864
y = -49.38x + 101848
y = -27.648x + 58028


Number of Honey Bee Colonies (in thousands)
y = -0.1315x² + 518.45x - 510331
CA
SD
y = 4.0133x - 7788.3


Number of Honey Bee Colonies (in thousands)
y = 2.6748x - 4728.8
CA
SD
y = -6.4012x + 13230
y = 4.0133x - 7788.3