# Pennsylvania Winter Colony Survival Analysis

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## Summary

We analyzed data from the PSBA surveys from 2017-2021. The results of the analysis determined:

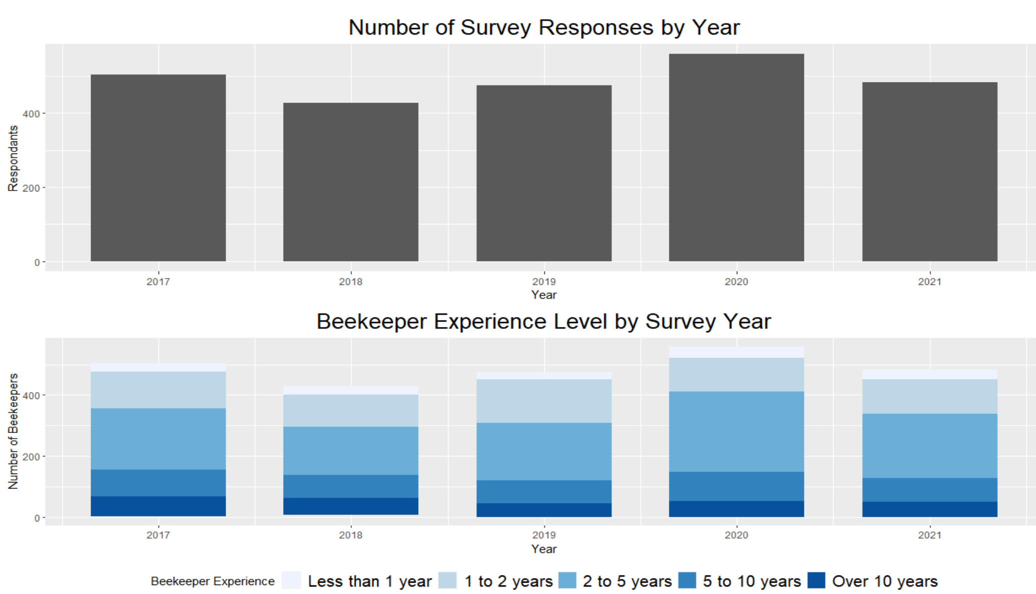
- Varroa treatment is critical for colony survival.
- Chemical treatment supports highest survival rates.
- Using multiple types of treatment yields higher survival than one type of treatment.
- Feeding had a slight significant effect on colony survival.
- Beekeeper years of experience and apiary size do not predict survival.
- Temperature and rainfall are critical for colony survival.
- Mid-ranges for both temperature and precipitation seem to promote the highest survival rates.
- Including addition years of data boosted the prediction accuracy of the model.

## Introduction

The Pennsylvania State Beekeepers Association (PBSA) conducts an annual survey of beekeepers across the state each year. This packet presents results of analysis of the data for the years 2017-2021, for which we conducted some exploratory analysis of survival and generated a machine learning model to understand environmental predictors of colony survival, as described in Calovi et al 2021.

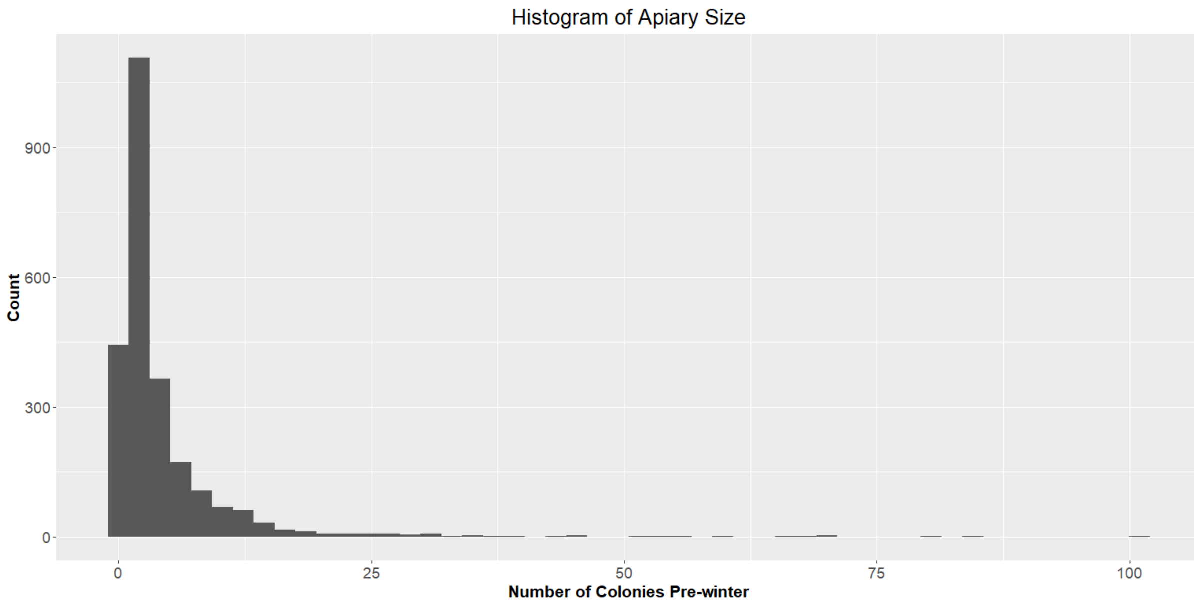
### *Responses*

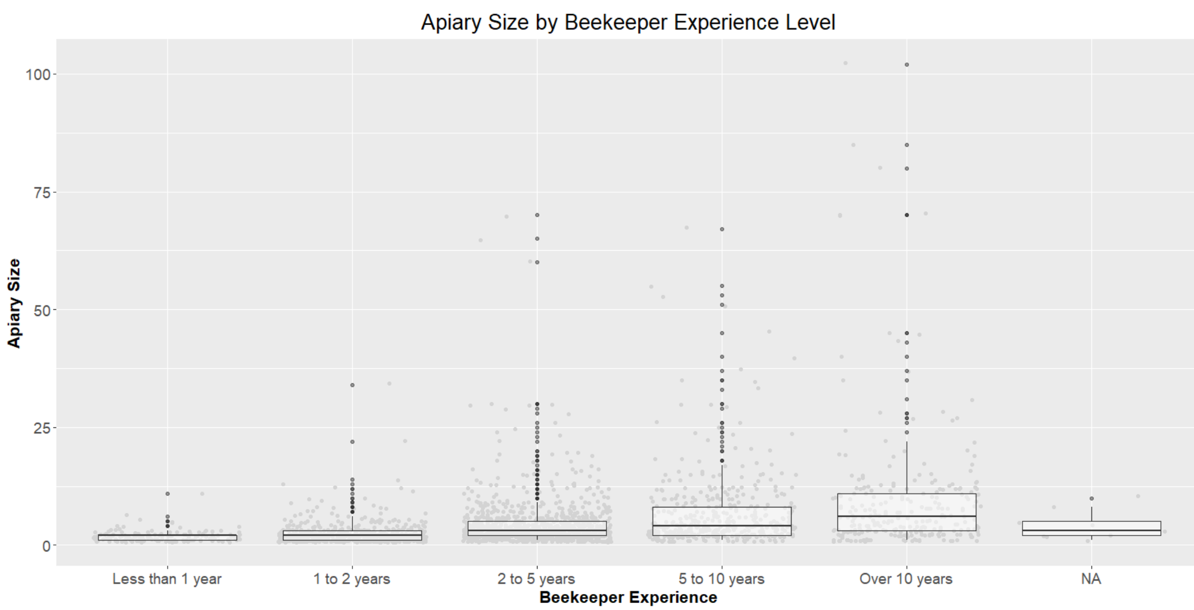
Overall, this analysis used 2,450 survey responses collected by the PBSA survey. For 2021 only that included 483 beekeepers and 1,793 pre-winter colonies. The distribution of survey responses across the years was relatively even, and levels of beekeeping experience were also consistent across the years of the survey.



## *Apiary Size*

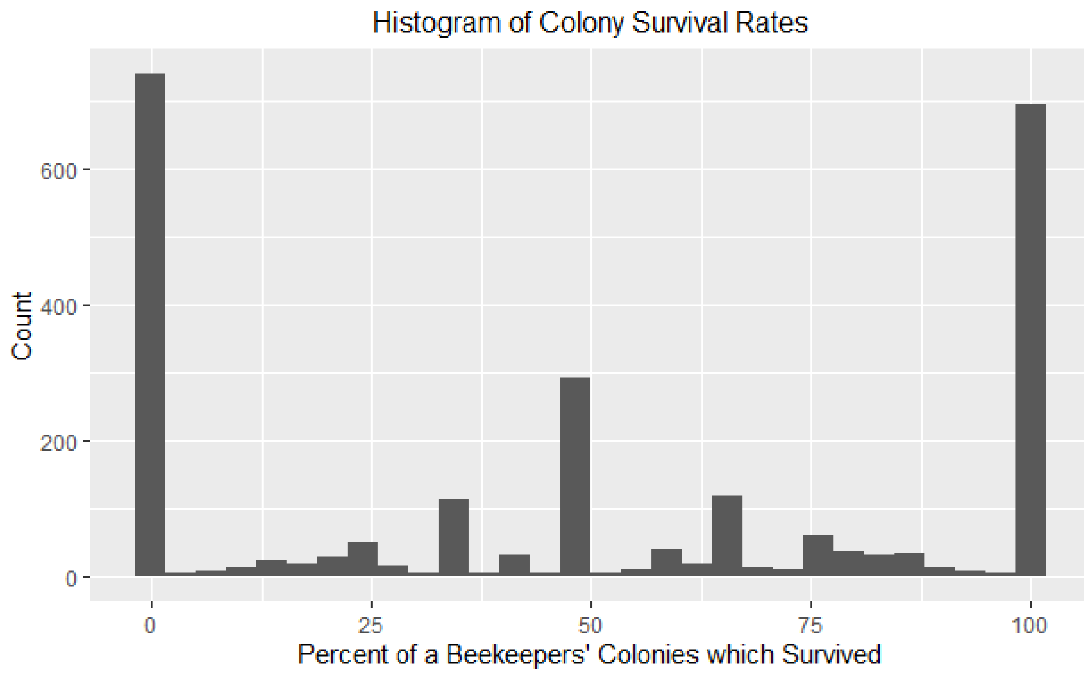
The survey asks about the number of colonies a beekeeper has before the preceding winter. The results show a left- skewed distribution, with most beekeepers having between 1 and 10 colonies. This can also be examined against beekeeper years of experience.



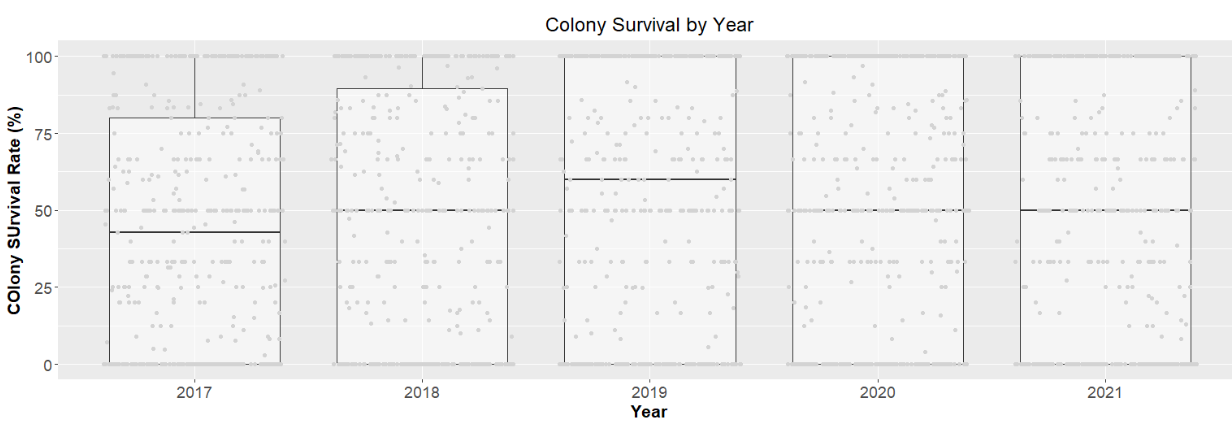



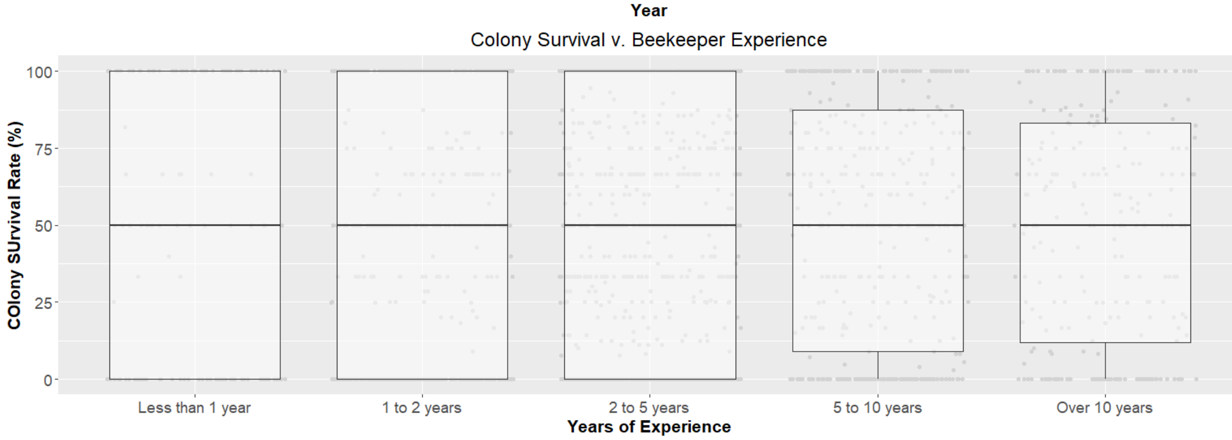

## *Colony Survival*

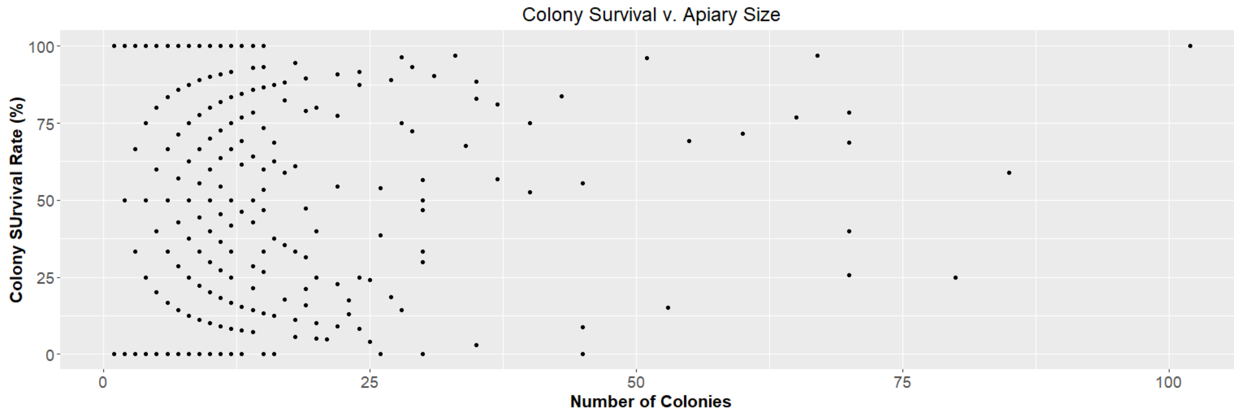
The survey asks beekeepers about the number of colonies they have pre- and post- winter. From this, we can derive winter survival as a percentage of the original colonies. The colony survival plot appears to have two peaks, with many beekeepers losing either 100% or 0% of their colonies and some losing 50%.




We can also explore other factors to see if they line up with survival in meaningful ways.



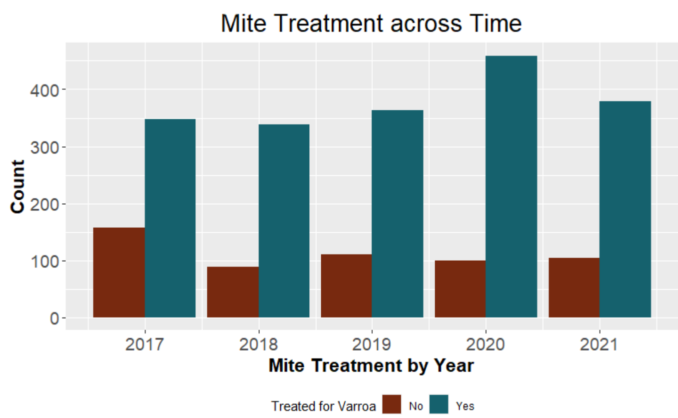


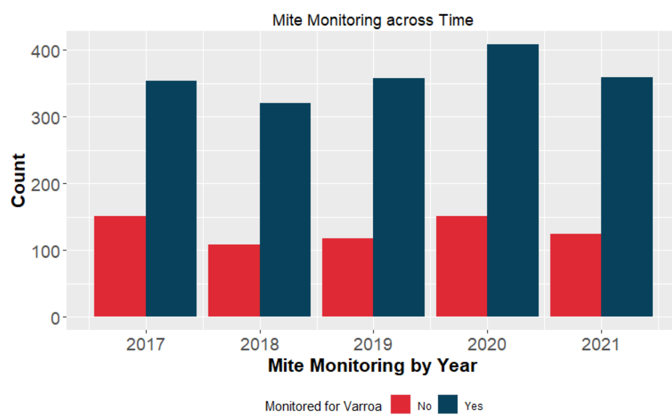

# Beekeeping Practices

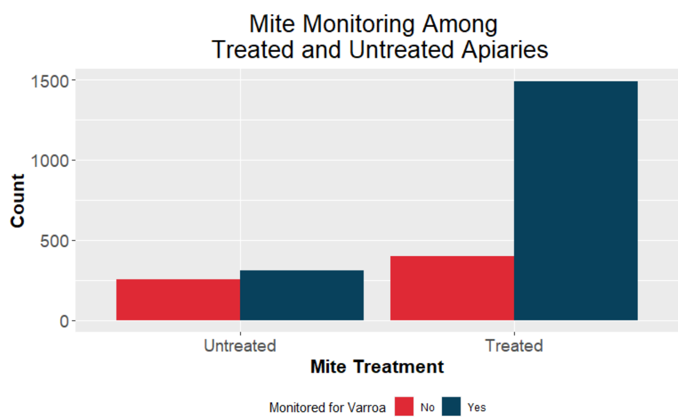
The survey asks beekeepers about varroa mite treatment and monitoring, supplemental feeding, and other husbandry practices.

## *Varroa Monitoring and Treatment*

Looking at the plots, we can see that the relative ratios of varroa treatment and monitoring are consistent across the years of the survey, and that beekeepers who treat their hives also seem more likely to monitor for mites.



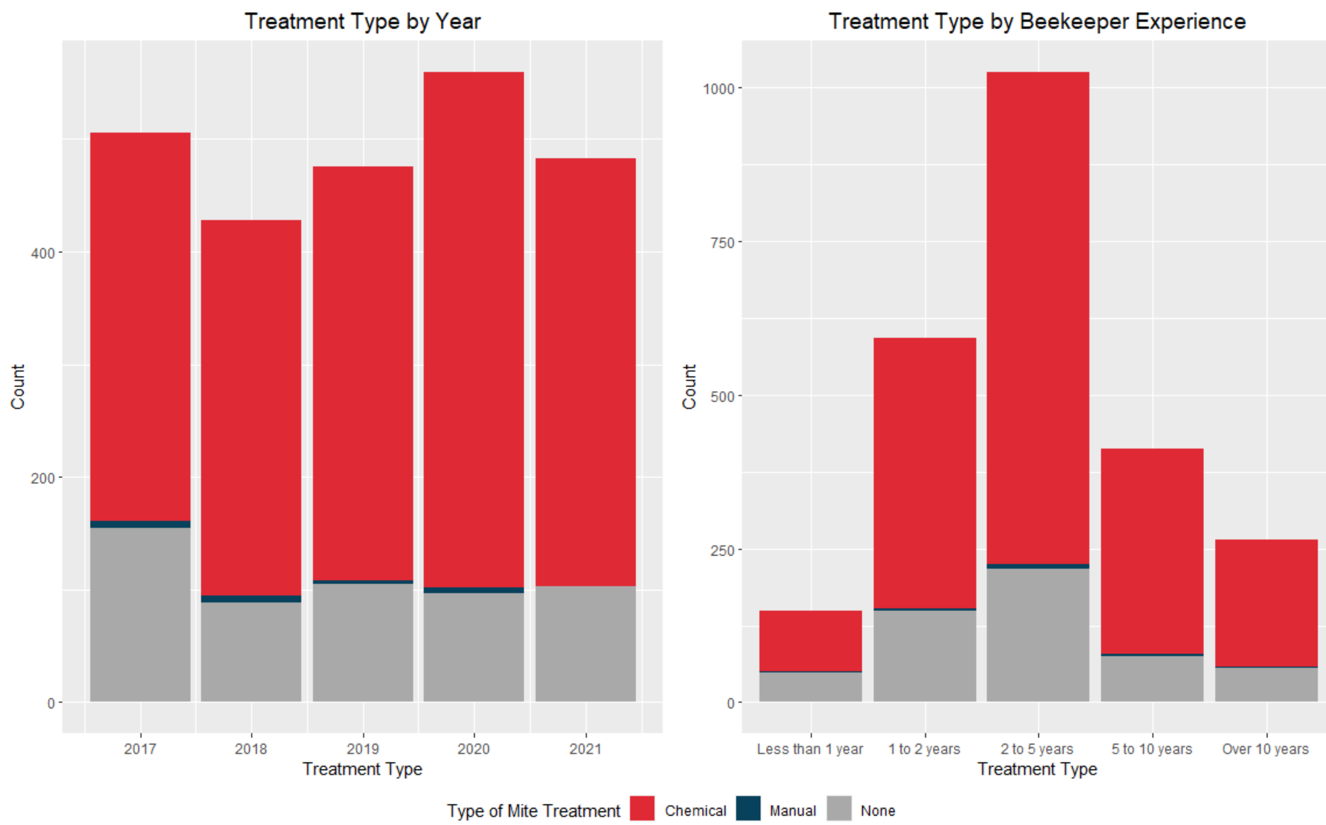



## *Treatment Types*

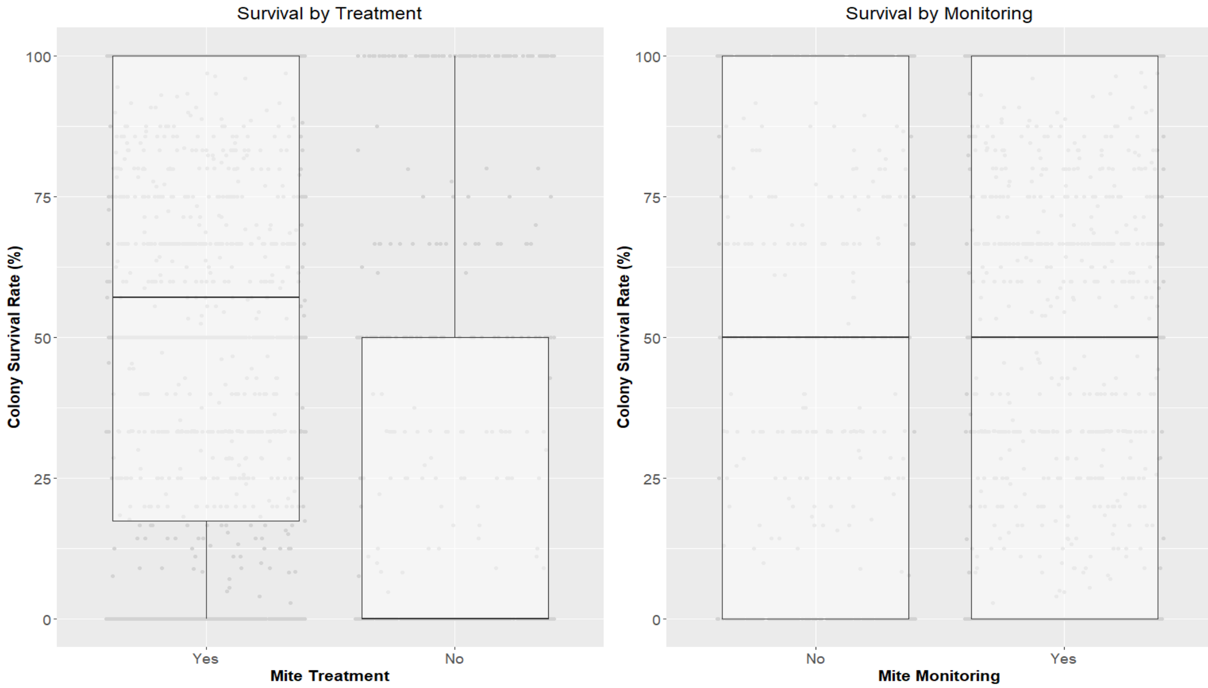
We can also look at the type of mite treatment used across the years of the survey. For the figures below, mite treatment types were divided into three categories:

- **Chemical**: includes organic treatments such as thymol, formic and oxalic acid and synthetic products including Apistan, Apivar and HopGuard.
- **Manual:** includes practices such as use of a screened bottom board, breaking the brood cycle with splits or drone trapping.
- **None:** no treatment for varroa mite.



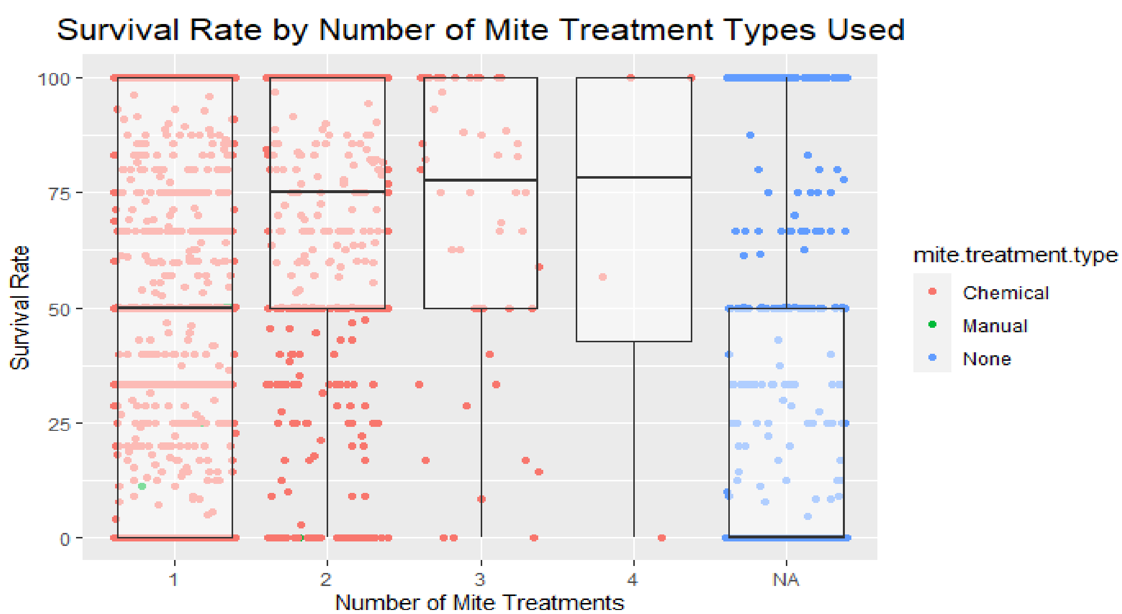

## *Mite Treatment v. Colony Survival*

Next, we can visualize the relationship between colony survival percentages and mite treatment approaches. There was a significant effect of mite treatment on colony survival rates, but no significant effect of monitoring. Beekeepers who used chemical treatments had higher rates of survival in their apiaries than manual treatments, and there was not a significant difference in survival between manual treatments no treatment, though only 21 beekeepers used manual treatments so more data is needed to assess this relationship.



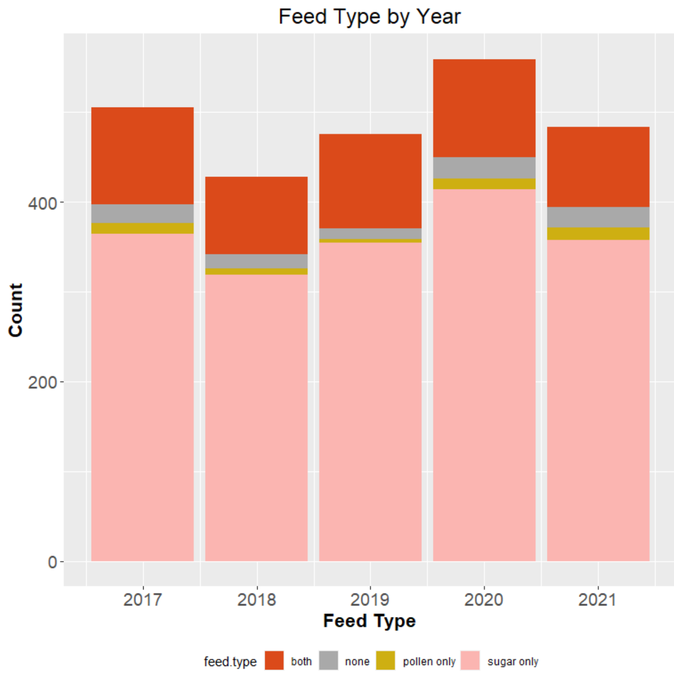

### *Combining Treatments*

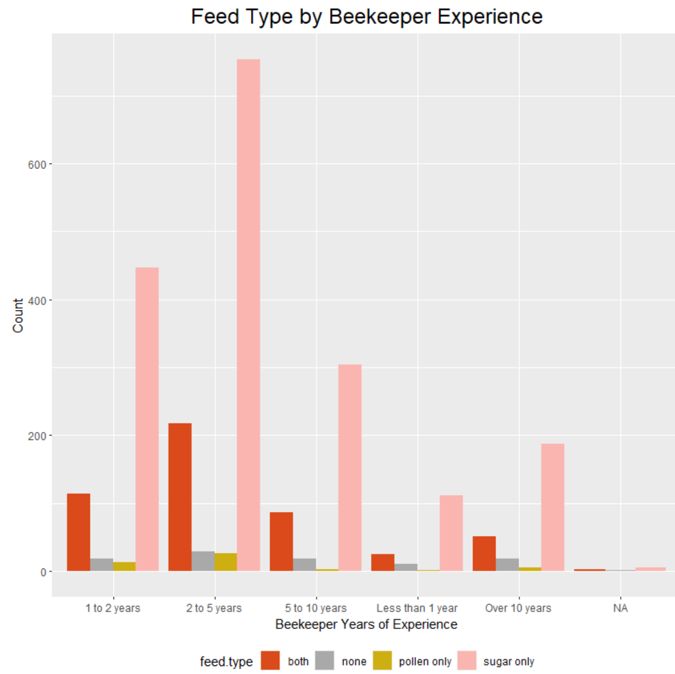
Many beekeepers reported using multiple types of treatments on their colonies. For example, a beekeeper's response to the question "What did you use to treat for varroa?" may have been "Oxalic acid and screened bottom boards." We investigated how the number of treatment types a beekeeper used influenced survival and found that using 2 or more treatments significantly influenced colony survival rates. Note that we do not know whether the beekeeper necessarily used these treatments on the same hives or at the same time.

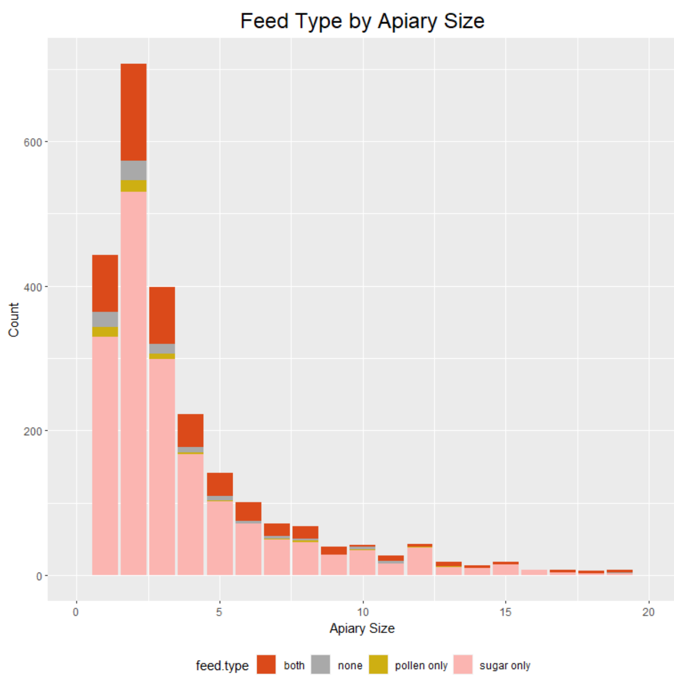


## *Supplemental Feeding*

The survey also asks beekeepers about whether they provide supplemental feed to their bees. Almost all the beekeepers provided supplemental feed; across all years only 26 beekeepers reported not feeding.

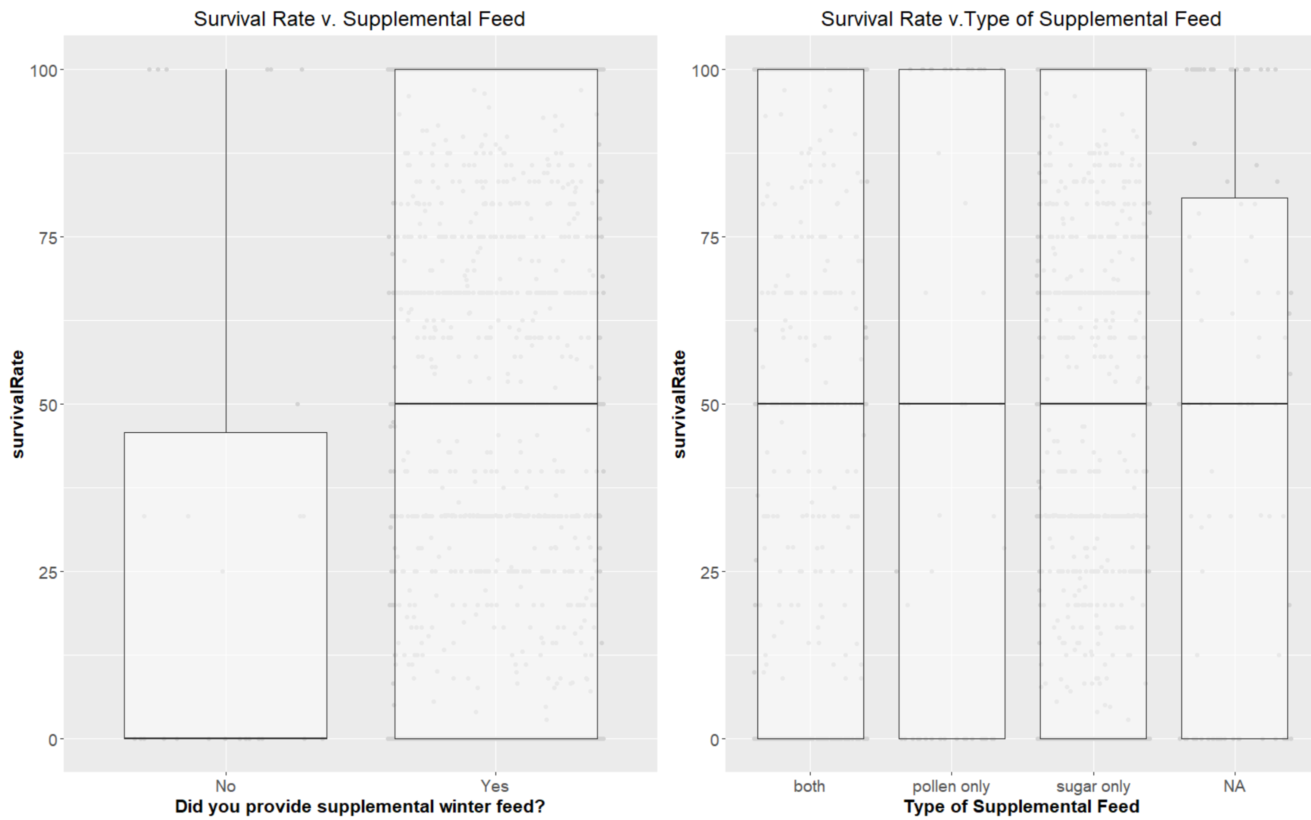


### *Supplemental Feeding v. Colony Survival*

Feeding had a slightly significant (p = 0.02) influence on colony survival but as mentioned, the number of beekeepers who did not feed their colonies was less than 30, so more data is needed to make a conclusive comparison between these two groups.




# Modelling Environmental Factors Related to Colony Survival

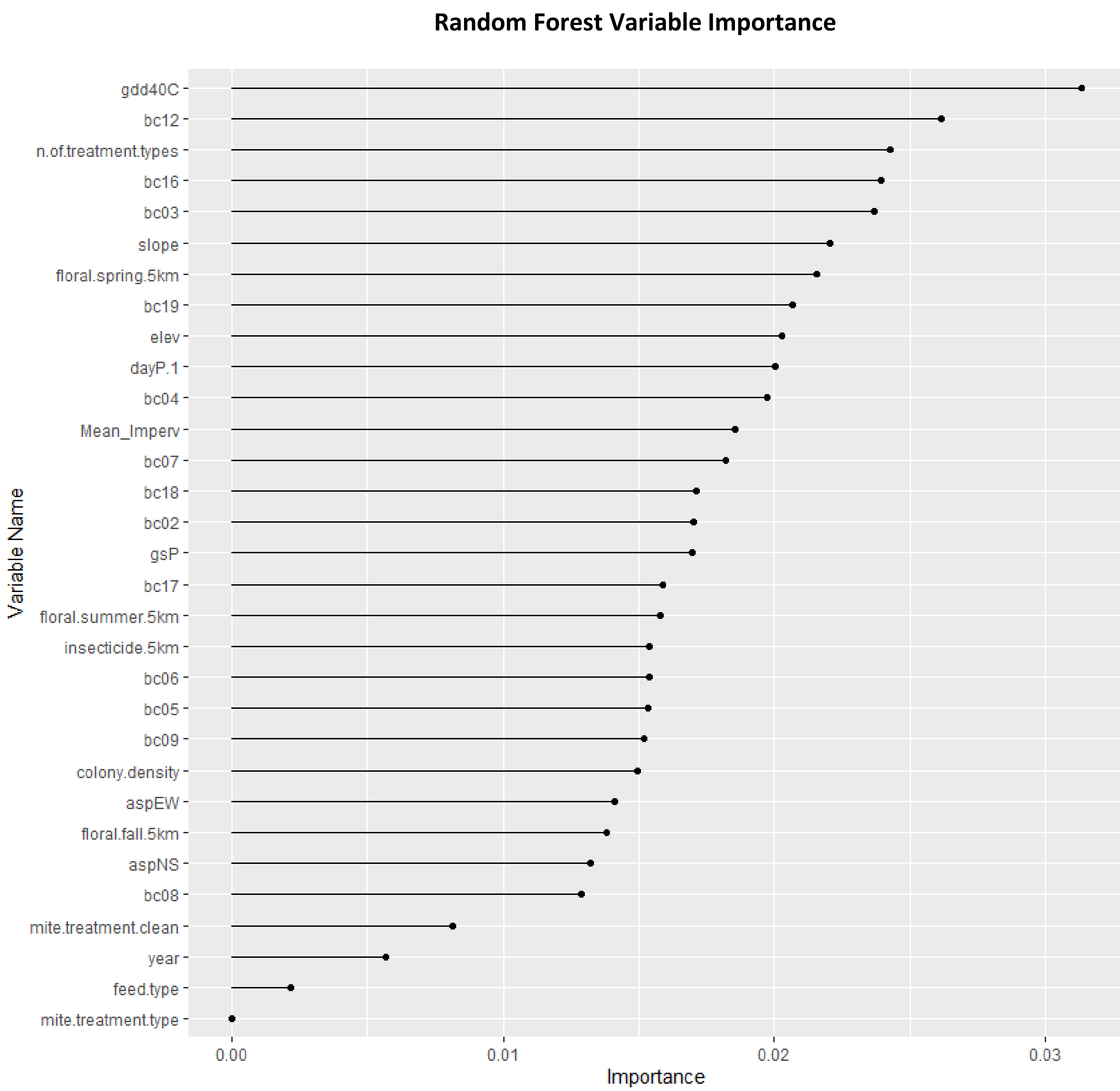
From the figures above, we can draw some conclusions about beekeeping practices that affect survival, but we can also see from how much noise is in the graphs that there are still factors affecting survival which are not reflected in the survey questions. In order to investigate the effects of climate and landscape on survival, we used the Random Forest model built by Calovi et al (2021) to model survival for the colonies which had locations associated with them. Colonies that were not treated for Varroa mites were dropped from the final datasets used in model development, due to the strong effect of treatment on survival. The model considers climate variables including an array of temperature and precipitation metrics, landscape variables including forage availability in each season, pesticide exposure, and impervious surface percentage, and beekeeping management variables.

The model trained on data from 2017 to 2021 predicts whether a given colony will survive with an 81% accuracy, which is an improvement over the original publication, demonstrating how additional years of data bolster the strength of the model.

## *Variable Importance*

One of the most important outputs of a Random Forest model is a ranking of variable importance, or which variables contributed most to the accuracy of the predictive model. This is calculated by removing each variable in turn from the model and observing how the accuracy changes when just that variable is left out. **The table below includes all the variables included in the model, listed by their importance**. This helps us answer the question "what factors have the most influence on colony survival?" The top variables are growing degree days and annual precipitation, which is consistent with the findings of Calovi et a (2019). Interestingly, number of treatment types is also one of the most important variables.

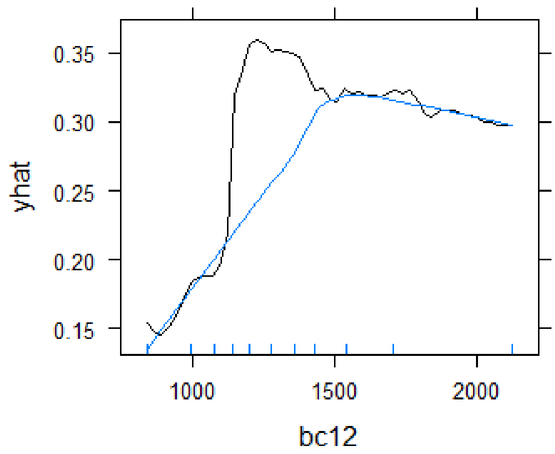
| Abbreviation | Variable | Importance |
|---|---|---:|
| gdd40C | growing degree days | 3.13E-02 |
| bc12 | annual precipitation | 2.62E-02 |
| n.of.treatment.types | number of treatment types | 2.43E-02 |
| bc16 | precipitation of wettest quarter | 2.39E-02 |
| bc03 | isothermality | 2.37E+00 |
| slope | slope | 2.21E-02 |
| floral.spring.5km | spring floral resources | 2.16E+00 |
| bc19 | precipitation of coldest quarter | 2.07E-02 |
| elev | elevation | 2.03E-02 |
| dayP.1 | days between precipitation events | 2.00E-02 |
| bc04 | temperature seasonality | 1.97E-02 |
| Mean_Imperv | mean impervious surface | 1.85E-02 |
| bc07 | annual temperature range | 1.82E-02 |
| bc18 | precipitation of warmest quarter | 1.71E-02 |
| bc02 | mean diurnal range | 1.70E-02 |
| gsP | gsP | 1.70E-02 |
| bc17 | precipitation of driest quarter | 1.59E-02 |
| floral.summer.5km | summer floral resources | 1.58E-02 |
| insecticide.5km | insecticide | 1.54E-02 |
| bc06 | min temperature of coldest month | 1.54E-02 |
| bc05 | max temperature of warmest month | 1.54E-02 |
| bc09 | mean temperature of driest quarter | 1.52E-02 |
| colony.density | honey bee colony density | 1.50E-02 |
| aspEW | east- west aspect | 1.41E-02 |
| floral.fall.5km | fall floral resources | 1.38E-02 |
| aspNS | north-south aspect | 1.32E-02 |
| bc08 | mean temperature of wettest quarter | 1.29E-02 |
| mite.treatment.clean | mite treatment type | 8.16E+00 |
| year | year | 5.71E-03 |
| feed.type | supplemental feed type | 2.20E-03 |
| mite.treatment.type | mite treatment category | 2.46E-07 |



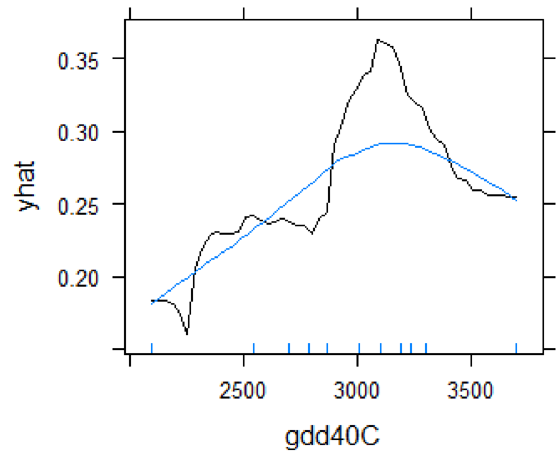

## *Partial Dependence Plots*

Another output of Random Forest models are figures called partial dependence plots, which indicate how each individual variable is influencing the predicted colony survival. The yhat value on the y axis represents predicted output- so we can interpret this as likelihood of colony survival. The plots below are for the top two variables, growing degree days and annual precipitation, and both show highest colony survival at mid-range values. It is important not to extrapolate too much- the hashmarks along the x axis each represent a tenth of the data used to generate the model, so areas where there are gaps may be more uncertain than areas with lots of hashes.

**Partial Dependence of Colony Survival on Annual Precipitation**

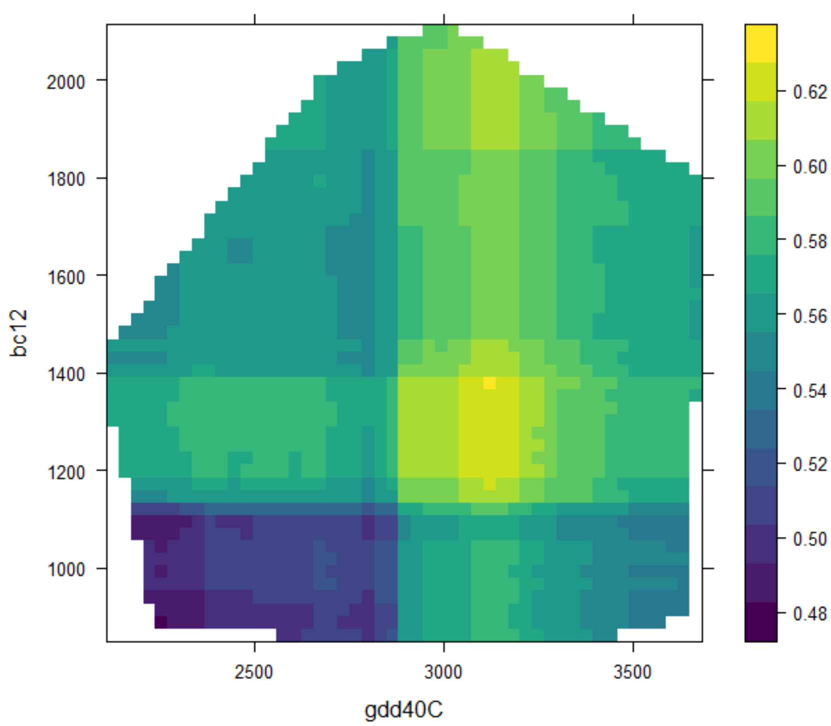



**Partial Dependence of Colony Survival on Growing Degree Days**




We can also look at these variables together. This plot shows annual precipitation in mm on the y axis and growing degree days on the x axis. The legend on the right demonstrates that yellow and light green values represent higher probability of survival, while dark blue represents lower probability of colony survival. We can see from this graph again that moderate precipitation and moderate temperature provide the highest likelihood of colony survival.

**Dependence of Colony Survival Probability on Growing Degree Days and Annual Precipitation**



*Original publication:*

Calovi, M., Grozinger, C. M., Miller, D. A., & Goslee, S. C. (2021). Summer weather conditions influence winter survival of honey bees (Apis mellifera) in the northeastern United States. *Scientific reports*, *11*(1), 1-12.