Supplemental Information for Risk Perception and Information Confidence as Barriers to Cooperative Disease Control: The Case of Huanglongbing in California

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1 Derived Parameters

1.1 Size of groves

Kallsen et al. (2021) gives the average number of trees per acre as 218. Each grove in the model has $11 \cdot 25 = 275$ trees, which is $275/218 = 1.261$ acres.

1.2 Yield

We choose the middling yield per acre for a mature grove in Kallsen et al. (2021), 564 cartons per year. Dividing this amongst the 218 trees per acre gives $564/218 = 2.587$ cartons per tree per year. Dividing this amongst the three harvest days per year gives $2.587/3 = 0.8623$ cartons per tree per harvest.

1.3 Annual costs

Kallsen et al. (2021) gives \$9,293 as the annual cost per acre. Multiplying this by the grove size of 1.261 acres gives $\$9,293 \cdot 1.261 = \$11,718.46$ per year.

1.4 Spray cost

Recommended insecticides were taken from the CDFA Action Plan (see https://www.cdfa.ca.gov/citruscommittee/docs/ActionPlan.pdf). We use Tempo SC Ultra as a foliar spray and

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Merit 2f as a soil application. Costs for the foliar and soil treatments are mentioned at https://www.domyown.com/tempo-sc-ultra-p-215.html and https://www.domyown.com/merit-2f-insecticide-p-html, respectively. Using product information provided on these pages, we calculate \$52.68 per foliar application per acre and \$6.19 per soil application per acre. The soil application is reccomended to be applied once annually. Adding the single soil application to the 6 annual sprays gives $\$52.68 \cdot 6 + \$6.19 = \$322.27$ per year per acre or \$53.71 per spray per acre. Since groves in our model are 1.261 acres, this gives $\$53.71 \cdot 1.261 = \$67.73$ per spray.

2 ODD

2.1 Agent-Based Model

To approach this problem, we construct an agent-based model of HLB spread featuring citrus growers, ACP, and citrus trees. A complete, detailed model description, following the ODD (Overview, Design concepts, Details) protocol (Grimm et al. 2006; Grimm et al. 2010; Grimm et al. 2020) is provided in the following paragraphs. The purpose of our model is to integrate an epidemiological model of HLB spread with rational agents who can act individually or in tandem to mitigate the disease. Specifically, we are adressing the following questions: How different patterns of insecticide application, cooperation, risk perception, and information confidence influence the spread of HLB.

2.1.1 Purpose and patterns

The purpose of this model is to predict how different patterns of insecticide application influence the spread of Huanglongbing (HLB) in an area of citrus groves, and how risk perception and information confidence influence these patterns. In particular, the model seeks to demonstrate the differences that arise when growers coordinate their insecticide applications to spray a large area in a small window of time instead of spraying individual groves at different times. The model results have applications to policy design in California, where HLB is still in its infancy. An action plan has already been set forth by the CDFA for areas where HLB is found[1], but little is known about how much compliance is required for this plan to be successful. Additionally, we have little information on what grower beliefs can influence compliance rates. Determining how risk perception and information confidence affect spraying behaviors can help policymakers understand the value of education as a tool to halt the spread of HLB. We evaluate the model on two patterns. First, coordination of spraying between neighbors within smaller windows will induce desirable outcomes for both an individual and their neighbors. Second, as this resembles a classic collective action problem, we expect to see a pattern of free-riding emerge.

2.1.2 Entities, state variables, and scales

There are four entities in the model: Citrus growers, psyllids, citrus flush, and the environment. A list of state variables by entity is given in Table 10. A full list of parameters

1. See https://www.cdfa.ca.gov/citruscommittee/docs/ActionPlan.pdf

used in the model and their source is given in Table 11. Flush are represented spatially in clusters called flush patches. The psyllids, flush, and environment constitute an epidemiological system that models the spread of HLB. Separate growers allow us to evaluate how HLB spread changes when individual growers defect from a coordinated group. The model is spatially explicit, consisting of a 33x75 grid of flush patches as its coordinate system. The borders of this grid are fixed, pysllids cannot move past the edges. Flush patches are further divided into a 3x3 grid of 11x25 groves, with each section being assigned to a grower who can apply insecticide to that grove throughout the simulation. The choice of 11x25 sized groves was inherited from Lee et al. (2015). Kallsen et al. (2021) estimates an average of 218 trees per acre. Since flush patches can also be interpreted as trees, 275 trees per grove in this model means each grove is approximately 1.261 acres and a total grid size of 11.349 acres. The model runs 1 day at a time, for a total duration of 1825 days or 5 years. Growers make decisions every 91 days, approximately once a season. The temporal resolution also comes from Lee et al. (2015). The model duration was chosen by observing how many days were needed for the entire grid to reach full infection without any grower intervention in preliminary experiments. Five years is sufficient time for this to occur, which allows for full observation of how a slowed HLB spread will progress over time.

2.1.3 Process overview and scheduling

The processes executed by the model on each day are as follows:

1. If it is currently a flushing period, additional flush are added at each flush patch. Each flush has a probability of being born infected that is equal to the current level of HLB at that flush patch.
2. Each psyllid has a random chance of migrating. During migration psyllids can move to an adjacent flush patch (i.e. cells immediately above, below, to the right of, and to the left of its current cell). The direction a psyllid moves is chosen randomly, with in-row movement weighted more heavily than between-row movement. Moving across grove borders is less likely than moving within grove borders.
3. Eggs are laid at each flush patch according to the number of females present and the number of available young flush.
4. Disease transmission occurs in two stages. (a) Nymphs feed on a random flush at a patch, with infected flush having a chance to infect the nymph feeding on it. (b) Infected adult psyllids feed on a random flush in their patch, which has a chance to infect that flush.
5. Flush age by one day. Flush above a certain age harden and become unsuitable to house eggs.
6. Psyllids age by one day. Survival probabilities are different for nymphs and adults and are modified based on the carrying capacity of the flush patch.
7. Growers execute actions. If a grower has a spray planned for the current model day, they spray the cells in their grove with insecticide.

8. On the first day of a planning period, growers who possess agency choose a profit maximizing strategy from the choices of no action, individual spraying, and group spraying.

9. Growers plan actions. On the first day of each year and after selecting a new behavior pattern, growers plan which days they will spray on according to their spraying parameters.

10. On the first day of a planning period, harvest days, and the first day of a year accounting occurs for strategy costs, crop returns, and annual fixed costs, respectively.

The first 6 of these processes and their order follows from Lee et al. (2015), in which the rationale for their inclusion and positioning was based on support from the previous literature and the results of the field experiments they conducted. Our additions were the minimum required processes associated with grower decision making and accounting. The position of these activities in the schedule is arbitrary, so long as all of the behavioral activities occur sequentially. These processes encapsulate the key activities of psyllids and flush, as well as providing a framework for strategy choice among growers that can extend beyond the spraying strategies implemented in this paper.

2.1.4 Design concepts

1. Basic Principles: The basic principle of this model is uniting the fine-grain detail of in-grove models, the scale of large acreage models, and private decision-making mechanisms from the bioeconomic literature. It does so by taking the existing in-grove framework from Lee et al. (2015) and expanding it to a 9-grove setting, as well as adding grower agents who can choose to spray insecticide on their own crops based on profit maximizing expectations about the future.

2. Emergence: The primary behavior that emerges from the model is free-riding behavior. By giving agents a parameter that represents their belief in the level of neighbor cooperation, we see that agents with high levels of belief tend to put off spraying until the infection has already established itself in their grove. This is a classic collective action problem that we did not impose on the model manually. In the same vein, reactionary behavior emerges from all growers. Growers that are not extremely risk averse tend to put off cooperation or spraying entirely until it is already too late.

3. Adaptation: Adaptation in the model comes from the grower agent's decision-making process. At the start of each planning period growers update their perception of risk based on their current perception, information from an external source, and their trust in that external source. Based on this expectation and their belief in neighbor's cooperation, the growers choose the strategy which maximizes profits over the next 5-10 years. These choices can and do change in subsequent planning periods.

4. Objectives: The only direct objective seeking behavior in the model is grower strategy choice, described above. Grower risk perception is driven by their information confidence and the environmental risk curve (see Figure 7). Expected strategy profits are

determined by a grower's perception of neighboring growers participation in coordinated spraying(α-perception) and the environment's expected value curve (see Figures 10 and 13), as well as the grower's insecticide efficacy. Further details on the algorithm can be found in the submodule element.

5. Learning: Learning is not implemented in this model.

6. Prediction: Prediction in the model comes from the environment's survival probability and expected value curves, both used in grower decision making. Further details on this algorithm can be found in the submodule element.

7. Sensing: Sensing in the model occurs during grower decision making. When determining their risk perception, growers have a probability of finding the virus equal to the level of HLB severity in their grove. Once found, their risk perception value is set to 1 for the remainder of the simulation.

8. Interaction: Interaction in the biological layer of the model occurs when psyllids lay eggs, migrate, and transmit disease to flush patches. Growers can also interact with psyllids via the spraying of insecticide which can kill psyllids.

9. Stochasticity: Stochasticity is integrated into every process in the model. Please see the submodule element for details on how stochasticity is implemented in each process.

10. Collectives: Two important collectives exist in the model. First, each cell on the grid is composed of many flushes which compose a flush patch. The attributes of these flush patches are based entirely on the composition of its parts, there are no unique characteristics. Second, flush patches are grouped in 11x25 plots arranged in a 3x3 grid that represent a single grove. Each grove belongs to a single grower agent who can take action on the cells within it.

11. Observation: Data collected from the model occurs in two steps, one for the biological layer and one for the behavioral layer. The biological layer collects information from each flush patch at every time step that consists of psyllid counts (infected and uninfected) and HLB level. The behavior layer collects 9 rows of data each time step. Each row corresponds to a grower, and provides information on their current accounting information, parameters, strategy choice, and HLB status in their grove.

2.1.5 Initialization

In the biological layer, initialization occurs in the creation of flush and distribution of psyllids. Flush patches are created at each grid cell containing no flush shoots and no psyllids. Psyllids are distributed according to the invasion location and modality parameters. Options for invasion location are each of the 9 cells in the 3x3 grid of growers and groves. Options for invasion modality are as follows.

1. 200 psyllids, evenly distributed amongst the 4 trees in the southwest corner of the grove.

2. Modality 1, and 35% of randomly selected trees from the remaining cells are occupied by 200 uninfected psyllids distributed evenly.

3. 200 psyllids, evenly distributed amongst 25% of trees on the southern edge (randomly chosen) and 100% of trees on the eastern edge.

4. Modality 3, and 35% of randomly selected trees from the remaining cells are occupied by 200 uninfected psyllids distributed evenly.

5. 200 psyllids distributed evenly amongst the 10 trees in the center of the grove.

6. Modality 5, and 35% of randomly selected trees from the remaining cells are occupied by 200 uninfected psyllids distributed evenly.

Each psyllid has a 50% chance of being male or female. For modalities 1, 3, and 5 each psyllid has an 18% chance of being infected. In the behavioral layer, initialization involves setting the initial risk perception of all growers to 0. All other values used in the behavioral layer are parameterized, as specified in Table 11.

2.1.6 Input Data

The only source of input data for the model are the survival probability and expected value curves. These curves facilitate behavior choice of the growers. The construction and rationale for the construction and selection of these curves can be found in the main paper in the "Calibration" section.

2.1.7 Submodels

We now describe each process of the model in detail, beginning with the biological processes adapted from Lee et al. (2015).

1. Birth New Flush

   (a) Only occurs during flushing periods. Each flush patch receives 20 new flush shoots of age 0. Each flush shoot has a chance of being infected equal to the HLB severity of the patch it is being birthed on.

2. Psyllid Migration

   (a) 40% of each psyllid subpopulation (males and females, infected and uninfected) are randomly chosen to migrate. Psyllids have a 95% chance of migrating within-row (45% for each direction), and a 5% chance of migrating between-row (2.5% for each direction). If the cell a psyllid attempts to migrate to is an invalid destination, they instead migrate to the cell opposite the invalid cell. That is, within-row and between-row movement is preserved. If a psyllid attempts to migrate to a cell that is across a grove border, the movement has a 1% success rate. If the psyllid is unsuccessful in crossing the border, they move to the opposite cell. If both cells of an associated direction are invalid, the psyllid does not migrate.

3. Egg Management

   (a) For each flush patch the number of mothers and young flush shoots are calculated. A number of age 0 nymphs are then added to the flush patch equal to the minimum of 10 times the number of mothers or 40 times the number of viable shoots.

4. Disease Transmission

   (a) Disease transmission occurs in two directions.

      i. Flush to psyllid

         A. The proportion of young flush that are infected is calculated. A number of uninfected nymphs are infected equal to the floor of the available uninfected nymphs multiplied by the proportion of infected young flush. Psyllids must be nymphs between the age of 8 and 17 days to be included in this population.

      ii. Psyllid to flush

         A. Each infected psyllid feeds on a randomly selected young flush shoot. If this flush shoot is uninfected, it has a 30% chance of being infected.

5. Age Flush

   (a) Each flush shoot is aged by one day. Flush turning 30 days old harden and become ineligible to house new nymphs or facilitate disease transmission.

6. Age Psyllids

   (a) Nymphs and adults face a base survival probability of 0.8614 and 0.9847, respectively. If the number of psyllids at a flush patch is higher than the carrying capacity of a flush patch (40,000), then the survival probabilities are multiplied by a modifier equal to the carrying capacity divided by the number of psyllids at that patch. Each psyllid is then subject to these modified probabilities, where a value less than or equal to the probability allows the psyllids to increase in age.

The processes in the behavioral layer are as follows.

1. Execution of Planned Actions

   (a) Each grower checks their action queue for an action to be performed on the current day. If there is an action (spraying), then the action is executed.

2. Behavior Determination

   (a) If it is the first day of a planning period, growers with agency select a new behavior.

      i. The grower updates their risk perception. This is equal to their previous risk perception plus the product of their λ value and the output of the survival probability curve (see Figure 7) for the current time and grower covariates. If HLB is present in their grove, growers have a probability of discovering it equal to the severity. If HLB is discovered, a growers risk perception is set to one for the current period and the remainder of the simulation.

ii. The grower calculates the expected value of each strategy. For each strategy, a projection is run from the current time period to t = 3650.
    A. On the first days of projected planning periods, strategy costs are subtracted from expected profit.
    B. On the first days of a projected new year, annual fixed costs are subtracted from expected profit.
    C. On harvest days, returns are calculated and added to expected profit. The yield of each flush patch on the projected day is based on Equation 5 (see main manuscript). HLB severity is taken from the expected HLB curve for the current strategy and grower covariates. If the grower has not found HLB, the input used for time since initial infection is the current projected day minus the initial projected day. If the grower has found HLB, the input used is the current projected day minus the day the infection was first found.

iii. The grower changes their strategy to the strategy with the highest expected value.

iv. The grower plans their behavior for the remainder of the year using their new strategy. Any previously planned actions are erased.

3. Accounting

   (a) Growers adjust their cumulative cost and returns.

      i. If it is the first day of a new year, growers add annual costs to their cumulative costs.

      ii. If it is the first day of a planning period, growers add strategy costs to their cumulative costs.

      iii. If it is a harvest day, growers add crop returns to their cumulative returns. Each flush patch gives returns equal to the cost of one unit of yield multiplied by the yield per harvest and infected yield modifier (see Equation 5 in main manuscript).

Processes are executed in the order they are listed for each time step.

Supplemental Tables and Figures

A number of tables and figures which are not seen in the main manuscript are included here. They include all regression results referenced in the main text as well as figures associated with the simulation experiments.

References

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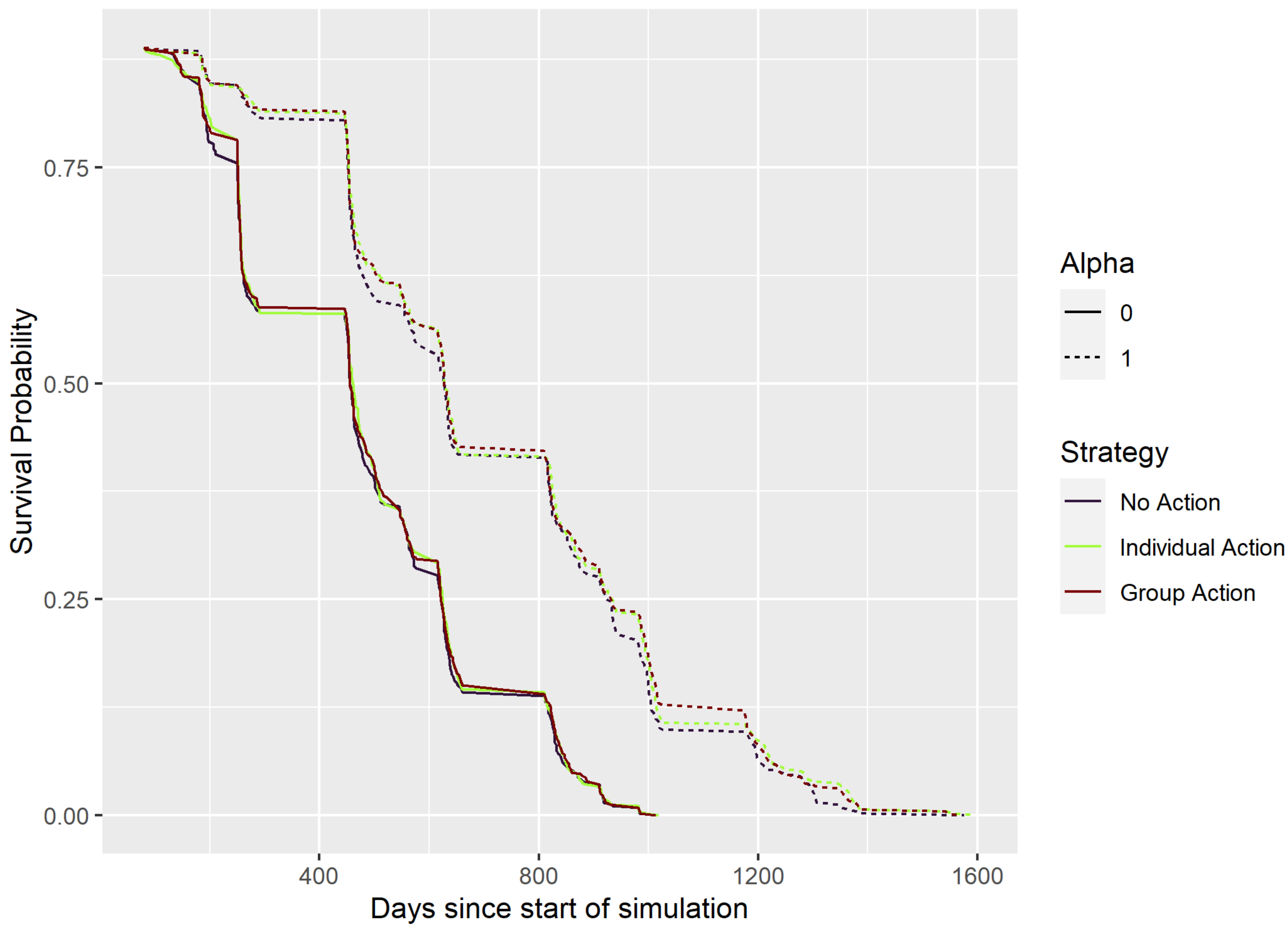

Figure 1: Average Survival Probability by Strategy and Alpha, 65% Efficacy

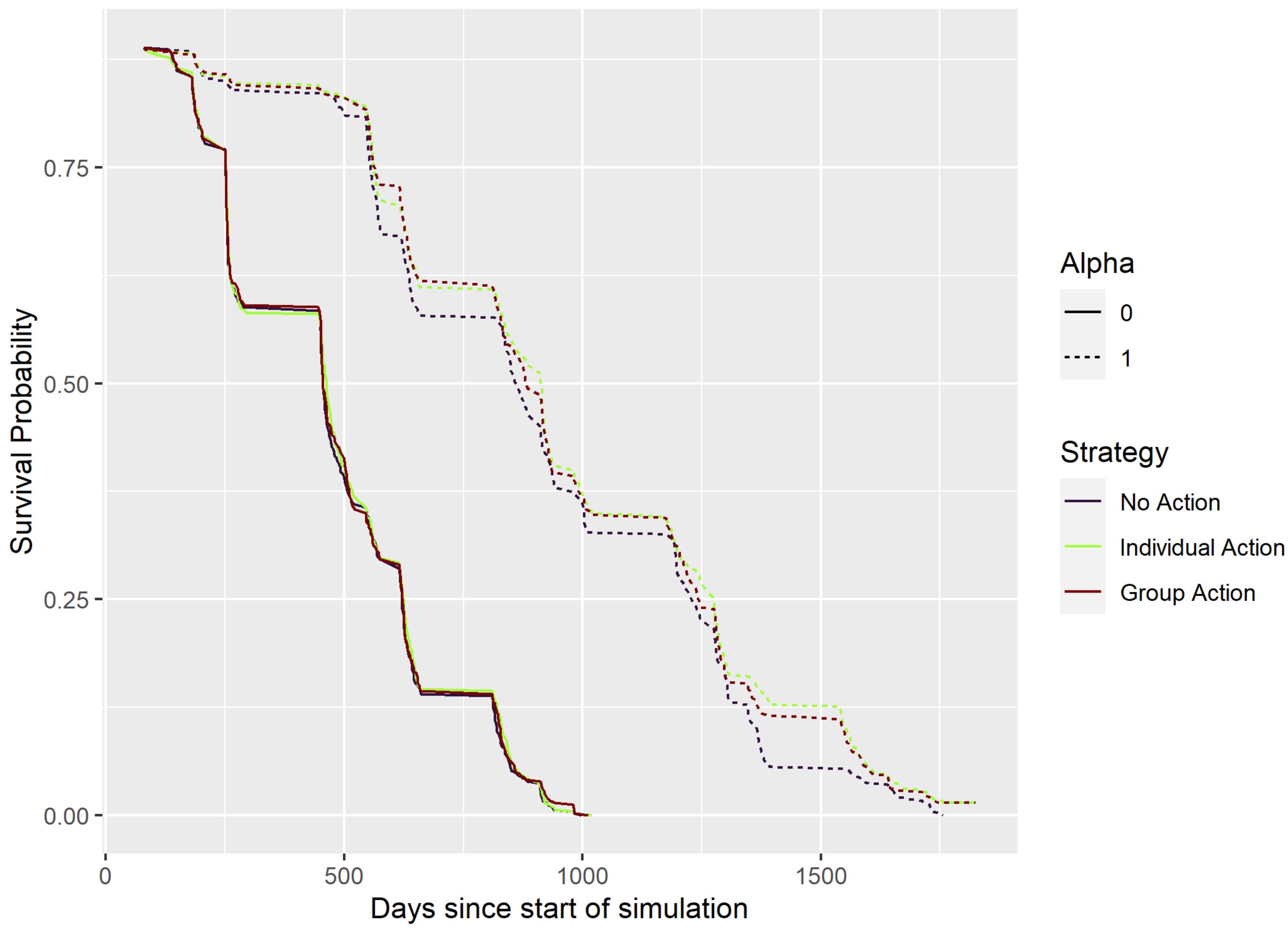

Figure 2: Average Survival Probability by Strategy and Alpha, 75% Efficacy

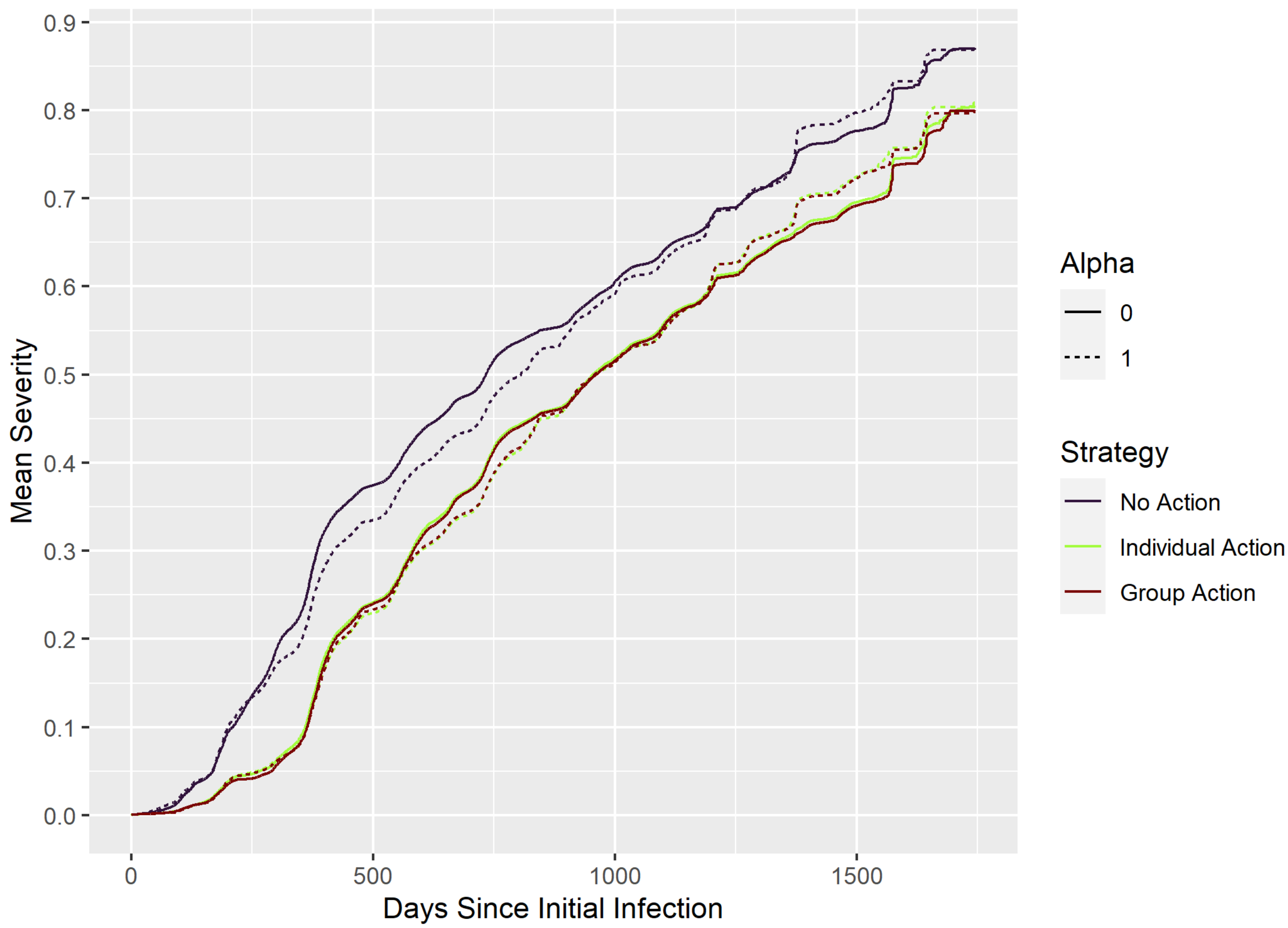

Figure 3: Average HLB Spread by Alpha and Strategy, 65% Efficacy

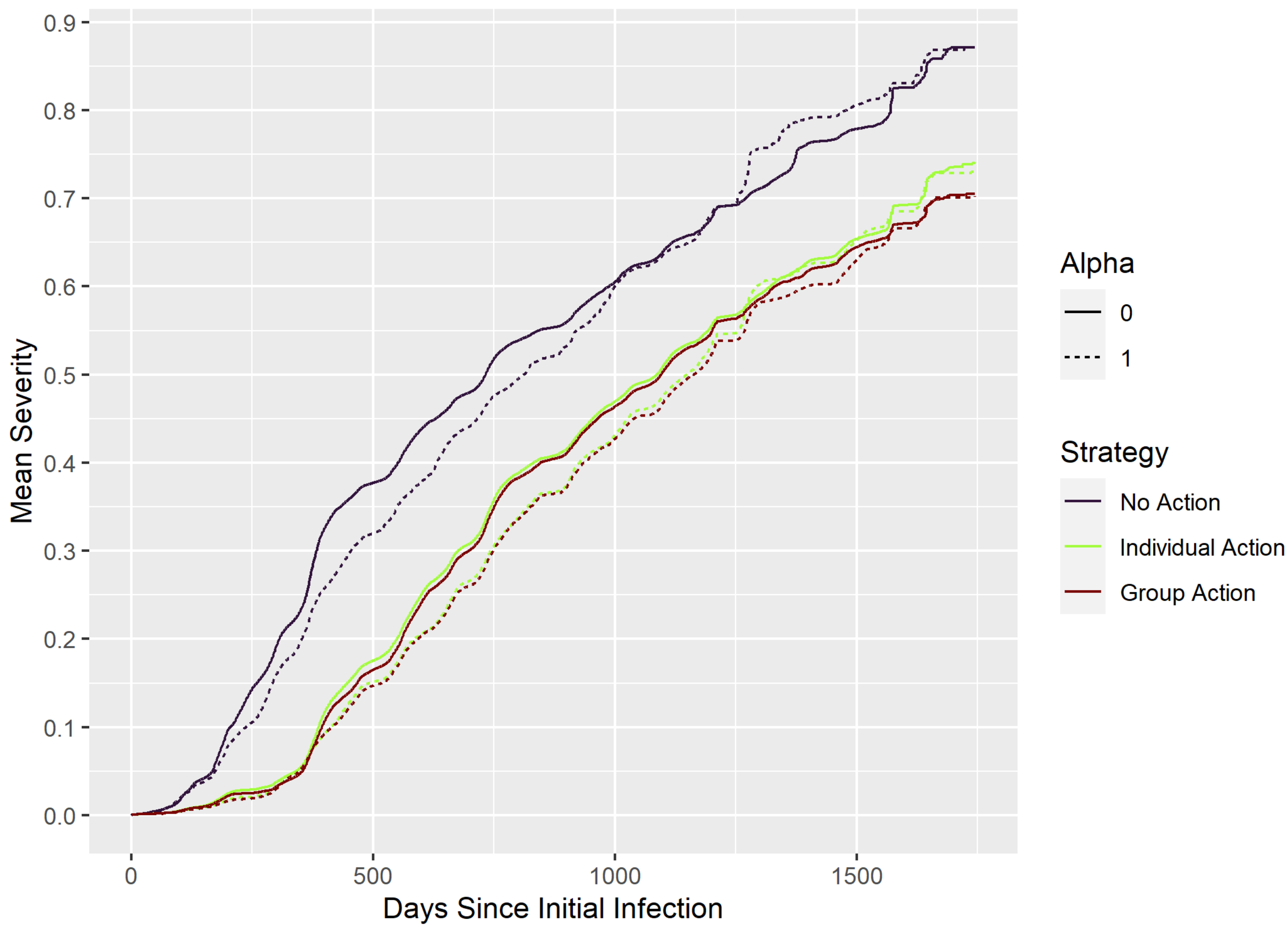

Figure 4: Average HLB Spread by Alpha and Strategy, 75% Efficacy

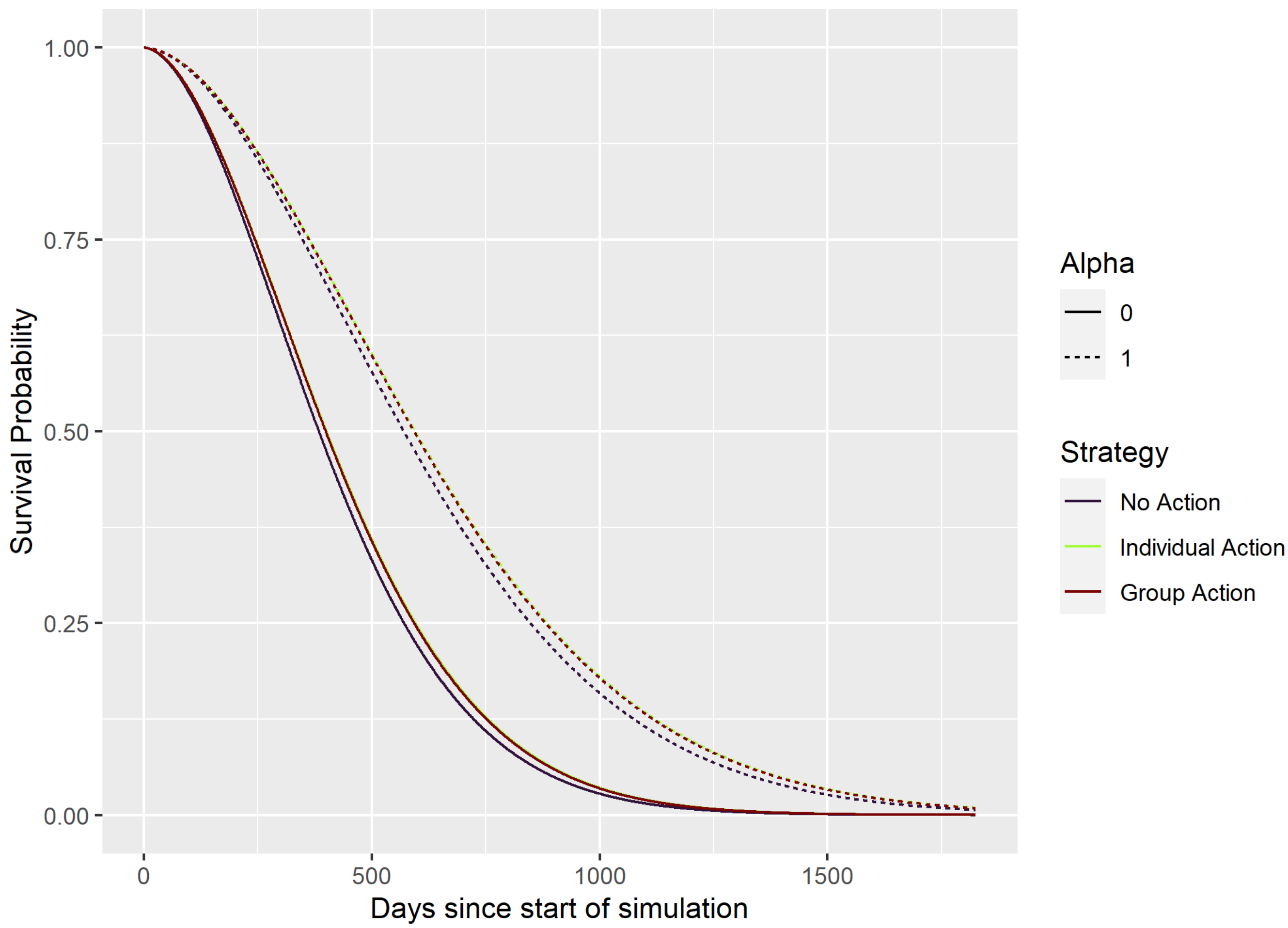

Figure 5: Predicted Survival Probability by Strategy and Alpha, 65% Efficacy

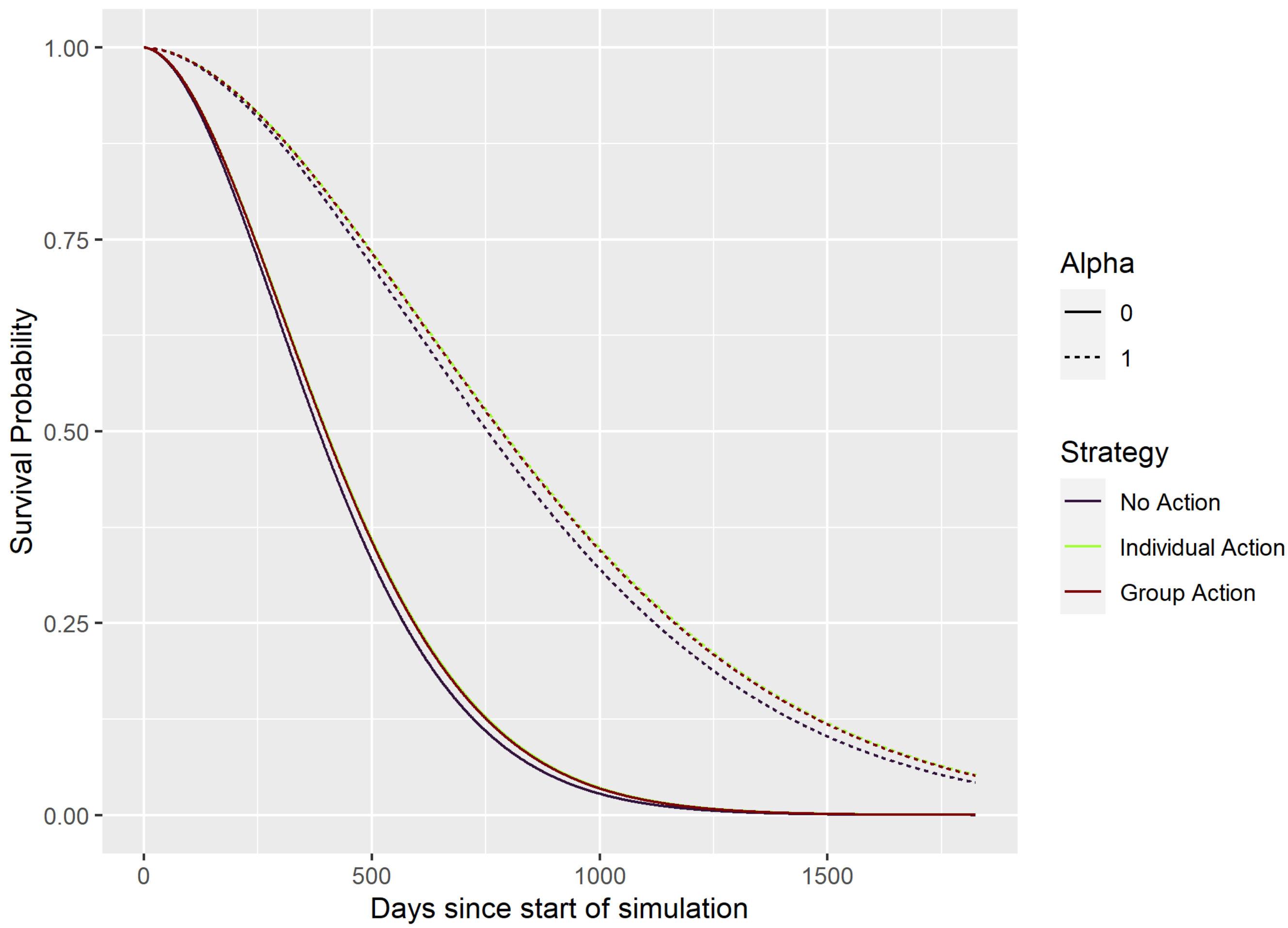

Figure 6: Predicted Survival Probability by Strategy and Alpha, 75% Efficacy

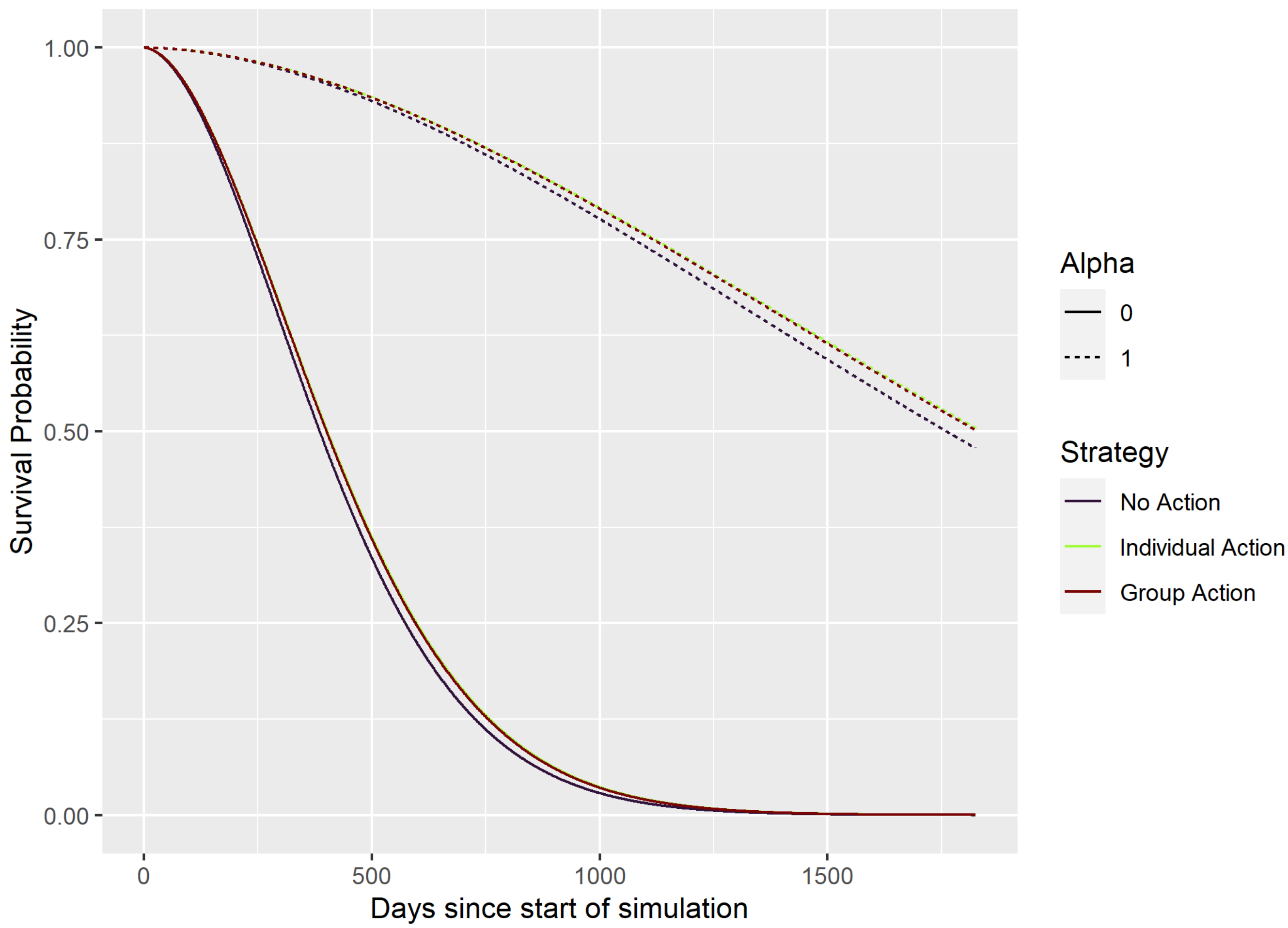

Figure 7: Predicted Survival Probability by Strategy and Alpha, 85% Efficacy

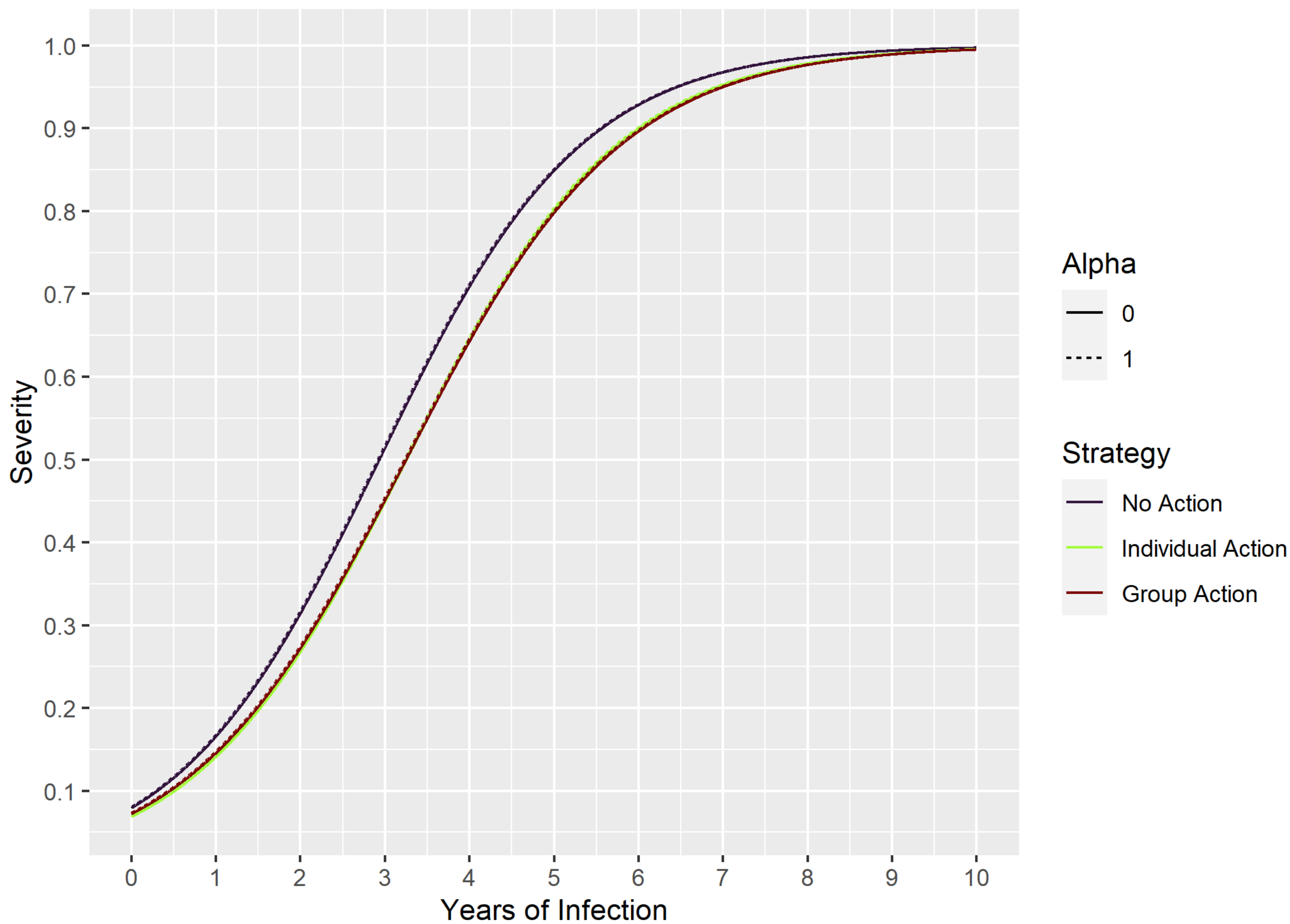

Figure 8: Predicted HLB Spread by Alpha and Strategy, 65% Efficacy

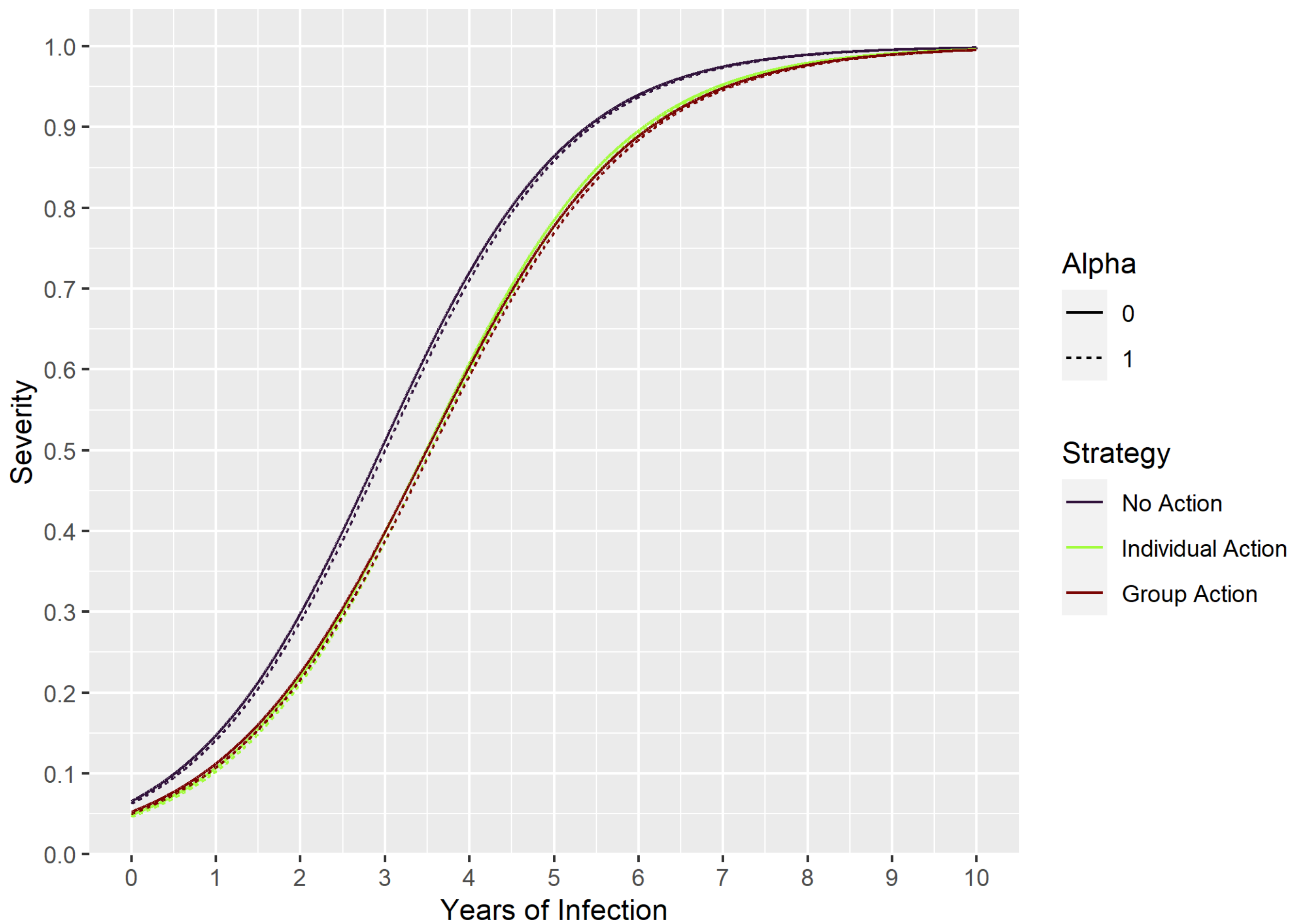

Figure 9: Predicted HLB Spread by Alpha and Strategy, 75% Efficacy

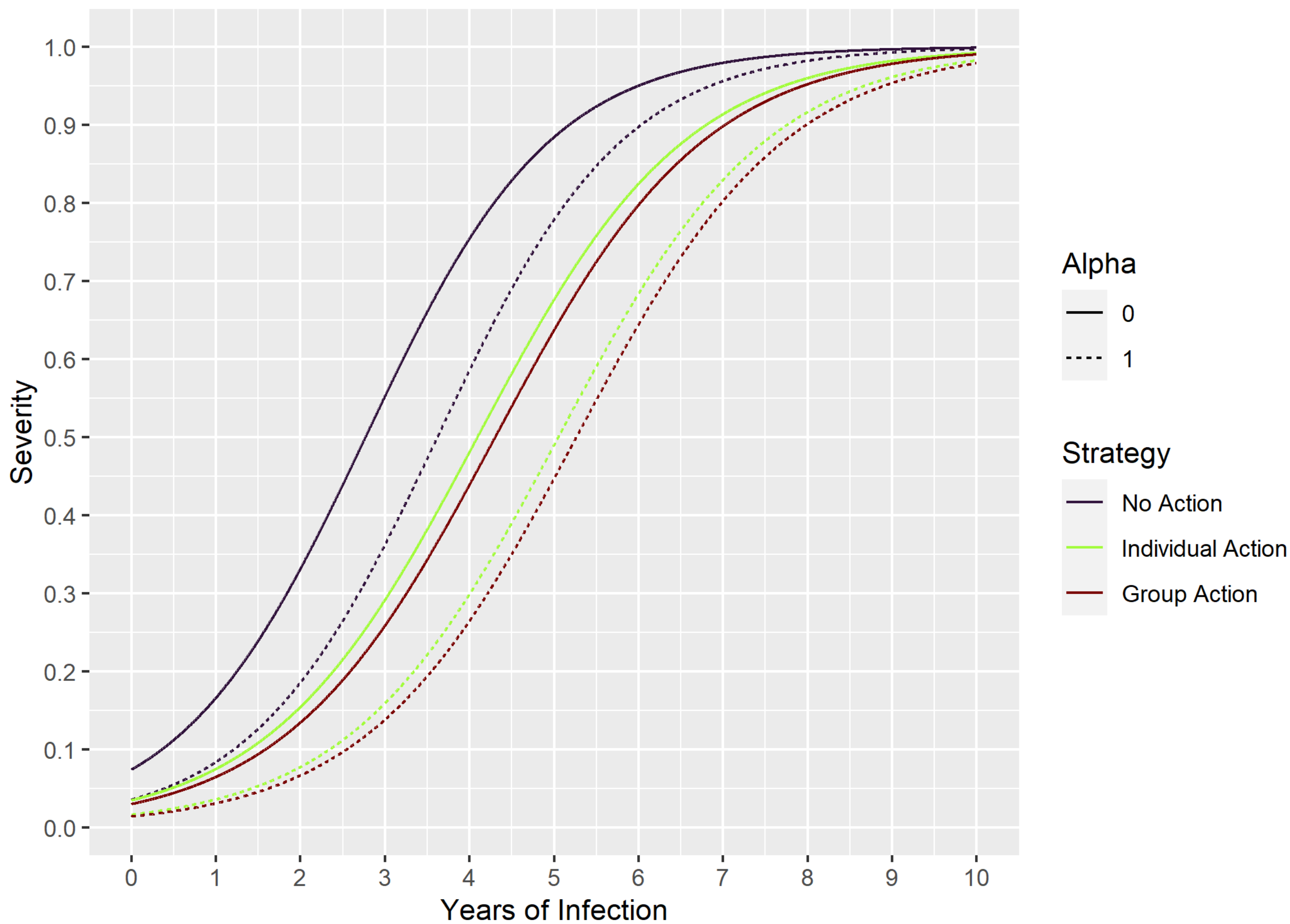

Figure 10: Predicted HLB Spread by Alpha and Strategy, 85% Efficacy

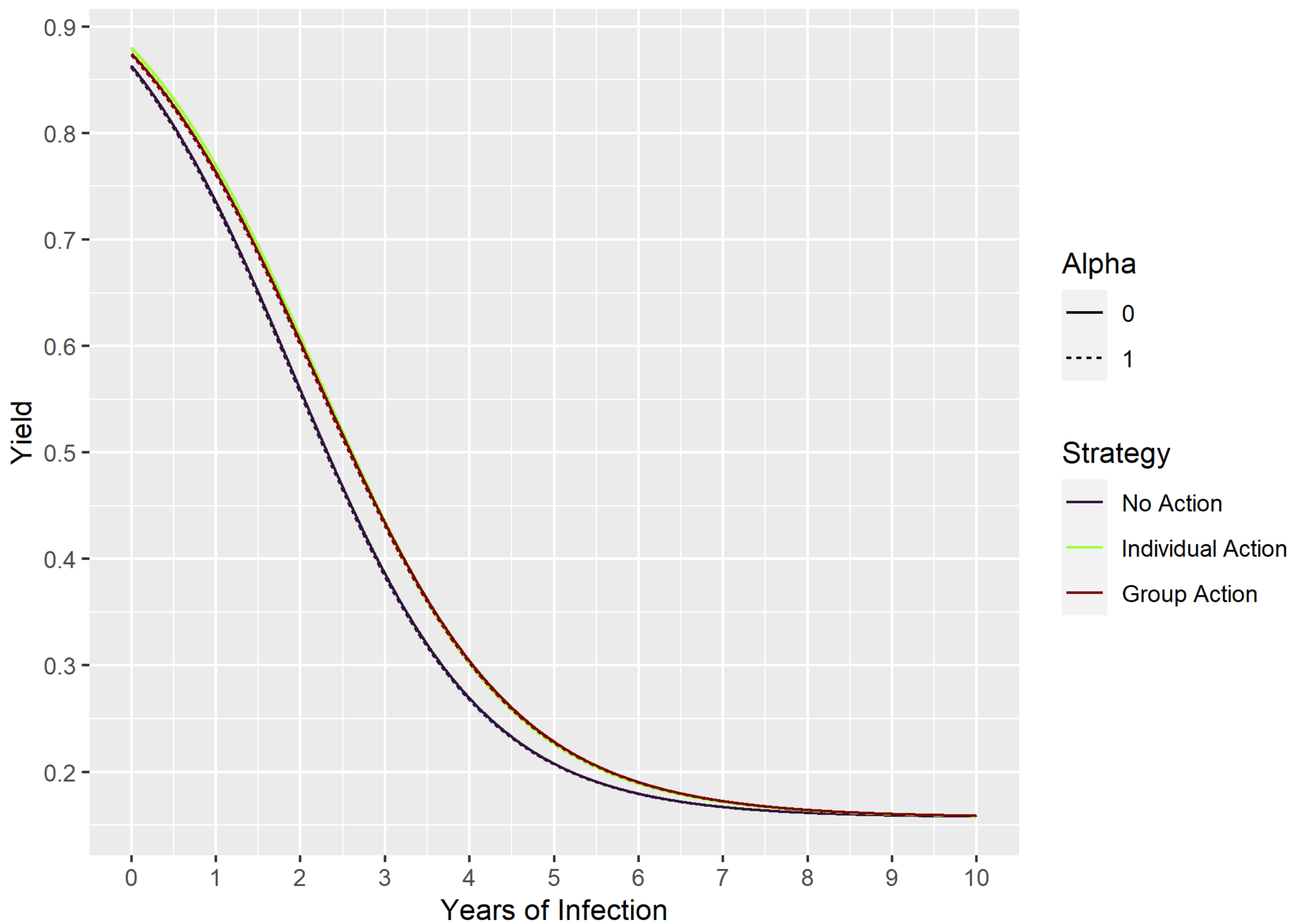

Figure 11: Predicted HLB Yield by Alpha and Strategy, 65% Efficacy

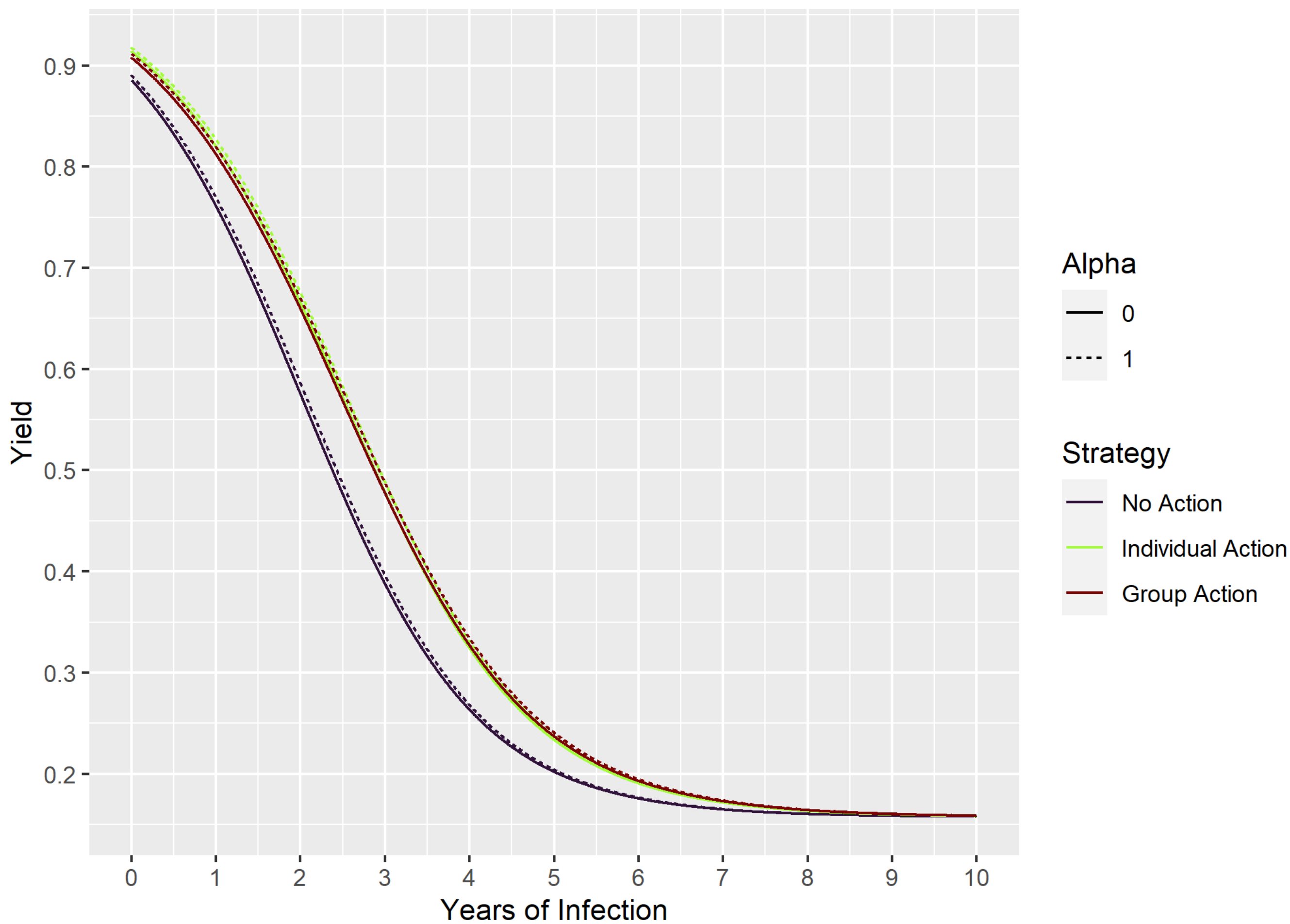

Figure 12: Predicted HLB Yield by Alpha and Strategy, 75% Efficacy

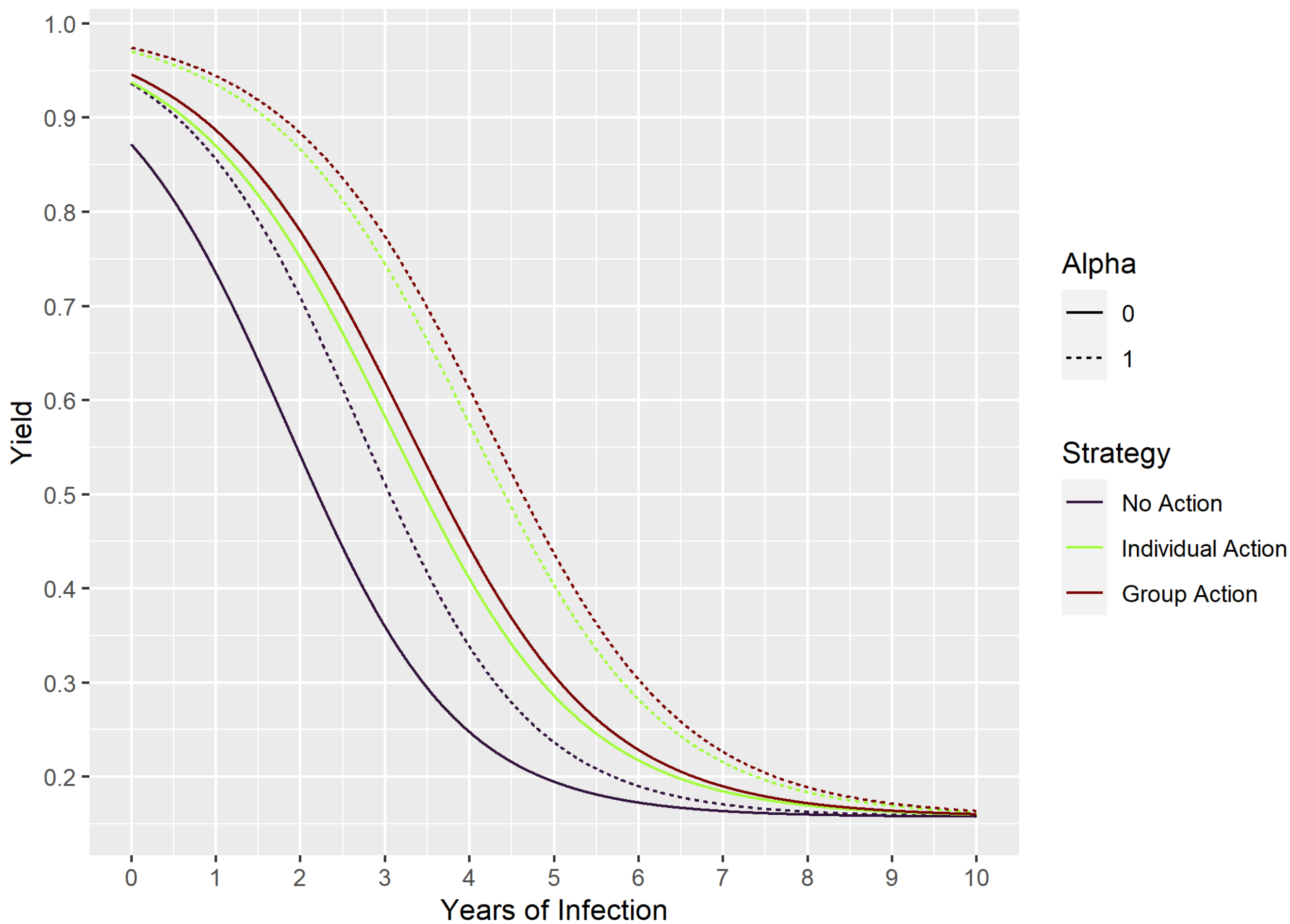

Figure 13: Predicted HLB Yield by Alpha and Strategy, 85% Efficacy

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	Dependent variable:					
	t					
	Weibull	Exponential	Gaussian	Logistic	Lognormal	Loglogistic
strategyIndividual Action	0.043***	0.056**	38.191***	32.556***	0.049**	0.052***
	(0.015)	(0.027)	(10.641)	(9.744)	(0.023)	(0.020)
strategyGroup Action	0.038**	0.049*	34.733***	29.264***	0.045**	0.047**
	(0.015)	(0.027)	(10.637)	(9.737)	(0.023)	(0.020)
efficacy0.75	−0.0004	0.001	0.255	0.474	0.003	0.002
	(0.020)	(0.037)	(14.901)	(12.753)	(0.032)	(0.028)
efficacy0.85	0.005	0.005	2.123	2.137	0.005	0.005
	(0.020)	(0.037)	(14.901)	(12.763)	(0.032)	(0.028)
alpha1	0.396***	0.405***	219.284***	225.057***	0.385***	0.438***
	(0.020)	(0.037)	(14.901)	(13.266)	(0.032)	(0.028)
efficacy0.75:alpha1	0.279***	0.283***	207.058***	217.835***	0.247***	0.282***
	(0.029)	(0.052)	(21.076)	(19.190)	(0.045)	(0.039)
efficacy0.85:alpha1	1.123***	1.453***	856.416***	1,006.090***	1.019***	1.099***
	(0.032)	(0.059)	(21.472)	(20.126)	(0.046)	(0.041)
Constant	6.334***	6.227***	518.556***	528.549***	5.994***	6.094***
	(0.024)	(0.044)	(17.340)	(15.828)	(0.037)	(0.033)
Observations	8,748	8,748		8,748	8,748	8,748
Log Likelihood	-58,026.980	-59,589.350	-60,107.190	-59,732.680	-59,663.980	-59,227.780
χ^2 (df = 15)	5,968.212***	3,357.036***	5,892.451***	6,253.058***	2,682.095***	3,576.694***
Note:						*p<0.1; **p<0.05; ***p<0.01

Table 1: Regression output across distribution for interaction specification of variable coordination model

	Dependent variable:					
	t					
	Weibull	Exponential	Gaussian	Logistic	Lognormal	Loglogistic
strategyIndividual Action	0.026	0.027	16.760	14.048	0.022	0.025
	(0.016)	(0.028)	(11.315)	(10.150)	(0.024)	(0.021)
strategyGroup Action	0.021	0.021	13.251	10.766	0.019	0.020
	(0.016)	(0.028)	(11.315)	(10.144)	(0.024)	(0.021)
efficacy0.75	−0.0005	0.001	0.255	0.473	0.003	0.002
	(0.020)	(0.037)	(14.883)	(12.735)	(0.032)	(0.028)
efficacy0.85	0.005	0.005	2.123	2.121	0.005	0.005
	(0.020)	(0.037)	(14.883)	(12.745)	(0.032)	(0.028)
alpha1	0.396***	0.405***	219.284***	225.041***	0.385***	0.438***
	(0.020)	(0.037)	(14.883)	(13.249)	(0.032)	(0.028)
Spray85a1	0.184***	0.301***	141.337***	175.876***	0.181***	0.196***
	(0.044)	(0.080)	(25.614)	(27.585)	(0.056)	(0.050)
efficacy0.75:alpha1	0.280***	0.283***	207.048***	217.798***	0.247***	0.281***
	(0.029)	(0.052)	(21.051)	(19.165)	(0.045)	(0.039)
efficacy0.85:alpha1	1.004***	1.259***	763.294***	887.025***	0.900***	0.971***
	(0.042)	(0.077)	(27.224)	(27.483)	(0.059)	(0.052)
Constant	6.346***	6.246***	532.879***	540.767***	6.012***	6.113***
	(0.024)	(0.044)	(17.513)	(15.929)	(0.038)	(0.033)
Observations	8,748	8,748		8,748	8,748	8,748
Log Likelihood	-58,018.400	-59,582.380	-60,091.990	-59,712.230	-59,658.730	-59,220.180
χ^2 (df = 16)	5,985.378***	3,370.975***	5,922.853***	6,293.958***	2,692.597***	3,591.886***
Note:						*p<0.1; **p<0.05; ***p<0.01

Table 2: Regression output across distribution for `threeterm` specification of variable coordination model

Table 3: Regression output for variable coordination model

	Dependent variable:	
	maxHLB	
	OLS	ML
efficacy0.75	0.012	-0.207^{***}
	(0.009)	(0.061)
efficacy0.85	0.092^{***}	-0.073
	(0.009)	(0.065)
alpha1	0.001	0.015
	(0.002)	(0.012)
strategyIndividual Action	-0.045^{***}	-0.155^{**}
	(0.009)	(0.061)
strategyGroup Action	-0.035^{***}	-0.102^{*}
	(0.009)	(0.061)
maxT	0.001^{***}	0.002^{***}
	(0.00001)	(0.00003)
efficacy0.75:alpha1	-0.018^{***}	-0.063^{***}
	(0.003)	(0.018)
efficacy0.85:alpha1	-0.105^{***}	-0.791^{***}
	(0.003)	(0.022)
efficacy0.75:strategyIndividual Action	0.013	-0.164^{**}
	(0.012)	(0.080)
efficacy0.85:strategyIndividual Action	0.001	-0.644^{***}
	(0.012)	(0.093)
efficacy0.75:strategyGroup Action	0.014	-0.139^{*}
	(0.011)	(0.080)
efficacy0.85:strategyGroup Action	0.006	-0.850^{***}
	(0.012)	(0.094)
efficacy0.75:maxT	-0.00000	0.0002^{***}
	(0.00001)	(0.00005)
efficacy0.85:maxT	-0.00005^{***}	0.0002^{***}
	(0.00001)	(0.00005)
strategyIndividual Action:maxT	-0.00001^{*}	-0.0001^{**}
	(0.00001)	(0.00005)
strategyGroup Action:maxT	-0.00002^{***}	-0.0001^{***}
	(0.00001)	(0.00005)
efficacy0.75:strategyIndividual Action:maxT	-0.00004^{***}	-0.00003
	(0.00001)	(0.0001)
efficacy0.85:strategyIndividual Action:maxT	-0.0001^{***}	-0.0002^{**}
	(0.00001)	(0.0001)
efficacy0.75:strategyGroup Action:maxT	-0.00004^{***}	-0.0001
	(0.00001)	(0.0001)
efficacy0.85:strategyGroup Action:maxT	-0.0002^{***}	-0.0001^{**}
	(0.00001)	(0.0001)
Constant	-0.046^{***}	-2.450^{***}
	(0.007)	(0.046)
AIC	-25201.77524	-22403.71158
BIC	-25048.03767	-22249.97401
Observations	8,007	8,007
R^2	0.945	0.828
Adjusted R^2	0.945	
Log Likelihood		11,223.840
Residual Std. Error	0.050 (df = 7986)	
F Statistic	$6{,}895.359^{***}$ (df = 20; 7986)	
Note:		*p<0.1; **p<0.05; ***p<0.01

	Dependent variable:					
	t					
	Weibull	Exponential	Gaussian	Logistic	Lognormal	Loglogistic
efficacy0.75	0.279***	0.283***	206.495***	211.549***	0.248***	0.276***
	(0.015)	(0.024)	(13.412)	(12.324)	(0.025)	(0.021)
efficacy0.85	1.133***	1.407***	898.295***	995.618***	1.071***	1.116***
	(0.018)	(0.029)	(14.063)	(13.592)	(0.026)	(0.022)
window	−0.002***	−0.002***	−1.701***	−1.696***	−0.002***	−0.002***
	(0.0002)	(0.0003)	(0.171)	(0.163)	(0.0003)	(0.0003)
Constant	6.830***	6.798***	872.206***	888.956***	6.517***	6.647***
	(0.024)	(0.039)	(20.198)	(19.363)	(0.038)	(0.032)
Observations	10,206	10,206		10,206	10,206	10,206
Log Likelihood	-65,936.590	-67,063.160	-67,304.950	-67,140.120	-67,899.640	-67,313.040
χ^2 (df = 11)	4,625.579***	3,070.729***	4,300.165***	4,894.231***	1,951.485***	2,728.570***
Note:						*p<0.1; **p<0.05; ***p<0.01

Table 4: Regression output across distribution for linear specification of full coordination model

	Dependent variable:					
	t					
	Weibull	Exponential	Gaussian	Logistic	Lognormal	Loglogistic
efficacy0.75	0.310***	0.321***	236.234***	244.236***	0.283***	0.312***
	(0.026)	(0.042)	(23.098)	(21.197)	(0.043)	(0.035)
efficacy0.85	1.359***	1.746***	1,078.961***	1,205.248***	1.301***	1.344***
	(0.033)	(0.053)	(24.427)	(23.673)	(0.046)	(0.039)
window	−0.0004	−0.0005	−0.302	−0.309	−0.001	−0.001
	(0.0003)	(0.001)	(0.289)	(0.257)	(0.001)	(0.0004)
efficacy0.75:window	−0.001	−0.001	−0.647	−0.713*	−0.001	−0.001
	(0.0005)	(0.001)	(0.409)	(0.376)	(0.001)	(0.001)
efficacy0.85:window	−0.005***	−0.007***	−3.864***	−4.526***	−0.005***	−0.005***
	(0.001)	(0.001)	(0.425)	(0.416)	(0.001)	(0.001)
Constant	6.772***	6.715***	807.945***	824.583***	6.438***	6.573***
	(0.026)	(0.043)	(22.824)	(21.408)	(0.043)	(0.035)
Observations	10,206	10,206		10,206	10,206	10,206
Log Likelihood	-65,896.460	-67,029.500	-67,258.390	-67,076.040	-67,878.410	-67,284.430
χ^2 (df = 13)	4,705.853***	3,138.033***	4,393.280***	5,022.391***	1,993.949***	2,785.786***

Note: *p<0.1; **p<0.05; ***p<0.01

Table 5: Regression output across distribution for interaction specification of full coordination model

Table 6: Regression output for Full Coordination In-Grove Spread Models

	Dependent variable:	
	maxHLB	
	OLS	ML
window	−0.00003	−0.0001
	(0.00003)	(0.0002)
efficacy0.75	0.007	−0.525***
	(0.005)	(0.031)
efficacy0.85	−0.029***	−2.920***
	(0.005)	(0.047)
maxT	0.001***	0.002***
	(0.00000)	(0.00002)
window:efficacy0.75	0.0001**	0.0004
	(0.00004)	(0.0003)
window:efficacy0.85	0.001***	0.011***
	(0.0001)	(0.0004)
efficacy0.75:maxT	−0.0001***	0.0002***
	(0.00000)	(0.00002)
efficacy0.85:maxT	−0.0002***	0.0004***
	(0.00000)	(0.00003)
Constant	−0.094***	−2.618***
	(0.004)	(0.023)
AIC	-23752.52068	-26117.93547
BIC	-23682.02836	-26047.44315
Observations	8,512	8,512
R^2	0.936	0.847
Adjusted R^2	0.936	
Log Likelihood		13,068.960
Residual Std. Error	0.060 (df = 8503)	
F Statistic	15,455.590*** (df = 8; 8503)	
Note:		*p<0.1; **p<0.05; ***p<0.01

	Dependent variable:
	hlb
lambda	-0.642^{***}
	(0.010)
alpha_perception	0.800^{***}
	(0.010)
premium	0.003^{***}
	(0.0002)
meanNeighborLambda	-0.695^{***}
	(0.029)
meanNeighborAP	0.854^{***}
	(0.028)
meanNeighborPremium	0.002^{***}
	(0.001)
Constant	1.329^{***}
	(0.075)
Observations	45,000
R^2	0.705
Log Likelihood	41,691.230
Note:	*p<0.1; **p<0.05; ***p<0.01

Table 7: Regression output for the grower level HLB spread model

	Dependent variable:
	hlb
lambda	−0.959***
	(0.034)
alpha_perception	1.201***
	(0.033)
premium	0.003***
	(0.001)
Constant	−0.457***
	(0.037)
Observations	5,000
R^2	0.726
Log Likelihood	7,467.687
Note:	*p<0.1; **p<0.05; ***p<0.01

Table 8: PMA level HLB severity regression output

Table 9: Comparisons of distributions for the invasion controls specifications

	Dependent variable:					
	t					
	Weibull	Exponential	Gaussian	Logistic	Log-normal	Log-logistic
	(1)	(2)	(3)	(4)	(5)	(6)
lambda	−0.005	−0.001	1.873	1.048	0.001	0.002
	(0.004)	(0.016)	(1.937)	(1.245)	(0.003)	(0.002)
alpha_perception	0.014***	0.003	−0.651	−0.808	0.001	−0.001
	(0.004)	(0.016)	(1.935)	(1.245)	(0.003)	(0.002)
premium	−0.00001	0.0001	0.048	0.034	0.0001	0.0001
	(0.0001)	(0.0003)	(0.034)	(0.022)	(0.00005)	(0.00004)
meanNeighborLambda	0.183***	0.177***	145.315***	70.373***	0.157***	0.116***
	(0.011)	(0.047)	(5.523)	(3.575)	(0.007)	(0.006)
meanNeighborAP	−0.164***	−0.195***	−164.055***	−80.875***	−0.175***	−0.130***
	(0.011)	(0.046)	(5.441)	(3.544)	(0.007)	(0.006)
meanNeighborPremium	−0.00004	−0.001	−0.420***	−0.212***	−0.001***	−0.0003***
	(0.0002)	(0.001)	(0.098)	(0.063)	(0.0001)	(0.0001)
Constant	4.377***	4.410***	95.061***	88.640***	4.410***	4.500***
	(0.026)	(0.112)	(13.198)	(7.662)	(0.017)	(0.015)
AIC	520278.411	616343.093	556485.318	536506.106	485943.781	480769.475
BIC	524574.619	620630.586	560781.526	540802.314	490239.989	485065.683
Observations	45,000	45,000		45,000	45,000	45,000
Log Likelihood	-259,646.200	-307,679.500	-277,749.700	-267,760.100	-242,478.900	-239,891.700
χ^2 (df = 491)	111,459.800***	24,053.490***	92,958.970***	110,032.600***	145,533.100***	153,032.600***
Note:						*p<0.1; **p<0.05; ***p<0.01

Entity	Variable Name	Description	Possible Values
Grower	Location	Location on the 3x3 grid of groves	$\{(i,j)\mid i,j \in \{0,1,2\}\}$
	λ	Trust in external information	$[0,1]$
	α-perception	Proportion of neighbors believed to be cooperating	$[0,1]$
	S	Current strategy	No Action, Individual Action, Group Action
	costs	Cumulative costs	$\mathbb{R}$
	returns	Cumulative returns	$\mathbb{R}$
	profit	Cumulative profit	$\mathbb{R}$
Flush Patch	Location	Location on the 33x75 grid	$\{(i,j)\mid i \leq numRows, j \leq numColumns, i,j \in \mathbb{N}\}$
	HLB Severity	Proportion of flush infected by HLB	$[0,1]$
Psyllid	Location	Location on the 33x75 grid	$\{(i,j)\mid i \leq numRows, j \leq numColumns, i,j \in \mathbb{N}\}$
	Infected	Indicator variable representing infection status	$\{0,1\}$
	Age	Age of psyllid in days	$\mathbb{N}$
	Female	Sex of Psyllid	$\{0,1\}$
Environment	t	Days since start of simulation	$\mathbb{N}$
	Temperature	Current temperature	$25°C$, $28°C$

Table 10: A summary of the state variables for each agent

Name	Description	Value	Source
maxFlushAge	Maximum flush age before hardening	30 days	Lee et al. (2015)
flushEmerging	Number of flush emerging per day in flushing period	20 flush	Lee et al. (2015)
eggAdultTransition	Age where psyllids become adults	17 days	Lee et al. (2015)
proportionMigrating	Proportion of psyllids that migrate	0.4	Lee et al. (2015)
withinRowP	Probability of a psyllid migrating within rows	0.95	Lee et al. (2015)
betweenRowP	Probability of a psyllid migrating across rows	0.05	Lee et al. (2015)
borderCrossingP	Probability of a psyllid migrating across grove borders	0.01	Chosen by authors
shootCapacity	Number of eggs a flush shoot can hold	40 eggs	Lee et al. (2015)
eggsPerFemaleAdult	Eggs a female adult is capable of laying in a day	10 eggs	Lee et al. (2015)
transmissionFlushNymph	Probability of a flush transmitting disease to a nymph	0.083	Lee et al. (2015)
transmissionAdultFlush	Probability of an adult transmitting disease to a flush	0.3	Lee et al. (2015)
nymphSurvivalP	Probability of nymph survival	0.8614	Lee et al. (2015)
adultSurvivalP	Probability of adult psyllid survival	0.9847	Lee et al. (2015)
minAgeToBeInfected	Minimum age for nymphs to be infected	6 days	Lee et al. (2015)
initialInfectedPortion	Proportion of initial invading populatin that is infected	0.18	Lee et al. (2015)
invasionDay	The day the invading population is introduced	Day 80	Lee et al. (2015)
carryingCapacity	The carrying capacity of a flush patch	40000 psyllids	Lee et al. (2015)

springFlushStart	Day that spring flushing period begins	Day 80	Lee et al. (2015)
springFlushEnd	Day that spring flushing period ends	Day 140	Lee et al. (2015)
summerFlushStart	Day that summer flushing period begins	Day 180	Lee et al. (2015)
summerFlushEnd	Day that the summer flushing period ends	Day 195	Lee et al. (2015)
fallFlushStart	Day that the fall flushing period starts	Day 250	Lee et al. (2015)
fallFlushEnd	Day that the fall flushing period ends	Day 280	Lee et al. (2015)
planningLength	The length of the grower planning period	91 days	Chosen by authors
yield	The number of cartons yielded by each flush patch per harvest	0.8623 cartons	Derived from Kallsen et al. (2021)
price	The real market price per carton	$17.60	Kallsen et al. (2021)
costs	The real annual fixed costs for a grower	$11,718.47	Kallsen et al. (2021)
projectionLength	The amount of days the choice function projects from the end of the model	1825 days	Chosen by authors
sprayCost	The cost of one insecticide application	$67.73	Derived from PMA reccomendations
groupWindow	The size of the window for Group Action	21	Based on PMA guidelines
individualWindow	The size of the window for Individual Action	60	Chosen by authors
harvestDays	The set of days on which harvesting occurs	$\{100, 200, 300\}$	Chosen by authors

Table 11: Model parameter values and descriptions