Optimizing HLB Surveillance in Southern California through Adaptive Risk-Based Surveys

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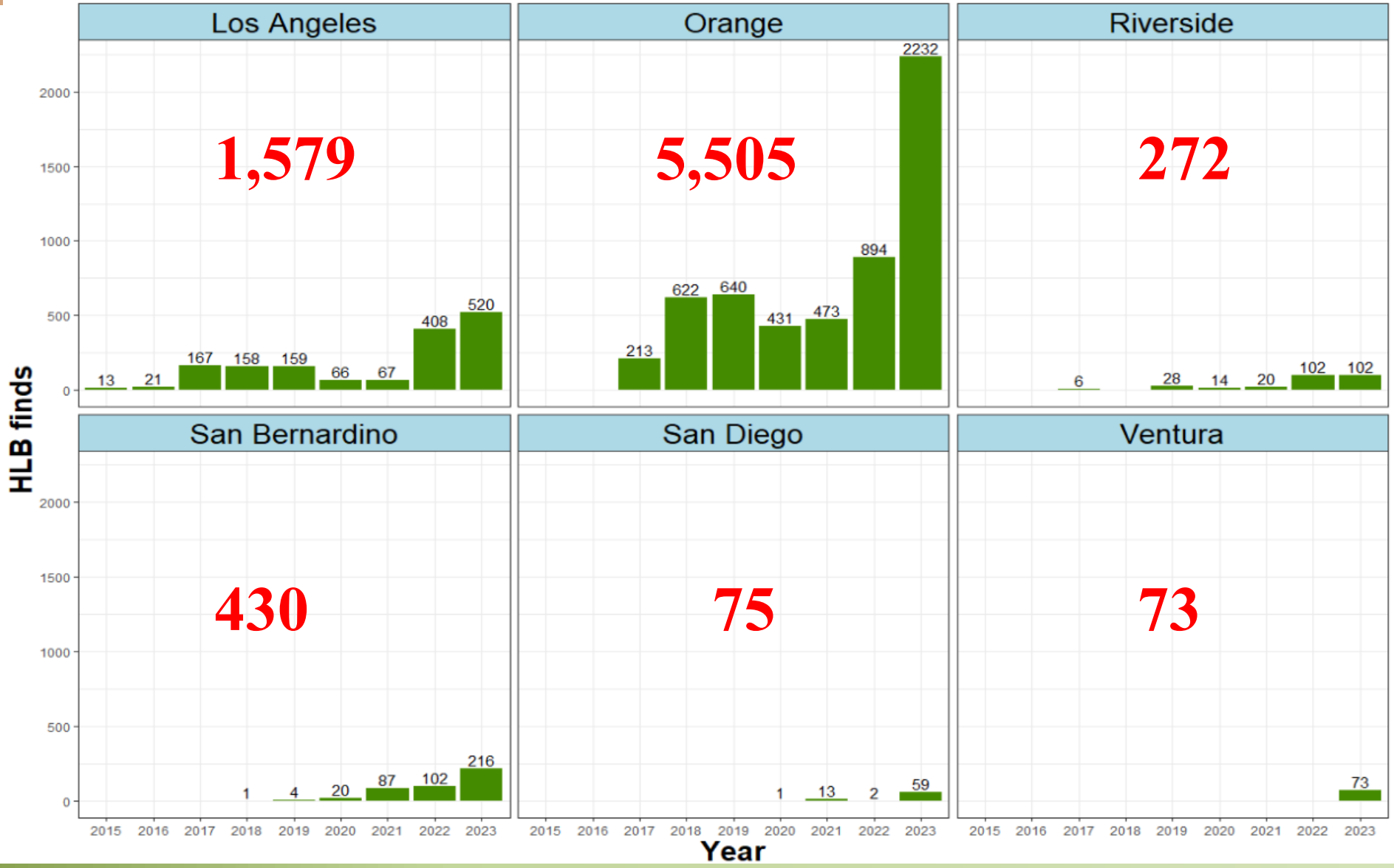
Support: CRB #5300-199

Background: HLB detections in Southern CA, 2015-2023

Fixed scale for cross comparison between counties

All panels have the same Y axis

Totally, 7,936 CLas+ trees or ACP detected by the end of 2023

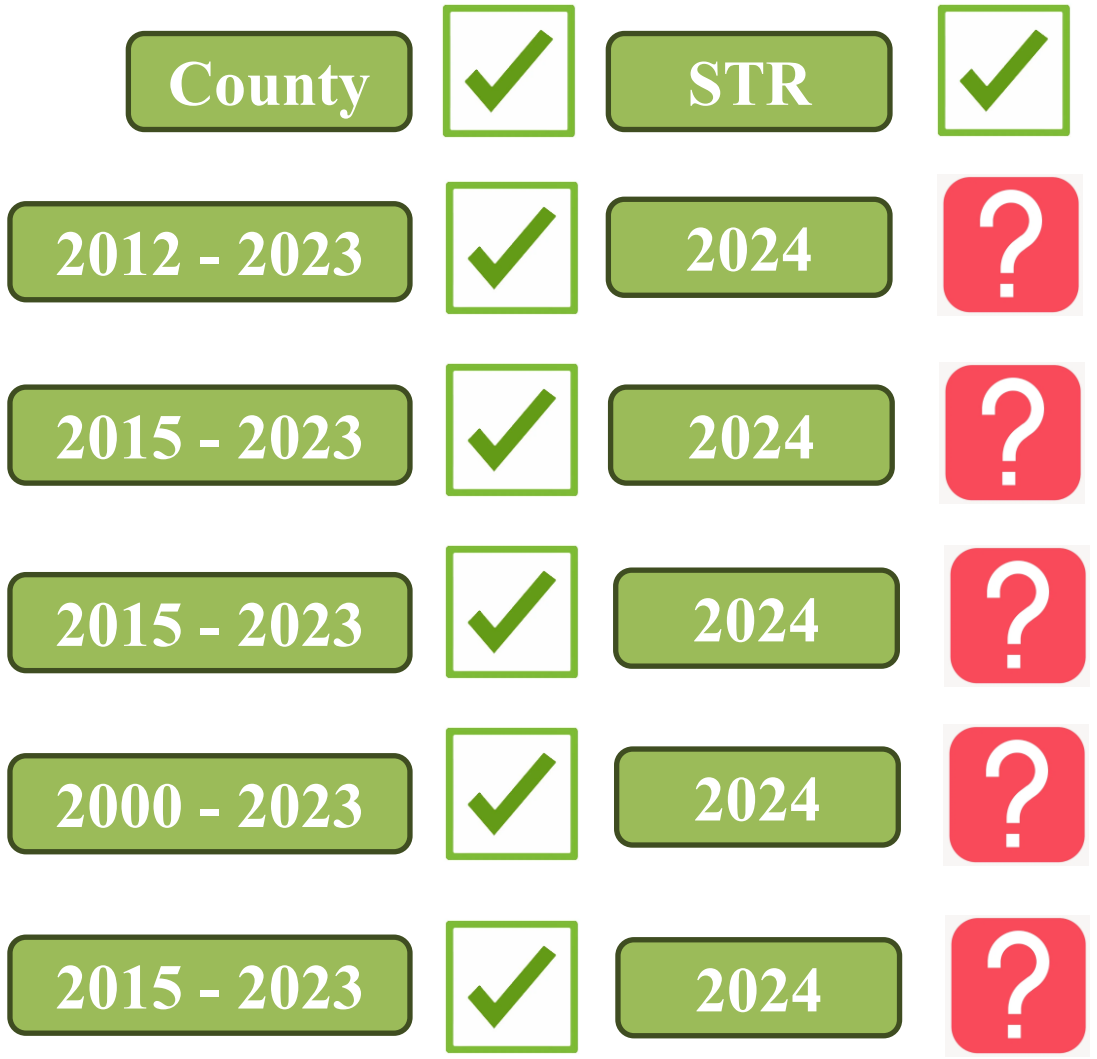


What we know so far for HLB epidemic in Southern CA

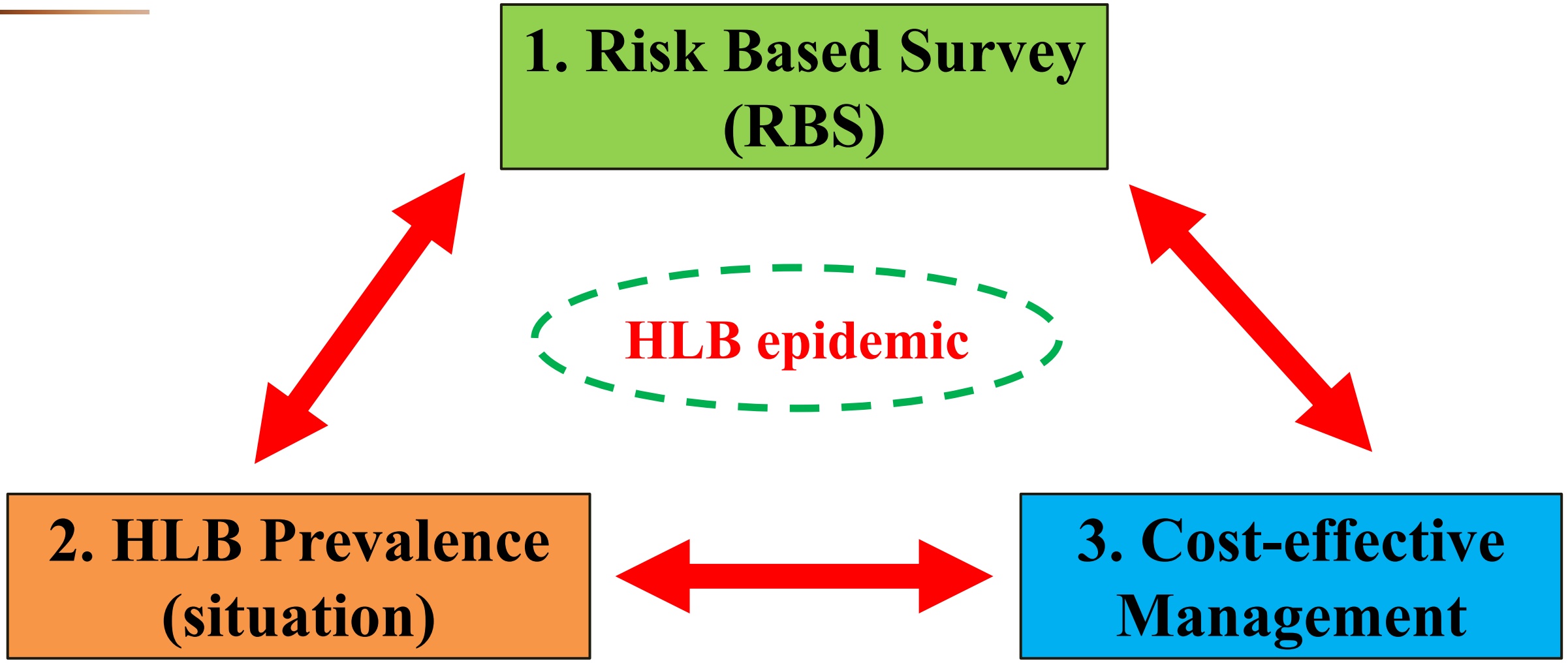
Questions we can answer

- **Residential and commercial citrus host map**
  i.e. How many dooryard citrus trees?
- **HLB (RBS or MPS) Survey coverage**
  i.e. Any areas we haven't surveyed in the past 5 years?
- **Sampled HLB prevalence and positivity rate**
  i.e. Any locations with higher trend of HLB detection?
- **Impact of different risk factors on HLB spread**
  i.e. Relationship with ACP density, citrus road, packinghouse, etc.?
- **Climate suitability for ACP development**
  i.e. Any adverse climate events (freezing winter) for ACP survival?
- **Actual HLB situation (min & max)**
  i.e. How many HLB infected trees out there?

Available outputs



Outline

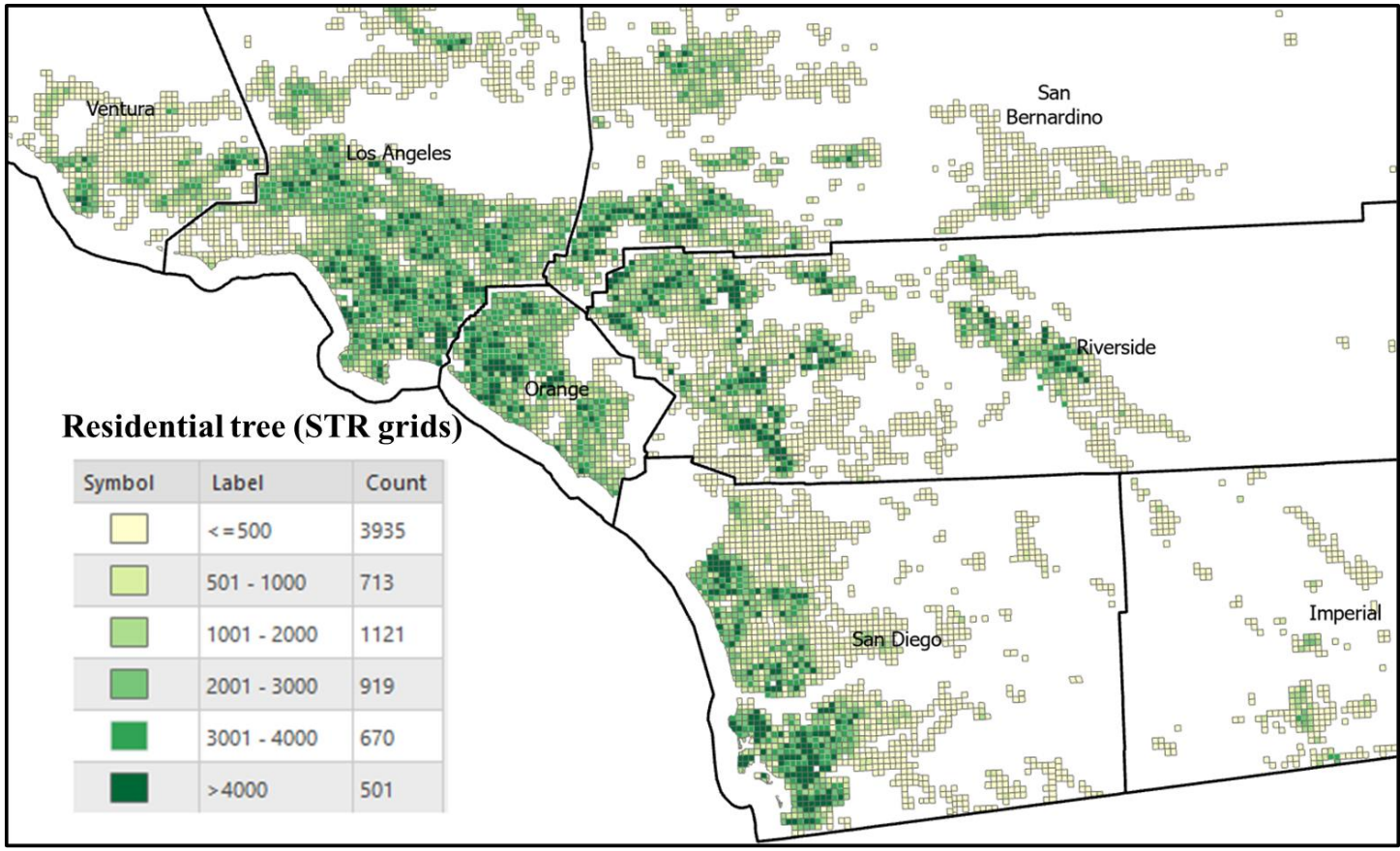

1. Risk Based Survey (RBS)
HLB epidemic
2. HLB Prevalence (situation)
3. Cost-effective Management

1. Risk Based Survey

How to pick samples from this massive landscape?

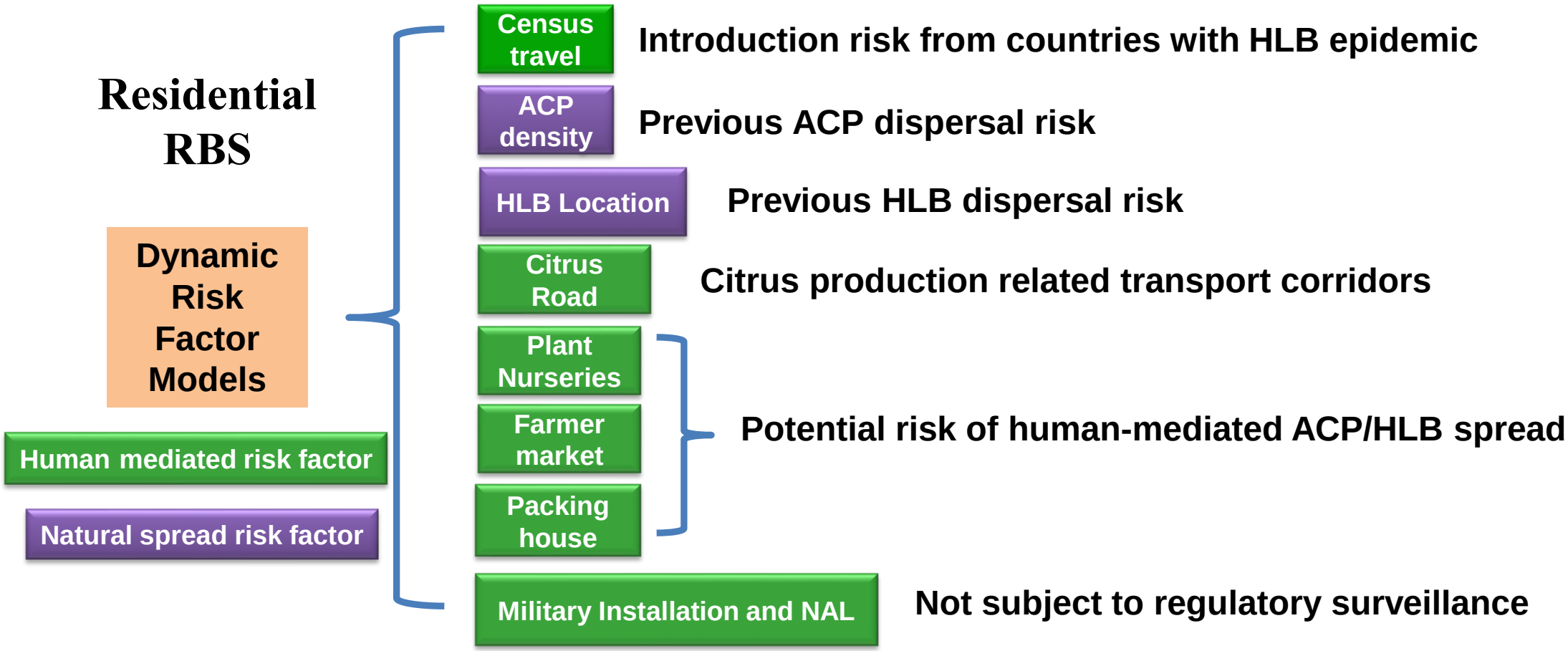
Average survey coverage per year (Southern CA)

Survey	YES	NO
STRs	~1,080 (15%)	6,137 (85%)
Samples	~75,000 (1.25%)	5,895,000 (98.75%)



Residential citrus STR (7221)
Residential citrus population (~6 million)

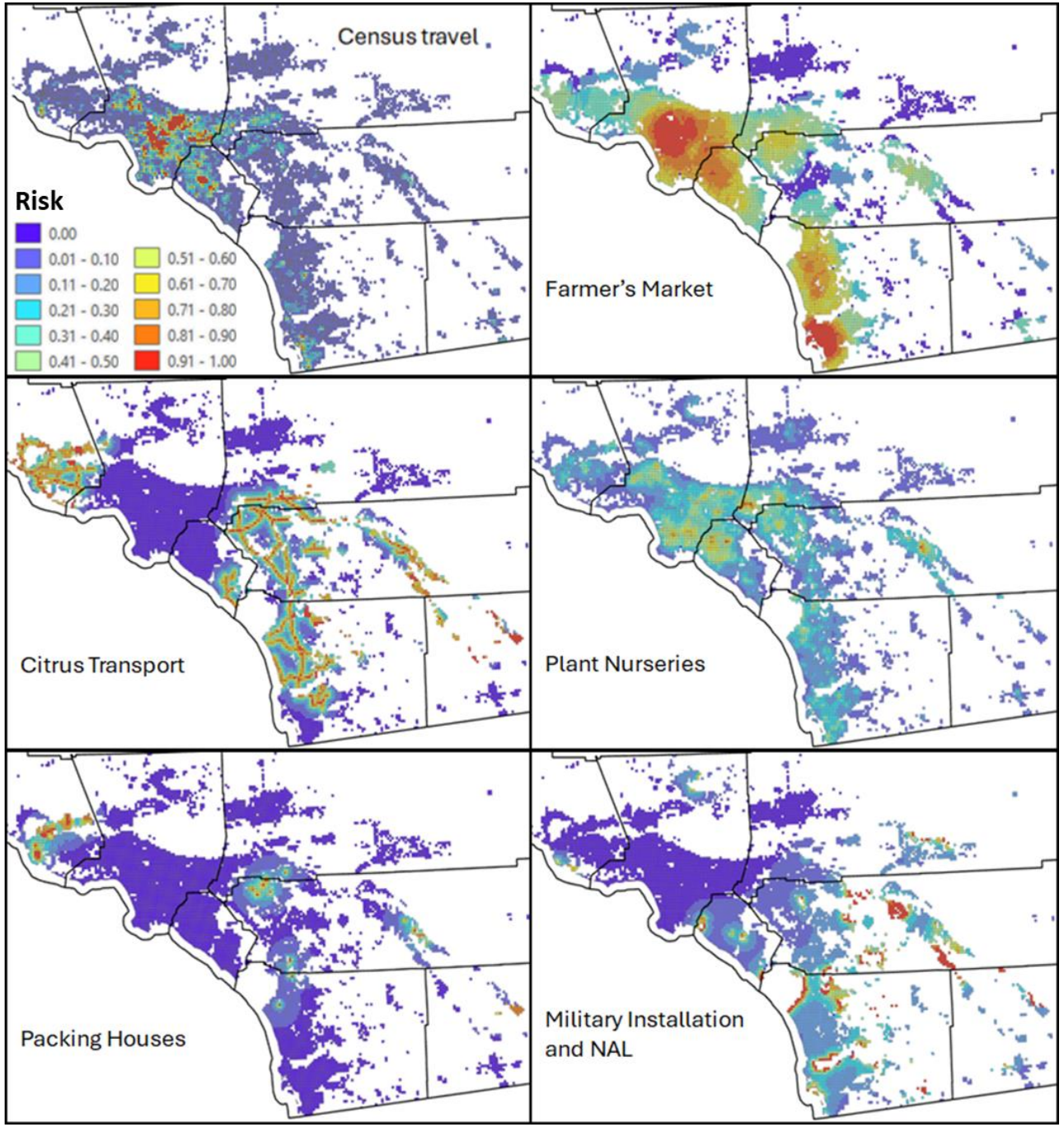
Risk factors considered in RBS model in Southern CA



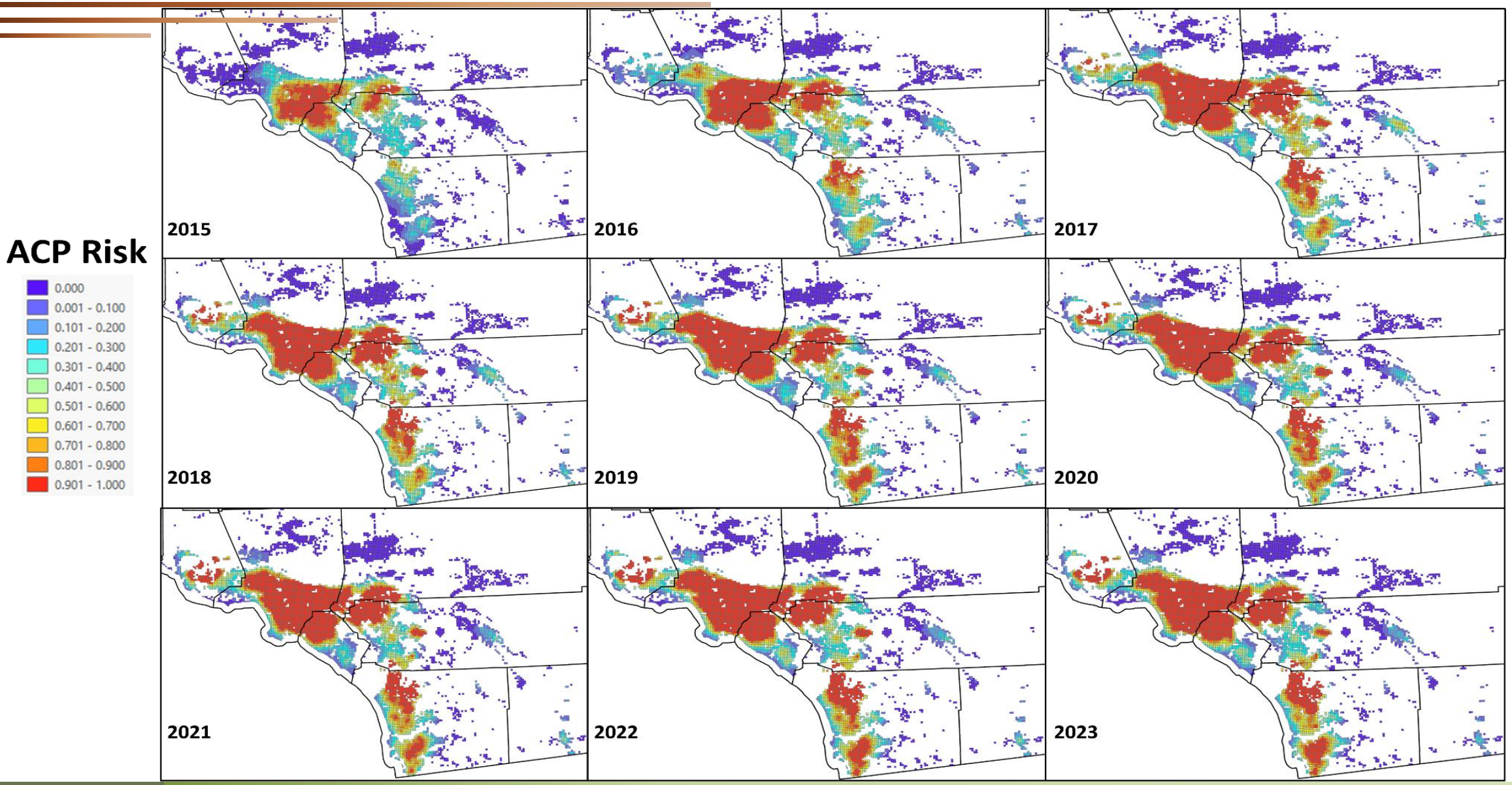
Luo et al., (2024) A smarter way to survey for HLB – Evaluating a risk-based model in Southern California. Citrograph, 15, 48-52;
Luo et al., (2024) Advancing HLB Management: A Risk-Based Survey Model for Residential Citrus in Southern California. Prepared for Journal submission in Apr.

Stable Risk Factors

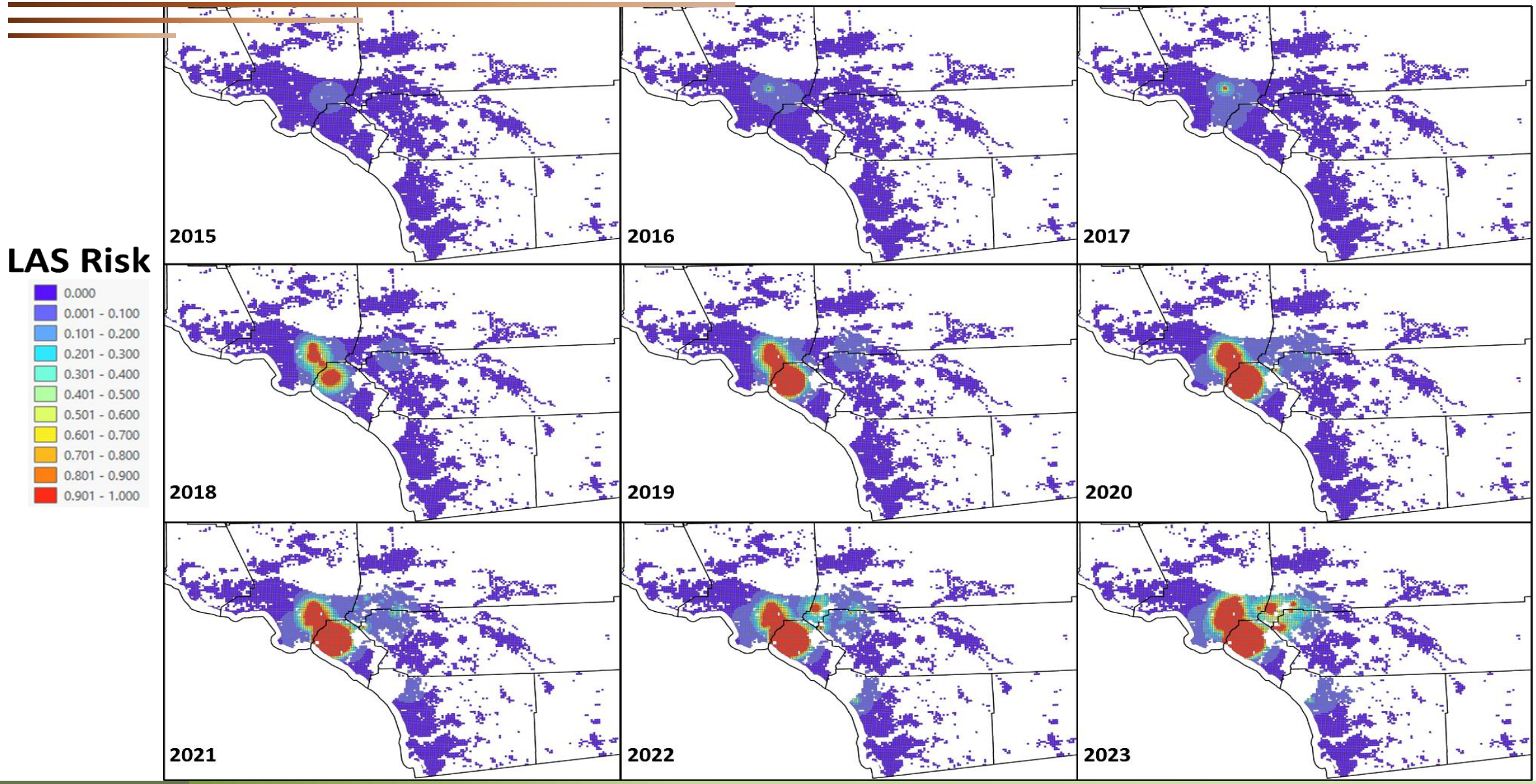
- Census travel
- Farmer's Markets
- Citrus Transportation
- Plant Nurseries
- Packing Houses
- Military Installations and NAL



Previous ACP location dispersal risk (dynamic risk factor)



Previous HLB location dispersal risk (dynamic risk factor)



Risk factor contribution and overall performance

Machine Learning Procedure

1.[0.30, 0.05, 0.47, 0.24, 0.16, 0.73, 0.01, 0.15]
2.[0.10, 0.51, 0.82, 0.21, 0.07, 0.70, 0.42, 0.55]
3.[0.64, 0.25, 0.12, 0.70, 0.70, 0.38, 0.98, 0.39]
4.[0.71, 0.88, 0.75, 0.34, 1.00, 0.31, 0.93, 0.97]
5. ……[**Random weight example**]

We investigate over 1,000,000 simulations of random weight combinations for various risk factors to identify the optimal weighting. This approach aims to achieve the highest predictive power in forecasting HLB locations one year in advance.

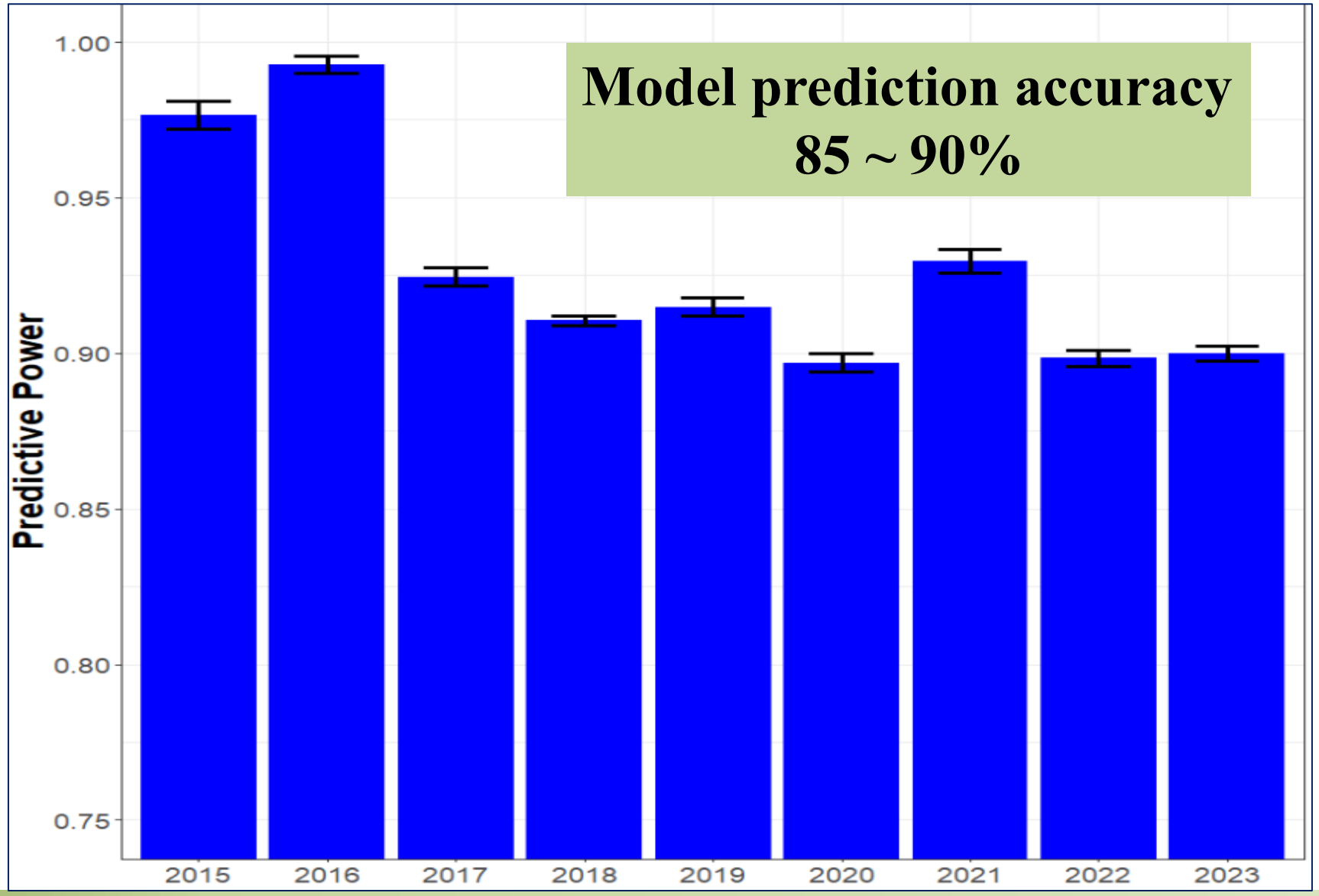
Factors	2015	2016	2017	2018	2019	2020	2021	2022	2023
Census Travel	0.05	0.05	0.07	0.10	0.14	0.07	0.09	0.08	**0.10**
Previous ACP Dispersal	0.12	0.50	0.53	0.13	0.14	0.15	0.14	0.22	**0.24**
Previous HLB Dispersal	0.60	0.11	0.14	0.60	0.68	0.61	0.67	0.53	**0.52**
Farmer's Market	0.05	0.11	0.08	0.08	0.06	0.02	0.02	0.00	**0.01**
Citrus Transport	0.00	0.00	0.09	0.05	0.07	0.00	0.07	0.12	**0.11**
Plant Nurseries	0.01	0.10	0.06	0.11	0.02	0.07	0.02	0.02	**0.02**
Packing Houses	0.00	0.00	0.02	0.02	0.01	0.02	0.04	0.01	**0.03**
MINAL	0.00	0.00	0.00	0.00	0.00	0.01	0.00	0.00	**0.00**

Risk factor contribution and overall performance

Predict HLB finds at STR level

The RBS model is used to increase the probability of early detection. Once a positive sample is detected, delimited response will be applied to that location. The RBS will then shift its priority to finding the next HLB site outside the delimited area.

RBS → **Delimited response**



2. HLB Prevalence

How many HLB+ trees in the landscape?

- **Disease surveys**, like snapshots, show part of the disease situation, but may miss the bigger story.
- **Mathematical modeling** can go beyond the limited view of surveys, painting the full picture of the disease landscape.
- Having a **comprehensive understanding of the actual HLB situation** will enable more effective surveillance design and support cost-efficient management decisions

Survey

+

Modeling

Methodology on HLB prevalence estimation

Method: We use the binomial probability law to estimate HLB prevalence with consideration of sampling effort and spatial pattern *(assuming no false negative for sampling).*

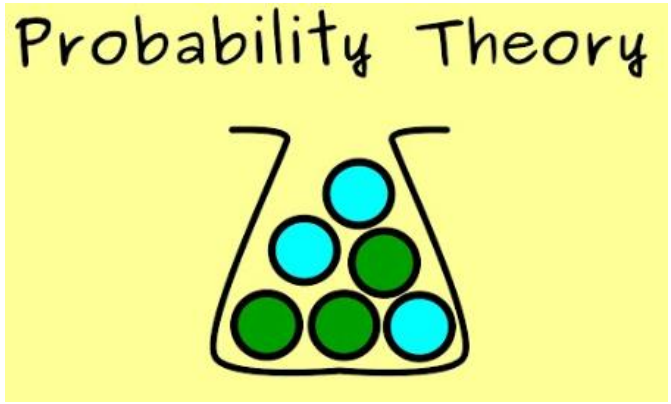
$$P(x|f,p) = (1-f)0^x + f\binom{n}{x}p_{\text{pool}}^x(1-p_{\text{pool}})^{n-x}$$

$$= (1-f)0^x + f\binom{n}{x}(1-q^m)^x q^{m(n-x)}$$

HLB Spatial Pattern

Sampling Effort

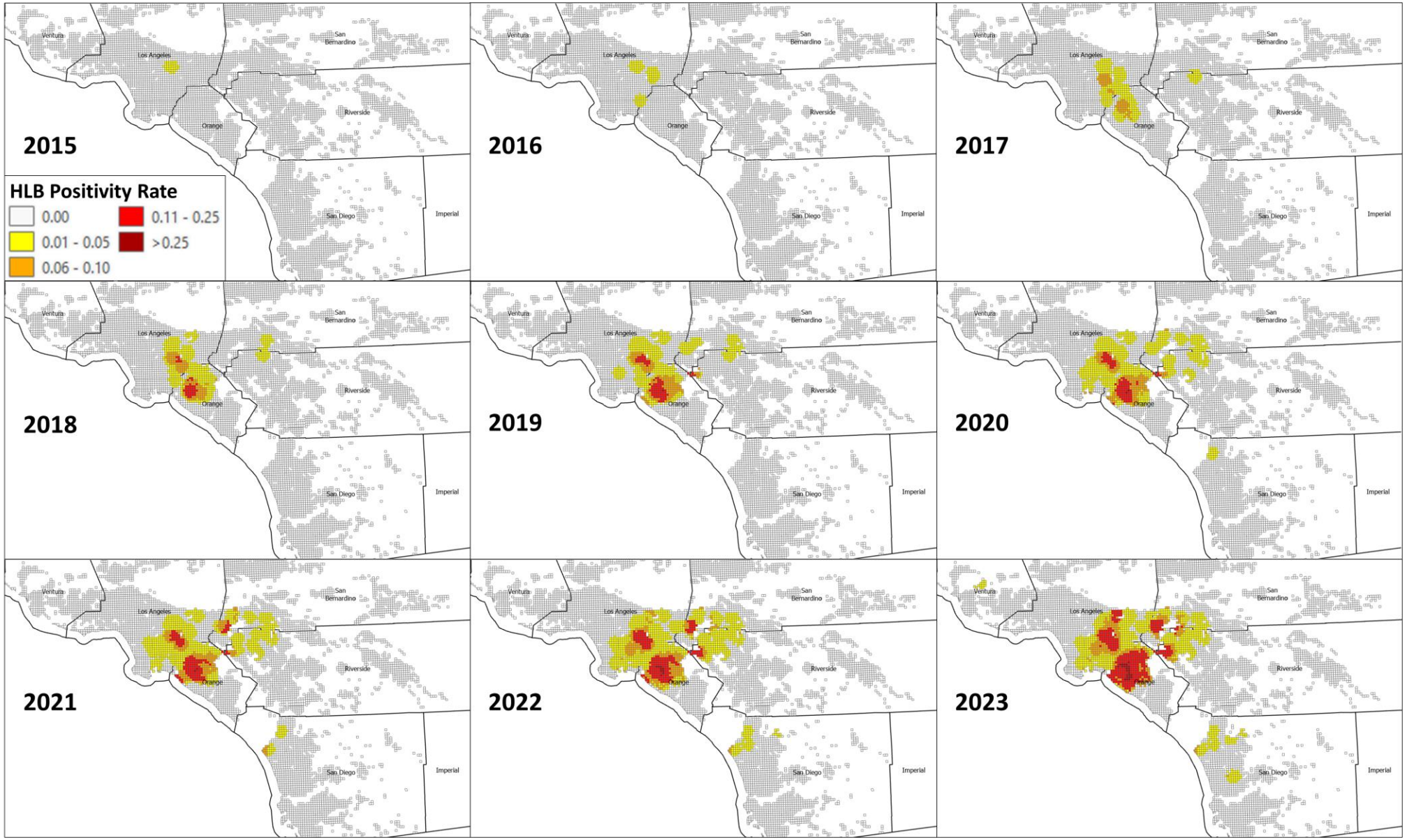
Distance to nearby HLB finds



Population: Mix of healthy and HLB+ trees in the landscape
Survey: Sampling a proportion of trees in different areas following RBS/MPS design

Determine **actual HLB prevalence and distribution** for optimized management

Estimated HLB Prevalence – 2015 to 2023



Estimated HLB prevalence (minimum and maximum)

Estimated Minimum HLB Prevalence (assuming no spread beyond confirmed HLB+ STRs)

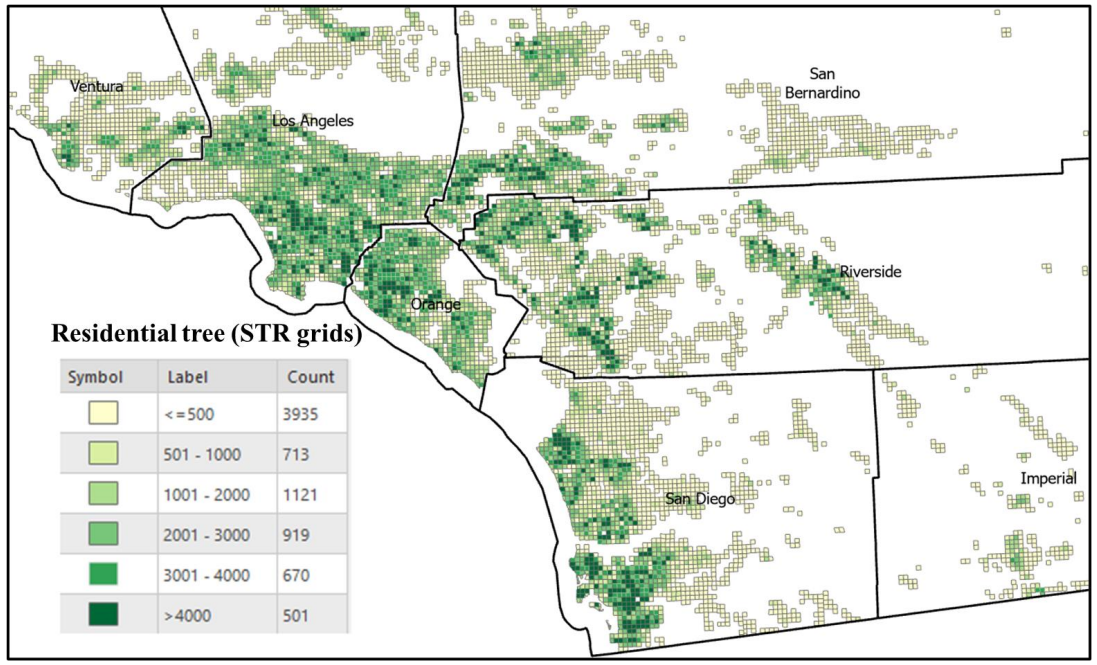
County	2015	2016	2017	2018	2019	2020	2021	2022	2023
Los Angeles	0.1%	0.3%	0.8%	1.5%	2.3%	2.9%	3.0%	4.9%	5.7%
Orange	0.0%	0.0%	3.1%	6.9%	11.0%	13.8%	15.3%	17.8%	24.7%
Riverside	0.0%	0.0%	0.2%	0.2%	0.2%	0.6%	0.7%	1.6%	2.2%
San Bernardino	0.0%	0.0%	0.0%	0.1%	0.4%	0.7%	1.0%	1.2%	1.5%
San Diego	0.0%	0.0%	0.0%	0.0%	0.0%	0.1%	0.2%	0.3%	0.6%
Ventura	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.5%

Estimated Maximum HLB Prevalence (assuming up to 5km spread from confirmed HLB+ locations)

County	2015	2016	2017	2018	2019	2020	2021	2022	2023
Los Angeles	2.0%	5.8%	11.0%	13.1%	17.7%	21.9%	23.3%	28.9%	30.6%
Orange	0.0%	1.3%	25.7%	41.3%	47.4%	53.6%	55.1%	58.6%	61.2%
Riverside	0.0%	0.0%	2.1%	2.1%	3.4%	10.7%	13.9%	17.3%	17.4%
San Bernardino	0.0%	0.0%	0.6%	3.1%	7.9%	12.7%	13.3%	14.7%	15.3%
San Diego	0.0%	0.0%	0.0%	0.0%	0.0%	2.2%	4.5%	7.6%	12.0%
Ventura	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	3.2%

How many undetected HLB+ trees in each county?

Total dooryard citrus trees in each county



Residential citrus density

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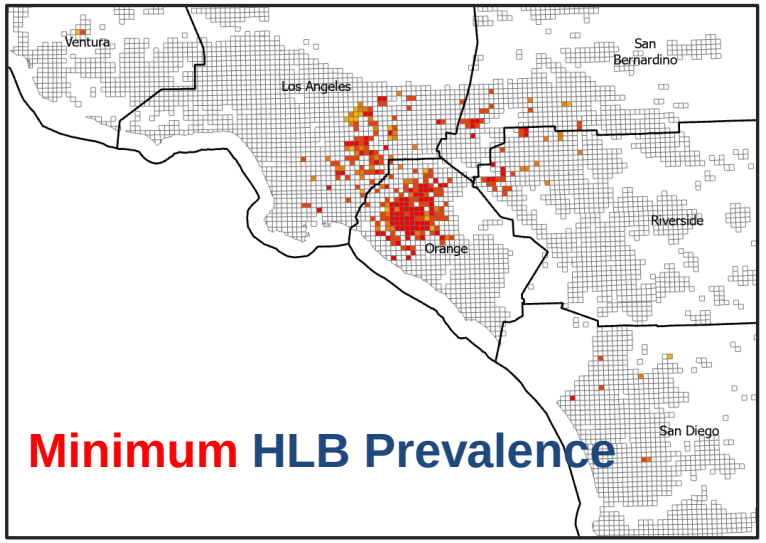
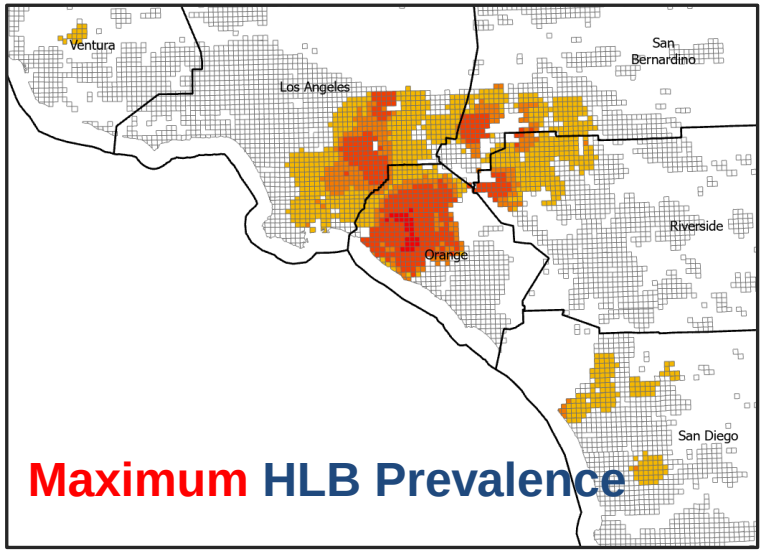




How many hidden HLB+ trees out there

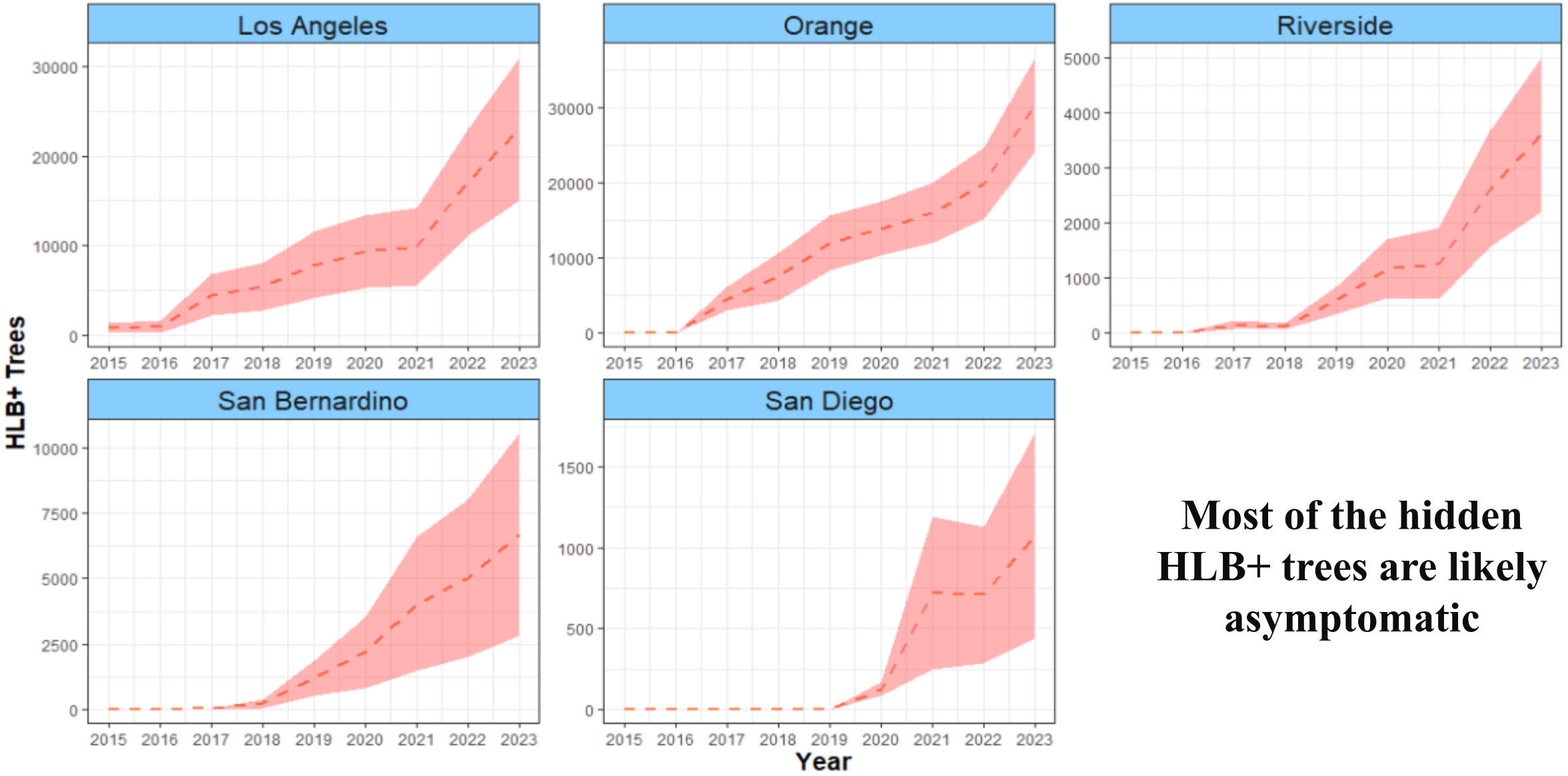
Estimated Minimum hidden HLB+ trees in the landscape

County	2015	2016	2017	2018	2019	2020	2021	2022	2023	% of total residential citrus tree (2023)
Los Angeles	154	245	2,105	2,757	4,112	5,291	5,543	11,141	15,005	0.79%
Orange	0	0	3,067	4,338	8,372	10,306	11,982	15,139	24,157	4.22%
Riverside	0	0	74	67	342	645	630	1,566	2,210	0.21%
San Bernardino	0	0	0	50	506	820	1,468	2,019	2,824	0.35%
San Diego	0	0	0	0	0	85	251	289	442	0.03%
Ventura	0	0	0	0	0	0	0	0	87	0.03%

Estimated Maximum hidden HLB+ trees in the landscape

County	2015	2016	2017	2018	2019	2020	2021	2022	2023	
Los Angeles	1,326	1,626	6,796	8,063	11,502	13,341	14,219	23,068	31,068	1.63%
Orange	0	36	6,178	10,656	15,656	17,534	20,039	24,706	36,721	6.41%
Riverside	0	0	230	193	845	1,704	1,904	3,682	5,011	0.48%
San Bernardino	0	0	46	387	1,843	3,562	6,589	8,029	10,571	1.32%
San Diego	0	0	0	0	0	169	1,188	1,131	1,710	0.12%
Ventura	0	0	0	0	0	0	0	0	118	0.04%

How many hidden HLB+ trees out there



Most of the hidden HLB+ trees are likely asymptomatic

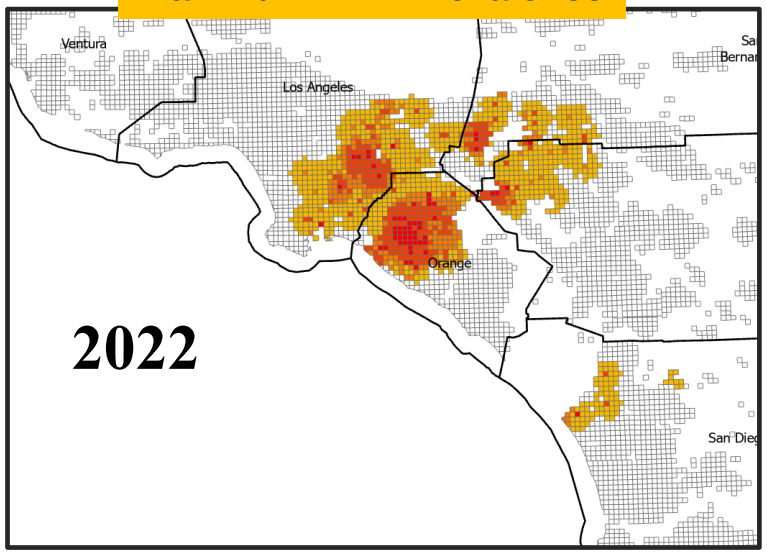
Cost-effective Management

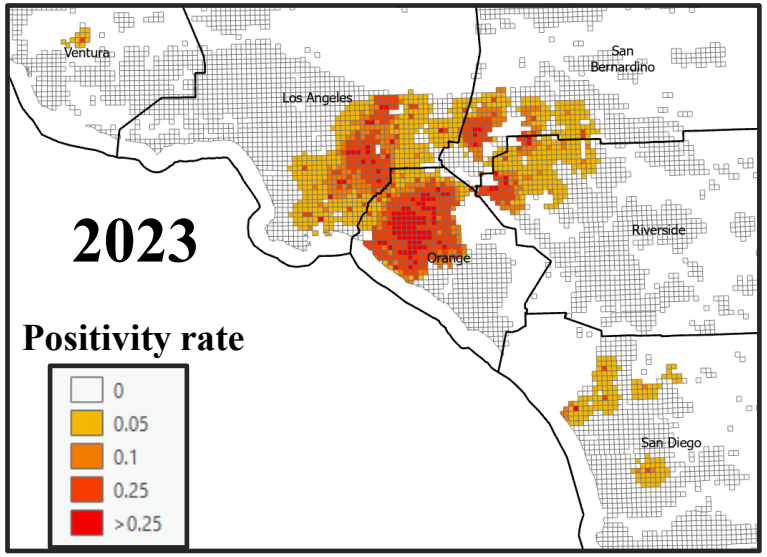
Do we have enough resource to put out all the HLB fire?

"Using the right resource for the right problem is key to effective problem-solving."

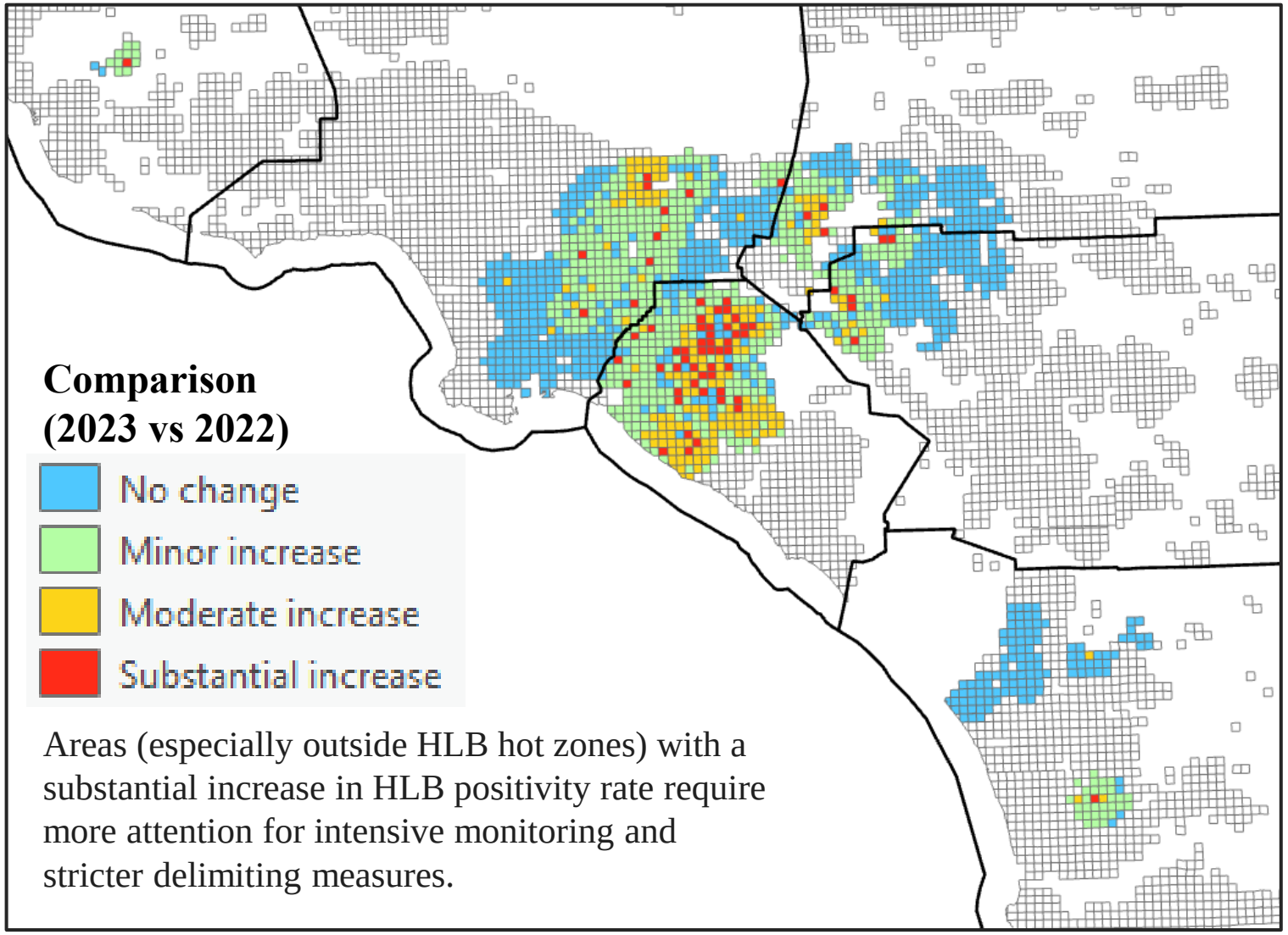
HLB Management Performance (2023)

Maximum HLB Prevalence





Temporal comparison for HLB prevalence 2023 vs 2022



Areas (especially outside HLB hot zones) with a substantial increase in HLB positivity rate require more attention for intensive monitoring and stricter delimiting measures.

Conclusion

- The RBS model has identified key risk factors and their impact on the spread of HLB in Southern CA.
- Our established methodology can provide reasonably accurate estimates of the actual HLB situation.
- We need to dynamically adjust the HLB control strategies according to the HLB situation.

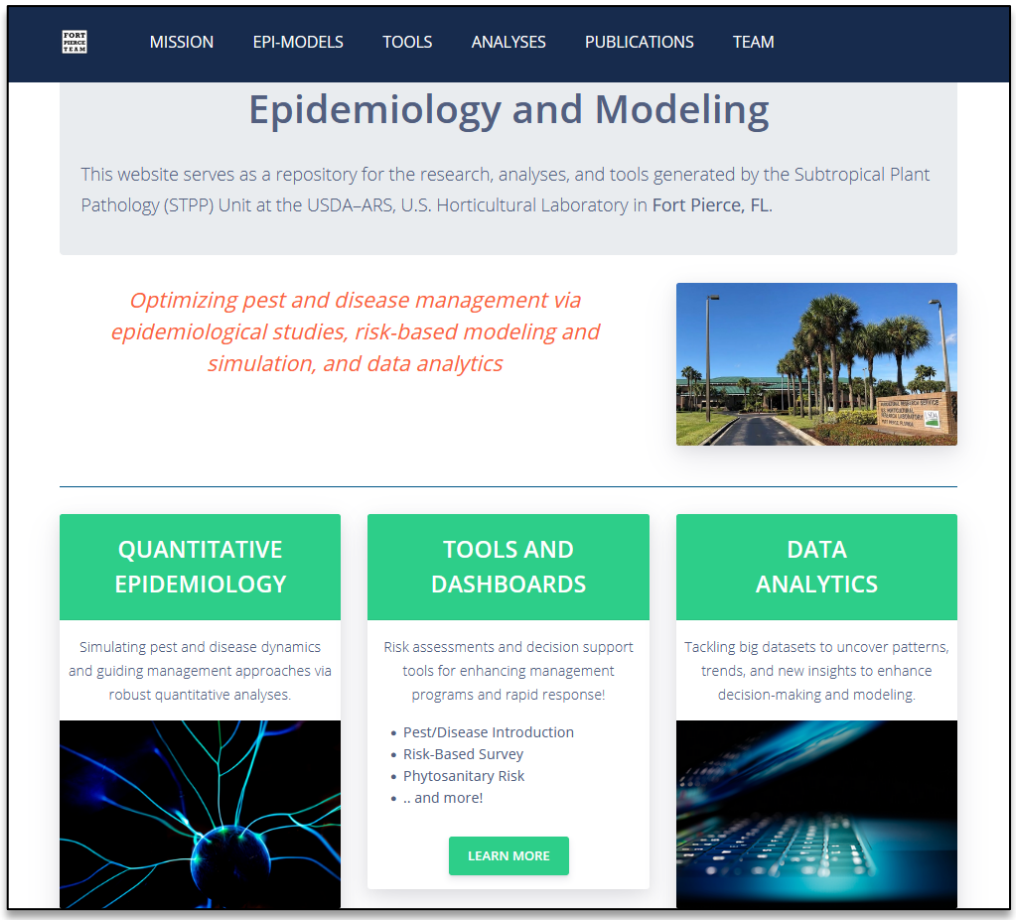
Benefits:

- **Strategic resource allocation**: Knowing the actual HLB situation allows us to improve survey design, efficiently assign manpower to areas with the greatest need.
- **Proactive measures**: Evaluate the performance of proactive actions (e.g. delimiting responses) in preventing exponential HLB growth in these areas.
- **Cost-effective management**: Measure the impact of knowing the HLB situation (Best & Worst Cases) on decision-making, leading to improved detection rates and resource savings in HLB management.

Additional information

Models, Tools, Dashboards and Statistical Analyses

https://agriskmodels.com



Thanks for your time and attention!

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Survey efforts by county and year

Total STRs sampled by county and year

County	2015	2016	2017	2018	2019	2020	2021	2022	2023
Los Angeles	905	1,021	615	842	656	603	642	487	185
Orange	318	218	166	288	284	333	280	231	195
Riverside	681	615	363	316	344	427	437	337	142
San Bernardino	266	248	153	129	178	214	193	179	62
San Diego	839	608	454	571	523	619	713	673	374
Ventura	210	252	240	220	190	268	227	227	145

Total samples by county and year

County	2015	2016	2017	2018	2019	2020	2021	2022	2023
Los Angeles	42,873	72,861	44,390	51,458	38,226	18,183	21,133	34,454	15,274
Orange	12,380	8,608	30,767	51,687	31,647	30,418	15,000	14,167	18,839
Riverside	23,660	16,959	15,816	11,468	12,010	12,530	13,027	12,317	5,291
San Bernardino	10,719	10,734	6,914	8,146	7,335	11,586	10,496	9,917	9,678
San Diego	16,221	13,176	15,954	20,218	16,757	16,644	18,305	20,623	7,181
Ventura	2,064	4,153	2,986	2,121	2,156	4,311	2,890	3,264	1,487