Supporting Information

Journal: Journal of Food Protection

Title: Performance of Cold Chains for Chesapeake Bay Farmed Oysters and Modeled Growth of *Vibrio parahaemolyticus*

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Temperature sensor pilot study. A pilot study was conducted in February 2017 where 34 sensors were deployed at the wholesale level. The purpose of the temperature sensor pilot study was to determine the variability in triplicate boxes shipped from wholesalers to retailers/restaurants. Sensors with usable data from the pilot are presented in Figure 1. The average standard deviations (grey error bars in Figure 1) were 0.62 for oyster sensors and 0.64 for sensors affixed to the outside of boxes. This finding suggests that replicate boxes provide greater accuracy than single boxes, however, the amount of variation between boxes was not large. After the pilot, wholesalers told us their preference was to add sensors to single boxes because many buyers do not order large enough volume to warrant delivery of triplicate boxes of the same product on the same day.

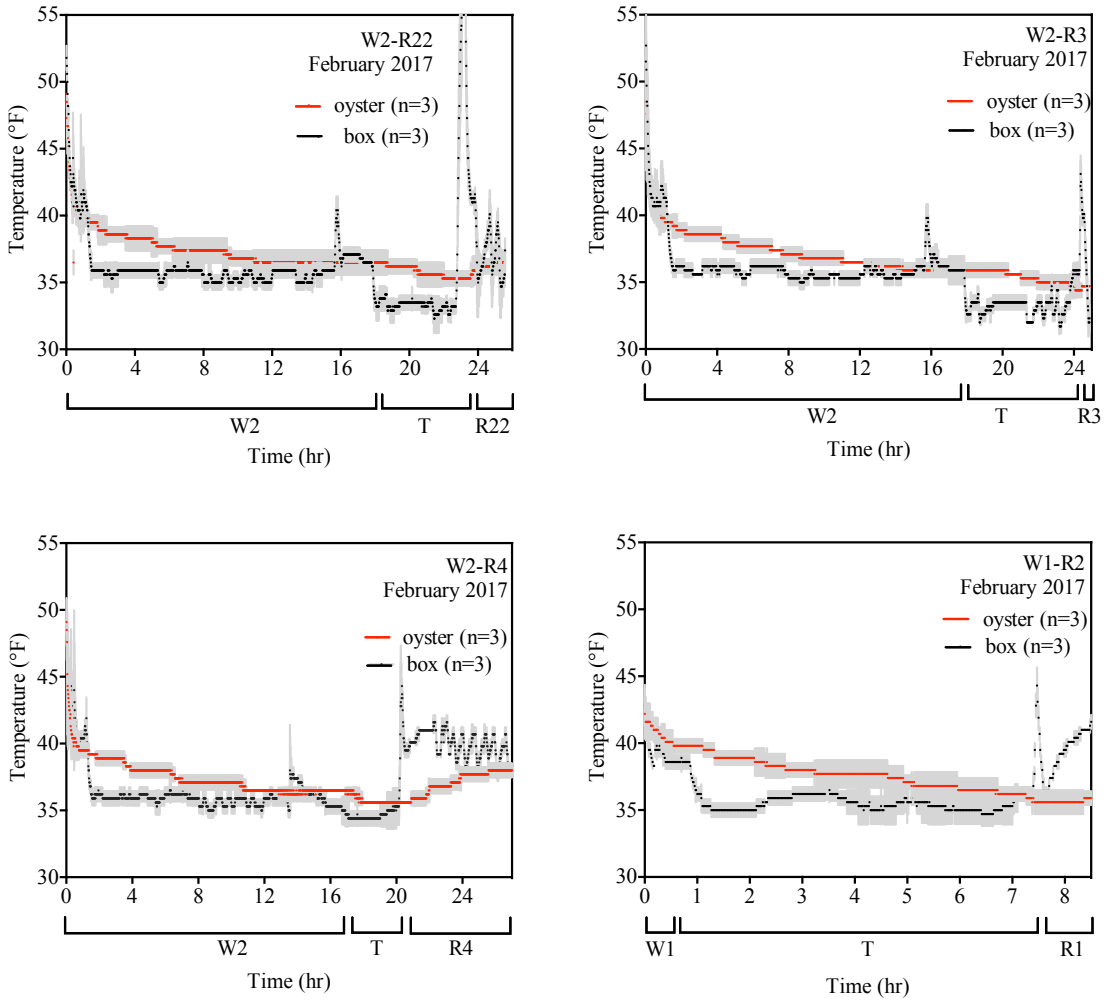

Figure S1. Pilot study to determine the variability in internal oyster temperature (red) and environment temperature (black) for triplicate 100-count boxes sent from wholesale to retail or restaurant customers. Grey bars indicate standard deviation (avg oyster st dev = 0.62, avg environment st dev = 0.64). The sensor sampling interval was 1 min. . P = producer; T = freight carrier (truck); W = wholesale; R = food retail or restaurant; C = consumer. The number following P, T, W, or R was assigned to each participant to provide anonymity

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Table S1. Study population in the Chesapeake Bay and self-reported cold chain temperatures.

Supply chain	Sample size		Median cold chain temperature (°C) (range)			Ice use (%) [b]
	Temp study	Interviews	Receiving room	Live room/ Refrigerator	Truck	
Producer	6	6	-	5.6 (3.3 -10.0) [a]	-	50
Freight carrier	5	4	-	-	1.11 (0.56 – 2.2)	25
Wholesale	2	2	1.4 (1.1 - 1.7)	4.4 (3.3 - 5.56)	2.78 (2.2 - 3.3)	50 [c]
Food retail/ Restaurant	26	13	-	3.3 (-1.7 -4.4)	-	58
Total	39	25	-	-	-	52

[a] measured by researchers
[b] the denominator is the interview sample size
[c] ice used only in delivery

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Table S2. Temperature control during oyster harvesting and on-farm processing during six farm visits, June to September, 2017.

Producer code	Harvest temp (°C)		Ice (yes/no)	Refrigerator temp (°C)	Time (hr) to achieve:		Oyster internal temp at pick-up (°C)	Ideal product temp (°C) [d]
	water	air			Environment temp <7.2 °F	Oyster internal temp <10.0 °F		
P1	26.7	21.1	yes [a]	6.7	4.0	4.5	8.5	4.4-7.2
P2	21.1	22.2	no	10.0	2.5	10.2	10.3	2.8-4.4
P3	21.7	21.1	yes [b,c]	3.3	1.8	8.9	5.3	5.0
P4	21.1	21.1	no	4.4	3.0	3.1	8.3	<10.0
P5	24.4	22.2	yes [a,b]	3.3	2.4	4.4	3.9	<7.2
P6	22.2	20.0	no	7.2	1.2	3.3	6.0	4.4

[a] layered ice
[b] ice slurry
[c] P3 typically uses an ice slurry to remove worms, but did not use an ice slurry on the day we visited.
[d] based on interviews with producers

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Comparing Vibrio Control Plan (VCP) months vs non-VCP months. We explored differences in product temperature between Vibrio Control Plan months (June - September) versus a non- Vibrio Control Plan month (March). We hypothesized that products under temperature control would maintain a similar internal oyster temperature regardless of the season. We found instead that producers and freight carriers maintained oyster boxes at elevated temperatures in Vibrio Control Plan months compared to a non-Vibrio Control Plan month ($p_{producer} = 0.001$; $p_{freight} = 0.001$), which led to higher internal oyster temperatures in Vibrio Control Plan months for producers and freight carriers ($p_{producer} = 0.007$; $p_{freight} < 0.0001$). (For producers, this statistical test only compares products under temperature control.) For wholesalers and wholesale delivery to retail/restaurants, the box temperature did not differ between Vibrio Control Plan months and a non-Vibrio Control Plan month. However, wholesalers did have elevated internal oyster temperatures in Vibrio Control Plan months compared to a non-Vibrio Control Plan month ($p = 0.02$), which appears to be a spill-over effect of higher internal oyster temperatures starting with producers and freight carriers. These effects wash out by the time the product reaches the food retailers and restaurants because there were no significant differences in internal oyster temperature or box temperature between Vibrio Control Plan months and non-Vibrio Control Plan month at food retailers and restaurants. (Supporting Information Table S1 lists all T-tests results.)

Table S3. Two tailed T-test comparing internal oyster temperature and environment temperature between groups in Vibrio Control Plan (VCP) months vs non-VCP months

Group	Internal oyster temperature (VCP vs non VCP months)	Environment temperature (VCP vs non VCP months)
Producer	** [a]	***
Freight Carrier	****	***
Wholesale	*	ns
Wholesale delivery	**	ns
Retail/Restaurant	ns	ns

[a] p values: * <0.05; ** <0.01; *** < 0.001; **** < 0.0001

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Table S4. Tukey's multiple comparison test comparing temperature in (A) oysters or (B) the environment by step of the supply chain for months with Vibrio control plans.

A) Oyster internal temperatures in Vibrio control plan months [a].

Group	Producer	Freight Carrier	Wholesale	Wholesale delivery	Retail/ Restaurant
Producer	-				
Freight Carrier	ns	-			
Wholesale	*** [c]	****	-		
Wholesale delivery	****	****	**	-	
Retail/Restaurant	****	****	ns	ns	-

B) Environment temperatures in Vibrio control plan months [a].

Group	Producer	Freight Carrier	Wholesale	Wholesale delivery	Retail/ Restaurant
Producer	-				
Freight Carrier	* [c]	-			
Wholesale	****	****	-		
Wholesale delivery	****	****	ns	-	
Retail/Restaurant	****	****	ns	ns	-

[a] based on n = 20 samples with complete data
[b] based on n = 21 samples with complete data
[c] p values: * <0.05; ** <0.01; *** < 0.001; **** < 0.0001

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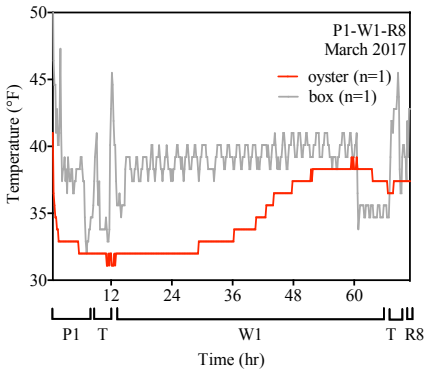
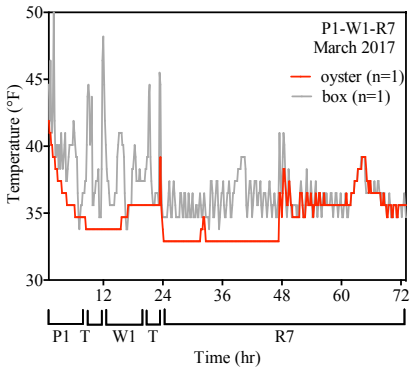
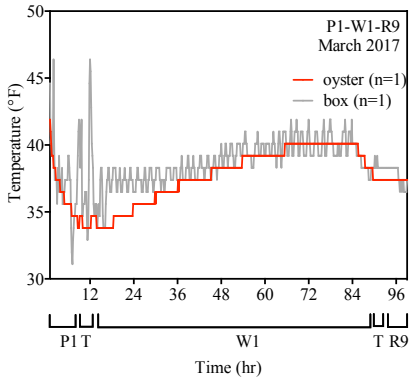
Figure S2. Internal oyster temperature and environment temperature profiles of all shipments. P = producer; T = freight carrier; W = wholesale; R = food retail or restaurant; C = consumer. The number following P, T, W, or R was assigned to each participant to provide anonymity.

Producer 1, March 2017







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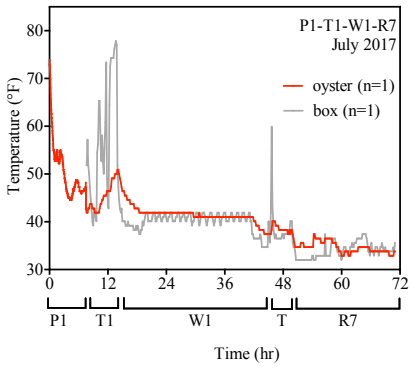
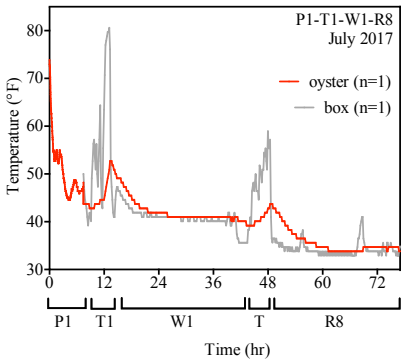
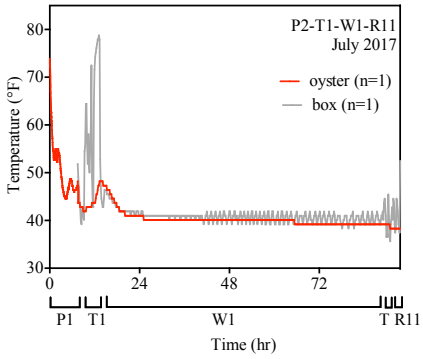
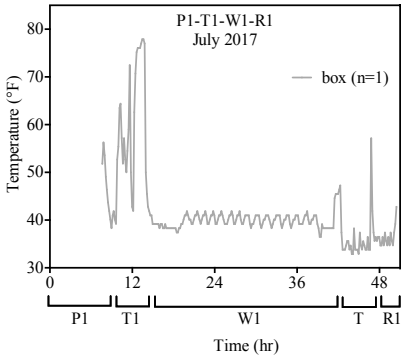
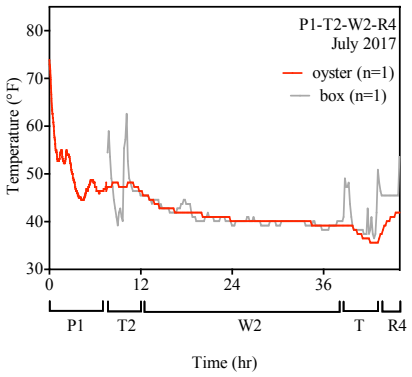
Producer 1, July 2017

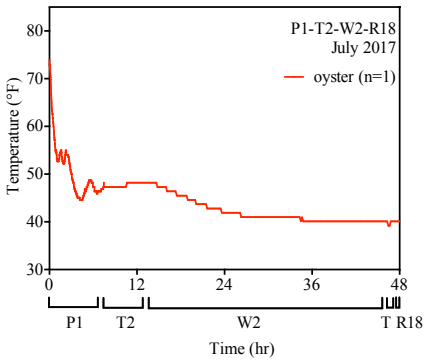












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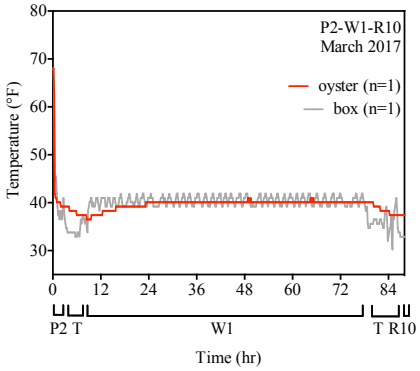

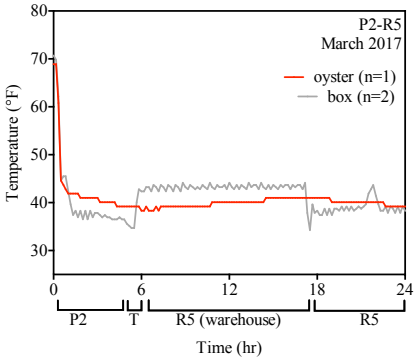

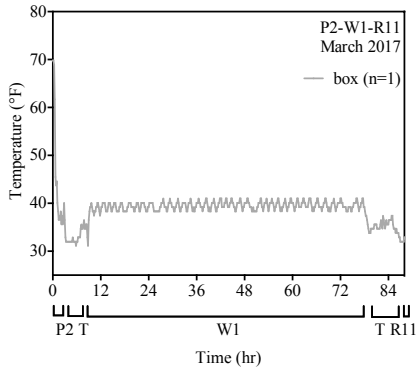

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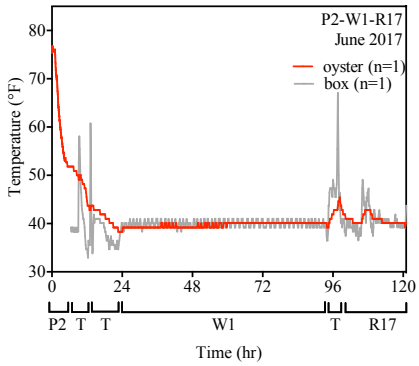

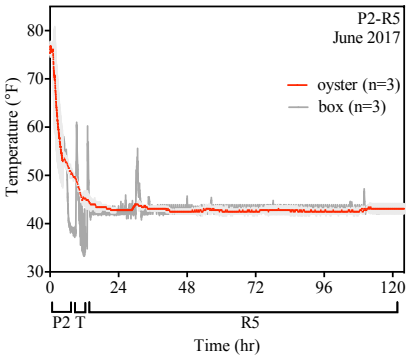

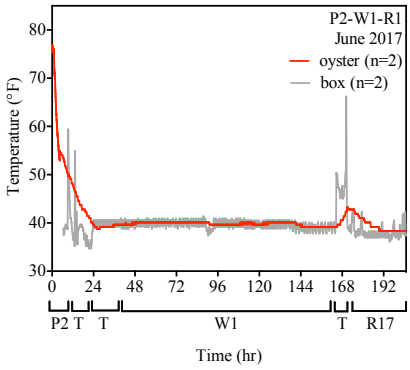

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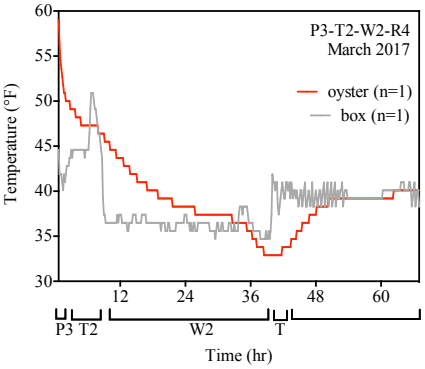

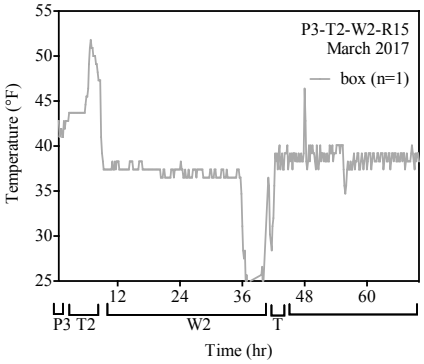

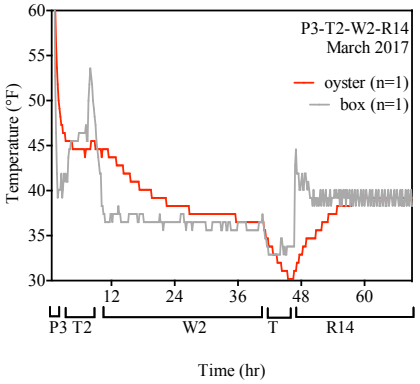

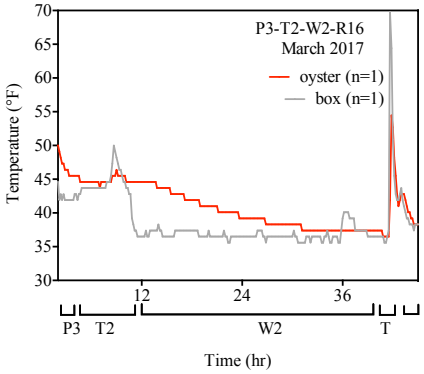

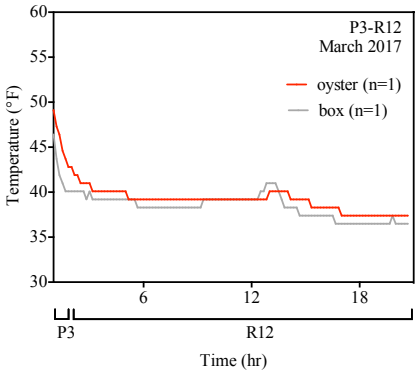

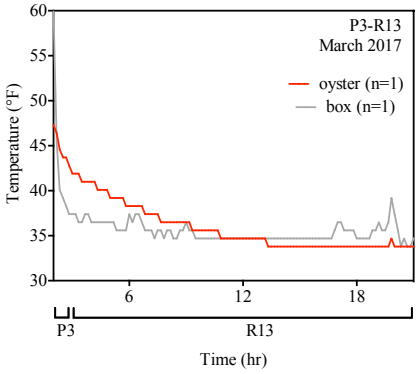

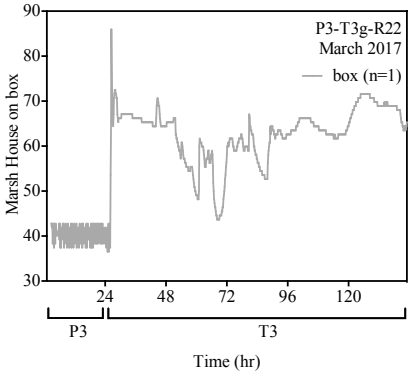

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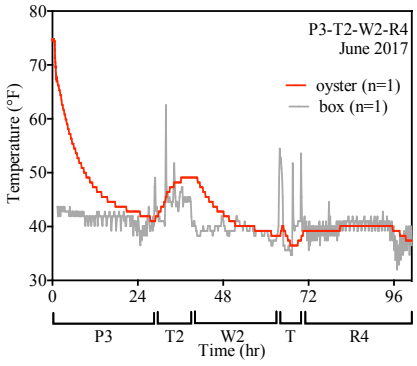

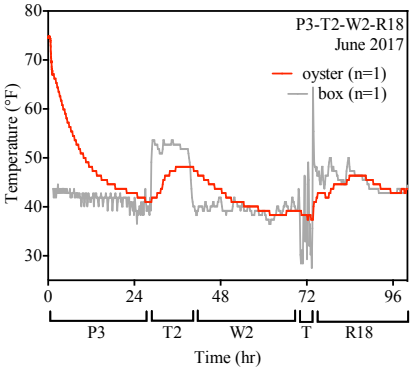

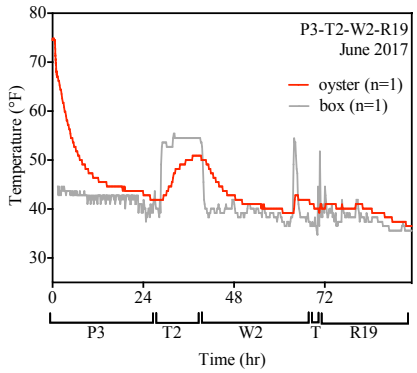

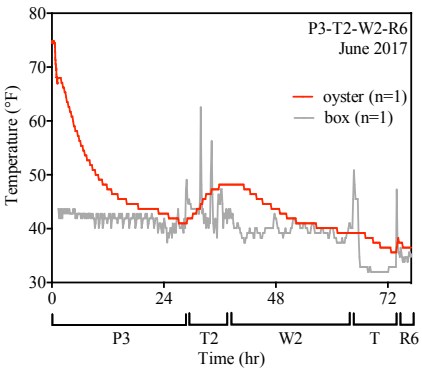

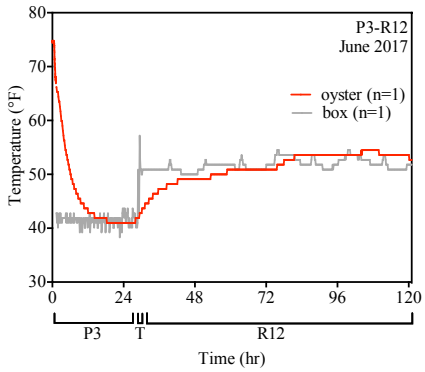

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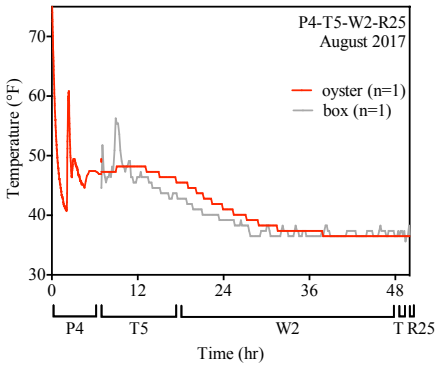

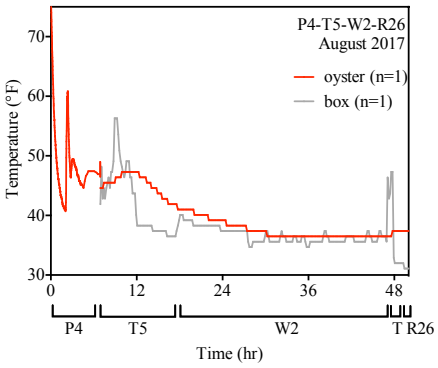

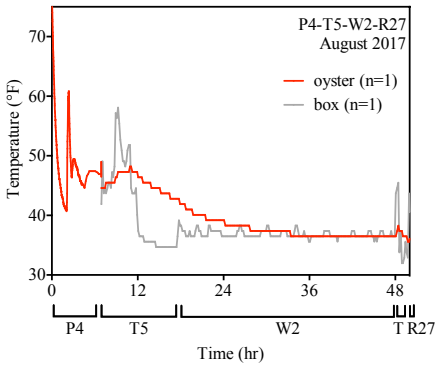

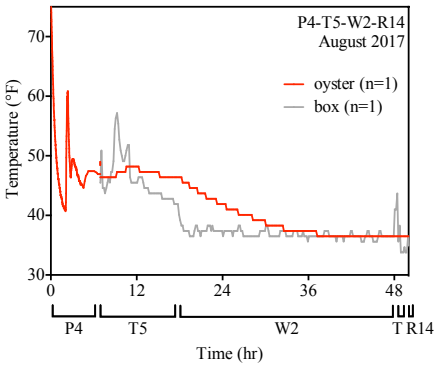

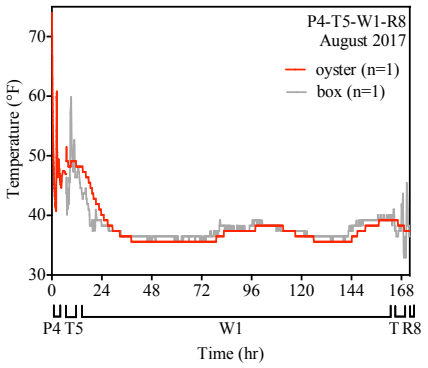

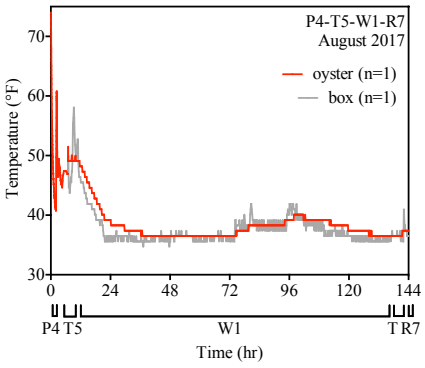

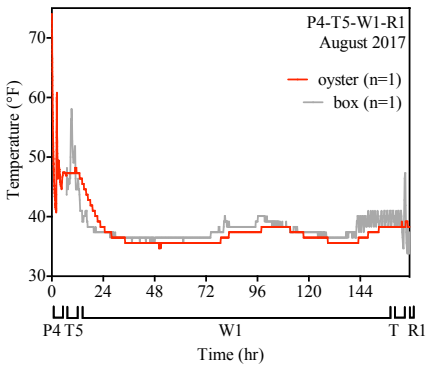

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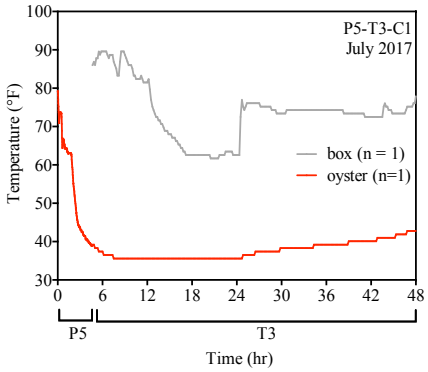

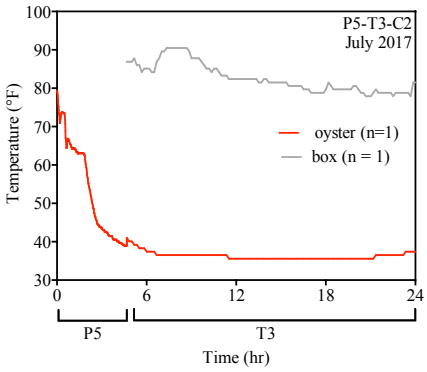

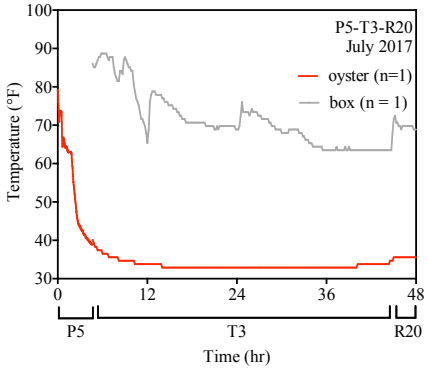

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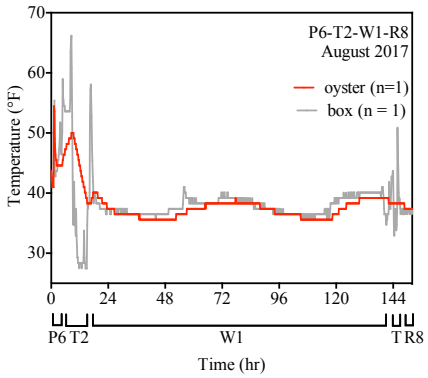

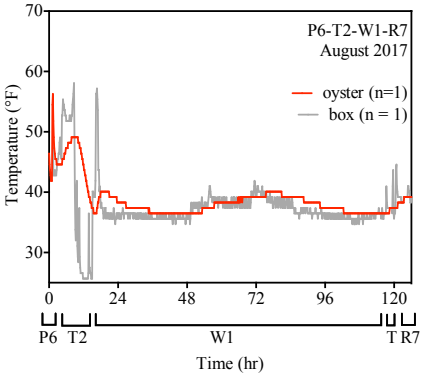

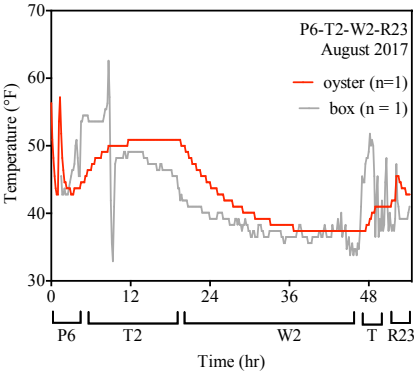

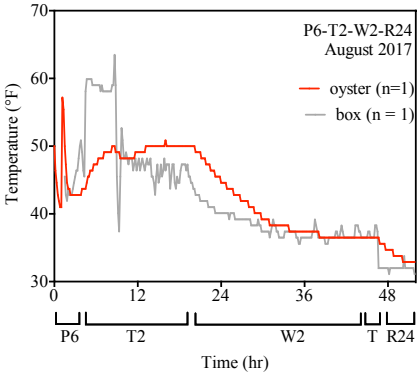

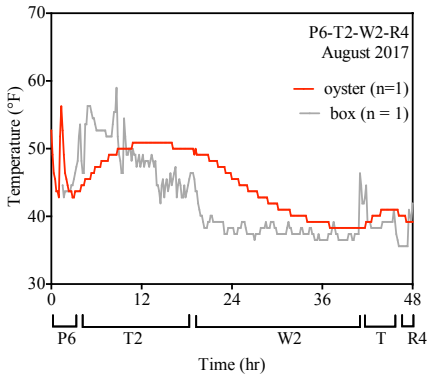

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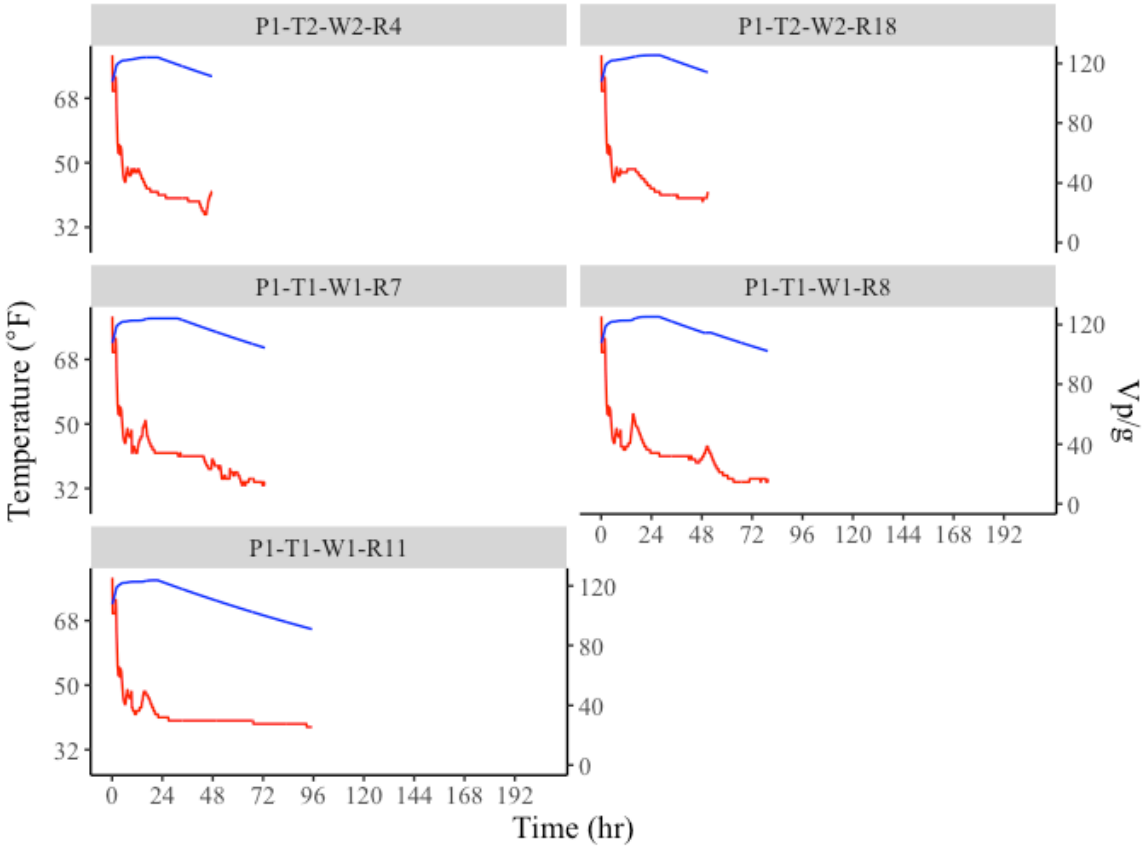
Figure S3. *Vibrio parahaemolyticus* concentrations (blue) and temperature (red) for all shipments during Vibrio Control Plan months. P = producer; T = freight carrier; W = wholesale; R = food retail or restaurant; C = consumer. The number following P, T, W, or R was assigned to each participant to provide anonymity.



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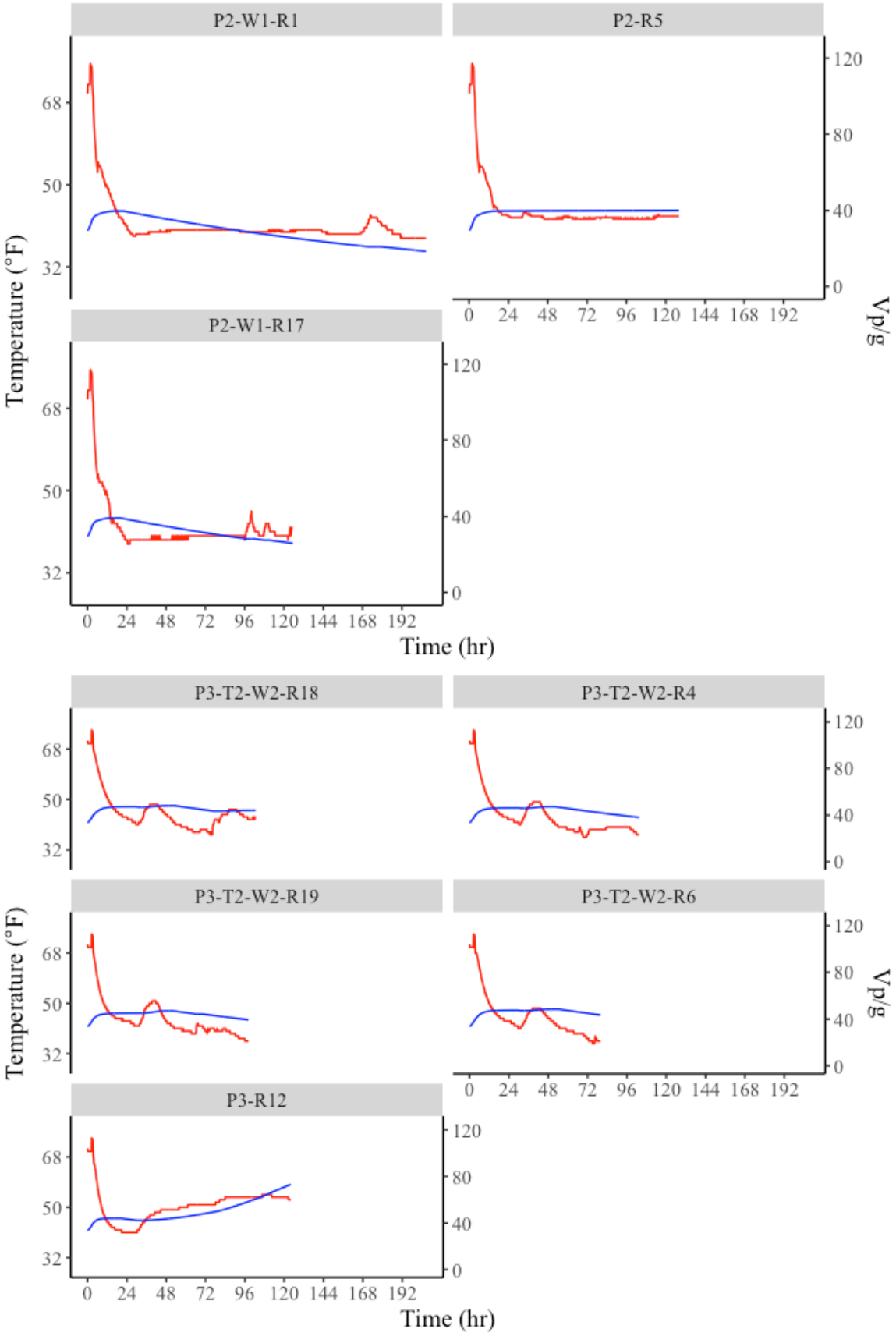

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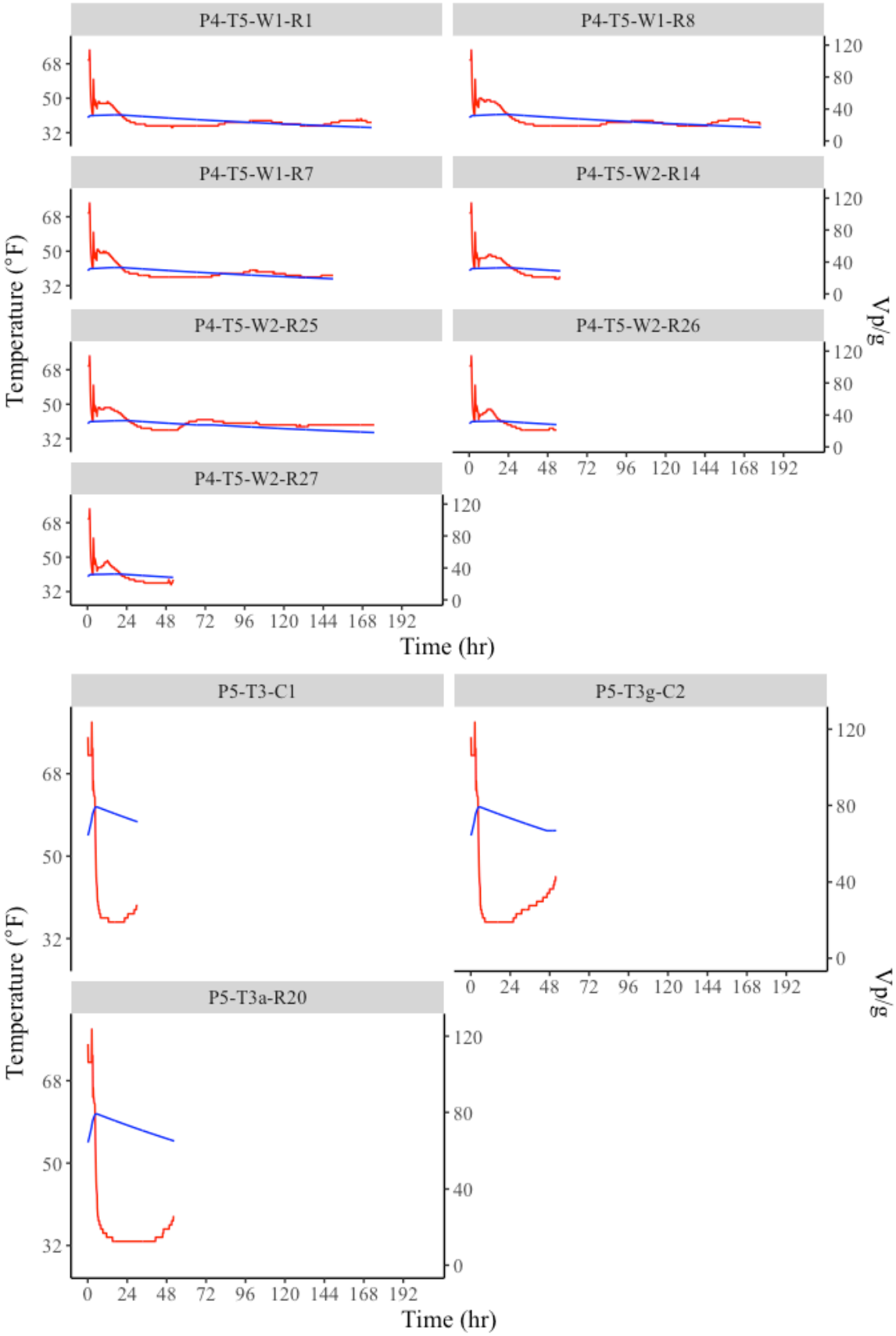

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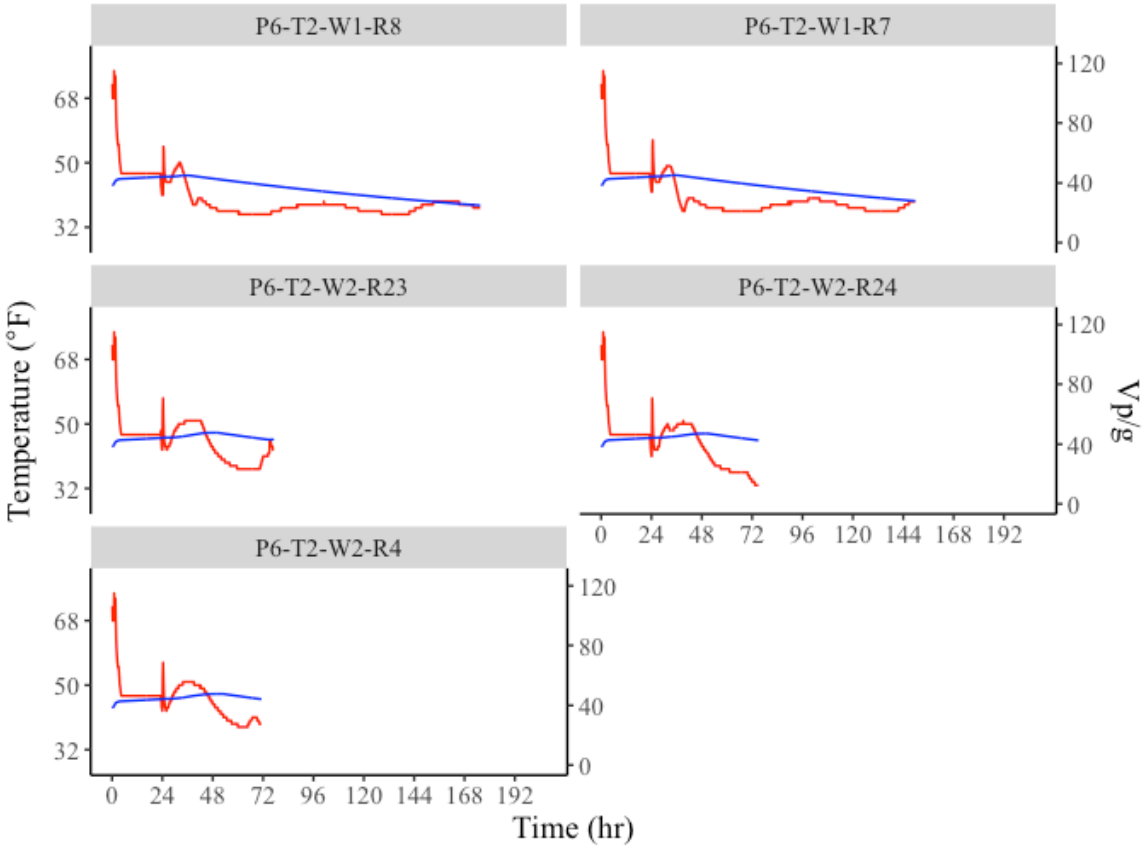

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