Analysis of Fish Guidance Structures in Downstream Migration

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Abstract

Hydraulic power stations in Swiss rivers are equipped with upstream fish guidance structures, so that fish don't get caught in the turbines in their migration. However, there is a lack of such structures for downstream migration, posing a significant risk for the fish being killed while passing through the stations. Experiments are planned in Autumn 2018 and Spring 2019 to test different types of downstream fish guidance structures, to be carried out by Julien Meister and Claudia Beck in the Laboratory of Hydraulics, Hydrology and Glaciology (ETH Hönggerberg). This project aims to design the experiment, in particular to specify the number of fish required for different power levels.

1. Set-Up

A fish guidance structure consists of 2 parts - a guidance rack in front of the turbines, and a bypass through which the fish should be safely guided (See Figure 1).

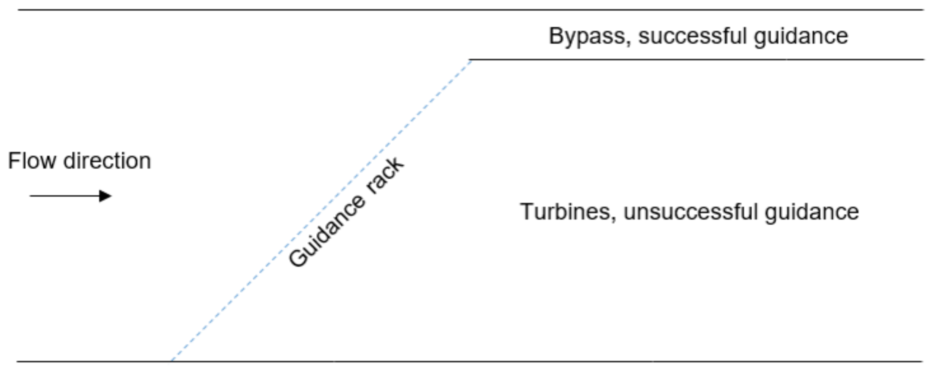

Figure 1: Illustration of the experimental setup

There are two different types of guidance racks under consideration - vertical and horizontal. The width of the gaps between the bars in the rack have already been optimised, based on previous experiments. In addition, there are three types of bypass structures to be tested, yielding six different combinations in total.

In each run of the experiment, three fish will be placed in the flume simultaneously. They will be given 30 minutes to acclimatise themselves with the environment, then will be observed for a further 30 minutes. The three possible outcomes are:

1. Fish swims successfully through the bypass (Success)
2. Fish swims through the guidance rack into the turbines (Failure)
3. Fish encounters the structure, and makes no further progress (Failure)

In particular, the last outcome is considered as a failure, since the objective of the structure is to guide the fish in their natural migration.

The experiment will be carried out on five species of fish, to be caught by the clients themselves.

In designing the experiment, there were a number of restrictions that had to be taken into account, as specified by the clients.

- **The rack and bypass configuration can only be changed daily**, while several runs of the experiment will take place each day. This means that the rack and bypass combination cannot be completely randomised to each run, and any model we consider has to take into account the possible correlation within the days.

- **Maximum of 70-80 days are available**, so the number of times the experiment is run cannot be increased arbitrarily to increase power.
- **Different species will be used in different seasons** to take into account the natural migration season of the particular species.
- **The storage capacity of fish in the lab is limited**, and fish will be caught once a week, meaning by the end of the week, not all species may be available.

2. Design & Model

Live fish experiments are extremely time-consuming in its nature, and as outlined above, the time available for the experiment is limited. The request from the clients was to estimate the smallest number of fish that they need to experiment on, so that their results are still significant, i.e. they are able to detect differences between the different configurations of the guidance structure in a statistically significant way. The obvious trade-off that arises from this primary request is that, in order to detect more subtle differences between the configurations, larger sample sizes will be required, while smaller sample sizes will make the experiment easier but the clients will only be able to detect crude differences between the configurations.

While the rack and bypass configuration was the variable of primary interest, there were others that the clients wanted to include in the model, to see how different configurations act under different conditions. These included the flow conditions, the temperature of the water, the light conditions, etc. However, encompassing all these variables in the model proved to be infeasible due to the blow-up of the number of parameters to be estimated, and the restriction on the number of experiments that can be conducted. Hence, after discussions with the clients, it was decided to keep these variables constant across all experiments.

Finally, we mention that, at each run of the experiment, the three fish that are placed together in the flume are assumed to have some correlation, i.e. there is some "schooling behaviour". The strength of this correlation depends on the fish, and the values used in the simulations have been agreed with the clients.

Figure 2 is a diagrammatical representation of how the experiment will be conducted, taking into account the information above. On each day, 5 experiments are conducted for a fixed rack and bypass configuration, one per species. This means that a set of 6 days is required to complete one cycle of all possible arrangements.

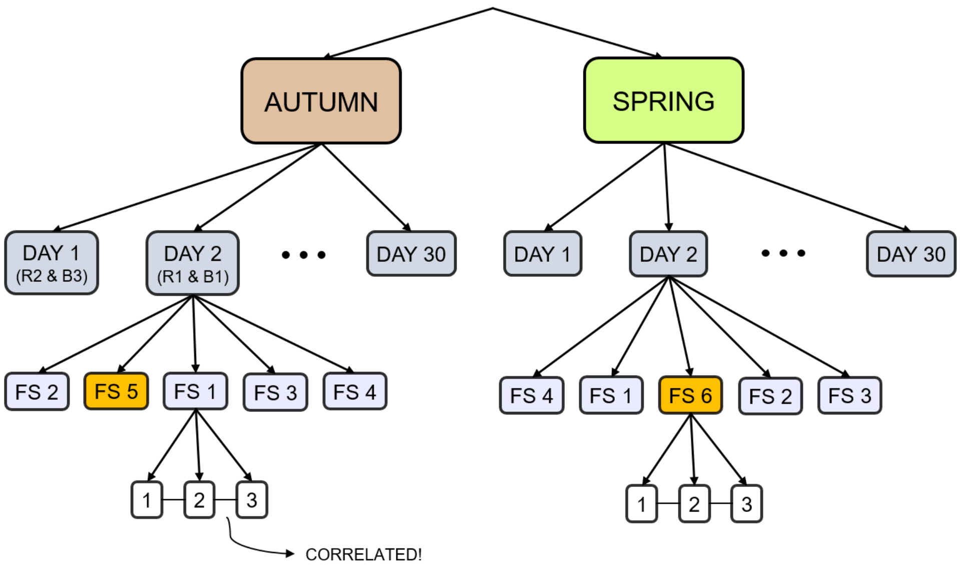

Figure 2: Plan of experiment

3. Simulations

The simulation proceeds as follows:

1. **We adjust the settings of the model,** i.e. specify how many fish will be used, place assumptions on the differences of the configurations, (e.g. Rack 1 is 20% more efficient than Rack 2), etc. This specifies the probability of success for each individual fish in each run.

2. **We simulate the whole experiment many times,** and at each simulation, we note whether there was a significant statistical difference between the configurations that we set to be different in Step 1, e.g. whether there was significant evidence that Rack 1 was better than Rack 2.

3. **We output the proportion of simulation runs which returned a significant result.** This is the **power**.

Thus the power of each model is calculated through simulation.

The simulations were conducted with 2 different levels of sample size - 1080 and 1260. They correspond to conducting the experiments over 72 and 84 days respectively. Figure 2 above shows the case with the sample size of 900, corresponding to conducting the experiments over 60 days, but this case was not explored in the simulations, since we deemed it realistic

Sample Size = 1080				
Assigned Difference (%)		Power Estimate		
		CI-Lower	Estimated Power	CI-Upper
Rack only	5	0.1708632	0.24	0.3091368
	10	0.6258167	0.7	0.7741833
	15	0.9472531	0.9733333	0.9994136
	20	1	1	1
Bypass only	5	0.158891	0.2266667	0.2944423
	10	0.5138153	0.5933333	0.6728513
	15	0.8514356	0.9	0.9485644
	20	1	1	1
Species only	5	0.08939738	0.1466667	0.20393595
	10	0.314256	0.3933333	0.4724107
	15	0.6981985	0.7666667	0.8351348
	20	0.9472531	0.9733333	0.9994136
Rack and Species	5	0.1529413	0.22	0.2870587
	10	0.1708632	0.24	0.3091368
	15	0.2320216	0.3066667	0.3813117
	20	0.3271487	0.4066667	0.4861847
Bypass and Species	5	0.1352475	0.2	0.2647525
	10	0.1829279	0.2533333	0.3237388
	15	0.2120216	0.2866667	0.3613117
	20	0.295033	0.3733333	0.4516336
Sample Size = 1260				
Assigned Difference (%)		Power Estimate		
		CI-Lower	Estimated Power	CI-Upper
Rack only	5	0.2633154	0.34	0.4166846
	10	0.7277853	0.7933333	0.8588814
	15	0.9666667	0.9376081	0.9957253
	20	1	1	1
Bypass only	5	0.1470169	0.2133333	0.2796498
	10	0.5903551	0.6666667	0.7429782
	15	0.9282779	0.96	0.9917221
	20	1	1	1
Species only	5	0.08382929	0.14	0.19617071
	10	0.3206947	0.4	0.4793053
	15	0.7806533	0.84	0.8993467
	20	0.9472531	0.9733333	0.9994136
Rack and Species	5	0.09500612	0.1533333	0.21166055
	10	0.1470169	0.2133333	0.2796498
	15	0.2320216	0.3066667	0.3813117
	20	0.3859061	0.4666667	0.5474273
Bypass and Species	5	0.1529413	0.22	0.2870587
	10	0.1768843	0.2466667	0.316449
	15	0.2507453	0.3266667	0.4025881
	20	0.3206947	0.4	0.4793053

Table 1: Power Estimates

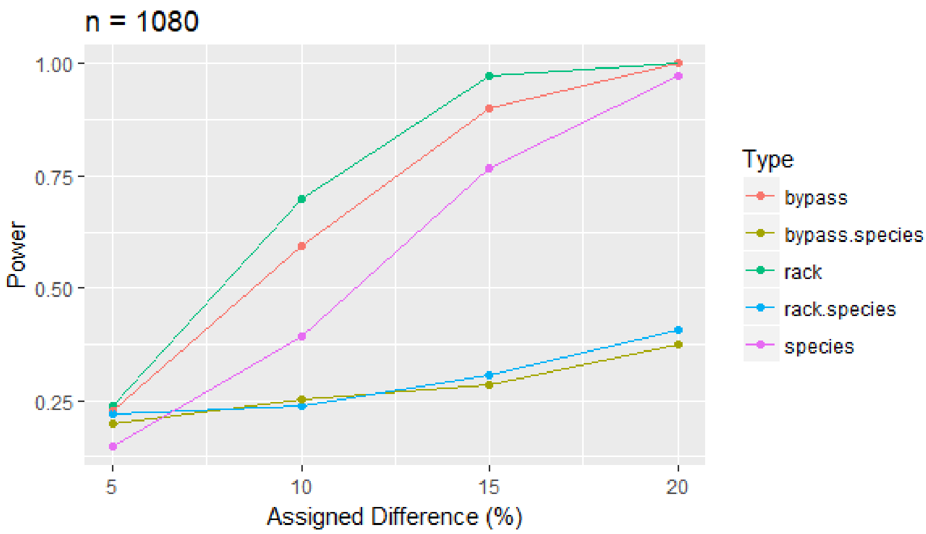

Figure 3: Power with n = 1080

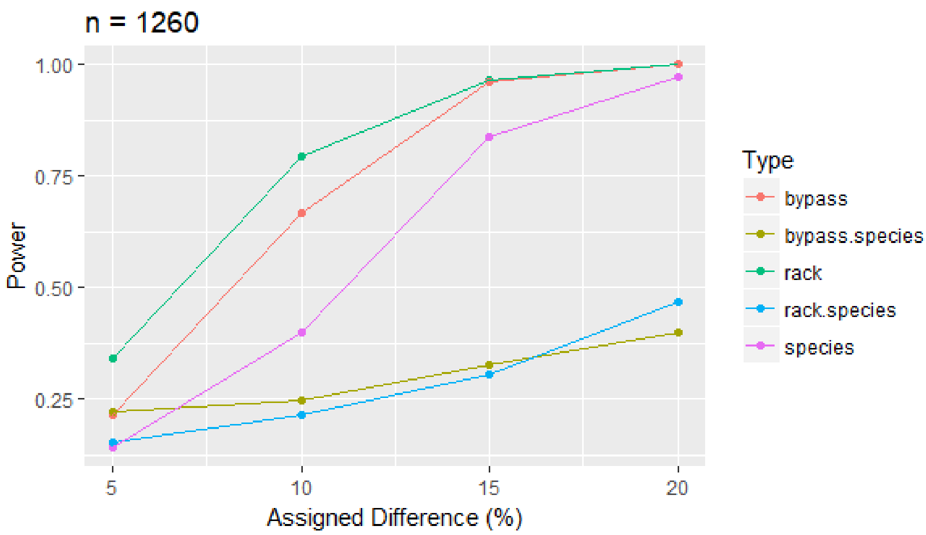

Figure 4: Power with n = 1260

to conduct at least 72 days of experiments. We also varied the assumed differences between the configurations, to see which differences are detected by which sample sizes with what frequency. Finally, we also considered the model with interactions between some of the variables (i.e. models in which the effect of one variable depends on another variable).

Table 1 shows the full list results from the simulations with sample size of 1060, including the 95% confidence intervals from the simulations we conducted. In Figures 3 and 4, we show plots of these results. Here are a couple of observations to make.

- With both sample sizes, and with any type of difference, it is difficult to detect the difference of 5% (power is around 20%-25%). The power is still not great for 10% differences of any kind, except maybe if we're using 1260 fish and only the two racks are different.
- For differences of 15% and 20% in just the racks, just the bypasses or just the species, the power is quite good - we can detect those differences.
- However large the sample size and however large the differences are in either the racks or the bypasses, we can't detect them with enough power if we assume that those differences are not uniform across all the species.

We should mention that, in our analysis of the simulated data, we assumed that every group of fish has the same random correlation effect. However, in reality, each species has its own distinct random correlation effect. We are not sure how much this will affect the analysis, and it's highly unlikely that the rough estimates of the sample sizes will be wildly off the mark, but for the sake of complete rigour, this approach should be taken when clients analyse the data after its collection.

4. Conclusions

The main conclusion that we can draw from the simulations is that, with the given amount of time and the realistic number of times we can run the experiment, we can hope to detect how the rack or the bypass performs differently across all species in a uniform manner, as long as the difference is at least 15%.

Unfortunately, we think it's unrealistic to be able to vary other parameters (such as flow conditions, temperature, light conditions, etc.) and observe the differences that they make. Further, we don't think it's realistic to expect to detect interaction effects with the species.

We do think that having a sample size of 1260 over 1080 (i.e. doing 7 experiments a day as opposed to 6) is worth the effort in terms of increased power. However, the clients will have to make the decision on that, based on how much that effort actually is, and their perceived benefits in power.

Appendix: Day-by-day Plan of Experiment

season	day	rack	bypass	species
Autumn	1	vertical	1	4
Autumn	1	vertical	1	3
Autumn	1	vertical	1	1
Autumn	1	vertical	1	2
Autumn	1	vertical	1	5
Autumn	2	vertical	3	4
Autumn	2	vertical	3	1
Autumn	2	vertical	3	3
Autumn	2	vertical	3	5
Autumn	2	vertical	3	2
Autumn	3	horizontal	2	5
Autumn	3	horizontal	2	1
Autumn	3	horizontal	2	2
Autumn	3	horizontal	2	4
Autumn	3	horizontal	2	3
Autumn	4	horizontal	2	3
Autumn	4	horizontal	2	5
Autumn	4	horizontal	2	2
Autumn	4	horizontal	2	4
Autumn	4	horizontal	2	1
Autumn	5	horizontal	3	3
Autumn	5	horizontal	3	1
Autumn	5	horizontal	3	2
Autumn	5	horizontal	3	4
Autumn	5	horizontal	3	5
Autumn	6	vertical	2	2
Autumn	6	vertical	2	1
Autumn	6	vertical	2	3
Autumn	6	vertical	2	4
Autumn	6	vertical	2	5
Autumn	7	vertical	2	4
Autumn	7	vertical	2	5
Autumn	7	vertical	2	2
Autumn	7	vertical	2	1
Autumn	7	vertical	2	3
Autumn	8	vertical	2	1
Autumn	8	vertical	2	5
Autumn	8	vertical	2	4
Autumn	8	vertical	2	3
Autumn	8	vertical	2	2

season	day	rack	bypass	species
Autumn	9	vertical	1	4
Autumn	9	vertical	1	3
Autumn	9	vertical	1	1
Autumn	9	vertical	1	5
Autumn	9	vertical	1	2
Autumn	10	horizontal	1	3
Autumn	10	horizontal	1	1
Autumn	10	horizontal	1	5
Autumn	10	horizontal	1	4
Autumn	10	horizontal	1	2
Autumn	11	vertical	1	3
Autumn	11	vertical	1	5
Autumn	11	vertical	1	1
Autumn	11	vertical	1	2
Autumn	11	vertical	1	4
Autumn	12	vertical	3	1
Autumn	12	vertical	3	2
Autumn	12	vertical	3	4
Autumn	12	vertical	3	3
Autumn	12	vertical	3	5
Autumn	13	vertical	3	1
Autumn	13	vertical	3	2
Autumn	13	vertical	3	4
Autumn	13	vertical	3	5
Autumn	13	vertical	3	3
Autumn	14	horizontal	1	4
Autumn	14	horizontal	1	2
Autumn	14	horizontal	1	5
Autumn	14	horizontal	1	1
Autumn	14	horizontal	1	3
Autumn	15	vertical	3	5
Autumn	15	vertical	3	4
Autumn	15	vertical	3	1
Autumn	15	vertical	3	2
Autumn	15	vertical	3	3
Autumn	16	vertical	1	1
Autumn	16	vertical	1	5
Autumn	16	vertical	1	3
Autumn	16	vertical	1	4
Autumn	16	vertical	1	2
Autumn	17	vertical	1	2
Autumn	17	vertical	1	5
Autumn	17	vertical	1	4

season	day	rack	bypass	species
Autumn	17	vertical	1	3
Autumn	17	vertical	1	1
Autumn	18	vertical	1	4
Autumn	18	vertical	1	5
Autumn	18	vertical	1	2
Autumn	18	vertical	1	3
Autumn	18	vertical	1	1
Autumn	19	vertical	2	1
Autumn	19	vertical	2	2
Autumn	19	vertical	2	5
Autumn	19	vertical	2	3
Autumn	19	vertical	2	4
Autumn	20	horizontal	1	4
Autumn	20	horizontal	1	5
Autumn	20	horizontal	1	3
Autumn	20	horizontal	1	1
Autumn	20	horizontal	1	2
Autumn	21	vertical	2	5
Autumn	21	vertical	2	1
Autumn	21	vertical	2	3
Autumn	21	vertical	2	2
Autumn	21	vertical	2	4
Autumn	22	vertical	3	3
Autumn	22	vertical	3	2
Autumn	22	vertical	3	1
Autumn	22	vertical	3	4
Autumn	22	vertical	3	5
Autumn	23	horizontal	3	1
Autumn	23	horizontal	3	5
Autumn	23	horizontal	3	4
Autumn	23	horizontal	3	2
Autumn	23	horizontal	3	3
Autumn	24	horizontal	1	2
Autumn	24	horizontal	1	1
Autumn	24	horizontal	1	3
Autumn	24	horizontal	1	4
Autumn	24	horizontal	1	5
Autumn	25	horizontal	3	5
Autumn	25	horizontal	3	2
Autumn	25	horizontal	3	4
Autumn	25	horizontal	3	3
Autumn	25	horizontal	3	1
Autumn	26	horizontal	2	3

season	day	rack	bypass	species
Autumn	26	horizontal	2	2
Autumn	26	horizontal	2	4
Autumn	26	horizontal	2	1
Autumn	26	horizontal	2	5
Autumn	27	vertical	3	4
Autumn	27	vertical	3	1
Autumn	27	vertical	3	2
Autumn	27	vertical	3	3
Autumn	27	vertical	3	5
Autumn	28	horizontal	2	2
Autumn	28	horizontal	2	4
Autumn	28	horizontal	2	5
Autumn	28	horizontal	2	3
Autumn	28	horizontal	2	1
Autumn	29	horizontal	2	3
Autumn	29	horizontal	2	1
Autumn	29	horizontal	2	4
Autumn	29	horizontal	2	2
Autumn	29	horizontal	2	5
Autumn	30	vertical	3	4
Autumn	30	vertical	3	2
Autumn	30	vertical	3	1
Autumn	30	vertical	3	5
Autumn	30	vertical	3	3
Autumn	31	horizontal	3	3
Autumn	31	horizontal	3	5
Autumn	31	horizontal	3	1
Autumn	31	horizontal	3	2
Autumn	31	horizontal	3	4
Autumn	32	horizontal	1	5
Autumn	32	horizontal	1	3
Autumn	32	horizontal	1	2
Autumn	32	horizontal	1	1
Autumn	32	horizontal	1	4
Autumn	33	vertical	2	5
Autumn	33	vertical	2	1
Autumn	33	vertical	2	3
Autumn	33	vertical	2	4
Autumn	33	vertical	2	2
Autumn	34	horizontal	3	4
Autumn	34	horizontal	3	1
Autumn	34	horizontal	3	3
Autumn	34	horizontal	3	2

season	day	rack	bypass	species
Autumn	34	horizontal	3	5
Autumn	35	vertical	1	1
Autumn	35	vertical	1	2
Autumn	35	vertical	1	3
Autumn	35	vertical	1	4
Autumn	35	vertical	1	5
Autumn	36	horizontal	1	2
Autumn	36	horizontal	1	3
Autumn	36	horizontal	1	4
Autumn	36	horizontal	1	1
Autumn	36	horizontal	1	5
Autumn	37	vertical	2	1
Autumn	37	vertical	2	3
Autumn	37	vertical	2	2
Autumn	37	vertical	2	5
Autumn	37	vertical	2	4
Autumn	38	horizontal	2	3
Autumn	38	horizontal	2	1
Autumn	38	horizontal	2	4
Autumn	38	horizontal	2	2
Autumn	38	horizontal	2	5
Autumn	39	horizontal	3	5
Autumn	39	horizontal	3	4
Autumn	39	horizontal	3	1
Autumn	39	horizontal	3	3
Autumn	39	horizontal	3	2
Autumn	40	horizontal	3	4
Autumn	40	horizontal	3	5
Autumn	40	horizontal	3	1
Autumn	40	horizontal	3	2
Autumn	40	horizontal	3	3
Autumn	41	horizontal	1	4
Autumn	41	horizontal	1	5
Autumn	41	horizontal	1	3
Autumn	41	horizontal	1	1
Autumn	41	horizontal	1	2
Autumn	42	horizontal	2	3
Autumn	42	horizontal	2	2
Autumn	42	horizontal	2	1
Autumn	42	horizontal	2	4
Autumn	42	horizontal	2	5
Spring	1	horizontal	3	5
Spring	1	horizontal	3	4

season	day	rack	bypass	species
Spring	1	horizontal	3	3
Spring	1	horizontal	3	2
Spring	1	horizontal	3	1
Spring	2	horizontal	1	4
Spring	2	horizontal	1	3
Spring	2	horizontal	1	2
Spring	2	horizontal	1	5
Spring	2	horizontal	1	1
Spring	3	vertical	1	4
Spring	3	vertical	1	3
Spring	3	vertical	1	5
Spring	3	vertical	1	1
Spring	3	vertical	1	2
Spring	4	horizontal	3	4
Spring	4	horizontal	3	2
Spring	4	horizontal	3	1
Spring	4	horizontal	3	3
Spring	4	horizontal	3	5
Spring	5	vertical	3	3
Spring	5	vertical	3	1
Spring	5	vertical	3	2
Spring	5	vertical	3	5
Spring	5	vertical	3	4
Spring	6	horizontal	3	4
Spring	6	horizontal	3	2
Spring	6	horizontal	3	5
Spring	6	horizontal	3	1
Spring	6	horizontal	3	3
Spring	7	horizontal	1	3
Spring	7	horizontal	1	4
Spring	7	horizontal	1	1
Spring	7	horizontal	1	2
Spring	7	horizontal	1	5
Spring	8	vertical	1	3
Spring	8	vertical	1	1
Spring	8	vertical	1	5
Spring	8	vertical	1	2
Spring	8	vertical	1	4
Spring	9	vertical	2	3
Spring	9	vertical	2	5
Spring	9	vertical	2	1
Spring	9	vertical	2	4
Spring	9	vertical	2	2

season	day	rack	bypass	species
Spring	10	vertical	3	5
Spring	10	vertical	3	3
Spring	10	vertical	3	2
Spring	10	vertical	3	4
Spring	10	vertical	3	1
Spring	11	vertical	2	3
Spring	11	vertical	2	2
Spring	11	vertical	2	5
Spring	11	vertical	2	4
Spring	11	vertical	2	1
Spring	12	horizontal	1	3
Spring	12	horizontal	1	5
Spring	12	horizontal	1	1
Spring	12	horizontal	1	4
Spring	12	horizontal	1	2
Spring	13	horizontal	2	3
Spring	13	horizontal	2	2
Spring	13	horizontal	2	5
Spring	13	horizontal	2	1
Spring	13	horizontal	2	4
Spring	14	vertical	3	2
Spring	14	vertical	3	5
Spring	14	vertical	3	3
Spring	14	vertical	3	4
Spring	14	vertical	3	1
Spring	15	horizontal	2	4
Spring	15	horizontal	2	3
Spring	15	horizontal	2	5
Spring	15	horizontal	2	2
Spring	15	horizontal	2	1
Spring	16	vertical	3	3
Spring	16	vertical	3	2
Spring	16	vertical	3	4
Spring	16	vertical	3	1
Spring	16	vertical	3	5
Spring	17	horizontal	3	3
Spring	17	horizontal	3	5
Spring	17	horizontal	3	4
Spring	17	horizontal	3	2
Spring	17	horizontal	3	1
Spring	18	horizontal	3	1
Spring	18	horizontal	3	2
Spring	18	horizontal	3	4

season	day	rack	bypass	species
Spring	18	horizontal	3	3
Spring	18	horizontal	3	5
Spring	19	horizontal	2	3
Spring	19	horizontal	2	5
Spring	19	horizontal	2	4
Spring	19	horizontal	2	2
Spring	19	horizontal	2	1
Spring	20	vertical	3	1
Spring	20	vertical	3	5
Spring	20	vertical	3	4
Spring	20	vertical	3	2
Spring	20	vertical	3	3
Spring	21	vertical	2	1
Spring	21	vertical	2	3
Spring	21	vertical	2	5
Spring	21	vertical	2	2
Spring	21	vertical	2	4
Spring	22	horizontal	2	5
Spring	22	horizontal	2	2
Spring	22	horizontal	2	1
Spring	22	horizontal	2	3
Spring	22	horizontal	2	4
Spring	23	horizontal	3	4
Spring	23	horizontal	3	5
Spring	23	horizontal	3	2
Spring	23	horizontal	3	3
Spring	23	horizontal	3	1
Spring	24	horizontal	1	3
Spring	24	horizontal	1	4
Spring	24	horizontal	1	5
Spring	24	horizontal	1	1
Spring	24	horizontal	1	2
Spring	25	vertical	3	4
Spring	25	vertical	3	2
Spring	25	vertical	3	3
Spring	25	vertical	3	1
Spring	25	vertical	3	5
Spring	26	vertical	2	5
Spring	26	vertical	2	2
Spring	26	vertical	2	3
Spring	26	vertical	2	4
Spring	26	vertical	2	1
Spring	27	vertical	1	1

season	day	rack	bypass	species
Spring	27	vertical	1	2
Spring	27	vertical	1	4
Spring	27	vertical	1	5
Spring	27	vertical	1	3
Spring	28	horizontal	1	2
Spring	28	horizontal	1	5
Spring	28	horizontal	1	3
Spring	28	horizontal	1	1
Spring	28	horizontal	1	4
Spring	29	horizontal	2	3
Spring	29	horizontal	2	2
Spring	29	horizontal	2	5
Spring	29	horizontal	2	4
Spring	29	horizontal	2	1
Spring	30	vertical	1	3
Spring	30	vertical	1	5
Spring	30	vertical	1	1
Spring	30	vertical	1	2
Spring	30	vertical	1	4
Spring	31	vertical	2	3
Spring	31	vertical	2	4
Spring	31	vertical	2	5
Spring	31	vertical	2	2
Spring	31	vertical	2	1
Spring	32	vertical	1	1
Spring	32	vertical	1	3
Spring	32	vertical	1	5
Spring	32	vertical	1	4
Spring	32	vertical	1	2
Spring	33	horizontal	2	5
Spring	33	horizontal	2	4
Spring	33	horizontal	2	2
Spring	33	horizontal	2	1
Spring	33	horizontal	2	3
Spring	34	horizontal	1	1
Spring	34	horizontal	1	3
Spring	34	horizontal	1	2
Spring	34	horizontal	1	4
Spring	34	horizontal	1	5
Spring	35	horizontal	1	2
Spring	35	horizontal	1	4
Spring	35	horizontal	1	5
Spring	35	horizontal	1	3

season	day	rack	bypass	species
Spring	35	horizontal	1	1
Spring	36	vertical	1	3
Spring	36	vertical	1	4
Spring	36	vertical	1	2
Spring	36	vertical	1	5
Spring	36	vertical	1	1
Spring	37	horizontal	2	5
Spring	37	horizontal	2	2
Spring	37	horizontal	2	1
Spring	37	horizontal	2	3
Spring	37	horizontal	2	4
Spring	38	vertical	2	3
Spring	38	vertical	2	5
Spring	38	vertical	2	4
Spring	38	vertical	2	1
Spring	38	vertical	2	2
Spring	39	vertical	1	4
Spring	39	vertical	1	3
Spring	39	vertical	1	2
Spring	39	vertical	1	1
Spring	39	vertical	1	5
Spring	40	vertical	3	2
Spring	40	vertical	3	4
Spring	40	vertical	3	3
Spring	40	vertical	3	1
Spring	40	vertical	3	5
Spring	41	vertical	2	5
Spring	41	vertical	2	1
Spring	41	vertical	2	2
Spring	41	vertical	2	4
Spring	41	vertical	2	3
Spring	42	horizontal	3	2
Spring	42	horizontal	3	4
Spring	42	horizontal	3	1
Spring	42	horizontal	3	5
Spring	42	horizontal	3	3