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BEHAVIORAL RESPONSES OF JUVENILE SALMONIDS TO STROBE AND MERCURY LIGHTS

by

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FINAL REPORT

to

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PREFACE

This research was supported by a contract from Stone and Webster Engineering Corporation, Boston, MA and was one component of the Electric Power Research Institute (EPRI) sponsored 'Phase II: EPRI Downstream Migrant Study.'

A major problem in evaluating the effectiveness of light as a tool for fish protection has been that investigators use different test conditions and equipment, and often have different objectives. This has made comparisons difficult. The Phase II: EPRI Downstream Migrant Study was an attempt, in part, to alleviate these problems by standardizing procedures. For this reason, the general methodology employed in the experiment herein was *stipulated* by Stone and Webster staff. Similarly designed and executed laboratory experiments on different species were completed at the University of Iowa. Complementary field studies were also overseen by Stone and Webster, thus providing a strong framework for evaluating the effectiveness of strobe and mercury lights as tools in fish protection systems.

ABSTRACT

The behavioral responses of juvenile coho (*Oncorhynchus kisutch*), chinook (*O. tshawytscha*) and Atlantic salmon (*Salmo salar*), and steelhead trout (*S. gairdneri*) to underwater strobe lights and mercury vapor lights were observed directly and by video. Tests were conducted in an enclosed outdoor raceway, and each lasted 60 min. At the beginning of an experiment, one test light located at one end of the raceway was turned on for 30 min. Next, this light was turned off and the test light at the opposite end of the raceway was turned on simultaneously for another 30 min. Tests were conducted in still water and both during the night with dark-adapted fish and during the day with light-adapted fish.

All species avoided the strobe light at night, and coho and chinook avoided the strobe light during the day. Responses to the mercury lights were variable, although steelhead fry were strongly attracted to the light. These results are discussed with reference to using light as a tool in fish guidance systems.

INTRODUCTION

Coho (*Oncorhynchus kisutch*), chinook (*O. tshawytscha*), and Atlantic salmon (*S. salar*), and steelhead (*Salmo gairdneri*) navigate past dams on their downstream journey toward the sea. Hydroelectric facilities are required by law to protect these fish; however, there presently is no effective and economical solution for all situations (EPRI 1986). It is likely that future fish protection systems will be tailored to fit each specific site, and this realization is partly responsible for renewed interest in behavioral barriers, including light.

The responses of salmonids and other fish to light has been studied extensively (reviewed by Woodhead 1966, Blaxter 1970, Hocutt 1980). The effectiveness of light as a fish protection system has also been investigated (reviewed by Hocutt 1980, EPRI 1986). These works provided a basic foundation for the more recent successful employment of strobe and mercury lights to guide fish. Strobe lights have been shown to repel fish from specific areas (Patrick et al. 1982, 1985, Sager et al. 1987), and mercury lights attract fish under some conditions (Haymes et al. 1984). The purpose of this study was to test whether the salmonid species investigated were repelled by strobe light and attracted to mercury lights in a still-water, laboratory setting.

METHODS

Fish Holding and Testing Facilities

All fish holding and testing facilities were located at the University of Washington hatchery. Depending upon development and other factors, fish were kept in wooden troughs (12 ft long x 1 ft wide x 0.5 ft deep), glass tanks (4 ft long x 2 ft wide x 2 ft deep), or cement circular tanks (5.3 ft dia x 3 ft deep). Water from Lake Washington continuously flowed through the holding tanks.

Experiments were conducted in an outdoor raceway that was 29 ft long, 5.3 ft wide, and 3.8 feet deep. The raceway bottom and sides were coated with white pigmented fiberglass resin. The bottom and sides were marked every 3 ft with 1 inch wide black tape. A 7-ft-high rectangular box, constructed with a 2 by 4 frame with 6 ml black plastic attached to it, was erected above the raceway to entirely enclose it. The enclosure roof was covered with corrugated, opaque white fiberglass.

Lake Washington water continuously flowed through the raceway (except during tests). Temperature and turbidity varied with ambient conditions, and the water in the tank was approximately 2 ft deep.

Three video cameras were mounted onto a rail which was suspended 6 ft above the top of the raceway (Fig. 1a). Two Dage-MTI Model 60 low-light video cameras and a Panasonic Model WV 1354 with an automatic iris were connected to a Panasonic AG-6200 VCR. Time to 0.01 s was recorded onto the video tape with a Panasonic Time Date Generator Model WJ-810. An ABC switch determined which camera signal was recorded at any given time.

Test Animals

Underyearling coho, chinook and Atlantic salmon, and steelhead trout were tested. The coho, chinook, and steelhead were reared at the University of Washington hatchery. Fish were fed according to normal hatchery schedule, thus growing to smolt size within four months. Atlantic salmon were obtained from Big Beef Creek Hatchery (Washington) and held at the hatchery in glass tanks for one week prior to testing. At the time of testing the Atlantic salmon were still bottom oriented.

Ambient Lighting, Test Lights, and Light Measurements

The indoor hatchery was exposed to natural light in addition to the regular daytime overhead room lighting. The glass-sided holding tanks provided more exposure to natural daylight than either the troughs or the circulars.

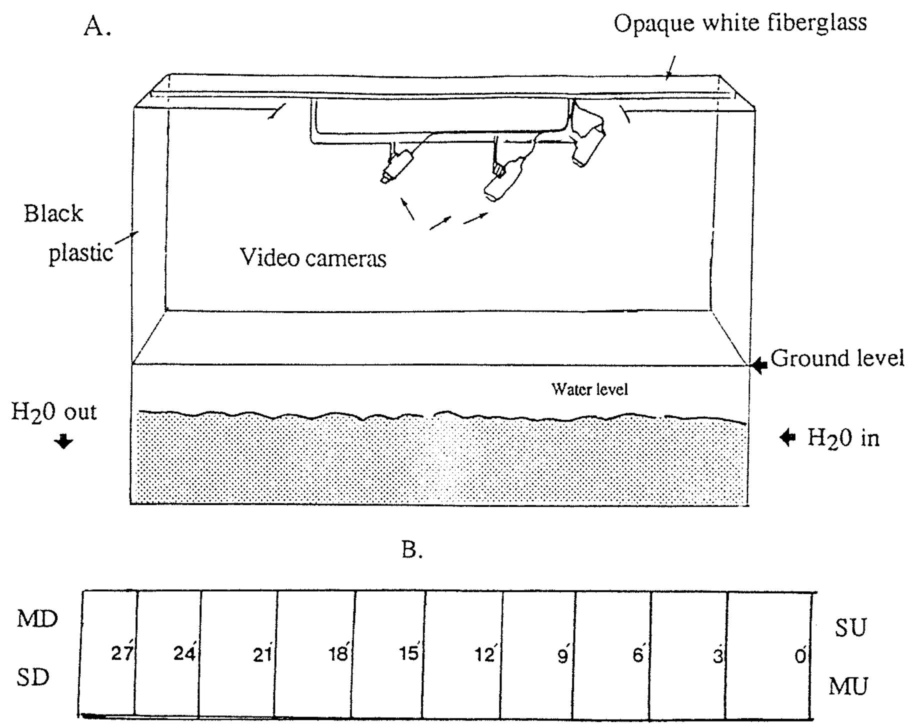

Fig. 1. A. Cut-away view into the test tank (sunken raceway) showing the positions of the three overhead video cameras. B. Floor plan of the test tank illustrating the positions of the underwater test lamps: upstream strobe (SU), downstream strobe (SD), upstream mercury lamp (MU), and downstream mercury lamp (MD).

Virtually no light other than that from the test lights entered the raceway at night, and diffuse natural daylight flooded the raceway during day studies.

A Hydro-Products Model L2 mercury vapor underwater light (1000 W) was placed at each end of the raceway (Fig. 1b). All mercury light tests were conducted under maximum intensity conditions. Next to the centrally placed mercury lights were EG&G Model SS-122 (modified) underwater strobe lights. Twilight intensity on the strobe controller box was selected for nighttime tests and daylight intensity was selected for daytime tests. Strobe flash frequency was set at 300 per minute for all tests.

Light measurements were taken with a Lambda LiCor LI-185B light meter attached to an LI-192S underwater quantum sensor. All measurements are presented as μmoles/s/m^2. Detailed light measurements were taken (once) in the raceway under several test light configurations.

These measurements were taken every 3 ft along the length of the raceway at 2 inches from each side and in the middle, with depths being 2 inches from the bottom and top and at mid-depth. These detailed measurements were taken at nighttime with one of the test lights on and the sensor facing the it. Detailed light measurements were not taken during the day because rapidly changing ambient light conditions swamped the test light intensities.

During nighttime tests, measurements were taken at lines 9, 12, 15, 18, and 21 on the east side of the raceway, at mid-depth, and with the sensor facing directly at the light. Only the second test light in a trial was measured per trial. During daytime tests, the above measurements were taken with the test light on and off. Readings were also taken at the center of each 3-ft mark, at mid-depth, and with the sensor facing up. The purpose of these measurements was to verify that test light conditions remained similar among tests. Since conditions were mostly stable, these measurements will be discussed further.

Test Procedure

Test lights were identified as upstream strobe (SU), downstream strobe (SD), upstream mercury (MU), and downstream mercury (MD). Since the experiment was carried out in still water, upstream and downstream indicate water input and output locations during non testing periods. A pair of test lights always refers to the upstream and downstream light of the same type, e.g., strobe or mercury. The response of each fish group to a pair of lights (SU,SD; SD,SU; MU,MD; or MD,MU) constituted a "trial." Four trials were completed per day and five replicates of each trial set (SU,SD + SD,SU + MU,MD + MD,MU) were completed for each species under both daytime (9 AM to 7 PM) and nighttime (6 PM to 3 AM) conditions

Table 1. Summary of test conditions

Species	Length (mean)	Weigth (mean)	Holding tank	Temp. mean	Feed	Test type	Test date	Condition
Chinook	8.7	8.5	Glass	13	No	Night	April 29-May 4; May 6, 11	Late fry, early smolt, no stress
Coho	8.9	8.7	Glass	15	No	Night	May 5, 11-14, 18	Late fry, early smolt, no stress
Atlantic	10.3	14.0	Glass	16	No	Night	May 17-20 and 26-28	Late fry, early smolt, stress due to high temp, handling, Columnari]
Steelhead	5.1	2.6	Trough	16	Yes	Night	May 20,21,25, 30,31; June 1-2	Fry, no stress
Chinook	8.7	7.4	Glass	13	No	Day	April 26-April 29, May 14	Late fry, early smolt, no stress
Coho	9.9	11.6	Circular	17	No	Day	June 8-12	Smolt; stress due to being held back, temp, *Columnaris*
Steelhead	7.1	5.0	Trough	18	Yes	Day	June 13, June 15-18	Fry, some *Columnaris* in group

(Table 1). In terms of analysis, SU,SD and SD,SU are replicates, as are MU,MD and MD,MU. The daily procedure was as follows.

If necessary, the raceway was cleaned prior to each day's test schedule. Cameras and video equipment were turned on and adjusted for the first test. Fifty fish were netted from the holding tanks and placed into the raceway. After the 30-min acclimation, the video recorder was turned on and one underwater light—either the upstream strobe (SU), downstream strobe (SD), upstream mercury (MU) or downstream mercury (MD)—was turned on. The behavior of the fish within the viewing zones of the cameras was recorded continuously for one-half hour.

After the first test light of the pair had been on for 30-min, it was turned off and the next test light was turned on; behavior of the fish was monitored as previously stated. Sometimes it was necessary to adjust camera iris openings with the change of lights and this was done at the switch point with all lights off; changing the iris took about 15 sec.

In addition, direct observations were recorded each minute for the first 5 min, and thereafter every 5 min until the test light was turned off. Observations included the number of fish between each 3-ft mark and general notations on movement. Fish were observed through a small window in the black plastic surrounding the raceway.

At the end of the second 30-min period, the video equipment and test lights were turned off and the fish were removed from the raceway. A new set of 50 fish were then transferred from the holding tanks to the raceway and another trial conducted.

RESULTS

In general, the direct observations provided the most useful data. We reviewed all video tapes (Appendix 1) to verify the direct observations and to fill in missing observations. Three types of information were obtained from the direct observation data, including qualitative observations, attraction and repulsion responses vs. time, and the equilibrium (stable, long-term) response to light.

Qualitative Observations

Most fish probably sank to the bottom and remained still during the nighttime acclimation period, but it was too dark to verify this. At night, all species appeared to be 'stunned' when the strobe lights were first turned on. A few fish darted randomly for short distances, but most fish remained stationary at first and later swam away from the light (Table 2). Coho often swam underneath the strobe lights when the light was turned on at night. Activity levels were low compared to daytime experiments.

During the day, most fish did not appear to be stunned by the strobe light and swam directly away. Chinook and coho occasionally swam continuously from one end of the tank to the other. Coho characteristically hid under the lights when placed into the raceway during the daytime acclimation period and remained there even after we turned on the test light.

Most fish gradually swam more actively as the mercury vapor lamp light intensity increased during the nighttime tests. For example, after about 15 min, coho and chinook swam continuously from one end of the tank to the other. Steelhead milled continuously in one large group near the test lamp.

During daytime tests, chinook often stayed at the downstream edge of the raceway before testing. When the downstream mercury lamp was turned on, the fish swam up and down the length of the raceway; yet, when the upstream mercury was on, the fish remained away from the light. A migratory urge may have been affecting the fish.

Attraction and Repulsion Responses vs. Time (Nighttime Tests)

The second type of data consisted of counts of fish by tank position. For expediency, we tabulated the data in terms of the number of fish within 9 ft of the light vs. time and the number of fish ≥21 ft from the test light (or hiding) vs. time. These distances represented the closest and farthest positions from the lights which we could reliably determine. Since this experimental constraint limited position discrimination, we used the constraint to define "attraction" and "repulsion" within the context of this experiment. Specifically, we defined attraction as the occurrence of more than 50% of the fish within 9 ft of the test light. We defined repulsion as

Table 2. Summary of basic behavioral responses to light. The behaviors listed represent the overall stable response of the fish. Terms are defined beneath the table.

		Chinook	Coho	Steelhead	Atlantic
Strobe	Day	Avoid	Hide	Inconsistent	No test
	Night	Avoid	Hide	Avoid	Avoid
Mercury	Day	Inconsistent	Hide	Inconsistent	No test
	Night	Oscillate	Oscillate	Attract	Inconsistent

Definition of terms:

avoid = swim away from light and stay away; does not include hiding under lights
hide = swim underneath the strobe lights and stay there (light is dim)
inconsistent = sometimes avoid light and sometimes attracted to light
attract = swim toward light and stay near light

the occurrence of more than 50% of the fish at a position ≥21 ft from the test light (or hiding). This technique allowed us to readily identify whether the fish had been attracted to the mercury lights or repelled by the strobe lights and to note how these responses changed with time.

These definitions also make sense with reference to light intensity. Light intensities from both the strobe (Fig. 2) and mercury vapor lamps (Fig. 3) decrease rapidly with distance from the test light (Appendix 2); at 21 ft from the strobe light, the intensity was less than 0.05 μmoles/s/m^2 and at 9 ft in front of the mercury lamp the intensity was 11 μmoles/s/m^2. We lumped 'hiding' with repulsion as defined above since light intensities in the hiding areas (under the lights) were similar to those at 21 ft away from the light. In some cases, particularly with coho, the fish might hide underneath the test light (as opposed to the opposite light); these fish where still counted in the 21 ft away group.

During the first 10 min of exposure to strobe light, increasing numbers of fish swam away from the light source (Fig. 4, Appendix 3). After 10 min, fish position was fairly stable for the remaining 50 min of the experiment. By our criterion, all species of fish were repelled by the strobe light.

Steelhead were attracted to the mercury test lamp (Fig. 5), but all other species failed to swim toward the light. The number of steelhead within 9 ft of the light increased with time for the first 15 min, and they swam relatively quickly toward the second test light at the 30-min switch point (Fig. 6). The exact form of this strong attraction is worth investigating further in other experiments, but clearly the attraction was a function of exposure time.

Both chinook and coho tended to swim up and down the length of the raceway during the mercury light tests, thus indicating a complex response to the lights. It appeared that the migratory urge was stronger than any attraction or repulsion response, and this is reflected in the data plotted in Figure 5.

The Equilibrium Response

The third type of data was obtained from the direct observations by determining fish group position at 30 and 60 min from the beginning of the experiment. This should represent an equilibrium response. For field applications, the equilibrium response is likely to be important since lights will operate continuously. Note that these data are the same raw counts as those discussed in the last section but are tabulated differently and only at time = 30 and 60.

This analysis is based upon fish group position; all species during all tests acted mostly as a unit. The average group size was 40 + 0.5 ($\bar{x}$ + 1 SE; N = 240), which represents 80% of all fish. Thus, the fish positions discussed below are descriptive of the dominant fish activity but do not reflect all variability in response.

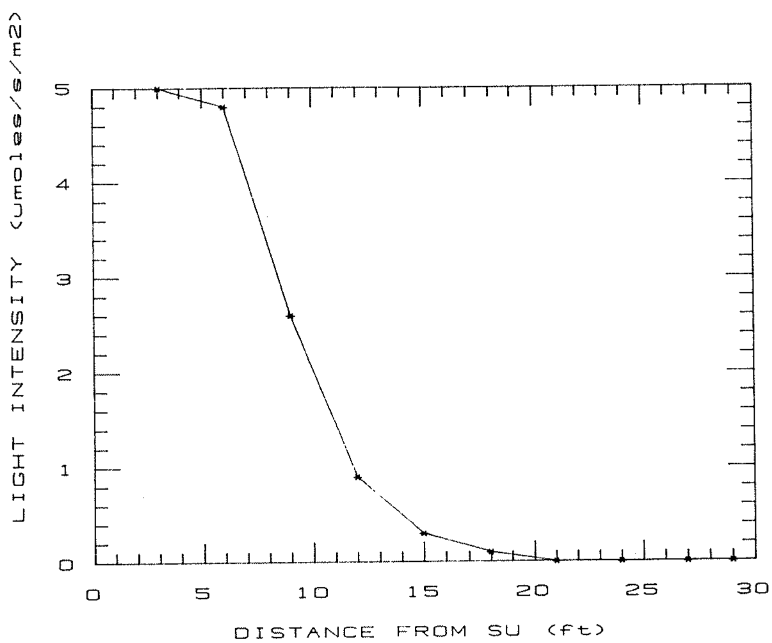

Fig. 2. Light intesity as a function of distance from the test (upstream strobe (SU)) light. These intensities were measured against a dark background so that the readings indicate only light emitted from the test lamp.

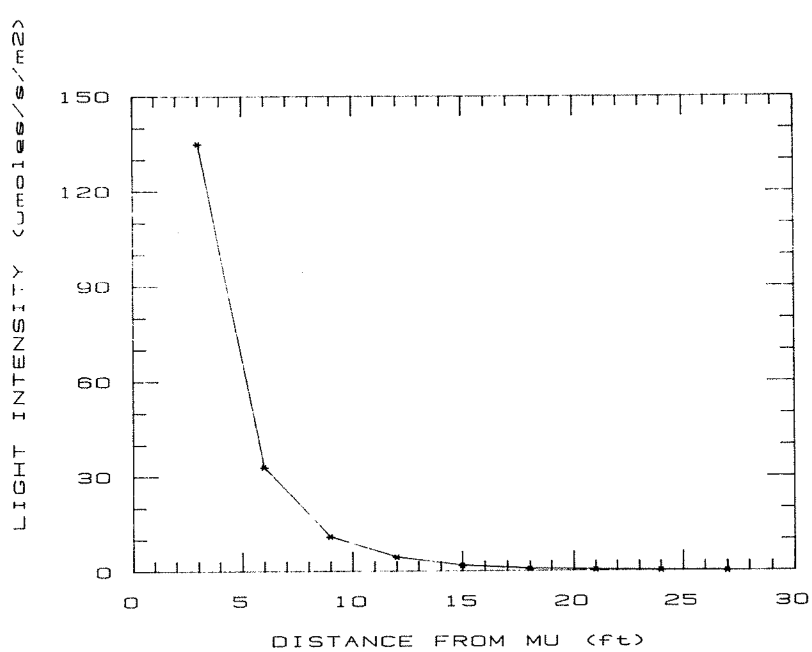

Fig. 3. Light intensity as a function of distance from the test (upstream mercury (MU)) light. These intensities were measured against a dark background so that the readings indicate only light emitted from the test lamp.

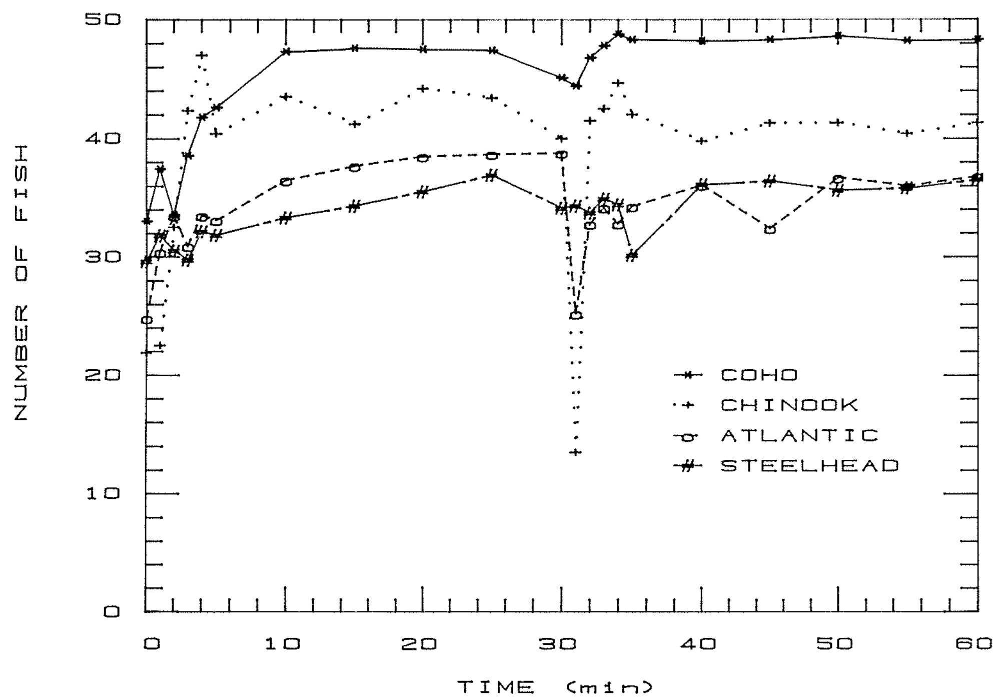

Fig. 4. Number of fish (N = 50) 21 or more ft from the test strobe light (or hiding) vs. time (nighttime tests only). At 30 min, the light at one end of the tank is turned off and the strobe at the other end is turned on simultaneously. This sometimes resulted in a momentary sharp decrease (at time = 31 min) in the number of fish 21 ft from the test light, because at the switch point those fish far from the initial test light were then near the second test light. For each species, more than 50% of the test group swam away from the light within the first 15 min of testing.

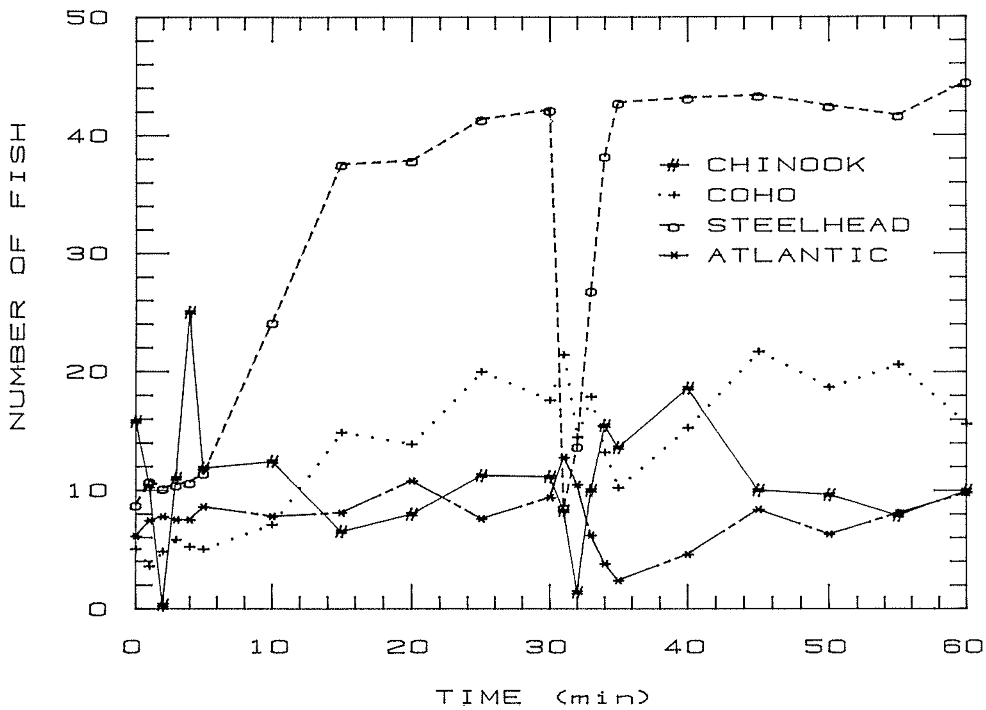

Fig. 5. Number of fish (N = 50) within 9 ft of the mercury vapor test lamp as a function of time (nighttime tests only). Steelhead swim to the light as a function of time. At 30 min, the light at one end of the tank is turned off and simultaneously the mercury lamp at the other end is turned on. This sometimes resulted in a momentary sharp decrease (at time = 31 min) in the number of fish within 9 ft from the test light, because at the switch point those fish near the initial test light were then far from the second test light.

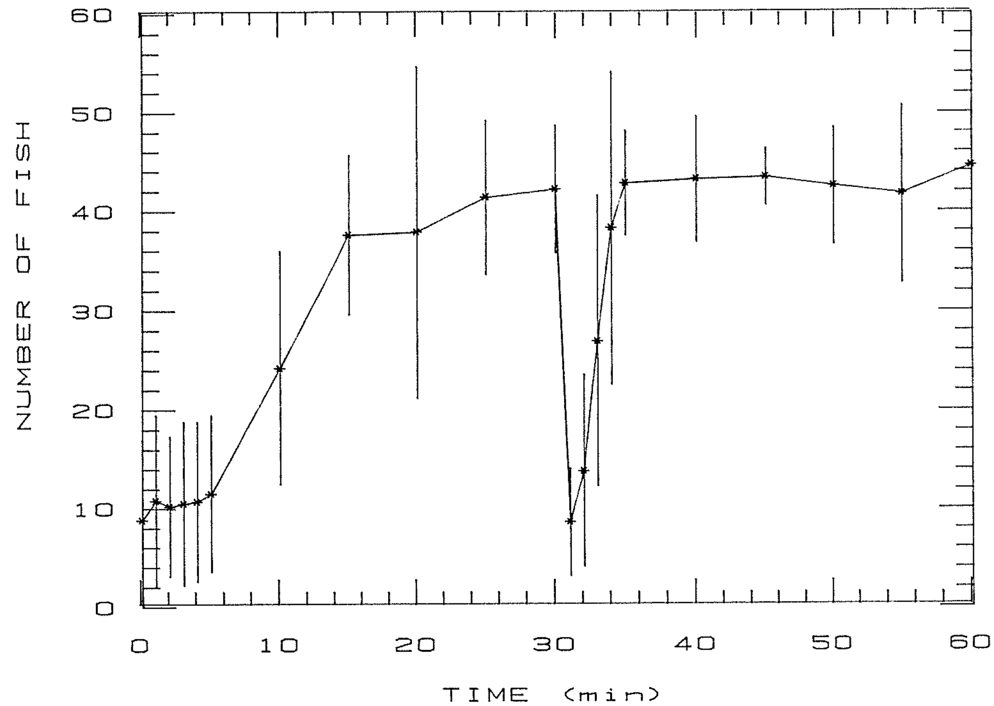

Fig. 6. Number of steelhead (N = 50) within 9 ft of the mercury vapor test lamp (nighttime tests only). At 30 min the light at one end of the tank is turned off and simultaneously the mercury lamp at the other end is turned on. This clearly resulted in a momentary sharp decrease (at time = 31 min) in the number of fish within 9 ft from the test light, but the fish rapidly swam the length of the tank to be near the new test light.

This analysis does not include chinook or coho response to mercury light at night because fish position was not stable (i.e., the salmon swam continuously from one end of the tank to the other). Atlantic salmon were not tested during the day so that data is also missing from this analysis (Appendix 3).

The basic conclusions from these data are clear. Except for steelhead tested during the day, all species avoid strobe light (Fig. 7; Table 3). Only steelhead tested at night displayed attraction to the mercury lights.

To detect differences in response, a four-way ANOVA (species, time of day, type of light, and time = 30 or 60) was the preferred test. However, the data did not meet the assumptions of ANOVA, and no common transformation improved this problem. Furthermore, the data set was nonorthogonal because of both technical and biological complications. Therefore, a nonparametric one-way analysis of variance was used to identify differences among means due to the various treatments, e.g., whether the fish were exposed to strobe light or mercury light, at night or during the day, etc. (see Table 4). Data at time 30 and 60 were treated separately for the statistical analysis since the light exposure history of the two groups was different.

The Kruskal-Wallis test showed that the means were significantly different from one another ($H = 99.8996$; $P < .001$). Some of these means, or groups of means, were then further tested against one another; for example, it was determined that strobe light response was significantly different than mercury light response ($S = 41.26$; $P < 0.05$). However, when distance from the light during day or night was compared, or distance at 30 min vs. 60 min was compared, no significant differences were detected.

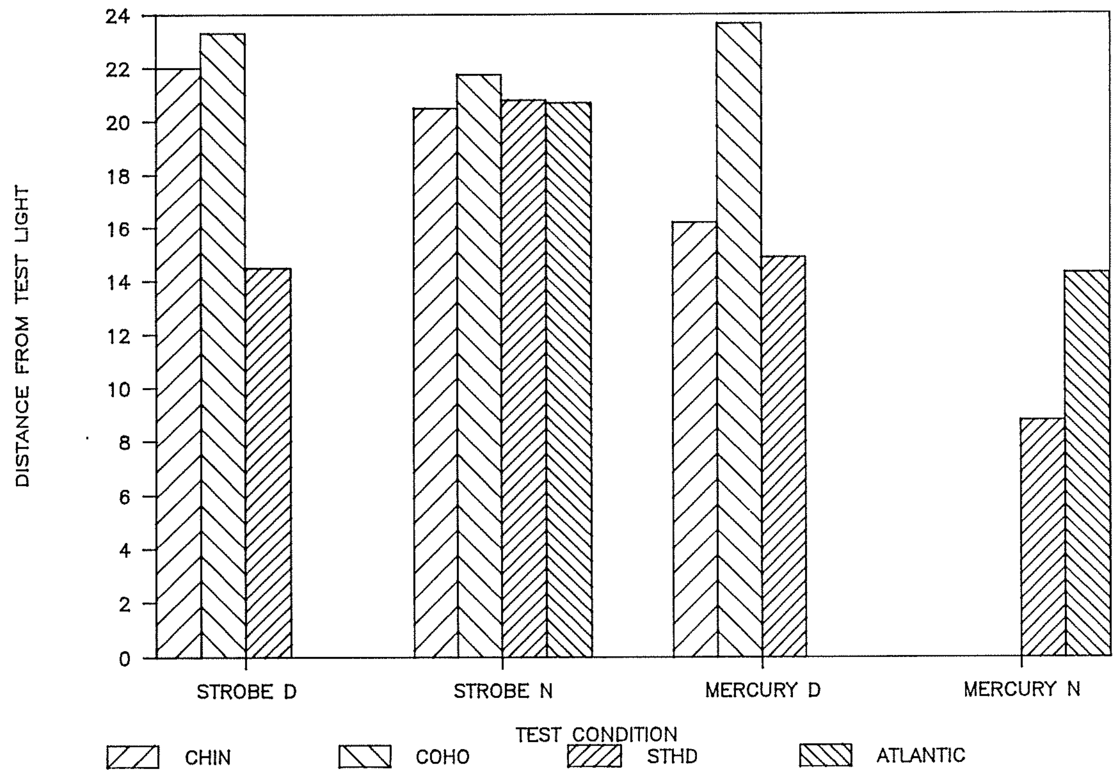

Fig. 7. Average stable position of the fish within the test tank in response to strobe light and mercury light. D indicates daytime tests and N indicates nighttime tests. Data at time=30 and 60 were considered replicates. This analysis does not include chinook or coho response to mercury light at night because fish position was not stable (i.e., the salmon swam continuously from one end of the tank to the other). Atlantic salmon were not tested during the day so that data is also missing from this analysis (Appendix 3).

Table 3. Salmonid group distance ($\bar{x}$) from the light. Data are those plotted in Figure 7. I_x is light intensity (from the test light) at the average position. OSC indicates that the fish responded by swimming from end to end of the tank.

			Chinook	Coho	Steelhead	Atlantic
Strobe	Day	I_x	0.0	0.0	0.3	
		$\bar{x}$	22	23	15	No test
		SE	1.6	0.7	1.3	
	Night	I_x	0.0	0.0	0.0	0.0
		$\bar{x}$	21	22	21	21
		SE	0.4	0.5	0.2	0.3
Mercury	Day	I_x	1.8	0.0	1.8	
		$\bar{x}$	16	24	15	No test
		SE	1.8	0.7	2.1	
	Night	I_x			11.0	1.8
		$\bar{x}$	OSC	OSC	8.8	14.3
		SE			0.2	1.2

Table 4. Data classes used in the one-way nonparametric analysis of variance to detect whether there were significant differences in the positions of the fish due to treatment effects (e.g., type of light, day or night, species, and test time (30 or 60 min). There were 10 replicates for each class. This analysis does not include chinook or coho response to mercury light at night because fish position was not stable (i.e., the salmon swam continuously from one end of the tank to the other). Atlantic salmon were not tested during the day so that data is also missing from this analysis (Appendix 3). Data under the column labelled 'Distance' are the arithmetic average distance from the test light for that class. The Kruskal-Wallis mean rank is also listed so that any interested reader can conduct othe tests of contrast.

Stimulus	Condition	Species	Test time	Distance	Rank
Strobe	Night	Chinook	30	20.6	123.2
Strobe	Night	Coho	30	20.9	134.4
Strobe	Night	Steelhead	30	20.7	133.7
Strobe	Night	Atlantic	30	21.0	140.0
Strobe	Night	Chinook	60	20.3	116.9
Strobe	Night	Coho	60	22.6	164.5
Strobe	Night	Steelhead	60	21.0	140.0
Strobe	Night	Atlantic	60	20.4	132.8
Strobe	Day	Chinook	30	19.2	135.4
Strobe	Day	Coho	30	23.0	170.2
Strobe	Day	Steelhead	30	15.4	90.0
Strobe	Day	Chinook	60	23.9	175.8
Strobe	Day	Coho	60	23.5	176.0
Strobe	Day	Steelheada	60	13.6	77.2
Merc	Night	Steelhead	30	9.0	32.0
Merc	Night	Atlantic	30	15.3	85.1
Merc	Night	Steelhead	60	8.6	29.35
Merc	Night	Atlantic	60	13.3	71.7
Merc	Day	Chinook	30	15.2	97.4
Merc	Day	Coho	30	22.8	165.8
Merc	Day	Steelhead	30	12.1	69.6
Merc	Day	Chinook	60	17.2	114.0
Merc	Day	Coho	60	24.5	190.1
Merc	Day	Steelhead	60	17.7	127.3

DISCUSSION

Strobe Light

The results of this still-water laboratory experiment are clear. Chinook, coho and Atlantic salmon, and steelhead trout all swam away from, and stayed away from strobe light for the 60-min duration of the test. These results are consistent with the avoidance responses shown by other species to strobe light both in the laboratory (Sager 1984; Patrick et al. 1985; Sager et al. 1987; McIninch and Hocutt 1987) and in the field (Patrick et al. 1982).

The fact that chinook and coho avoided the strobe light during the daytime tests is surprising since we anticipated that reduced contrast between ambient light and test light would decrease avoidance (Puckett and Anderson in press). We think that these results reflect experimental conditions rather than the true open water response that is important for successful strobe light deployment, and thus the results demand explanation. First, the very high contrast at night (due to the small test space and the white walls of the tank) tended to 'stun' the fish and thereby impeded strobe light avoidance. During the day, chinook were not stunned and swam immediately away from the light. Therefore, in out test tank the fish were better able to avoid strobe light during the day than at night. This situation is unlikely to occur in the field since natural turbidity and open space would allow the fish to respond before they become stunned. During the day, contrast in the natural environment might render the lights ineffective.

Strobe light has both positive and negative features as a fish guidance tool. On the positive side, the species tested have consistently avoided the light during both the day and night under laboratory conditions. Furthermore, the salmon did not appear to acclimate to the light. The main disadvantage of strobe lights is that keeping fish away from an area is often only one part of a fish bypass system. It may be necessary to guide the fish toward a bypass and strobe lights are not helpful in this regard.

Finally, these tests were conducted under very specific conditions and do not necessarily reflect the behavior of fish under guidance conditions.

Mercury Light

We expected all species tested at night to first avoid the mercury light and then swim toward it. This idea was well illustrated by the steelhead fry but not by chinook, coho, or Atlantic smolts. We have strong evidence from previous experiments that chinook fry would have responded to this test similarly to the steelhead fry (Puckett and Anderson, In press), and therefore we suspect a shift in light sensitivity with age (see also Pinhorn and Andrews 1963, 1965). We cannot explain why coho and chinook swam actively from tank end to end, but it may be related to a migratory urge.

We reasoned that during the daytime tests the contrast between the mercury vapor test light and the ambient light would be too low to invoke a consistent response. Our data for chinook and steelhead were consistent with this idea. The coho came from a relatively dark holding tank and were so sensitive to the ambient light that they immediately hid under the strobe lights during the acclimation period and failed to reappear throughout the rest of the test.

When mercury lights work to attract fish they are *very* effective; that is, the response of the fish to the light is consistent and strong. Therefore, in general, attraction is a more useful tool in fish guidance than is repulsion. More basic research is needed to enhance our understanding of fish response to mercury light, but the payoff could be great.

ACKNOWLEDGMENTS

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APPENDIX 1

Video Tape Analysis

Each video tape (Table A1) was reviewed briefly for information retrieval. We found that, in general, the direct observations were more useful than the video tapes. The reasons for this are discussed below.

First, the nature of the tests made filming difficult. The test area was large, and even with three cameras, not all areas were visible under all conditions. The range of light conditions where viewing would have been useful varied from dark to very bright (at least 10 orders of magnitude). Thus, while our eyes are superior to any ordinary video camera, even we could not see under all of these conditions. Our low-light camera did will in dim light, but poorly in high light. None of our cameras could cope with all the light conditions encountered, and in fact, if such a camera exists, it would be extremely expensive. Visibility was particularly poor during the strobe light tests (even by eye).

The camera settings and arrangements that optimized viewing under the strobe light tended to minimize viewing under the mercury light and vice versa. The mercury lights changed intensity with time and thus required an automatic iris for each camera (we had only one camera with an automatic iris).

In conclusion, we recommend that if further video work of this nature is desired, serious consideration should be given to the objections noted above. Spin-up time should be increased because of the difficulty of the project. We recommend that future strobe light tests (and possibly mercury light tests also) be done under infra-red lighting and with an infra-red filter on the video camera. Using infra-red with the strobe light would entail development time but this technique would ensure fish visibility regardless of white-light intensity.

TABLE A1: VIDEO TAPE SUMMARY DATA SHEET

TAPE#	TAPE LAP	TEST	SPECIES	TOD	MONTH	DAY	HOUR	MIN	TEMP
1	0:00:00	SUSD	CHIN	DAY	4	26	11	47	13
1	1:00:31	MUMD	CHIN	DAY	4	26	13	34	13
2	0:01:52	SDSU	CHIN	DAY	4	26	15	13	13
2	1:03:25	MDMU	CHIN	DAY	4	26	17	12	13
3	0:02:	SUSD	CHIN	DAY	4	27	9	2	13
3	1:02:47	MUMD	CHIN	DAY	4	27	10	48	13
4	0:00:02	SDSU	CHIN	DAY	4	27	12	42	13
4	1:02:12	MDMU	CHIN	DAY	4	27	14	28	13
5	0:02:	SUSD	CHIN	DAY	4	28	12	2	13
5	1:07:00	MUMD	CHIN	DAY	4	28	13	58	13
6	0:02:00	SDSU	CHIN	DAY	4	28	15	40	13
6	1:02:06	MDMU	CHIN	DAY	4	28	17	24	13
7	0:03:05	MDMU	CHIN	DAY	4	29	9	22	13
7	1:03:59	SDSU	CHIN	DAY	4	29	11	13	13
8	0:01:35	MUMD	CHIN	DAY	4	29	13	2	13
8	1:04:10	SUSD	CHIN	DAY	4	29	14	49	14
9	0:7:00	MDMU	CHIN	NITE	4	29	20	59	14
9	1:03:58	MUMD	CHIN	NITE	4	29	22	52	14
10	0:00:00	SUSD	CHIN	NITE	5	1	22	33	12
10	1:03:04	MDMU	CHIN	NITE	5	1	23	24	12
11	0:00:00	SDSU	CHIN	NITE	5	2	21	7	12
11	1:03:49	SUSD	CHIN	NITE	5	2	23	6	12
12	0:00:00	SUSD	CHIN	NITE	5	3	20	16	12
12	1:02:04	SDSU	CHIN	NITE	5	3	21	57	12
13	0:00:00	SDSU	CHIN	NITE	5	3	23	36	12
13	1:01:12	SUSD	CHIN	NITE	5	3	1	15	12
14	0:00:00	SDSU	CHIN	NITE	5	4	20	26	12
14	1:01:24	SUSD	CHIN	NITE	5	4	22	6	12
15	0:00:00	SDSU	CHIN	NITE	5	4	23	43	12
15	1:02:35	SUSD	COHO	NITE	5	5	1	19	13
16	0:00:00	SDSU	COHO	NITE	5	5	17	29	13
16	1:00:51	SUSD	COHO	NITE	5	5	20	0	14
17	0:00:00	SDSU	COHO	NITE	5	5	21	51	14
17	1:01:23	SUSD	COHO	NITE	5	5	23	35	13
18	0:00:00	MDMU	CHIN	NITE	5	6	17	33	15
18	1:04:31	MUMD	CHIN	NITE	5	6	19	21	15
19	0:00:00	MDMU	CHIN	NITE	5	6	21	5	14
19	1:02:38	MUMD	CHIN	NITE	5	6	22	49	15
20	1:02:12	MDMU	CHIN	NITE	5	11	20	0	17
20	0:00:00	MUMD	CHIN	NITE	5	11	18	14	17
21	1:03:24	MUMD	COHO	NITE	5	11	23	41	17
21	0:00:00	MUMD	CHIN	NITE	5	11	21	39	17
22	0:00:00	SUSD	COHO	NITE	5	12	17	35	15
22	1:02:49	MUMD	COHO	NITE	5	12	19	38	15
23	0:00:00	MDMU	COHO	NITE	5	12	21	25	15
23	1:02:02	SDSU	COHO	NITE	5	12	23	10	15
24	0:00:00	MUMD	COHO	NITE	5	13	18	41	16
24	1:01:39	MDMU	COHO	NITE	5	13	20	29	16
25	0:00:00	MUMD	COHO	NITE	5	13	22	15	16
25	1:01:29	MDMU	COHO	NITE	5	13	0	0	16
26	0:00:00	SDSU	COHO	NITE	5	14	18	5	15
26	1:02:12	MUMD	COHO	NITE	5	14	19	59	15
27	0:00:00	MDMU	COHO	NITE	5	14	21	45	15

27	1:01:42	MDMU	COHO	NITE	5	14	23	35	15
28	0:00:00	SDSU	ATLANTIC	NITE	5	17	18	0	16
28	1:01:58	MDMU	ATLANTIC	NITE	5	17	19	53	16
29	0:00:00	MUMD	ATLANTIC	NITE	5	17	21	35	15
29	1:01:26	SUSD	ATLANTIC	NITE	5	17	23	20	15
30	0:00:00	SUSD	COHO	NITE	5	18	19	30	15
30	1:01:58	SDSU	COHO	NITE	5	18	21	10	15
31	0:00:00	MUMD	ATLANTIC	NITE	5	18	22	50	15
31	1:01:33	MDMU	ATLANTIC	NITE	5	18	0	45	15
32	0:00:00	MUMD	ATLANTIC	NITE	5	19	19	15	15
32	1:02:00	MDMU	ATLANTIC	NITE	5	19	21	5	15
33	0:00:00	MUMD	ATLANTIC	NITE	5	19	23	0	15
33	1:01:29	MDMU	ATLANTIC	NITE	5	20	1	53	15
34	0:00:00	MDMU	ATLANTIC	NITE	5	20	20	0	15
34	0:58:14	MUMD	ATLANTIC	NITE	5	20	21	55	15
35	0:00:00	MUMD	STEELHEAD	NITE	5	20	23	45	15
35	1:01:15	MDMU	STEELHEAD	NITE	5	20	1	30	15
36	0:00:00	MDMU	STEELHEAD	NITE	5	21	20	0	16
36	1:01:34	MUMD	STEELHEAD	NITE	5	21	20	30	16
37	0:00:00	MDMU	STEELHEAD	NITE	5	21	23	27	16
37	1:00:36	MUMD	STEELHEAD	NITE	5	21	1	11	16
38	0:00:00	MUMD	STEELHEAD	NITE	5	21	21	25	16
38	1:01:31	MDMU	STEELHEAD	NITE	5	31	23	5	16
39	0:00:00	MUMD	STEELHEAD	NITE	5	25	19	30	17
39	1:01:39	MDMU	STEELHEAD	NITE	5	25	20	45	17
40	0:00:00	SUSD	ATLANTIC	NITE	5	26	19	35	16
40	1:01:52	SDSU	ATLANTIC	NITE	5	26	21	30	16
41	0:00:00	SUSD	ATLANTIC	NITE	5	26	23	15	16
41	1:03:05	SDSU	ATLANTIC	NITE	5	26	1	0	16
42	0:00:00	SUSD	ATLANTIC	NITE	5	28	20	5	16
42	1:02:00	SDSU	ATLANTIC	NITE	5	28	21	55	16
43	0:00:00	SUSD	ATLANTIC	NITE	5	28	23	40	16
43	1:01:59	SDSU	ATLANTIC	NITE	5	28	1	15	16
44	0:00:00	SUSD	STEELHEAD	NITE	5	30	19	30	16
44	1:02:03	SDSU	STEELHEAD	NITE	5	30	21	10	16
45	0:00:00	SDSU	STEELHEAD	NITE	5	30	22	50	16
45	1:02:10	SUSD	STEELHEAD	NITE	5	31	19	40	16
46	0:00:00	SDSU	STEELHEAD	NITE	5	31	21	20	16
46	1:00:00	SUSD	STEELHEAD	NITE	5	31	23	0	14
47	0:00:00	SDSU	STEELHEAD	NITE	6	1	0	40	16
47	1:02:06	SUSD	STEELHEAD	NITE	6	2	20	30	16
48	0:00:00	SDSU	STEELHEAD	NITE	6	2	22	10	16
48	1:02:39	SUSD	STEELHEAD	NITE	6	2	23	55	16
49	0:00:00	SUSD	COHO	DAY	6	8	9	30	17.5
49	1:01:15	MUMD	COHO	DAY	6	8	11	25	17.5
50	0:00:00	SDSU	COHO	DAY	6	8	13	10	17.5
50	0:59:51	MDMU	COHO	DAY	6	8	15	0	17.5
51	0:02:00	MDMU	COHO	DAY	6	9	8	55	17
51	1:05:21	SDSU	COHO	DAY	6	9	10	45	17
52	0:02:00	MUMD	COHO	DAY	6	9	12	30	17
52	1:03:52	SUSD	COHO	DAY	6	9	14	20	17
53	0:02:00	MUMD	COHO	DAY	6	10	9	0	17.5
53	1:09:02	SDSU	COHO	DAY	6	10	10	55	17
54	0:00:30	MDMU	COHO	DAY	6	10	12	40	17.5
54	1:02:38	SUSD	COHO	DAY	6	10	14	25	17.5
55	0:00:00	MDMU	COHO	DAY	6	11	10	5	17

55	1:01:57	SUSD	COHO	DAY	6	11	12	12	17
56	0:00:00	MUMD	COHO	DAY	6	11	14	40	17.5
56	1:01:48	SDSU	COHO	DAY	6	11	16	40	18
57	0:02:00	SDSU	COHO	DAY	6	12	9	38	17
57	1:05:11	SUSD	COHO	DAY	6	12	11	30	17.5
58	0:00:30	MUMD	COHO	DAY	6	12	13	30	17.5
58	0:59:30	MDMU	COHO	DAY	6	12	15	20	17.5
59	0:00:30	SUSD	STEELHEAD	DAY	6	13	9	50	17.5
59	1:01:36	MUMD	STEELHEAD	DAY	6	13	12	0	17.5
60	0:00:30	SDSU	STEELHEAD	DAY	6	13	14	0	18
60	1:01:05	MDMU	STEELHEAD	DAY	6	13	16	0	18
61	0:00:30	SDSU	CHIN	DAY	6	14	16	45	18
61	1:01:30	MDMU	CHIN	DAY	6	14	10	30	18
62	0:00:30	SUSD	CHIN	DAY	6	14	12	30	18
62	1:01:30	MUMD	CHIN	DAY	6	14	14	15	18
63	0:02:54	MUMD	STEELHEAD	DAY	6	15	10	30	18
63	1:05:00	SUSD	STEELHEAD	DAY	6	15	12	30	18
64	0:00:35	MDMU	STEELHEAD	DAY	6	15	14	15	18
64	1:01:30	SDSU	STEELHEAD	DAY	6	15	19	45	18
65	0:01:13	SDSU	STEELHEAD	DAY	6	16	10	20	17.5
65	1:02:00	MDMU	STEELHEAD	DAY	6	16	12	0	17.5
66	0:01:00	SUSD	STEELHEAD	DAY	6	16	13	45	17.5
66	1:02:40	MUMD	STEELHEAD	DAY	6	16	15	30	18
67	0:00:00	MDMU	STEELHEAD	DAY	6	17	9	30	17
67	1:01:02	SDSU	STEELHEAD	DAY	6	17	11	45	17
68	0:00:00	MUMD	STEELHEAD	DAY	6	17	13	45	17.5
68	1:01:22	SUSD	STEELHEAD	DAY	6	17	15	45	18
69	0:00:00	MUMD	STEELHEAD	DAY	6	18	10	0	17.5
69	1:01:06	MDMU	STEELHEAD	DAY	6	18	12	15	17.5
70	0:00:00	SDSU	STEELHEAD	DAY	6	18	14	15	18
70	1:01:04	SUSD	STEELHEAD	DAY	6	18	16	15	18

APPENDIX 2

Detailed Light Measurements

SU ON

LTH	DTH	WEST	MI	EAST
0	B	0.1		0.4
	M	1.0		0.5
	T	1.0		0.7
3	B	2.4	5.0	3.0
	M	4.5	5.0	4.5
	T	5.0	5.0	4.9
6	B	4.8	4.8	4.8
	M	4.9	4.8	5.0
	T	4.8	4.8	5.0
9	B	4.5	2.2	4.5
	M	4.6	2.6	4.5
	T	4.8	2.6	4.5
12	B	1.7	0.5	1.7
	M	2.2	0.9	2.1
	T	1.8	1.0	1.9
15	B	0.5	0.2	0.6
	M	0.5	0.3	0.7
	T	0.5	0.3	0.8
18	B	0.2	0.1	0.2
	M	0.2	0.1	0.3
	T	0.2	0.1	0.3
21	B	0.0	0.0	0.1
	M	0.0	0.0	0.1
	T	0.0	0.0	0.1
24	B	0.0	0.0	0.0
	M	0.0	0.0	0.0
	T	0.0	0.0	0.0
27	B	0.0	0.0	0.0
	M	0.0	0.0	0.0
	T	0.0	0.0	0.0
29	B	0.0	0.0	0.0
	M	0.0	0.0	0.0
	T	0.0	0.0	0.0

SD ON

LTH	DTH	WEST	MI	EAST
0	B	0.0	0.0	0.0
	M	0.0	0.0	0.0
	T	0.0	0.0	0.0
3	B	0.0	0.0	0.0
	M	0.0	0.0	0.0
	T	0.0	0.0	0.0
6	B	0.0	0.0	0.0
	M	0.0	0.0	0.0
	T	0.0	0.0	0.0
9	B	0.1	0.1	0.1
	M	0.1	0.1	0.1
	T	0.1	0.1	0.1
12	B	0.2	0.2	0.2
	M	0.2	0.2	0.2
	T	0.2	0.2	0.2
15	B	0.5	0.6	0.6
	M	0.3	0.7	0.6
	T	0.2	0.4	0.6
18	B	1.2	1.5	1.8
	M	1.2	1.8	1.8
	T	1.2	1.8	1.8
21	B	3.1	5.0	4.8
	M	3.1	5.0	4.8
	T	3.1	4.8	4.8
24	B	4.8	4.8	4.8
	M	4.2	5.0	4.8
	T	4.2	5.0	4.8
27	B	1.0	5.0	4.5
	M	1.0	5.0	5.0
	T	1.0	5.0	5.0
29	B	0.5		1.1
	M	0.8		1.5
	T	1.0		1.5

MD ON

LTH	DTH	WEST	MI	EAST
0	B	0.1		0.0
	M	0.1		0.0
	T	0.1		0.1
3	B	0.1	0.1	0.1
	M	0.1	0.2	0.1
	T	0.1	0.2	0.1
6	B	0.3	0.2	0.2
	M	0.3	0.3	0.2
	T	0.2	0.3	0.2
9	B	0.4	0.5	0.4
	M	0.4	0.5	0.5
	T	0.5	0.6	0.6
12	B	0.7	1.0	1.0
	M	0.9	1.0	1.0
	T	0.9	1.0	1.5
15	B	1.5	2.0	2.0
	M	2.0	2.0	2.5
	T	2.0	2.0	2.5
18	B	4.5	5.0	4.0
	M	5.0	5.0	4.0
	T	5.0	5.0	4.0
21	B	10.0	13.0	10.0
	M	12.0	14.0	11.0
	T	12.0	14.0	11.0
24	B	37.0	34.0	20.0
	M	42.0	40.0	24.0
	T	45.0	42.0	25.0
27	B	170.0	110.0	8.0
	M	200.0	100.0	12.0
	T	195.0	100.0	13.0
29	B	21.0		3.0
	M	29.0		5.8
	T	15.0		8.0

MU ON

LTH	DTH	WEST	MI	EAST
0	B	1.0		20.0
	M	5.0		30.0
	T	8.0		30.0
3	B	15.0	95.0	100.0
	M	25.0	135.0	110.0
	T	25.0	110.0	130.0
6	B	21.0	31.0	25.0
	M	24.0	33.0	30.0
	T	25.0	34.0	33.0
9	B	9.0	10.0	9.0
	M	10.0	11.0	11.0
	T	11.0	12.0	11.0
12	B	3.5	4.0	3.0
	M	4.0	4.5	4.0
	T	4.0	4.5	4.0
15	B	1.5	1.5	1.3
	M	1.7	1.8	1.6
	T	1.8	1.9	1.7
18	B	0.7	0.7	0.5
	M	0.8	0.7	0.6
	T	0.8	0.8	0.6
21	B	0.3	0.3	0.3
	M	0.4	0.4	0.3
	T	0.4	0.4	0.3
24	B	0.1	0.1	0.1
	M	0.2	0.2	0.2
	T	0.2	0.2	0.2
27	B	0.1	0.1	0.1
	M	0.1	0.1	0.1
	T	0.1	0.1	0.1
29	B	0		0
	M	0		0
	T	0		0

APPENDIX 3

Listing of Attraction and Repulsion Data

APPENDIX 3: ATTRACTION AND REPULSION RAW DATA LISTING

NUMBER OF FISH WITHIN 9 FT OF TEST LIGHT

MO	DAY	HOUR	SPEC	TEST	TM: 0	1	2	3	4	5	10	15	20	25	30	31	32	33	34	35	40	45	50	55	60
5	11	23	COHO	MUMD		10	10	7	7	8	2	3	2	1	1		25	2	2	2	2	2	2	2	2
5	12	19	COHO	MUMD	0	0	0	0	0	1	15	35	5	5	0	50	0	35	0	0	0	25	15	0	0
5	13	22	COHO	MUMD	13	8	8	8	7	4	5	20	2	15	42	15	15	25	25	25	25	15	15	30	15
5	13	18	COHO	MUMD	3	1	0	0	0	0	48	0	25	47	18	40	15	35	20	20	50	50	50	49	48
5	14	19	COHO	MUMD	3	2	3	5	1	3	1	15	20	25	25	24	15	0	10	35	0	25	40	23	44
5	17	21	ATLC	MUMD	5	5	6	4	2	2	12	1	39	46	39	12	3	0	9	10	25	29	31	30	30
5	18	22	ATLC	MUMD	11	14	10	12	9	6	8	15	8	1	5	25	20	15	0	0	10	35	2	15	1
5	19	23	ATLC	MUMD	9	9	10	6	6	6	0	2	1	0	0	2	6	6	5	4	3	1	2	1	2
5	19	19	ATLC	MUMD	0	4	2	5	7	10	8	8	8	8	8	0	0	0	0	0	0	0	0	0	0
5	20	21	ATLC	MUMD	15	15	15	15	15	29	18	35	40	15	27	5	4	3	0	0	1	2	7	2	2
5	6	19	CHIN	MUMD						15	0	0	0	0	0					0	0	0	0	0	0
5	6	22	CHIN	MUMD	33					25	2	1	0	0	0	0	0	0		0	0	0	0	0	0
5	11	21	CHIN	MUMD	41	6	1	44	25	3	35	1	6	49	34	2		0	12	44	44	25	32	23	23
5	11	18	CHIN	MUMD	0			0		0	0	0	0	35	0	0	0	0		0	25	0	0	25	25
4	29	22	CHIN	MUMD																					
5	20	23	STHD	MUMD	12	14	11	11	12	15	20	25	49	49	49	0	1	2	3	44	48	42	47	46	50
5	21	1	STHD	MUMD	16	15	10	11	11	9	17	42	46	43	41	7	8	29	46	45	39	44	33	40	37
5	21	21	STHD	MUMD	20	20	20	20	20	20	20	45	0	50	50	8	25	25	36	37	48	45	42	42	47
5	21	20	STHD	MUMD	10	20	16	18	18	18	13	39	40	30	48	4	12	20	41	43	32	45	48	47	48
5	25	19	STHD	MUMD	2	6	9	5	5	12	25	37	35	34	37	11	11	20	36	37	45	42	44	46	48
5	12	21	COHO	MDMU	10	3	3	5	3	3	0	10	43	25	20	12	15	35	0	5	25	20	25	5	5
5	13	0	COHO	MDMU		3	2	3	11	15	0	25	12	37	25	15	25	25	25	0	15	25	10	0	0
5	13	20	COHO	MDMU			5	5	5	1	0	12	30	15	15	35	15	15	15	15	34	25	30	47	15
5	14	21	COHO	MDMU	5	2	2	10	3	0	0	0	0	0	0	0	0	7	25	0	0	15	0	20	15
5	14	23	COHO	MDMU	1	3	15	15	15	15	0	29	0	30	30	2	20	0	10	0	2	15	0	30	12
5	17	19	ATLC	MDMU	0	4	4	4	4	4	2	6	3	2	9	20	7	6	4	3	4	15	20	20	35
5	18	0	ATLC	MDMU	4	4	12	5	7	7	3	5	2	3	3	4	43	30	15	4	0	0	1	10	1
5	19	21	ATLC	MDMU				12	10	9	16		0	0	0	25	7	0	0	1	0	2	0	0	0
5	20	20	ATLC	MDMU	9	10	9	6	6	6	7	1	7	1	3	20	15	2	2	2	2	0	0	1	2
5	26	1	ATLC	MDMU	2	2	2	6	9	7	4	0	0	0	0	15	0	0	3	0	1	0	0	2	25
5	1	23	CHIN	MDMU	0	0	0	0	0	0	0	0	0	0	0	0	0	50	50	50	50	0	0	0	0
5	6	17	CHIN	MDMU							0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	6	21	CHIN	MDMU						40		0		1		6				0	0	5	0	0	2
5	11	20	CHIN	MDMU	5	25	0	0	50	0	50	50	50	5	44	50	7		0	15	30	50	45	15	30
4	29	20	CHIN	MDMU																					
5	21	20	STHD	MDMU	0	0	0	0	1	1	40	44	45	45	40	5	6	20	48	46	46	47	38	45	45
5	21	23	STHD	MDMU	6	10	10	10	10	10	29	29	41	35	36	12	25	35	43	45	42	40	39	31	40
5	25	20	STHD	MDMU	1	1	4	4	4	4	35	41	41	40	42	12	12	33	36	36	40	46	46	44	45
5	31	23	STHD	MDMU	15	16	16	20	20	20	10	32	35	44	35	15	23	40	47	48	42	40	40	26	35
5	20	1	STHD	MDMU	6	6	6	6	6	6	33	42	47	44	44	12	15	45	47	47	50	43	48	50	50

APPENDIX 3: ATTRACTION AND REPULSION RAW DATA LISTING

NUMBER OF FISH COUNTED 21 FT OR MORE FROM TEST LIGHT (OR HIDING)

MO	DAY	HOUR	SPEC	TEST TM:	0	1	2	3	4	5	10	15	20	25	30	31	32	33	34	35	40	45	50	55	60
5	5	23	COHO	SUSD	27	30	27	40	40	44	49	49	49	49	49	47	48	49	49	49	49	49	48	48	48
5	5	1	COHO	SUSD			13	29	36	35	43	45	43	43	46	45	45	47	47	47	50	47	49	48	47
5	5	20	COHO	SUSD		40	49	45	50	50	50	48	47	47	30	48	47	46	48	46	46	48	48	48	48
5	12	17	COHO	SUSD						45	50	50	50	49	49	43	48	50	50	49	47	49	50	49	49
5	18	19	COHO	SUSD		43	38	49	46	50	50	50	50	50	50	47	50	48	49	49	49	49	49	48	50
5	17	23	ATLC	SUSD	28	26	34	33	34	34	32	30	34	36	36	25	23	27	27	22	30	38	36	36	30
5	26	19	ATLC	SUSD	32	38	38	38	37	39	36	41	41	42	40	17	30	36	32	35	39	39	40	33	32
5	26	23	ATLC	SUSD	19	20	25	37	31	29	36	36	38	39	40	19	32	31	24	33	34	35	33	32	33
5	28	20	ATLC	SUSD	36	44	42	43	40	40	39	43	44	43	42	36	41	38	41	41	39	41	41	41	41
5	28	23	ATLC	SUSD	10	29	32	3	29	30	38	37	35	41	40	21	36	32	29	30	32	32	29	32	38
5	1	22	CHIN	SUSD						50	47	47	48	48	48					46	49	49	49	49	49
5	2	23	CHIN	SUSD				44		45	40	40	40	40	40	10						50	50	50	50
5	3	1	CHIN	SUSD	9					44	47	49	44	44	44					44	42	40	36	34	36
5	3	20	CHIN	SUSD	49			49		50	45	45	45	45	45					44	46	44	43	43	43
5	4	22	CHIN	SUSD	0	25		34		37	42	47	41	44		1	43		43	49	45	39	40	47	48
6	2	20	STHD	SUSD	20	22	20	26		25	26	35	36	38	38	37	34	38	34	37	34	38	35	28	28
6	2	23	STHD	SUSD	26	25	28	22	21	24	25	31	37	33	0	34	30	34	34	32	34	34	35	34	37
5	30	19	STHD	SUSD			26	33	40	39	36	35	39	42	39	38	27	33	33	33	31	30	30	25	26
5	31	19	STHD	SUSD	30	30	38	37	37	38	38	40	36	44	40	30	40	35	35	36	42	35	35	38	40
5	31	19	STHD	SUSD	34	31	28	28	29	26	34	26	30	33	35	32	31	36	36	31	35	37	38	35	35
5	5	21	COHO	SDSU			31	37	40	38	50	49	50	50	46	47	45	48	47	49	49	49	47	46	46
5	5	17	COHO	SDSU	49	40	44	48	48	48	48	49	47	49	49	49	49	50	49	49	49	49	49	49	49
5	12	23	COHO	SDSU	15	26	20	21	30	35	41	40	43	42	38	20	36	40		45	43	43	46	46	46
5	14	18	COHO	SDSU	50	48	48	50	50	49	47	49	50	48	49	50	50	50	50	50	50	50	50	50	50
5	18	21	COHO	SDSU	24	35	32	28	36	32	45	47	46	47	45	48	50	50	50	50	50	50	50	50	50
5	17	18	ATLC	SDSU		30	40	41	38	39	38	37	39	36	40	43	41	49	48	48	49	40	45	43	44
5	26	1	ATLC	SDSU	19	33	22	23	27	25	40	40	38	37	36	14	27	31	32	36	38	32	32	35	38
5	26	21	ATLC	SDSU	31	32	34	37	35	33	37	37	42	37	37	26	27	32	24	28	31	33	31	31	32
5	28	1	ATLC	SDSU	28	24	34	28	31	37	34	42	42	43	44	27	42	40	44	41	41	4	44	40	40
5	28	21	ATLC	SDSU	20	28	34	26	33	25	35	34	32	33	33	24	29	26	27	29	28	30	36	37	40
5	2	21	CHIN	SDSU						47	47	47	50	50	50				50	50	49	45	50	44	44
5	3	23	CHIN	SDSU	26					37	43	36	38	33	35	0				18	25	25	29	37	24
5	3	21	CHIN	SDSU	15					22	40	17	48	48		0				39	15	26	19	17	27
5	4	20	CHIN	SDSU	39		42		47	42	43	43	44	43		36		43		45	42	48	48	44	43
5	4	23	CHIN	SDSU	15	20	23			30	41	41	44	39	18	34	40	42	41	43	45	47	49	39	49
6	1	0	STHD	SDSU	21	33	41	41	34	37	36	37	34	33	37	31	26	21	26	27	28	26	29	35	35
6	2	22	STHD	SDSU	26	36	28	29	33	32	31	35	35	37	37	31	37	35	34	34	37	39	38	37	44
5	30	22	STHD	SDSU	35	36	31	28	37	31	33	36	35	40	37	35	36	38	36	33	34	40	39	43	44
5	30	21	STHD	SDSU	41	37	29	29	31	38	41	39	37	40	44	38	39	39	42	2	43	42	43	43	38
5	31	21	STHD	SDSU	33	36	36	24	27	28	33	29	36	29	34	37	37	40	34	36	43	43	34	40	38

APPENDIX 4
Listing of Equilibrium Data

SPECIES	TOD	TEST	TIME	DIST	SIZE
sthd	nite	SDSU	60	21	44
sthd	nite	SDSU	60	21	38
sthd	nite	SUSD	60	21	35
sthd	nite	SDSU	60	21	44
sthd	nite	SUSD	60	21	28
sthd	nite	SDSU	60	21	40
sthd	nite	SUSD	60	21	40
sthd	nite	SUSD	60	21	35
sthd	nite	SDSU	60	21	37
sthd	nite	SUSD	60	21	26
sthd	nite	SUSD	30	21	31
sthd	nite	SDSU	30	21	35
sthd	nite	SUSD	30	21	35
sthd	nite	SDSU	30	21	37
sthd	nite	SUSD	30	21	38
sthd	nite	SDSU	30	18	27
sthd	nite	SDSU	30	21	40
sthd	nite	SDSU	30	21	44
sthd	nite	SUSD	30	21	40
sthd	nite	SUSD	30	21	38
sthd	nite	MDMU	60	9	45
sthd	nite	MUMD	60	5	50
sthd	nite	MDMU	60	9	45
sthd	nite	MUMD	60	9	45
sthd	nite	MDMU	60	9	35
sthd	nite	MUMD	60	9	50
sthd	nite	MDMU	60	9	45
sthd	nite	MUMD	60	9	40
sthd	nite	MUMD	60	9	37
sthd	nite	MDMU	60	9	50
sthd	nite	MDMU	30	9	44
sthd	nite	MUMD	30	9	35
sthd	nite	MDMU	30	9	40
sthd	nite	MUMD	30	9	49
sthd	nite	MDMU	30	9	35
sthd	nite	MUMD	30	9	42
sthd	nite	MUMD	30	9	43
sthd	nite	MDMU	30	9	42
sthd	nite	MDMU	30	9	35
sthd	nite	MUMD	30	9	35
coho	nite	SDSU	60	21	50
coho	nite	SUSD	60	21	48
coho	nite	SDSU	60	21	50
coho	nite	SDSU	60	21	35
coho	nite	SUSD	60	28	30
coho	nite	SDSU	60	27	40
coho	nite	SUSD	60	21	50
coho	nite	SUSD	60	21	48
coho	nite	SUSD	60	21	48
coho	nite	SDSU	60	24	45
coho	nite	SUSD	30	21	50
coho	nite	SUSD	30	22	40
coho	nite	SDSU	30	21	49
coho	nite	SUSD	30	21	49
coho	nite	SDSU	30	20	30
coho	nite	SUSD	30	21	47
coho	nite	SDSU	30	21	50
coho	nite	SDSU	30	21	48
coho	nite	SDSU	30	20	40
coho	nite	SUSD	30	21	49
chin	nite	SUSD	60	23	35
chin	nite	SDSU	60	21	40
chin	nite	SDSU	60	21	30
chin	nite	SDSU	60	18	35
chin	nite	SUSD	60	20	40
chin	nite	SDSU	60	21	49
chin	nite	SUSD	60	20	40
chin	nite	SUSD	60	20	35
chin	nite	SUSD	60	21	49
chin	nite	SDSU	60	18	40
chin	nite	SUSD	30	21	44
chin	nite	SUSD	30	21	35
chin	nite	SDSU	30	17	45
chin	nite	SUSD	30	24	35
chin	nite	SDSU	30	20	40
chin	nite	SUSD	30	21	40
chin	nite	SDSU	30	21	39
chin	nite	SDSU	30	20	30
chin	nite	SDSU	30	20	40
chin	nite	SUSD	30	21	40
atlantic	nite	SDSU	60	21	37
atlantic	nite	SDSU	60	21	45
atlantic	nite	SDSU	60	21	40
atlantic	nite	SDSU	60	21	41
atlantic	nite	SUSD	60	21	32
atlantic	nite	SDSU	60	15	29
atlantic	nite	SUSD	60	21	34
atlantic	nite	SUSD	60	21	30
atlantic	nite	SUSD	60	21	30
atlantic	nite	SUSD	60	21	31
atlantic	nite	SDSU	30	21	43
atlantic	nite	SUSD	30	21	35
atlantic	nite	SUSD	30	21	36
atlantic	nite	SUSD	30	21	44
atlantic	nite	SDSU	30	21	44
atlantic	nite	SUSD	30	21	30
atlantic	nite	SDSU	30	21	30
atlantic	nite	SDSU	30	21	40
atlantic	nite	SDSU	30	21	39
atlantic	nite	SUSD	30	21	30
atlantic	nite	MDMU	60	9	45
atlantic	nite	MDMU	60	9	34
atlantic	nite	MUMD	60	21	39
atlantic	nite	MDMU	60	21	46
atlantic	nite	MUMD	60	21	30
atlantic	nite	MDMU	60	9	41
atlantic	nite	MDMU	60	9	50
atlantic	nite	MUMD	60	10	42
atlantic	nite	MUMD	60	12	45
atlantic	nite	MUMD	60	12	40
atlantic	nite	MDMU	30	12	40

coho	day	SDSU	60	27	30
coho	day	SUSD	60	27	30
coho	day	SUSD	60	21	35
coho	day	SUSD	30	24	45
coho	day	SDSU	30	21	50
coho	day	SUSD	30	27	35
coho	day	SDSU	30	21	45
coho	day	SUSD	30	21	30
coho	day	SDSU	30	21	50
coho	day	SUSD	30	21	50
coho	day	SUSD	30	27	35
coho	day	SDSU	30	21	30
coho	day	SDSU	30	26	30
coho	day	MUMD	60	21	40
coho	day	MUMD	60	27	50
coho	day	MDMU	60	27	35
coho	day	MUMD	60	21	40
coho	day	MDMU	60	27	30
coho	day	MUMD	60	21	35
coho	day	MDMU	60	21	50
coho	day	MDMU	60	26	40
coho	day	MDMU	60	27	40
coho	day	MUMD	60	27	30
coho	day	MDMU	30	21	30
coho	day	MDMU	30	21	49
coho	day	MUMD	30	21	30
coho	day	MUMD	30	27	40
coho	day	MUMD	30	21	50
coho	day	MDMU	30	21	40
coho	day	MUMD	30	27	35
coho	day	MUMD	30	27	40
coho	day	MDMU	30	21	35
coho	day	MDMU	30	21	40
chin	day	SDSU	60	26	40
chin	day	SUSD	60	27	45
chin	day	SDSU	60	18	45
chin	day	SUSD	60	21	50
chin	day	SDSU	60	27	40
chin	day	SUSD	60	19	50
chin	day	SUSD	60	21	45
chin	day	SDSU	60	25	45
chin	day	SDSU	60	29	45
chin	day	SUSD	60	26	40
chin	day	SUSD	30	27	30
chin	day	SDSU	30	0	40
chin	day	SUSD	30	23	45
chin	day	SDSU	30	21	40
chin	day	SUSD	30	25	45
chin	day	SDSU	30	26	45
chin	day	SDSU	30	18	49
chin	day	SUSD	30	20	50
chin	day	SUSD	30	24	50
chin	day	SDSU	30	8	45
chin	day	MUMD	60	12	50
chin	day	MDMU	60	4	40
chin	day	MDMU	60	21	45

atlantic	nite	MUMD	30	21	40
atlantic	nite	MUMD	30	21	50
atlantic	nite	MDMU	30	9	25
atlantic	nite	MUMD	30	12	49
atlantic	nite	MUMD	30	21	45
atlantic	nite	MDMU	30	18	32
atlantic	nite	MDMU	30	9	45
atlantic	nite	MDMU	30	21	46
atlantic	nite	MUMD	30	9	30
sthd	day	SDSU	60	22	35
sthd	day	SDSU	60	9	50
sthd	day	SDSU	60	15	3
sthd	day	SUSD	60	12	30
sthd	day	SUSD	60	9	50
sthd	day	SUSD	60	15	46
sthd	day	SUSD	60	12	30
sthd	day	SUSD	60	9	26
sthd	day	SDSU	60	9	32
sthd	day	SDSU	60	24	45
sthd	day	SUSD	30	12	30
sthd	day	SDSU	30	21	45
sthd	day	SDSU	30	23	44
sthd	day	SUSD	30	18	25
sthd	day	SDSU	30	12	45
sthd	day	SUSD	30	18	32
sthd	day	SUSD	30	23	50
sthd	day	SDSU	30	6	40
sthd	day	SDSU	30	9	46
sthd	day	SUSD	30	12	30
sthd	day	MUMD	60	27	32
sthd	day	MDMU	60	6	24
sthd	day	MDMU	60	9	30
sthd	day	MDMU	60	27	50
sthd	day	MUMD	60	6	50
sthd	day	MDMU	60	27	50
sthd	day	MUMD	60	12	50
sthd	day	MUMD	60	27	30
sthd	day	MUMD	60	12	50
sthd	day	MDMU	60	24	30
sthd	day	MDMU	30	9	30
sthd	day	MUMD	30	9	45
sthd	day	MDMU	30	3	49
sthd	day	MUMD	30	6	50
sthd	day	MDMU	30	7	50
sthd	day	MUMD	30	24	50
sthd	day	MUMD	30	21	40
sthd	day	MUMD	30	27	50
sthd	day	MDMU	30	9	50
sthd	day	MDMU	30	6	23
coho	day	SDSU	60	27	45
coho	day	SUSD	60	21	50
coho	day	SDSU	60	27	50
coho	day	SDSU	60	21	30
coho	day	SUSD	60	16	30
coho	day	SUSD	60	21	35
coho	day	SDSU	60	27	50

chin	day	MUMD	60	10	45
chin	day	MDMU	60	18	49
chin	day	MUMD	60	25	40
chin	day	MDMU	60	25	40
chin	day	MUMD	60	12	50
chin	day	MDMU	60	24	40
chin	day	MUMD	60	21	35
chin	day	MUMD	30	26	40
chin	day	MDMU	30	5	40
chin	day	MDMU	30	6	40
chin	day	MUMD	30	14	49
chin	day	MDMU	30	21	40
chin	day	MUMD	30	11	35
chin	day	MUMD	30	22	45
chin	day	MUMD	30	27	50
chin	day	MDMU	30	3	50
chin	day	MDMU	30	17	45