THESIS

PHYSICAL FACTORS INFLUENCING TROUT DENSITY IN A SMALL STREAM

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Phillip A. Stewart

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ABSTRACT

PHYSICAL FACTORS INFLUENCING TROUT DENSITY IN A SMALL STREAM

A two phase study was conducted in a small trout stream in north central Colorado. Phase I concerned the relationship of 15 physical variables to density of wild brook trout (*Salvelinus fontinalis*) and rainbow trout (*Salmo gairdneri*) in stream sections. Phase II was concerned with the effect of physical variables, built into experimental fright cover devices, on use of structures by wild rainbow trout when frightened. Variables in phase II were structure height above and below the water surface, structure size, percentage of surface area of structure punched out with holes, and water depth in which structure was located.

Variables, in order of their importance to density of brook and rainbow trouts were mean section depth and underwater, overhanging rock cover. Undercut banks and areas of deep turbulent water seemed to be of some importance to brook trout density, but not rainbow trout density. No other variables could be shown to be statistically important to density of either species.

Rainbow trout use of experimental fright cover devices increased with increasing structure size, decreasing structure height, and decreasing percentage holes. No effect of two water depths was found. The variables height, size, and percentage holes affected light intensity under structures as well as fish use. Fish use of structures was strongly related to light intensity under structures.

Small sized rock cover, found to be important to trout density in phase I, may increase density by increasing visual isolation of fish,

rather than functioning as fright cover. Additional experiments in phase II indicate that deep water areas can function as fright cover. Mean depth in phase I may be important in determining trout density in that it reflects the presence of deep water areas.

Phillip A. Stewart
Department of Fishery and Wildlife Biology
Colorado State University
Fort Collins, Colorado, 80521
June, 1970

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INTRODUCTION

Small trout streams are important in providing recreational fishing; demand for this type of fishing will probably increase with human population. Current management practices have relied heavily on stocking of catchable sized fish, with some exceptions (White and Brynildson, 1967; Whitney, 1964). Additional knowledge concerning the environmental requirements of wild stream trout is needed to develop management techniques that will enhance production and decrease emphasis on stocking.

Although methods for physical measurements of streams can be made with a high degree of accuracy, the relevance of these measurements to stream fish populations is unsubstantiated. Lagler (1956) described methods for evaluating streams, but gave little evidence for the relevance of his methods to stream fish populations.

In trout streams physical variables appear to be important in determining fish density. Small streams lack the large, physically homogenous areas found in lakes. Wickham (1967) and Baldes and Vincent (1969) found that stream trout are subjected to high water velocities for only short periods. Focal points, positions held in the stream by fish, were of relatively low velocity. Each trout in a stream requires an area supplying low velocity resting microhabitat, high velocity water (carries higher concentrations of drift food), and cover.

Trout are adapted to natural streams, but not to those which have been physically modified. These modifications have been largely due to highway and railroad construction (Peters and Alvord, 1964). Trout densities are several times greater in natural than in modified streams (Whitney and Bailey, 1959; Peters and Alvord, 1964). The importance of trout density is emphasized by Hunt (1969). He found that differences in annual production of stream trout were effected through density changes and not through changes in growth rates.

Physical characteristics of unmodified stream channels have been described by Matthes (1941), Leopold and Maddock (1953), Leopold and Wolman (1960), and Leopold (1962). Modifications from the natural state include straightening, removal of bank vegetation, and bank rip-rapping (Peters and Alvord, 1964). These modifications cause disappearance of pool-riffle periodicity, deep-slow water areas, and all types of cover (Elser, 1968).

Cover is an important component of trout streams. Boussu (1954) was able to increase the number and weight of trout in stream sections by addition of artificial brush cover, and to decrease numbers and weight by removal of brush cover and undercut bank. Lewis (1969) found that amount of cover present was important in determining the number of trout 7 inches and longer in sections of a Montana stream. Brook trout (*Salvelinus fontinalis*) microhabitats were spatially correlated with cover (Wickham, 1967). Saunders and Smith (1962) reported larger trout were generally found near overhead cover.

Other physical factors have been considered important to stream trout. Larger brown trout (*Salmo trutta*) were more common in deeper stream sections (Schuck, 1943). Lewis (1969) observed that number of trout per unit of stream pool surface area increased significantly as current velocity became greater. By increasing mean water depth and overhanging bank cover, Hunt (1969) increased standing crop, production and yield of brook trout in a Wisconsin stream. Water depth was positively correlated with distribution of age I steelhead (*Salmo gairdneri*) (Everest, 1969).

The general objective of my study was to identify and define physical factors that limit trout density in a small stream. Few investigators have taken this approach. Much work has been done in describing the effect of single environmental variables on stream trout, but Lewis (1969) appears to be the only investigator who has studied, by multiple regression and correlation analysis, the simultaneous effect of several environmental variables on stream trout populations.

My project was done in two phases. The objectives of the first phase were to evaluate the relationship in stream sections of mean depth, mean velocity, velocity distributions, and cover to standing crop of trout larger than 18 cm total length. In phase two an attempt was made, using experimental cover devices, to define the physical variables that determine acceptability of fright cover to trout.

Laboratory experiments concerning use of cover by salmonids have generally been made without frightening the fish. An exception is the work of Male (1966). He found that the fright response of wild juvenile landlocked salmon (*Salmo salar*) toward artificial overhead cover did not vary with two room-light intensities nor with two depth-velocity levels. Butler and Hawthorne (1968) reported that the order of use of plywood cover in a stream tank was brown trout > brook trout > rainbow trout. Covers 3 ft x 3 ft in size were heavily used, while covers 1 ft x 1 ft were only very lightly used. Brook trout in aquaria remained under artificial cover except at low room-light intensities (Gibson and

Keenleyside, 1966). McCrimmon and Kwain (1966) found similar results in a stream tank with rainbow trout, except that yearling trout had a much greater tendency to remain under cover than did fingerlings. It may be that cover use by trout is composed of two behavioral patterns: a fright reaction and a more complex light reaction. No author seems to have any evidence for a thigmotactic response toward cover, although its existence has been proposed.

STUDY AREA DESCRIPTION

Virginia Dale Creek, a small stream in north central Colorado, (T12N,R71W) was chosen as the study area because of: (1) its small size (modal flows less than 0.25 m^3/sec) allowed efficient electrofishing; (2) minimal flow fluctuations; (3) known self-sustaining trout populations; (4) no stocking; (5) very light fishing pressure in the vicinity of the study area.

The study portion of the creek was 1.6 km long and near the Wyoming-Colorado border. Elevation is approximately 2200 m. The study area is surrounded by low partially wooded hills. Mean January and July temperatures approximate -8 C and 18 C respectively. Winter snowfall is generally light, but can be considerable at times. Mean annual precipitation is probably between 40 and 50 cm.

The only fish present are rainbow and brook trouts, and the long-nose sucker (*Catostomus catostomus*).

Portions of the stream banks are trampled and vegetation denuded because of cattle grazing.

METHODS - PHASE I

General procedure consisted of a detailed survey of the 1.6 km study area. This distance was divided into 68 sections, of which 41 were selected as study sections by consideration of sample size needed and suitable range of values for each of the variables. The fish populations were censused by electrofishing in these 41 sections. Data were analyzed by multiple regression and correlation. The weight of fish in sections was the dependent variable; means or totals of physical factors were used as independent variables.

Stream Survey Methods

The stream was surveyed during the late summer and fall, 1967. Transects were made at 3 m distances along the creek. At each of these transects width, depths, and velocities were measured. Mean depth at each transect was approximated by the method of Lagler (1956). Water depth was measured halfway between one shore and the middle of the stream, at the middle, and midway between the middle and the opposite bank. The depth measurements were summed for each transect and divided by four to allow for zero depth at each bank.

Water velocities were measured with an Ott C 1 current meter using an F 10 revolution counter. Where water depth allowed, a surface, bottom, and mid-depth velocity measurement was made at each point that a depth measurement was made. The three measurement technique was used to obtain information on velocity distributions as well as means. For calculation of mean velocity at a transect, the sum of the velocities was divided by one more than the number of measurements made. The velocity measurements were always made with the propeller pointing directly into the direction of flow whether this flow was directed downstream, or at some angle to downstream. This procedure was considered biologically sound, because fish and other organisms are subjected to the sort of velocity measured and not only to the downstream component of the velocity vector.

All possible physical situations that might provide overhead protection (fright cover) were located and the surface area calculated as if they were flat. These physical situations included overhanging rocks in the water providing an under side accessible to fish, brush and branch piles in the stream, undercut banks, semi-terrestrial grasses and other plants growing along the shore, and water at least 30 cm deep and having enough turbulence to prevent visibility of the creek bottom. In addition, amount of tree branches between the water surface and two meters above the water surface (a measure of degree of shading) was measured and located. For brush and branch piles in the creek a subjective measure of density was made and termed density-within-perimeter (DWP). This was recorded in percentage. For example a 50% DWP rating for a brush pile indicated that it was estimated to be half open space and half solid.

Independent variables chosen after the field survey and calculated for each section, with code names for further reference in parentheses, were:

1. Mean depth (mean depth)
2. Mean velocity (mean velocity)
3. Percentage of velocity measurements greater than 60 cm per second (vel. > 60)

4. Percentage of velocity measurements between 10 and 25 cm per second (vel. 10-25)
5. Mean velocity for the area of stream 30 m immediately upstream from each section (velups)
6. Rock cover less than 0.10 m^2 in size (rock < 0.10)
7. Rock cover 0.10-0.30 m^2 in size (rock 0.10-0.30)
8. Rock cover greater than 0.30 m^2 in size (rock > 0.30)
9. Brush and branches in water with greater than 70% DWP (brush > 7)
10. Brush and branches in water with 50-69% DWP (brush 5-7)
11. Brush and branches in water with less than 50% DWP (brush < 5)
12. Vertical surface of tree branches less than 2 m above water surface (branches)
13. Undercut bank (undctbnk)
14. Semi-terrestrial grass and weeds in the water (grs + wds)
15. Water over 30 cm deep and having sufficient surface turbulence to prevent visibility of the stream bottom (dptbwt)

For further reference variables 6-15 are collectively termed cover variables.

Rationale for each of the independent variables follows. Schuck (1943) found that larger brown trout were more common in deeper water. Intuitively, in small streams, deeper water areas would seem important to catchable size trout. Water velocity is a factor to which stream trout are constantly subjected. Lewis (1969) found that mean water velocity in stream sections accounted for a considerable portion of the variability in numbers of rainbow and brown trouts longer than 7 inches. The variable, vel. 10-25, was arrived at by consideration of the velocity characteristics of brook trout microhabitat as described by Wickham (1967) and Baldes and Vincent (1969).

Drift rate and drift production of benthic invertebrates seems to be related to water velocity. Waters (1962) found high production of a mayfly (*Baetes vagans*) across riffles and negative production in pools (indicating consumption). Invertebrate drift reaching a point in a stream seems to come from a considerable, but unknown, distance upstream (Waters, 1965). Waters (1969) discussed drifting organisms as constituting a major portion of the stream trout diet. Mason and Chapman (1965) have found higher standing crop of fish in stream sections having higher incoming drift. In light of the preceeding information the variables, vel. > 60 and velups were chosen. The value 60 cm/sec was commonly exceeded in riffles. The value 30 m was chosen arbitrarily because of the lack of knowledge concerning the distance upstream from which drift at a given point in a stream originates.

Size limits for the three rock cover variables were arbitrarily chosen to find an approximate minimum size acceptable to trout. Boussu (1954) demonstrated the importance of undercut bank and in-water brush piles. A greater density-within-perimeter (DWP) for in-water brush and branch cover would give less light and presumably greater suitability as fright cover. The DWP class limits were chosen to determine if this rating was associated with trout density. Chapman and Bjornn (1969) and Everest (1969) suggested that water turbulence may serve as fright cover. Tree branches within 2 m of the stream surface is a measure of degree of shading. Semi-terrestrial grass and weeds in the water along the banks might also serve as fright cover.

Fish Censusing

Each of the 41 stream sections was censused four times, once for each section during the months of June, July, August, and September, 1968. The upper and lower end of each section was blocked off with a net. Electrofishing was done with a 120 volt gasoline generator using a variable voltage pulsator. Fish were placed in a holding box as they were captured. Successive electrofishing trips were made through each section until a trip was made which captured no fish. Generally at least three trips were required. Fish were returned to the section after being weighed to the nearest gram and measured for total length (caudal compressed) to the nearest cm.

Whitney and Bailey (1959), Saunders and Smith (1954), and Miller (1966) have shown that over 90% of the fish greater than 6 inches, 3 inches, and 90 mm, respectively, could be captured in small streams using direct current electrofishing with blocking nets. No data in my study were collected on efficiency of electrofishing, but it was assumed that the electrofishing was nearly 100% effective for fish of 18 cm and larger.

Results - Phase I

Preliminary Observations

Values for the physical variables are shown in Table 1. Sections are not numbered consecutively because only 41 of the 68 original sections were chosen for electrofishing.

Results of the electrofishing censusing are shown in Table 2 (brook trout) and Table 3 (rainbow trout). Brook trout of 20-25 cm

TABLE 1. Means or totals of physical variables for the 41 study sections.

Section	Length (m)	Mean depth (cm)	Mean velocity (cm/sec)	Percentage velocity readings >60 cm/sec	Percentage velocity readings 10-25 cm/sec	Mean velocity for 30 m upstream cm/sec
1	26.5	12.2	26.1	10.9	31.3	13.9
2	17.4	8.0	28.9	9.7	12.9	26.8
3	20.7	15.5	18.8	7.7	32.7	23.9
4	18.0	10.2	20.3	0.0	35.0	21.1
5	27.1	16.1	15.0	0.0	32.3	15.6
7	21.3	13.8	15.4	0.0	22.2	12.5
9	21.3	14.3	19.6	3.8	15.1	34.9
11	24.7	10.8	27.7	10.9	14.6	16.4
12	22.6	9.8	28.0	17.9	19.6	26.7
13	20.1	12.3	16.0	3.9	31.4	28.0
14	31.1	12.7	20.1	3.7	25.6	18.1
17	21.3	19.1	12.9	0.0	20.7	16.9
18	30.5	14.7	7.8	0.0	27.7	14.6
19	25.6	18.6	6.4	0.0	27.4	7.8
20	20.1	9.8	31.6	12.5	20.8	6.3
21	19.8	16.0	12.6	6.9	6.9	22.9
22	29.0	21.3	6.2	0.0	17.1	20.7
23	22.9	13.3	21.2	8.2	25.0	6.2
24	16.8	7.3	18.3	2.7	21.6	18.2
26	24.4	15.7	14.1	1.5	24.6	28.3
27	29.0	13.0	19.9	3.9	26.0	14.7
28	24.4	24.6	4.8	0.0	9.7	19.9
29	15.2	9.3	20.6	9.7	25.8	6.4
30	31.4	18.4	12.0	0.0	25.9	11.9
32	18.3	11.9	16.7	4.9	29.3	12.7
34	27.4	15.5	14.5	1.6	18.8	13.9
36	27.1	12.1	18.2	3.3	23.3	10.8
38	21.9	14.1	10.4	0.0	14.1	14.3
39	23.5	14.5	14.1	1.7	36.7	10.4
41	18.3	19.6	6.1	0.0	23.1	12.5
42	15.8	12.7	20.9	2.8	25.0	6.3
43	23.8	17.6	5.7	0.0	20.6	12.6
44	21.3	12.4	12.4	0.0	34.0	18.5
45	19.5	11.8	15.8	0.0	30.0	21.2
46	29.3	9.7	20.5	5.7	20.0	20.5
47	24.4	12.1	23.3	1.7	20.3	17.6
53	24.4	13.7	15.2	4.4	29.0	26.9
54	18.3	7.8	35.6	19.4	5.6	10.3
56	24.1	13.0	14.3	1.7	32.2	24.4
58	24.4	8.0	23.9	9.8	29.4	22.6
62	25.9	16.9	9.1	1.4	30.1	13.6

TABLE 1. (Continued)

Section	Rock Cover: <0.10 m2 in size (m^2)	Rock Cover: 0.10-0.30 m^2 in size (m^2)	Rock Cover: >0.30 m2 in size (m^2)	Brush and Branches in water: >70% DWP (m^2)	Brush and Branches in water: 50-69% DWP (m^2)	Brush and Branches in water: <50% DWP (m^2)
1	0.43	0.54	1.15	1.72	0.56	0.00
2	0.22	0.66	1.52	9.29	0.00	0.00
3	0.00	1.18	2.50	0.00	0.00	0.00
4	0.43	1.38	1.49	0.31	0.00	0.00
5	0.35	0.56	0.00	8.54	2.14	0.00
7	0.26	1.01	0.55	0.00	0.00	0.93
9	0.51	0.56	2.23	0.00	2.14	0.93
11	0.22	0.26	0.37	3.16	0.65	4.46
12	0.36	1.02	0.31	0.83	3.16	0.00
13	0.27	0.85	0.37	3.34	0.00	9.75
14	0.46	0.58	0.28	6.50	0.74	0.00
17	0.00	0.00	0.00	0.00	6.04	0.00
18	0.06	0.00	0.00	0.00	8.36	5.95
19	0.14	0.74	0.00	0.00	0.00	0.00
20	0.79	0.69	0.74	6.41	0.74	3.90
21	0.14	1.49	4.89	0.28	2.04	0.19
22	0.22	0.41	1.98	0.00	4.37	4.55
23	0.66	1.48	0.70	4.92	0.00	2.14
24	0.35	0.29	0.00	0.00	0.00	3.07
26	0.27	0.71	0.46	0.00	5.30	0.37
27	0.22	0.53	0.00	7.80	1.30	0.37
28	0.08	0.51	0.00	4.46	7.90	0.65
29	0.30	0.55	1.21	0.00	0.00	5.02
30	0.47	0.99	2.29	2.13	3.72	1.67
32	0.05	0.00	0.00	2.97	0.00	2.32
34	0.11	0.67	0.28	13.38	0.00	0.37
36	0.52	0.23	0.00	9.29	0.00	2.04
38	0.11	0.62	0.00	1.76	2.32	9.38
39	0.23	0.55	0.68	0.00	1.02	1.39
41	0.05	0.00	0.00	0.46	2.23	2.60
42	0.58	0.63	0.00	0.21	1.30	0.84
43	0.00	0.51	0.00	15.14	6.69	14.96
44	0.06	0.09	0.00	2.14	0.00	5.01
45	0.52	0.73	0.37	2.79	0.00	7.99
46	0.74	0 84	1.32	0.00	1.77	0.93
47	0.20	0.31	0.00	0.54	0.00	1.30
53	0.03	0.12	0.00	0.18	2.51	0.09
54	0.00	0.00	0.00	0.00	0.37	0.46
56	0.27	0.25	0.27	0.93	4.09	1.11
58	0.27	0.09	0.00	1.67	1.11	0.00
62	0.00	0.27	0.00	1.30	0.00	0.00

TABLE 1. (Continued)

Section	Tree branches within 2 m of water (m^2)	Undercut bank (m^2)	Grass and weeds in water (m^2)	Deep turbulent water (m^2)
1	14.8	0.12	0.00	0.37
2	5.0	0.00	0.00	1.30
3	29.5	1.58	0.00	1.25
4	3.6	1.50	0.00	1.49
5	19.5	2.97	4.83	1.11
7	6.4	0.46	0.56	0.98
9	18.7	1.20	16.54	1.49
11	36.9	0.00	1.95	6.13
12	15.2	0.46	0.00	2.23
13	13.2	0.05	0.00	4.65
14	20.2	0.11	2.69	3.53
17	9.0	0.93	13.75	0.00
18	4.5	3.25	18.02	0.00
19	2.2	0.14	42.73	0.00
20	32.9	1.49	0.00	0.37
21	6.9	0.28	0.00	1.40
22	22.0	2.51	0.00	0.00
23	23.6	0.09	0.00	1.40
24	16.1	0.00	0.00	0.23
26	9.2	0.33	0.00	0.00
27	20.6	0.46	0.00	1.86
28	27.8	0.37	0.00	0.00
29	0.6	0.00	0.00	0.00
30	32.7	0.19	0.00	1.95
32	28.6	0.00	7.62	0.00
34	32.1	0.19	2.32	0.00
36	23.8	0.37	0.00	0.00
38	40.2	0.00	0.00	0.00
39	16.4	0.00	3.34	0.00
41	33.4	1.11	0.28	0.00
42	15.3	1.39	0.00	0.37
43	63.2	1.77	0.00	0.00
44	24.4	0.84	0.00	0.00
45	20.3	0.00	1.86	1.95
46	34.7	0.00	1.39	0.00
47	9.8	0.27	0.00	0.00
53	66.1	0.00	0.00	0.00
54	17.2	0.18	0.00	0.00
56	29.0	0.00	0.00	0.74
58	22.1	0.00	0.00	0.00
62	0.0	1.30	20.90	0.00

TABLE 2. Weight in grams of brook trout greater than 18 cm, by months and sections.

Section	June	July	Aug.	Sept.	Mean	Section length (m)	Mean weight/m of section length
1	546	854	846	1112	839	26.5	31.7
2	190	254	144	335	230	17.4	13.3
3	263	360	316	528	366	20.7	17.6
4	349	459	258	368	358	18.0	19.9
5	749	805	642	537	683	27.1	25.2
7	732	994	826	459	752	21.3	35.2
9	643	1029	863	643	794	21.3	37.2
11	550	687	856	554	661	24.7	26.8
12	743	561	464	419	546	22.6	24.2
13	117	500	851	827	573	20.1	28.5
14	699	690	580	486	613	31.1	19.7
17	271	424	291	301	321	21.3	15.1
18	851	1038	531	564	746	30.5	24.5
19	587	474	451	572	521	25.6	20.3
20	561	551	463	528	525	20.1	26.1
21	383	755	988	1120	811	19.8	40.9
22	874	866	904	497	785	29.0	27.1
23	317	404	580	538	459	22.9	20.1
24	68	134	136	243	145	16.8	8.7
26	838	526	529	545	609	24.4	25.0
27	328	424	566	751	517	29.0	17.8
28	728	884	1067	893	893	24.4	36.6
29	123	61	65	76	81	15.2	5.3
30	687	810	732	513	685	31.4	21.8
32	135	496	232	53	229	18.3	12.5
34	349	107	268	306	257	27.4	9.4
36	0	0	377	251	157	27.1	5.8
38	200	453	350	301	326	21.9	14.9
39	411	757	766	803	684	23.5	29.1
41	496	1036	855	604	747	18.3	40.8
42	497	653	726	1010	721	15.8	45.5
43	833	1369	710	644	889	23.8	37.4
44	578	636	471	185	467	21.3	21.9
45	606	906	794	846	788	19.5	40.4
46	474	810	407	253	486	29.3	16.6
47	192	171	364	267	248	24.4	10.2
53	565	575	525	541	551	24.4	22.6
54	0	99	169	0	67	18.3	3.7
56	471	429	331	113	336	24.1	13.9
58	584	902	712	488	671	24.4	27.5
62	1026	520	629	903	769	25.9	29.7

TABLE 3. Weight in grams of rainbow trout greater than 18 cm, by months and sections.

Section	June	July	Aug.	Sept.	Mean	Section length (m)	Mean weight/m of section length
1	1246	956	796	516	879	26.5	33.2
2	493	344	354	167	339	17.4	19.5
3	1184	1291	1466	1065	1251	20.7	60.3
4	650	118	330	350	362	18.0	20.1
5	922	699	873	791	821	27.1	30.2
7	277	543	490	367	419	21.3	19.6
9	900	940	1037	908	946	21.3	44.3
11	376	527	240	229	343	24.7	13.9
12	253	344	408	239	311	22.6	13.8
13	381	987	240	413	505	20.1	25.1
14	484	456	597	465	500	31.1	16.1
17	313	380	416	163	318	21.3	14.9
18	367	684	627	184	465	30.5	15.3
19	510	335	313	616	443	25.6	17.3
20	834	348	467	192	460	20.1	22.9
21	868	401	643	561	618	19.8	31.2
22	1123	953	783	469	832	29.0	28.7
23	559	768	576	859	690	22.9	30.2
24	367	336	125	0	207	16.8	12.3
26	574	484	294	805	539	24.4	22.1
27	1056	877	1228	709	967	29.0	33.4
28	1370	1984	1222	1821	1599	24.4	65.6
29	167	547	478	379	392	15.2	25.7
30	2388	1789	2183	644	1751	31.4	55.8
32	216	0	97	111	106	18.3	5.8
34	685	739	653	654	682	27.4	24.9
36	0	786	442	534	440	27.1	16.2
38	0	593	285	315	298	21.9	13.6
39	793	501	483	481	564	23.5	24.0
41	434	436	607	291	442	18.3	24.2
42	685	412	279	275	412	15.8	26.0
43	933	510	354	292	522	23.8	21.9
44	130	473	235	202	260	21.3	12.2
45	842	764	910	692	802	19.5	41.1
46	556	1150	1260	585	887	29.3	30.3
47	687	791	713	448	659	24.4	27.0
53	853	917	785	790	836	24.4	34.3
54	203	0	0	0	51	18.3	2.8
56	639	481	718	378	554	24.1	23.0
58	629	366	563	231	447	24.4	18.3
62	943	965	904	316	782	25.9	30.2

(100-150 g) and rainbow trout of 20-30 cm (100-200 g) were common. Maximum length of trouts was 32 cm, of longnose suckers, 36 cm.

Weight of both species varied considerably from month to month (Tables 2 and 3). The hypothesis that variability within sections was as great as that among sections was tested and rejected (Table 4). The conclusion was that the effect of sections on density of fish was real.

Table 5 shows all possible values of r (the correlation coefficient) for the previously described 17 variables. The lower diagonals are omitted to avoid duplication. Although the multiple correlations are of greater interest, some of the simple correlations in Table 5 should be examined. Significant (5% level of probability) positive correlations are brook trout with mean depth, brush 5-7, undctbnk, and negatively with mean velocity. Simple positive correlations for rainbow trout are with mean depth and rock > 0.30.

These simple correlations, while informative, are not as important as the multiple case. The desired information is the simultaneous relationship of the several physical variables to trout density. The most desirable method of determining this relation requires previous knowledge concerning the relative importance of the physical variables to trout density. Were this knowledge available, an equation of the form:

$$\hat{Y} = B_o + B_1X_1 + B_2X_2 + \cdots B_nX_n \quad (1)$$

would be written where B is an empirically derived least-square constant, $\hat{Y}$ the predicted trout density, and X_1, $X_2 \ldots X_n$ the physical variables in order of their importance in determining trout density. The data would then be fitted to equation (1).

TABLE 4. One-way analysis of variance for effect of stream sections on weight of brook and rainbow trouts captured in sections.

Source of variation	Sum of squares	Degrees of freedom	Mean square	F ratio	Conclusion
		Brook trout			
Among sections	8.8987	40	0.2225	7.2636	Since F of 1.8709 is required for significance at the 0.005 level, effect of sections is highly significant
Within sections	3.7672	123	0.0306		
Total	12.6659	163			
		Rainbow trout			
Among sections	19.8017	40	0.4950	9.0803	Since F of 1.8907 is required for significance at the 0.005 level, effect of sections is highly significant
Within sections	6.7058	123	0.0545		
Total	26.5075	163			

TABLE 5. Correlation matrix of r values for the 2 dependent (brook and rainbow trouts) and the original 15 independent variables chosen, based on the 41 study sections (n=41).

	Weight of brook trout >18 cm	Weight of rainbow trout >18 cm	Mean depth	Mean velocity	Vel. >60	Vel. 10-25	Velups
Weight of brook trout >18 cm	1.00	0.369*	0.408*	-0.326*	-0.232	0.025	0.126
Weight of rainbow trout >18 cm		1.00	0.490*	-0.260	-0.208	0.041	0.220
Mean depth			1.00	-0.808*	-0.604*	-0.070	-0.049
Mean velocity				1.00	0.828*	-0.162	0.016
Vel. >60					1.00	-0.315	0.013
Vel. 10-25						1.00	-0.066
Velups							1.00
Rock <0.10							
Rock 0.10-0.30							
Rock >0.30							
Brush >7							
Brush 5-7							
Brush <5							
Branches							
Undctbnk							
Grs + wds							
dptbwt							

* Indicates a correlation significantly greater than zero, at the 5% level

TABLE 5. (Continued)

	Rock <0.10	Rock 0.10-0.30	Rock >0.30	Brush >7	Brush 5-7	Brush <5	Branches	Undctbnk	Grs + wds	dptbwt
Weight of brook trout >18 cm	0.134	0.214	0.176	-0.075	0.323*	0.166	0.095	0.361*	0.025	0.188
Weight of rainbow trout >18 cm	0.066	0.303	0.359*	-0.029	0.201	-0.124	0.097	0.085	-0.093	0.051
Mean depth	-0.441*	-0.093	0.015	-0.037	0.608*	-0.011	0.068	0.300	0.295	-0.223
Mean velocity	0.451*	0.134	0.072	0.093	-0.513*	-0.241	-0.073	-0.243	-0.317	0.298
Vel. >60	0.196	0.110	0.179	-0.018	-0.290	-0.192	0.019	-0.270	-0.236	0.226
Vel. 10-25	0.081	-0.021	-0.245	-0.144	-0.243	0.165	-0.120	0.285	0.083	-0.016
Velups	-0.125	0.094	-0.296	-0.162	0.170	-0.192	0.024	-0.157	-0.087	0.325*
Rock <0.10	1.00	0.456*	0.140	0.050	-0.331*	0.003	-0.108	0.011	-0.203	0.209
Rock 0.10-0.30		1.00	0.651*	-0.004	-0.253	-0.019	-0.231	0.034	-0.182	0.363*
Rock >0.30			1.00	-0.173	-0.104	-0.129	-0.219	0.052	-0.114	0.203
Brush >7				1.00	-0.044	0.159	0.290	-0.031	-0.207	0.070
Brush 5-7					1.00	0.043	0.169	0.268	0.080	-0.255
Brush <5						1.00	0.194	0.264	-0.176	0.089
Branches							1.00	-0.114	-0.303	-0.047
Undctbnk								1.00	0.073	-0.188
Grs + wds									1.00	-0.136
dptbwt										1.00

* Indicates a correlation significantly greater than zero at the 5% level

Because the order of importance, or even whether or not they had any importance, of the physical variables was unknown and was one of the goals of the study, a stepwise multiple regression computer program was used in the data analysis. This program designates X_1, $X_2 \ldots X_n$ on the basis of variability in the dependent variable removed. In other words, X_1 is the variable in the correlation matrix (Table 5) that removes the largest portion of the dependent variable sum of squares (is best correlated with the dependent variable). After the first step, in which X_1 is designated, the correlation matrix no longer is relevant to the question of which independent variable becomes X_2. The variable designated X_2 is the variable which by its inclusion removes the largest portion of the remaining unaccounted for variability in the dependent variable. This is continued through X_n. An independent variable with a very low correlation with the dependent variable in the original correlation matrix, may be entered as X_2, because X_2 can become highly correlated with the dependent variable after consideration of X_1.

Stepwise Regression Analysis

The results of several regression analyses suggest that mean depth is the variable of first importance to both brook and rainbow trouts. Of somewhat secondary importance are the three rock cover variables. There is some evidence that undctbnk and dptbwt are important to brook trout density. Other variables were not of any statistical significance to density of either species.

Table 6 gives results of step-wise regression using all of the 15 independent variables. Only the variables mean depth and rock < 0.10,

TABLE 6. Results of stepwise regression using the 15 independent variables. Only independent variables entering the regression with an F of 1.0000 or larger are shown.

Step No.	Independent variable entered	Multiple R^2	Increase in R^2	F to enter	Sign of the correlation
			Brook trout		
1	Mean depth	0.1666	0.1666	7.7966*	+
2	Rock < 0.10	0.2892	0.1226	6.5541*	+
3	Dptbwt	0.3488	0.0596	3.3857	+
4	Undctbnk	0.4039	0.0551	3.3287	+
5	Velups	0.4257	0.0218	1.3267	+
6	Branches	0.4439	0.0182	1.1142	+
			Rainbow trout		
1	Mean depth	0.2397	0.2397	12.2973*	+
2	Rock > 0.30	0.3635	0.1237	7.3867*	+
3	Rock < 0.10	0.4315	0.0680	4.4263*	+
4	Velups	0.4761	0.0446	3.0678	+
5	Grs + wds	0.5076	0.0315	2.2367	-
6	Brush 5-7	0.5310	0.0234	1.6945	-
7	Mean velocity	0.5481	0.0171	1.2498	+
8	Vel. 10-25	0.5787	0.0307	2.3286	+
9	Undctbnk	0.6051	0.0264	2.0721	-

* Indicates significance at the 5% level of confidence

in that order, accounted for a significant portion of the variability in mean weight of brook trout in sections. Mean depth, rock > 0.30, and rock < 0.10 are the corresponding variables for rainbow trout. The partial correlations for all of these variables are positive. Negative significant correlations, while statistically allowable, would be biologically meaningless, because all of the independent variables chosen were hypothesized to have a positive effect on trout density. Values for partial regression coefficients are not shown as these values change at each step and depend on which and how many independent variables are included in the regression.

The remainder of the data analysis consists of grouping various combinations of cover variables to form a single variable. This was done under the hypothesis that one type of cover might substitute functionally for the lack of another type of cover. For example, if we assumed that both brush cover and rock cover were important, that one could substitute functionally for the other, and that many sections had considerable amounts of the one type of cover and very little of the other, neither cover variable would show a significant correlation with weight of trout. However, by combining the two variables in a way that gave both equal weight in a new variable, the combined variable would be expected to show a significant correlation.

In all cases of combining cover variables, these were combined in a manner that gave each component variable equal weight in the new combined variable. This was done by converting the value for each cover variable in each section to a rating between zero and 100. Sections lacking a given type of cover were given a rating of zero for that variable. The section having the highest value was assigned a rating of 100 for that particular cover variable. Intermediate rating values for each section and for each cover variable were assigned in the following manner:

$$\frac{X_1}{H} = \frac{X_2}{100} \qquad (2)$$

where X_1 is the value of a cover variable for a given section, H is the highest value for that variable in any of the sections, and X_2 is the value to be solved for (the rating). Solving for X_2 we have:

$$X_2 = (100)\,\frac{X_1}{H} \qquad (3)$$

This method makes all ratings for all variables and sections directly proportional to the absolute amount of that cover variable present in each section.

After ratings were assigned, if it were desired to test the effect of a particular combination of variables, it was only necessary to sum the appropriate ratings, thereby generating values for a new combined variable.

The first combined variable generated was a combination of the 10 cover variables (cover 10). Table 7 gives results of a step-wise regression using cover 10 and the original five non-cover variables. For brook trout cover 10 entered the regression first (with a significant F), indicating the importance of at least a few of the cover components of cover 10. Mean depth entered second with a significant F. This variable had been of first importance to brook trout when cover 10 was not available for inclusion. No other variable entered with a significant F. Cover 10 was non-significant with respect to rainbow trout, indicating that most of the components of cover 10 were unimportant to rainbow trout.

TABLE 7. Results of stepwise regression with the 10 cover variables (coded cover 10) grouped to form a single independent variable. The other 5 independent variables are unchanged. Only independent variables entering the regression with an F of 1.0000 or larger are shown.

Step No.	Independent variable entered	Multiple R^2	Increase in R^2	F to enter	Sign of the correlation
			Brook trout		
1	Cover 10	0.2662	0.2662	14.1484*	+
2	Mean depth	0.3669	0.1007	6.0466*	+
3	Velups	0.3858	0.0188	1.3344	+
			Rainbow trout		
1	Mean depth	0.2369	0.2369	12.1051*	+
2	Velups	0.2976	0.0607	3.2835	+
3	Mean velocity	0.3586	0.0611	3.5239	+
4	Vel. 10-25	0.3989	0.0403	2.4135	+
5	Cover 10	0.4308	0.0318	1.9577	+

* Indicates significance at the 5% level of confidence

Since cover 10 was important to brook trout but not rainbow trout, the pertinent questions are: (1) what components can be taken out of cover 10 to improve the combined cover variables relation to brook trout? (2) with respect to rainbow trout, what components of cover 10 beside rock > 0.30 and rock < 0.10 (Table 6) are important?

Table 8 shows results of an attempt to answer these questions. Ratings for branches and grs + wds were taken out of the cover 10 variable to form the new variable, cover 8 (a combination of the remaining 8 cover variables). With this adjustment made, for brook trout cover 8 enters with a significant F, but does not account for as much variability as cover 10 (Table 7). However, mean depth is the second variable entered in Table 8, and the two variables cover 8 and mean depth together account for nearly as much variability as cover 10 and mean depth (Table 7). It seems cover 8 is an improvement over cover 10, with respect to brook trout, as it accounts for nearly as much variability with mean depth as cover 10 with mean depth, but with two fewer components.

Cover 8 is still of no relevance to rainbow trout (Table 8).

Table 9 gives results of another regression in which a new cover variable (cover 6), made up of the original variables rock 0.10-0.30, rock > 0.30, brush 5-7, brush > 7, undctbnk, and dptbwt is used. Cover 6 differs from cover 8 in that it lacks components for rock < 0.10 and brush < 5. For brook trout cover 6 enters first, with a significant F, and accounts for about the same amount of variability as did cover 8 (Table 8). However, mean depth accounts for less variability after cover 6 than it did after cover 8.

TABLE 8. Results of stepwise regression with 8 of the 10 cover variable ratings (coded cover 8) summed to form one variable. The cover variables branches and grs + wds were left as separate variables, as were the original 5 non-cover independent variables. Only variables entering the regression equation with an F of 1.0000 are shown.

Step No.	Independent variable entered	Multiple R^2	Increase in R^2	F to enter	Sign of the correlation
		Brook trout			
1	Cover 8	0.2076	0.2076	10.2191*	+
2	Mean depth	0.3527	0.1451	8.5157*	+
3	Velups	0.4069	0.0542	3.3821	+
		Rainbow trout			
1	Mean depth	0.2386	0.2386	12.2188*	+
2	Grs + wds	0.3005	0.0619	3.3629	-
3	Mean velocity	0.3412	0.0407	2.2867	+
4	Vel. 10-25	0.3760	0.0348	2.0086	+
5	Cover 8	0.4014	0.0254	1.4861	+

* Indicates significance at the 5% level

TABLE 9. Results of stepwise regression with the 6 variables, rock 0.10-0.30, rock >0.30, brush >7, brush 5-7, undctbnk, and dptbwt combined to form a single variable (coded cover 6). Other independent variables are unchanged. Only variables entering the regression with an F of 1.0000 are shown.

Step No.	Independent variable entered	Multiple R^2	Increase in R^2	F to enter	Sign of the correlation
			Brook trout		
1	Cover 6	0.2080	0.2080	10.2428*	+
2	Mean depth	0.2998	0.0918	4.9835*	+
3	Rock <0.10	0.3578	0.0579	3.3375	+
4	Velups	0.3762	0.0185	1.0654	+
5	Brush <5	0.4034	0.0272	1.5956	+
			Rainbow trout		
1	Mean depth	0.2386	0.2386	12.2188*	+
2	Rock < 0.10	0.3377	0.0991	5.5687*	+
3	Velups	0.4286	0.0909	5.8856*	+
4	Grs + wds	0.4671	0.0385	2.6014	-
5	Mean velocity	0.4929	0.0258	1.7794	+
6	Vel. 10-25	0.5221	0.0292	2.0808	

* Indicates significance at the 5% level

As we go from Tables 7 to 8 and to 9, and at the same time take cover components out of the combined cover variable by going from cover 10 to cover 8 and cover 6, the predictive power (R^2 value) for the combined cover variable, with respect to brook trout, remains about the same. In other words, the variables, branches, grs + wds, and brush < 5 seem to be non-significant for brook trout.

Table 9, for rainbow trout, still shows no importance of cover 6. Little importance can be assigned to the significant entry of velups in Table 9, because it would not enter as a significant variable if rock > 0.30 were available (Table 6).

Two new combined variables are used in the next regression. Results are shown in Table 10. These new variables are: (1) 3 brush + brnch (contains the original three brush cover variables and branches): (2) 3 rock + undct + dptbwt (the original three rock cover variables plus undctbnk and dptbwt). In addition two new uncombined variables, calculated by examination of the stream survey data are used in this regression. These are: brush $< 50,30$ and brush $> 50,30$ (amount of brush-in-water in each section having a water depth of 30 cm underneath and less than 50% DWP or greater than 50% DWP, respectively).

The original brush variables had not shown any importance to either species in previous regressions. It was thought that much bank shade might compensate for brush in water, thus the combination of the brush and branch variables. Although undctbnk and dptbwt had not shown any individual importance, it was thought these two might function in the same capacity as rock cover. Brush $< 50,30$ and brush $> 50,30$ were formed under the hypothesis that brush cover might be important only when associated with some minimum water depth.

TABLE 10. Results of stepwise regression using all of the original 15 independent variables plus the following combined variables: the 3 brush cover variables + branches combined (3 brush + brnch); the 3 rock cover variables plus undctbnk + dptbwt (3 rock + undct + dptbwt). In addition 2 new variables are used: brush cover with less than 50% DWP and having a minimum depth of 30 cm underneath (brush < 50,30): and brush cover with greater than 50% DWP and having a depth of at least 30 cm underneath (brush > 50,30). Only variables entering the regression with an F of 1.0000 are shown.

Step No.	Independent variable entered	Multiple R^2	Increase in R^2	F to enter	Sign of the correlation
			Brook trout		
1	Mean depth	0.1659	0.1659	7.7573*	+
2	3 rock+undct+ dptbwt	0.3560	0.1901	11.2136*	+
3	Rock 0.10- 0-30	0.3941	0.0382	2.3319	-
4	Branches	0.4211	0.0270	1.6793	-
5	Brush >50,30	0.4397	0.0186	1.1593	-
6	3 brush + brnch	0.4641	0.0244	1.5500	+
			Rainbow trout		
1	Mean depth	0.2369	0.2369	12.1073*	+
2	3 rock+undct+ dptbwt	0.3636	0.1267	7.5651*	+
3	Undctbnk	0.4193	0.0557	3.5467	+
4	Grs + wds	0.4530	0.0337	2.2191	-
5	Brush <50,30	0.4848	0.0318	2.1593	-
6	Vel. 10-25	0.5083	0.0235	1.6243	+
7	Branches	0.5334	0.0251	1.7747	+
8	Rock >0.30	0.5523	0.0190	1.3575	+
9	Mean velocity	0.5768	0.0244	1.7890	
10	Rock <0.10	0.6000	0.0233	1.7426	+

* Indicates significance at the 5% level

Table 10 shows results of a regression using these new variables. For brook trout, mean depth and 3 rock + undct + dptbwt enter as significant variables in that order. The two account for 35.6% of the variability in brook trout. This regression is as successful as any of the previous regressions except for the regression in Table 7 (mean depth and cover 10). However, the small loss in R^2 of 1.1% (Table 7 to Table 10) is obtained with a reduction from 10 to 5 component variables (cover 10 vs 3 rock + undct + dptbwt). By taking five variables out of the component variable and losing only 1.1% from the multiple R^2, only unimportant variables are removed. The regression shown in Table 10 for brook trout seems the most successful to this point.

In Table 10 for the first time a combined cover variable has entered the regression with a significant F for rainbow trout. Mean depth and 3 rock + undct + dptbwt enter as significant variables in that order and account for 36% of the variability in rainbow trout among sections. Comparing Tables 6-10, Table 10 shows the most success with rainbow trout, except for Table 6. Both of these tables, however, seem to indicate an importance of rock cover variables after mean depth, for rainbow trout.

In Table 11 the combined cover variable, rock sum 3, has been reduced to components of only the three rock cover variables. Comparing Tables 10 and 11 for brook trout, this reduction in component variables results in a loss of about 10% in the multiple R^2 at the point of entrance of the last significant variable, indicating some importance for dptbwt and undctbnk. Further evidence for the importance of undctbnk and dptbwt is seen in Table 11 where these 2 variables are not

TABLE 11. Results of stepwise regression with the 3 rock cover variables (coded rock sum 3) grouped to form a single variable. Remainder of the independent variables are the original 12. Only variables entering the regression with an F of 1.0000 are shown.

Step No.	Independent variable entered	Multiple R^2	Increase in R^2	F to enter	Sign of the correlation
	Brook trout				
1	Mean depth	0.1659	0.1659	7.7573*	+
2	Rock sum 3	0.2753	0.1094	5.7382*	+
3	Undctbnk	0.3206	0.0453	2.4665	+
4	Dptbwt	0.3772	0.0566	3.2702	+
5	Branches	0.4059	0.0287	1.6915	+
	Rainbow trout				
1	Mean depth	0.2369	0.2369	12.1073*	+
2	Rock sum 3	0.4206	0.1837	12.0458*	+
3	Velups	0.4659	0.0453	3.1364	+
4	Mean velocity	0.4963	0.0304	2.1758	+
5	Vel. 10-25	0.5367	0.0404	3.0522	+
6	Branches	0.5678	0.0311	2.4439	+
7	Undctbnk	0.5890	0.0213	1.7065	-
8	Dptbwt	0.6016	0.0126	1.0092	-

* Indicates significance at the 5% level

part of the combined cover variable. Here, these two variables enter in steps three and four, although the increase in the multiple R^2 is not large enough to give significant F values.

The rainbow trout relationship in Table 11 is improved by removing the undctbnk and dptbwt components from the combined cover variable (leaving only the three rock cover components in the Table 11 combined cover variable). This lends strong evidence for the importance of rock cover after mean depth and indicates that undctbnk and dptbwt are of negligible importance to rainbow trout. Tables 6 and 9 give added evidence for the importance of rock cover after mean depth.

Table 12 shows results of reducing the combined cover variable to only two components (rock 0.10-0.30 and rock > 0.30 included and rock < 0.10 excluded). For brook trout, the 2 component cover variable (rock sum 2) is of no importance when it lacks the smallest rock cover variable. In fact rock < 0.10 gives a larger increase in R^2 after mean depth (Table 12) than does rock sum 3 (Table 11). This casts doubt on the importance of rock 0.10-0.30 and rock > 0.30 to brook trout.

For rainbow trout in Table 12, rock sum 2 entered in the second step with a significant F, but R^2 for rock sum 2 after mean depth was less than R^2 for rock sum 3 after mean depth (Table 11). In Table 12 rock < 0.10 enters in the third step, although with a non-significant F. The first three steps in Table 12 give a multiple R^2 almost equal to the R^2 value of Table 11 with only two steps. This seems to indicate some importance for rock < 0.10 to rainbow trout.

Summarizing results to this point, variables important to brook trout in order of their importance seem to be mean depth, rock < 0.10,

TABLE 12. Results of stepwise regression with the two rock cover variables (rock 0.10-0.30 and >0.30) combined to form a single variable (coded rock sum 2). Other independent variables are unchanged. Only variables entering the regression with an F of 1.0000 are shown.

Step No.	Independent variable entered	Multiple R^2	Increase in R^2	F to enter	Sign of the correlation
		Brook trout			
1	Mean depth	0.1659	0.1659	7.7573*	+
2	Rock <0.10	0.2824	0.1235	6.6046*	+
3	Dptbwt	0.3488	0.0593	3.3718	+
4	Undctbnk	0.4043	0.0556	3.3596	+
5	Velups	0.4258	0.0215	1.3078	+
6	Branches	0.4443	0.0185	1.1340	+
		Rainbow trout			
1	Mean depth	0.2369	0.2369	12.1073*	+
2	Rock sum 2	0.3847	0.1478	9.1316*	+
3	Rock < 0.10	0.4201	0.0353	2.2528	+
4	Velups	0.4736	0.0535	3.6622	+
5	Grs + wds	0.5023	0.0287	2.0202	-
6	Brush 5-7	0.5295	0.0272	1.9627	-
7	Mean velocity	0.5509	0.0214	1.5758	+
8	Vel. 10-25	0.5737	0.0228	1.7107	+
9	Undctbnk	0.5927	0.0190	1.4480	-

* Indicates significance at the 5% level

dptbwt, and undctbnk. The corresponding variables for rainbow trout are mean depth and the three rock cover variables.

In results already discussed no importance has been shown for the brush cover variables. In Tables 8-10 the multiple R^2 due to mean depth and one of the combined cover variables is not decreased by removing brush cover components from the combined cover variables.

Several other attempts were made to show some importance of the brush cover variables, but in none of them did an individual or combined cover variable even approach entry in a regression with a significant F.

The following regressions were run in attempts to show some importance of the brush cover variables: (1) a combined variable made up of the 3 brush variables (brush sum 3) was run in a regression with the other 12 original variables; (2) brush sum 3 with the nine original variables and rock sum 3; (3) brush > 7 and brush 5-7 combined in a single variable (brush sum 2) and run with the other 13 original variables; (4) brush sum 2 and rock sum 2 run with the other original 11 variables.

Regressions reported to this point have been done assuming a linear relationship between the dependent and independent variables. One regression was run with the original 15 independent variables and with a squared term for each of these same 15 variables. Some of the squared variables entered with a significant F, but there was no overall improvement in percentage of variability accounted for. It was concluded that the curvilinear regression was not a significant improvement for any of the variables.

METHODS - PHASE II

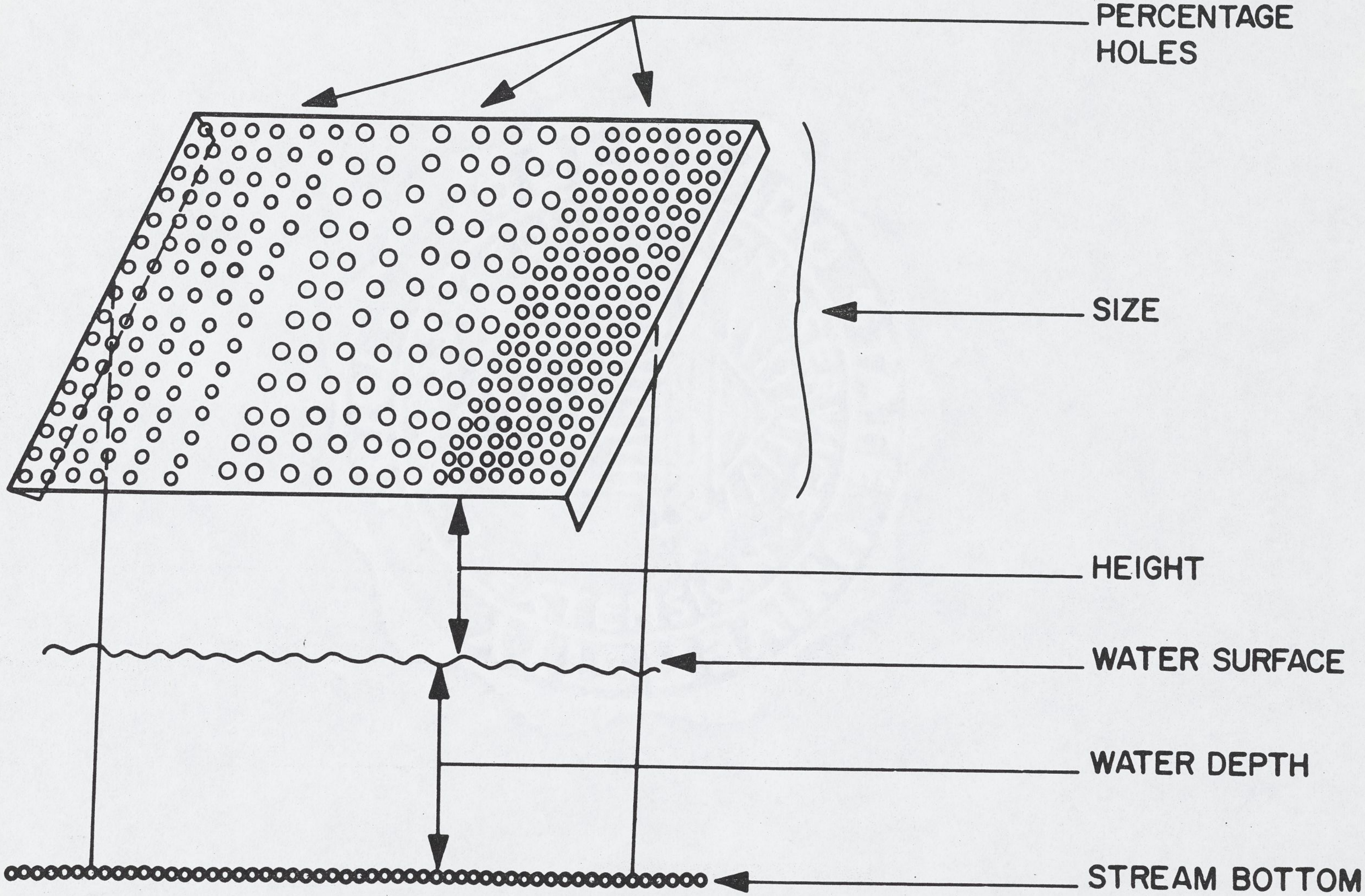
The overall procedure for this phase of the study consisted of confining rainbow trout of 20-30 cm total length in two stream sections of approximately 15 m length. Sheet metal cover devices were placed in the stream sections. Observations were made through the daylight hours of which structures the fish were under when frightened.

Variables incorporated into experimental cover structures are shown in Figure 1. Each of these variables was thought to have a possible independent effect on the acceptability of a given piece of artificial or natural cover to trout. Size is simply the surface area in square units. Height is a positive or negative distance of the structure above or below the water surface. Percentage holes is the percentage of surface area of a structure drilled out with 0.95 cm diameter circular holes. Water depth is the depth of water associated with a structure regardless of whether the structure is above or below the water surface.

These variables were chosen with very little experimental evidence concerning what variables were pertinent to use of fright cover by trout. In laboratory work with landlocked salmon parr Male (1966) found that wild parr had a strong fright reaction toward cover at both high and low room-light intensities. Neither did the fright reaction seem to vary with water depth or velocity under cover structures.

Butler and Hawthorne (1968), working with brook, brown, and rainbow trouts found significant differences due to size of structure in use of plywood cover on the water surface of a stream tank. Cover 3 ft x 3 ft in size was much used, while cover 1 ft x 1 ft was used very little.

FIGURE 1. Diagramatic representation of the four variables, size, height, percentage holes, and water depth, chosen for phase II of the study. Although three densities of holes are shown, only a single density of holes was used on a given structure.


PERCENTAGE
HOLES
SIZE
HEIGHT
WATER SURFACE
WATER DEPTH
STREAM BOTTOM

Haines and Butler (1969) working with fingerling smallmouth bass (*Micropterus dolomieui*) reported that fish use of "coverts" increased with increasing structural complexity and with addition of an area of darkness. Observations in these two studies were made with the fish undisturbed by the observers, so their applicability to studies on fright cover is questionable.

Figure 1 is a diagramatic representation of the structures used. They were constructed of 22 gauge sheet metal and painted a drab olive green. All structures had a 5 cm 90° overhang which ran the length of the longer axis on either side of the structure. Holes were drilled on a drill press. Threaded rods of 1.3 cm diameter were bolted to each end of structures and driven into the creek bottom to anchor the structures.

Two 15 m long sections of the stream were used to confine fish with experimental structures. Physical parameters for these two sections are shown in Table 13. These two sections were chosen because they virtually lacked in-water cover, had little bank vegetation, and consisted of sand and silt bottom which allowed driving of the structure anchoring rods. Both sections were nearly straight. The stream bottom was quite flat with no abrupt changes in water depth. What little potential in-water cover was present was removed before field observations were begun.

Fish were located and counted under structures by one of two methods. When there was sufficient light underneath a structure, a fish scope consisting of a 20 cm diameter metal tube with a piece of clear plastic in one end was placed underneath the downstream edge of

TABLE 13. Physical parameters of the two study sections used in phase II of the study. Upper and lower refers to relative position upstream.

Description	Length (m)	Mean depth (cm)	Maximum depth (cm)	Mean width (m)	Mean velocity (cm/sec)
Upper	14.9	10.4	35.6	3.3	15.5
Lower	14.5	10.9	38.1	3.2	17.9

a structure. Fish under the structure, if any, were counted by direct observation. The fish were then physically displaced from under the structure with a short piece of board. If light was not sufficient to use the fish scope, the fish were simply pushed out from under the structure with the board, and counted. If a fish counted under one structure went under a second structure, that fish was counted only for the first structure. Fish were left undisturbed between observations.

For all experiments, light was measured in foot-candles at the upper surface of each structure, and at the creek bottom below structures. Light measurements were made once for each experiment at mid-day with no cloud cover. A model 756 Weston illumination meter was used for this purpose. Accuracy of the measurements was ± 1 foot-candle in the range 0-120 foot-candles, ± 10 in the range 120-1200, and ± 100 above 1200 foot-candles.

Eight different experiments were conducted. Procedures for each of the experiments, numbered one through four, required four days. On the first day rainbow trout of appropriate size were captured from nearby portions of the stream by electrofishing and kept in a holding box in the stream. The particular structures to be used were then randomly located in the two sections and blocking nets were placed at the upper and lower end of each of the two sections. Any fish present in the two sections were removed by electrofishing. Ten rainbow trout were then placed in each of the two sections and were left undisturbed on the following day to give ample opportunity for investigation of the new environment. Observations were begun at eight A.M. on the third day and were made on the hour through three P.M., yielding eight counts for each structure per day. After the last observation the 10 fish were removed by electrofishing from both sections; four of the ten fish were immediately returned to both sections. Observations were made on the following (fourth day) as on the third day.

The 4 and 10 fish densities were used to test the effect of fish density on structure choice. These two densities were chosen on the basis of densities naturally found in Virginia Dale Creek.

Experiments five through eight differed only in the following ways: (1) five days were required for completion of each of these experiments; (2) all observations were made at a density of six fish per section; (3) each experiment was replicated with two different sets of six fish in both sections. Again, the fish were left undisturbed for one day between confining the fish in the sections and the beginning of observations.

In experiments one through four only two levels of each of the four variables, height, size, percentage holes, and water depth, were used (Table 14). In each of these experiments only three of the four variables were varied in a particular experiment. For example, in experiment one, height, size, and percentage holes varied in both the upper and lower sections, while all structures in the upper section were at level one (15 cm) of the variable water depth, and all structures in the lower section were at level two (25 cm). This necessitated eight structures in each of the two sections (all possible combinations of three variables with two levels per variable). Table 15 illustrates the combinations resulting from the variables and their levels.

The procedures outlined in experiment one were continued, with height, percentage holes, and size constant in experiments two through four respectively.

TABLE 14. Levels of variables used for experiments one through four. Plus sign indicates above water surface; minus indicates below water surface.

Variable	Height (cm)	Size (cm)	Percentage holes	Water depth (cm)
Level 1	+ 15	30 x 30	25	15
Level 2	- 5	60 x 75	0	25

TABLE 15. Experimental procedure for experiments one through four. Each of the squares represents one of the eight structures used in each section. Letters A, B, and C represent any three of the four variables. Subscripts 1 and 2 designate the two levels.

		Variable C	
Variable A	Variable B	C_1	C_2
A_1	B_1	$A_1B_1C_1$	$A_1B_1C_2$
	B_2	$A_1B_2C_1$	$A_1B_2C_2$
A_2	B_1	$A_2B_1C_1$	$A_2B_1C_2$
	B_2	$A_2B_2C_1$	$A_2B_2C_2$

In experiments five through eight (Table 16) only a single variable (with six levels) was used per experiment. No further experiments were done with water depth; this was kept constant at 20 cm. When height and percentage holes were not variables, structures were 5 cm below the water surface and with no holes. Structures in experiment six were 60 x 75 cm in size, and 45 x 50 cm for experiment seven.

One additional experiment (number eight) was conducted to see how deep water areas might serve as fright cover. Procedures were the same as experiments five through seven unless otherwise stated. Two structures, 60 x 75 cm, no holes, and 5 cm below the water surface were placed in water 20 cm deep in each of the two sections. Also for each section two semi-conical holes were dug; these were 1.2 m diameter at the level of the normal creek bottom and 55-60 cm deep. They had a flat area in the bottom of 0.1 m^2.

Results - Phase II

Most fish seemed to stay under structures at times when they were not frightened. Butler and Hawthorne (1968) also observed this behavior. Fish had a high degree of attachment for structures when the observer was present in the stream. They were reluctant to leave the particular structure chosen and were not frightened by the fish-scope.

When observations were being made, fish not using structures were usually found at the upstream end of the section. For both sections this position was the deepest water available. A small percentage of

TABLE 16. Levels of variables used for experiments five through seven. Plus sign indicates above water surface; minus indicates below water surface.

Exp. No.	Variable	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6
6	Height (cm)	+ 20	+ 10	+ 5	0*	- 5	- 10
5	Size (cm)	18 x 18	30 x 30	35 x 40	45 x 50	50 x 60	60 x 75
7	Percentage holes	33	25	15	8	4	0

* Indicates on surface

fish were not accounted for at some observation periods. This was probably caused by miscounting when two or more fish were present under a structure.

Total number of fish for eight observations per structure, range in number of fish per structure, and light intensity under structures are shown in Tables 17-20 for experiments one through four. Eight fish were used instead of 10 for experiment four. It was a particularly warm day when these fish were collected, causing handling mortality.

A low percentage of fish using structures was caused by the lack of any desirable structures. For example in experiment two, lower section, all structures were 15 cm above the water surface. Only 10 of a possible 80 fish (12.5%) were counted under structures at the 10 fish density, and 11 of 32 (34.4%) at the four fish density. The numbers 80 and 32 are calculated by multiplying the number of observations per day (8) by the number of fish in each section.

Experiments one through four were designed for a three way analysis of variance (Table 15). Results for the main effects for the analysis of variance are shown in Table 21. The hypothesis of no effect of levels was tested and rejected for the variables percentage holes, height, and size, and accepted for the variable water depth. The levels no holes, height below water surface, and large size were preferred to the alternative levels (25% holes, height above water surface, and small size). In all experiments in which percentage holes was a variable, the less desirable level never received greater fish use. The less desirable level of the variables size and height received greater fish use in one experiment each. The levels of the variable water depth received about equal use.

TABLE 17. Total and range of number of fish using structures over eight observations in experiment one. All structures are in water 15 cm deep in upper section, and 25 cm deep in lower section. Large = 60 x 75 cm; small = 30 x 30 cm; below = 5 cm below water surface; above = 15 cm above water surface; 0% = no holes; 25% = 25% holes.

		10 fish per section		Four fish per section	
Structure description	Light under structure (ft-candles)	Total no. of fish	Range in no. of fish per observation	Total no. of fish	Range in no. of fish per observation
		UPPER SECTION			
Large, below, 25%	560	1	0-1	1	0-1
Small, below, 25%	700	0	0-0	1	0-1
Large, above, 25%	180	0	0-0	0	0-0
Large, above, 0%	55	12	0-3	15	0-3
Small, above, 25%	2500	0	0-0	0	0-0
Large, below, 0%	0	20	1-4	6	0-3
Small, above, 0%	650	0	0-0	0	0-0
Small, below, 0%	8	0	0-0	1	0-0
Totals		33		24	
		LOWER SECTION			
Large, below, 25%	320	1	0-1	0	0-0
Large, below, 0%	3	35	1-6	9	0-2
Small, above, 0%	420	1	0-1	0	0-0
Small, above, 25%	740	0	0-0	0	0-0
Small, below, 25%	1000	2	0-1	4	0-2
Large, above, 25%	260	0	0-0	1	0-1
Large, above, 0%	58	2	0-1	2	0-1
Small, below, 0%	20	12	0-3	15	1-3
Totals		53		31	

TABLE 18. Total and range of number of fish using structures over eight observations in experiment two. All structures are 5 cm below surface in upper section, and 15 cm above surface in lower section. Structure descriptions are as in Table 17, except that 15 cm = structure is located in water 15 cm deep, and 25 cm = water 25 cm deep.

Structure description	Light under structure (ft-candles)	10 fish per section		Four fish per section	
		Total no. of fish	Range in no. of fish per observation	Total no. of fish	Range in no. of fish per observation
UPPER SECTION					
Large, 25%, 15 cm	1200	6	0-2	6	0-1
Small, 25%, 15 cm	1500	3	0-2	0	0-0
Large, 0%, 15 cm	1	15	0-5	13	0-2
Small, 0%, 15 cm	6	7	0-2	1	0-1
Small, 25%, 25 cm	1500	2	0-1	0	0-0
Large, 25%, 25 cm	1500	0	0-0	1	0-1
Small, 0%, 25 cm	10	2	0-1	0	0-0
Large, 0%, 25 cm	1	27	2-5	5	0-1
Totals		62		26	
LOWER SECTION					
Small, 0%, 15 cm	420	0	0-0	0	0-0
Large, 25%, 15 cm	1600	0	0-0	2	0-1
Large, 0%, 15 cm	55	0	0-0	0	0-0
Small, 25%, 15 cm	1700	0	0-0	0	0-0
Small, 0%, 25 cm	300	0	0-0	1	0-1
Small, 25%, 25 cm	1600	0	0-0	1	0-1
Large, 25%, 25 cm	1200	2	0-1	1	0-1
Large, 0%, 25 cm	35	8	0-3	6	0-2
Totals		10		11	

TABLE 19. Total and range of number of fish using structures over eight observations in experiment three. All structures are 0% holes in upper section, and 25% holes in lower section. Structure descriptions are as in Tables 17 and 18.

Structure description	Light under structure (ft-candles)	10 fish per section: Total no. of fish	10 fish per section: Range in no. of fish per observation	Four fish per section: Total no. of fish	Four fish per section: Range in no. of fish per observation
UPPER SECTION					
Large, above, 15 cm	54	0	0-0	5	0-2
Large, below, 15 cm	1	12	0-3	11	1-2
Small, above, 15 cm	420	0	0-0	0	0-0
Small, below, 15 cm	7	1	0-1	0	0-0
Small, above, 25 cm	540	0	0-0	0	0-0
Small, below, 25 cm	78	0	0-0	4	0-1
Large, below, 25 cm	2	45	3-6	8	0-2
Large, above, 25 cm	80	0	0-0	0	0-0
Totals		58		28	
LOWER SECTION					
Small, below, 15 cm	1800	0	0-0	0	0-0
Large, below, 15 cm	1900	1	0-1	2	0-1
Large, above, 15 cm	1700	0	0-0	0	0-0
Small, above, 25 cm	1650	0	0-0	0	0-0
Small, below, 25 cm	1500	9	0-2	6	0-2
Small, above, 15 cm	1950	1	0-1	0	0-0
Large, below, 25 cm	420	13	0-3	4	0-1
Large, above, 25 cm	1400	0	0-0	0	0-0
Totals		24		12	

TABLE 20. Total and range of number of fish using structures over eight observations in experiment four. All structures small in upper section, and large in lower section. Descriptions of structures are as in Tables 17-19.

Structure description	Light under structure (ft-candles)	10 fish per section*: Total no. of fish	10 fish per section*: Range in no. of fish per observation	Four fish per section: Total no. of fish	Four fish per section: Range in no. of fish observation
		UPPER SECTION			
15 cm, 0%, below	4	21	1-4	19	1-3
15 cm, 25%, above	2500	0	0-0	0	0-0
15 cm, 0%, above	430	0	0-0	0	0-0
15 cm, 25%, below	2400	7	0-2	5	0-2
25 cm, 25%, above	2200	0	0-0	0	0-0
25 cm, 25%, below	1800	8	0-3	2	0-1
25 cm, 0%, below	104	16	1-3	3	0-1
25 cm, 0%, below	46	2	0-1	0	0-0
Totals		54		29	

*8 fish instead of 10 used in this experiment

Structure description	Light under structure (ft-candles)	10 fish per section*: Total no. of fish	10 fish per section*: Range in no. of fish per observation	Four fish per section: Total no. of fish	Four fish per section: Range in no. of fish observation
		LOWER SECTION			
15 cm, 25%, above	1700	5	0-1	0	0-0
15 cm, 0%, above	42	0	0-0	0	0-0
15 cm, 0%, below	0	1	0-1	9	1-2
25 cm, 0%, above	66	1	0-1	0	0-0
25 cm, 25%, below	1500	7	0-2	2	0-1
15 cm, 25%, below	700	4	0-1	3	0-1
25 cm, 25%, above	200	0	0-0	0	0-0
25 cm, 0%, below	1	24	2-4	8	0-3
Totals		42		22	

TABLE 21. F values from three-way analysis of variance for experiments one-four. Each F has 1 and 56 degrees of freedom. A indicates upper section 10 fish, B = upper section, four fish; C = lower section, 10 fish; D = lower section, four fish. F of 4.04 is required for significance at the 5% level.

Experiment number	Percentage Holes	Size	Height	Depth
1A	49.84	56.47	4.20	
1C	52.78	12.64	52.78	
1B	18.42	18.42	1.66*	
1D	27.33	3.04*	38.72	
2A	31.82	22.85		0.00
2C	3.32	9.21		9.21
2B	14.00	56.00		19.06*
2D	1.03	5.62		5.62
3A		146.36	156.99	47.99
3C		0.97	29.21	24.14
3B		27.79	24.13	1.19*
3D		0.00	18.00	8.00
4A	17.83		77.40	0.13*
4C	6.04		54.32	29.21
4B	17.69		66.13	28.39*
4D	8.84		29.72	0.25*

* Experiment in which a less desirable level of a variable received greater total use by fish

The overall significance of the F ratios for each variable in Table 21 was tested by a chi-square test where Z is distributed as chi-square with 2k degrees of freedom. This chi-square was calculated as follows:

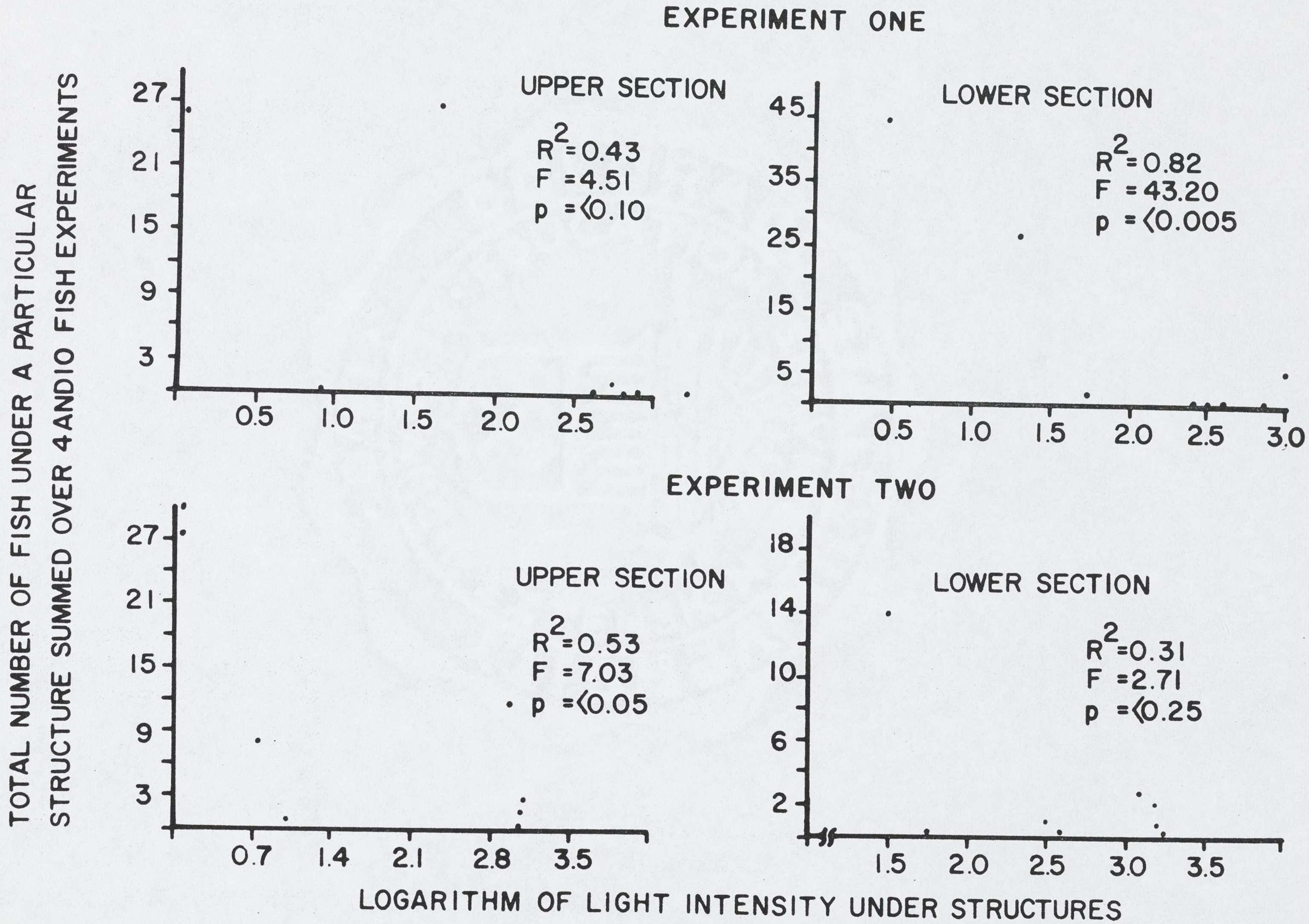
$$Z = -2\sum \ln pi \qquad (4)$$

where pi is the probability of each F value and k is the number of F values. The F values for size and height (one F value each) that resulted from a less desirable level receiving greater fish use were not used in the computation from equation 4. This computation was also not done for the F values resulting from the variable water depth, because there was no consistency in which of the two levels was causing the F ratio to depart from unity (Table 21). The effect of the variable water depth was considered nonexistent. The chi-square values resulting from equation (4) were significant at the 0.005 level of probability for percentage holes, height, and size.

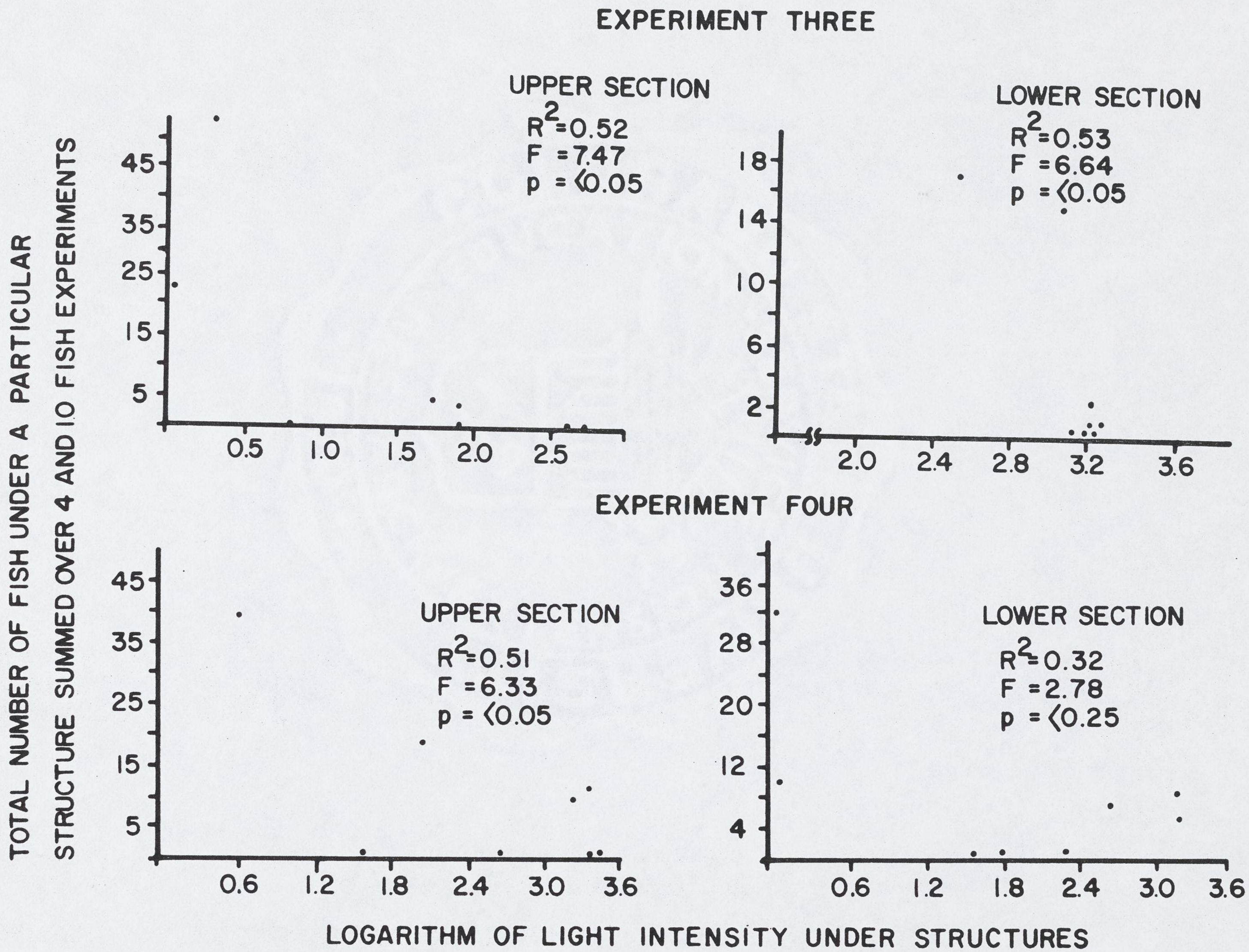
The data of Tables 17-20 can also be considered as if light intensity under structures were the independent variable (Figure 2). Relationships were consistently stronger by using logarithm of light intensity instead of simple light intensity. By using equation (4) to combine the individual probabilities of the eight regressions in Figure 2, chi-square = 43.5 with 16 d.f. and is significant at the 0.005 level of probability.

Considering Table 21 and Figure 2 it appears that fish use of structures can be explained with equal success by consideration of the variables, height, size, and percentage holes, or simply by consideration

FIGURE 2. Relationship of total fish use to logarithm of light intensity under structures for experiments one through four. (pages 54 and 55).



EXPERIMENT ONE
UPPER SECTION
R^2 = 0.43
F = 4.51
p = <0.10
27
21
15
9
3
0.5
1.0
1.5
2.0
2.5
LOWER SECTION
R^2 = 0.82
F = 43.20
p = <0.005
45
35
25
15
5
0.5
1.0
1.5
2.0
2.5
3.0
EXPERIMENT TWO
UPPER SECTION
R^2 = 0.53
F = 7.03
p = <0.05
27
21
15
9
3
0.7
1.4
2.1
2.8
3.5
LOWER SECTION
R^2 = 0.31
F = 2.71
p = <0.25
18
14
10
6
2
1.5
2.0
2.5
3.0
3.5
TOTAL NUMBER OF FISH UNDER A PARTICULAR STRUCTURE SUMMED OVER 4 AND 10 FISH EXPERIMENTS
LOGARITHM OF LIGHT INTENSITY UNDER STRUCTURES


EXPERIMENT THREE
UPPER SECTION
R2=0.52
F =7.47
p = <0.05
LOWER SECTION
R2=0.53
F =6.64
p = <0.05
EXPERIMENT FOUR
UPPER SECTION
R2=0.51
F =6.33
p = <0.05
LOWER SECTION
R2=0.32
F =2.78
p = <0.25
TOTAL NUMBER OF FISH UNDER A PARTICULAR STRUCTURE SUMMED OVER 4 AND 10 FISH EXPERIMENTS
LOGARITHM OF LIGHT INTENSITY UNDER STRUCTURES

of light intensity under structures. This suggests that height, size, and percentage holes may influence fish use of structures by controlling light intensity under structures.

The hypothesis of no effect of the variables on light intensity was tested in Table 22. This hypothesis was rejected, except for the variable water depth. The paired t calculated for the effect of height was so close to the value required for rejection at the 0.05 level, that the effect of height on light intensity was considered significant. The conclusion was that height, size, and percentage holes affect light intensity under structures.

We have seen that the variables percentage holes, size, and height, but not water depth, had a significant effect on fish use of structures (Table 21) and on light intensity under structures (Table 22). This information, together with the strong effect of light intensity under structures on fish use (Figure 2), indicates that the three variables exert their effect on fish use through their effect on light intensity under structures.

Experiments one through four were conducted with only two levels of each of the four variables. Since conclusions based on only two levels of variables are somewhat precarious, experiments five through seven were with six levels of each variable and with only one variable per experiment (Table 16).

Again a variable, but sometimes large, (over half in some experiments) portion of the fish were not under structures when observations were made. It should be noted that structures are not in the same order when ranked by level number and by light intensity, because some

TABLE 22. Effect of the variables height, size, percentage holes, and water depth on light under structures. Descriptions are as in Tables 17-20.

1	2	3	4	5	6
Structure description	light reading (ft-candles) lower sect.	light reading (ft-candles) upper sect.	Column 2-3	paired t for difference	Probability of larger t
Experiment 1 - Water depth constant within a section					
Large, below, 25%	320	560	-240	-1.009	≃ 1.00
Small, below, 25%	1000	700	300		
Large, above, 25%	260	180	80		
Large, above, 0%	58	55	3		
Small, above, 25%	740	2500	-1760		
Large, below, 0%	3	0	3		
Small, above, 0%	420	650	-230		
Small, below, 0%	20	8	12		
Experiment 2 - Height constant within a section					
Large, 25%, 15 cm	1600	1200	400	1.805*	< 0.10
Small, 25%, 15 cm	1700	1500	200		
Large, 0%, 15 cm	55	1	54		
Small, 0%, 15 cm	420	6	416		
Small, 25%, 25 cm	1600	1500	100		
Large, 25%, 25 cm	1200	1500	-300		
Small, 0%, 25 cm	300	10	290		
Large, 0%, 25 cm	35	1	34		

* 1.895 needed for significance at 5% level, so probability is much closer to 0.05 than 0.10

TABLE 22. (Continued)

1	2	3	4	5	6
Structure description	light reading (ft-candles) lower sect.	upper sect.	Column 2-3	Paired t for difference	Probability of larger t
Experiment 3 - Percentage holes constant within a section					
Large, above, 15 cm	1700	54	1646		
Large, below, 15 cm	1900	1	1899		
Small, above, 15 cm	1950	420	1530		
Small, below, 15 cm	1800	7	1793	7.829	< 0.005
Small, above, 25 cm	1650	540	1110		
Small, below, 25 cm	1500	78	1422		
Large, below, 25 cm	420	2	318		
Large, above 25 cm	1400	80	1320		
Experiment 4 - Size constant within a section					
15 cm, 0%, below	4	0	4		
15 cm, 25%, above	2500	1700	800		
15 cm, 0% above	430	42	388		
15 cm, 25%, below	2400	700	1700	2.395	< 0.025
25 cm, 25%, above	2200	200	2000		
25 cm, 25%, below	1800	1500	300		
25 cm, 0%, below	104	1	103		
25 cm, 0%, above	46	66	-22		

positions in the two sections were shaded at mid-day. These positions were used hopefully to distinguish between the effects of particular variables and light intensity on fish use of structures.

The relationship of fish use to each of the variables, size, height, and percentage holes is shown in Figure 3. Each of these experiments was replicated, in both sections, with one day of observation (eight observations per day) on each of two different sets of six fish. The numbers plotted are total counts of fish under each structure for one day. On the whole, linear regressions tended to give the best fit. The effect of height and size is strong; fish use decreased as structure height above the water surface increased, and as structure size decreased.

The effect of the variable percentage holes was as expected in the upper section, with a relationship highly significant and the slope of the regression line as expected. Results, however, in experiment seven, lower section, are not significant at the 5% level. The slope of the line, while not significantly different from zero, is entirely anomalous.

The data of Tables 23-25 are used to construct the graphs of Figure 4. Again, the logarithm of light intensity gave a better fit than simple light intensity or percentage of surface light under structure. Experiments five and six again show fish use of structures highly significantly related to logarithm of light intensity; results are similar to those of Figure 2 for experiments one through four. In experiment seven (Figure 4) the relationship of fish use of structures to logarithm of light intensity was non-significant. In the upper section a significant relationship was obtained by using a simple light-fish use regression, but this was not the case for the lower

FIGURE 3. Relationship of total fish use for one day to structure size, height, and percentage holes.

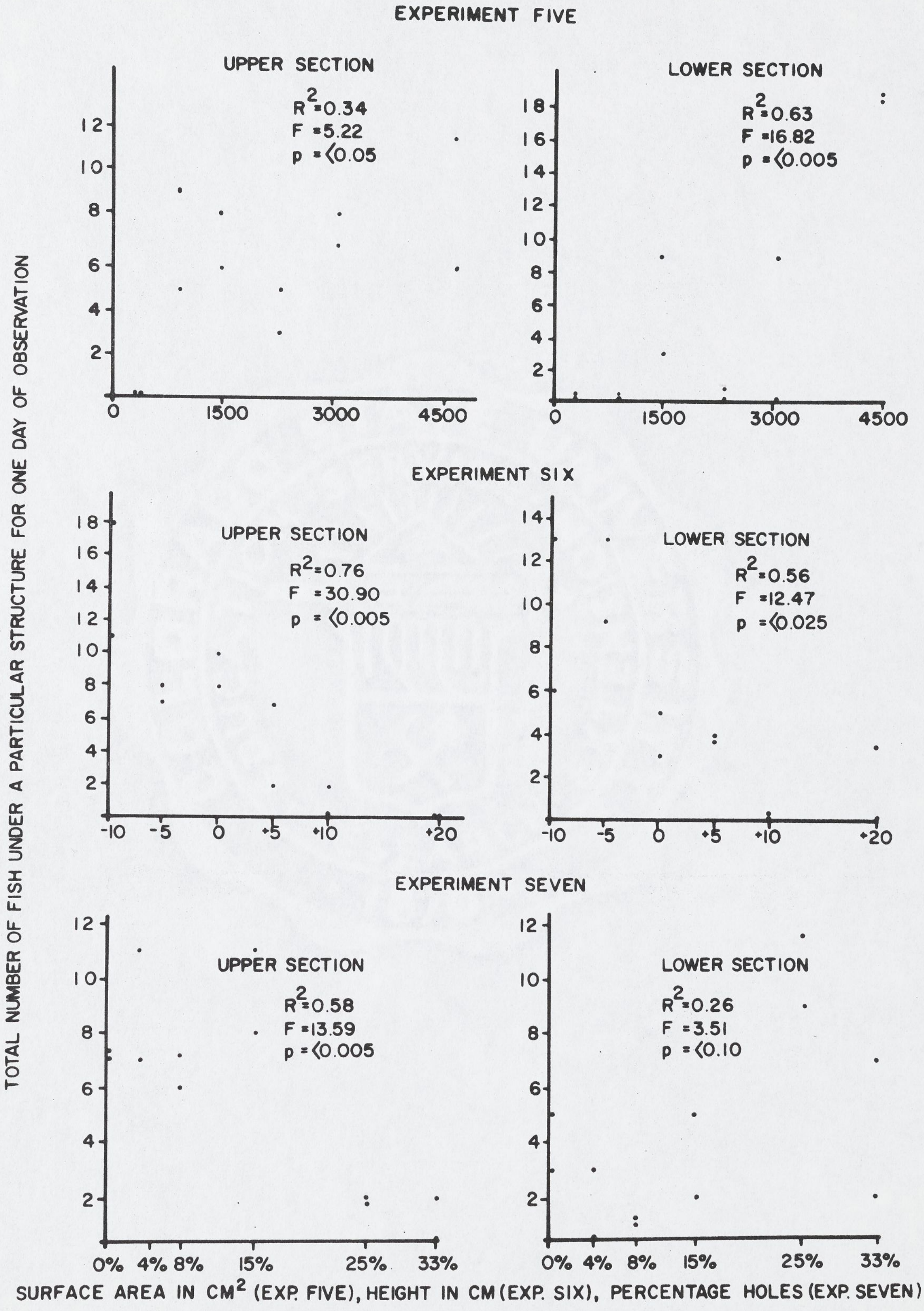

EXPERIMENT FIVE
UPPER SECTION
R2=0.34
F =5.22
p =<0.05
LOWER SECTION
R2=0.63
F =16.82
p =<0.005
0
1500
3000
4500
EXPERIMENT SIX
UPPER SECTION
R2=0.76
F =30.90
p =<0.005
LOWER SECTION
R2=0.56
F =12.47
p =<0.025
-10
-5
0
+5
+10
+20
EXPERIMENT SEVEN
UPPER SECTION
R2=0.58
F =13.59
p =<0.005
LOWER SECTION
R2=0.26
F =3.51
p =<0.10
0%
4%
8%
15%
25%
33%
TOTAL NUMBER OF FISH UNDER A PARTICULAR STRUCTURE FOR ONE DAY OF OBSERVATION
SURFACE AREA IN CM2 (EXP. FIVE), HEIGHT IN CM (EXP. SIX), PERCENTAGE HOLES (EXP. SEVEN)

TABLE 23. Results of experiment five. Structure size is varying. All structures are no holes, 5 cm below surface, and located in water 20 cm deep.

		1st day of observation		2nd day of observation	
Structure size (cm)	Light under structure (ft-candles)	Total number of fish observed	Range in number of fish per observation	Total number of fish observed	Range in number of fish per observation
		UPPER SECTION			
35 x 40	2	6	0-2	8	0-2
30 x 30	4	9	0-3	5	0-1
18 x 18	34	0	0-0	0	0-0
75 x 60	3	11	0-4	6	0-1
45 x 60	4	3	0-1	5	0-1
50 x 60	3	7	0-2	8	0-4
		LOWER SECTION			
30 x 30	2	0	0-0	0	0-0
45 x 60	3	1	0-1	0	0-0
50 x 60	3	9	0-2	0	0-0
35 x 40	2	9	0-4	3	0-1
18 x 18	6	0	0-0	0	0-0
75 x 60	1	19	0-5	19	0-3

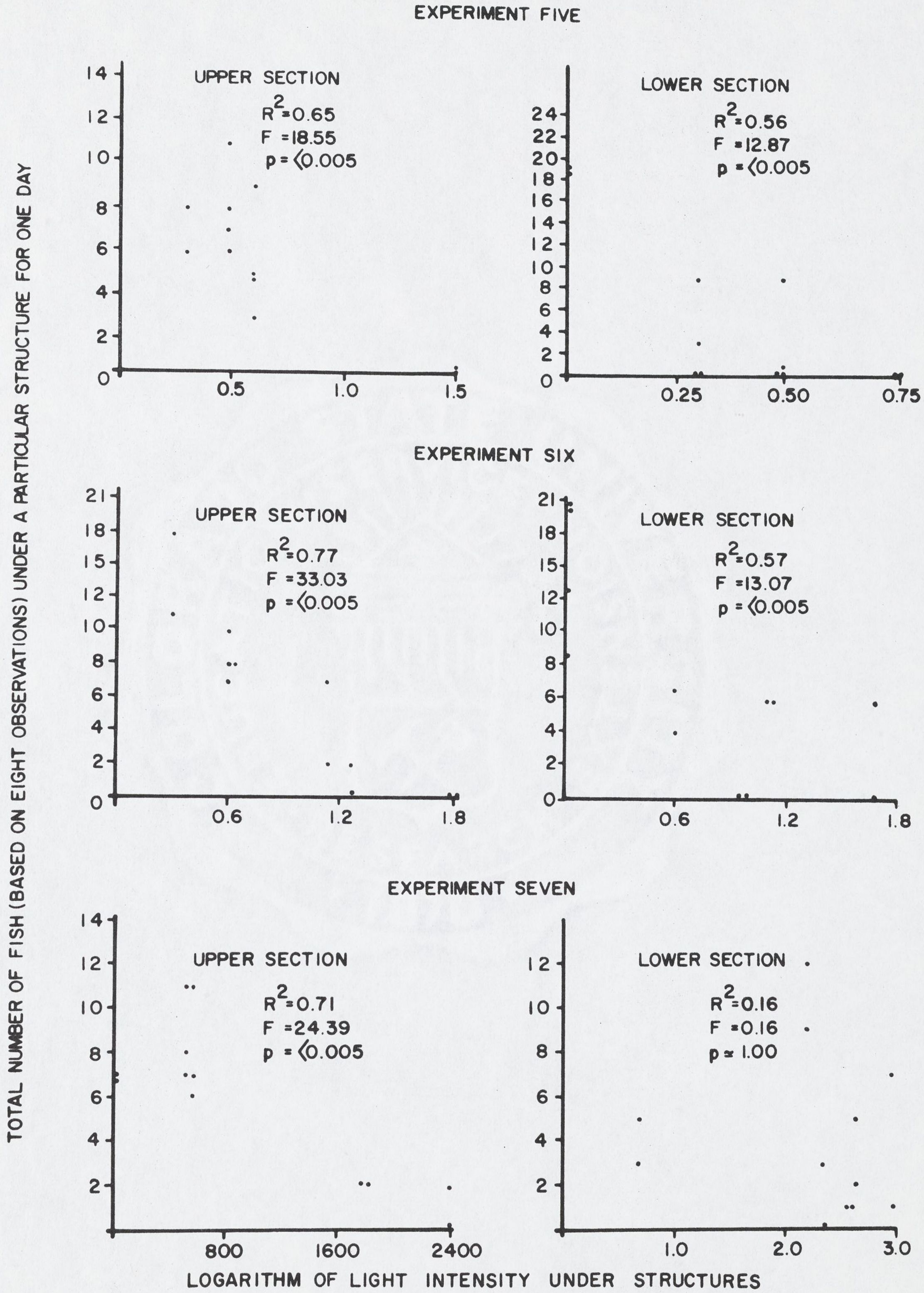
TABLE 24. Results of experiment six. Structure height is varying. All structures are no holes, 60 x 75 cm, and 20 cm water depth.

Structure description	Light under structure (ft-candles)	1st day of observation: Total number of fish observed	1st day of observation: Range in number of fish per observation	2nd day of observation: Total number of fish observed	2nd day of observation: Range in number of fish per observation
UPPER SECTION					
5 cm above	13	7	0-2	2	0-1
10 cm above	19	2	0-2	0	0-0
20 cm above	71	0	0-0	0	0-0
5 cm below	4	7	0-3	8	0-2
on surface	4	8	0-2	10	0-2
10 cm below	2	11	0-3	18	1-4
LOWER SECTION					
20 cm above	52	0	0-0	4	0-1
5 cm above	11	4	0-2	4	0-1
on surface	4	5	0-1	3	0-1
10 cm below	1	6	0-2	13	0-2
5 cm below	1	9	0-2	13	0-3
10 cm above	9	0	0-0	0	0-0

TABLE 25. Results of experiment seven. Percentage holes is varying. All structures are 45 x 50 cm in size, 5 cm below water surface, and in water 20 cm deep.

Structure description	Light under structure (ft-candles)	1st day of observation		2nd day of observation	
		Total number of fish observed	Range in number of fish per observation	Total number of fish observed	Range in number of fish per observation
UPPER SECTION					
4% holes	500	11	0-2	7	0-2
0% holes	4	7	0-2	7	0-2
15% holes	480	8	0-2	11	0-2
8% holes	500	6	0-2	7	0-1
25% holes	1800	2	0-1	2	0-1
33% holes	2600	2	0-1	0	0-0
LOWER SECTION					
8% holes	490	1	0-1	1	0-1
4% holes	290	3	0-1	0	0-0
0% holes	5	5	0-1	3	0-2
15% holes	540	2	0-2	5	0-1
25% holes	180	12	0-2	9	0-2
33% holes	1400	7	0-1	1	0-1

FIGURE 4. Relationship of total fish use to logarithm of light intensity under structures for experiments five, six, and seven (lower section). Simple light intensity is used for experiment seven, upper section.



EXPERIMENT FIVE
UPPER SECTION
R2=0.65
F =18.55
p=<0.005
LOWER SECTION
R2=0.56
F =12.87
p =<0.005
EXPERIMENT SIX
UPPER SECTION
R2=0.77
F =33.03
p =<0.005
LOWER SECTION
R2=0.57
F =13.07
p =<0.005
EXPERIMENT SEVEN
UPPER SECTION
R2=0.71
F =24.39
p =<0.005
LOWER SECTION
R2=0.16
F =0.16
p ≃ 1.00
TOTAL NUMBER OF FISH (BASED ON EIGHT OBSERVATIONS) UNDER A PARTICULAR STRUCTURE FOR ONE DAY
LOGARITHM OF LIGHT INTENSITY UNDER STRUCTURES

section. It seems worthy of attention that for experiment seven, lower section, fish use of structures cannot be explained by the variable percentage holes (Figure 3) or by light intensity under structures (Figure 4), while both percentage holes and light under structures give a strong relationship with fish use in experiment seven, upper section. The overall results of experiment seven (lower section) are unexplainable with available knowledge.

The paired t test method used in Table 22 to determine effect of the variables on light under structures is not applicable to experiments five through seven, because structures in upper and lower sections did not differ in level of one variable as did structures in experiments one through four. Regressions for levels of each of the variables height, size, and percentage holes vs. light intensity under structures were attempted for experiments five through seven, but results were mostly non-significant because some of the structures were shaded when light measurements were made. In the absence of this shading, light intensity under structures would probably be correlated with levels of each of the variables height, size, and percentage holes in experiments five through seven.

Regardless of the preceeding information, it seems likely that height, size, and percentage holes influence fish use of structures by affecting light intensity under structures.

There did not seem to be a threshold light intensity value below which structures were heavily used, and above which they were not used. An examination of Tables 17-20 and 23-25 indicates that fish tended to use the structures offering the darkest area available, regardless of the absolute light intensity. It did seem true, however, that when the darkest structure available had a relatively high light intensity underneath, a lower percentage of the fish used structures. For example in experiment three, lower section (Table 19), there were no structures available offering a light intensity in the range of 0-50 foot-candles. The darkest structure in this experiment had a subsurface light intensity of 420 foot-candles; only 24 of a possible total of 80 fish (10 fish density) and 12 of a possible total of 32 fish (four fish density) were counted under structures. Even in this case the darkest structure tended to receive greater fish use.

One additional experiment, number eight, previously described in the methods section, was conducted to see if deep water, which was found to be important to trout density in phase I, might serve as fright cover. Results of this experiment are shown in Table 26. Considerable numbers of fish utilized the bottom of the deep holes as fright cover despite the presence of a desirable structure.

In fact in the upper section, second day of observation, more fish were counted at the bottom of the deep holes than under structures. Using a one-way analysis of variance for each section and each day on the individual observations, an individual degree of freedom for structures vs. holes was calculated. Both days of observation in the lower section and the first day of observation in the upper indicated a greater use of structures than of deep holes, with significance at the 0.005 level. The second day of observation in the upper section indicated a significantly greater (0.05 level of probability) use of deep holes than of structures. Deep water areas seem suitable as fright cover.

TABLE 26. Total fish use of structures and deep holes in experiment eight.

Description	Light (ft-candles)*	Total number of fish for 8 observations: First day	Second day**
		Upper Section	
Structure	1	20	4
hole	3700	2	7
Structure	2	7	3
hole	3600	9	6
		Lower Section	
Structure	1	7	4
hole	4400	0	1
Structure	1	26	14
hole	3200	11	3

* Measured at bottom of holes

** Only 3 fish in upper section and 4 in lower section

One additional observation is of interest. One of the reasons for doing each of experiments one through four at both 10 and 4 fish densities was to examine the possible effect of fish density on use of fright cover. Before the experiments were done, it was hypothesized that social interaction at the 10 fish density might force some fish to use structures that would be rejected at the four fish density.

Table 27 shows data used in accepting the hypothesis of no effect of fish density on structure use. At the 10 fish density, if some fish were forced to use less desirable structures, a greater number of structures should have been used. The data in Table 27 were used in a paired t test. The calculated t was 1.239 with 1.895 being needed to reject the hypothesis of no effect of fish density on structure use. It was concluded that the 10 fish density did not limit choice of structures by fish. This conclusion is supported by the fact that as many as six fish were counted under a single structure at some observation periods (Tables 17-20). Although only eight fish instead of 10 were used for experiment four (Table 20), this experiment was used for the paired t-test as if 10 fish were present. The difference between 8 and 10 fish was not considered sufficient to affect the conclusion. Exclusion of this experiment for calculations of the paired t would decrease the value of the calculated t and strengthen the conclusion already reached.

TABLE 27. Total number of structures used over the eight observations by fish density (10 and 4) and sections.

Experiment number	Section	10 fish density	Four fish density	10 fish density minus four fish density
1	Upper	16	14	2
	Lower	21	20	1
2	Upper	30	20	10
	Lower	7	10	-3
3	Upper	15	23	-8
	Lower	14	11	3
4*	Upper	28	16	12
	Lower	24	18	6

* Only eight fish instead of 10 used in this experiment

DISCUSSION AND CONCLUSIONS

Stream salmonids are territorial and compete through establishment of social hierarchies (Kalleburg, 1958). Stream trout compete for a limited number of microhabitats (terminology of Wickham, 1967) within a stream. Jenkins (1968), working with brown and rainbow trouts, found that subordinate fish took up positions held by dominant fish when dominant fish were removed. In other words all fish in a local site preferred the same position in the stream. This information suggests that populations of stream trout may limit their own density through the quality of the habitat. A description of the type of stream environment allowing greater trout densities has been one of the purposes of this study.

Kalleburg (1958), using juvenile salmon and brown trout, found that habitats increasing **visual** isolation of fish decreased territory size and allowed a greater density of fish. Stream sections, in phase I of this study, having much rock cover also tended to have a large number of rocks of various sizes jutting up into the water from the stream bottom. These might cause an increase in visual isolation of fish and explain the importance of rock cover apart from its function as fright cover. Rocks providing an under-surface area of less than 0.10 m^2 were important to trout density, but appear (results of phase II) to be too small to function as fright cover. It seems likely that rock cover less than 0.10 m^2 (and rocks not supplying cover) may be important to trout density by increasing visual isolation.

The results of the artificial cover work of phase II seem helpful in explaining the results of phase I. In the phase I regressions the variable mean depth was consistently included with a significant F ratio for both brook and rainbow trouts. As a general rule, sections with a greater mean depth contained a small percentage of bottom area of 55-60 cm deep. This was the depth of the artificial holes used in experiment eight (Table 26) as fright cover by rainbow trout. It seems that the variable mean depth may have importance in that it reflects the availability of deep water areas suitable for fright cover. Were the minimum water depth suitable for fright cover known, it would be interesting to use this variable in the phase I regressions.

A rather surprising result from phase I was the lack of importance of brush-cover-in-water variables to trout density. Boussu (1954) was able to decrease and increase trout densities in stream sections by adding and taking away this physical component, although he didn't indicate what DWP (page 7) rating might be assigned to these brush covers. Phase II of my study indicates the importance of light intensity under cover as a parameter influencing fish use. The rock cover, which proved important to trout density in phase I would be expected to have a lower light intensity underneath than brush cover; this type of cover always allowed some light penetration through even dense brush piles. No brush piles were estimated to have a DWP greater than 90%, few had ratings higher than 80%. Experimental cover devices having 25% of the surface area punched out with holes (corresponds to 75% DWP rating for natural brush piles) were not used or very lightly used. It seems that the natural brush piles may have allowed too much light penetration, compared to the underside of rock cover, to be useful in serving as fright cover. It would be interesting to have measurements of light under brush cover and rocks. This information might clarify the apparent lack of importance of brush piles to trout density in the stream sections.

No effect of the variable water depth under structures was found in phase II (Table 21). In all likelihood the difference between the two levels (15 cm and 25 cm) was too small to reveal an effect of the variable even if there were a real effect. Considerations of water depths available and space under structures for fish prevented the use of a greater range of water depths. Since deep water seems to be utilized as cover, deeper water under fright cover should augment utility.

There is a consistently low degree of variability accounted for (R^2) by variables entering the regressions with a significant F in in phase I (Tables 6-12). This suggests that some variables important to trout density were not available for inclusion in the regressions, and are unrecognized at the present time.

Percentage of variability accounted for by the variables used in phase II is somewhat higher (Figures 2-4), but it should be remembered that in these figures, the dependent variable is the total number of fish observed under a particular structure for one day. Use of totals masks variability. Were individual observations shown in Figures 2-4, the variability accounted for by the regressions would be less, although, due to the increase in degrees of freedom, conclusions about the significance of the regressions would be the same.

The recurring theme in the phase II results was that use of structures could be predicted with equal accuracy by consideration of the variables, height, size, and percentage holes, or simply by knowledge of light intensity under structures. This indicated that height, size, and percentage holes exerted their effect on fish use of structures through their effect on light under structures. Experiments in which light is kept constant while height, size, and percentage holes vary would reveal an effect of these variables, independent of light intensity, if this effect exists.

Information concerning light wave length discrimination (color vision) in fishes is scattered through the literature, however, information concerning intensity discrimination seems to be absent. Information of this sort would be useful in explaining fright cover reaction with respect to light intensity. Nikolsky (1963) stated that bluegills (*Lepomis macrochirus*) can sense light intensities as low as 10^{-10} of normal daylight (0.00001 foot-candles). Lagler, Bardach, and Miller (1962), summarizing results of Ali (1959), report that fishes of the genus *Oncorhynchus* can detect intensities as low as 0.0001 foot-candles. This information, however, gives no insight to the ability of fish to distinguish intensities within the range of intensities sensed.

The following conclusions seem warranted by the study. (1) Variables, in order of their importance, to brook and rainbow trout density in the stream sections were mean depth and rock cover variables. Deep, turbulent water and undercut bank seemed to be of some importance to brook trout. (2) The variables height, size, and percentage holes were important in determining fish use of artificial cover structures. These variables probably exert their effect largely through light intensity reduction under artificial cover structures.

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