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Effects of artificial shading on distribution and abundance of juvenile chinook salmon (*Oncorhynchus tshawytscha*)

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EFFECTS OF ARTIFICIAL SHADING ON DISTRIBUTION AND ABUNDANCE OF JUVENILE CHINOOK SALMON (*ONCORHYNCHUS TSHAWYTSCHA*)

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ABSTRACT.—The influence of artificial shade on the distribution and abundance of juvenile chinook salmon was studied in a side channel of the South Fork Salmon River, Idaho. Fish biomass and abundance were greater in shaded than in unshaded areas when compared to both cumulative incident light reaching the study sections during the 72-hour test runs and instantaneous incident light conditions at the end of the 72-hour test runs. Because conditions may be atypical at the time of instantaneous light measurement, we prefer cumulative incident light for relating light and shade conditions to daytime distribution (abundance and biomass) of juvenile chinook salmon.

Cover is one of the most important habitat components for anadromous salmonids during the freshwater-rearing phase of their life cycle. Cover can be described either as submerged cover or overhead cover (Reiser and Bjornn 1979). Examples of submerged cover are rocks and boulders, large organic debris, and aquatic vegetation. Overhead cover includes riparian vegetation, water turbulence, logs and other debris on or close to the water surface, and overhanging or undercut banks.

Many of these cover types can also be classed as cover with form; for example, rocks, large organic debris, and undercut banks (Brusven et al. 1986). Riparian vegetation can be classified as either cover with form or cover without form. Cover without form provides shade or insulation against temperature extremes. Shade may be important in maintaining cool water; it may also provide protection for fish from predators.

Several studies have demonstrated the use of shade by salmonids where the cover is on or below the water surface. In a shallow (24–29 cm) tank, small brook trout (*Salvelinus fontinalis* [Mitchill]) preferred shade as did Atlantic salmon (*Salmo salar* Linnaeus) parr when they were the only species present; in the presence of trout, salmon parr were generally found in unshaded areas (Gibson and Power 1975). Gibson and Power (1975) found that in a deep tank (43–50 cm) neither species preferred shade. Rainbow trout (*Salmo gairdneri* Richardson) fry showed no apparent preference for overhead cover in an artificial tank, but yearlings preferred the covered portion of the tank at all light intensities, except when the yearlings were randomly distributed in total darkness (McCrimmon and Kwain 1966). Juvenile Atlantic salmon were negatively phototactic at all but the very lowest light intensities (Pinhorn and Andrews 1963, Gibson and Keenleyside 1966). Gibson and Keenleyside (1966) showed that at all light intensities brook trout in laboratory aquaria generally positioned themselves in the dark areas at edges of shadows created by overhead cover. Butler and Hawthorne (1968) found a direct relation between amount of shade provided by overhead cover and its use by rainbow trout, brown trout (*Salmo trutta* Linnaeus), and brook trout. Hoar et al. (1957) found that, when given a choice between light and dark areas, schools of chum salmon (*Oncorhynchus keta* [Walbaum]) or pink salmon (*O. gorbuscha* [Walbaum]) fry remained in the light, and sockeye salmon (*O. nerka* [Walbaum]) fry preferred the dark; coho salmon (*O. kisutch* [Walbaum]) fry showed no preference between light and dark areas. Sockeye and coho smolts stayed in the dark more than did sockeye and coho underyearlings.

Other studies suggested that cover with form plays a much more important role than does shade. DeVore and White (1978) found no significant difference in response between

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brown trout in different intensities of incident light due to canopy shading; they found, however, a significant difference in response to physical cover with the highest correlation occurring when the cover was closest to the substrate (provided fish could still get under it). Gibson (1978) observed that shade was attractive to both Atlantic salmon parr and brook trout in shallow water; but given the choice of a shallow (30-cm) tank with shade or a deeper (50-cm) tank with no shade, the majority of both species selected the deeper tank. In this study Gibson noted that a turbulent water surface was more attractive to salmon parr than was shade.

The studies cited above were conducted for the most part in laboratory tanks or aquaria. In natural stream conditions, Gibson (1966) found that brook trout generally remained under overhanging cover, such as alder bushes, except at times of low illumination in early morning and in the evening. He noted that Atlantic salmon parr usually were observed away from such cover; they fed all day in brightly lit open areas of the stream. No significant difference was found between distributions on cloudy and on sunny days for either trout or salmon. When artificial shade was installed along a previously unshaded stream reach, brook trout were attracted to the shaded area (Gibson 1966). In a field study of simulated undercut banks, Brusven et al. (1986) found that 85% of the juvenile chinook salmon (*O. tshawytscha* [Walbaum]) biomass occurred in covered sections of a stream channel.

Hawkins et al. (1983) reported a positive correlation between abundance of salmonids and abundance of invertebrates in several streams in Oregon and northern California. In general they found an inverse relation between shade and density of invertebrates (hence salmonids). Use of specific types of shade cover by salmonids within study reaches was not studied, however.

In a study of temperature selection by young brook trout, Sullivan and Fisher (1954) found that at low light intensities trout responded to temperature without regard to shade, but at high light intensities the trout were not observed in the illuminated part of the laboratory trough—that is, shade was sought in preference to temperature.

The purpose of our study was to evaluate the role of artificial shade on the distribution, abundance, and biomass of juvenile chinook salmon in a flow-regulated channel.

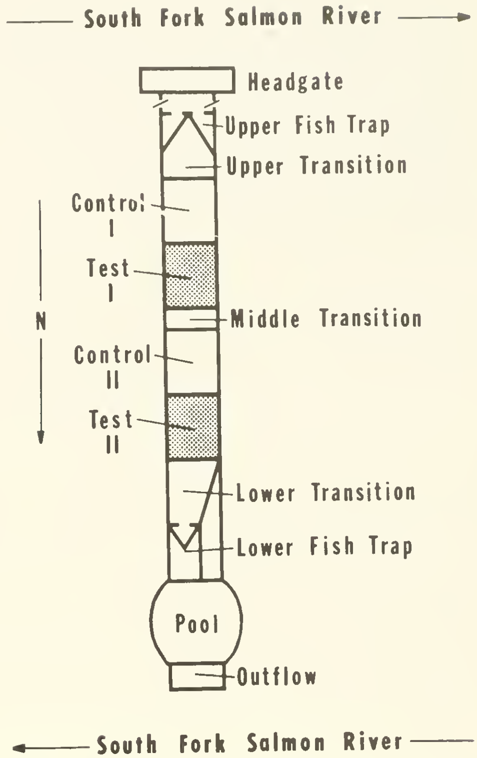

Fig. 1. Study sections of artificial stream channel, South Fork Salmon River, Idaho.

STUDY AREA

The study was conducted in 1977 and 1978 in an abandoned spawning and rearing channel in the South Fork Salmon River drainage in west central Idaho, about 50 km east of Cascade. The channel was constructed over 20 years ago by cutting across an oxbow in the South Fork Salmon River. Since then, the banks have been stabilized by indigenous vegetation. The channel is 160 m long and drops 0.58 m over its length. It has an upper channel (110 m long) and a lower pool (50 m long) (Fig. 1). The substrate is primarily sand (< 1.5 mm) and pebbles (1.0–3.0 cm). A steel headgate controls flow into the channel. The lower 48 m of the channel (exclusive of the pool) was used to investigate fish distribution in relation to simulated shade-producing riparian vegetation.

Fig. 2. Shade canopy in treatment section.

The banks of the channel were trimmed to remove rooted aquatic plants, to minimize shading from riparian grasses, and to create a homogeneous habitat throughout the channel. Lodgepole pine (*Pinus contorta* Dougl. ex Loud.), Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco), and willows (*Salix* spp.) are sparsely represented on the oxbow. During midday, shading from these plants is minimal; during early morning and late afternoon, however, some shading is apparent on the channel.

Summer-run chinook salmon spawn near the channel, and juveniles use the channel as a rearing area during most years. Steelhead trout (*Salmo gairdneri* Richardson), bull trout (*Salvelinus confluentus* Suckley), mountain whitefish (*Prosopium williamsoni* Girard), and sculpins (*Cottus* spp.) are also found in the main river and occasionally in the channel.

Fish traps were installed at the upper and lower ends of the study reach to determine fish outmigration. Two test units were created within the study reach; each test unit had a treatment section and a control section. Each section was about 7.6 m long and 2.4 m wide; water depth averaged 35–40 cm. Test units and sections within each test unit were also separated by imbedded sills fitted with recessed fish netting. The paired test units were further separated by a 2.8-m transition area to remove the shading effects of a canopy installed over the upstream treatment section.

MATERIALS AND METHODS

SOLAR RADIATION.—To test shade as a factor influencing distribution and abundance of fish, two A-frames were constructed of 19-mm I.D. pipe. They were 7.6 m long, 3.1 m wide at the bottom, and 2.5 m high at the center. In 1977 dark green saran screen[4,5] (20 meshes per 2.5 cm) was placed over the frames in the two treatment sections to form shading canopies (Fig. 2). The control sections were without artificial shade. Light transmittance through a single layer of the screen was 47% when the

[4]Chicopee Manufacturing Company, Lumite saran screen, fabric no. 50038–00.

[5]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

TABLE 1. Water temperature (C) measured at end of each test run in 1977 and 1978, SFSR channel.

Test date	Run	Test sections[1] 1T	2T	1C	2C
		.... °C	....		
June 1977	1	12.47	12.41	12.48	12.51
	2	14.71	14.64	14.84	14.79
August 1977	1	13.32	13.26	13.38	13.30
	2	13.56	13.60	13.57	13.58
	3 (shade removed)	12.41	12.44	12.43	12.43
July 1978	1	10.56	10.70	10.62	10.61
	2	12.28	12.34	12.41	12.39
August 1978	1	10.00	9.92	10.08	10.11
	2	9.17	9.19	9.21	9.18
	3 (shade removed)	10.21	10.22	10.34	10.22

[1]Sections 1T and 2T are shaded except when otherwise indicated, sections 1C and 2C are unshaded.

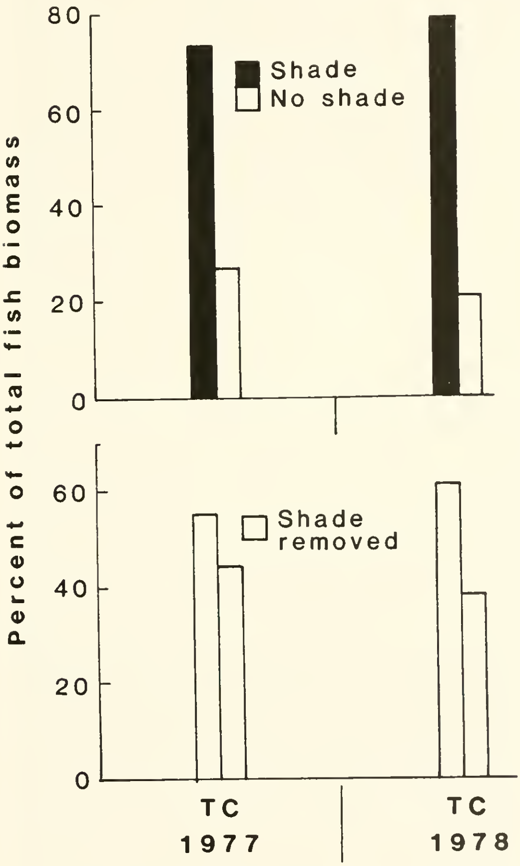

Fig. 3. Fish biomass in shaded (T) and unshaded (C) test sections of study channel, 1977 and 1978.

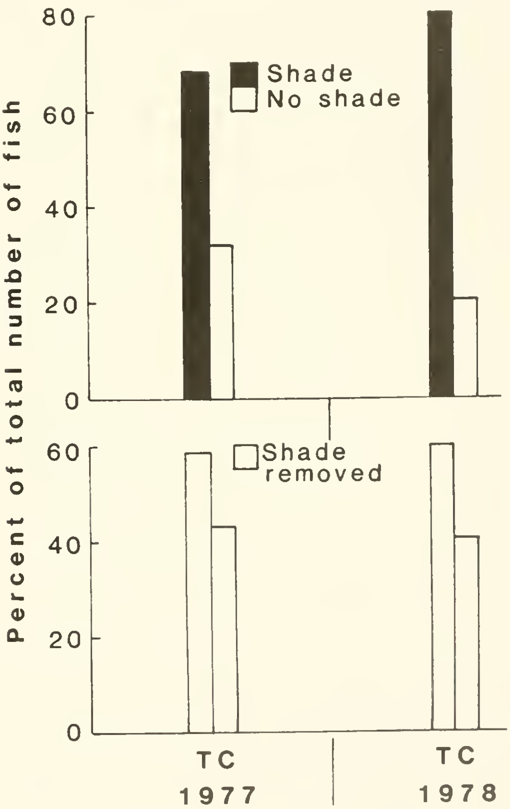

Fig. 4. Fish abundance in shaded (T) and unshaded (C) test sections of study channel, 1977 and 1978.

sun was perpendicular to the material, as determined by a hand-held solarimeter.[6] Sunlight transmittance under semishade among conifers and hardwoods near the channel was 15–55%. Thus, the artificial canopy was similar to the sparse natural canopy of the area. In 1978 darker shade was tested by doubling the screen and rotating the second layer 45 de-

[6]Matrix Inc., Mark VI Sol-a-meter.

TABLE 2. Cumulative incident light (g cal/cm²) measured during test runs in 1977 and 1978, SFSR channel.

Test date	Run	Test sections[1] 1T	2T	1C	2C
		g cal/cm²			
June 1977	1	221	187	509	509
	2	635	574	1532	1446
August 1977	1	448	433	1006	1159
	2	484	517	936	1213
	3 (shade removed)	714	788	832	832
Mean[2]		447.0	427.8	995.8	1081.8
		($\bar{X}T$ = 437.4)		($\bar{X}C$ = 1038.8)	
July 1978	1	225	196	1152	1114
	2	343	296	1710	1694
August 1978	1	182	171	960	1084
	2	188	205	1120	1209
	3 (shade removed)	1028	1007	1115	1210
Mean[2]		234.5	217.0	1235.5	1275.3
		($\bar{X}T$ = 225.8)		($\bar{X}C$ = 1255.4)	

[1]Sections 1T and 2T are shaded except when otherwise indicated; sections 1C and 2C are unshaded.
[2]Mean for runs with shade in place.

TABLE 3. Incident light (g cal/cm² per min) recorded at time of fish capture in 1977 and 1978, SFSR channel.

Test date	Run	Test sections[1] 1T	2T	1C	2C
		g cal/cm² per min			
June 1977	1	0.5	0.5	1.0	1.0
	2	0.5	0.5	1.0	1.0
August 1977	1	0.4	0.5	0.9	1.0
	2	0.1	0.1	0.2	0.2
	3 (shade removed)	0.7	0.6	0.8	0.8
Mean[2]		0.38	0.40	0.78	0.80
		($\bar{X}T$ = 0.39)		($\bar{X}C$ = 0.79)	
July 1978	1	0.2	0.3	1.1	1.1
	2	0.2	0.3	1.1	1.1
August 1978	1	0.2	0.2	1.0	1.0
	2	0.2	0.2	0.5	0.8
	3 (shade removed)	0.7	0.7	0.8	0.8
Mean[2]		0.20	0.25	0.93	1.00
		($\bar{X}T$ = 0.23)		($\bar{X}C$ = 0.96)	

[1]Sections 1T and 2T are shaded except when otherwise indicated, sections 1C and 2C are unshaded.
[2]Mean for measurements with shade in place.

grees over the mesh alignment of the earlier screen, producing 75% shade—more typical of a dense, natural canopy.

Four recording pyranographs[7] measured solar radiation along the four treatment and control sections of the channel during the tests. These were mounted at about the center of each section on 1-m-high stands above the substrate. Incident light intensity in gram calories per square centimeter per minute was read off a pyranograph chart when a test run was completed. The cumulative incident light during a 72-hour test run, in gram calories per square centimeter, was determined by reading the incident light off the pyranograph chart at 2-hour intervals, multiplying each of these readings by 120 (minutes per interval), and summing the 36 observations.

STREAM FLOW.—Water flow through the artificial channel was maintained at approximately 0.11 m³/s (3.9 cfs) during the tests by an adjustable head gate at the upper end of the channel.

WATER TEMPERATURE.—Water temperatures were measured and recorded in each test section simultaneously by Peabody Ryan Model G-45 recording thermographs.

FISH POPULATIONS.—Juvenile chinook salmon were captured with a 12-volt direct-current backpack electroshocker and a seine

[7]Weather Measure Corporation mechanical pyranograph, model R401-S.

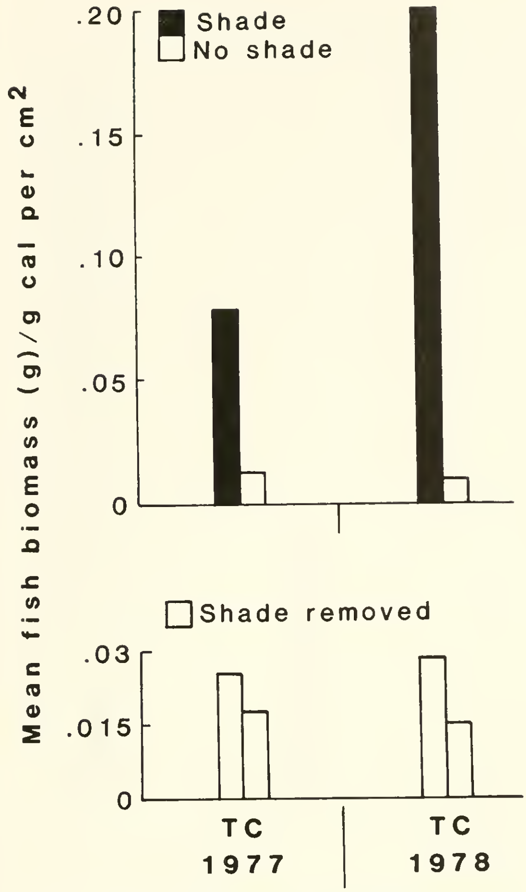

Fig. 5. Ratio of fish biomass to cumulative incident light in shaded (T) and unshaded (C) test sections of study channel, 1977 and 1978.

from the main South Fork Salmon River in the immediate vicinity of the artificial channel. All captured fish were mixed together. Before each test run, all fish were removed from the study reach by electrofishing. Test fish were then added to the study reach until the carrying capacity was established; the carrying capacity was determined by allowing surplus numbers of fish to migrate from the channel. The duration of a test was 72 hours that commenced and ended between 1030 and 1200. This length of time allowed the fish to acclimate and select preferred habitat. After 72 hours elapsed, a series of block nets were pulled simultaneously to isolate each of the four test sections.

After the block nets were in place, fish were removed from each test section, measured (fork length in mm), and weighed to the

Fig. 6. Ratio of fish abundance to cumulative incident light in shaded (T) and unshaded (C) test sections of study channel, 1977 and 1978.

nearest 0.1 g. After processing, all test fish were released into the main South Fork Salmon River below the artificial channel.

SCHEDULE OF TESTS AND DATA ANALYSIS.—During 1977 and 1978, tests were conducted in late June to early July and again in mid to late August. Two tests were run during each of the two test periods each year. The first test used shade canopies over the treatment sec-

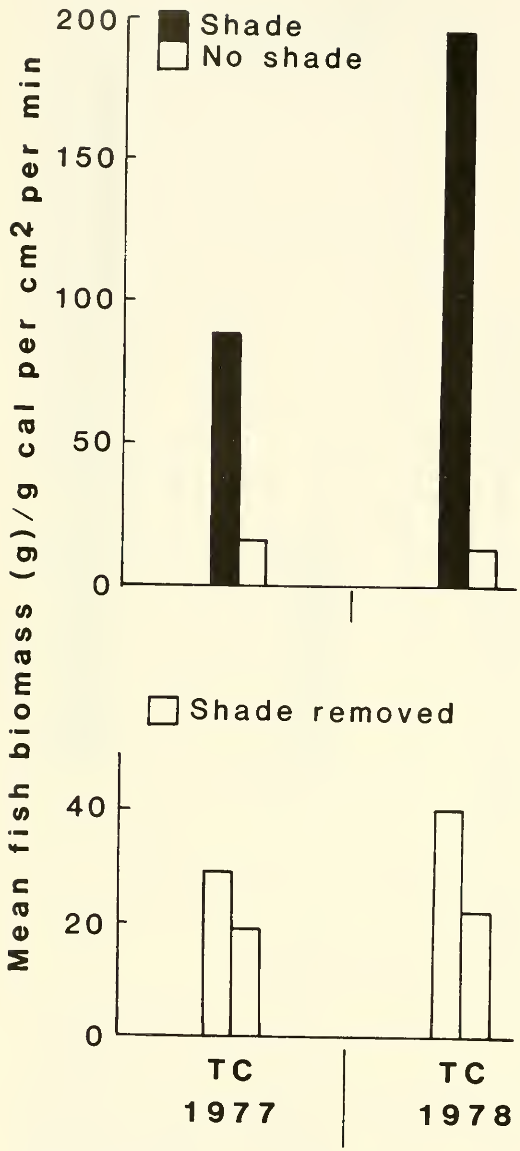

Fig. 7. Ratio of fish biomass to incident light in shaded (T) and unshaded (C) test sections of study channel, 1977 and 1978.

tions. In the second test, shade canopies were removed from the treatment sections to establish fish distribution in the channel without regard to shade.

Results and Discussion

Because water temperature was essentially the same in each test section (Table 1), choice of section by fish can be attributed to shade.

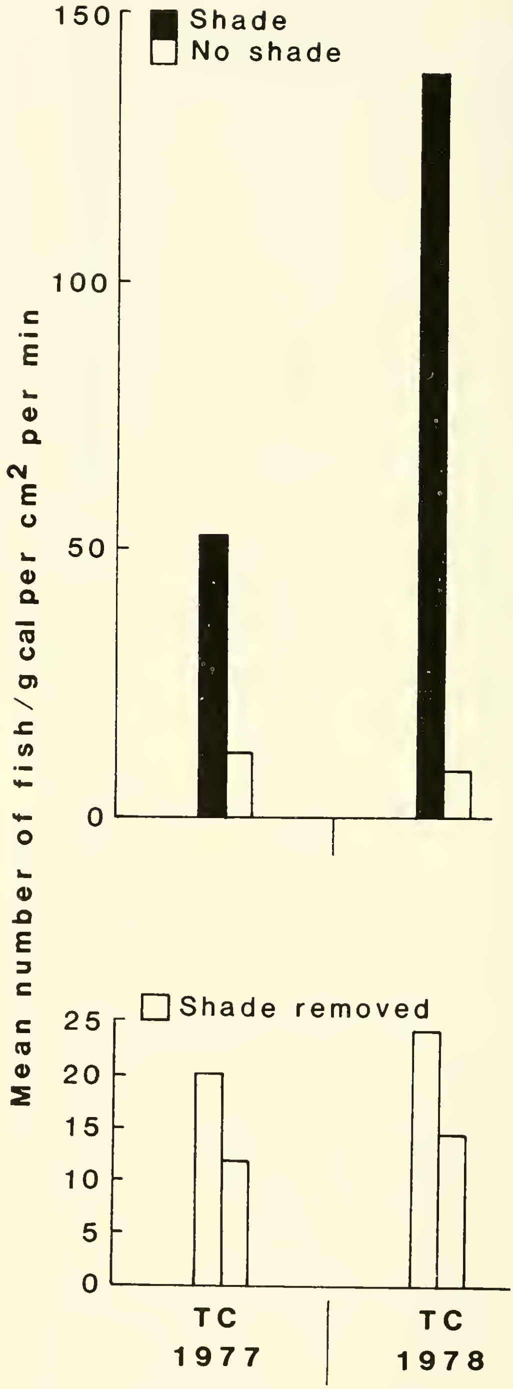

Fig. 8. Ratio of fish abundance to incident light in shaded (T) and unshaded (C) test sections of study channel, 1977 and 1978.

Fish biomass and abundance were greater in shaded than in unshaded areas when the re-

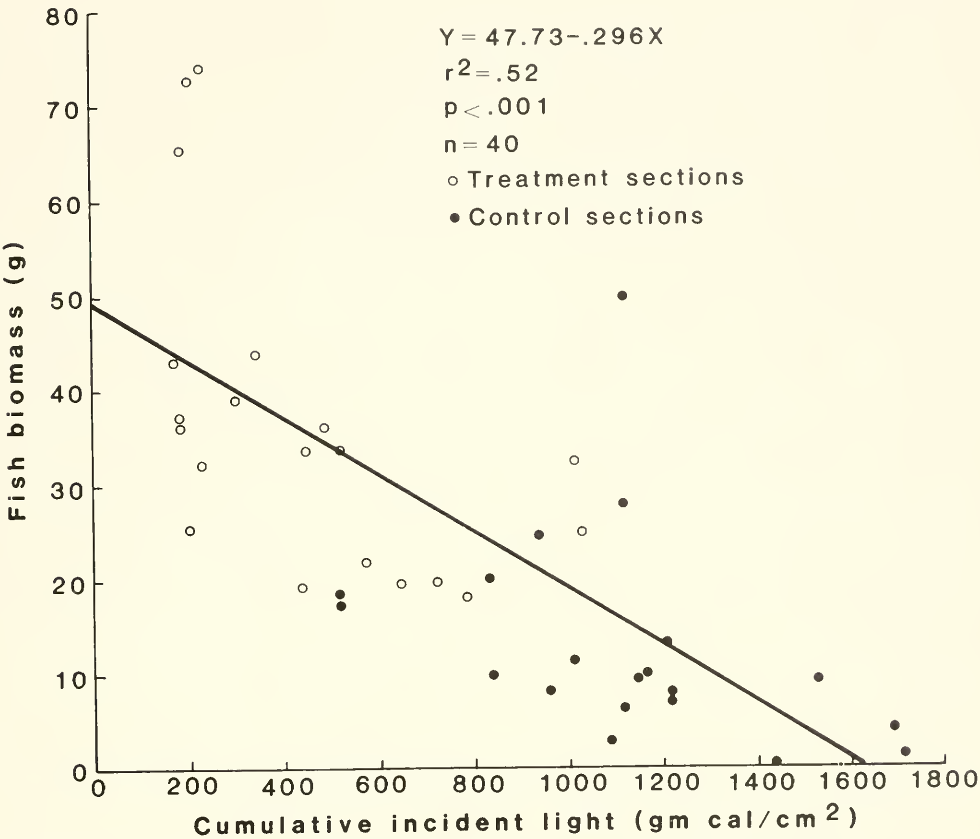

Fig. 9. Relation between cumulative incident light and fish biomass for all test runs, 1977 and 1978 combined.

sults of the June–August tests were pooled for 1977 and 1978 (Figs. 3, 4). Differences between years in fish response to shade were evident, particularly when tests of the shade–no shade choice were compared to tests of shade removal. These differences between years are less apparent when fish biomass and abundance are compared to cumulative incident light during the test runs (Table 2, Figs. 5, 6) and to incident light when the fish were captured (Table 3, Figs. 7, 8).

The only physical variable altered between the two years was the light transmittance of the saran screening. During the 1978 test, 75% shade was achieved, and 47% shade was maintained during the 1977 tests. The cumulative incident light and incident light values during the tests were about two times greater in the unshaded sections than in the shaded sections in 1977 and about four times greater in the unshaded sections than in the shaded sections in 1978 (Tables 2, 3). This corresponds to the difference in light transmittance through the screening between the two years. Although Hoar et al. (1957) determined that juvenile salmon were less photonegative than older fish, the relative age structure of the juvenile salmon used in our study was comparable between the two years and cannot be construed as an explanation of differences between years. The intensity of light, as measured by the pyranographs, was about 20% higher in 1978 than in 1977 (Tables 2, 3). If fish were negatively phototactic, we can hypothesize that the differences in abundance and possibly biomass between shaded and unshaded sections should have been even greater in 1978 than in 1977. This hypothesis was not clearly substantiated when the results for the percentage of fish biomass and abundance were evaluated without regard to incident and cumulative incident light (Figs. 3, 4). We can, however, infer that the hypothesis was substantiated when fish biomass and

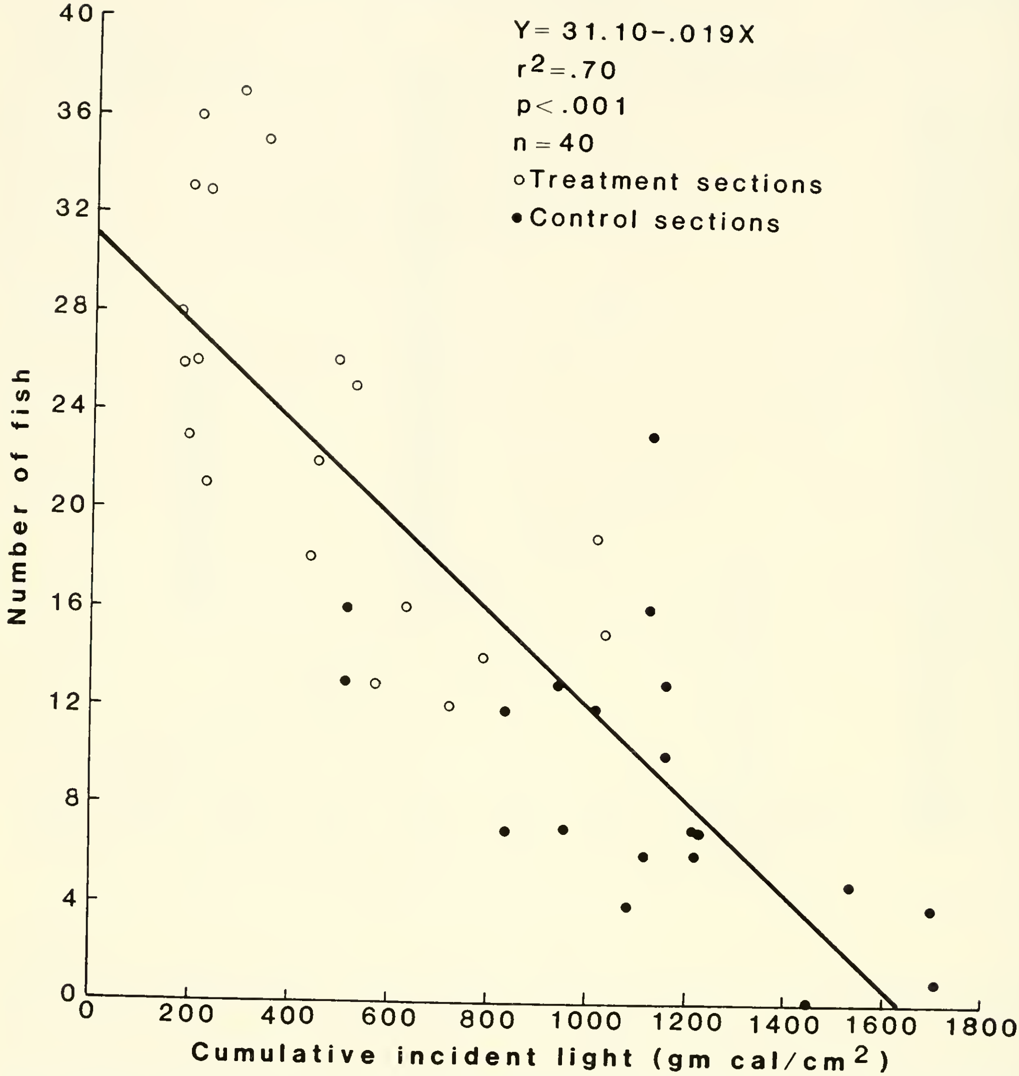

Fig. 10. Relation between cumulative incident light and fish abundance for all test runs, 1977 and 1978 combined.

abundance in relation to cumulative incident light (Figs. 5, 6) and to instantaneous incident light (Figs. 7, 8) were compared between the two years. The hypothesis was further substantiated when data from all tests for both years were combined; highly significant correlations were found between cumulative incident light and fish biomass and abundance (Figs. 9, 10). Chapman and Knudsen (1980) and Hawkins et al. (1983) report that reduced cover supports higher standing crops of salmonids in western streams. Although this is generally true, the studies cited earlier (for example, Gibson and Keenleyside 1966, Butler and Hawthorne 1968) have fairly well demonstrated that most salmonids seek shade cover, particularly at high light intensities. Standing crops may therefore be greater in unshaded stream reaches, but within those reaches, the fish probably seek out shaded habitats. We frequently observed fish maintaining position in the shade provided by the screen covers, but darting momentarily into the unshaded area to secure food and then returning to the shade.

Our results strongly suggest that shade is an important feature of stream habitat and influences the daytime distribution, abundance, and biomass of juvenile salmonids. Under the conditions of cover without form that we simulated and that occur naturally, shade may be a relatively more important feature than in habitats having cover with form, such as overhanging banks, logs, and other debris on or directly over the stream surface. These latter types of cover cast a shade mosaic on the stream surface and substrate that not only changes constantly with the changing angle of the sun but also affects a much smaller area than would general shade provided by a dense canopy of riparian vegetation.

The effectiveness and importance of shade as a cover feature for salmonids likely vary with fish species, age, and the species (or predator-prey) mix. We suggest that measuring cumulative incident light may be important in explaining the daytime distribution, abundance, and biomass of fishes that display strong territorial behavior, such as some salmonids. Validating this hypothesis is an area for future investigation.

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