AN EVALUATION OF HABITAT IMPROVEMENT STRUCTURES IN THE BOULDER RIVER, MONTANA

by

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APPROVAL

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VITA

Jon Michael Streu was born August 22, 1965 in Green Bay, Wisconsin to Glen Richard and Mary Harriet Denil Streu. He grew up in the Green Bay area and graduated from Preble High School of Green Bay in May, 1983. In May of 1988, he earned a Bachelor of Science degree in Zoology from the University of Wisconsin. In June of 1987, he began a Master of Science degree in Fish and Wildlife Management with the Montana Cooperative Fishery Research Unit at Montana State University.

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My gratitude also goes out to the faculty and graduate students of the Biology Department of Montana State University for the assistance throughout my stay there. Last, but not least, my thanks go out to my friends and family for their love and support which sustained me throughout my graduate career.

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ABSTRACT

The trout biomasses and selected physical parameters associated with five types of habitat improvement structures (HIS) were measured in a section of the Boulder River near Basin, Montana in 1987 - 1989. The study sites consisted of three log jetties, three check dams and their plunge pools, three boulder clusters, three log bank hides, four shore anchored habitat structures (SAHS), and two control sections (no structures). During the summer and fall seasons, sections with all types of HIS had mean total salmonid and rainbow trout biomasses that were significantly greater ($p<0.10$) than the means for the control sections, indicating HIS provided some improvement . Of the five structure types, check dams and log bank hides had the highest mean total salmonid and rainbow trout biomasses during the summer and fall seasons. Simple and stepwise regression procedures indicated that maximum associated depth (MAD), a measure of pool presence and depth, was the most important physical parameter explaining variation in both total salmonid biomasses. Check dams, bank hides, and boulder piles were the least expensive structure types to install. Check dams and bank hides were also the most physically durable of the five HIS types. The high relative attraction to salmonids, relatively low construction cost, and high physical durability indicate that check dams were the most advantageous form of habitat improvement structure.

INTRODUCTION

In 1983, the Montana Department of Highways (MDH) moved portions of the Boulder River above the town of Basin, Montana (Figure 1) from its natural channel into sections of artificially constructed channel. This was done to facilitate the construction of U.S. Interstate 15 through the Bernice - Basin canyon.

To enhance fish habitat in the artificial channel, the MDH installed a variety of habitat improvement structures (HIS). HIS are used to enhance the cover, depth, velocity, and pool-to-riffle ratios in a stream, thus improving the habitat for fish populations (Hunt 1971; Binns and Eisermann 1979; Wesche 1980).

Five different types of structures were installed. Log bank hides and shore anchored habitat structures (SAHS) were built to provide overhead cover by simulating undercut stream banks. Log and rock check dams were installed to create pools and thereby increase the stream's pool to riffle ratio. Log jetties and boulder clusters were installed primarily as current deflectors to increase channel depth, but also to function as HIS.

The performance of HIS have varied substantially on improving both physical habitat and fish populations. Babcock (1982) reported that rock dams, log dams, log deflectors, and boulder deflectors in Tenmile Creek,

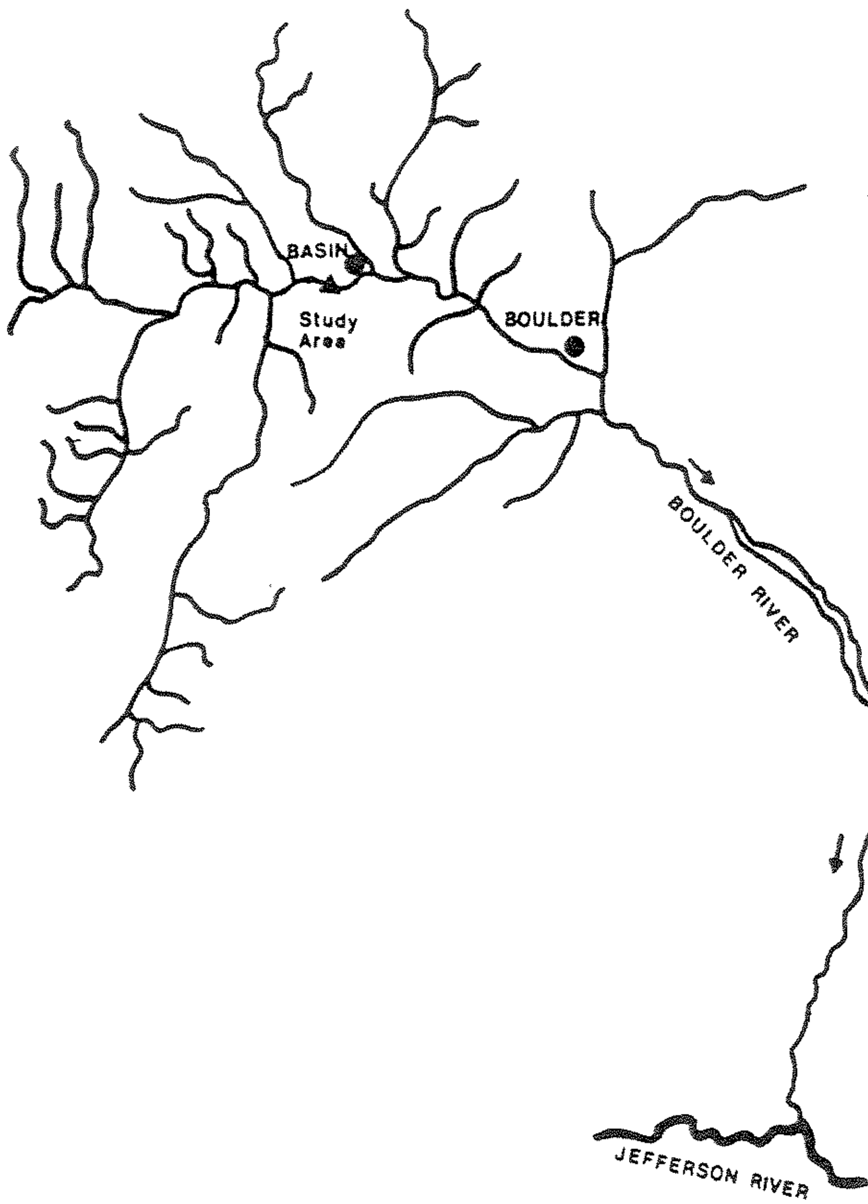

Figure 1. Map showing the location of the Boulder River study area (arrows indicate direction of flow).

Colorado, were providing little suitable physical habitat after 2 years. Elser (1970) found that rock jetties installed in altered portions of Prickley Pear Creek and the East Gallatin River, Montana provided physical habitat similar to that present in the prealteration channels of those streams although fish populations and biomasses showed marked postalteration reductions. In contrast, Schaplow (1976) found that trout populations and biomass in sections of the St. Regis River of Montana altered with step dams, random rocks, and jetties, were similar to those of unaltered sections. Lere (1982) noted varied results among three Montana streams improved with the emplacement of boulders and rock jetties. Trout biomasses and populations increased in altered sections of the St. Regis River but not in altered sections of Sheep Creek and Prickley Pear Creek (Lere 1982).

The purpose of this study was to evaluate the performance and characteristics of HIS types and of individual HIS in the Boulder River. Evaluation involved measuring the fish biomass, water depth, water velocity, and overhead cover associated with each of 16 study structures during spring, summer, and fall seasons. Of the five types of HIS constructed in the Boulder River, SAHS, log jetties, and log bank hides, have not been evaluated in Montana, previously. Analyses were implemented to identify the most productive HIS type and individual HIS and to identify the particular habitat features that made structures attractive or unattractive to fish. In addition, the durability and cost effectiveness of the structures were evaluated.

STUDY SITE

The Boulder River originates in the Boulder Mountains of Jefferson County in southwestern Montana at an approximate elevation of 2,200 m (Figure 1). It flows north for approximately 17 km then turns southeast near the town of Basin and enters the Jefferson River near the town of Cardwell. The average discharge of the Boulder River near the town of Boulder, for a 58 year period ending in 1988, was 11.8 m^3/s (U.S. Geological Survey 1988). Maximum and minimum discharges for that period were 98.8 m^3/s and 0.0 m^3/s, respectively. Annual precipitation averages approximately 90 cm at the town of Basin (North Boulder Drainage and Jefferson Conservation District 1975).

The study structures are located in two areas situated approximately 2.1 to 5.1 km upstream from Basin (Figure 1). Both areas are located above the section of river influenced by heavy metals (Nelson 1976). The lower area lies adjacent to U.S. Interstate 15. Its entire highway side consists of riprap, while the far side consists mainly of a narrow riparian zone and steep rock walls. There is no vegetative overhead cover. Stream width in this area varied from 12.2 m in June of 1988 to 3.2 m in August of 1987.

The upper study site has steep stream banks and lies in a flood plain containing greater amounts of riparian vegetation than the lower site. The dominant floodplain vegetation consisted of conifers and alders (Alnus spp.), but these provided little overhead cover. Stream width varied from 8.7 m in June of 1987 to 2.6 m in August of 1988.

Mean, maximum, and minimum measured discharges during the three study seasons were 0.71 m^3/s, 1.42 m^3/s, and 0.30 m^3/s, respectively. Seasonal discharges are presented in Figure 2. Dissolved oxygen concentrations, conductivity, and pH (Table 1) were similar to those found in the area by Nelson (1976). Alkalinity for this section of the Boulder River averaged a relatively low 40.6 mg/l $CaCO_3$ (Gardner 1977).

Table 1. Water chemistry measurements of the Boulder River during 1989. Number of measurements are in parentheses.

Characteristic	Upper section	Lower section
pH	6.96-7.22 (3)	6.85-6.86 (3)
Specific conductivity (umhos/cm)	150 (2)	148 (2)
Dissolved oxygen (mg/l)	10.0 (2)	10.0 (2)

Rainbow trout (Oncorhynchus mykiss) were the most

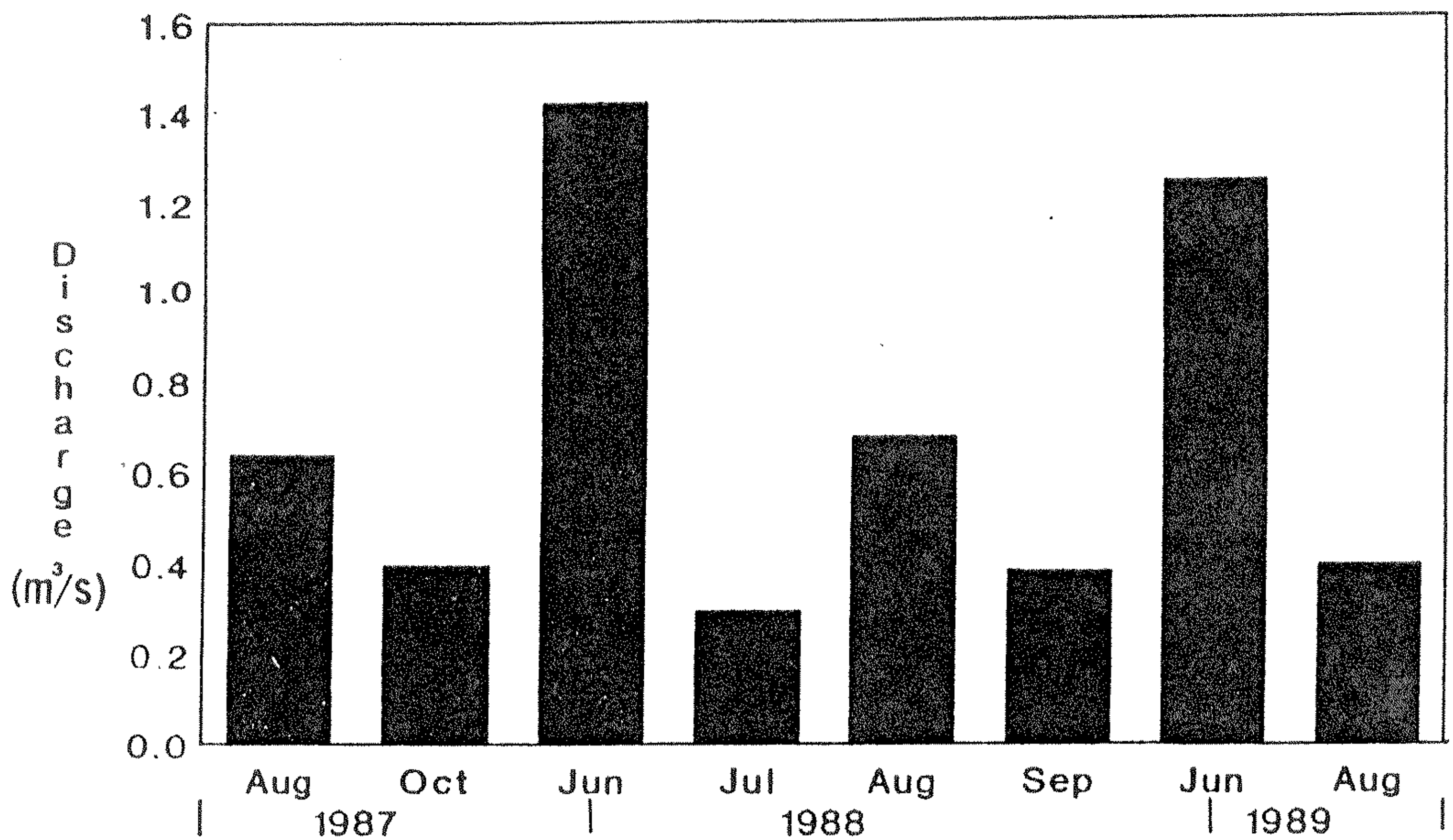

Figure 2. Monthly discharge data for the Boulder River, 1987-1989.

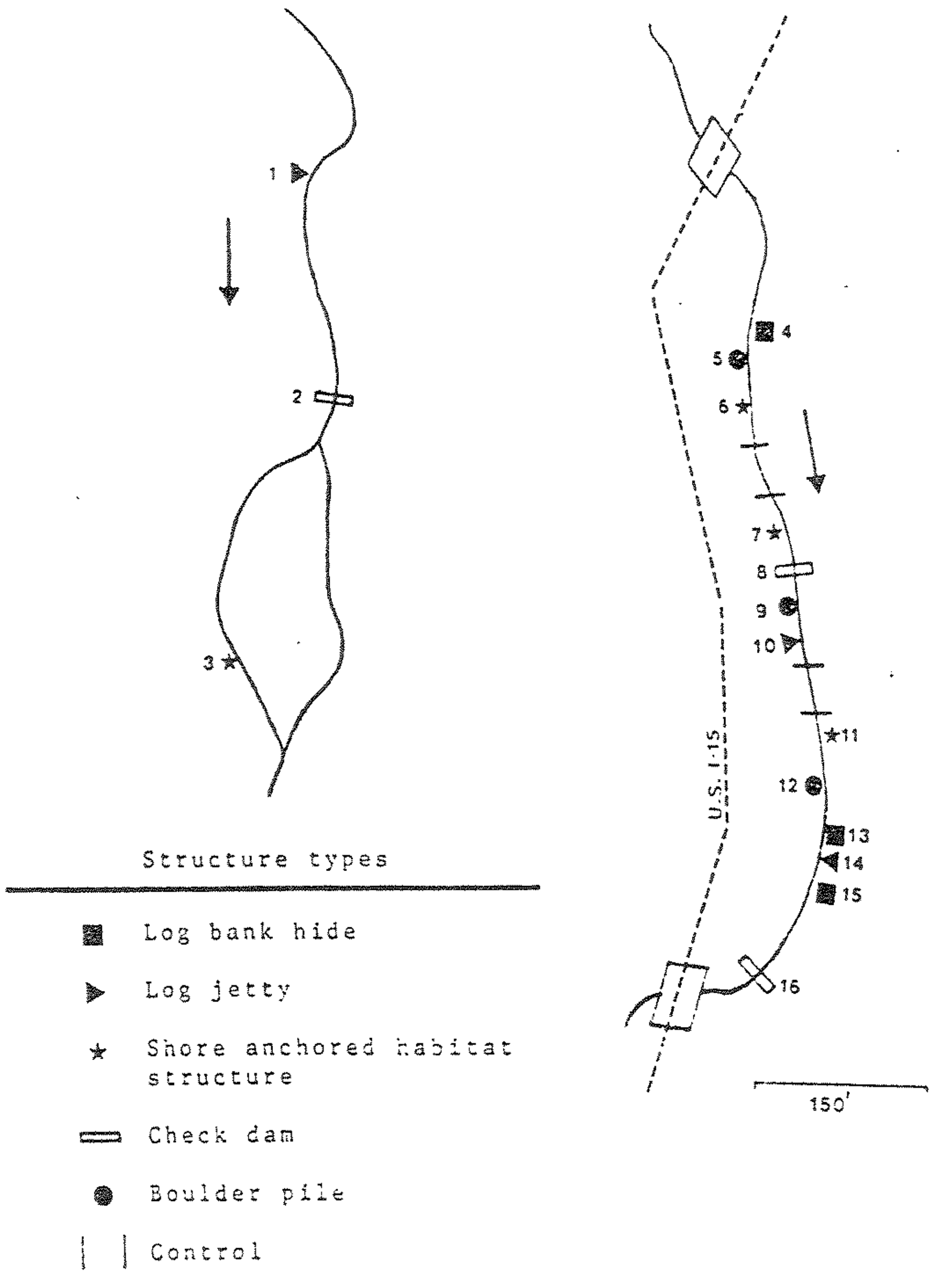

Figure 3. Upper (left) and lower (right) study sections showing general placement of study structures (arrows indicate direction of flow).

common salmonids in the study area. Brook trout (*Salvelinus fontinalis*), mountain whitefish (*Prosopium williamsoni*), and mottled sculpin (*Cottus bairdi*) were also present.

Sixteen structures were studied, thirteen in the lower area and three in the upper area (Figure 3). They consisted of four SAHS, three log bank hides, three log jetties, three boulder clusters, two rock check dams and one log check dam. Within a structure type, structures with differing physical features were selected. Two river sections with no structures were chosen for controls.

METHODS

Fish Biomass Measurements

Block nets were placed across the river immediately above and below each study structure and control section. The resulting enclosures were then electrofished with either a Coffelt Model BP-1C electrofishing unit or a bank electrofishing unit. Three passes were made over each enclosure as recommended by Armour and Platts (1983). Captured fish were anaesthetized, identified to species, measured to the nearest 1.0 mm total length (TL), and weighed to the nearest 1.0 g with an Ohaus Lume-O-Gram digital balance. Each rainbow trout over 200 mm was tagged with an individually numbered Floy T-tag. Recaptured fish with tags were used to obtain information on fish movements. Fish were released at the site where they had been collected.

Habitat Measurements

Water depth and water velocity along the edge of each structure and overhead cover were measured. The amount of overhead cover provided by each structure was determined by obtaining the average width and length of portions of the structure overhanging water greater than or equal to 15.0

cm in depth (Platts et al. 1987). Surface turbulence (bubbles) primarily associated with check dams, also was considered to be overhead cover (Armour and Platts 1983; Arnette 1976).

Depths and velocities at the edges of structures and around the circumferences of the boulder clusters were measured in accordance with the methods described in Armour and Platts (1983). The maximum associated depth (MAD) and the maximum associated velocity (MAV) were determined in the water adjacent to each structure. The distance from the MAD to the midpoint of the nearest HIS and distances between structures also were measured.

Parameters measured in each of the two control sections (no HIS) included maximum depth and velocity on a transect across the section. For the control sections, the maximum depth and maximum velocity in the section were used as the MAD and MAV, respectively.

All velocities were measured with a Teledyne Gurley Model 622 current meter at 0.6 depth. Depths were measured with either the current meter rod or a meter stick.

Statistical Analyses

Fish biomass associated with the structures fluctuated greatly by season so analyses were performed on a seasonal basis to limit variance. In addition, a log transformation of seasonal biomass data was utilized to eliminate the influence of non-constant variance in the data.

Tukey's studentized range test (Christensen 1987) was employed to identify significant differences among mean biomasses per structure type. Significant differences in biomass means were considered to occur at the alpha error level of 0.10.

Modified F-Tests (Christensen 1987) were used to determine whether structure types, measured physical variables, or both together, best explained the variation in rainbow trout biomass. To determine the effect of physical parameters on biomass the following equation was used:

$$F = \frac{SSE_1 - SSE_2 \ / \ d.f._1 - d.f._2}{SSE_2/d.f._2}$$

where SSE_1 = sum of squares error for model one containing rainbow trout biomass as the dependent variable and time factors as the independent variables.

SSE_2 = sum of squares error for model two containing rainbow trout biomass as the dependent variable and time factors and stream parameters as the independent variables.

To determine the effect of structure type the following equation was used:

$$F = \frac{SSE_1 - SSE_3 \ / \ d.f._1 - d.f._3}{SSE_3 \ / \ d.f._3}$$

Where SSE_1 = same as above

SSE_3 = sum of squares error for model three containing rainbow trout biomass as the dependent variable and the the time variables and structure types as the independent variables.

To eliminate variables not supplying useful information, the variable selection procedure STEPWISE, with a significance level of 0.10, in the SAS statistical computer package was utilized. Differences among the physical variables and the biomasses associated with individual HIS were analyzed with the COMP procedure in the MSUSTAT statistical analysis package (Lund 1987).

RESULTS

Biomass

The means of total salmonid biomass (Table 2) for each structure type were greater than the means for the control sections during all seasons. However, the only statistically significant differences occurred in the summer and fall.

Table 2. Means and standard deviations (in parentheses) for total salmonid biomasses* (g/m²) per habitat improvement structure (HIS) type on the Boulder River, 1987-1989.

	Season		
HIS type	Spring (June)	Summer (July and August)	Fall (October)
Check dams	7.04 (7.19)	56.40 (66.23)	32.02 (40.01)
Bank hides	5.88 (3.99)	32.49 (46.31)	28.16 (30.30)
SAHS**	9.71 (10.58)	18.63 (21.55)	22.61 (30.36)
Jetties	12.59 (12.82)	31.49 (27.01)	23.17 (18.53)
Boulder piles	3.12 (2.58)	14.34 (15.91)	13.91 (12.02)
Controls	1.49 (2.32)	1.93 (2.29)	2.32 (2.24)

* Includes rainbow trout, mountain whitefish, and brook trout.

** Shore-anchored habitat structure

The means of total biomasses at each HIS type during the summer, and at each HIS type except boulder piles during the fall, were significantly greater than means in the control sections. This indicated that, during summer and fall, study sections with HIS were more attractive to salmonids than those without HIS. No significant differences among the HIS types were present during either season.

The total salmonid biomasses captured at individual sites on each sampling date are given in Table 10 (Appendix). Comparisons of mean seasonal total salmonid biomasses for each individual structure and control (Table 3) indicated two significant differences . During the summer, log bank hide HIS 13 had a mean total salmonid biomass that was significantly greater than the means of log bank hides 4 and 15. During the fall, check dam HIS 16 had a mean total salmonid biomass significantly greater than the means for the check dams HIS 2 and 10 in the study.

Seasonal mean rainbow trout biomasses (Table 4) in sections with HIS were greater than means for the control sections during all collection seasons, indicating that the structures provided improved habitat for this species. However, as with the total salmonid biomasses, the only significant differences between the HIS and controls were found in the summer and fall.

Table 3. Seasonal mean total salmonid biomasses and standard deviations (in parentheses) for habitat improvement structures (HIS) and controls in the Boulder River, 1987 - 1989.

HIS	HIS type	Spring (June)	Summer (July and August)	Fall (October)
1	Jetty	0.00 (0.00)	31.97 (12.65)	9.28 (11.58)
2	Dam	10.34 (4.42)	20.25 (12.19)	14.31 (9.57)
3	SAHS	22.14 (15.32)	40.34 (34.76)	70.42 (11.53)
4	Hide	2.88 (3.68)	11.86 (10.77)	40.89 (43.82)
5	Pile	4.82 (3.94)	17.73 (19.64)	25.93 (9.28)
6	SAHS	3.66 (1.03)	1.91 (0.08)	3.63 (5.13)
7	SAHS	1.47 (1.20)	9.22 (2.75)	2.85 (1.62)
8	Dam	18.66 (7.44)	23.77 (29.02)	17.51 (13.92)
9	Pile	1.45 (0.59)	4.83 (2.58)	4.00 (2.42)
10	Jetty	2.04 (2.88)	6.27 (6.17)	5.16 (5.09)
11	SAHS	11.59 (4.57)	23.05 (7.13)	23.44 (6.69)
12	Pile	3.10 (2.48)	20.47 (20.27)	11.80 (11.68)
13	Hide	8.68 (5.43)	100.23 (8.43)	40.17 (28.78)
14	Jetty	19.11 (17.03)	38.72 (41.81)	42.74 (13.13)
15	Hide	6.08 (1.73)	5.77 (2.84)	6.89 (6.95)
16	Dam	8.76 (12.39)	125.42 (76.50)	76.60 (42.90)
C1	Control	0.04 (0.05)	0.39 (0.55)	0.42 (0.12)
C2	Control	2.95 (2.78)	3.48 (2.39)	1.93 (1.78)

During the summer, all structure types except SAHS had mean rainbow trout biomasses that were significantly greater than those of the control sections. Among HIS types, check dams had mean rainbow trout biomasses that were significantly greater than those associated with the boulder piles during the summer. During the fall, only check dams and bank hides had significantly greater mean rainbow trout biomasses than the control sections.

Table 4. Mean and standard deviations (in parentheses) for rainbow trout biomasses (g/m^2) per habitat improvement structure (HIS) type collected in the Boulder River, 1987-1989.

	Season		
HIS type	Spring (June)	Summer (July and August)	Fall (October)
Check dams	3.10 (7.08)	15.73 (10.33)	25.99 (29.61)
Bank hides	2.83 (2.20)	15.25 (14.50)	17.81 (21.08)
SAHS*	3.59 (3.49)	11.40 (20.91)	15.08 (18.56)
Jetties	0.65 (1.17)	17.04 (16.23)	11.07 (12.5)
Boulder piles	1.45 (2.04)	4.74 (5.38)	6.97 (6.36)
Controls	0.26 (.48)	1.42 (1.11)	1.06 (0.78)

* Shore-anchored habitat structures

Rainbow trout biomasses captured at each individual site on each sampling date are given in Table 11 (Appendix). As with total salmonid biomass, only two significant differences were present among the rainbow trout biomass means (Table 5). During the summer, log bank hide HIS 13 had a significantly greater mean rainbow trout biomass than the means for hides HIS 4 and 15. During the fall, the mean rainbow trout biomass for check dam HIS 16 was significantly greater than the means for the other check dams (HIS 2 and #10).

Physical Variables

During the springs of 1988 and 1989 there were no statistical differences between the mean measured physical parameters at individual structure. Physical parameter measurements at each individual structure at each sampling date are given in Appendix Tables 12-21. In addition, no significant differences were found between the structure types in the springs of 1988 or 1989 (Table 6).

Several statistically significant differences were present among the HIS types during the summers of the study (Table 7). The mean MAV for boulder piles in the summer of 1987 was significantly higher than in 1988 and 1989. SAHS had a significantly lower maximum velocity along their edges in 1988 than 1987 and 1989. Check dams had a significantly lower MAV in 1988 than in 1987. The lower velocities

Table 5. Seasonal mean rainbow trout biomasses and standard deviations (in parentheses) for habitat improvement structures (HIS) and controls in the Boulder River, 1987 - 1989.

HIS	HIS type	Spring (June)	Summer (July and August)	Fall (October)
1	Jetty	0.00 (0.00)	25.81 (22.88)	4.49 (4.80)
2	Dam	0.00 (0.00)	17.77 (10.00)	9.29 (2.48)
3	SAHS	8.14 (4.48)	30.83 (39.64)	42.49 (10.69)
4	Hide	2.88 (3.68)	8.46 (4.87)	17.05 (15.44)
5	Pile	1.52 (2.14)	6.39 (8.11)	10.02 (4.25)
6	SAHS	1.47 (2.07)	1.11 (1.00)	0.73 (1.03)
7	SAHS	1.47 (1.20)	4.43 (4.97)	1.45 (0.21)
8	Dam	1.46 (2.06)	14.49 (16.66)	6.24 (7.96)
9	Pile	0.00 (0.00)	1.99 (2.60)	1.36 (1.05)
10	Jetty	0.53 (0.74)	6.27 (6.17)	4.90 (5.46)
11	SAHS	3.31 (0.16)	9.23 (1.90)	15.67 (2.74)
12	Pile	2.82 (2.87)	5.84 (5.07)	9.54 (9.41)
13	Hide	2.71 (3.02)	33.78 (5.04)	33.74 (31.84)
14	Jetty	0.51 (0.71)	10.81 (8.33)	22.50 (17.33)
15	Hide	2.90 (1.23)	3.50 (1.10)	2.63 (0.93)
16	Dam	8.76 (12.39)	23.15 (8.11)	63.79 (6.59)
C1	Control	0.04 (0.05)	0.36 (0.56)	0.90 (0.80)
C2	Control	0.49 (0.69)	1.86 (1.74)	1.23 (1.03)

Table 6. Means (standard deviations in parentheses) of physical parameters for structure types and controls on the Boulder River during two springs (June).

Variable	Check dams 1988	Check dams 1989	Bank hides 1988	Bank hides 1989	SAHS* 1988	SAHS* 1989	Jetties 1988	Jetties 1989	Boulder piles 1988	Boulder piles 1989	Controls 1988	Controls 1989
Maximum velocity (m/s)	0.94 (0.26)	0.83 (0.40)	0.76 (0.19)	0.86 (0.51)	0.33 (0.17)	0.29 (0.19)	0.95 (0.38)	1.17 (0.22)	0.84 (0.39)	0.82 (0.33)	0.67 (0.01)	0.74 (0.18)
Minimum velocity (m/s)	0.12 (0.03)	0.14 (0.06)	0.14 (0.05)	0.28 (0.29)	0.08 (0.08)	0.06 (0.02)	0.11 (0.11)	0.31 (0.19)	0.02 (0.02)	0.05 (0.02)	0.00 (0.00)	0.11 (0.07)
Mean velocity (m/s)	0.42 (0.11)	0.51 (0.20)	0.42 (0.20)	0.48 (0.38)	0.17 (0.11)	0.14 (0.06)	0.60 (0.14)	0.63 (0.28)	0.33 (0.15)	0.32 (0.12)	0.36 (0.17)	0.43 (0.02)
Overhead cover (m^2)	13.16 (12.25)	13.13 (11.73)	0.51 (0.15)	0.87 (0.24)	4.68 (1.23)	4.01 (0.46)	6.07 (9.20)	8.02 (12.27)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
MAV** (m/s)	0.41 (0.47)	0.63 (0.33)	0.62 (0.16)	1.09 (0.57)	0.27 (0.08)	0.81 (0.59)	0.91 (0.34)	0.97 (0.44)	0.94 (0.20)	0.80 (0.30)	0.67 (0.01)	0.74 (0.18)
MAD*** (m)	0.69 (0.20)	0.92 (0.14)	0.66 (0.19)	0.67 (0.07)	0.66 (0.13)	0.63 (0.19)	0.67 (0.08)	0.67 (0.06)	0.63 (0.07)	0.61 (0.15)	0.52 (0.17)	0.42 (0.01)
Maximum depth (m)	0.64 (0.24)	0.70 (0.17)	0.60 (0.12)	0.58 (0.14)	0.76 (0.13)	0.67 (0.18)	0.69 (0.15)	0.71 (0.11)	0.62 (0.14)	0.67 (0.27)	0.52 (0.17)	0.42 (0.01)
Minimum depth (m)	0.13 (0.12)	0.24 (0.06)	0.37 (0.11)	0.36 (0.11)	0.38 (0.13)	0.31 (0.05)	0.14 (0.13)	0.13 (0.11)	0.31 (0.10)	0.27 (0.13)	0.0 (0.0)	0.0 (0.0)
Mean depth (m)	0.46 (0.17)	0.41 (0.13)	0.49 (0.12)	0.30 (0.04)	0.57 (0.06)	0.40 (0.05)	0.44 (0.05)	0.30 (0.10)	0.44 (0.07)	0.29 (0.08)	0.36 (0.13)	0.25 (0.10)
Ht. of cover (m)****	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.23 (0.17)	0.22 (0.18)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

* Shore-anchored habitat structures
** Maximum associated velocity
*** Maximum associated depth
**** Height of cover above water

Table 7. Means and standard deviations (in parentheses) for physical parameters of the structure types and controls on the Boulder River during the summers (July and August).

Variable	Check dams 1987	Check dams 1988	Check dams 1989	Bank hides 1987	Bank hides 1988	Bank hides 1989	Boulder piles 1987	Boulder piles 1988	Boulder piles 1989	SAHS 1987	SAHS 1988	SAHS 1989	Jetties 1987	Jetties 1988	Jetties 1989	Controls 1987	Controls 1988	Controls 1989
Maximum velocity (m/s)	0.66 (0.18)	0.39 (0.08)	0.66 (0.21)	0.25 (0.03)	0.46 (0.11)	0.35 (0.14)	0.23 (0.16)	0.20 (0.17)	0.19 (0.17)	1.22 (0.06)	0.64 (0.09)	1.29 (0.50)	0.53 (0.15)	0.24 (0.11)	0.39 (0.22)	0.52 (0.06)	0.31 (0.04)	0.35 (0.04)
Minimum velocity (m/s)	0.09 (0.02)	0.05 (0.08)	0.08 (0.03)	0.08 (0.02)	0.14 (0.05)	0.17 (0.13)	0.03 (0.03)	0.05 (0.06)	0.01 (0.01)	0.11 (0.08)	0.04 (0.06)	0.42 (0.27)	0.03 (0.03)	0.02 (0.03)	0.0 (0.0)	0.20 (0.22)	0.06 (0.09)	0.09 (0.12)
Mean velocity (m/s)	0.24 (0.05)	0.22 (0.07)	0.24 (0.07)	0.16 (0.01)	0.27 (0.08)	0.24 (0.07)	0.13 (0.08)	0.11 (0.09)	0.08 (0.06)	0.41 (0.02)	0.29 (0.01)	0.66 (0.15)	0.22 (0.09)	0.13 (0.08)	0.27 (0.13)	0.25 (0.11)	0.16 (0.07)	0.19 (0.07)
Overhead cover (m)	5.43 (4.47)	4.30 (5.22)	6.37 (5.12)	2.66 (.99)	0.61 (.79)	2.38 (4.13)	5.69 (2.52)	4.21 (1.74)	4.37 (1.47)	1.88 (.31)	2.82 (2.48)	2.38 (2.46)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
MAV** (m/s)	0.66 (0.19)	0.19 (0.09)	0.32 (0.10)	0.80 (0.27)	0.37 (0.14)	0.44 (0.24)	0.51 (0.13)	0.11 (0.05)	0.16 (0.05)	0.89 (0.35)	0.46 (0.15)	0.84 (0.18)	0.93 (0.21)	0.22 (0.13)	0.66 (0.17)	0.52 (0.06)	0.31 (0.04)	0.35 (0.04)
MAD*** (m)	0.59 (0.20)	0.60 (0.14)	0.54 (0.18)	0.48 (0.09)	0.50 (0.13)	0.45 (0.06)	0.52 (0.22)	0.55 (0.19)	0.54 (0.17)	0.60 (0.10)	0.55 (0.18)	0.51 (0.13)	0.53 (0.13)	0.50 (0.10)	0.45 (0.08)	0.40 (0.19)	0.34 (0.12)	0.35 (0.12)
Maximum depth (m)	0.63 (0.21)	0.49 (0.16)	0.55 (0.21)	0.46 (0.08)	0.45 (0.11)	0.37 (0.03)	0.53 (0.14)	0.52 (0.11)	0.48 (0.11)	0.65 (0.17)	0.45 (0.12)	0.51 (0.07)	0.57 (0.21)	0.46 (0.11)	0.47 (0.15)	0.40 (0.19)	0.34 (0.12)	0.35 (0.12)
Minimum depth (m)	0.13 (0.02)	0.10 (0.10)	0.11 (0.04)	0.24 (0.09)	0.23 (0.09)	0.18 (0.02)	0.26 (0.02)	0.25 (0.05)	0.24 (0.09)	0.19 (0.08)	0.05 (0.07)	0.10 (0.04)	0.14 (0.04)	0.15 (0.06)	0.13 (0.06)	0.14 (0.05)	0.07 (0.04)	0.09 (0.07)
Mean depth (m)	0.34 (0.12)	0.34 (0.12)	0.41 (0.13)	0.35 (0.07)	0.34 (0.11)	0.30 (0.04)	0.34 (0.09)	0.28 (0.08)	0.29 (0.08)	0.41 (0.10)	0.41 (0.06)	0.40 (0.05)	0.35 (0.08)	0.28 (0.03)	0.30 (0.10)	0.26 (0.13)	0.24 (0.11)	0.25 (0.09)
Ht. of cover (m)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.34 (0.19)	0.33 (0.25)	0.34 (0.18)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

present in 1988 are probably a result of the severe drought that year.

There were also statistically significant differences in mean physical parameters among HIS types in the falls (Table 8). The mean MAV for SAHS in the fall of 1988 was significantly lower than the mean MAV for SAHS in 1987. Again, this is probably attributable to the drought of 1988. Overhead cover for SAHS in the fall was significantly greater than in all structure types, except check dams. Bank hides rested on the substrate, eliminating overhead cover for this type of HIS.

Several physical variables at structures were significantly greater during springs than during summers. The MAD for both check dams and bank hides were significantly greater in the spring of 1989 than in the summer of 1989. The mean MAV for boulder piles was higher during the springs of 1988 and 1989 than during the summers of those years. Also, the MAV for both log jetties and controls were significantly higher in the spring of 1988 than the summer of 1988. These differences were caused by the higher spring flows.

Maximum velocities along the structure edge were significantly higher in the spring of 1988 than in the summer of 1988 for log jetties, controls, and check dams. Significantly higher maximum velocities were also

Table 8. Means (standard deviations in parentheses) of physical parameters for structure types and controls on the Boulder River during two falls (October).

Variable	Check dams		Bank hides		SAHS*		Jetties		Boulder piles		Controls	
	1987	1988	1987	1988	1987	1988	1987	1988	1987	1988	1987	1988
Maximum velocity (m/s)	0.37 (0.15)	0.70 (0.49)	0.29 (0.04)	0.41 (0.16)	0.24 (0.17)	0.14 (0.10)	0.69 (0.08)	0.65 (0.15)	0.45 (0.02)	0.46 (0.20)	0.40 (0.01)	0.53 (0.21)
Minimum velocity (m/s)	0.07 (0.04)	0.07 (0.03)	0.06 (0.03)	0.11 (0.07)	0.03 (0.01)	0.02 (0.03)	0.11 (0.08)	0.18 (0.14)	0.03 (0.01)	0.03 (0.03)	0.05 (0.04)	0.11 (0.02)
Mean velocity (m/s)	0.21 (0.07)	0.26 (0.07)	0.15 (0.03)	0.23 (0.08)	0.11 (0.09)	0.09 (0.06)	0.36 (0.21)	0.41 (0.15)	0.16 (0.07)	0.16 (0.09)	0.23 (0.07)	0.33 (0.06)
Overhead cover (m^2)	3.82 (3.39)	2.29 (2.45)	1.66 (0.66)	0.30 (0.53)	5.18 (2.23)	5.51 (2.27)	2.08 (0.64)	0.54 (0.54)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)
MAV** (m/s)	0.55 (0.18)	0.56 (0.15)	0.77 (0.38)	0.31 (0.07)	0.43 (0.17)	0.07 (0.05)	0.75 (0.25)	0.41 (0.19)	0.67 (0.37)	0.11 (0.09)	0.40 (0.01)	0.53 (0.21)
MAD*** (m)	0.51 (0.20)	0.51 (0.20)	0.42 (0.08)	0.48 (0.07)	0.43 (0.12)	0.57 (0.17)	0.43 (0.13)	0.46 (0.12)	0.50 (0.06)	0.47 (0.09)	0.31 (0.13)	0.21 (0.07)
Maximum depth (m)	0.51 (0.20)	0.54 (0.21)	0.40 (0.06)	0.41 (0.10)	0.48 (0.16)	0.51 (0.08)	0.53 (0.12)	0.48 (0.11)	0.41 (0.09)	0.42 (0.16)	0.31 (0.13)	0.21 (0.07)
Minimum depth (m)	0.09 (0.05)	0.03 (0.01)	0.20 (0.10)	0.11 (0.11)	0.16 (0.08)	0.26 (0.03)	0.27 (0.16)	0.03 (0.02)	0.13 (0.09)	0.14 (0.06)	0.08 (0.02)	0.03 (0.03)
Mean depth (m)	0.36 (0.11)	0.33 (0.10)	0.31 (0.06)	0.30 (0.09)	0.37 (0.10)	0.42 (0.05)	0.39 (0.15)	0.28 (0.01)	0.27 (0.07)	0.26 (0.08)	0.24 (0.11)	0.14 (0.01)
Ht. of cover (m)****	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.38 (0.16)	0.37 (0.16)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)	0.0 (0.0)

Structure type: all columns above.

* Shore-anchored habitat structure
** Maximum associated velocity
*** Maximum associated depth
**** Height of cover above water

present during the spring of 1989 for boulder piles and log jetties. SAHS had significantly higher maximum velocities during the summers of 1988 and 1989 than during the springs of those years, for some unexplained reason.

Maximum depth along the structure edge was greater for SAHS in the spring of 1988 than in the summer of 1988. It was also higher for log jetties during the spring of 1989 than during the summer of 1989. No other significant differences were present between variables for the spring and summer seasons. Most of these differences are probably related to the higher discharges present in the spring.

There were several significant differences between physical variables within HIS types during the summer and fall seasons. MAD, MAV and maximum velocity were significantly higher for SAHS during the summer than the fall of 1987. Maximum velocities along the edges of SAHS and log jetties were significantly higher in the fall of 1988 than the summer of 1988. Maximum velocity was also significantly higher for boulder piles during the fall than during the summer of 1987.

Surprisingly few significant differences occurred in the habitat variables in a comparison of spring and fall seasons. MAD for log jetties was significantly higher in the spring than in the fall of 1988. MAV was significantly higher for SAHS, boulder piles, and bank hides during the spring than during the fall of 1988. Maximum depths along the edges of bank hides and SAHS were significantly higher in the spring than in the fall of 1988. Again, these differences probably were caused by the higher spring flows.

Regressions

The modified F-tests used to test the significance of structure types and habitat variables indicated that both significantly contributed to the variation in total salmonid and rainbow trout biomasses. Each habitat variable was tested individually for significant associations with total salmonid and rainbow trout biomass by simple linear regression. This procedure indicated that the habitat variable MAD explained more of the seasonal variation in total salmonid biomass than any other single variable (Table 7). The coefficient of determination (R^2) for this habitat parameter doubled in value from spring (24%) to fall (48%). This increase was probably due to the increased value of pools during periods of decreased water flow.

Regressions for the habitat variables and rainbow trout biomass indicated minimum depth along the structure's edge (MINDPTH) accounted for the most variation (27%) in spring rainbow trout biomass (Table 7). During the summer and fall, MAD accounted for the greatest amounts of variation, 24 and 41%, respectively.

Stepwise multiple regression analyses of seasonal total salmonid biomasses and the measured physical variables produced the following equations. During the spring the best fit equation was:

Table 9. Seasonal coefficients of determination (R^2) per season between total salmonid biomass (rainbow trout in parentheses) and physical parameters for the Boulder River HIS and controls.

Parameter	Season: Spring (June)	Season: Summer (July and August)	Season: Fall (October)
Overhead cover (m^2)	0.15 (0.00)	0.27 (0.20)	0.08 (0.11)
Maximum velocity (m/s)	0.00 (0.04)	0.08 (0.06)	0.03 (0.00)
Minimum velocity (m/s)	0.01 (0.02)	0.02 (0.04)	0.02 (0.02)
Mean velocity (m/s)	0.00 (0.04)	0.12 (0.10)	0.01 (0.01)
Maximum depth (m)	0.14 (0.08)	0.30 (0.13)	0.44 (0.34)
Minimum depth (m)	0.09 (0.26)	0.01 (0.00)	0.00 (0.02)
Mean depth (m)	0.24 (0.23)	0.31 (0.17)	0.30 (0.24)
Height of structure (m)	0.04 (0.11)	0.00 (0.00)	0.00 (0.01)
MAD (m)	0.26 (0.11)	0.34 (0.24)	0.48 (0.41)
MAV (m)	0.02 (0.01)	0.10 (0.06)	0.05 (0.01)

$$Y = -0.97 + 0.05X_1 + 2.66X_2 + 2.28X_3$$

where: X_1 = MAD
X_2 = Overhead cover
X_3 = Minimum depth along the structures edge

This equation described 42% of the variation in total salmonid biomass.

During the summer, 62% of the variation in total salmonid biomass was described by the equation:

$$Y = -1.37 + 3.56X_1 + 0.15X_2 + 1.17X_3 + 0.48X_4 + 1.14X_5$$

where: X_1 = MAD
X_2 = Overhead cover
X_3 = Mean velocity along the structures edge
X_4 = Year
X_5 = MAV

In the fall, 51 % of the variation in total salmonid biomass was described by:

$$Y = -0.68 + 6.64X_1 + 2.04X_2$$

where: X_1 = MAD
X_2 = Minimum velocity along the structures edge.

A similar analysis for spring rainbow trout biomasses and physical variables produced the equation:.ls1

$$Y = -0.03 + 3.15X_1$$

where: X_1 = Minimum depth along the structures edge

This accounted for 26% of the variation in rainbow trout biomass. No other variables were included in the equation by the stepwise regression procedure.

During the summer, 48% of the variation in rainbow trout biomass was described by the equation:

$$Y = -1.52 + 0.63X_1 + 0.13X_2 + 2.49X_3 + 1.24X_4$$

where: X_1 = Year
X_2 = Overhead cover
X_3 = MAD
X_4 = MAV

During the fall, 41% of the variation in rainbow trout biomass was described by the equation:

$$Y = -0.82 + 6.10X_1$$

where: X_1 = MAD

Tagged Fish

Eighty-three rainbow trout were tagged during the 3 years of the study. Twenty recaptures (24%) of tagged fish were recorded, 11 within 6 weeks of the initial capture.

Eleven of the twenty marked fish were recaptured at or near (at an adjacent structure) the original tagging site. In addition, two rainbow trout were recaptured at or near their original capture site for 3 consecutive years. This indicates that some salmonids are returning each spring to a specific site.

Structural Integrity

Eight of the sixteen HIS evaluated in this study showed significant amounts of structural deterioration between their installation in 1983 and 1989. Two log jetties (HIS 1 and 14) have logs resting on the substrate thus, eliminating much of their available overhead cover). One log jetty (HIS 10) had logs above the water level at even the highest spring discharges and was, therefore, ineffective in deflecting currents or providing overhead cover.

During summer and fall, three boulder piles (HIS 5, 9, and 12) accumulated significant amounts of fine bottom materials on their downstream sides. This greatly reduced fish habitat quality.

Two SAHS (HIS 3 and 11) had developed holes in the fibrous material used to retain the soil and gravel which form the roofs of the SAHS.

DISCUSSION

Effectiveness of Structures

The average total salmonid and rainbow trout biomasses associated with structure types were lower and had higher variances in spring than those in the summer and fall. They were not significantly different from the controls. The lower spring biomasses may have been caused by the emigration of the salmonids out of the study area during the winter and the sampling of structures prior to their full summer-fall recolonization. Statistical analyses were not useful in identifying differences among structure types or important physical habitat factors associated with spring biomasses.

Analyses of summer and fall biomasses yielded more information. Comparison of mean total salmonid and rainbow trout biomasses in the five HIS types and the control sections during these two seasons indicated that all of the HIS types had significantly higher means than the control sections. This indicated that all types of HIS provided some habitat improvement.

Of the five HIS types, check dams and their attendant plunge pools and bank hides contained the greatest total salmonid and rainbow trout biomasses during the summer and fall sampling seasons. The depth of water in the plunge pools was probably the cause for the performance level of the check dams. The attractiveness of the log bank hides is not understood.

Lere (1982) found significant increases in cutthroat and brook trout biomasses in sections of the St. Regis River, installed with random boulders. However, no such increases occurred with boulder piles in the Boulder River. In the St. Regis River, boulders provided an increased amount of slow water habitat around their circumferences. However, much of the habitat on the downstream side of the boulder piles in the Boulder River was unavailable to fish because large amounts of sediment were deposited in these areas during the lower summer and fall discharges.

The design of the log jetties allowed sediments and woody debris to be deposited under those structures during the summer and fall. This severely reduced their potential for providing overhead cover. In addition, one of the original objectives of the jetties was to force the stream to meander more and create more pools. Pools were not formed and little meandering occurred because the channel was bordered by large riprap on the side adjacent to U.S. Interstate 15 and by a steep rock wall on the other side.

Addition of SAHS and the deepening of pools in Wisconsin streams increased standing crops of brook trout (age I and older) 86% (Hunt 1971). However, the SAHS in the Boulder River were not nearly as effective with rainbow trout. Rainbow trout in the Boulder River appeared to prefer pools to SAHS. Perhaps the depths under the SAHS may not have been great enough to be attractive to them.

Among all structures, the greatest summer and fall total salmonid biomasses and the greatest fall rainbow trout biomasses were associated with check dam HIS 16 and its plunge pool. During the summer, this structure also had the third greatest mean rainbow trout biomass. These standing crops identified this structure as the most productive of the 16 HIS studied in the Boulder River.

Important Physical Parameters

The explanatory powers of measured physical and chemical values differs among studies. In Wyoming, Wesche et al. (1987) explained 56% of the trout biomass variation with two variables (modified trout cover rating and the average annual base flow). Also in Wyoming streams, Binns and Eisermann (1979) predicted 96% of the variation in brown, rainbow, and brook trout standing crop with nine variables in their Habitat Quality Index (HQI). However, these variables only accounted for 9.2% of the biomass variation in southern Ontario streams (Bowlby and Roff 1986). The physical factors measured in this study varied seasonally and accounted for 42 - 62% of total salmonid biomass and from 26 - 48% of rainbow trout biomass during summer and fall, respectively.

The single most important habitat variable in explaining standing crops also differs among studies. In the present study, MAD (Maximum Associated Depth) was the most important single habitat variable in simple and multiple regression analyses accounting, for total salmonid and rainbow trout biomass in the summer and fall. MAD was a measure of both pool presence and depth, and became increasingly important as the seasons progressed from spring to fall. This reflected the increasing importance of pools as flows decreased (Figure 3). In Scarnecchia and Bergersen (1987) elevation of the stream explained more of the variation in trout standing stock than any other single variable. Channel width to depth ratio was most closely correllated with trout standing stock in Kozel et al. (1989).

The largest and deepest pools in both the upper and lower study sections (Figure 2) were below the check dam structures. They provided depth of water and surface turbulence which could be utilized as cover (Giger 1973). Depth of water in plunge pools was directly related to the total salmonid and rainbow trout biomasses. The pool with HIS 16 was the deepest, having a mean maximum depth of 0.76 m, and the most consistant in retaining that depth (S.D.=0.09m) and generally held the greatest biomass. Raleigh et al. (1984) noted the importance of pools to rainbow trout by including it in that species Habitat Suitability Index.

Cost of Structures

The average costs of types of habitat structures calculated from the construction contractor's estimates are shown in Table 10. Log bank hides, boulder piles, and check dams had similar estimated costs and were less expensive than the log jetties and SAHS. Since check dams and their plunge pools, and log bank hides had the greatest biomasses they were the most cost effective HIS types.

Table 10. Average estimated cost (costs obtained from 1983 construction estimates) per structure type for the HIS installed in the Boulder River, Montana.

HIS type	Average Cost
Log bank hide	$650.00
Log jetties	$1,000.00
Check dams (rock and log)	$650.00
Boulder piles	$650.00
SAHS*	$2,100.00

* Shore-anchored habitat structures

Durability of Structures

Johnson (1967) found that randomly placed boulders in Little Prickley Pear Creek, Montana were ineffective as HIS 4 years after installation because many became buried in the unconsolidated substrate. There seems to be little probability of the boulder piles in the Boulder River doing this as they generally rest on a layer of bedrock. With little chance of being buried, boulder piles in the Boulder River should endure in their present condition for many years. Lere (1982) found that boulders installed in the St. Regis River, Montana were functionally intact 8 years after installation.

Log jetties in the Kaweah River, California were still functionally intact 18 years after being installed (Ehlers 1956). They stayed highly functional as long as the ends of the structures were well anchored. Three jetties in the Boulder River appear to have logs that have either become elevated or depressed which indicates a loosening of the end piece anchors and a lack of long term durability.

In general, the SAHS in the Boulder River were physically intact, although two have developed openings in their roofs. During high spring discharges water was observed flowing over the tops of these structures. These flows are probably the cause of the openings and will undoubtedly exert a destructive influence over time.

The three log bank hides in the Boulder River showed no physical deterioration. No estimates of durability for this type of structure were found in the literature.

Log and rock check dams in the Boulder River appear to be physically intact. Frequently, erosion of the banks around the ends of the dam logs (endcutting) render them inoperative. This was not observed on Boulder River log dams. Log step dams can function for decades. In Sheep Creek, Montana Lere (1982) found several that were intact 19 years after installation.

Ehlers (1956) found that loose rock dams (similar in form and function to rock check dams) need frequent maintenance because rocks often became displaced during periods of higher discharge. No displacement of the rocks in Boulder River check dam was observed in this study probably because larger sized rocks were used in their construction.

CONCLUSIONS

1. All five types of HIS enhance the total salmonid and rainbow trout biomasses in the Boulder River to some degree. Check dams and bank hides appeared to provide the greatest enhancement.

2. The presence of a pool near the structure and the depth of that pool appear to be important to the success of the structure.

3. Check dams and bank hides are the most cost effective of the five types of HIS installed in the Boulder River.

4. Check dams and bank hides are the most durable of the structure types in the Boulder River.

5. Based on enhancement provided, relative cost, and durability, check dams and bank hides appear to be the best HIS for streams that lack pools such as the Boulder River.

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APPENDIX

Table 11. Total* salmonid biomasses (g/m²) associated with the habitat improvement structures (HIS) and controls (C1 and (C2) on the Boulder River.

	Month/year						
HIS	08/87	10/87	06/88	07/88	10/88	06/89	08/89
1	18.49	1.09	0.00	33.84	17.47	0.00	43.59
2	6.56	7.54	7.21	29.94	21.07	13.46	24.24
3	76.56	78.57	32.97	37.22	62.27	11.31	7.25
4	5.39	71.87	0.27	5.91	9.90	5.48	24.29
5	6.59	19.37	2.03	6.19	32.49	7.60	40.40
6	1.97	7.25	4.38	1.95	0.00	2.93	1.82
7	9.14	1.70	0.62	6.52	3.99	2.31	12.01
8	3.52	27.35	13.40	10.78	7.66	23.92	57.01
9	4.43	5.71	1.03	2.47	2.29	1.86	7.58
10	13.11	8.76	0.00	1.12	1.56	4.07	4.59
11	27.14	18.71	14.82	14.82	28.17	8.36	27.20
12	3.41	3.54	4.85	42.88	20.06	1.34	15.12
13	101.31	19.82	4.84	108.07	60.52	12.52	91.32
14	10.00	33.45	31.16	19.48	52.02	7.07	86.69
15	3.13	1.97	7.30	5.41	11.80	4.86	8.77
16	84.05	106.93	17.52	213.70	46.26	0.00	78.51
C1	0.15	0.50	0.00	0.00	0.33	0.07	1.01
C2	3.06	3.19	4.91	6.05	0.67	0.98	1.32

* Includes rainbow trout, brook trout, and mountain whitefish.

Table 12. Rainbow trout (g/m^2) biomasses associated with the habitat improvement structures (HIS) and controls (C1 and C2) on the Boulder River.

	Month/year						
HIS	08/87	10/87	06/88	07/88	10/88	06/89	08/89
1	0.00	1.09	0.00	33.84	7.88	0.00	43.59
2	6.26	7.54	0.00	22.82	11.04	0.00	24.24
3	76.56	34.93	4.97	8.81	50.05	11.31	7.09
4	5.39	27.97	0.27	5.91	6.13	5.48	14.08
5	2.67	7.01	0.00	0.81	13.02	3.03	15.70
6	0.00	1.45	0.00	1.95	0.00	2.93	1.37
7	3.49	1.59	0.62	0.00	1.30	2.31	9.81
8	0.00	11.87	2.91	10.78	0.61	0.00	32.69
9	0.35	2.10	0.00	0.64	0.61	0.00	4.99
10	13.11	8.76	0.00	1.12	1.04	1.05	4.59
11	7.16	13.73	3.42	10.90	17.61	3.19	9.64
12	0.43	2.88	4.85	10.49	16.19	0.79	6.61
13	39.53	11.22	4.84	30.12	56.25	0.57	31.68
14	10.00	10.24	0.00	2.92	34.75	1.01	19.51
15	2.62	1.97	2.03	3.15	3.29	3.77	4.74
16	28.88	59.13	17.52	13.88	68.45	0.00	26.70
C1	0.08	1.46	0.00	0.00	0.33	0.07	1.01
C2	0.86	1.96	0.00	3.87	0.50	0.98	0.85

Table 13. Maximum velocity (m^3/s) near the edges of the habitat improvement structures (HIS) and controls (C1 and C2) on the Boulder River.

	Month/year						
HIS	08/87	10/87	06/88	07/88	10/88	06/89	08/89
1	1.15	0.61	1.36	0.68	0.53	0.91	1.02
2	0.86	0.55	1.08	0.46	0.51	0.75	0.85
3	0.45	0.50	0.41	0.41	0.26	0.21	0.45
4	0.23	0.26	0.58	0.34	0.58	0.97	0.29
5	0.46	0.24	0.40	0.14	0.24	0.46	0.18
6	0.21	0.13	0.33	0.13	0.11	0.24	0.09
7	0.05	0.16	0.09	0.00	0.03	0.14	0.06
8	1.26	0.68	0.86	0.55	0.81	1.31	1.87
9	0.43	0.40	1.00	0.23	0.65	0.90	0.38
10	0.60	0.26	0.65	0.29	0.34	0.48	0.43
11	0.24	0.19	0.48	0.24	0.14	0.56	0.19
12	0.70	0.70	1.12	0.36	0.48	1.10	0.61
13	0.28	0.34	0.97	0.55	0.38	1.31	0.51
14	1.24	0.76	0.61	0.71	0.61	1.27	0.98
15	0.26	0.28	0.73	0.50	0.26	0.31	0.24
16	0.53	0.31	1.10	0.41	1.26	1.27	0.71
C1	0.48	0.40	0.68	0.27	0.38	0.61	0.33
C2	0.56	0.41	0.66	0.34	0.68	0.86	0.38

Table 14. Minimum velocity (m^3/s) near the edges of the habitat improvement structures (HIS) and controls (C1 and C2) on the Boulder River.

	Month/year						
HIS	08/87	10/87	06/88	07/88	10/88	06/89	08/89
1	0.06	0.06	0.11	0.00	0.08	0.14	0.51
2	0.11	0.11	0.11	0.00	0.11	0.09	0.09
3	0.03	0.05	0.03	0.00	0.03	0.05	0.00
4	0.09	0.09	0.09	0.11	0.18	0.11	0.11
5	0.00	0.03	0.03	0.00	0.03	0.05	0.00
6	0.08	0.03	0.08	0.06	0.06	0.05	0.03
7	0.00	0.03	0.03	0.00	0.00	0.05	0.00
8	0.19	0.06	0.21	0.11	0.11	0.26	0.11
9	0.03	0.05	0.00	0.05	0.06	0.03	0.00
10	0.08	0.03	0.09	0.00	0.05	0.13	0.11
11	0.03	0.03	0.19	0.13	0.00	0.09	0.00
12	0.06	0.03	0.05	0.00	0.00	0.06	0.00
13	0.08	0.03	0.19	0.19	0.11	0.61	0.33
14	0.06	0.21	0.00	0.00	0.34	0.51	0.63
15	0.06	0.06	0.14	0.11	0.05	0.13	0.09
16	0.08	0.06	0.16	0.14	0.06	0.21	0.05
C1	0.36	0.08	0.00	0.13	0.09	0.16	0.18
C2	0.05	0.03	0.00	0.00	0.13	0.06	0.00

Table 15. Mean velocity (m^3/s) near the edges of the habitat improvement structures (HIS) and controls (C1 and C2) on the Boulder River.

	Month/year						
HIS	08/87	10/87	06/88	07/88	10/88	06/89	08/89
1	0.387	0.194	0.747	0.277	0.244	0.479	0.730
2	0.291	0.288	0.479	0.177	0.227	0.462	0.311
3	0.232	0.237	0.160	0.177	0.177	0.127	0.160
4	0.150	0.177	0.210	0.194	0.311	0.294	0.194
5	0.146	0.096	0.177	0.046	0.064	0.227	0.064
6	0.134	0.083	0.160	0.079	0.079	0.111	0.064
7	0.024	0.042	0.046	0.000	0.027	0.079	0.027
8	0.418	0.277	0.579	0.311	0.445	0.462	0.495
9	0.211	0.144	0.328	0.144	0.244	0.277	0.160
10	0.194	0.164	0.294	0.177	0.210	0.344	0.244
11	0.119	0.088	0.311	0.177	0.079	0.227	0.094
12	0.316	0.238	0.479	0.210	0.177	0.462	0.277
13	0.173	0.122	0.599	0.361	0.227	0.914	0.411
14	0.428	0.599	0.481	0.294	0.529	0.948	0.764
15	0.152	0.150	0.462	0.244	0.144	0.227	0.194
16	0.248	0.181	0.479	0.294	0.344	0.730	0.177
C1	0.328	0.277	0.479	0.210	0.294	0.411	0.244
C2	0.165	0.177	0.244	0.111	0.378	0.445	0.144

Table 16. Maximum velocity (m^3/s) associated (MAV) with the habitat improvement structures (HIS) and controls (C1 and C2) on the Boulder River.

	Month/year						
HIS	08/87	10/87	06/88	07/88	10/88	06/89	08/89
1	1.102	0.914	0.747	0.411	0.629	0.479	1.018
2	0.445	0.546	0.160	0.277	0.462	0.780	0.227
3	0.613	0.633	0.361	0.177	0.127	0.177	0.160
4	0.881	0.579	0.797	0.529	0.311	0.445	0.361
5	0.780	0.378	0.713	0.079	0.000	0.512	0.579
6	0.328	0.277	0.194	0.094	0.079	0.562	0.160
7	0.512	0.311	0.311	0.046	0.000	0.948	0.094
8	0.479	0.462	0.680	0.344	0.344	1.307	0.663
9	0.831	0.546	1.085	0.344	0.144	0.797	0.546
10	0.764	0.730	0.948	0.210	0.730	0.244	0.294
11	0.599	0.495	0.227	0.127	0.064	1.562	0.210
12	1.169	1.085	1.018	0.244	0.177	1.102	0.847
13	1.018	1.205	0.579	0.311	0.378	1.307	0.713
14	1.085	0.881	1.307	0.629	0.261	1.135	0.428
15	0.495	0.512	0.479	0.277	0.227	1.528	0.244
16	0.780	0.378	0.111	0.094	0.495	0.864	0.428
C1	0.000	0.000	0.000	0.000	0.000	0.000	0.000
C2	0.000	0.000	0.000	0.000	0.000	0.000	0.000

Table 17. Maximum depth (m) in waters associated (MAD) with the habitat improvement structures (HIS) and controls (C1 and C2) on the Boulder River.

	Month/year						
HIS	08/87	10/87	06/88	07/88	10/88	06/89	07/89
1	0.62	0.37	0.70	0.54	0.46	0.70	0.53
2	0.63	0.52	0.67	0.59	0.54	0.80	0.58
3	0.84	0.55	0.78	0.80	0.65	0.82	0.68
4	0.39	0.34	0.56	0.35	0.40	0.60	0.44
5	0.66	0.55	0.62	0.55	0.55	0.78	0.50
6	0.38	0.34	0.59	0.44	0.43	0.42	0.40
7	0.37	0.31	0.52	0.36	0.42	0.51	0.38
8	0.50	0.34	0.57	0.38	0.34	0.60	0.37
9	0.40	0.44	0.57	0.38	0.37	0.50	0.36
10	0.38	0.31	0.50	0.47	0.30	1.08	0.34
11	0.49	0.52	0.76	0.58	0.58	0.76	0.68
12	0.52	0.52	0.70	0.57	0.48	0.54	0.48
13	0.56	0.49	0.75	0.57	0.53	0.74	0.40
14	0.69	0.58	0.92	0.74	0.58	0.70	0.62
15	0.54	0.43	0.67	0.57	0.51	0.66	0.52
16	0.77	0.70	0.90	0.74	0.69	0.88	0.70
C1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C2	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 18. Height (m) of habitat improvement structures (HIS) and controls (C1 and C2) above the water on the Boulder River.

	Month/year						
HIS	08/87	10/87	06/88	07/88	10/88	06/89	08/89
1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
2	0.00	0.00	0.00	0.00	0.00	0.00	0.00
3	0.56	0.58	0.41	0.58	0.58	0.41	0.57
4	0.00	0.00	0.00	0.00	0.00	0.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	0.38	0.38	0.29	0.42	0.36	0.30	0.37
7	0.32	0.37	0.20	0.33	0.33	0.17	0.27
8	0.00	0.00	0.00	0.00	0.00	0.00	0.00
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	0.00	0.00	0.00	0.00	0.00	0.00	0.00
11	0.11	0.19	0.00	0.00	0.19	0.00	0.14
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	0.00	0.00	0.00	0.00	0.00	0.00	0.00
14	0.00	0.00	0.00	0.00	0.00	0.00	0.00
15	0.00	0.00	0.00	0.00	0.00	0.00	0.00
16	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C2	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Table 19. Maximum depth (m) near the edges of the habitat improvement structures (HIS) and controls (C1 and C2) on the Boulder River.

	Month/year						
HIS	08/87	10/87	06/88	07/88	10/88	06/89	08/89
1	0.74	0.55	0.75	0.49	0.54	0.82	0.53
2	0.63	0.52	0.59	0.54	0.51	0.74	0.50
3	0.70	0.64	0.81	0.65	0.59	0.91	0.62
4	0.39	0.34	0.49	0.33	0.31	0.51	0.34
5	0.76	0.43	0.76	0.57	0.59	0.96	0.60
6	0.41	0.34	0.58	0.46	0.46	0.56	0.42
7	0.42	0.34	0.88	0.41	0.42	0.50	0.36
8	0.46	0.40	0.52	0.32	0.36	0.60	0.44
9	0.34	0.31	0.49	0.34	0.27	0.44	0.30
10	0.42	0.31	0.44	0.32	0.35	0.51	0.38
11	0.58	0.58	0.76	0.54	0.57	0.70	0.52
12	0.60	0.49	0.61	0.47	0.40	0.60	0.51
13	0.56	0.46	0.72	0.55	0.51	0.74	0.37
14	0.76	0.64	0.81	0.55	0.54	0.72	0.57
15	0.44	0.40	0.59	0.47	0.40	0.50	0.40
16	0.84	0.70	0.90	0.62	0.77	0.84	0.78
C1	0.26	0.21	0.40	0.25	0.20	0.41	0.26
C2	0.53	0.40	0.64	0.42	0.21	0.40	0.43

Table 20. Minimum depth (m) near the edges of the habitat improvement structures (HIS) and controls (C1 and C2) on the Boulder River.

	Month/year						
HIS	08/87	10/87	06/88	07/88	10/88	06/89	08/89
1	0.22	0.46	0.18	0.02	0.02	0.06	0.06
2	0.11	0.15	0.01	0.00	0.04	0.20	0.16
3	0.25	0.06	0.43	0.26	0.24	0.36	0.20
4	0.14	0.09	0.25	0.13	0.05	0.31	0.18
5	0.17	0.21	0.41	0.19	0.21	0.42	0.20
6	0.28	0.25	0.36	0.30	0.28	0.31	0.32
7	0.27	0.18	0.20	0.27	0.30	0.34	0.30
8	0.10	0.15	0.25	0.13	0.02	0.26	0.12
9	0.16	0.02	0.221	0.08	0.11	0.20	0.10
10	0.14	0.06	0.14	0.10	0.02	0.31	0.08
11	0.25	0.15	0.51	0.18	0.23	0.24	0.12
12	0.10	0.15	0.30	0.17	0.10	0.19	0.10
13	0.31	0.24	0.47	0.30	0.24	0.48	0.19
14	0.25	0.21	0.00	0.00	0.06	0.06	0.12
15	0.28	0.28	0.38	0.25	0.04	0.28	0.16
16	0.13	0.06	0.24	0.19	0.02	0.20	0.10
C1	0.10	0.09	0.00	0.04	0.05	0.11	0.04
C2	0.17	0.06	0.00	0.10	0.01	0.04	0.14

Table 21. Mean depth (m) near edges of habitat improvement structures (HIS) and controls (C1 and C2) on the Boulder River.

	Month/year						
HIS	08/87	10/87	06/88	07/88	10/88	06/89	08/89
1	0.38	0.49	0.48	0.29	0.28	0.49	0.20
2	0.34	0.38	0.45	0.34	0.31	0.48	0.40
3	0.51	0.47	0.62	0.47	0.44	0.61	0.46
4	0.28	0.24	0.39	0.24	0.24	0.43	0.26
5	0.42	0.33	0.51	0.35	0.35	0.56	0.37
6	0.35	0.32	0.52	0.40	0.40	0.50	0.38
7	0.31	0.26	0.52	0.33	0.35	0.46	0.33
8	0.26	0.22	0.39	0.24	0.18	0.41	0.29
9	0.25	0.20	0.38	0.19	0.20	0.33	0.22
10	0.23	0.24	0.30	0.22	0.24	0.44	0.29
11	0.48	0.42	0.63	0.43	0.47	0.59	0.41
12	0.34	0.27	0.44	0.31	0.22	0.40	0.28
13	0.41	0.35	0.63	0.45	0.41	0.61	0.33
14	0.41	0.47	0.46	0.30	0.38	0.52	0.40
15	0.35	0.35	0.46	0.34	0.26	0.42	0.30
16	0.46	0.45	0.63	0.45	0.43	0.61	0.54
C1	0.16	0.16	0.27	0.16	0.15	0.29	0.18
C2	0.35	0.32	0.45	0.32	0.13	0.24	0.32

Table 22. Overhead cover (m^2) created by the habitat improvement structures (HIS) and controls (C1 and C2) on the Boulder River.

	Month/year						
HIS	08/87	10/87	06/88	07/88	10/88	06/89	07/89
1	1.56	1.56	0.85	0.38	0.55	0.68	0.66
2	5.23	3.40	24.24	2.79	2.00	23.63	7.62
3	5.16	4.30	4.53	4.34	3.88	3.38	3.93
4	2.07	0.98	0.42	0.00	0.00	1.00	0.00
5	0.00	0.00	0.00	0.00	0.00	0.00	0.00
6	3.91	3.80	3.86	3.25	4.73	4.15	3.65
7	4.31	4.11	3.86	2.64	4.55	4.47	3.36
8	2.18	2.80	16.69	4.65	1.08	22.18	5.20
9	0.00	0.00	0.00	0.00	0.00	0.00	0.00
10	1.07	0.65	0.00	0.00	0.00	0.47	0.75
11	9.39	8.50	6.45	6.60	8.87	4.02	6.54
12	0.00	0.00	0.00	0.00	0.00	0.00	0.00
13	3.80	2.30	0.68	1.50	0.91	0.60	7.15
14	1.90	1.90	0.67	0.00	0.00	1.19	1.28
15	2.10	1.70	0.42	0.32	0.000	1.02	0.00
16	10.00	7.40	15.24	10.10	4.88	15.30	10.75
C1	0.00	0.00	0.00	0.00	0.00	0.00	0.00
C2	0.00	0.00	0.00	0.00	0.00	0.00	0.00