3.0 SUITABILITY CRITERIA SELECTION, TESTING, AND DEVELOPMENT

3.1 Habitat Suitability Criteria and Species Periodicity

Initially, brook trout, brown trout, white sucker, blacknose dace, and slimy sculpin were considered as possible evaluation species for this study. White sucker, blacknose dace, and slimy sculpin were considered because they can serve as forage species for trout and frequently occur with trout in coldwater streams. HSC are available for all life stages of white sucker (Twomey and others, 1984). However, white sucker adults are not generally abundant in many of the small headwater trout streams used in this study. Only a limited number of HSC have been developed for blacknose dace and slimy sculpin, and HSC do not exist for all life stages (Sheppard and Johnson, 1984; Mecum, 1984; Trial and others, 1983). Brook and brown trout are the most recreationally and economically important species in the study streams. For that reason, only brook and brown trout were used as evaluation species.

Existing brook and brown trout HSC from the following sources were considered for use in this study: Bovee (1978, oral communication, 1994); Aceituno and others (1985); Raleigh and others (1986); Jirka and Homa (1990); Harris and others (1992); Normandeau Associates Inc. (1992); and Gary Whelan, Michigan Department of Natural Resources (oral communication, 1994).

3.1.1 <u>Depth and velocity criteria</u>

The same depth and velocity HSC were used for brook and brown trout, for transferability testing because the literature indicated very little difference in the criteria for these species. Velocity criteria based on mean water column velocity were used throughout this study. Nose velocity HSC were not used in this study, and were not considered for transferability testing.

The criteria selected for testing are summarized in Table 3.1 and included in Figures 3.1-3.8 (pages 44-51). For adults and juveniles, Normandeau Associates'(1992) depth and velocity HSC were tested. For spawning, Whelan's (oral communication, 1994) depth and velocity HSC were tested. The spawning life stage includes redd (nest) construction, egg incubation, and immature trout to the time of emergence from the substrate.

For brook and brown trout fry, Normandeau Associates'(1992) depth and mean column velocity HSC were originally proposed for transferability testing. However, based on general observations made in the field, SRBC staff believed the Normandeau HSC for fry would not be transferable to the study streams. The Normandeau HSC indicated a suitability index of 1 (optimum) at water depths of 1.31 to 1.61 feet. During field investigations, most fry were observed in shallower water, although deeper water was available. Also, the Normandeau HSC indicated that areas with no current velocity had a suitability index of 0 (unusable). In the field, many fry were found in areas with little or no velocity. The fry criteria in the literature cited above were reexamined, resulting in the conclusion that the Bovee (1978) HSC were more realistic and consistent with the field observations. Bovee's (1978) brown trout fry depth and velocity HSC were used for transferability testing for both brook and brown trout fry.

Table 3.1. Depth and Velocity Habitat Suitability Criteria Used for Transferability Testing

Depth Habitat Suitability Criteria								Velocity Habitat Suitability Criteria							
Normandeau (1992)		Normandeau (1992)		Whelan (1994)		Bovee (1978)		Normandeau (1992)		Normandeau (1992)		Whelan (1994)		Bovee (1978)	
Adult		Juvenile		Spawning		Fry		Adult		Juvenile		Spawning		Fry	
Depth	Index	Depth	Index	Depth	Index	Depth	Index	Velocity	Index	Velocity	Index	Velocity	Index	Velocity	Index
ft		ft		ft		ft		ft/sec		ft/sec		ft/sec		ft/sec	
0	0	0	0	0	0	0.12	0.10	0	0.21	0	0.58	0	0	1.10	1.00
1.00	0	0.50	0.12	0.10	0.08	0.40	0.40	0.10	0.70	0.10	0.88	0.10	0.34	1.20	0.94
1.60	0.40	1.00	0.61	0.20	0.22	0.60	0.93	0.50	1.00	0.50	1.00	0.20	0.72	1.65	0.52
2.00	0.80	2.00	0.84	0.30	0.50	0.85	1.00	1.00	0.69	1.00	0.92	0.30	0.84	2.00	0.30
2.60	1.00	3.00	1.00	0.40	0.96	1.70	1.00	1.50	0.50	1.50	0.70	0.60	1.00	2.20	0.20
4.00	1.00	4.00	0.27	0.50	1.00	1.90	0.97	2.40	0.20	2.00	0.26	1.70	1.00	2.50	0.10
7.00	0.21	7.00	0.24	1.10	1.00	2.20	0.80	3.10	0.03	3.50	0.05	3.00	0	2.65	0.05
100.00	0.21	8.00	0.08	3.00	1.00	2.50	0.54	5.00	0.03	4.30	0			3.00	0
		100.00	0.08	4.00	0	2.70	0.44	6.00	0	100.00	0				
						2.90	0.38	100.00	0						
						3.10	0.36								
						3.25	0.33								
						3.75	0.14								
						4.20	0.08								
						4.70	0.05								
						5.00	0								

3.1.2 Substrate/cover criteria

The substrate and cover classification schemes shown in Table 3.2 were used in this study. Combined substrate/cover HSC, that were tested are shown in Table 3.3. Both the classification scheme and the HSC were based on professional judgment of the investigators. Substrate and cover combinations were identified based on a two-digit coding system. The first digit referred to the substrate type, and the second digit referred to the cover type. Fifteen substrate/cover combinations were therefore possible. For example, substrate/cover type 1.1 consists of silt or sand with no cover, type 1.2 consists of silt or sand with object cover, and so forth.

Table 3.2. Classification Scheme for Substrate and Cover

Substrate Type

1 - Diameter of <3 mm. (silt, sand)
2 - Diameter of 3 mm.–64 mm.
3 - Diameter of >64 mm.

Cover Type

1 - No cover
2 - Object at least 6 inches high and with a cross section horizontal measurement of at least 1 foot
3 - Undercut object along bank
4 - Aquatic vegetation
5 - Terrestrial vegetation <1 foot above water surface

Table 3.3. Substrate/Cover Habitat Suitability Criteria Used for Transferability Testing

Substrate/ Cover Codes	Spawning HSC	Fry HSC	Juvenile HSC	Adult HSC
1.1	0	0.5	0.5	0.5
1.2	0	1	0.8	0.8
1.3	0	1	1	1
1.4	0	1	0.8	0.8
1.5	0	1	0.8	0.8
2.1	1	0.5	0.5	0.5
2.2	1	1	0.8	0.8
2.3	1	1	1	1
2.4	1	1	0.8	0.8
2.5	1	1	0.8	0.8
3.1	0	1	0.8	0.5
3.2	0	1	0.8	0.8
3.3	0	1	1	1
3.4	0	1	0.8	0.8
3.5	0	1	0.8	0.8

3.1.3 Periodicity chart

One important component of the Instream Flow Study is the recognition of specific time periods when the various life stages of each species will be present in the study streams, which is called periodicity. The periodicity chart, shown in Table 3.4, was developed after reviewing pertinent literature and discussing brook and brown trout life history information with PFBC and Penn State University fisheries biologists.

Table 3.4. Periodicity Chart for Brook and Brown Trout

	Month											
Life Stage	**Jan.**	**Feb.**	**Mar.**	**Apr.**	**May**	**June**	**July**	**Aug.**	**Sep.**	**Oct.**	**Nov.**	**Dec.**
Adult	x	x	x	x	x	x	x	x	x	x	x	x
Juvenile	x	x	x	x	x	x	x	x	x	x	x	x
Spawning	x	x								x	x	x
Fry			x	x	x	x						

3.2 Selection of Study Streams for Transferability Testing

Lanka and others (1987) state that trout stream habitat in the Rocky Mountains is greatly influenced by drainage basin geomorphology. Similarly, Nelson and others (1992) found trout distribution in the North Fork Humboldt River drainage area of northeastern Nevada to be related to geologic district and land type association.

The physical and biological characteristics of reproducing trout streams vary greatly among physiographic regions in Pennsylvania, as well as between limestone and freestone streams. No one stream could be selected for HSC modeling that contained all habitat types found in reproducing brook and brown trout streams in the commonwealth. Transferability testing could not be performed for all study streams described in section 4.0 because of resource limitations. To evaluate whether the HSC could be transferred to the study streams, it was assumed that if the HSC could be transferred to one stream in each study region, they also could be transferred to other streams in the same study region. In the Ridge and Valley Limestone region, only one stream (Big Spring Creek, Cumberland County) was identified that has only a reproducing brook trout population. For that reason, that region and species combination was not considered for transferability testing. Therefore, transferability studies were proposed for one stream from each of the following categories:

- Ridge and Valley Limestone study region, reproducing brown trout stream;
- Ridge and Valley Freestone study region, reproducing brown trout stream;
- Ridge and Valley Freestone study region, reproducing brook trout stream;
- Unglaciated Plateau study region, reproducing brown trout stream; and
- Unglaciated Plateau study region, reproducing brook trout stream.

Streams with reproducing trout populations were identified from PFBC data (PFBC, 1993). The criteria used for selecting potential streams for transferability testing were a drainage area of less than 100 square miles, large numbers of reproducing trout, excellent water quality and visibility, and good structural and hydraulic diversity. To facilitate trout identification during sampling, an attempt was made to select streams that did not contain significant numbers of more than one trout species

Field reconnaissance, including electrofishing, was performed in the streams shown in Table 3.5. Results are shown in the table.

Based on the reconnaissance, Elk Creek, Cherry Run, Little Fishing Creek, Young Womans Creek, and Whitehead Run were initially selected as study streams. Both Young Womans Creek and Elk Creek are relatively large streams, compared to the other streams selected. Elk Creek was deleted from the study because of limited water clarity and time and cost constraints. Also, a transferability study on a second large stream would have required more resources than were available.

The study streams finally selected represented the Ridge and Valley Freestone and Unglaciated Plateau study regions.

All four study sites are located on forested land, and classified by the PFBC as Class A Wild Trout Waters. PFBC had not stocked the streams with hatchery trout in recent years.

3.3 Description of Study Streams

3.3.1 Cherry Run

Cherry Run originates from a spring in Bald Eagle State Forest, Hartley Township, Union County, Pa. The stream flows in a southwesterly direction into Centre County, continuing onward in that direction until bending towards the southeast to pass through a gap in Paddy Mountain. From the gap, the stream continues in a southeasterly direction, flowing back into Union County and discharging into Penns Creek, about 3.2 miles southwest of Weikert in Hartley Township.

The portion of Cherry Run selected as a study site is about 4 miles long, extending from the mouth upstream through Centre County to the Centre-Union County line. The drainage area at the downstream limit of the study site is 5.9 square miles.

3.3.2 Little Fishing Creek

Little Fishing Creek originates on Nittany Mountain in Bald Eagle State Forest, Spring Township, Centre County, Pa. The stream flows in a northeasterly direction through Hecla Gap, and enters the Nittany Valley at Mingoville in Walker Township. The stream continues onward in a northeasterly direction into Clinton County, where it discharges into Fishing Creek near Lamar, Porter Township.

The portion of Little Fishing Creek selected as a study site is about 4.6 miles long, and extends from Hecla Gap upstream above the Greens Valley Roadbridge. The drainage area at the downstream limit of the study site is 5.9 square miles. Althoughparts of the Little Fishing Creek Watershed are underlain by limestone rocks, this part is underlain by freestone rocks.

3.3.3 Young Womans Creek

Young Womans Creek originates in Sproul State Forest at the confluence of Baldwin Branch and County Line Branch in Chapman Township, Clinton County,Pa. The stream flows in a southerly direction, entering the West Branch Susquehanna River at North Bend in Chapman Township. The U.S. Geological Survey's stream gaging station No. 01545600 is located on Young Womans Creek, about 3.7 miles upstream from the mouth and 1.5 miles upstream from Left Branch Young Womans Creek, which is the largest tributary.

Table 3.5. Streams Considered for Transferability Study

Stream Name	County	Study Region	Expected Trout Species	Date Sampled	Results of Reconnaissance Sampling
Little Fishing Creek	Centre	Ridge and Valley Freestone	Brook	May 16, 1994	Large numbers of brook trout adults, juveniles and fry. Excellent habitat diversity and water clarity.
Elk Creek	Centre	Ridge and Valley Limestone	Brown	May 16, 1994	Large numbers of brown trout, some brook trout. Good habitat diversity, limited water clarity.
Cherry Run	Centre and Union	Ridge and Valley Freestone	Brown	May 16, 1994	Many adult and juvenile brown trout. Excellent habitat diversity and water clarity.
Young Womans Creek	Clinton	Unglaciated Plateau	Brown	May 19, 1994	Large numbers of adult and juvenile brown trout. Excellent habitat diversity and water clarity.
John Summerson Branch	Clinton	Unglaciated Plateau	Brook	May 19, 1994	Insufficient numbers at sampling site near mouth. More abundant upstream according to PFBC, but access to that area was poor.
Trout Run	Clinton	Unglaciated Plateau	Brook	May 19, 1994	Insufficient numbers of fish.
Lost Creek	Juniata	Ridge and Valley Freestone	Brown	June 9, 1994	Large numbers of adult brown trout, relatively few juveniles and fry. Significant numbers of adult brook trout. Excellent habitat diversity and water clarity.
Wallace Run	Centre	Ridge and Valley Freestone	Brown	June 20, 1994	Small numbers of fish. Mixed population of about half brook and half brown trout.
Swift Run	Mifflin	Ridge and Valley Freestone	Brown	June 20, 1994	Mixed population about half brook and half brown trout.
Grove Run	Cameron	Unglaciated Plateau	Brook	June 21, 1994	Large numbers of brook trout, many brown trout.
Montour Run	Clinton and Cameron	Unglaciated Plateau	Brook	June 21, 1994	Insufficient numbers of fish.
Whitehead Run	Cameron	Unglaciated Plateau	Brook	June 21, 1994	Large numbers of brook trout, easily accessible. Good habitat diversity and water clarity. A few brown trout.
Laurel Run	Union	Ridge and Valley Freestone	Brown	June 22, 1994	Mixed population of brook and brown trout. Streambank shading made observations difficult.
Lackawanna River	Lackawanna	Ridge and Valley Freestone	Brown	June 23, 1994	Mixed population of brook, brown, and rainbow trout. Good habitat diversity. Trash and household debris caused health and safety concerns.

The portion of Young Womans Creek selected as a study site extends from the vicinity of the U.S. Geological Survey stream gaging station upstream about 5.2 miles to the vicinity of Beechwood Trail. The drainage area upstream from the gaging station is 46.2 square miles.

3.3.4 Whitehead Run

Whitehead Run originates in Elk State Forest about 4.3 miles northeast of Cameron in Lumber Township, Cameron County, Pa. The stream flows in a westerly direction to meet Hunts Run in Lumber Township.

The entire length of Whitehead Run, including its major tributary, Rock Run, was selected as the study site. The drainage area at the downstream end of the study site is 4.4 square miles.

3.4 Field Data Collection

3.4.1 Procedures

Transferability studies were conducted using the general methodology described by Thomas and Bovee (1993). Field work was performed in general accordance with the field manual, which is included as Appendix A of this report. Microhabitat measurements were taken at locations where undisturbed fish were observed, and in randomly-selected locations where fish were absent.

Bovee (1986) identified size-class as a good method for classifying groups of fish for HSC development. For the purpose of this investigation, fish less than 2 inches in total length were considered to be fry; fish between 2 and 6 inches long were considered juveniles; and fish 6 or more inches long were considered adults. This size stratification scheme is consistent with that cited in most of the HSC literature listed in section 3.1. Spawning locations were identified by the presence of a totally- or partially-completed redd (nest).

All sampling was performed during daylight hours. Sampling was not performed during extremely low flows when habitat diversity was limited, or during extremely high flows when observations would have been difficult or dangerous. At least one flow measurement was taken near the downstream end of the sampling area on all trips, except the spawning sampling trip to Cherry Run, when the flow was estimated.

Equal areas of all mesohabitat types were sampled, regardless of which mesohabitat types were most abundant, or had the greatest concentrations of fish. The locations of all undisturbed fish (or redds) at each mesohabitat sampling site were marked, and appropriate data were recorded.

If two (nonspawning) fish were located within 1 foot of each other, they were considered to be in the same location (PHABSIM cell), and only one set of microhabitat measurements was taken. If a group of fish had individuals less than a foot apart, but the group was spread out over 2 or more feet (which occurred on some occasions with fry), several measurements were made within the occupied area at locations spaced a foot apart. Sampling for adults, juveniles, and fry was generally performed by a three-person crew. However, a four-person crew was used on a few of the juvenile and adult sampling trips, allowing two crew members to simultaneously make microhabitat measurements, and thereby speed up the data collection process. A two-person crew was used for all field trips involving spawning adult fish.

Snorkel gear, surface observations, and electrofishing were used to observe fish locations, which were documented. When identifying fish locations, a conscious effort was made to avoid fish fright and investigator bias.

The effectiveness of using snorkel gear to make direct underwater observations of undisturbed fish has been well documented (Bovee, 1986; Bovee and Zuboy, 1988). For this reason, snorkel gear was used to the maximum extent possible in making in-situ observations of adults, juveniles, and fry for the transferability studies. Snorkel gear was used extensively, and was the preferred means of identifying adult, juvenile, and fry locations in Young Womans Creek. However, the method could not be effectively used in Whitehead Run and Cherry Run, because nearly all of the sampling area were too shallow to sample with snorkel gear. For the same reason, snorkel gear could not be effectively used to sample adult and juvenile locations in Little Fishing Creek, but was used to a limited extent to sample fry locations in pool habitat during higher water conditions. For habitat types that could not be effectively sampled with snorkel gear, surface observations and electrofishing were used to identify fish locations.

When making observations with snorkel gear, the diver used his hands and legs to pull or push quietly along the bottom, moving systematically in an upstream direction to identify the locations of undisturbed fish. In deep water and in areas with extremely fast current, the diver pulled himself through the study reach on a rope, which had been previously anchored.

Surface observations were used in clear, shallow water to locate fish or redds at each mesohabitat sampling site. Because of low flow conditions and excellent water clarity, surface observations were the only means used to identify spawning locations. The observer wore drab or camouflage clothing, and made a cautious approach in an upstream direction through the sampling area, taking care not to frighten fish. Surface observations were generally made with the aid of polarized sunglasses. In some instances, binoculars also were used to assist in making surface observations.

Electrofishing was generally performed with a backpack DC shocker and two hand-held electrodes. However, an AC shocker was used on one of the adult/juvenile sampling trips to Cherry Run, due to equipment malfunction. A rat-tail probe was used as one of the electrodes when sampling fry on all streams, except Young Womans Creek, because of equipment problems. For each point sampled, the electrodes were carefully positioned, the electrical current was then activated, and the locations of fish identified. If necessary, fish were collected with a dipnet for identification or measurement. All collected fish were returned to the stream.

Fish and redd locations were marked with a lead fishing sinker, to which a numbered piece of plastic surveyor's tape was attached. The date, time, mesohabitat type, observation technique, marker tag number, species, length, and life stage were recorded. A copy of the field data sheets used for occupied locations is shown as Appendix 3 of the field manual for HSC transferability testing.

After fish and redd locations were marked, water depth was measured and recorded to the nearest 0.01 foot, using a top-setting rod equipped with a current meter. The number of cup rotations per unit of time was recorded on the data sheet so that mean current velocity for each location could be calculated. Where the water depth was less than 2.5 feet, one current meter reading was taken at six-tenths of the distance from the water surface to the stream bottom. Where the water depth was greater than 2.5 feet, one current meter reading was taken at two-tenths and another reading was taken at eight-tenths of the distance from the water surface to the stream bottom. The results of the two velocities were averaged. Water temperature in degrees Celsius was periodically measured and recorded.

Before removing the fish location markers from the stream bottom, a random sampling procedure was used to select locations that were unoccupied by fish. The procedure is described in Appendix A.

Unoccupied locations were not selected within 1 foot of an occupied location. Data were collected and recorded on a copy of the field data sheet for unoccupied locations, shown as Appendix 4 of the field manual.

The dates of field observations and a record of streamflow measurements are shown in Table 3.6. Relatively large variations in streamflow occurred in Young Womans Creek due to rain and thunderstorm activity. On some occasions, sampling had to be delayed until water clarity improved and stream conditions stabilized. Under these circumstances, care was taken to avoid delays in taking microhabitat measurements after occupied and unoccupied locations were identified, because of changing flow conditions.

3.4.2 General observations

Young Womans Creek was ideally suited for use of snorkel gear. Excellent water clarity normally allowed a diver to spot adult fish that were more than 20 feet away, if they were approached cautiously by moving in an upstream direction. The tendency of fish to remain in position when approached by a diver varied with the life stage, water conditions, current velocity, and cover being used by the fish and diver at the time of observation. In general, adult fish were more difficult to approach than juveniles, and juveniles were more difficult to approach than fry. As a general rule, adult fish in open, moving water could be approached to within about 10 feet before showing fright reactions (ceasing to feed on drifting material, making jerky or tense body movements, preparing to dart away, gradually moving away from the diver, etc.). When cover was available, adult trout could be approached even more closely. Some large brown trout resting under rock ledges could almost be touched by the diver. Many juveniles continued to feed when only a few feet from the diver, and some fry could be approached to within inches of theface mask.

Initially, only brown trout data were collected when sampling for adults and juveniles in Young Womans Creek. However, both brook trout and brown trout were observed in the stream. During the second field visit, microhabitat data were collected for both species.

In Young Womans Creek, positive species identification of undisturbed adults and juveniles was an easy matter because of excellent underwater visibility, the magnification effect caused by looking through the diver's mask, and the fact that fish were moving naturally with fins spread and markings easily visible. Species identification of fry was dependent on being able to see a dark spot on the adipose fin of brook trout. This spot is not present on brown trout. Eighty-nine fry locations were sampled in Young Womans Creek. However, because of the small size of the fry (0.75 to 1.25 inches) and the fact that many of the smaller fish were heavily pigmented, field identification to the species level was not always possible. Thirty-three of the fry from these locations were identified as brook trout, 14 were identified as brown trout, and 42 could not be accurately identified.

In Young Womans Creek, brook trout seemed to be more commonly associated with pool habitat, while brown trout appeared to be more closely associated with cover. Brown trout were more abundant in the lower region of the study area (in the vicinity of the U.S. Geological Survey gaging station). Brook trout were more abundant in upstream areas (from Bull Run upstream to the vicinity of Beechwood Trail).

Table 3.6. Sampling Dates and Streamflow Measurements

Type of Fish/ Dates Sampled and Streamflow	Cherry Run	Little Fishing Creek	Young Womans Creek	Whitehead Run
Adult/Juvenile Sampling, First Data Set				
Dates Sampled	July 25-27, 1994	July 11-13, 1994	July 6,7,8,13, & 14, 1994 July 20-21, 1994 August 8-9, 1994	July 18-20, 1994
Streamflow	1.68 cfs (July 25, 1994)	1.54 cfs (July 11, 1994)	110 cfs (July 6, 1994) 80 cfs (July 7, 1994) 47 cfs (July 13, 1994) 45 cfs (August 8, 1994)	4.84 cfs (July 20, 1994)
Adult/Juvenile Sampling, Second Data Set				
Dates Sampled	August 22-25, 1994	September 6-8, 1994	August 10-11, 1994 August 15-17, 1994	August 29-31, 1994 September 1, 1994
Streamflow	5.90 cfs (August 23, 1994)	2.80 cfs (September 8, 1994)	36 cfs (August 10, 1994) 31 cfs (August 11, 1994) 219 cfs (August 15, 1994) 186 cfs (August 16, 1994) 153 cfs (August 17, 1994)	9.58 cfs (September 1, 1994)
Spawning Sampling				
Dates Sampled	November 3-4, 1994 November 7-8, 1994	October 18-21, 1994	October 24-26, 1994	October 10-14, 1994
Streamflow	4 cfs (estimated)	2.21 cfs (October 21, 1994)	12 cfs (October 24, 1994)	0.78 cfs (October 14, 1994)
Fry Sampling				
Dates Sampled	April 17-19, 1995	April 24-26, 1995	May 8-11, 1995	May 1-3, 1995
Streamflow	6.73 cfs (April 19, 1995)	8.15 cfs (April 24, 1995)	27 cfs (May 8, 1995) 26 cfs (May 10, 1995) 156 cfs (May 11, 1995)	2.20 cfs (May 3, 1995)

During all of the field trips to Little Fishing Creek, the only species of trout observed was brook trout. Some brown trout were observed during the fall in the lower portion of Whitehead Run, but the predominant species present was brook trout. The predominant species present in Cherry Run was brown trout, although some brook and rainbow trout also were observed.

When identifying redd locations, it was important to look very carefully for gravel that had been disturbed. In many cases, the pit (depression) and tailspill (downstream area of loose gravel) of redds were difficult to identify, especially if the redd was small and not recently constructed. Because small brook trout make small redds, it was necessary to look carefully in even small pockets of gravel. The tailspills for some redds were only slightly larger than the 6- or 7-inch long fish that made them. Larger fish made larger redds, and some brown trout redds in Young Womans Creek were found with tailspills that were more than a foot long. Redds were frequently found in the tails of pools, but they were found in all mesohabitat types (riffles, runs, and pools).

As recommended by Dr. Robert Carline of Penn State University, field crews used a walking stick to poke into potential redd locations to determine if the sediments were loose and may have been excavated by trout. It was often possible to dislodge eggs to confirm the site was, in fact, a redd by digging with the stick to a depth of several inches (depending on the size of the redd). Crews initially dug into the bottom sediments by hand to confirm redd locations, and used a fine-meshed screen colander to catch dislodged eggs. However, digging with a walking stick was just as effective, and was much less damaging to redds.

Redds were much easier to identify with good lighting (such as during the middle of a sunny day) and when there was little or no wind to create a surface disturbance on the water. Most redds were found in relatively flat, shallow water. However, some were found in areas with almost no flow, and a few were found in relatively choppy water. Side channels seemed to be especially productive locations, probably because flow was reduced and gravel was more abundant in many of these areas. Redds were more easily identified when they were occupied by fish.

Although brown trout were actively constructing redds when Cherry Run was sampled for spawning, no eggs were recovered from redd locations. For this reason, it was assumed that sampling had been conducted at the beginning of the spawning period.

Eggs were recovered from redds on all three of the other streams sampled. Based on the appearance of redds and the activity of fish, sampling was conducted somewhat after the peak spawning activity on Little Fishing Creek and Whitehead Run. Many brown trout were found occupying redds in Young Womans Creek, indicating sampling probably occurred during the time of peak spawning activity. Although a few brook trout also were seen on redds in Young Womans Creek, the majority of redds observed in that stream were made by brown trout.

3.5 Transferability Study Data Analysis Procedures

Field data were used to perform transferability testing of HSC in accordance with the procedures cited by Thomas and Bovee (1993). The number of occupied and unoccupied sites (cells) having optimum usable, suitable, and unsuitable habitat were calculated for the appropriate study streams, species, and life stages. For this test, optimum habitat was assumed to have a suitability index of 0.8 or more, and suitable habitat was assumed to have a suitability index of 0.1 or more (Bovee, oral communication, 1994). One-sided chi-square tests (alpha = .05) were performed using the formula shown below.

$$T = \frac{\sqrt{N}\,(ad - bc)}{\sqrt{(a+b)(c+d(a+c)(b+d)}}$$

where: T = the test statistic
a = the number of occupied optimum (or suitable) cells;
b = the number of occupied usable (or unsuitable) cells;
c = the number of unoccupied optimum (or suitable) cells;
d = the number of unoccupied usable (or unsuitable) cells; and
N = the total number of cells.

To be considered transferable, the test statistic had to be greater than 1.6449.

For the purpose of data analysis, all redds observed in Young Womans Creek were assumed to be brown trout redds, unless brook trout were observed at a particular redd location. Insufficient brook trout redds were observed to warrant use of data from these redds for transferability testing.

Brook, brown, and unidentified fry data from Young Womans Creek were considered collectively for the purpose of transferability testing.

3.6. Transferability Study Data Analysis Results

Transferability testing indicated the HSC discussed in section 3.1 were not transferable to most of the streams tested. The results of transferability testing are summarized in Table 3.7. Chi-square test results used in compiling Table 3.7 are shown in Appendix B.

Table 3.7. Results of Transferability Testing

Stream and Species	Life Stage	Transferable?
Cherry Run, Brown Trout	Adult	No
	Juvenile	No
	Spawning	No
	Fry	No
Little Fishing Creek, Brook Trout	Adult	No
	Juvenile	No
	Spawning	No
	Fry	No
Young Womans Creek, Brown Trout	Adult	Yes
	Juvenile	No
	Spawning	No
	Fry (Brook and Brown)	No
Young Womans Creek, Brook Trout	Adult	Yes
	Juvenile	No
Whitehead Run, Brook Trout	Adult	No
	Juvenile	No
	Spawning	No
	Fry	No

3.7 Criteria Development

3.7.1 Procedures

Because only a few of the HSC were transferable, the following options were considered:

1. Collect additional data and develop new HSC for testing;
2. Test other existing HSC;
3. Modify the HSC and rerun the transferability test; and
4. Develop new criteria from data already collected.

Option 1 would have been the most desirable, if additional time and funds had been available. Development of individual sets of new criteria for each of the transferability study streams would have required about four times as much work as the transferability testing that had already been performed. Therefore, new criteria were developed based on the data available from the transferability studies. All the data collected for each species and/or life stage were pooled to develop the new HSC.

Prior to developing the new criteria, histograms were prepared of the occupied and unoccupied site data used for transferability testing. Additional HSC were identified and compared visually to the histograms to see whether there was a match. Since there was no match, the modified forage index and the linear index, described by Schreck and Moyle (1990), were both used in a systematic approach to developing new HSC.

The forage ratio is an electivity index used to measure the degree to which fish select for specific food items available to them in the environment. It also may be used to describe the degree of preference for various microhabitat conditions (Bovee, 1986). This concept was applied to the selection for depth, current velocity, substrate, and cover in the environment per the histogram analyses. Modified forage index ratios were calculated for each depth, velocity, and substrate/cover bin[1] used in the histogram analyses. The formula used to calculate the modified forage index is:

$$FR = r_i/(p_i+1)$$

where: FR = the modified forage index;
r_i = the percentage of occupied sites in depth, velocity, or substrate/cover bin i; and
p_i = the percentage of unoccupied sites in depth, velocity, or substrate/cover bin i.

The formula cited by Schreck and Moyle (1990) used only "p_i" as the denominator. However, we decided to add 1 percent to the denominator so that an index could be calculated when the number of unoccupied sites was zero. After calculating the modified forage indexes, they were normalized (put on a scale of 0 to 1) to permit comparison with the HSC.

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[1] The first depth bin for adults, juveniles, and spawning (0.13 feet) was for water depths of 0-0.25 feet, the second bin (0.38 feet) for water depths of 0.25-0.50 feet, etc.

The first velocity bin for adults, juveniles, and spawning (0.13 feet/second) was for velocities of 0-0.25 feet/second, the second bin (0.38 feet/second) for 0.25 to 0.50 feet/second, etc.

Depth and velocity bins used for fry were made half as large as the above (intervals of 0.06 feet or feet/second, instead of 0.13 feet or feet/second, respectively) because of the narrow range of depths and velocities for sites occupied by fry.

The linear food index was first proposed by Strauss (1979) and is

$$L = r_i - p_i$$

where: L = the linear index, and r_i and p_i are as defined above.

The modified forage index always has positive values. However, values for the linear index range from -1 to +1, with positive values indicating preference and negative values indicating avoidance. No attempt was made to normalize the linear indexes.

3.7.2 Depth and velocity criteria

Normalized modified forage indexes (NMFIs) for depth and velocity for each life stage and stream were plotted on the same graphs as the depth and velocity HSC used for transferability testing, and are shown as Figures 3.1 through 3.8.

Brook trout NMFIs for Little Fishing Creek, Whitehead Run, and Young Womans Creek were used to develop new adult and juvenile brook trout HSC. Brown trout NMFIs for Young Womans Creek and Cherry Run were used to develop new adult and juvenile brown trout HSC.

New HSC for spawning brook trout were developed using NMFIs for Little Fishing Creek and Whitehead Run. New HSC for spawning brown trout were developed from NMFIs for Young Womans Creek and Cherry Run.

Because of the close similarity of fry NMFIs for all four streams, new HSC for fry were developed from data collected from all four streams, and brook and brown trout fry HSC were considered identical.

When developing new depth and velocity HSC using data from several streams, the data point with the higher NMFI from each bin was generally used. The new HSC may, therefore, be considered conservative because they encompass data from all of the streams considered. If a question arose regarding a particular data point (such as a modified forage index calculated from relatively few fish observances), the linear index also was considered in developing the new HSC.

The NMFI for fry depth in Whitehead Run (Figure 3.4) is a value of 1 at depths of 0.94 feet and 1.19 feet. This produced an unusual peak in the graph for Whitehead Run that was much different from peaks in the graphs for the other streams. Because of the small number (2 out of 57) of fry observations made at the above depths in Whitehead Run, these data points were not used to construct the revised criteria, and the depth with the next highest NMFI (0.56 ft.) was considered to have a suitability index of 1.

3.7.3 Substrate and cover

Prior to constructing new substrate/cover HSC, modified forage indexes were calculated for all 15 combined substrate/cover categories. Modified forage indexes also were calculated independently for all three substrate types and for all five cover types. The independently calculated substrate and cover modified forage indexes were most easily analyzed and were used to develop new HSC. The NMFIs used to develop new substrate/cover HSC are shown in Table 3.8.

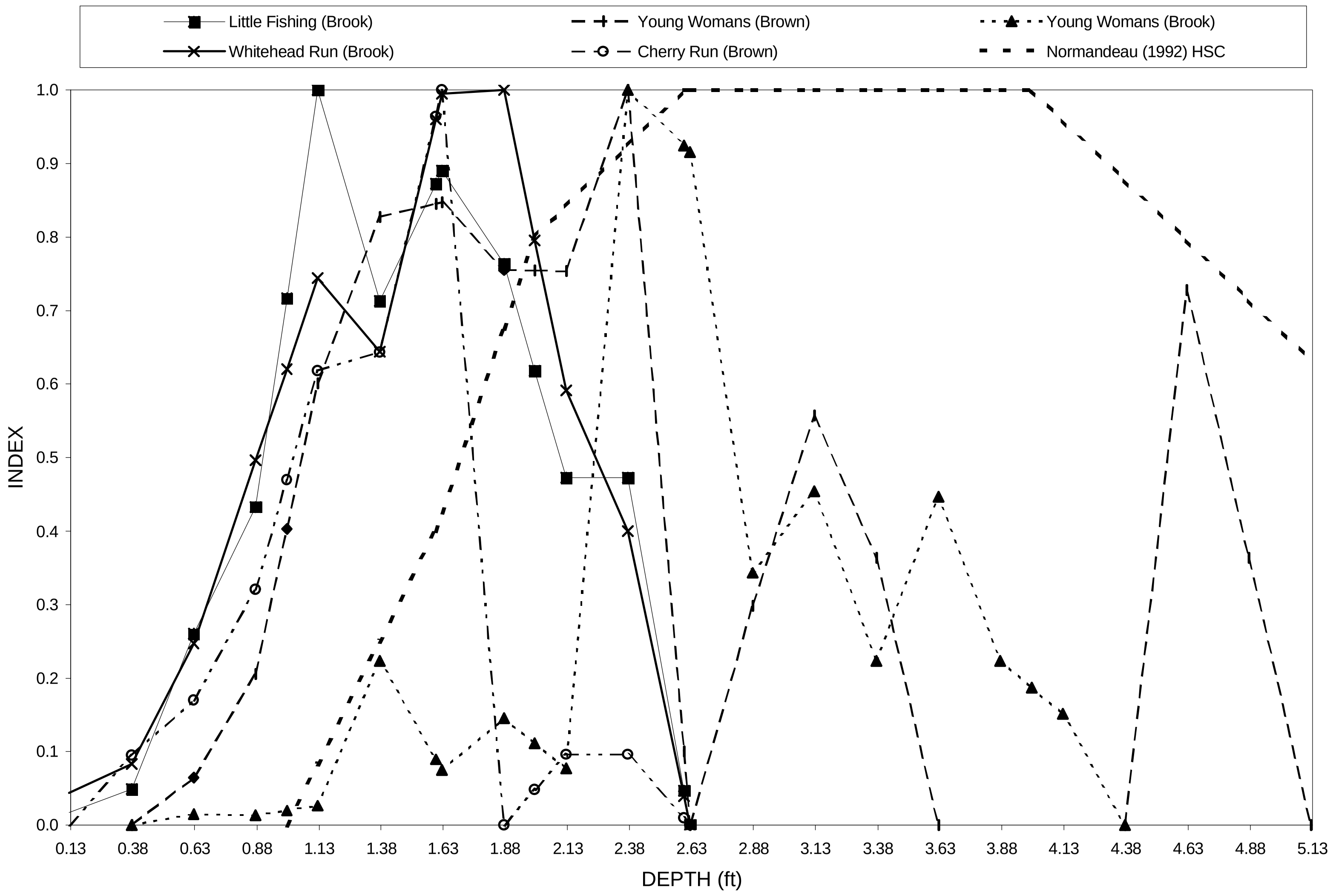

Figure 3.1. Adult Normalized Modified Forage Indexes for Depth

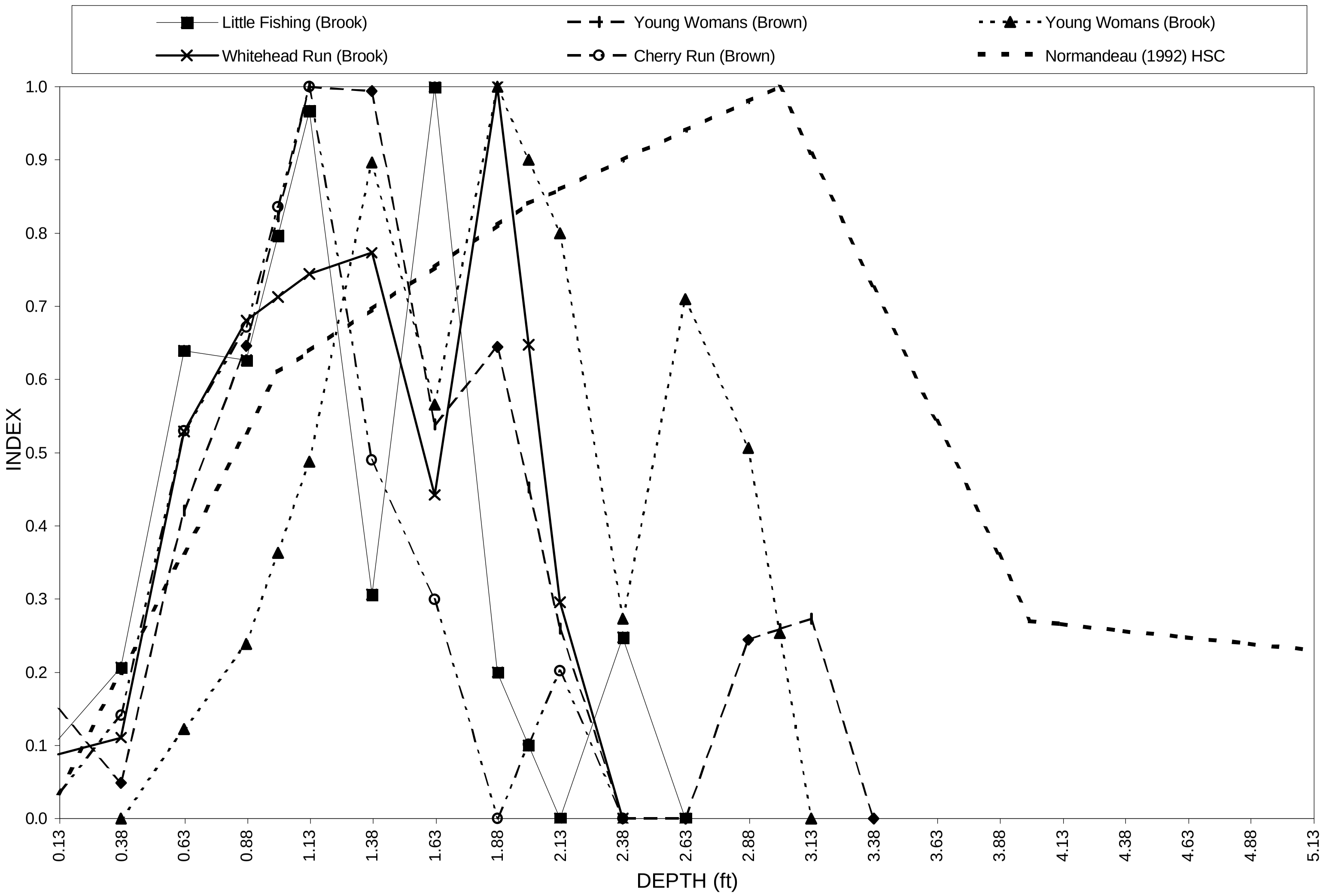

Figure 3.2. Juvenile Normalized Modified Forage Indexes for Depth

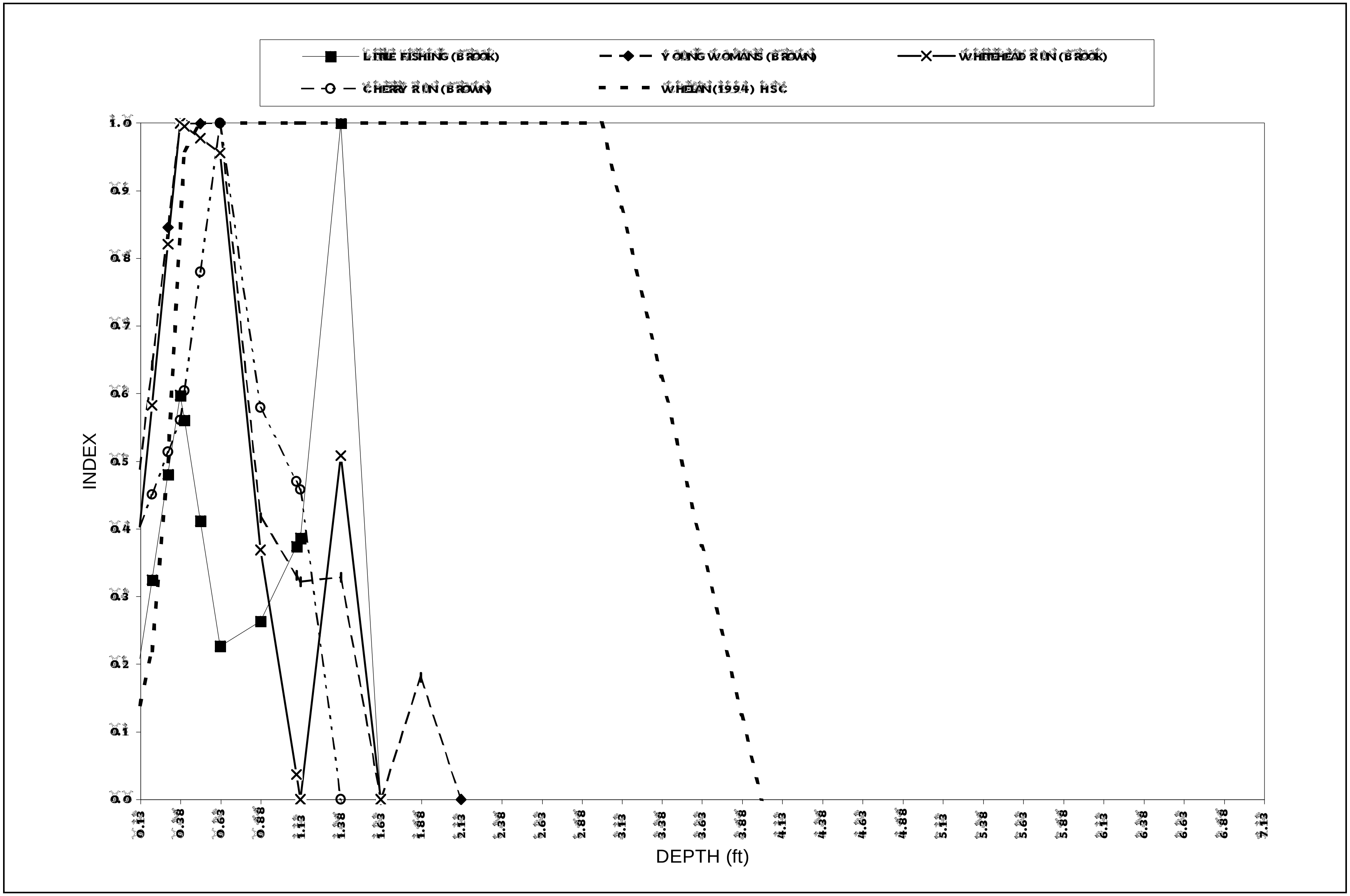

Figure 3.3. Spawning Normalized Modified Forage Indexes for Depth

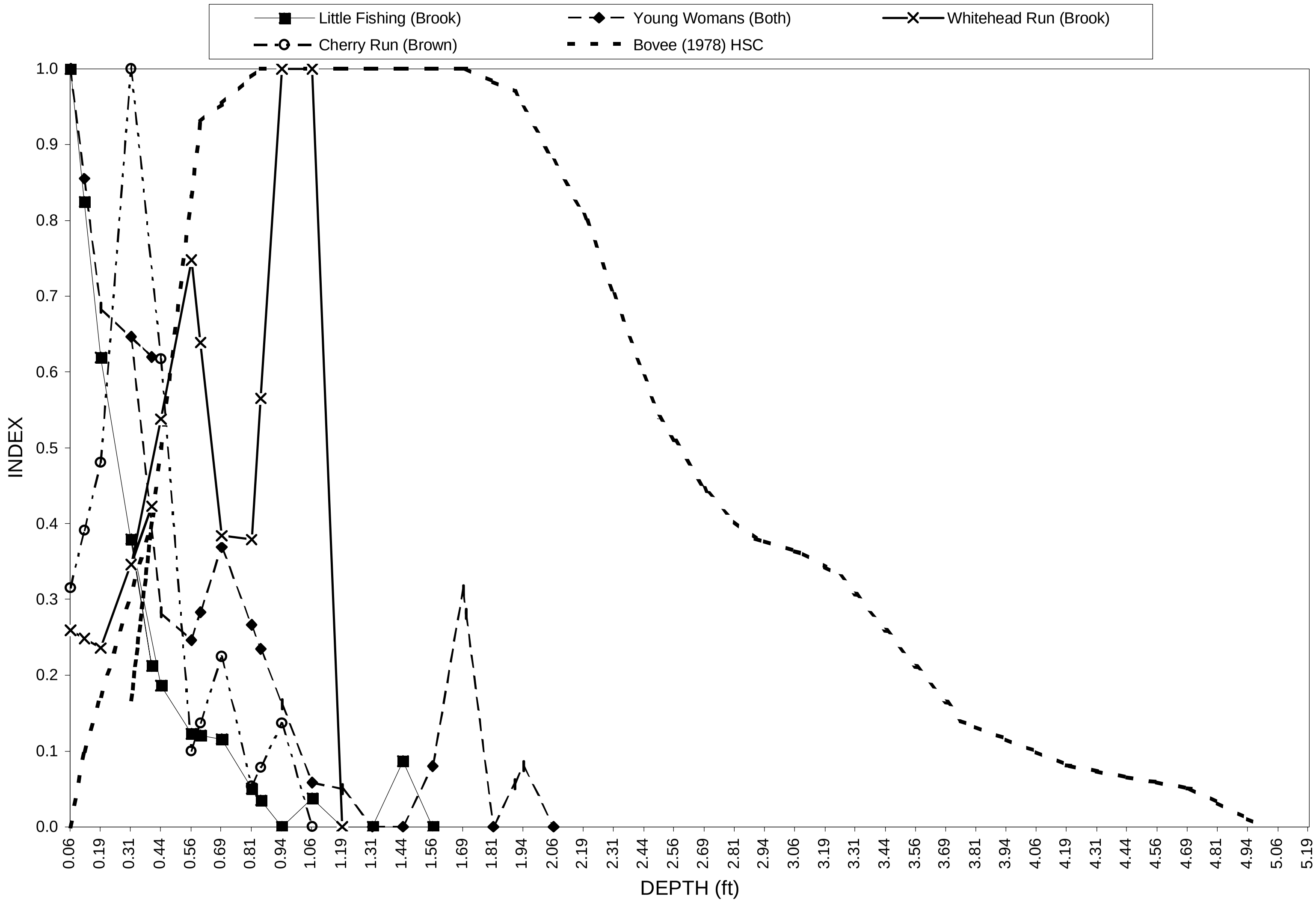

Figure 3.4. Fry Normalized Modified Forage Indexes for Depth

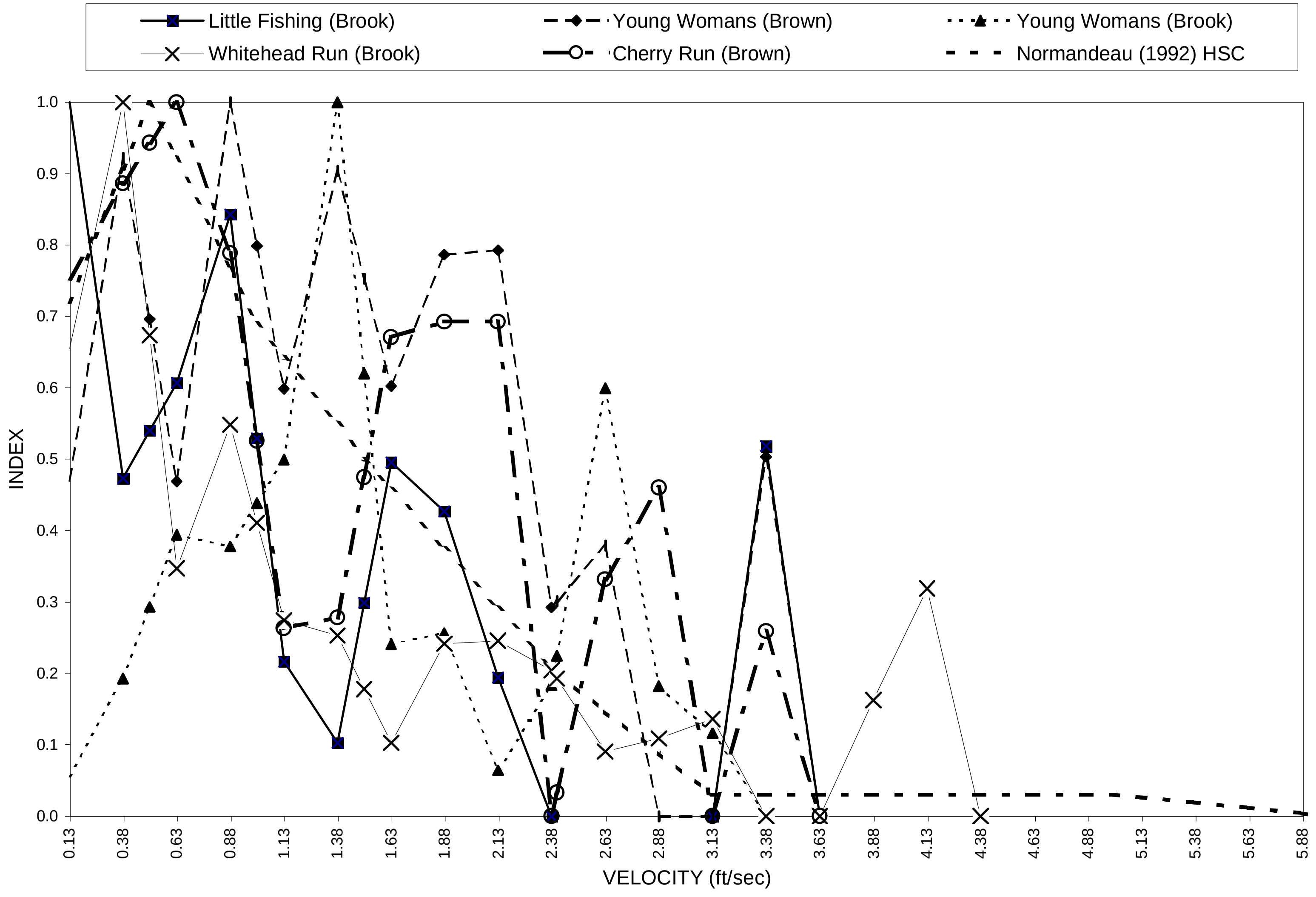

Figure 3.5. Adult Normalized Modified Forage Indexes for Velocity

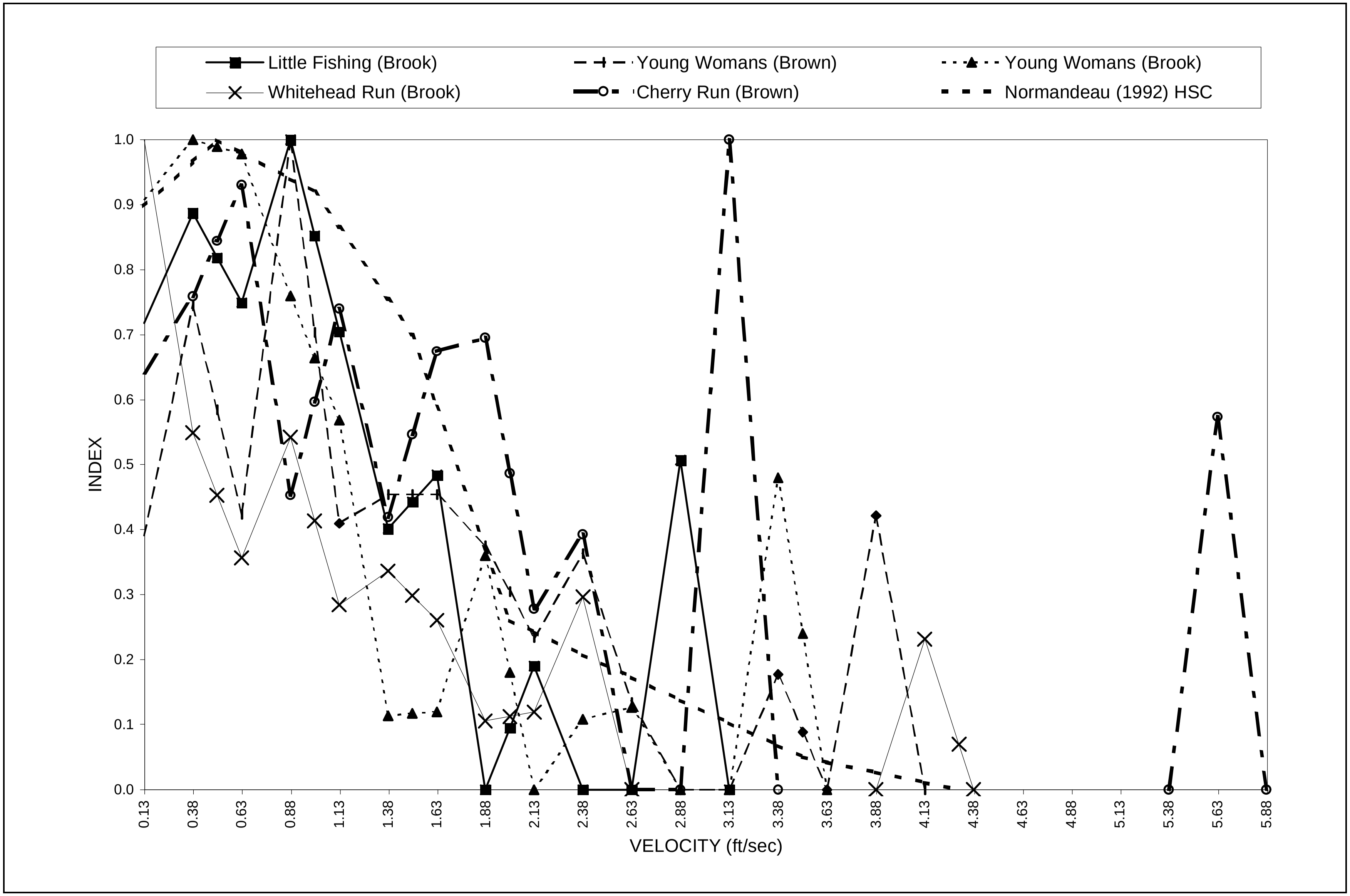

Figure 3.6. Juvenile Normalized Modified Forage Indexes for Velocity

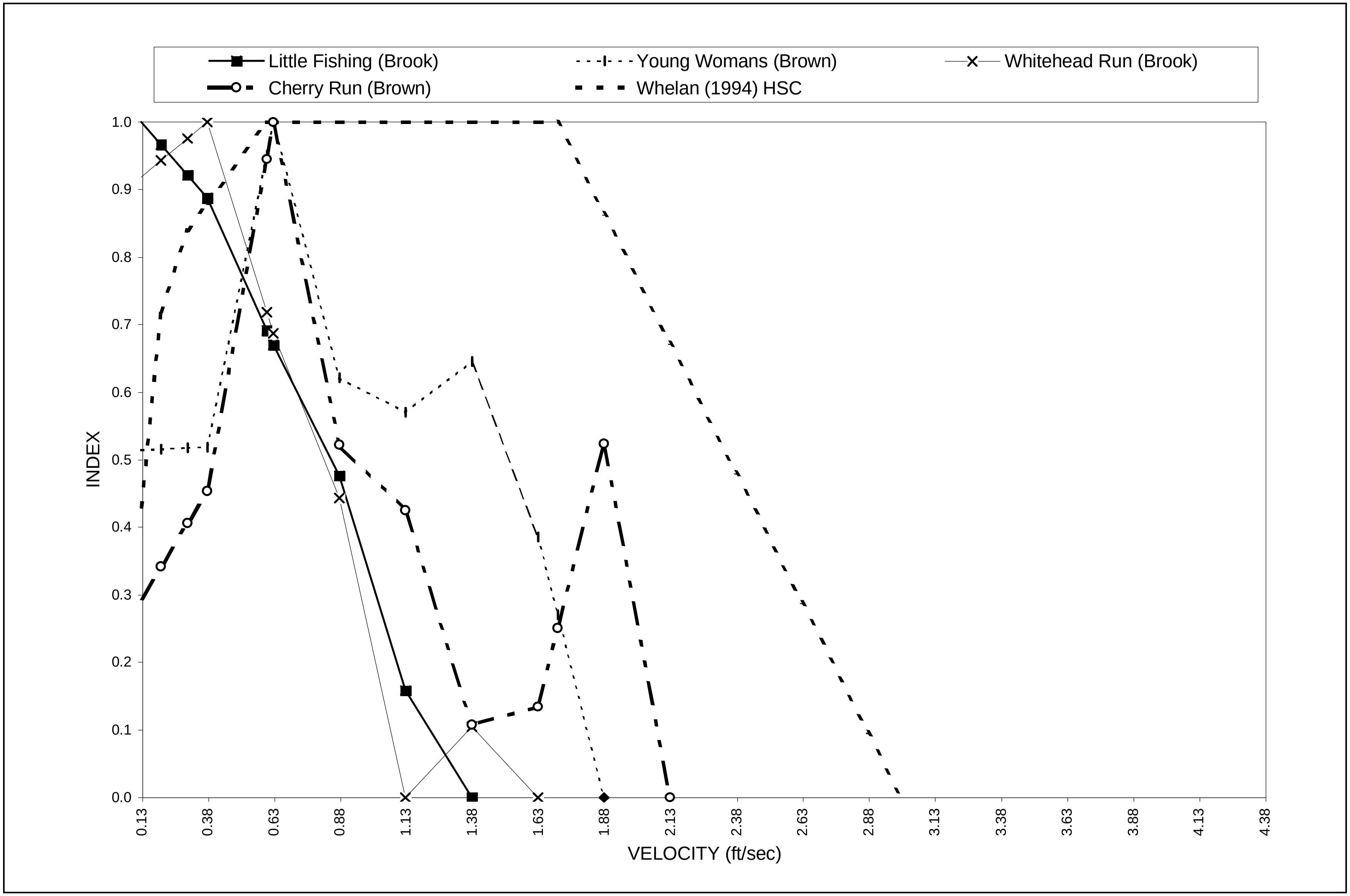

Figure 3.7. Spawning Normalized Modified Forage Indexes for Velocity

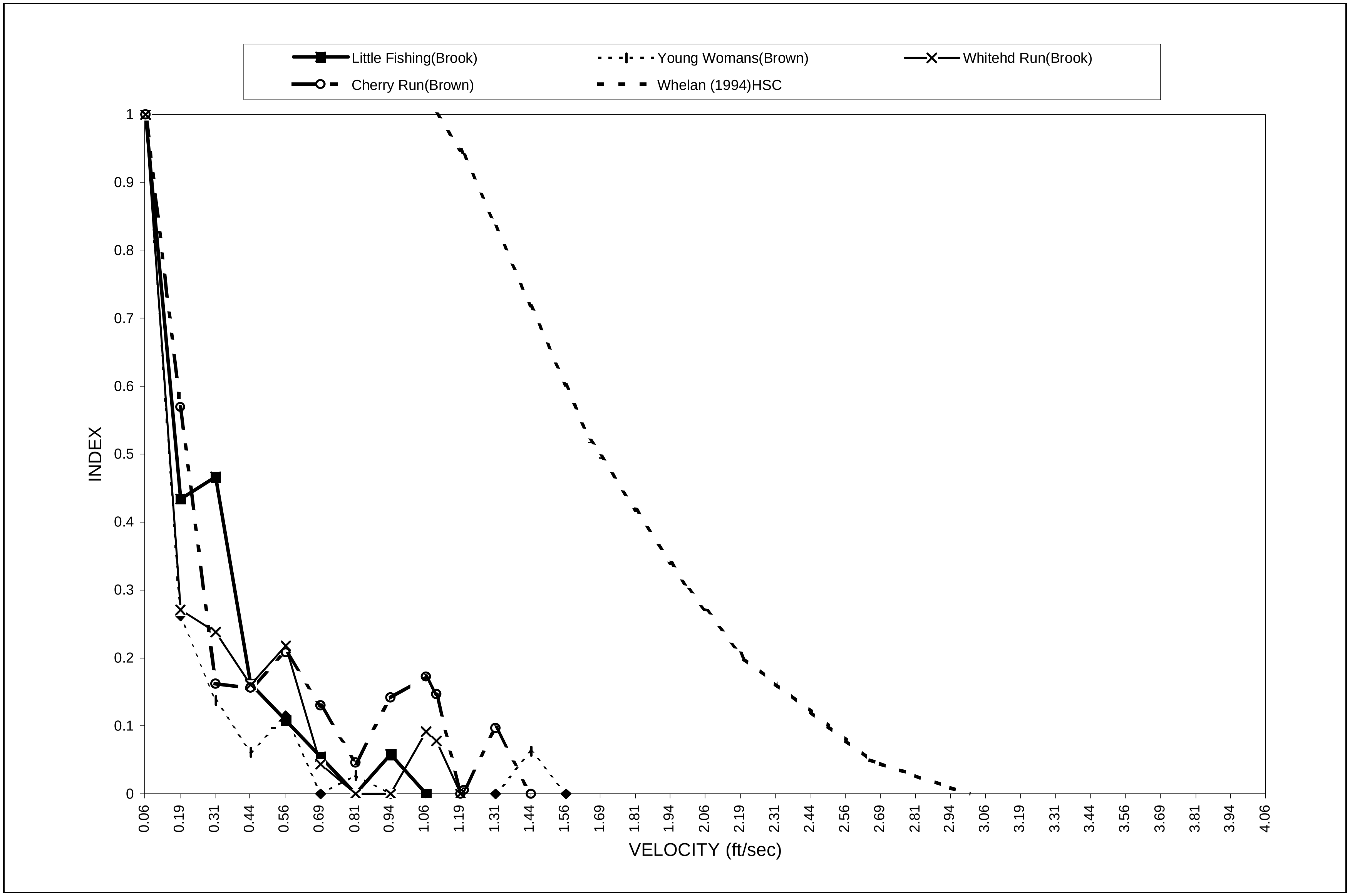

Figure 3.8. Fry Normalized Modified Forage Indexes for Velocity

Table 3.8. Normalized Modified Forage Indexes for Substrate and Cover

Type of Fish/ Name of Stream	Substrate Type			Cover Type				
	1	2	3	1	2	3	4	5
Adult Brook Trout								
Little Fishing Creek	1	0.2	0.6	0	0.5	1	0	0.3
Young Womans Creek	0	1	0.7	0.8	0.8	1	0	0
Whitehead Run	1	0.4	0.5	0	0.6	1	0	0
Adult Brown Trout								
Young Womans Creek	0.9	0.6	1	0.1	0.2	1	0.2	0
Cherry Run	0.5	0.4	1	0.1	0.4	1	0.2	0
Juvenile Brook Trout								
Little Fishing Creek	1	0.6	0.8	0.1	0.4	1	0.2	0.5
Young Womans Creek	1	0.1	0	0.3	0.2	1	0.4	0
Whitehead Run	1	0.6	0.6	0	1	0.9	0	0.1
Juvenile Brown Trout								
Young Womans Creek	0.6	1	0.8	0.1	0.3	1	0.2	0.1
Cherry Run	0.2	0.7	1	0.3	0.8	1	0.8	0
Spawning Brook Trout								
Little Fishing Creek	0	1	0	0.1	0.1	1	0	0.1
Whitehead Run	0.2	1	0	0.3	0.6	1	0	0.5
Spawning Brown Trout								
Young Womans Creek	0	1	0	0.1	0	1	0.2	0
Cherry Run	0	1	0.1	0.6	0.2	1	0.1	0
Fry (Brook/Brown Trout Combined)								
Little Fishing Creek	1	0.3	0.1	0.4	0.3	0.8	0	1
Whitehead Run	1	0.1	0.1	0.5	0.8	0.5	1	0
Young Womans Creek	1	0.6	0.1	0.1	0.2	0.1	0	1
Cherry Run	1	0.4	0.1	0.6	0.4	1	0	0

Note: Substrate and cover type are defined in Table 3.2.

When cover and substrate were analyzed independently, adult brook trout appeared to show strong preference for cover, but little preference for substrate type. Adult brook trout NMFIs for substrate type 1 (silt) ranged from a value of 1 in Little Fishing Creek and Whitehead Run to a value of 0 in Young Womans Creek. The apparent explanation for this difference is that substrate type is unimportant, compared to cover type for the adult life stage. Because no definite pattern could be identified with respect to substrate preference, new adult brook trout substrate/cover HSC were developed based entirely on cover type.

Adult brook trout NMFIs for cover type 1 (no cover) were 0 for both Little Fishing Creek and Whitehead Run. For this reason, cover type 1 was assigned a suitability index of 0 for adult brook trout. Therefore, substrate/cover codes 1.1, 2.1, and 3.1 also were given HSC values of 0. Although the adult brook trout NMFI for cover type 1 in Young Womans Creek was 0.8, this value was not used for new HSC development because adult brown trout appeared to be competing with adult brook trout for cover in this stream. It appears that adult brook trout were being forced into the "no cover" situation as a result of this competition. Brown trout were not found in the section sampled in Little Fishing Creek, and were found in limited numbers in only some parts of Whitehead Run. In Young Womans Creek, adult brown trout seemed to be more closely associated with cover, while adult brook trout appeared to be more closely associated with pool habitat. Adult brook trout would probably have made more extensive use of cover on Young Womans Creek if much of the cover had not already been occupied by adult brown trout.

Adult brook trout NMFIs for cover type 2 (object at least 6 inches high, and with a cross-section horizontal measurement of at least 1 foot) were 0.5 for Little Fishing Creek and 0.6 for Whitehead Run. Therefore, a suitability index of 0.6 was assigned to cover type 2 for adult brook trout. Although the adult brook trout NMFI for cover type 2 in Young Womans Creek was 0.8, this value was not used for HSC development because of possible effects of competition between brook and brown trout previously cited. Selection of the higher value was consistent with the approach used in modifying depth and velocity HSC, as described above.

Cover type 3 (undercut object along bank) had an NMFI of 1 for adult brook trout on all of the streams tested, and was assigned a suitability index of 1.

Only a limited amount of adult brook trout data for cover types 4 (aquatic vegetation) and 5 (terrestrial vegetation less than 1 foot above water surface) were available for the streams sampled. However, if these cover types had been present, adult brook trout probably would have used them in much the same way that they used cover type 2 (object cover). For this reason, the suitability index value assigned to brook trout adults for cover type 2 also was assigned to cover types 4 and 5.

Adult brown trout also appeared to show strong preferences for cover and not for substrate type. Therefore, new adult brown trout substrate/cover HSC also were developed, based solely on cover type. Adult brown trout NMFIs for cover type 1 (no cover) were 0.1 for both Young Womans Creek and Cherry Run. For this reason, cover type 1 was assigned a suitability index of 0.1 for adult brown trout. Adult brown trout NMFIs for cover type 2 (object cover) were 0.2 for Young Womans Creek and 0.4 for Cherry Run. Therefore, a suitability index of 0.4 was assigned to cover type 2 for adult brown trout. Cover type 3 (undercut object along bank) had an NMFI of 1 for adult brown trout in both Young Womans Creek and Cherry Run, and was assigned a suitability index of 1. Cover types 4 (aquatic vegetation) and 5 (terrestrial vegetation less than 1 foot above water surface) were uncommon. Because these are types of object cover, they were given the same HSC values as cover type 2 (object cover) for brown trout.

As with adults, juvenile brook trout did not appear to show preferences for substrate type, and new substrate/cover HSC were developed based entirely on cover type. Juvenile brook trout NMFIs for cover type 1 (no cover) were 0.1 for Little Fishing Creek, 0.3 for Young Womans Creek, and 0 for Whitehead Run. Cover type 1 was assigned a suitability index of 0.3 for juvenile brook trout based on the Young Womans Creek value. Although there appeared to be competition between brook and brown trout adults for available cover in Young Womans Creek, it did not appear to be an important factor for juveniles, because both species appeared to use the available habitat in a similar manner.

Juvenile brook trout NMFIs for cover type 2 (object cover) were 0.4 for Little Fishing Creek, 0.2 for Young Womans Creek, and 1 for Whitehead Run. A suitability index of 1 was assigned to cover type 2 for juvenile brook trout. Cover type 3 (undercut object along bank) had an NMFI of 1 for juvenile brook trout in Little Fishing Creek and Young Womans Creek, and a value of 0.9 for juvenile brook trout in Whitehead Run. Cover type 3 was assigned a suitability index of 1 for juvenile brook trout. As described above for brook trout adults, only a limited amount of juvenile brook trout data were available for cover types 4 (aquatic vegetation) and 5 (terrestrial vegetation less than 1 foot above water surface), and these cover types were given the same suitability index values as cover type 2 for juvenile brook trout.

New juvenile brown trout substrate/cover HSC also were developed, based entirely on cover type. Juvenile brown trout NMFIs for cover type 1 (no cover) were 0.1 for Young Womans Creek, and 0.3 for Cherry Run. Cover type 1 was assigned a suitability index of 0.3 for juvenile brown trout.

Juvenile brown trout NMFIs for cover type 2 (object cover) were 0.3 for Young Womans Creek, and 0.8 for Cherry Run. A suitability index of 0.8 was assigned to cover type 2 for juvenile brown trout. Cover type 3 (undercut object along bank) had an NMFI of 1 for juvenile brown trout for both of the streams sampled. Cover type 3 was assigned a suitability index of 1 for juvenile brown trout. Only a limited amount of juvenile brown trout data were available for cover types 4 (aquatic vegetation) and 5 (terrestrial vegetation less than 1 foot above water surface), and these cover types were given the same suitability index values as cover type 2 for juvenile brown trout.

Based on the data for occupied sites, cover appeared to be unimportant for spawning brook trout and brown trout, but substrate was extremely important. Substrate type 2 (coarse sand/gravel) had an NMFI of 1 on all four streams, and was given a suitability index of 1 for both brook and brown trout. Substrate types 1 (silt/fine sand) and 3 (pebbles and larger) were used to a much lesser extent by both species. However, substrate type 1 had an NMFI of 0.2 for Whitehead Run, and therefore, was given a suitability index of 0.2 for brook trout. Substrate type 3 had an NMFI of 0.1 in Cherry Run, and therefore, was given a suitability index of 0.1 for brown trout.

When NMFIs for fry substrate and cover were analyzed separately, substrate was important, but cover usually did not appear to be. Although fry were found in association with cover type 5 (terrestrial vegetation less than 1 foot above water surface) where it was available on Young Womans Creek and Little Fishing Creek, fry may have been selecting more for low velocity water near shore, rather than specifically for cover type 5, which had an NMFI of 1 for both of these streams. Cover type 5 was not present at any of the occupied or unoccupied fry sampling sites on Whitehead Run or Cherry Run. Cover type 5 was assigned a suitability index of 1 in association with all substrate types.

For fry, substrate type 1 (silt/fine sand) had an NMFI of 1 for all four streams. This substrate was given a suitability index of 1 in association with all of the five cover types. When not in association with cover type 5 (terrestrial vegetation less than 1 foot above water surface), substrate type 2 (coarse sand/gravel) had NMFIs ranging from 0.1 to 0.6. Substrate type 2 was given a suitability index of 0.6, except when it was in association with cover type 5, when substrate type 2 was given a value of 1. Substrate type 3 (pebbles and larger) had an NMFI of 0.1 for all streams, so this substrate was given a suitability index of 0.1, except in association with cover type 5, when it was given a value of 1.

In summary, the approach used to develop the new fry substrate/cover HSC recognized the importance of fine substrate, but also put a premium on shoreline habitat with terrestrial vegetation as cover. This approach serves as a check against selecting the flow with the lowest velocity and depth (drought condition) for optimum fry habitat.

3.7.4 Results

The new HSC, based on the NMFIs, are listed in Table 3.9. New depth and velocity HSC are presented graphically as Figures 3.9 through 3.16.

A rerun of the transferability tests on the revised HSC was not performed. The tests would not have been statistically valid, because the transferability test data were used to generate the new HSC.

If the same HSC could be used for brook and brown trout, the amount of time required for PHABSIM modeling could be reduced. To improve modeling efficiency, this option was considered. However, separate HSC were recommended for adults, juveniles, and spawning for the two species, because of the significant differences in NMFIs. NMFIs for brook and brown trout fry were similar; therefore, the same criteria were used for both species for this life stage.

3.8 Conclusions and Recommendations

The new HSC were developed using the best field data available with the resources available for the study. Although all adult and juvenile microhabitat data for the transferability studies were collected in the summer and early fall during daylight hours, microhabitat use may vary seasonally, diurnally, and with the presence of other species competing for the same habitat. Shuler and others (1994) documented differences in microhabitat selection by adult brown trout during the day versus at night. Fausch and White (1981) observed that adult brown trout in the East Branch of the Au Sable River, Michigan, excluded brook trout from preferred resting positions, which were a critical and scarce resource.

Future studies are desirable to test transferability of the newly-developed criteria to other streams, and collect additional data for further HSC refinement. The development of the HSC used in this study assumed that the usability was independent of study region. Also, HSC curves could be further refined by developing separate curves for each study region. Some streams in Pennsylvania have naturally reproducing rainbow trout populations. HSC could be developed for rainbow trout, so that habitat could be modeled and instream flow needs developed for that species. Data collection could be further stratified to consider the season, time of day, and other trout species present.

Table 3.9. Habitat Suitability Criteria Used for Pennsylvania-Maryland Instream Flow Study

Adults			Juveniles			Spawning			Fry		
Depth (feet)	Brook Trout HSC	Brown Trout HSC	Depth (feet)	Brook Trout HSC	Brown Trout HSC	Depth (feet)	Brook Trout HSC	Brown Trout HSC	Depth (feet)	Brook Trout HSC	Brown Trout HSC
0	0	0	0	0	0	0	0	0	0	0	0
0.13	0.04	0	0.13	0.11	0.15	0.13	0.4	0.49	0.06	1	1
0.38	0.08	0.09	0.38	0.21	0.15	0.38	1	1	0.19	1	1
0.63	0.26	0.17	0.63	0.64	0.53	0.63	1	1	0.31	1	1
0.88	0.5	0.32	0.88	0.68	0.67	0.88	1	0.58	0.44	1	1
1.13	1	0.62	1.13	1	1	1.13	1	0.46	0.56	1	1
1.38	1	0.83	1.38	1	1	1.38	1	0.33	0.69		
1.63	1	1	1.63	1	0.82	1.63	0	0.26	0.81	0.5	0.5
1.88	1	1	1.88	1	0.64	1.88	0	0.18	0.94	0.2	0.2
2.13	1	1	2.13	0.8	0.27	2.13	0	0	1.06	0.1	0.1
2.38	1	1	2.38	0.75	0.27	2.38	0	0	1.19	0.1	0.1
2.63	1	1	2.63	0.7	0.27	2.63	0	0	1.31	0.1	0.1
2.88	0.45	0.56	2.88	0.5	0.27	2.88	0	0	1.44	0.1	0.1
3.13	0.45	0.56	3.13	0	0.27	3.13	0	0	1.56	0.1	0.1
3.38	0.45	0.56	3.38	0	0	3.38	0	0	1.69	0.1	0.1
3.63	0.45	0.56	3.63	0	0	3.63	0	0	1.81	0.1	0.1
3.88	0.45	0.56	3.88	0	0	3.88	0	0	1.94	0.1	0.1
4.13	0.45	0.56	4.13	0	0	4.13	0	0	2.06	0	0
4.38	0.45	0.56	4.38	0	0	4.38	0	0	2.19	0	0
4.63	0.45	0.56	4.63	0	0	4.63	0	0	2.31	0	0
4.88	0.45	0.56	4.88	0	0	4.88	0	0	—	0	0
5.13	0.45	0.56	5.13	0	0	5.13	0	0	5.94	0	0

Table 3.9. Habitat Suitability Criteria Used for Pennsylvania-Maryland Instream Flow Study—Continued

Adults			Juveniles			Spawning			Fry		
Velocity (ft/sec)	**Brook Trout HSC**	**Brown Trout HSC**	**Velocity (ft/sec)**	**Brook Trout HSC**	**Brown Trout HSC**	**Velocity (ft/sec)**	**Brook Trout HSC**	**Brown Trout HSC**	**Velocity (ft/sec)**	**Brook Trout HSC**	**Brown Trout HSC**
0	1	0.66	0	1	0.58	0	1	0.5	0	1	1
0.13	1	0.75	0.13	1	0.64	0.13	1	0.51	0.06	1	1
0.38	1	0.92	0.38	1	0.76	0.38	1	0.52	0.19	0.6	0.6
0.63	0.92	1	0.63	1	1	0.63	0.69	1	0.31	0.5	0.5
0.88	0.84	1	0.88	1	1	0.88	0.48	0.65	0.44	0.2	0.2
1.13			1.13	0.71	0.74	1.13	0.16		0.56	0.2	0.2
1.38		0.9	1.38			1.38	0.1	0.65	0.69	0.1	0.1
1.63	0.5		1.63	0.48		1.63	0	0.39	0.81	0.1	0.1
1.88	0.43		1.88		0.7	1.88			0.94	0.1	0.1
2.13	0.25	0.79	2.13	0.19		2.13	0	0	1.06	0.1	0.1
2.38	0.2	0.5	2.38		0.39	2.38			1.19	0.1	0.1
2.63			2.63	0	0.13	2.63			1.31	0.1	0.1
2.88			2.88	0	0	2.88			1.44	0.1	0.1
3.13	0.14		3.13			3.13			1.56	0	0
3.38	0	0.5	3.38			3.38			1.69		
3.63		0	3.63			3.63			1.81		
3.88			3.88			3.88			1.94		
4.13			4.13			4.13			2.06		
4.38			4.38			4.38			2.19		
4.63			4.63			4.63			2.31		
4.88			4.88			4.88			2.44		
5.13			5.13			5.13			2.56		
5.38			5.38			5.38			2.69		
5.63			5.63			5.63			—		
5.88	0	0	5.88	0	0	5.88	0	0	4.06	0	0

Table 3.9. Habitat Suitability Criteria Used for Pennsylvania-Maryland Instream Flow Study—Continued

Adults			Juveniles			Spawning			Fry		
Substrate/ Cover Code	Brook Trout HSC	Brown Trout HSC	Substrate/ Cover Code	Brook Trout HSC	Brown Trout HSC	Substrate/ Cover Code	Brook Trout HSC	Brown Trout HSC	Substrate/ Cover Code	Brook Trout HSC	Brown Trout HSC
1.1	0	0.1	1.1	0.3	0.3	1.1	0.2	0	1.1	1	1
1.2	0.6	0.4	1.2	1	0.8	1.2	0.2	0	1.2	1	1
1.3	1	1	1.3	1	1	1.3	0.2	0	1.3	1	1
1.4	0.6	0.4	1.4	1	0.8	1.4	0.2	0	1.4	1	1
1.5	0.6	0.4	1.5	1	0.8	1.5	0.2	0	1.5	1	1
2.1	0	0.1	2.1	0.3	0.3	2.1	1	1	2.1	0.6	0.6
2.2	0.6	0.4	2.2	1	0.8	2.2	1	1	2.2	0.6	0.6
2.3	1	1	2.3	1	1	2.3	1	1	2.3	0.6	0.6
2.4	0.6	0.4	2.4	1	0.8	2.4	1	1	2.4	0.6	0.6
2.5	0.6	0.4	2.5	1	0.8	2.5	1	1	2.5	1	1
3.1	0	0.1	3.1	0.3	0.3	3.1	0	0.1	3.1	0.1	0.1
3.2	0.6	0.4	3.2	1	0.8	3.2	0	0.1	3.2	0.1	0.1
3.3	1	1	3.3	1	1	3.3	0	0.1	3.3	0.1	0.1
3.4	0.6	0.4	3.4	1	0.8	3.4	0	0.1	3.4	0.1	0.1
3.5	0.6	0.4	3.5	1	0.8	3.5	0	0.1	3.5	1	1

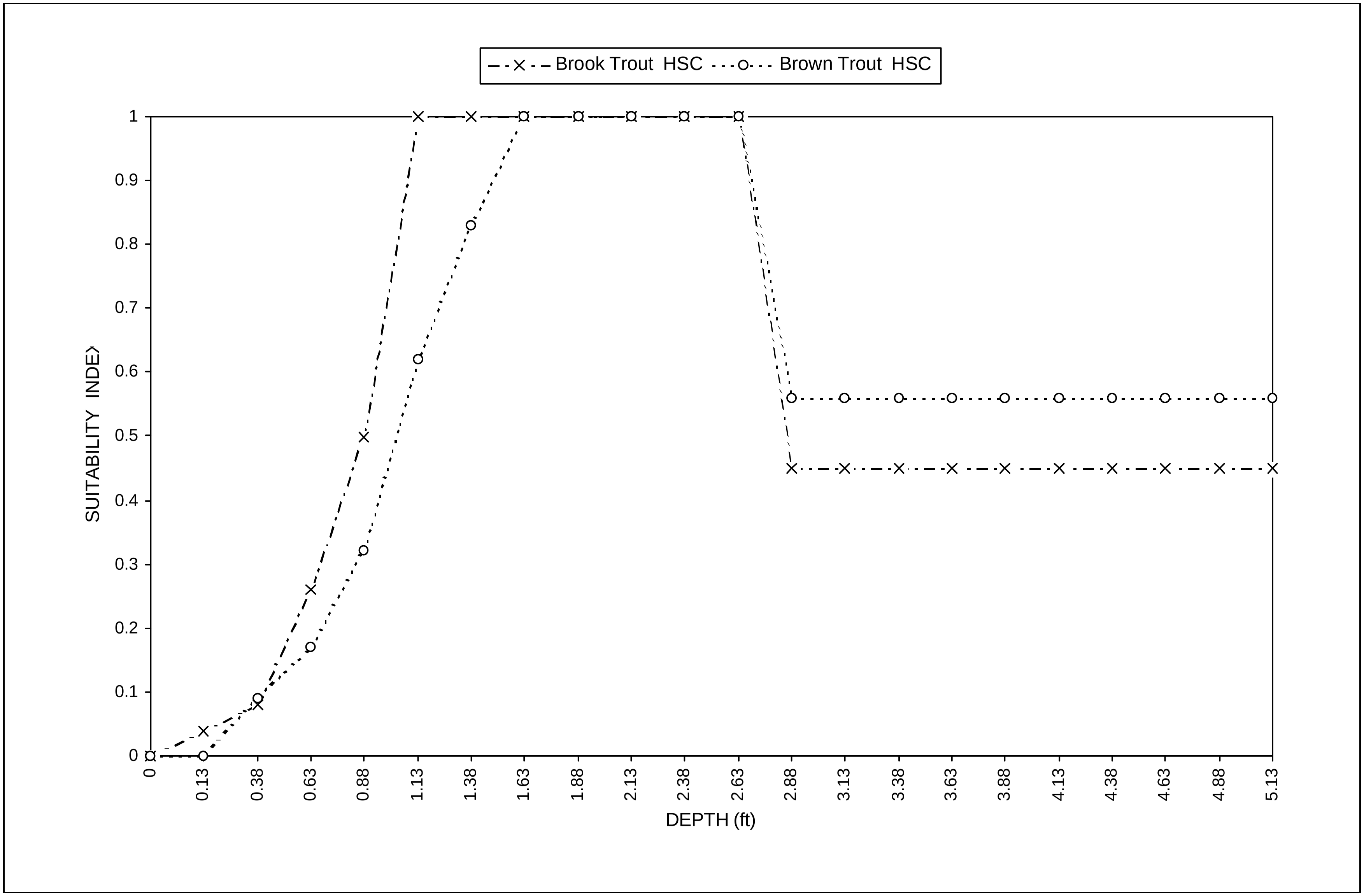

Figure 3.9. Adult Habitat Suitability Criteria for Depth

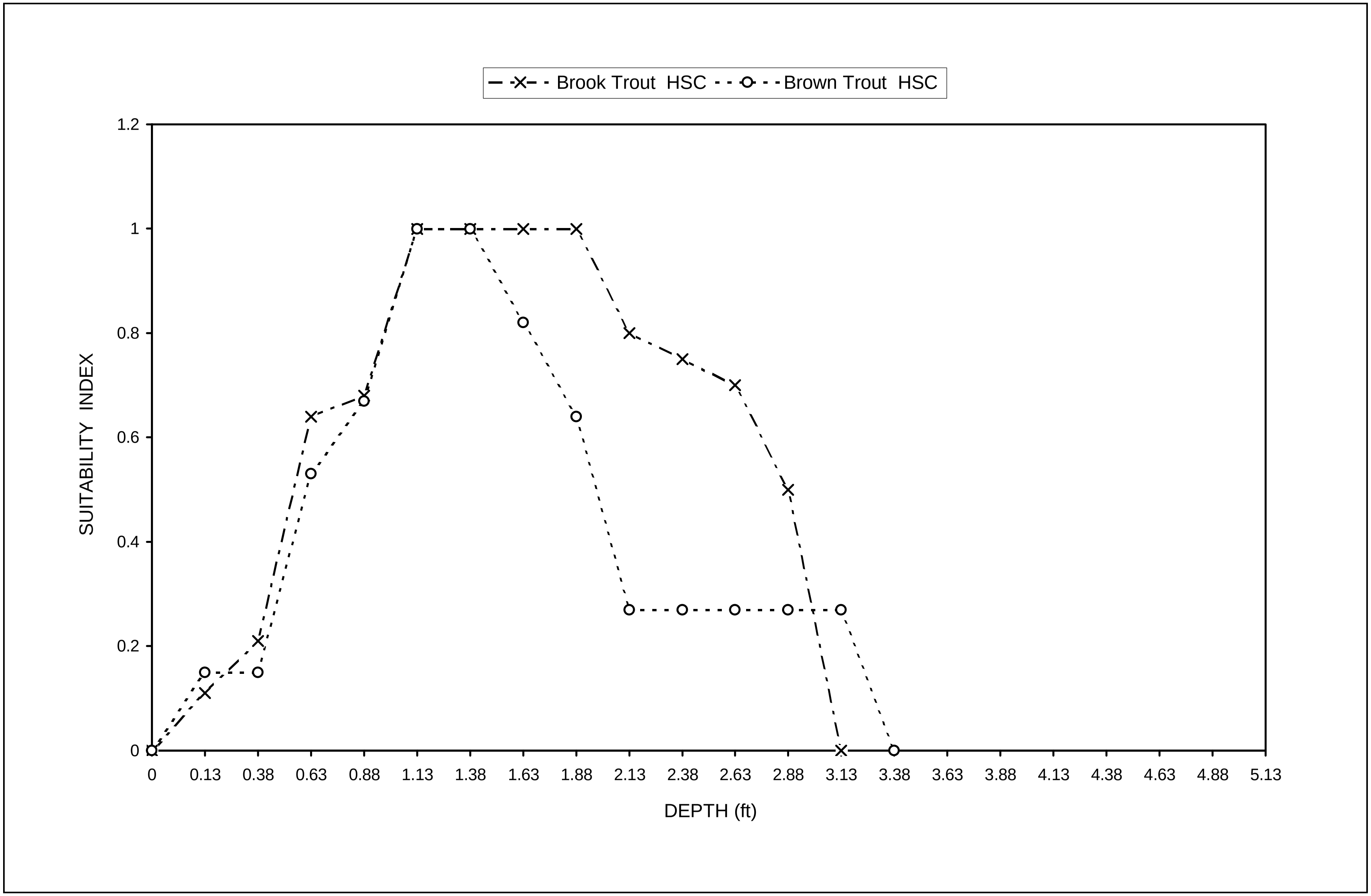

Figure 3.10. Juvenile Habitat Suitability Criteria for Depth

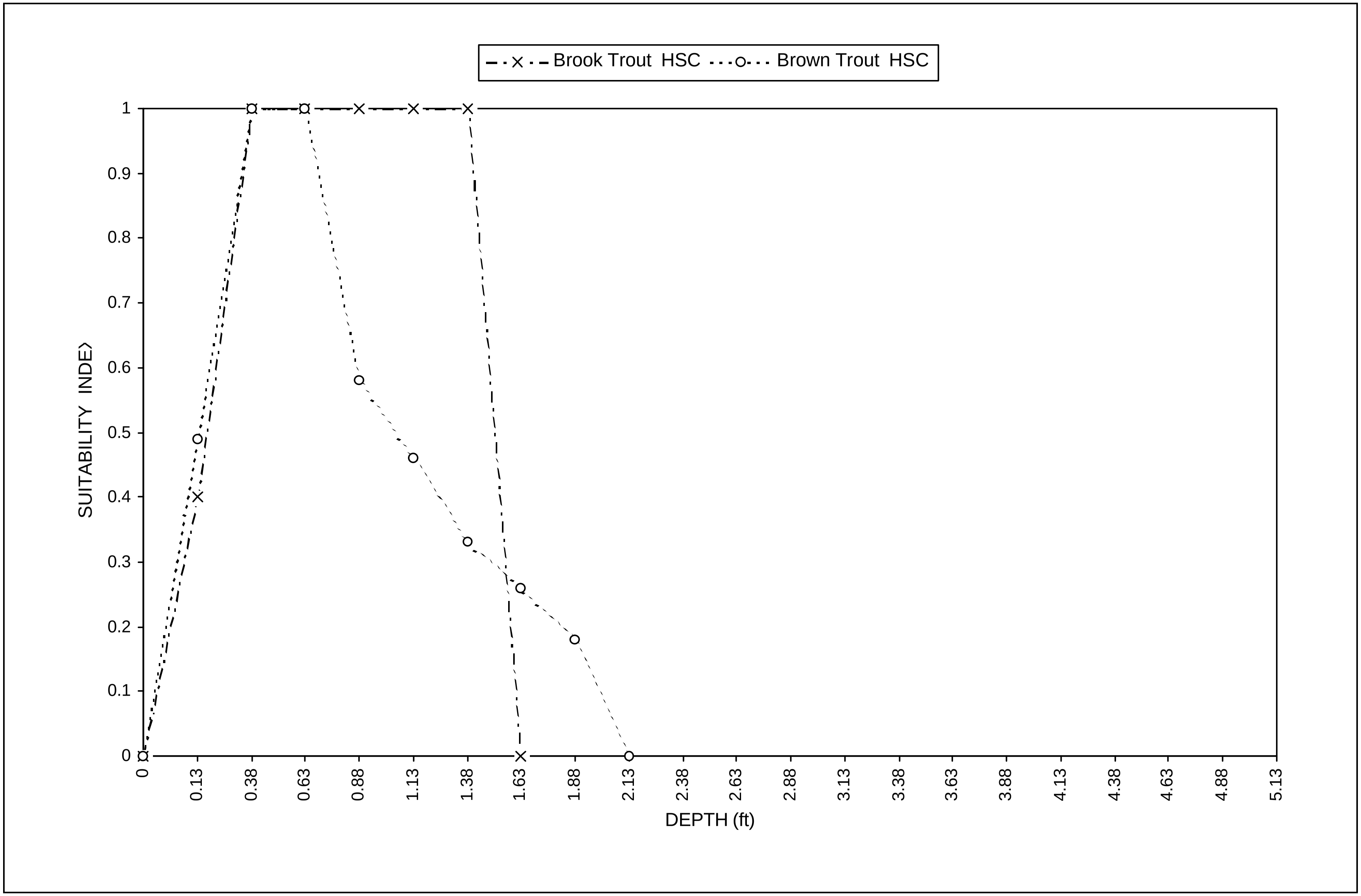

Figure 3.11. Spawning Habitat Suitability Criteria for Depth

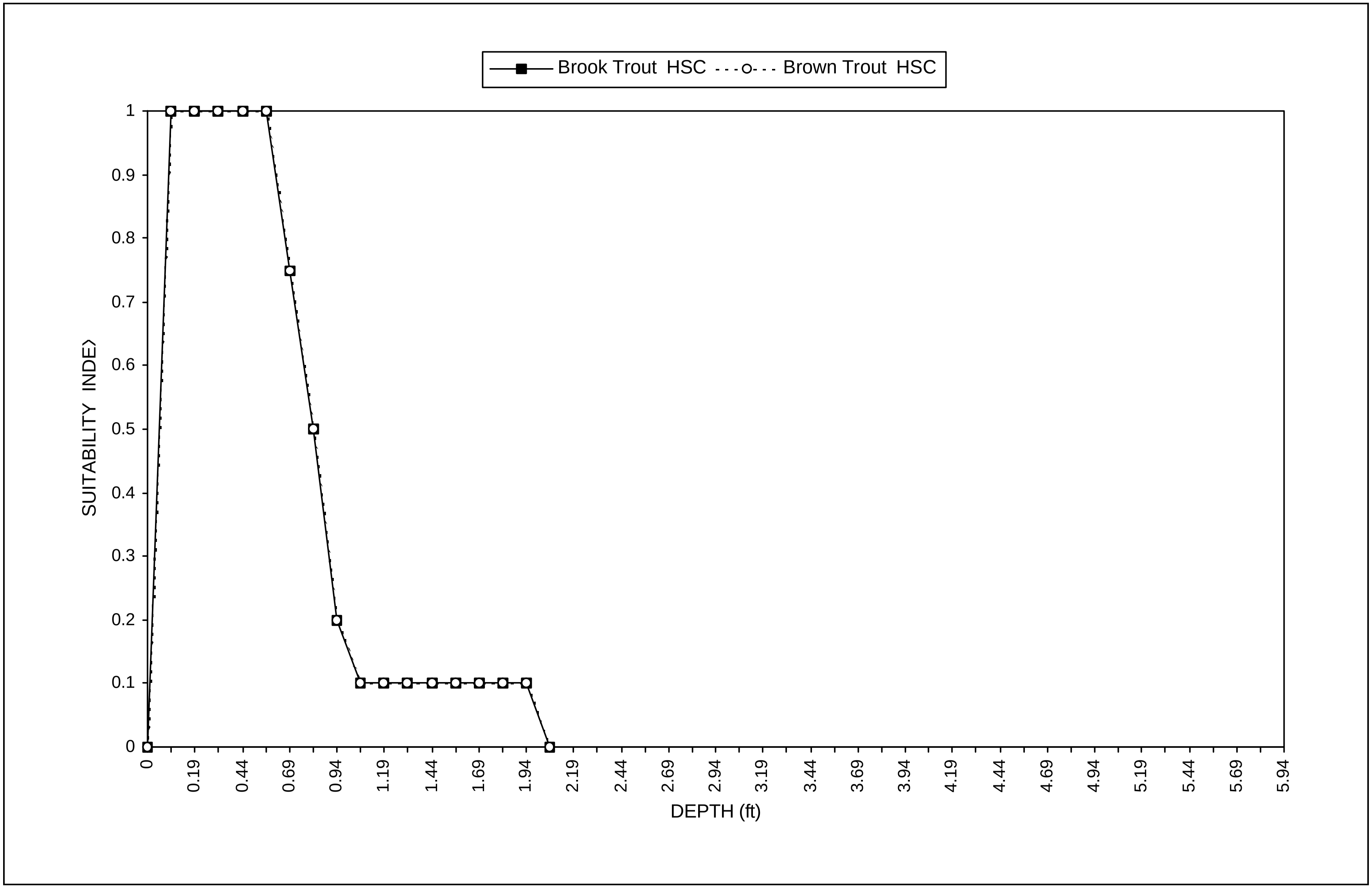

Figure 3.12. Fry Habitat Suitability Criteria for Depth

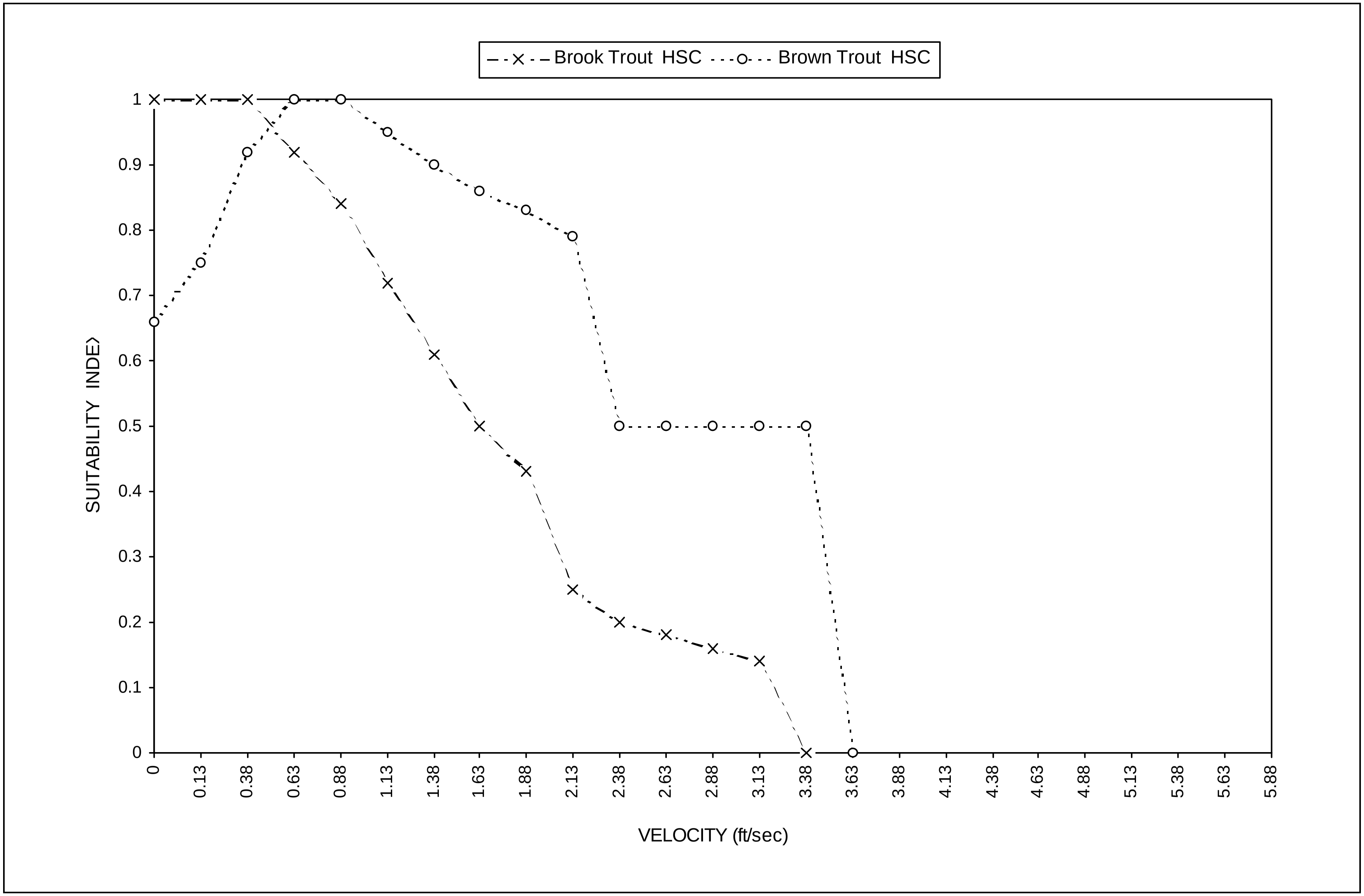

Figure 3.13. Adult Habitat Suitability Criteria for Velocity

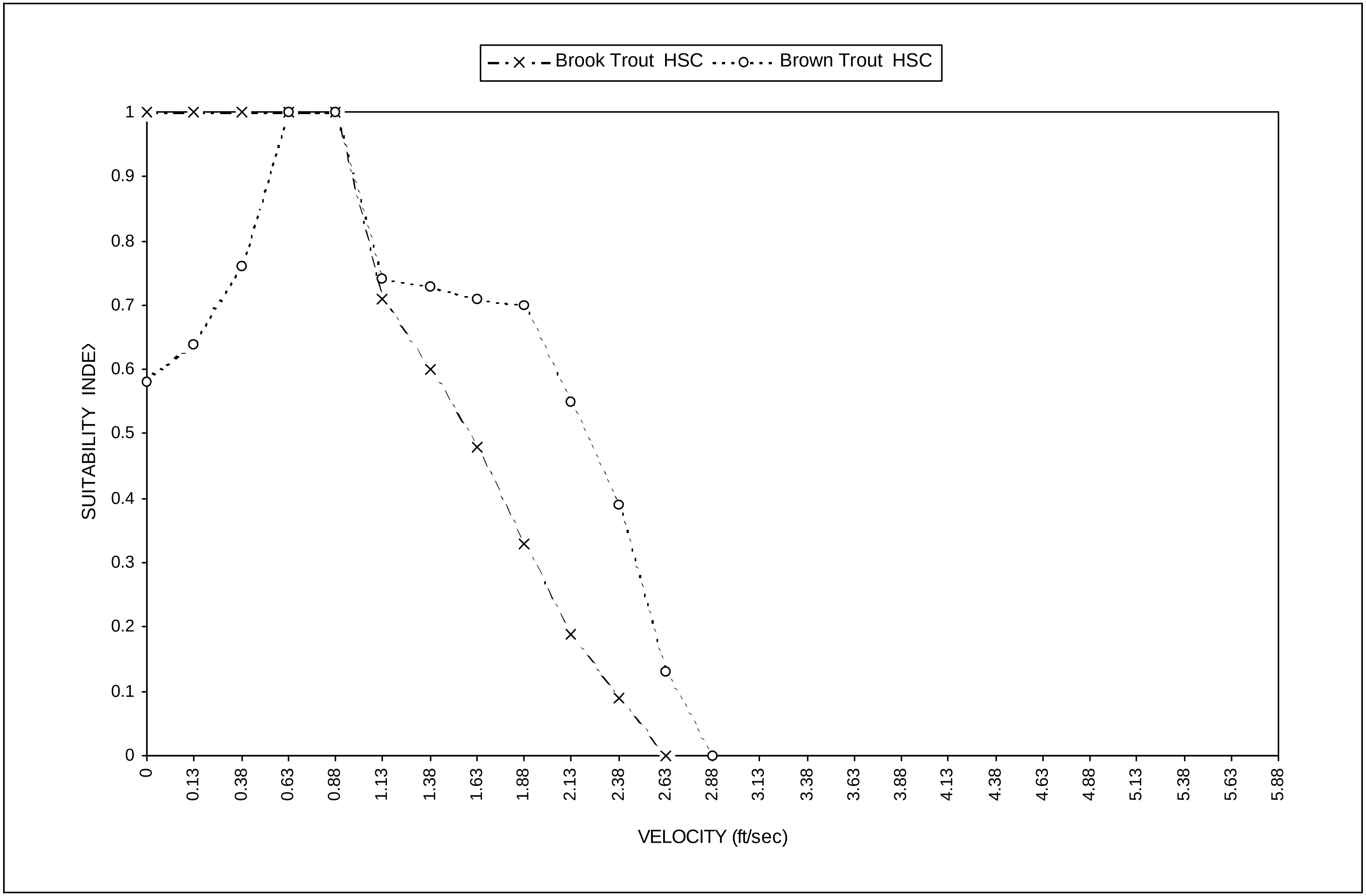

Figure 3.14. Juvenile Habitat Suitability Criteria for Velocity

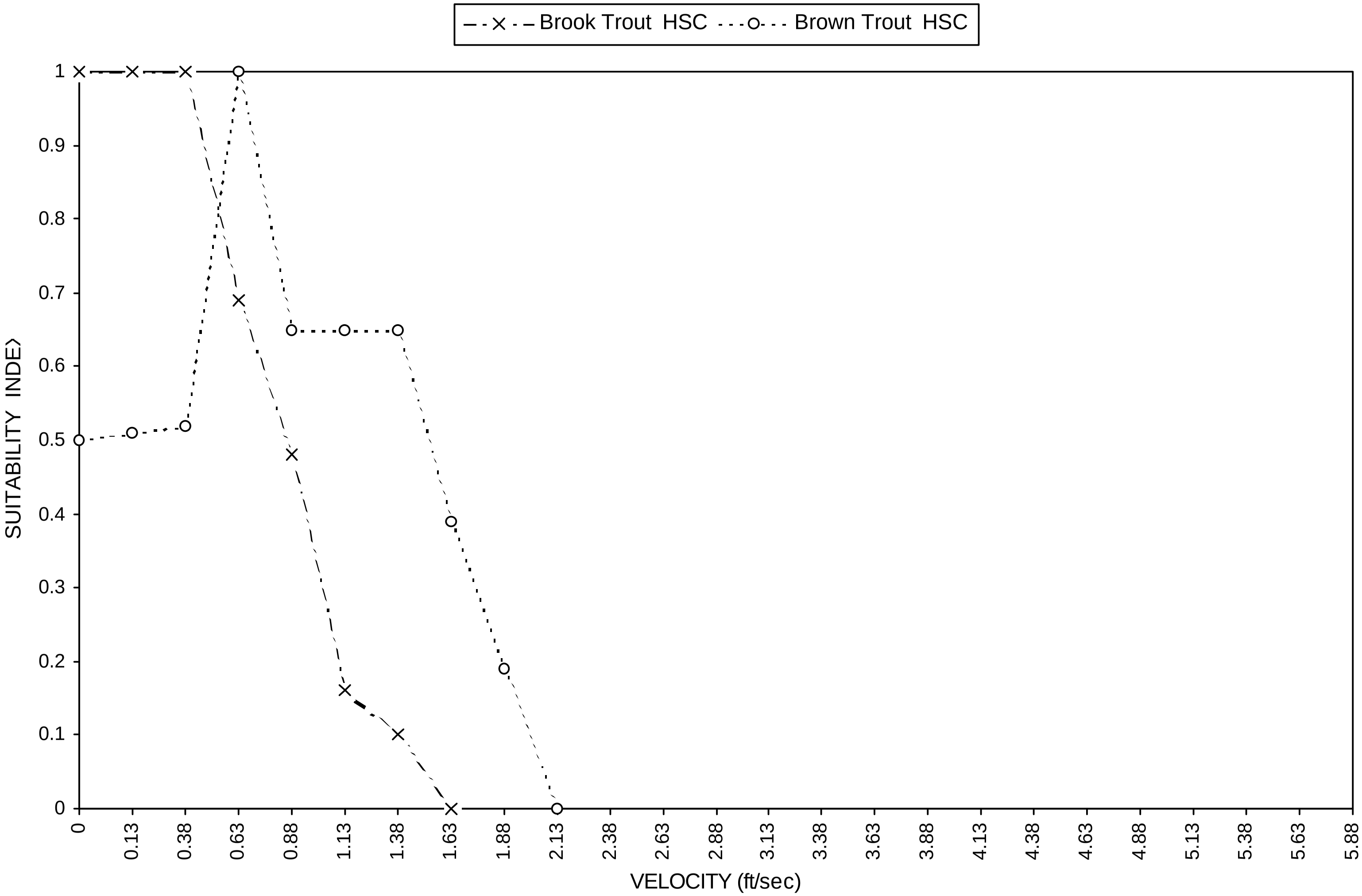

Figure 3.15. Spawning Habitat Suitability Criteria for Velocity

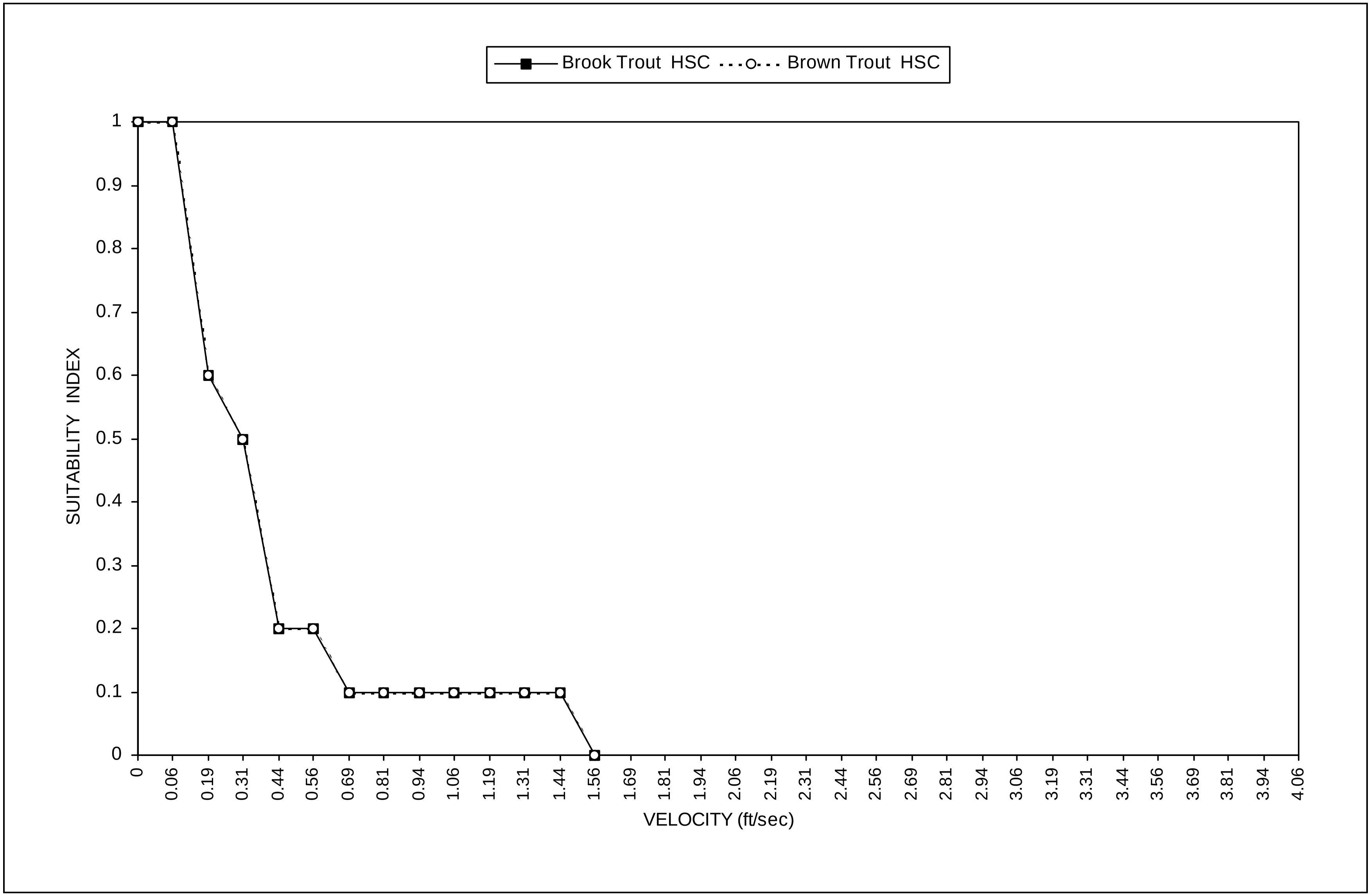

Figure 3.16. Fry Habitat Suitability Criteria for Velocity