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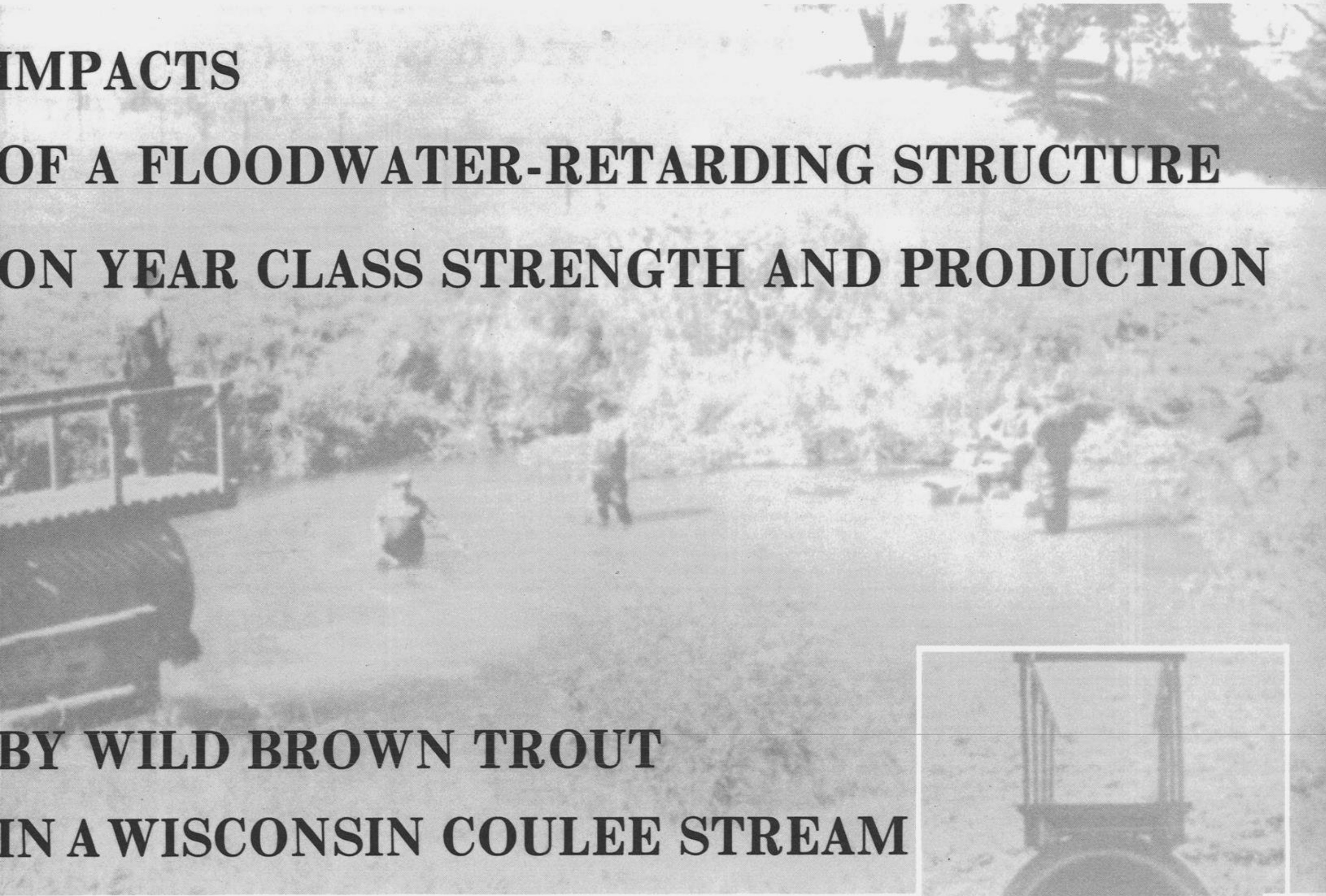
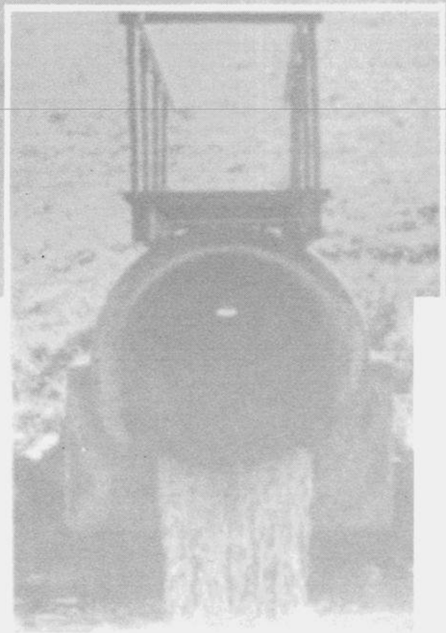
IMPACTS OF A FLOODWATER-RETARDING STRUCTURE ON YEAR CLASS STRENGTH AND PRODUCTION BY WILD BROWN TROUT IN A WISCONSIN COULEE STREAM





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Meet the authors . . .

The Brynildson brothers—Oscar (above) and Cliff (left)—have been fisheries biologists with the Wisconsin Department of Natural Resources for 25 and 30 years, respectively. Said one person who reviewed this manuscript: "I think it is just tremendous that the Brynildson brothers, in the twilight of their careers, will have a publication together. It means a lot to all of us."

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ABSTRACT

To eliminate severe channel erosion caused by flooding, a dry floodwater-retarding structure (FRS) was installed in 1964 on Trout Creek in southwestern Wisconsin. Because this FRS was built at a valley constriction that was also a prime spawning area for wild brown trout *(Salmo trutta)*, a study was initiated on the impacts of the FRS on the trout population. These impacts were determined primarily through comparison of trout population response upstream from the FRS with that downstream during 16 years after construction of the FRS (1964-79), but also through comparison of some preconstruction data on trout populations (1960-64) with the postconstruction data.

During the years studied, the FRS had occasional but no overall adverse effects on wild brown trout populations in Trout Creek. Population characteristics evaluated for possible impact by the FRS included reproduction, survival, production, and distribution.

Trout reproduction at stations 20 and 21 just upstream from the FRS was eliminated because the FRS resulted in standing silt-laden water which deprived eggs and nonswimming sac-fry of oxygen, and sedimentation which covered gravel spawning sites. Elimination of reproduction at this particular site—the prime spawning ground on Trout Creek—did not lower reproduction for the entire stream reach studied because spawning trout compensated by using spawning grounds above the flood pool at stations 23-29 more extensively and intensively than they had prior to construction of the FRS. At this area, spawning gravel is inferior but winter water temperatures and sedimentation are moderate. Of significant benefit to wild brown trout above the FRS is the fact that the FRS blocked upstream migration of fish that compete with and prey upon trout.

In addition to increased use by trout of spawning grounds above the FRS, the limited trout reproduction that occurred below the FRS generally stabilized because of controlled water flow through the FRS during winter floods.

Average survival of wild brown trout from potential February-March fry to September fingerlings in Trout Creek was similar to that in 2 area coulee streams. Likewise, production in Trout Creek was similar to that in 1 of these other area streams.

KEY WORDS: Wild Trout, Brown Trout, Trout Streams, Wisconsin, Flood Control, Dams, Reproduction, Survival, Movement, Growth, Production.

IMPACTS OF A FLOODWATER-RETARDING STRUCTURE ON YEAR CLASS STRENGTH AND PRODUCTION BY WILD BROWN TROUT IN A WISCONSIN COULEE STREAM

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CONTENTS

INTRODUCTION

Research on the trout stocks in an 8.2-km study area of lower Trout Creek, Iowa County, began in 1960 and continued through 1979. Up to 1973, the focus of these studies was to determine survival and growth of domesticated brook (*Salvelinus fontinalis*), brown (*Salmo trutta*), and rainbow (*Salmo gairdneri*) trout stocked as young-of-the-year (age 0) in June or October in the lower 3 km of the study area (Brynildson 1965, Mason et al. 1966). The lower 3 km, unlike the 5.2 km section above, contains sparse populations of wild brown trout.

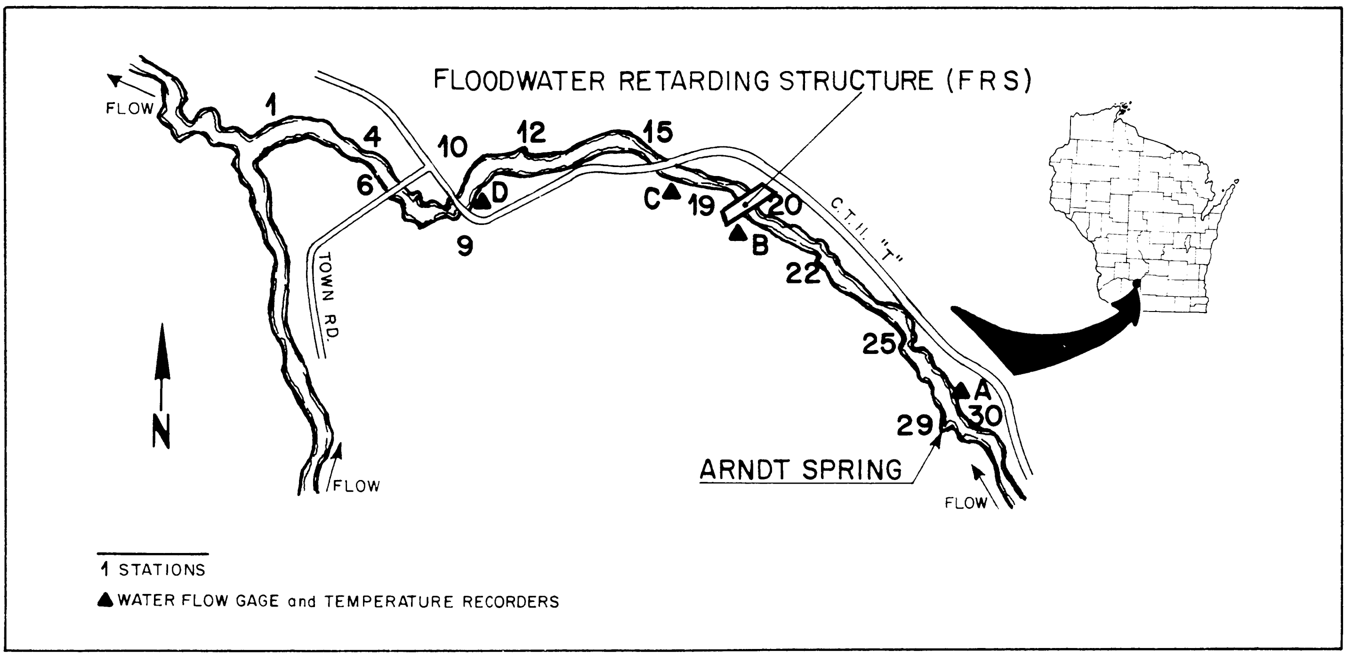
Since 1973, our principle objective was to determine the impact on the wild brown trout in Trout Creek of a dry floodwater-retarding structure (FRS) installed in the trout water reach that contained prime trout spawning grounds. During floods, Trout Creek, like most coulee streams in the "Driftless Area" of southwestern Wisconsin, is subjected to severe channel erosion. When they occur during winter, such floods can kill developing trout eggs and sac-fry within the gravel (redds) by washing away the gravel, resulting in partial or near destruction of a potential year class of wild trout. Such flood damage to trout redds is well documented (Allen 1951; Brynildson 1956, 1957; McFadden and Cooper 1962; White 1962, 1964; Frankenberger and Fassbender 1967; Elwood and Waters 1969; Seegrist and Gard 1972; Brynildson and Mason 1975).

During May 1964, a FRS was constructed on the lower 67 m of station 20, approximately 3 km below the upper end of the 8.2-km study area (Figs. 1 and 2). Water velocity through the 69-m concrete tube of the FRS ranged from 0.8 to 1.2 m/sec at various points within the tube. The waterfall from the outlet of the tube was 30 cm high as it dropped into the plunge pool (water stilling basin) of the FRS during 1964-66. After that, the waterfall began to increase in height and fluctuated between 58 and 66 cm during 1973-79, depending on water volume and amount of sediment that was deposited or removed by the water at or near the lip of the plunge pool.

Since 1964 when the FRS was completed, heavy silting of the reach between stations 19 and 21 has occurred. This was a prime trout spawning area that contained 30% of the total trout redds in Trout Creek during 1963. In addition to sedimentation between stations 19 and 21, silt deposition below the FRS has also occurred because peaks of the floodwaters have been reduced by the slow-release tube of the FRS. Now there are no more spring freshets or other high water to wash the gravel clean, which so commonly happens on the coulee streams without flood protection. In Jones Creek, Georgia, sediment deposited below a FRS being constructed was removed by high stream flows, but after the FRS was completed, sediment data showed that more sediments existed below the completed FRS than above the FRS (Van Kirk 1969).

Because of heavy siltation on the trout spawning grounds, the U.S. Soil

FIGURE 1. The 8.2-km study area in Trout Creek, stations 1 through 30.



Conservation Service initiated a study in 1976 to determine the effects of sedimentation on the wild brown trout in Trout Creek. Studies on trout reproduction and populations were undertaken by the Wisconsin Department of Natural Resources; studies on stream flow, sedimentation characteristics, and stream channel morphology by the U.S. Geological Survey (USGS); and studies on stream bottom fauna, in relation to sedimentation, by the University of Wisconsin at Madison. An overview report on these studies was published by Wentz and Graczyk (1982). One of 6 chapters of that report summarizes our findings on trout populations; this technical bulletin presents those findings in more detail.

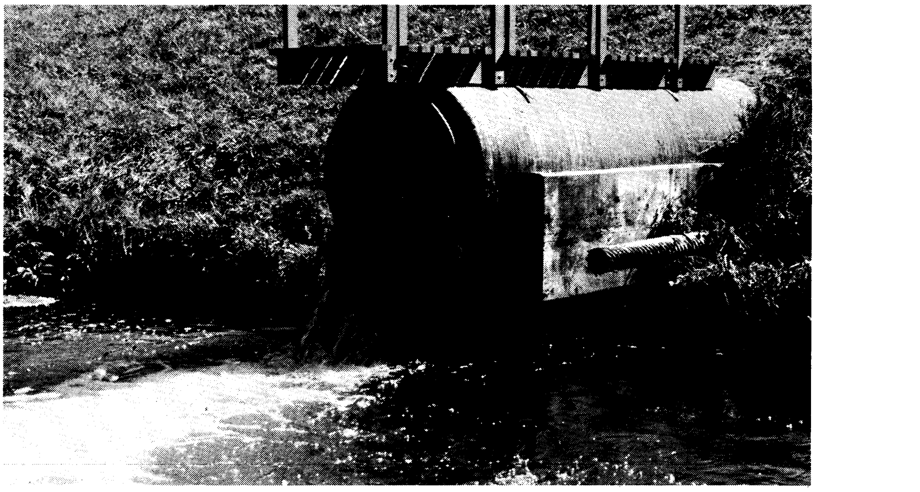


FIGURE 2. The outfall of the FRS at station 19 of Trout Creek.

STUDY AREA

DESCRIPTION OF STREAM AND DRAINAGE BASIN

Trout Creek, a "coulee stream", is part of the large drainage system of the Wisconsin River. It drains 44.5 km^2 of hilly farm and forest land of red, black, bur, and white oak with scattered hickory, paper birch, large-toothed aspen, and quaking aspen on the steep hillsides and white pine around sandstone outcroppings.

Along the upper 8 km of its approximately 13-km course, Trout Creek is confined to a narrow, steep-sided valley (coulee) where the shallow water flows over rubble and gravel of dolomite and chert. The lower 5 km of the stream meanders down an ever-widening valley of pasture land formed by alluvium of silt and sand. The mean gradient of the 13-km course is 11 m/km (Piening and Threinen 1968). The valley lies in the "Driftless Area" of east central Iowa County, 40 km west of Madison, Wisconsin. Stream mouth location is T7N, R4E, Section 13, SW 1/4 of the SW 1/4 (Piening and Threinen 1968). The bedrock in Iowa County is mainly Galena-Platteville dolomite with windblown loess deposited in a blanket of variable thickness from 2 to 25 cm (Klingelhoets 1962).

The average annual rainfall in Iowa County (which includes the Trout Creek drainage basin) is 79 cm, falling mainly during the growing season. Snowfall averages 99 cm/year. Iowa County has an abundant supply of underground water. All geologic formations (especially the Upper Cambrian sandstone) underlying the soils contain water (Klingelhoets 1962). The managed trout water of Trout Creek begins at Arndt Spring (4,500 L/min) 4.8 km below Birch Lake (a 4.5-ha water retention structure), and continues to the confluence of Mill and Trout creeks 8.2 km below Arndt Spring (Fig. 1). At Arndt Spring, the ground water (10 C) discharged into Trout Creek increases the water volume by 56%. This water is the magnesium-bicarbonate type with total alkalinity of 248 mg/L (Piening and Threinen 1968).

The drainage area and volume of water flow at various stations is presented in Table 1. These measurements of flow within the trout water of Trout Creek were made by USGS hydrologists Stephen Field and Stephen Grant on 4 August 1976, the driest August since 1965 when the smaller springs along Trout Creek went dry. Volume of flow in August 1976, from Arndt Spring down to station 1, therefore, was probably lower than it was in August at any time during 1969-79. Ground water is discharged at intervals

TABLE 1. *Drainage areas of Trout Creek above various stations and the volume of water flow at those stations at or near base flow on 4 August 1976.*

Station Numbers	Drainage Area Above Stations (in km^2)	Volume of Water Flow (m^3/sec)
30*	**	0.08
29	21.6	0.16[a]
19[b]	23.4	0.19
16	31.5	0.24
9	35.1	0.24
1	44.5	0.25

*Uppermost station of study area.
**Drainage area between stations 29 and 30 not available.
[a]Sudden increase in volume due to ground water discharge of 0.06 m^3/sec and 0.02 m^3/sec from Arndt Spring and from a small tributary just above flow gage A, respectively.
[b]Station 19 is at the FRS.

along Trout Creek from the lower 50 m of station 30 down to station 4, the exception being the reach from station 16 to 9 where no measurable gain in water volume was detected on 4 August 1976 (Table 1).

Since 1960, when observations on ice cover began, Trout Creek has been ice-free during the winter from 50 m above Arndt Spring downstream to station 19. Edge ice forms on the coldest days from station 19 to 14. From stations 14 to 9, the ice cover is intermittent while below station 9, ice covers the stream during normal winters. During the cold winter of 1976-77, anchor ice formed on a gravel cattle crossing between stations 9 and 10, approximately 3 km below the FRS. This was the site where trout redds were found in November 1975 and 1976, and was as far downstream as trout redds were ever found during the study. Water temperatures within the 8.2-km study area rarely exceed 20 C during the summer.

Water temperatures in the 4.8-km reach of stream from the study area up to Birch Lake are marginal for trout (except near widely scattered small springs) during most summers. However, during winter a few trout (probably fall migrants from the study area below) have been captured by electrofishing in this reach of stream, and anglers have reported catching trout here during the spring. During March 1980, dead trout (250) were found in this reach of stream after liquid nitrogen fertilizers accidentally escaped into the stream that flows into Birch Lake. One dead trout was observed in the study area. The trout population in Trout Creek subsequently recovered rapidly after 1 season of no fishing and 2 seasons of catch and release regulations.

Willow and box elder covered the banks of Trout Creek between stations 19 and 22 before the dry basin above the FRS was developed during the summer of 1963. Above station 22, the stream flowed through meadow. The whole reach from the FRS upstream through station 30 was heavily grazed by beef and dairy cattle until 1963. Currently nonwoody and woody vegetation grows lush on the banks of Trout Creek in this same reach where livestock grazing is now forbidden on this publicly controlled land. From the FRS downstream to station 16, a sparse stand of mature box elder with a scattering of willow remain along the stream banks that are heavily grazed by beef cattle. Except for a stand of mature white and black oak and large-toothed aspen in upper station 13 and lower station 14, and a scattering of young willow in stations 12 and 7, the stream meanders through a combination of box elders and meadow downstream through station 3. From station 3 downstream the ungrazed meadow is characterized by clusters of box elder and willow along with widely scattered silver maple.

FIGURE 3. Watercress dominates the instream rooted vegetation from stations 20 to 30 of the study area during the summer months.

Watercress (*Nasturtium officinale*) dominates the instream rooted vegetation (Fig. 3) from station 20 upstream into the lower 50 m of station 30, where significant ground water discharge (spring flow) ceases. White water-crowfoot (*Ranunculus longirostris*) dominates the sparsely scattered instream vegetation below station 20. *Veronica connata* is common throughout the study area while the less common *Potamogeton crispus* appears to be on the increase above station 23, an increase that has been observed in a neighboring coulee stream, Black Earth Creek.

FISHES OF TROUT CREEK

The wild trout fishery in Trout Creek is one of the best in southern Wisconsin and annually attracts many anglers from Wisconsin and northern Illinois. The fishing season has opened on 1 January since 1975.

The only resident fishes that are abundant in the study area of Trout Creek are wild and stocked domesticated brown trout, *Salmo trutta* Linnaeus; white sucker, *Catostomus commersoni* (Lacepède); and the introduced (1968) mottled sculpin, *Cottus bairdi* Girard. Other fishes that are uncommon to common are: American brook lamprey, *Lampetra appendix* (DeKay); creek chub, *Semotilus atromaculatus* (Mitchill); fathead minnow, *Pimephales promelas* Rafinesque; spotfin shiner, *Notropis spilopterus* (Cope); central stoneroller, *Campostoma anomalum* (Rafinesque); longnose dace, *Rhinichthys cataractae* (Valenciennes); blacknose dace, *Rhinichthys atratulus* (Hermann); and brook stickleback, *Culaea inconstans* (Kirtland). Fishes that move up into Trout Creek from the Wisconsin River drainage system are: bluegill, *Lepomis macrochirus* Rafinesque; largemouth bass, *Micropterus salmoides* (Lacepède); burbot, *Lota lota* (Linnaeus); common carp, *Cyprinus carpio* Linnaeus; grass pickerel, *Esox americanus vermiculatus* Lesueur; northern pike, *Esox lucius* Linnaeus; and hybrid muskellunge, *Esox masquinongy* Mitchill X northern pike. During September electrofishing, these fishes were found sparsely scattered from station 1 to the FRS, a barrier for these fishes to further movement upstream.

Trout species present during some years were stocked and wild rainbow trout, *Salmo gairdneri* Richardson, and stocked brook trout, *Salveinus fontinalis* (Mitchill).

Taxonomy of the fishes named above follows American Fisheries Society (1980).

METHODS

DETERMINATION OF MOVEMENT BY FISHES THROUGH THE FRS

In 1964, there was considerable speculation about whether the 30-cm high waterfall from the tube and/or the high water velocity in the tube of the FRS was a barrier to upstream movement of trout, white sucker, and other fishes in Trout Creek. Therefore, on 8 September 1964, we captured (by electrofishing) and marked (by clipping the maxillaries or removing the anal fin) 64 wild brown trout (age I and older: 19-43 cm in total length), 81 wild brown trout (age 0: 10-15 cm in total length) and 24 wild rainbow trout (age 0: 12-16 cm in total length) in stations 24-26 above the FRS, and then transferred them to stations 17-19 below the FRS (Fig. 1). In addition to the trout, we captured and marked (by clipping the upper tip of the caudal fin) 189 white sucker (10-36 cm in total length) in stations 24-26 and transferred them to stations 17-19.

By 1973, when the waterfall from the tube in the FRS had increased to 66 cm, there was concern that such a height might block the October spawning run of wild brown trout from below to above the FRS. To determine whether the 66-cm waterfall was a barrier to the upstream spawning run, we removed the anal fin from 159 spawning-aged wild brown trout (age II and older: 25-48 cm in total length) in the 5.2-km stretch of the study area below the FRS during the trout population sampling on 17-20 September 1973. In addition, on 18 September 1973 we captured 30 wild brown trout (age III: 30-48 cm in total length) in stations 25-26 (above the FRS), removed their dorsal fins, and then transferred these large trout down to the plunge pool (stilling basin) below the FRS.

DETERMINATION OF TROUT REPRODUCTION

The potential number of wild brown trout fry emerging from the redds in Trout Creek during February-March was calculated from the estimated egg production of the wild female parent as determined for wild brown trout in New Zealand (Allen 1951). The percentage (80%) of fry emerging from the redds was based on the observed average success of egg development to sac-fry within the redds in Trout Creek during flood-free winters.

Before 1975, records of winter floods were obtained by the USGS at a flow gage on Black Earth Creek in neighboring Dane County. During 1975-79, water flow and temperatures were recorded at 4 gages on Trout Creek (Fig. 1).

DETERMINATION OF FISH DISTRIBUTION AND DENSITY

Estimates of the trout populations in the 8.2-km study area of Trout Creek began in September 1960, and continued through September 1979. The study area was subdivided into 30 stations, each of which was 273 m in length, except for stations 16 (348 m), 20 (207 m), 22 (316 m), and 30 (119 m). Estimates of the trout populations were made during April or early May and during September. Direct current electrofishing units were employed to capture trout for estimates of their populations within each station. We used the mark and recapture method, making 2 runs with the electrofishing units. Details on procedure and efficiency of the electrofishing units were discussed by McFadden (1961), Hunt et al. (1962), and White (1964). Recapture values (during the second run) on trout 10-15 cm in total length were 50-60% of the original numbers captured, marked, and then released within each station during the first run of the electrofishing units. On larger trout, these values rose to 70-90%.

All trout, age I and older captured on the first electrofishing run were measured to the nearest tenth of an inch (2.54 mm) in total length and weighed in grams. On the second run, these age groups of trout were measured, but only those that were not captured and marked on the first run were weighed. A representative sample of fingerling trout (age 0) were measured and weighed on the first run, but only measured on the second run. For future identification of wild brown trout year classes, selected fins were removed on successive year classes, age 0 in September and the unmarked age I the following spring.

Fins removed were adipose (a fin that does not regenerate), adipose-left ventral, adipose-right ventral, and adipose-both ventrals, thus allowing 4 years before any fins in the above series would again be removed from a young year class. Only a few trout live to age V in Trout Creek; hence, there is no confusion in separating the year classes of wild brown trout. A ventral or a pectoral fin was removed from domesticated trout before they were stocked below station 10. Since 1974, the left pectoral and right pectoral fin have been removed in alternate years, because carryover of domesticated trout to their third year of life in Trout Creek is rare.

No population estimates of white sucker in Trout Creek were made during this study. The number of white sucker is lower here than in most other southern Wisconsin streams, for example, Black Earth Creek, a stream in neighboring Dane County (Brynildson 1964, 1966; White 1964). At least 1 estimate of sculpin populations in Trout Creek has been made each year (mainly during the spring when the smaller sculpin are easier to catch by electrofishing after the instream vegetation has died away during the winter) since 1968, when approximately 500 adult sculpin were stocked (on 18 April 1968) at station 25 where gravel, rubble, and spring water are abundant (Brynildson and Brynildson 1978).

DETERMINATION OF TROUT PRODUCTION

Production of trout as used here is defined as the growth in weight by all trout in the population during a period of time, including growth by trout that died during that period. Production was calculated for each year class of trout as the product of the average standing stock in weight and its instantaneous rate of growth during the period of production. Instantaneous rate of growth is the logarithmic rate of increase in weight of a fish during a period of time. The time interval for determining production of trout was between the periods when trout population estimates were made, that is, from fall to spring and from spring to fall. The number of trout fry at the time of emergence from redds in February-March was calculated from the estimated egg production by the parent trout as determined for female brown trout in New Zealand (Allen 1951). The average weight of individual wild brown trout fry at time of emergence from redds was assumed to be 0.1 g, based on data from Bagenal (1969). Lifetime production of stocked domesticated brown trout was calculated from the time they were stocked as fingerlings (8-10 cm in total length) in June 1960, to the end of their lives.

RESULTS AND DISCUSSION

MOVEMENT BY FISHES THROUGH THE FRS

Results of our studies in 1964 show that the 30-cm high waterfall from the tube of the FRS and/or the high water velocity through the tube was a barrier to upstream movement (through the FRS) of all fishes, resident or transferred (8 September 1964) from above to the section of Trout Creek below the FRS, except for wild rainbow and brown trout over 13 and 20 cm in total length, respectively.

During the trout population sampling on 15-21 September 1964, we captured 3 (13-16 cm in total length) of the 24 transferred wild rainbow trout (age 0) and 8 (20-42 cm in total length) of the 64 transferred wild brown trout (age I and older) that had moved upstream through the tube of the FRS. None of the transferred wild brown trout (age 0) and white sucker were captured above the FRS during 15-21 September 1964. Moreover, none of these transferred age 0 brown trout or white sucker were found above the FRS during the trout population sampling conducted 22-24 April 1965 (a period when the white sucker spawning run upstream occurs); however, 20 of the age I and older wild brown trout transferred from above to below the FRS were captured above the FRS in April 1965. None of the age 0 rainbow trout transferred from above to below the FRS were captured above the FRS in April 1965.

Of the 159 spawning-aged wild brown trout marked below the FRS 17-20 September 1973, and the 30 wild brown trout (age III) that were transferred 18 September 1973 from stations 25-26 above the FRS to the plunge pool below the FRS, 22 and 18, respectively, were recaptured by electrofishing in stations 20-29 (above the FRS) on 24 October 1973. When spawning grounds just upstream from the FRS (stations 20-21) were eliminated by siltation in the flood pool, the spawning trout adapted by using spawning grounds above the flood pool (stations 23-29) more extensively and intesively. Van Kirk (1969) reported that adult brown trout from immediately above a FRS in Georgia were displaced below the FRS after floods and could not return through the tube in the dike to their former home upstream. (No information was given in the abstract on height of the waterfall from the tube or the water velocity through the tube in the FRS.)

Rarely were domesticated brook, brown, and rainbow trout (that were stocked in the 5.2-km stream section below the FRS on Trout Creek) found in the stream section above the FRS. Before the FRS was constructed in 1964, a relatively high number of domesticated brown trout fingerlings stocked 20 May 1963 in stations 5-10, below the FRS (Fig. 1), moved upstream above the future site of the FRS all the way to station 29 by the time of the 20-23 September 1963 trout population estimate (Brynildson 1967). Domesticated brook, brown, and rainbow trout, stocked as June or September-October fingerlings in widely scattered streams of Wisconsin, tended to move upstream more than downstream from their stocking sites (Brynildson 1967).

The occasional stocked domesticated trout captured by electrofishing above the FRS would usually be a spawning-aged brown trout that had survived to its second year of life in Trout Creek. The survival of stocked trout to their second year of life in Trout Creek is less than 1% (see Fig. 7).

Northern pike, hybrid muskellunge, grass pickerel, bluegill, largemouth bass, burbot, and common carp migrating upstream from Mill Creek (Fig. 1), have never been captured above the FRS during electrofishing. These fishes were present in the study area above the FRS before the structure was completed in 1964.

Of significant benefit to the wild brown trout population above the FRS were: (1) elimination of competition for food and space from domesticated trout and other migrating fishes, and (2) elimination of trout predators such as northern pike and hybrid muskellunge, which feed mainly on trout below the FRS. Stomachs of northern pike and hybrid muskellunge captured by electrofishing below the FRS during 1976-79 contained mainly trout (up to 28 cm in total length). The rest of the stomachs examined were either empty or contained the white sucker.

REPRODUCTION AND SURVIVAL OF YOUNG

Potential egg deposition and estimated survival of wild brown trout from February-March fry to September fingerlings (age 0) in Trout Creek are presented in Table 2.

The 1973 year class, with a relatively high egg deposition potential, was nearly wiped out by a winter flood and had the lowest survival rate from February-March fry to September fingerlings during the 20-year span of the study. The 1962 year class, hatched during a stable water year, had the highest survival rate (Table 2 and Fig. 4).

There is evidence from the data presented in Table 2 that: (1) low populations of September fingerlings were a result of winter floods; (2) the number of mature female trout in September can be relatively low and yet produce a relatively large number of September fingerlings whenever the stream environment is stable as it was, for example, for the 1962, 1963, 1968, 1969, and 1970 year classes; and (3) a large year class of wild brown trout, such as in 1969, had sufficient survivors so that the number of mature females in September 1971, was more than twice the 20-year average (Table 2). The 1969 year class contributed 90% to the total number (499) of mature female trout in September 1971.

Survival of potential February-March fry to September fingerlings averaged 1.5% (1.2% from egg to September fingerlings) in Trout Creek over the 20-year span of study. This average compares favorably with the average 1.7% and 1.2% survival (Table 3) of potential February-March wild brown trout fry to September fingerlings in Black Earth and Mt.

TABLE 2. *Potential reproduction and the estimated survival of various year classes of wild brown trout to September fingerlings (age 0) in Trout Creek, 1960-79.*

Year Class Hatched	Number of Mature Females* Preceding Sep	Potential Number of Eggs Deposited in Nov	Potential Number of Fry in Feb - Mar	Number of Fingerlings in Sep	Percentage Survival of Fry to Sep Fingerlings
1960	112	121,440	97,150	487	0.5**
1961	116	125,280	100,220	826	0.8**
1962	43	46,580	37,260	1,678	4.5
1963	58	53,500	42,800	1,539	3.6
1964	91	84,300	67,440	1,402	2.1
1965	148	156,850	125,480	428	0.3**
1966	162	139,360	111,490	2,113	1.9
1967	218	217,500	174,000	777	0.4**
1968	123	143,480	114,780	3,168	2.8
1969	188	169,530	135,620	4,142	3.0
1970	153	155,860	124,690	2,918	2.3
1971	287	265,530	212,420	1,672	0.8**
1972	499[a]	307,460	245,970	663	0.3**
1973	202	202,640	162,110	351	0.2**
1974	352	324,860	259,890	1,645	0.6**
1975	216	207,800	166,240	2,002	1.2
1976	101	108,260	86,610	536	0.6**
1977	188	168,560	134,850	972	0.7**
1978	345	293,700	234,960	2,876	1.2
1979	336	341,040	272,830	3,498	1.3
Avg.	197	181,680	145,340	1,685	1.5

*Mature wild female brown trout in Trout Creek outnumbered the wild male brown trout by an average of 60% (range 51-68%) during the 20 years of investigation.
**Survival during years of winter floods.
[a]The large 1969 year class contributed 90% to the total number of mature female trout in September 1971.

TABLE 3. *Potential reproduction and the estimated survival of various year classes of wild brown trout to September fingerlings (age 0) in Black Earth and Mt. Vernon creeks, Dane County, Wisconsin.*

Year Class Hatched	Number of Mature Females* Preceding Sep	Potential Number of Eggs Deposited in Nov	Potential Number of Fry in Feb - Mar	Number of Fingerlings in Sep	Percentage Survival of Fry to Sep Fingerlings
Black Earth Creek					
1955	47	65,800	52,640	345	0.6**
1956	36	54,470	43,570	360	0.8**
1960	44	58,080	46,460	2,307	5.0
1961	136	165,920	132,740	1,462	1.1**
1962	116	160,080	128,060	1,781	1.4
1967	163	213,530	170,820	136	0.1**
1968	105	147,000	117,600	1,310	1.1
1969	135	171,450	137,160	2,046	1.2
1970	82	114,800	91,840	2,875	3.1
1971	178	184,470	147,580	3,168	2.1[a]
1972	271	308,940	247,150	4,390	1.8[a]
Avg.	119	149,500	119,600	1,834	1.7
Mt. Vernon Creek					
1955	28	41,440	33,150	755	2.3
1956	25	37,830	30,260	260	0.9**
1960	64	96,000	76,800	820	1.1**
1963	129	172,860	138,290	744	0.5**
Avg.	62	87,030	69,630	645	1.2

*The average number of wild female brown trout in the spawning populations was 50% (range 42-47%) in Black Earth Creek and 52% (range 40-66%) in Mt. Vernon Creek during the 11 and 4 years of study, respectively.
**Survival during years of recorded winter floods.
[a]No flood until mid-March when fry were free swimming.

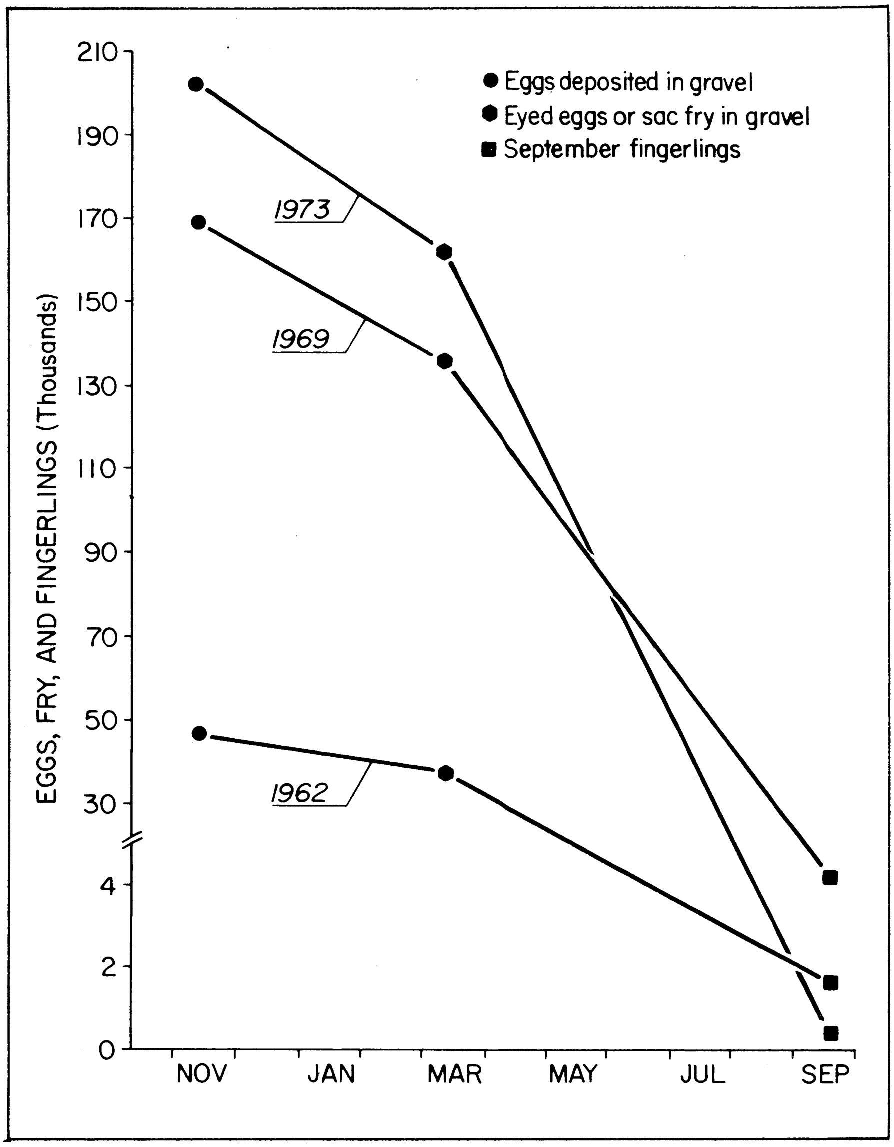


FIGURE 4. Potential egg deposition and survival of 3 year classes of wild brown trout from eyed eggs or sac-fry to September fingerlings in the 8.2-km study area of Trout Creek.

Vernon creeks, 2 coulee streams in neighboring Dane County. In the Pigeon River in Michigan (less flood-prone than Wisconsin coulee streams), survival of wild brown trout from egg to fall fingerlings averaged 3.0% (range 1.4-5.8%) (Cooper 1953).

After the February-March fry live to become September fingerlings, their survival rate is relatively high during the following months. For example, in Trout Creek the overwinter survival of the September fingerlings (10-13 cm in total length) to the following April was 72% in stations 28-29 during 1978-79.

The 1965 year class in Trout Creek had one of the lowest survival rates, from potential fry to September fingerlings, of the 20 year classes (Table 2). This year class experienced 2 severe environmental blows: (1) freezing water temperatures were recorded below station 16 during the 1964-65 winter because of the lowest ground water discharge in 12 years (the 1,500-L/min spring 46 m above station 16 went dry); and (2) late February-early March floods occurred when trout fry were still in the gravel of the redds, and hence fry were killed when the gravel washed away. Because winter water temperatures are higher above the FRS than below (Carline 1976), the floodwaters and the water backed up by the FRS were probably more damaging to the 1965 year class still developing in the redds above the FRS than was cold water. Conversely, the FRS (with its slow-release tube), helped to protect eggs and sac-fry below station 19 from destruction by floodwater, but because the spring just above station 16 went dry there was no protection from freezing water flowing over and through the redds and retarding or preventing the trout eggs from developing normally. Eggs taken from redds below station 16 during February 1965, were mostly dead or developing slowly. A redd at station 10 was covered with anchor ice in January 1977 and when excavated was found to contain only dead eggs (Eddie Avery, Wis. Dep. Nat. Resour., pers. comm.).

Brown trout eggs excavated from redds in Black Earth and Mt. Vernon creeks in areas where freezing water occurred during winter were all dead by January (Brynildson 1955, 1966; Brynildson et al. 1955). Combs and Burrows (1957) utilized controlled water temperatures in a salmon culture laboratory to incubate chinook and pink salmon eggs. They reported that: (1) chinook salmon eggs incubated at a constant 40 F or below had high mortality with practically total losses at 35 F, and (2) chinook and pink salmon eggs could tolerate long periods of very low (33 F) temperatures if the initial incubation temperatures were above 42 F for a month.

Brown trout in Trout Creek spawn mainly during November. By then, air temperatures are generally below freezing and water away from spring flow is nearing the freezing mark, as in the reach below station 14 where egg mortality was the highest in Trout Creek.

Except during winters (as 1964-65) when freezing water below station 16 killed most of the trout eggs or delayed their development, the populations of September fingerlings have been relatively stable below the FRS since it was completed in 1964, even though winter floods above the dry basin and standing water in the basin (after floods) killed trout eggs and fry. This stability is probably due to a combination of events that all but eliminated the 1972, 1973, and 1976 year classes above the FRS but did not affect the stability of September fingerling numbers below the FRS (see Fig. 6). In September 1972, 1973, and 1976 (years with severe winter floods), when September fingerling populations were low in the study area (Table 2), 90%, 86%, and 89%, respectively, of the fingerlings were resident below the FRS as compared to 24%, 17%, and 27%, in September 1969, 1978, and 1979, respectively, when stream flow in Trout Creek was stable.

Whether floodwater is more destructive to trout eggs and fry than is standing water (temporarily backed up by the FRS) is, of course, speculative based on data at hand. During the 27 February and 4 and 12 March 1976 floods on Trout Creek, USGS hydrologists monitored the stream flow in the upper 3.7 km of the study area. At gage A (Fig. 1), Trout Creek at its highest volume of flow rose 0.8 m and increased in velocity from the approximate normal 0.3 m/sec to 0.9 m/sec. On 12 March 1976, the standing water backed up by the FRS extended as far upstream (1,344 m) as station 24 (Stephen Field, USGS Wis. Dist., pers. comm.) thus covering the trout redds (found in the dry basin of the FRS in November 1975) with standing silt-laden water, thereby depriving the trout eggs and nonswimming sac-fry of adequate oxygen. Swimming fry above the standing water were probably carried downstream by the floodwaters. Instead of continuing downstream, to perhaps some safety, they were interrupted by the standing water behind the FRS and the slow release of that water through the dike tube. Here the fry may have spread out into the standing water and become stranded among winter remains of the tall and densely growing nonwoody vegetation in the water-filled dry basin above the FRS. The swimming fry of the 1972 year class may also have been trapped in the dry basin during the mid-March floods in 1972 because their survival to September was low (Table 2) and their numerical density above the FRS (stations 20-30) was low (see Fig. 6). In contrast, the 1972 year class in free-flowing Black Earth Creek survived better than average (Table 3).

SURVIVAL OF ADULTS

Survival of the large 1969 year class, 3 medium year classes (1962, 1963, and 1974), and a small year class (1973) beyond September fingerlings was similar (Fig. 5). Where both summer and winter survival records are available as they are for the 1962 and 1963 year classes, it is evident that the age I and II wild brown trout had lower survival in summer than in winter (Fig. 5), as a result of an open fishing season during summer only during those years. However, when the fishing season opened 1 January 1975, the difference in the winter and summer survival was less pronounced. Survival of the small (351) 1973 year class throughout its lifetime was more uniform than was lifetime survival of larger year classes (Fig. 5). This pattern may indicate that a small year class of wild brown trout is less vulnerable to exploitation by angling

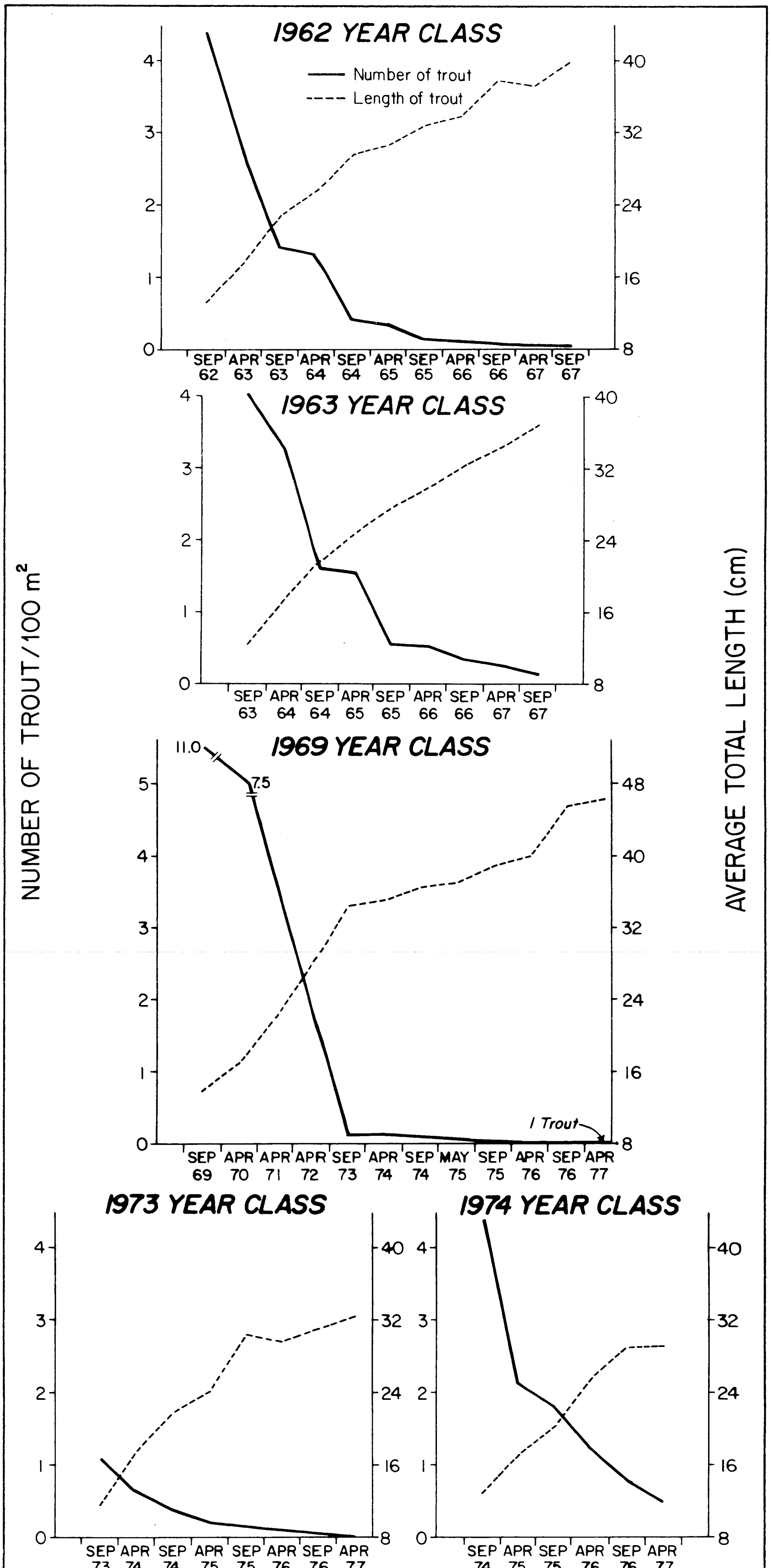


FIGURE 5. Survival of 5 year classes of wild brown trout beyond September fingerlings in the 8.2-km study area of Trout Creek.

FIGURE 6. The distribution and numerical density of wild brown trout fingerlings in September during various years in the 8.2-km study area of Trout Creek.

than are larger year classes, because fishing pressure decreases when catches decrease. Whether due to natural or angling mortality, the medium-sized year classes (1962 and 1963) and the large year class of 1969 all were at low population levels by the time they had lived 4 years (Fig. 5).

DISTRIBUTION AND DENSITY OF FINGERLINGS

After the FRS was completed in May 1964, water backed up (through most of station 20) in the stream channel behind the dike. The tube, in the dike of FRS, at its inlet was placed approximately 0.9 m above the stream bed in order to provide sufficient gradient through the tube for efficient discharge of water from the FRS during periods of high water, and to allow for future settling of the tube along with the newly completed earthen dike. Subsequent effects of decreased water velocity and siltation of the stream channel in station 20 and the lower half of station 21 on reproduction and distribution of wild brown trout fingerlings could not be determined until September 1966, because the 1965 year class was severely damaged by winter floods. Stations 20 and 21 were prime spawning grounds before the FRS was completed in May 1964, and the wild brown trout fingerlings during 1962-64 had similar patterns of distribution in September, with peak numbers between stations 19 and 21 (Fig. 6). By September 1966, however, the highest numerical density of fingerling trout was above station 20, and this became the general pattern of distribution (Fig. 6) in years without winter floods (see Table 2) to the present (1979).

GROWTH AND PRODUCTION

Average total length of 5 year classes of wild brown trout during successive years of their life span is presented in Figure 5. Lifetime production of three year classes of wild brown trout and one year class of domesticated brown trout (stocked as June fingerlings in 1960) is presented in Figure 7. Winter, summer, and annual production by all year classes of wild brown trout in the 8.2-km study area of Trout Creek during various years is presented in Appendix Figures 1-5. Numerical density, biomass, and annual production of wild brown trout in selected stations during various years are presented in Table 4.

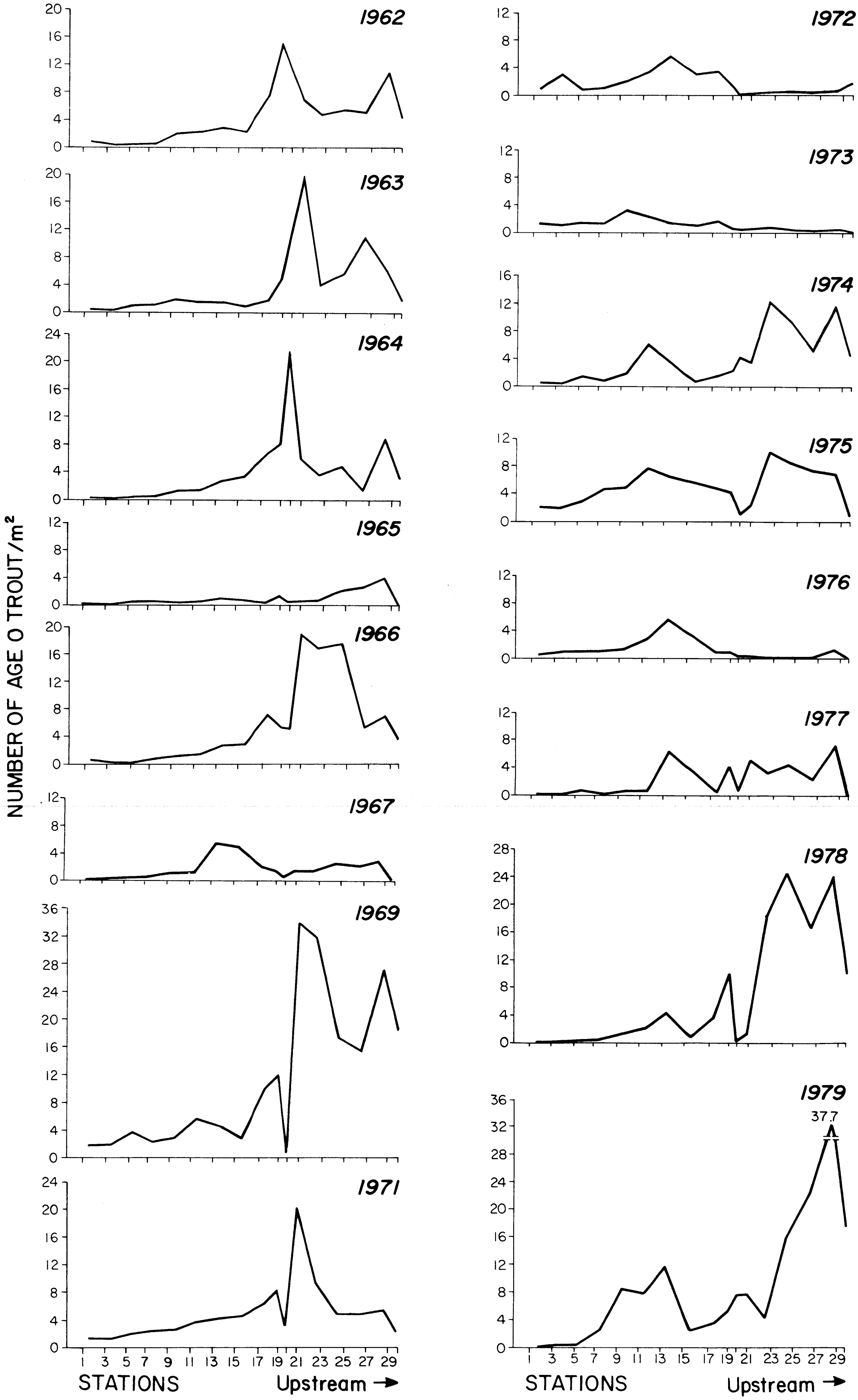
TABLE 4. *Numerical density, biomass, and annual production of wild brown trout in selected sections of Trout Creek, 1962-79.*

Stations Along Stream	Periods of Production	No. Trout/ 100 m^2	Biomass (g/m^2)	Production (g/m^2)	B:P*
7-8 (549 m)	Sep 62-Sep 63	2.5	2.1	2.9	1:1.4
	Sep 64-Sep 65	1.4	1.6	2.6	1:1.0
	Sep 66-Sep 67	1.8	2.0	1.6	1:0.8
	Sep 74-Sep 75	4.0	1.0	3.3	1:3.3**
	Sep 75-Sep 76	4.0	1.5	3.3	1:2.2**
	Sep 78-Sep 79	3.3	3.6	4.2	1:1.2
17-19 (750 m)	Sep 62-Sep 63	7.4	4.2	5.5	1:1.3
	Sep 64-Sep 65	6.9	5.0	4.8	1:1.0
	Sep 66-Sep 67	6.8	4.5	7.6	1:1.7
	Sep 74-Sep 75	5.5	3.5	4.4	1:1.3
	Sep 75-Sep 76	6.3	4.6	3.6	1:0.8[a]
	Sep 78-Sep 79	8.0	4.2	3.9	1:0.9
20-21 (482 m)	Sep 62-Sep 63	16.4	5.0	10.8	1:2.2**
	Sep 64-Sep 65	7.8	4.9	6.6	1:1.4
	Sep 66-Sep 67	7.1	4.8	7.3	1:1.5
	Sep 74-Sep 75	6.6	4.9	10.8	1:2.2**
	Sep 75-Sep 76	3.5	4.8	2.0	1:0.4[a]
	Sep 78-Sep 79	9.2	8.4	9.0	1:1.1
28-29 (549 m)	Sep 62-Sep 63	12.3	5.8	9.5	1:1.6
	Sep 64-Sep 65	12.3	9.6	12.2	1:1.3
	Sep 66-Sep 67	14.8	16.1	15.7	1:1.0
	Sep 74-Sep 75	13.9	8.3	10.7	1:1.3
	Sep 75-Sep 76	12.0	11.7	11.2	1:1.0
	Sep 78-Sep 79	51.7	25.1	36.0	1:1.4

*Biomass:production.

**Efficiency of production increased because of relatively large numbers of trout age 0 and/or age I in these stations during the given period of production.

[a]Efficiency of production decreased because of relatively small numbers of trout age 0 and/or age 1 in these stations during the given period of production.


1962
1963
1964
1965
1966
1967
1969
1971
1972
1973
1974
1975
1976
1977
1978
1979
37.7
NUMBER OF AGE O TROUT/m²
STATIONS
Upstream →

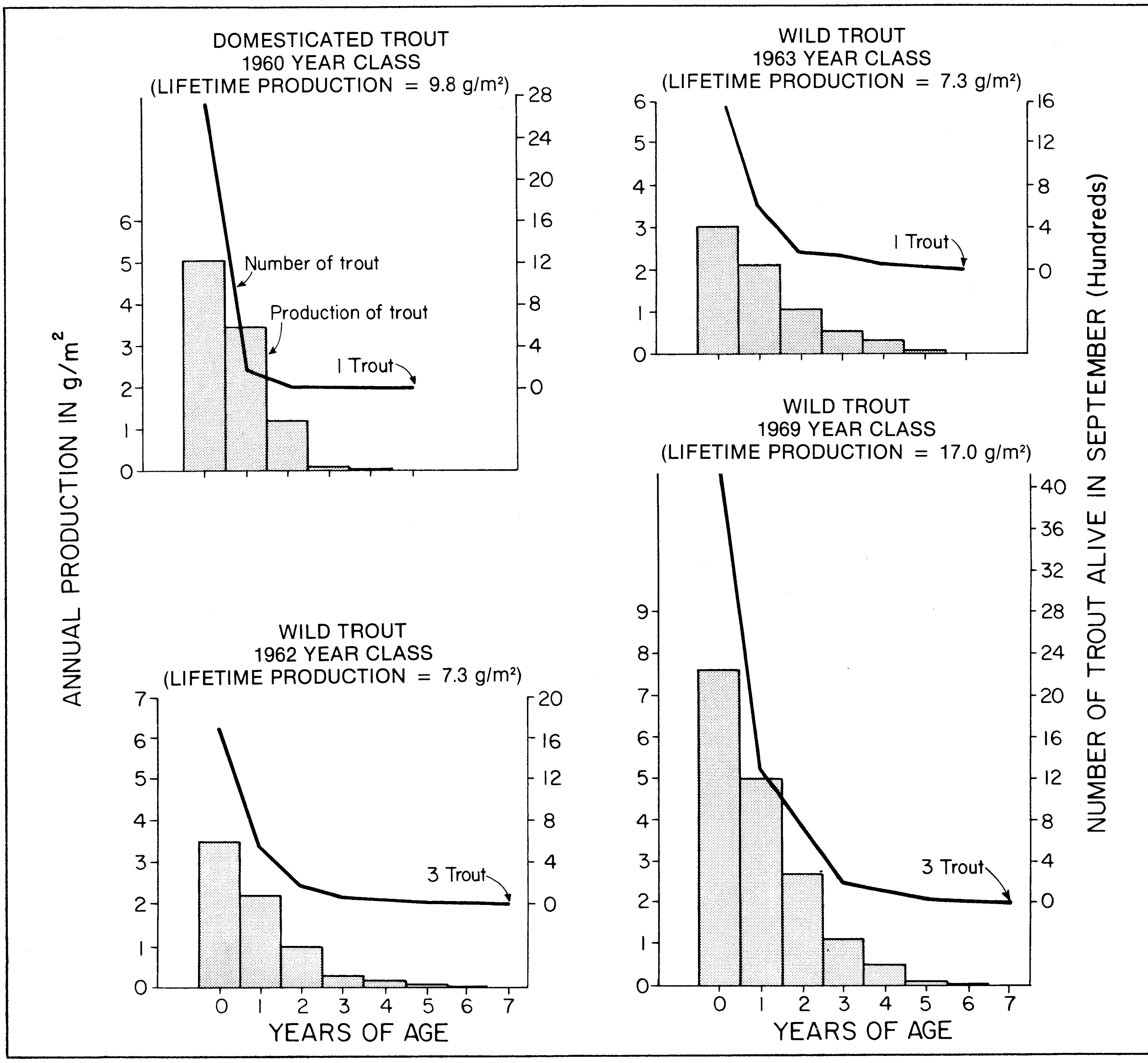


FIGURE 7. The annual production during the lifetime of 1 year class of stocked domesticated brown trout and 3 year classes of wild brown trout in the 8.2-km study area of Trout Creek.

LeCren (1972) reported that increased trout population density increased trout production to a point until a maximum is reached which is then maintained regardless of further increase in numerical density. Production of wild brown trout in Trout Creek increased with an increase in numerical density of wild trout. This indicates that numerical density of wild brown trout in Trout Creek has not reached a level where further increase in numbers of wild brown trout would slow their production. Similar observations were made on wild brook trout (Hunt 1966), wild brown trout (Brynildson and Mason 1975), and coho salmon (Chapman 1965).

Annual trout production in relation to biomass (B:P) in Trout Creek was generally higher in stations 7-8 and 20-21 in comparison to stations 17-19 and to stations 28-29, which had the highest number of wild trout (Table 4) and consequently lower growth rates. The highest annual production of all year classes of trout combined was 36.0 g/m^2 in stations 28-29 (39.5 g/m^2 in station 28 alone) during 1978-79, with the large 1979 year class (numbering 38/100 m^2 of stream in these 2 stations) contributing 15.3 g/m^2 to the total.

This annual production of wild brown trout compares favorably with annual production of wild brown trout in Black Earth Creek. The highest annual production recorded in Black Earth Creek was 25.6 g/m^2 and 39.6 g/m^2 in the upper section and middle section during 1972-73, respectively (Brynildson and Mason 1975). The upper section of Black Earth Creek (like all of Trout Creek) is free of domestic sewage fertility while the middle section is enriched by such fertility, and consequently, growth and production is relatively higher in the middle section.

The 1969 year class had the highest production by any one year class of wild brown trout in Trout Creek during its first year of life. This year class produced 28.0 g/m^2 of trout tissue during its first 14 months of life in station

23 (Append. Fig. 4).

The highest annual wild brown trout production in Black Earth Creek or Trout Creek falls short of the annual production of 54 g/m^2 by wild brown trout in the Horokiwi in New Zealand (Allen 1951), but substantially exceeds the annual 2-12 g/m^2 of production by wild brown trout in small streams in England (Le Cren 1972), and the average 5.8 g/m^2 and 6.9 g/m^2, respectively, in the Au Sable River (Alexander and Ryckman 1976) and Gamble Creek (Gowing 1975) in Michigan.

The relatively high efficiency of production by wild brown trout during their first year of life in Trout Creek is evident when the biomass:production ratios are examined for the different year classes (Table 5). Efficiency of production by the total wild brown trout population drops or rises, during a production period in Trout Creek, whenever there is a weak or strong year class, respectively, within that period.

When annual production during the lifetime of 3 year classes of wild brown trout is examined (Fig. 7), it is evident that the bulk of year class production occurred at age 0 and age I. The average contribution to lifetime production was 45% for age 0 and 29% for age I trout, while age II and age III trout contributed 15 and 6%, respectively.

The 12,000 domesticated brown trout stocked as June fingerlings (8-10 cm in total length) in 1960 also had their greatest production (Fig. 7) at ages 0 and 1 (production while in the hatchery was not included), but by age III there were only 6 of these trout remaining in the study area. This indicates that brown trout of domestic origin, even when stocked as young fingerlings in June, were more easily taken on hook and line than their wild counterparts inhabiting the same stream.

In Lawrence Creek, Wisconsin, the average contribution to lifetime production by 8 year classes of wild brook trout was 40.8% for age 0 and 41.0% for age I trout (Hunt 1974). Lifetime production (Fig. 7) by the 3 year classes of wild brown trout in Trout Creek was 17.0 g/m^2 for the large 1969 year class and 7.3 g/m^2 for both the 1962 and 1963 year classes. The latter 2 year classes contained approximately the same number of September fingerlings (Table 2). For the 8 year classes of wild brook trout in Lawrence Creek, lifetime production ranged from 9.1 to 15.9 g/m^2 or 372-650 kg (Hunt 1974). As a comparison, production by the 1969 year class of wild brown trout in Trout Creek during 8 years was 525 kg, of which 389 kg were produced during the first 2 years of life. The 1961 year class with the highest production (650 kg) in Lawrence Creek numbered approximately 14,000 September fingerlings compared to 4,142 in the 1969 year class in Trout Creek. That the 1969 year class of wild brown trout in Trout Creek could approach the lifetime production of the 1961 year class of wild brook trout in Lawrence Creek was because the 1969 year class had representatives that lived and had positive production for 8 years while the 1961 year class of brook trout was extinct after only 4 years.

The 1969 year class from Trout Creek had 3 living representatives in September 1976 (Fig. 7) and only 1 in April 1977, a relatively slow-growing trout of only 46 cm in total length at 8 years of age. The oldest known-aged wild brown trout recorded by the authors was a 69-cm (in total length) female (age 9 years) captured in Mt. Vernon Creek in April 1972. This trout had its adipose fin (which does not regenerate) removed as a 13-cm fingerling in September 1963. Lennon (1967) stated that wild brook trout in the Great Smoky Mountains National Park did not live to 5 years. Hunt (1970) recorded 6 years for the oldest known-aged wild brook trout in central Wisconsin.

TABLE 5. *Numerical density, biomass, and production of wild brown trout within selected stations of Trout Creek from 5-8 May 1975 to 19-23 April 1976.*

Year Class of Trout	Avg. No. Trout/100 m^2	Avg. Biomass (g/m^2)	Production (g/m^2)	B:P*
Stations 7-8 (549 m)				
1975	4.3	0.8	3.5	1:4.4
1974	0.4	0.3	0.3	1:1.0
1973	0.2	0.3	0.4	1:1.3
1972-71	0.1	0.1	0.0	—
Stations 17-19 (750 m)				
1975	4.4	0.6	2.7	1:4.5
1974	1.4	1.6	2.3	1:1.4
1973	0.8	0.3	0.0	—
1972	0.1	0.2	0.2	1:1.0
1971-68	0.3	0.9	0.3	1:0.3
Stations 20-21 (482 m)				
1975	1.9	0.4	2.0	1:5.0
1974	3.7	4.2	5.0	1:1.2
1973	0.1	0.5	0.6	1:1.2
1972-70	0.1	0.6	0.1	1:0.2
Stations 22-23 (590 m)				
1975	8.6	1.6	8.3	1:5.2
1974	2.7	3.6	5.2	1:1.4
1973	0.1	0.4	0.4	1:1.0
1972	0.1	0.1	0.1	1:1.0
1971	0.1	0.5	0.4	1:0.8
1970	0.1	0.7	0.8	1:1.1
Stations 28-29 (549 m)				
1975	6.3	1.1	4.8	1:4.4
1974	5.3	5.3	6.3	1:1.2
1973	0.1	0.3	0.1	1:0.3
1972	0.1	0.2	0.1	1:0.5
1971	0.3	1.0	0.2	1:0.2
1970	0.2	0.9	0.2	1:0.2
1969	0.1	0.5	0.2	1:0.4
1968	0.1	0.4	0.1	1:0.2

*Biomass:production.

MANAGEMENT IMPLICATIONS

From 1964 to 1979, sedimentation was added to winter floods and freezing water temperatures as another enemy of developing trout eggs in the stream gravel. Sedimentation intensified after the FRS was constructed in 1964. The heaviest deposits of sediment were in the dry floodwater-retarding basin of the FRS, which extends 1,050 m upstream from the FRS, a reach of stream that before 1964 was the best trout spawning area in Trout Creek. Sedimentation occurred also on trout spawning grounds from station 13 (below the FRS) up to the FRS, apparently, because of the stable water flow that decreased flushing of the stream channel by spring freshets and summer floods.

Because water flow is now considerably more stable below the FRS on Trout Creek, destruction of trout redds by flowing water is minimal. Perhaps stream deflectors, by narrowing the stream channel and thus increasing water velocity over areas with suitable spawning gravel, would keep sediment from settling on and within the gravel in this stream reach. Past failures to retain man-made spawning grounds for brown trout in Wisconsin streams resulted from floodwater washing the gravel downstream after a couple of years and destroying the spawning area constructed by man. Gravel placed below the FRS in potential trout spawning sites would probably be more stable and serve as brown trout spawning grounds for many (yet unknown) years.

The destruction of trout spawning grounds in the dry basin of the FRS due to sedimentation or to standing water cannot be easily alleviated. Creation of such conditions is the function of a FRS, i.e., to catch and hold water and to settle out at least the coarse sediment as the retarded floodwater behind the FRS is slowly released downstream. It would be questionable management of the wild trout resource to install stream deflectors in the stream channel in the dry basin of the FRS to remove and prevent deposition of sediment on trout spawning gravel. If that were indeed done, spawning trout would be attracted to these spawning grounds, only to have their progeny suffocate in the developing egg and sac-fry stages by silt-laden water from winter floods. It would be wiser to encourage these trout to continue upstream to spawn above the dry basin of the FRS where some of the spawning gravel is inferior but where winter water temperatures and sedimentation are moderate.

Because suitable gravel substrate did exist upstream, the FRS built on Trout Creek did not lower the overall reproduction of trout in the stream. This condition — alternative spawning grounds — may not exist in other streams proposed for FRS construction. For this reason, we strongly advise that whenever a dry floodwater-retarding structure is constructed on a trout stream, it should be located above or below trout spawning grounds or on nontrout producing tributaries that drain into the main trout stream. The cost:benefit ratio resulting from early 1960 calculations would probably then be less favorable if it had been so located, but when the wild trout resource and sport fishery are given their proper values in the formula, as they are today, the ratio could become more favorable.

Positive factors of the FRS on Trout Creek are: (1) the controlled water flow below the FRS during winter floods has been a stabilizing influence on the limited trout reproduction below the FRS; and (2) because the FRS blocks the upstream movement of competing and predatory fishes, the wild trout population above the FRS has benefited and should continue to benefit.

SUMMARY

The main objective for investigating the wild brown trout populations in Trout Creek was to determine the characteristics of such populations in a Wisconsin coulee stream. After construction of a dry floodwater-retarding structure (FRS) on Trout Creek in 1964, emphasis was placed on effects of the FRS on wild brown trout ecology.

Trout reproductive success was determined by the relationship of the calculated number of eggs deposited in the redds during a given November and the estimated number of wild trout fingerlings present in the study area the following September. During the trout population estimates with electrofishing gear, all trout age II and older were sexed and estimates of their number were calculated. Data on density, distribution, survival, growth, and production of trout were obtained during April and September trout population estimates conducted over a span of 20 years (1960-79).

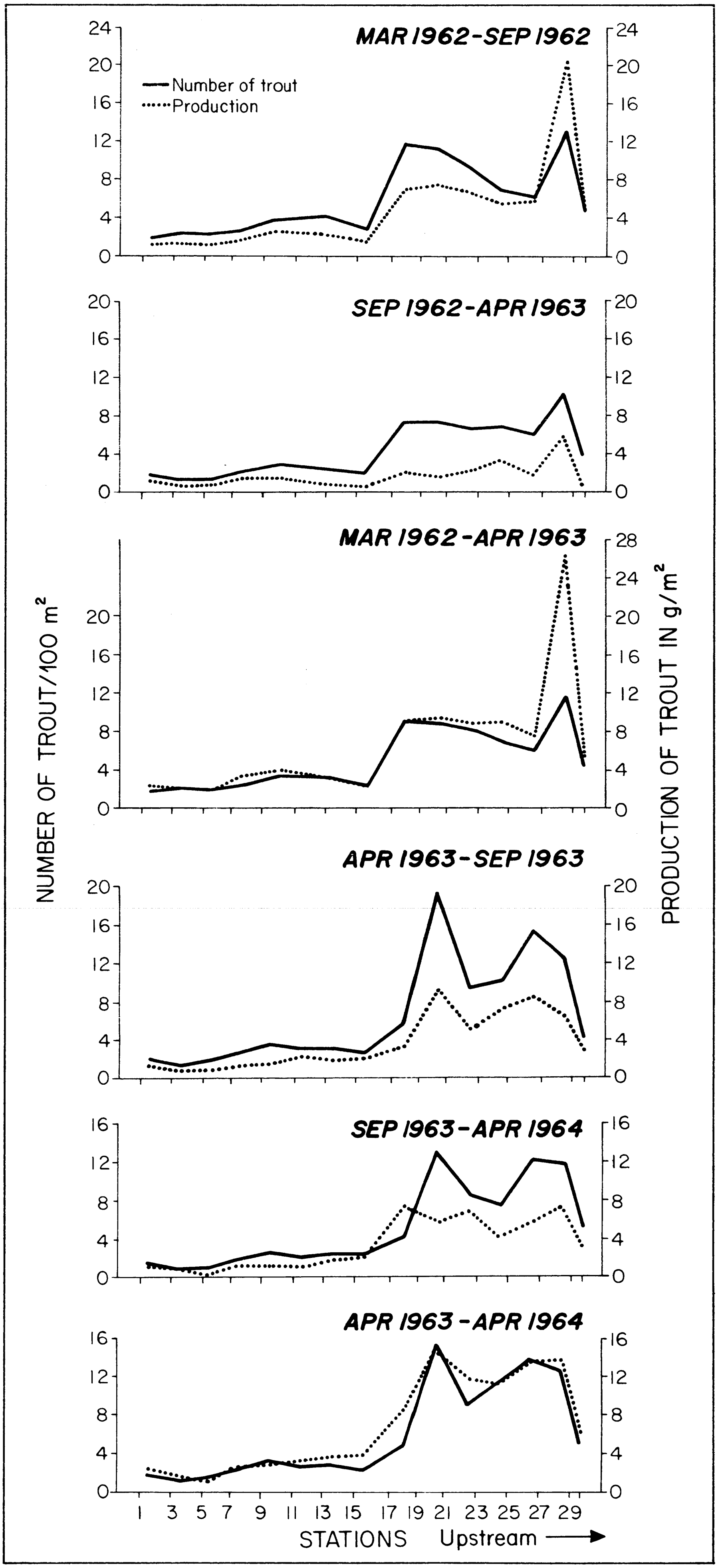
During some winters, floods and freezing water temperatures decreased normal survival of developing trout eggs and sac-fry. Spawning gravel in the stream channel within the dry basin of the FRS was covered by sediment after the FRS was completed in 1964.

Production of wild brown trout in Trout Creek was similar to that in a neighboring coulee stream whenever numerical density of wild brown trout in the 2 streams was similar. Production of wild brown trout in both streams increased with an increase in numerical density. Numerical density of wild brown trout varied during the 20 years of study because various year classes were severely reduced by winter floods.

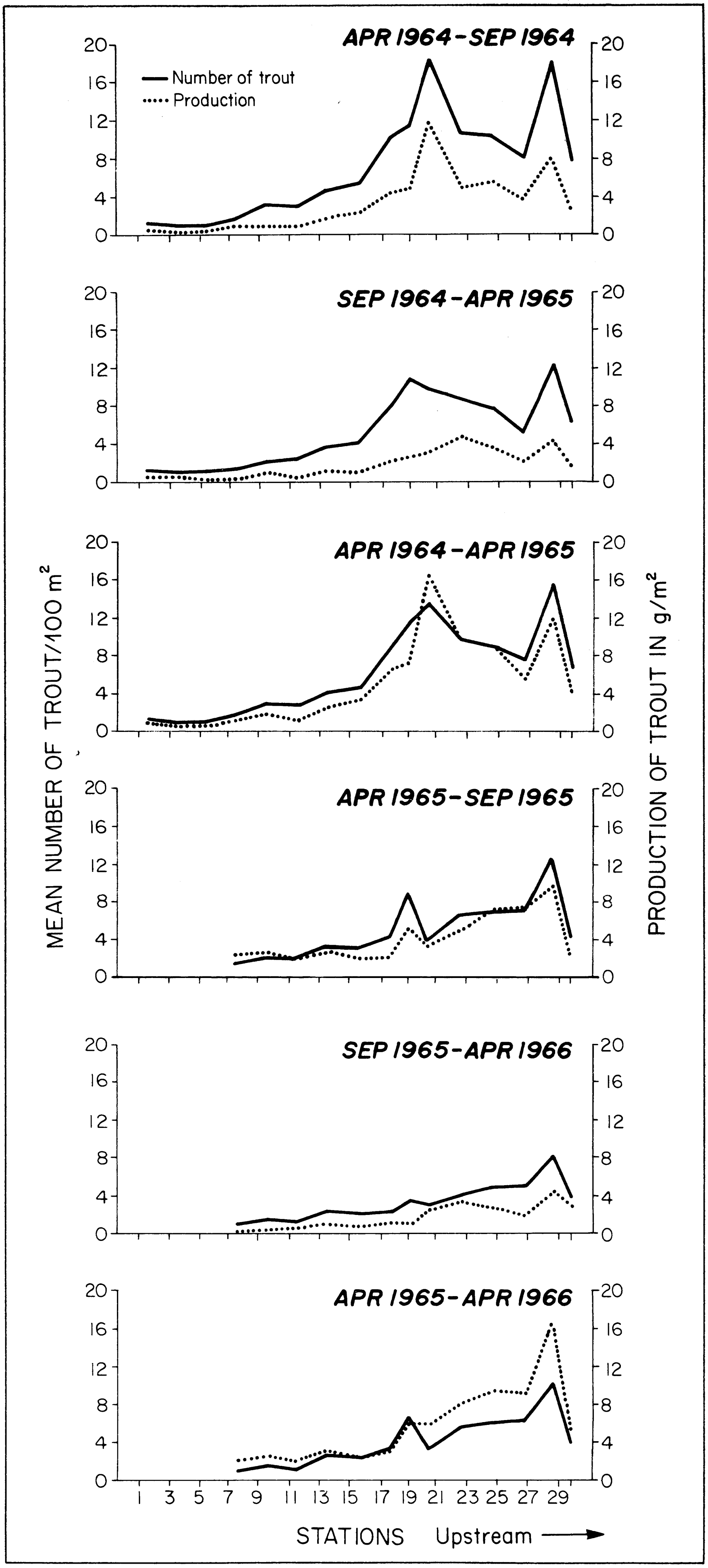
In 1964, the 30-cm waterfall from the tube in the dike of the FRS and/or the high water velocity through the tube was a barrier to upstream movement of all fishes except wild rainbow trout over 13 cm and wild brown trout over 20 cm in total length. When the waterfall had increased to 66 cm in height by 1973, it was not a barrier to wild brown trout age II and older (28-48 cm in total length) on their way to spawning grounds above the FRS.

Of benefit to the wild brown trout population above the FRS, was that the FRS blocked competing and predatory fishes below the FRS access to the reach of stream above the FRS. The FRS controlled stream flow below its outlet and thus stabilized the limited trout reproduction below the structure.

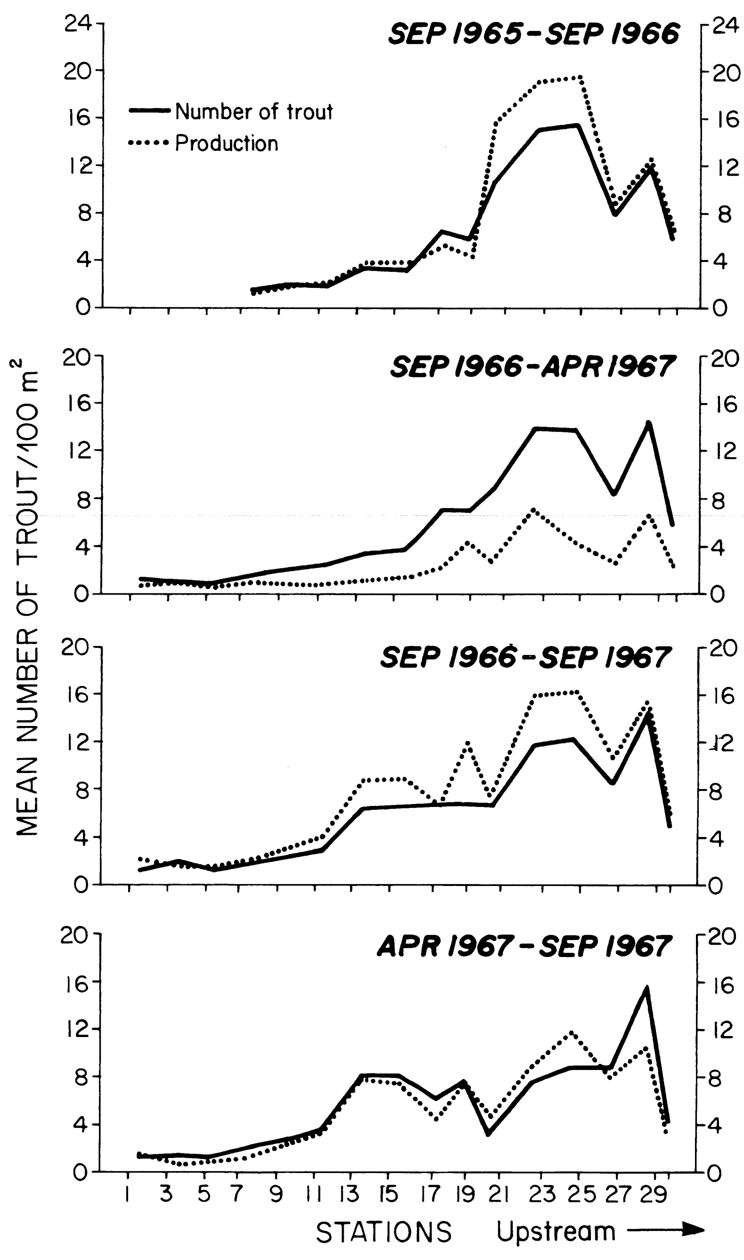
APPENDIX



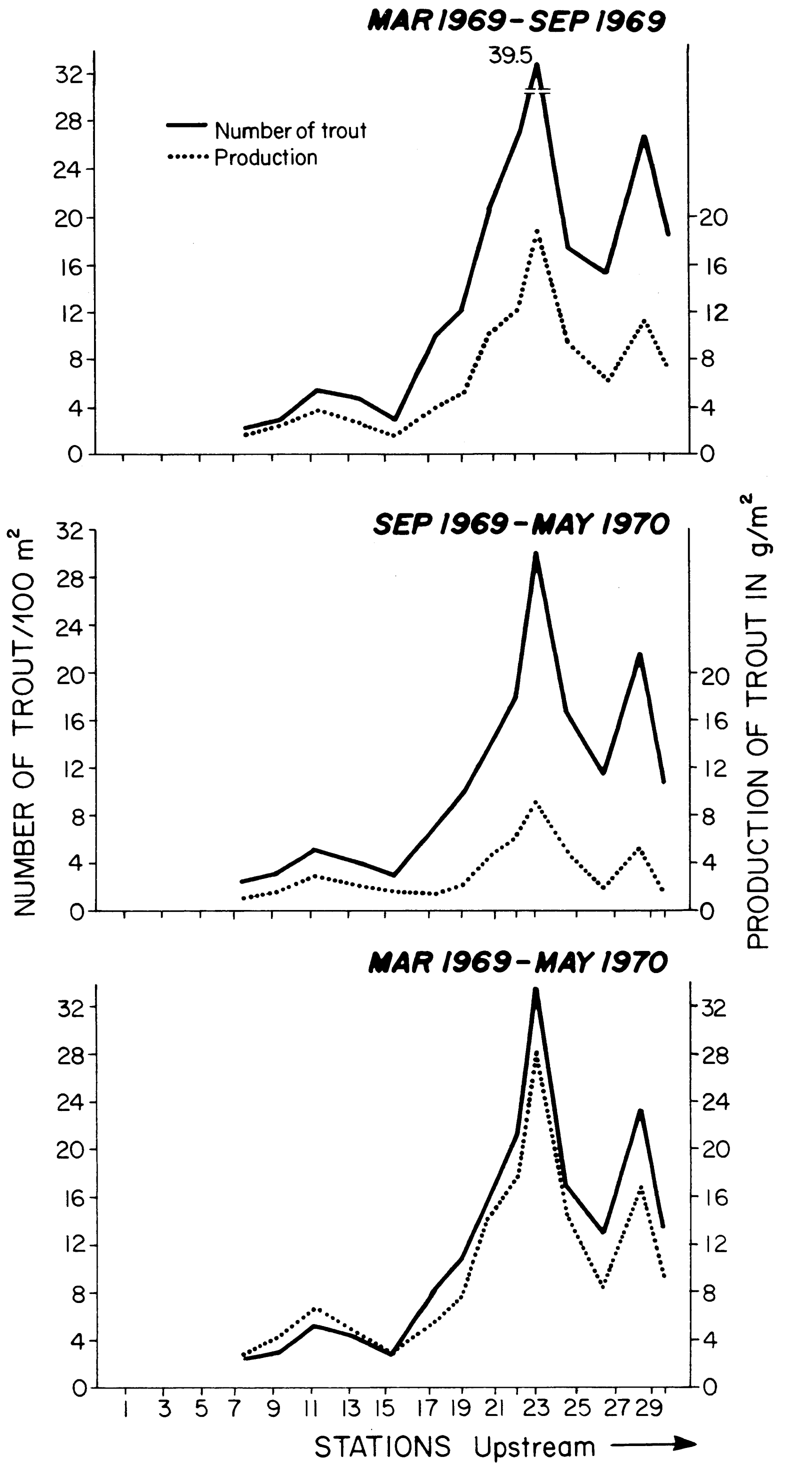
APPENDIX FIGURE 1. Distribution, numerical density, and production of wild brown trout in the 8.2-km study area of Trout Creek before installation of the FRS in the early summer of 1964.



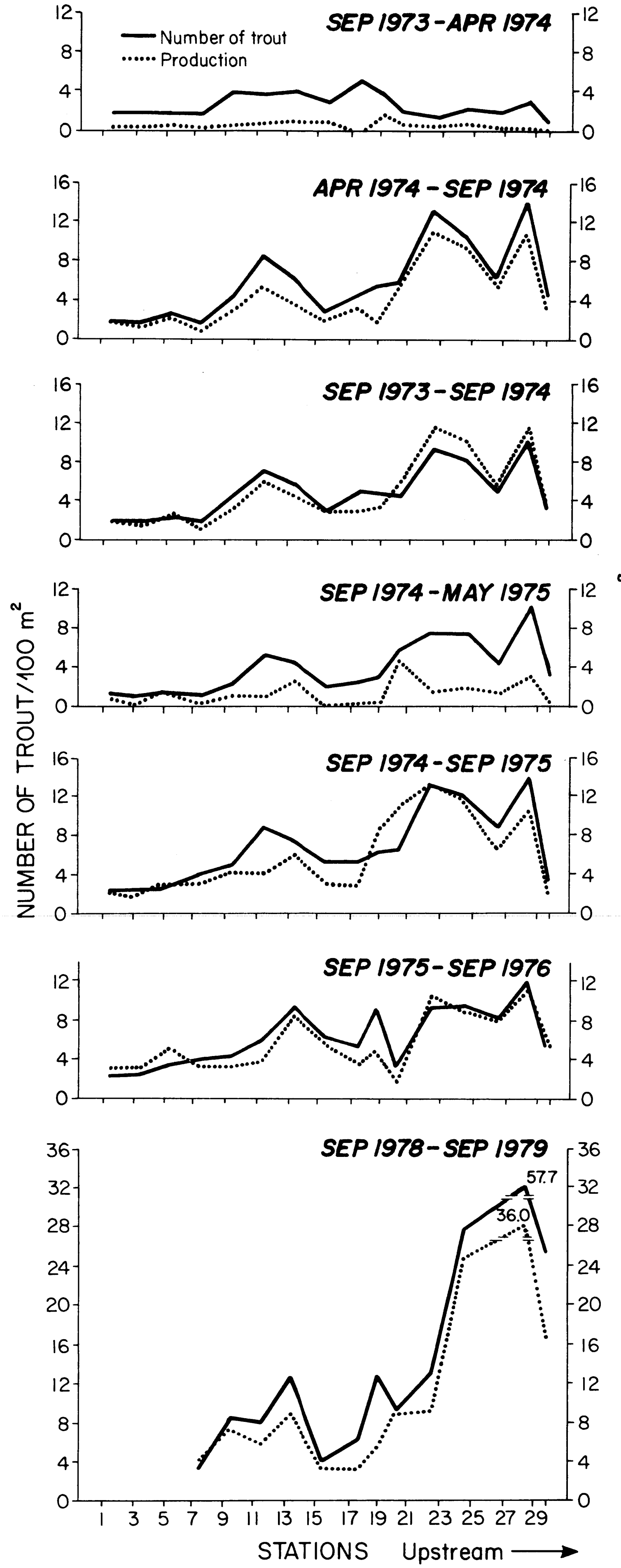
APPENDIX FIGURE 2. Distribution, numerical density, and production of wild brown trout in the 8.2-km study area of Trout Creek during the 2 years following completion of the FRS in the early summer of 1964.



APPENDIX FIGURE 3. Distribution, numerical density, and production of wild brown trout in the 8.2-km study area of Trout Creek from September 1965 through September 1967.



APPENDIX FIGURE 4. Distribution, numerical density, and production of the 1969 year class of wild brown trout during its first summer, winter, and year in the 8.2-km study area of Trout Creek.



APPENDIX FIGURE 5.
Distribution, numerical density, and production of wild brown trout in the 8.2-km study area of Trout Creek during selected periods from September 1973 through September 1979.

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METRIC—ENGLISH CONVERSIONS

	Metric	English
Length		
	1 cm	0.3937 inches
	1 m	3.281 ft
	1 km	0.6214 mile
Area		
	1 m^2	1.196 yd^2
	1 km^2	0.3861 $miles^2$
	1 ha	2.471 acres
Weight		
	1 g	0.0353 oz
	1 kg	2.205 lb
Volume		
	1 m^3/sec	35.31 cfs
	1 L/min	5.886×10^{-4}cfs

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