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Dimensions of Riparian Buffer Strips Required to Maintain Trout Habitat in Southern Ontario Streams

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ABSTRACT

The relationships between riparian land use and environmental parameters that define the suitability of southern Ontario streams for trout were examined for 40 sites on 38 streams. Weekly observations of maximum and minimum temperature, coarse and fine suspended matter, and discharge were made during June, July, and August 1980. Land use was determined from aerial photographs of each stream. Fish were surveyed at each site during August by electrofishing and seining.

The only environmental variable which clearly distinguished between trout and nontrout streams was weekly maximum water temperature: streams with trimean weekly maxima less than 22 C had trout; warmer streams had, at best, only marginal trout populations. Trout streams tended to have low concentrations of fine suspended solids and a more stable discharge, but so did many of the other streams. Water temperature, concentration of fine particulate matter, and variability of discharge were inversely related to the fraction of the upstream banks covered by forest. Fifty-six percent of the observed variation in weekly maximum water temperature could be explained by the fraction of bank forested within 2.5 km upstream of a site. Other land uses were not clearly related to stream variables, except that high concentrations of fine suspended solids were most often observed in reaches used as pasture.

Analysis of data from sites located within buffer strips yielded a regression relating maximum weekly temperatures to buffer strip length and width. The regression accounted for 90% of the observed variation in water temperature for these sites. The model was verified further by comparisons with observed temperatures at a second set of sites located downstream from buffer strips.

Agricultural development has resulted in the elimination of the original forests from most of eastern North America. Streams and rivers draining deforested watersheds may exhibit increased or decreased total discharge (Burns 1970; Hornbeck et al. 1970), increased export of organic and inorganic material (Bormann et al. 1969; Moring 1975), and higher water temperatures (Brown and Krygier 1970). Agricultural practices may reduce total discharges but still result in a greater total export of various ions (Hibbert 1969; Taylor et al. 1971; Hill 1980). Such changes have been accompanied by alterations of biotic communities, particularly the invasion by warmwater species into formerly cool headwater reaches (Schlosser 1982).

Several studies have shown that many of the effects of forest clearing on streams can be minimized or even eliminated by leaving an undisturbed border or buffer strip of riparian vegetation along the watercourse (Brazier and Brown 1973; Moring 1975; Lee and Samuel 1976; Newbold et al. 1980; see also reviews by Burns 1970, and Karr and Schlosser 1976). Buffer strips of various widths have been recommended as part of the logging practice in many areas and as part of general land development along British Columbia salmon rivers (Fisheries and Marine Service 1978).

With the exception of work by Brazier and Brown (1973), recommended widths for buffer strips have not been firmly based on data relating buffer strip dimensions to effects on streams. Because many factors, such as terrain, type of vegetation, soils, climate, etcetera, should all contribute to the effectiveness of buffer strips, some geographic variation in requirements is to be expected. Furthermore, because most deforestation associated with development of agriculture in eastern North America occurred more than a century ago, reclamation is often of greater importance than simple protection during a temporary disturbance. This means that it is essential to know not only how wide buffer strips should be, but also how long.

In this paper, we detail the results of a study undertaken to describe the relationships among riparian land use, the composition of the fish communities, and three important parameters which affect the quality of fish habitat—temperature, suspended solids, and variability in discharge. We considered the presence of trout populations to indicate high quality (least disturbed) fish habitat, because brook trout (*Salvelinus fontinalis*) were originally the dominant fish in low order streams in southern Ontario. We first examined the relationship between these parameters and the presence of trout at 40 sites in 38 southern Ontario streams, then the relationship between trout and other fishes. Next, the stream parameters were examined with respect to the presence or absence of buffer strips. Lastly, we used an empirical approach to determine the length and width of buffer strips needed to sustain populations of brook trout, brown trout (*Salmo trutta*), or rainbow trout (*Salmo gairdneri*).

METHODS

Preliminary selection of study sites was based on the amount of riparian forest shown on 1:50,000 topographic maps and on a list of known trout streams provided by the Ontario Ministry of Natural Resources. Each potential site and several upstream road crossings were examined in the field for correspondence with map features and 40 sites were selected for study. These sites represented a complete range of riparian tree cover from 0 to nearly 100%, and included streams in each of the major physiographic regions of agricultural southern Ontario. Two sites were chosen on each of Carroll and Swan creeks to examine changes in streams flowing out of forested areas. The general characteristics of each of the sites are summarized in Table 1. None of the stream reaches chosen for study had been stocked with any salmonid species for at least 10 years preceding 1980. Several of the streams (Credit River, Bronte Creek, Saugeen River) were stocked with rainbow trout and Pacific salmon, but only below impassable barriers.

A maximum-minimum mercury thermometer was placed in the stream in a shaded area whenever possible at each site on the first visit in May. The discharge was estimated on the first visit and in each subsequent month by the velocity-area technique (John 1978) using a portable current meter (Edington and Molyneux 1960). A reference point was established (e.g., a steel fence post driven into the stream or a mark on a bridge abutment) to monitor pool water level.

Each site was visited weekly from mid-May through August 1980. On each visit, a 1-liter water sample was collected from mid-depth at midstream, the water level was recorded, and the thermometer was read to the nearest 1 C and reset. Water levels were transformed to discharges using a discharge vs. water level relationship developed for each site. Temperature and discharge measurements could not be obtained from the Bailey Creek site after it was channelized during the week of 10 July.

Water samples were returned to the laboratory and refrigerated (4 C) overnight, then shaken thoroughly and passed through two oven-dried (40 C for at least 48 hours) pre-weighed filters with 50-μm (Nitex) and 0.45-μm (Millipore HA) apertures. Material retained by the 50-μm filter was designated coarse particulate matter (CPM); the 0.45–μm filter retained fine particulate matter (FPM). The entire sample was passed through the coarse filter but usually only a subsample passed the fine filter. The filters were dried for 48 hours at 40 C and re-weighed to the nearest 0.1 mg. The habitat variables derived from these field, laboratory, and map observations to characterize each study site were as follows:

Coarse particulate matter (CPM): material from water samples retained by 50-μm filter.
Fine particulate matter (FPM): material from water samples passing through a 50-μm filter but retained by 0.45-μm filter.
Stream size: median discharge, May–August.
Variability of discharge:
- a. Tendency toward low flow = median/minimum discharge.
- b. Tendency toward spate (i.e., much greater

Table 1. Locations of 40 stream sites and general characteristics of their watersheds upstream. Width, depth, and bank cover are based on direct field measurements; basin area and gradient were measured from 1:50,000 topographic maps; and percent bank forested was determined from 1:10,000 aerial photographs.

Stream		Site		Basin	Gradient (m/km)		Riffles		Percent bank forested		
Number	Name	Latitude (N)	Longitude (W)	area (hectares)	Study reach	Overall	Width (m)	Depth (cm)	Whole watershed	Weighted	Bank cover
1.	Amaranth Creek	43°51′	80°16′	3,710	3.8	3.0	2.1–3.8	4.8–20.0	6.9	0	grass, shrubs
2.	Bailey Creek	44°06′	79°50′	7,820	1.8	3.2	3.3–5.0	12.1–42.3	31.1	0	shrubs; raw soil after 10 July
3.	Barlow Creek	43°16′	80°09′	3,530	1.3	3.0	0–14.5	0–9.5	17.8	0	grass, willows, *Typha*
4.	Beeton Creek	44°04′	79°48′	7,530	2.2	2.4	3.8–5.4	22.0–44.2	14.4	0	pasture, clay
5.	Bethel Creek	43°56′	80°44′	4,500	7.6	2.9	4.0–4.9	18.2–26.8	13.3	9.0	shrubs, grass
6.	Black Creek	43°17′	80°34′	2,620	0.9	1.0	1.5–5.2	10.1–32.5	90.4	78.1	pasture
7.	Boomer Creek	43°32′	80°41′	5,370	2.2	2.4	2.0–3.0	5.4–16.3	7.8	0	shrubs, grass (channelized)
8.	Boyne River	44°06′	80°08′	7,870	5.1	7.6	2.8–7.4	12.7–36.8	42.4	80.0	deciduous trees
9.	Bronte Creek	43°23′	80°01′	3,960	3.0	3.6	1.2–6.2	13.0–50.5	54.0	57.4	willows, deciduous trees
10.	Canagagigue Creek	43°39′	80°34′	2,850	5.1	6.8	3.4–4.2	4.5–21.1	24.1	36.8	pasture, shrubs
11.	Lower Carroll Creek	43°40′	80°30′	2,680	5.1	7.0	3.0–4.5	10.6–18.0	41.7	57.7	deciduous trees
12.	Upper Carroll Creek	43°41′	80°31′	2,090	3.8	8.1	2.3–6.5	3.8–15.2	55.5	53.5	cedars, grass
13.	Cedar Creek	43°18′	80°26′	3,550	2.2	2.1	4.0–4.6	32.0–44.3	67.6	100	cedar bush
14.	Cox Creek	43°36′	80°24′	3,010	1.5	2.3	0–5.5	0–36.8	20.3	7.7	*Typha*, grass, shrubs
15.	East Credit River	43°47′	80°03′	1,700	2.5	4.8	0.8–3.0	2.6–41.8	61.6	0	deciduous/cedar
16.	West Credit River	43°47′	80°03′	1,670	5.1	7.1	2.1–4.4	8.5–20.1	85.3	47.1	cedar, pasture
17.	Ellis Creek	43°47′	80°21′	3,680	1.4	2.0	0.5–3.8	9.5–53.6	13.5	10.3	grass
18.	Fairchild Creek	43°17′	80°13′	4,080	3.0	3.2	0.1–7.0	2.0–62.1	14.0	0	pasture
19.	Four-mile Creek	43°52′	80°35′	6,590	1.9	2.1	0.2–2.5	11.8–47.6	0	0	grass
20.	Galt Creek	43°25′	80°14′	7,860	1.1	1.4	4.6–6.1[a]	28.3–44.6	74.2	99.4	cedar, willows
21.	Grand River	44°08′	80°22′	7,090	1.4	1.6	2.1–6.0	17.1–31.8	12.9	8.7	pasture
22.	Hopewell Creek	43°30′	80°24′	4,520	1.5	2.0	3.1–6.2	10.8–36.8	7.9	23.2	pasture
23.	Humber River	43°58′	79°52′	6,700	5.1	9.8	4.2–4.9	31.0–52.1	70.1	83.9	cedar
24.	Humber Tributary	43°56′	79°50′	3,080	7.6	12.0	2.8–4.8	16.6–33.0	97.1	99.0	cedar
25.	Hunsberger Creek	43°21′	80°39′	1,440	3.8	8.7	2.4–4.8	30.7–48.0	27.0	19.4	grass (channelized)
26.	Irvine Creek	43°48′	80°22′	8,560	1.3	2.0	3.1–6.0	3.5–11.9	34.1	0	pasture
27.	Lutteral Creek	43°40′	80°15′	6,150	5.1	3.5	2.2–7.4	12.8–27.6	64.5	92.9	cedar
28.	North Maitland River	43°55′	80°50′	6,350	1.5	2.3	1.9–4.8	21.7–32.8	13.1	0	grass, pasture
29.	South Maitland River	43°54′	80°51′	3,420	3.8	2.5	1.0–1.5	4.3–11.6	8.7	0	grass, willow (channelized)
30.	Mallet River	43°50′	80°43′	5,420	1.4	2.3	0–1.7	0–17.2	27.8	5.3	grass, *Typha*
31.	Nottawasaga River	43°57′	80°05′	3,730	8.5	18.0	3.5–5.0	9.7–13.4	53.5	97.6	deciduous
32.	Pine River	44°09′	80°11′	6,140	15.2	25.5	3.7–5.2	27.4–42.1	68.6	99.2	cedar
33.	Saugeen River	44°06′	80°29′	5,160	1.7	2.3	2.0–4.5	9.1–44.1	42.4	28.4	shrubs, grass
34.	Sheldon Creek	44°04′	80°03′	2,750	15.2	13.3	3.3–3.7	27.7–46.0	95.8	100	cedar

Table 1. Continued.

Stream		Site		Basin	Gradient (m/km)		Riffles		Percent bank forested		
Num-ber	Name	Latitude (N)	Longitude (W)	Basin area (hectares)	Study reach	Overall	Width (m)	Depth (cm)	Whole water-shed	Weighted	Bank cover
35.	East Speed River	43°42′	80°16′	4,080	2.5	3.4	4.6–8.9	12.0–42.3	32.9	4.4	pasture, grass
36.	West Speed River	43°41′	80°17′	3,150	5.1	4.6	1.3–3.2	5.6–16.8	22.5	51.9	deciduous
37.	Lower Swan Creek	43°39′	80°25′	3,810	2.5	4.6	2.0–3.0	9.0–18.4	59.3	0	grass, shrubs
38.	Upper Swan Creek	43°40′	80°22′	1,970	3.8	4.4	0.4–3.5	5.5–15.2	83.1	76.1	cedar
39.	Washington Creek	43°18′	80°34′	1,730	3.0	4.4	2.4–5.8	9.4–34.8	31.7	14.8	grass
40.	Willow Brook	43°56′	80°16′	6,070	1.9	1.2	2.9–6.6	11.9–38.8	6.3	0	grass, *Typha*

[a] Width at point of discharge measurement. Much of the channel upstream was > 10 m wide.

than average discharge, but not necessarily a flood) = $\log_e$(maximum/median discharge).

Gradient: estimated from 1:50,000 topographic sheets for the immediate area of the study site.

Temperature: weekly maximum and weekly range—trimean (Tukey 1977) values for the period 20 May through 31 August.

Fish were collected at each site during the month of August using a backpack electroshocker (Coffelt Electronics Co., Model BP-2), with blocking nets (6-mm square mesh) isolating a 25–50 m reach. Three passes were made at sites where trout were collected on the first or second pass. At the other sites, two passes were made with the electroshocker; in either case, the total species catch was supplemented with two seine hauls through the pools. Fish that could be positively identified in the field (e.g., *Salvelinus fontinalis, Salmo* spp., *Micropterus* spp., *Ambloplites rupestris, Rhinicthys* spp., and some *Etheostoma* spp.) were counted and released, others were preserved in 10% formalin for identification in the laboratory.

Riparian land use upstream from each site was determined from 1:10,000 aerial photographs taken in 1978 and obtained from the Ontario Ministry of Natural Resources. Interpretation of features was aided by inspection during field trips. No significant changes in land use between 1978 and 1980 were noted except on Bailey Creek. Each stream, including upstream tributaries, was divided into segments classified as either forested (bordered by a continuous canopy of deciduous or coniferous trees), bush (broken canopy with intervening shrubs and grass), bog (cedar bush with large water surface), pond, grass (ungrazed and uncut), pasture (cattle or grazing evident in photograph or direct observation), or cultivated. The length of stream (L) in each riparian segment was measured with an opisometer and areas (A) classified as forested, bush or bog were measured with a planimeter. Average width (W) of the riparian vegetation was calculated from the equation: W = A/2L.

Analysis of Environmental Variables

Trout streams were defined as those in which young of the year or representatives of at least two year classes of trout were collected during the August survey. Streams in which only a very small number of mature trout were collected or

Table 2. Selected habitat variables for 40 southern Ontario streams: trimean weekly maximum temperature (WMT), trimean weekly temperature range (WTR), median suspended fine particulate matter (FPM), median suspended coarse particulate matter (CPM), median discharge (DISCH), median/minimum discharge (MED/MIN), $\log_e$(maximum/median discharge) (MAX/MED).

Stream	WMT (C)	WTR (C)	FPM (mg/liter)	CPM (mg/liter)	DISCH (liters/second)	MED/MIN	MAX/MED
Amaranth Creek	26.5	12.5	17.9	6.7	124.7	5.22	3.15
Bailey Creek	24.5	14.0	61.4	21.5	Site channelized—no data		
Barlow Creek	23.0	6.8	51.6	7.5	4.95		7.61
Beeton Creek	24.0	9.5	60.9	9.8	147.2	2.03	2.65
Bethel Creek	23.8	9.8	24.5	4.9	80.0	1.89	1.03
Black Creek	24.0	9.3	26.8	17.5	48.9	2.24	2.54
Boomer Creek	26.8	11.3	128.6	25.3	36.3	1.59	4.61
Boyne River	20.5	10.3	15.3	6.9	279.6	1.98	1.54
Bronte Creek	25.3	10.6	24.0	10.3	32.8	2.84	3.88
Canagagigue Creek	22.8	10.5	46.5	32.2	159.5	1.56	1.19
Lower Carroll Creek	24.8	10.1	30.9	12.5	113.8	5.10	2.04
Upper Carroll Creek	24.5	9.3	60.0	13.7	61.0	2.17	2.56
Cedar Creek	17.0	6.8	18.2	12.8	195.2	1.29	1.54
Cox Creek	22.8	8.8	23.6	7.5	35.3	2.74	2.78
East Credit River	24.0	11.7	10.1	6.0	13.6	2.35	1.51
West Credit River	21.8	11.3	17.0	6.6	70.1	2.40	1.36
Ellis Creek	23.9	8.9	32.8	3.6	52.2	1.52	1.37
Fairchild Creek	28.2	12.4	51.8	5.6	26.9	6.04	4.10
Four-mile Creek	26.8	11.3	57.1	3.7	77.1	2.37	1.55
Galt Creek	21.4	6.0	22.1	20.4	373.2	2.71	2.40
Grand River	25.1	11.1	23.6	12.9	145.2	6.06	4.41
Hopewell Creek	26.7	11.9	34.6	6.4	69.2	1.24	2.72
Humber River	20.5	7.0	23.4	18.5	261.0	1.47	2.57
Humber Tributary	21.9	10.0	26.5	10.2	96.4	1.33	1.02
Hunsberger Creek	23.0	13.8	69.0	8.5	33.9	3.74	2.43
Irvine Creek	28.6	12.5	70.0	6.8	60.8	6.25	6.11
Lutteral Creek	22.5	8.3	25.2	7.7	403.0	3.15	5.73
North Maitland River	26.6	11.1	22.4	5.4	54.0	11.84	4.44
South Maitland River	23.8	9.8	24.6	6.5	19.3	3.52	3.08
Mallet River	24.8	10.5	27.4	13.1	31.0	2.77	2.03
Nottawasaga River	21.0	9.1	10.8	4.0	96.0	1.48	1.50
Pine River	18.3	5.6	11.9	10.7	420.1	1.23	0.08
Saugeen River	26.0	11.8	30.9	4.8	69.3	1.41	2.09
Sheldon Creek	20.8	7.0	27.8	18.1	78.0	1.71	2.69
East Speed River	23.5	12.1	29.7	15.1	94.8	1.98	0.68
West Speed River	23.5	9.4	24.9	7.7	95.3	3.93	0.99
Lower Swan Creek	24.7	10.8	25.1	5.5	38.0	2.05	2.87
Upper Swan Creek	21.9	9.7	18.7	18.1	80.2	4.27	1.34
Washington Creek	24.3	10.3	40.9	7.8	12.0	3.43	9.50
Willow Brook	25.8	9.5	23.4	4.5	157.4	1.53	1.13

seen in the possession of anglers were classified as marginal. Sites where trout were neither collected nor observed were designated nontrout streams. Because the abundance of fish appeared to be strongly influenced by exploitation pressure, no further assessment of relative quality among trout and marginal streams was possible.

On the basis of the August survey and observations during each sampling visit, nine sites were designated as trout streams (Boyne—rainbow trout; Cedar—brook trout; Galt—brown trout; Humber—brook trout and brown trout; Humber tributary—brook trout and brown trout; Nottawasaga—rainbow trout; Pine—brook trout and rainbow trout; Sheldon—brook trout; and Upper Swan—brook trout), and four as marginal (Bethel—brook trout; Bronte—brook trout; East Credit—brook trout; and Lutteral—rainbow trout).

Environmental Variables Distinguishing Trout Streams

The first step in the analysis was to examine the variation in habitat variables among streams (Table 2), with particular emphasis on discovering variables that differed between trout and nontrout streams.

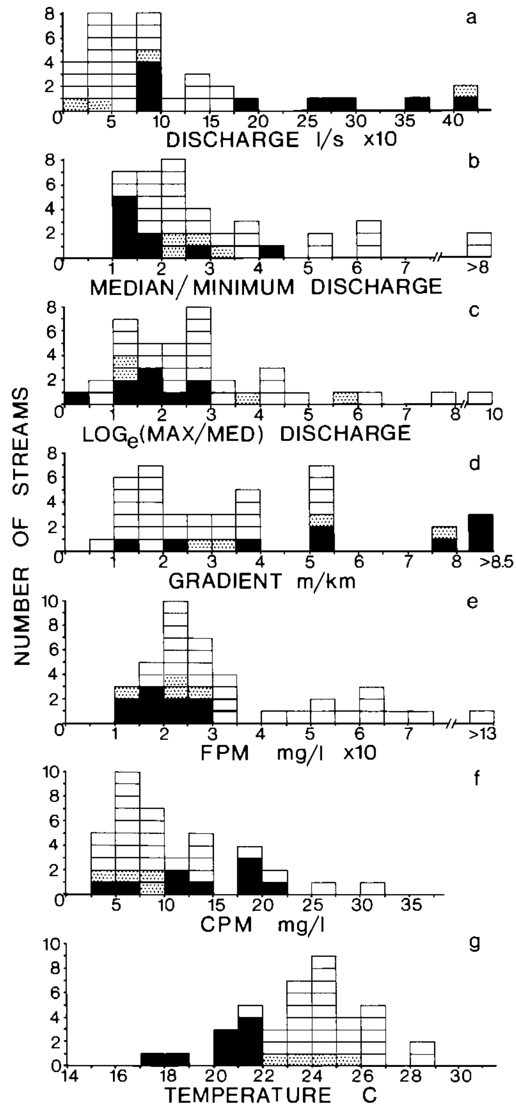

Figure 1. Frequency histograms for median discharge (a), median/minimum discharge (b), $\log_e$(max/med discharge) (c), gradient (d), median fine particulate matter (e), median coarse particulate matter (f), and trimean weekly maximum temperature (g). Trout streams, marginal trout streams, and nontrout streams are solid, stippled, and open, respectively.

Trout and marginal trout streams occurred over the entire range of stream sizes, expressed as median discharge (Fig. 1a), thus suggesting that size is not an important factor in determining the presence or absence of trout. Trout streams tended not to have periods of very low or very high discharge (Fig. 1b, c), but neither parameter unequivocably discriminated between trout and nontrout streams.

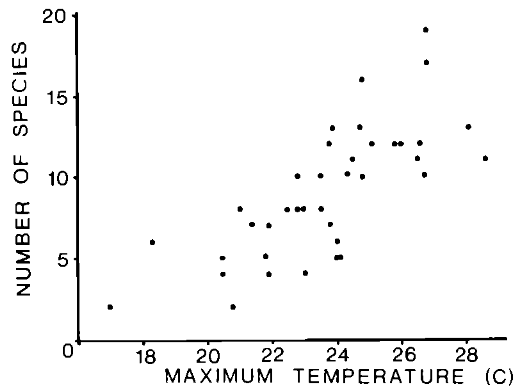

Figure 2. Trimean weekly maximum temperature vs. number of fish species collected from 38 sites in southern Ontario streams.

Similarly, no distinction could be made on the basis of gradient in the study reach or the amounts of fine and coarse particulate matter (Fig. 1d, e, f). Trout streams tended to have low amounts of FPM, but so did many nontrout streams. Quantities of CPM usually were lower than FPM (median 3.6 to 32.2 mg/liter CPM vs. 10.1 to 128.6 mg/liter FPM). Median amounts of CPM and FPM were only weakly correlated ($r = 0.313$). There was a tendency for trout streams to have a high ratio of CPM : FPM.

Maximum temperatures of the streams were summarized by calculating trimean weekly maximum temperatures. Trimeans are related to medians but are weighted according the shape of the "tails" of the distribution (Tukey 1977). With the exception of West Credit, all streams with trimean weekly maximum temperatures less than 22 C were trout streams (Fig. 2g). All streams with trimean weekly maximum temperatures above 22 C were marginal or without trout. Temperature ranges tended to increase with weekly maximum temperatures ($r = 0.683$), but weekly temperature range did not clearly distinguish the stream categories.

Environmental Variables and the Composition of Fish Communities

The above results suggested that temperature was the most important variable distinguishing trout from nontrout streams. We next examined

Table 3. Species of fish collected from 39 stream sites in southern Ontario. Numbers correspond to stream numbers in Table 1. The asterisk indicates species observed during the study period but not collected during the August survey.

Species	Collection sites
Petromyzontidae	
Petromyzon marinus	24
Salmonidae	
Salmo gairdneri	8, 27, 31, 32
Salmo trutta	20, 23
Salvelinus fontinalis	5*, 9*, 13, 15, 24, 32, 34, 38
Umbridae	
Umbra limi	3, 6, 9, 19, 20, 21, 29, 33, 35, 36, 40
Esocidae	
Esox sp.	17*, 18*
Cyprinidae	
Chrosomus eos	3, 9, 14, 15, 16, 22, 24, 31
Chrosomus neogaeus	3
Clinostomus elongatus	9
Cyprinus carpio	18*
Hybognathus hankinsoni	1, 7, 12, 19, 21, 22, 30, 33
Nocomis biguttatus	1, 5, 7, 11, 12, 17, 18, 19, 21, 22, 23, 26, 28, 29, 30, 32, 37, 39, 40
Nocomis micropogon	7
Notemigonus crysoleucas	18
Notropis sp.	3, 4
Notropis atherinoides	7, 19, 39
Notropis cornutus	1, 5, 6, 7, 11, 12, 14, 17, 18, 19, 21, 22, 26–31, 33, 39, 40
Notropis heterolepis	30
Notropis rubellus	7, 28, 30
Pimephales notatus	1, 6, 7, 10, 14, 17, 19, 21, 26, 28, 29, 30, 33, 36, 37, 40
Pimephales promelas	30
Rhinichthys atratulus	1, 7, 8, 10, 11, 14, 15, 16, 17, 19, 20, 21, 23, 24, 25, 27, 29–40
Rhinichthys cataractae	1, 4, 7, 8, 11, 12, 16, 19, 21, 27, 31, 32, 39, 40
Semotilus atromaculatus	1, 4, 5, 6, 7, 8, 10, 11, 12, 14–22, 24–31, 33, 35, 36, 37, 40
Semotilus margarita	35
Catostomidae	
Catostomus commersoni	1, 5, 6, 7, 9, 10, 11, 12, 14, 15, 17–22, 24, 25, 26, 28–33, 35, 36, 37, 39, 40
Hypentelium nigricans	7, 9, 12, 19, 23, 35, 37
Moxostoma erythrurum	7
Ictaluridae	
Noturus flavus	17, 19, 30, 37, 39
Gasterosteidae	
Culea inconstans	1, 3, 4, 14, 21, 22, 26, 27, 33, 38, 40
Centrarchidae	
Ambloplites rupestris	3, 5, 7, 10, 12, 14, 17–20, 22, 26, 28, 29, 30, 36, 37, 40
Lepomis gibbosus	18
Lepomis macrochirus	3
Micropterus dolomieui	7, 28, 36
Micropterus salmoides	18
Percidae	
Etheostoma caeruleum	1, 5, 7, 10, 11, 12, 17–20, 26, 28, 29, 30, 33, 36, 37, 39
Etheostoma flabellare	5, 7, 11, 12, 17, 19, 26, 27, 28, 30, 35, 36, 37, 39
Etheostoma microperca	11, 12, 17, 18, 21, 22, 26, 28, 29, 30, 33, 37, 40
Etheostoma nigrum	4, 7, 10, 11, 14, 17, 18, 19, 22, 26, 28, 29, 30, 33, 37, 39
Percina maculata	19
Cottidae	
Cottus bairdi	1, 3, 8, 10, 13, 14, 16, 21, 24, 25, 27, 29, 31, 33, 35, 36, 38, 40

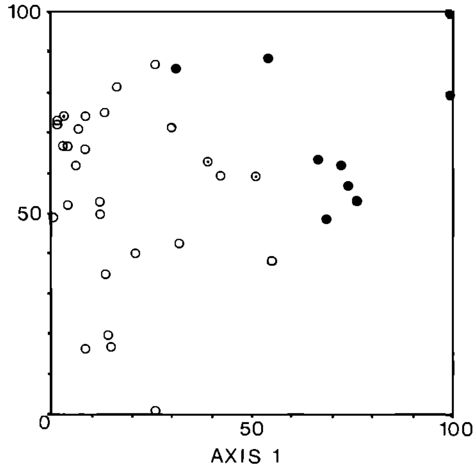

Figure 3. Reciprocal averaging ordination of sites by fish collections. See text for details. (●) = trout streams, (⊙) = marginal trout streams, (○) = nontrout streams.

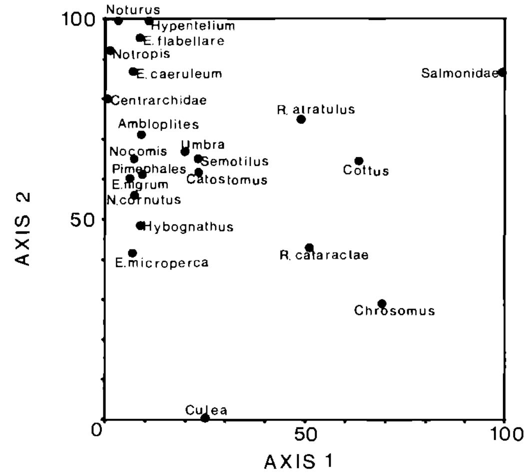

Figure 4. Reciprocal averaging ordination of fish taxa by their distribution among sites. See text for details.

the relationships between habitat variables and species richness and composition of fish communities at 38 of the sites (no fish were found at Bailey Creek during the August survey, and Bronte Creek was examined only qualitatively for the presence of trout). A total of 40 species of fish was collected (Table 3), ranging from 2 at Cedar Creek to 19 at Boomer Creek. A positive relationship was observed between the number of species and the trimean weekly maximum temperature (Fig. 2); colder streams tended to have fewer fish species. There was no apparent relationship between the number of species and either gradient, discharge, variability in discharge, or suspended solids.

The relationships between the fish communities and stream variables were investigated using Reciprocal Averaging ordination (Gauch 1977). Species counts (x) were transformed as $\log_e(x + 1)$. All trout, *Chrosomus* spp., and centrarchids (except *Ambloplites rupestris*) were each treated as one taxon, and nine species collected in small numbers at only one site were not used in the ordination. This ordination technique simultaneously calculates similarity between all pairs of sites (by species composition) and species (by frequency of co-occurrence) and projects these relationships onto a series of orthogonal, linear axes. Each axis is scaled to 100 units, but each reflects sequentially less of the variance in the original data matrix. The scores of species or sites are compared with environmental parameters to discover which parameters are most related to community composition.

Ordination of sites by their fish communities yielded two axes that accounted for 41% of the original variation. Axis 1 appeared to separate streams with trout from those without and was correlated with weekly maximum temperature. Axis 2 isolated Barlow Creek which had a unique fish community dominated by *Chrosomus eos, Chrosomus neogaeus, Culea inconstans,* and *Umbra limi.* In order to clarify the relationship among the other streams, Barlow Creek was omitted from a second ordination (Fig. 3). Again, Axis 1 was correlated with weekly maximum temperature ($r^2 = 0.824$). Axis 2 could not be interpreted with respect to any single environmental variable.

The complementary ordination of taxa by sites (Fig. 4) isolated trout from the other taxa, reinforcing the observation that trout streams have few species. The taxa most similar to trout in their distribution among sites were *Rhinichthys atratulus* and *Cottus.* The former was one of the four most common species, along with *Semotilus atromaculatus, Catostomus commersoni,* and *Notropus cornutus.* These, along with most of the remaining taxa, occurred primarily in warmer streams.

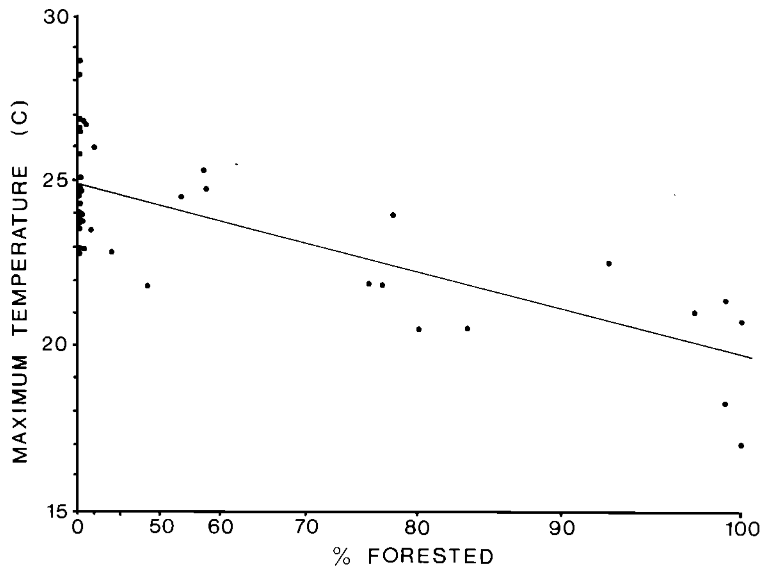

Figure 5. Linearized plot of trimean weekly maximum temperature vs. the weighted percent bank forested.

Relationship between Riparian Land Use and Quality of the Stream Habitat

The next step in the analysis was to relate the measured habitat variables to use of the riparian border. As stated above, the maximum temperature appeared to be the most critical variable in determining the suitability of streams for trout, so temperature/land use relationships were emphasized. Riparian forest cover (i.e., a continuous canopy of deciduous or coniferous trees immediately adjacent to the stream) was expected to be the most important land use parameter on the basis of previously published studies (e.g., Brazier and Brown 1973), and this was confirmed by examination of the relationship between land use categories and observed temperatures in our set of streams.

Temperature

The stream above each study site was first divided into uniform reaches whose lengths varied from 0.1 to 3.0 km. Exploratory regressions of maximum temperature vs. the proportion of forested bank upstream (including all tributaries) demonstrated that the amount of variation in maximum temperature explained increased as the distance upstream was increased—to 45% for a distance of 0.5 km and 52% for a distance of 1.0 km, but declined thereafter. This observation suggested that the influence of forest cover declines beyond a certain distance upstream of a given point. It was found also that cubing the independent variable (percent forested) was necessary to linearize the relationship.

To reflect this decreasing importance of land use with increasing distance upstream, the following model was fitted, varying C between 0 and 1 in increments of 0.1:

$$y = a + b\left(\frac{x_1 + Cx_2 + C^2x_3 + C^3x_4 + C^4x_5}{C^0 + C + C^2 + C^3 + C^4}\right)^3$$

where

- y = trimean weekly maximum temperature,
- x_1 to x_5 = percent forested for five 0.5-km segments upstream of the study site,
- a, b = constants fitted by least squares regression,
- C = a weighting coefficient.

The best regression (least residual sums of squares) was produced with $C = 0.5$ (Fig. 5). The term inside the brackets may be considered the "weighted percent of forested bank." The final equation was

$$y = 24.949 - 5.051 \times 10^{-6}x^3$$

where

$$x = \frac{x_1 + 0.5x_2 + 0.25x_3 + 0.125x_4 + 0.0625x_5}{1.9375}$$

which explained 56.2% of the observed variation in the typical (trimean) weekly maximum temperature. The total range of observed temperatures was from 17 to 28.6 C, while the regression line predicts 19.9–24.9 for 100% and 0% forested, respectively. The standard deviation from the regression is 1.66.

Five stream temperatures were more than 2 C from their predicted temperature (Irvine, Fairchild, Cedar, West Credit, and Cox), and these accounted for 42% of the residual sums of squares. That nearby streams often were similar distances and directions from the fitted regression line (Fig. 5) suggests that this residual variation was not entirely error, but we were not able to relate it to another independent variable. This plot emphasized that a large fraction of the bank within 2.5 km upstream of a site must be forested to significantly reduce maximum temperatures, and predicts that, on average, trout streams (i.e., with a trimean weekly maximum temperature of 22 C or lower) will be more than 80% forested.

Suspended Particulate Matter

Trout streams were noted earlier as having small amounts of fine suspended material in the water. The relationship between FPM and the percentage of all banks upstream of the site which were forested is shown in Fig. 6a. Streams whose banks were mostly forested had low amounts of FPM, but open streams were variable. Our stream sites with at least 0.5 km of forest cover upstream had moderate to low FPM (≤30 mg/liter). This suggests that riparian forest cover may somehow influence stream turbidity, perhaps through improved bank stability or by limiting autochthonous primary production.

Instability of discharge might be expected to increase stream turbidity through increased erosion of the bed and banks. A weak relationship was observed between median FPM and $\log_e$ (MAX/MED) discharge (r = 0.366), but stable streams (like unforested streams) may have a high or low FPM. Grazing along the banks appeared to be closely related to high levels of FPM. At 9 of the 15 most turbid streams examined in this study, the land immediately upstream of the site was in pasture.

Concentrations of coarse particulate matter

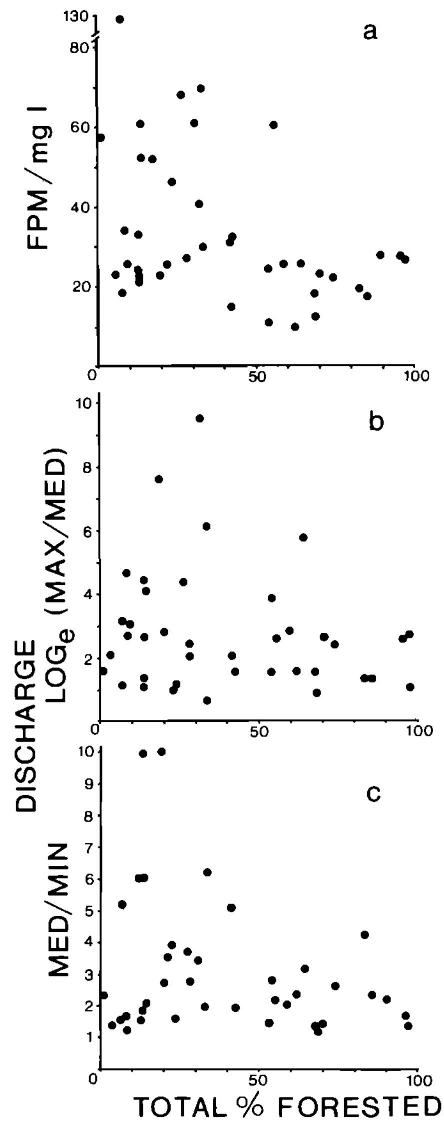

Figure 6. Relationship between the percent of bank forested upstream of sites and median fine particulate matter (a), $\log_e$(max/med discharge) (b), and median/minimum discharge (c).

(CPM) were usually less than FPM (Table 2) and the two were weakly correlated. Amounts of CPM did not differ between trout and nontrout streams. The median amount of CPM also was independent of the stream's tendency to spate (r = 0.067). It was our general observation that the nature of CPM differed between forested and open streams,

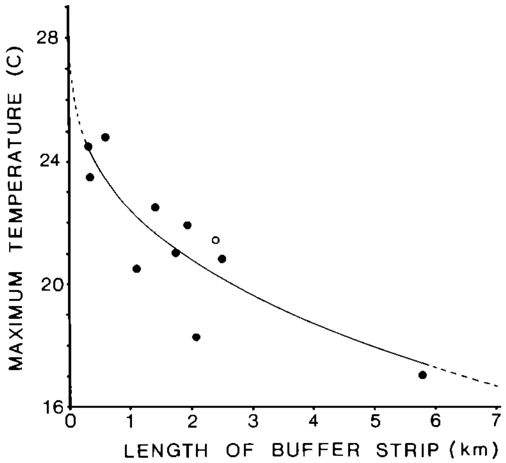

Figure 7. Relationship between length of buffer strip and weekly maximum temperature for streams located within buffer strips.

consisting mostly of leaf and wood fragments in the former and algal filaments in the latter.

Variability in Discharge

The flow regime of a stream obviously will be less responsive than temperature and suspended solids to small-scale changes in land use. However, riparian forest cover over much of a stream's length may have a moderating effect by either increasing bank storage (Freeze and Cherry 1979) or reducing overland flow. The relationship between the forested fraction of all stream banks upstream of the study sites and stability of discharge is illustrated in Fig. 6 (b and c). Both graphs suggest that buffer strips, if extensive, may contribute to the stabilization of discharge. It must be acknowledged, however, that the fraction of the bank that is forested may be correlated with the fraction of the entire drainage basin that is forested.

Effects of Buffer Strips

The final stage of the analysis was to consider the effect of specific areas of riparian forest on stream temperature by focusing on streams with forested buffer strips immediately upstream of the sampling site. Streams with unforested tributaries entering within the buffer strip were excluded from this analysis, leaving 11 stream sites located within or at the downstream edge of forested buffer strips.

The first step was to relate trimean weekly

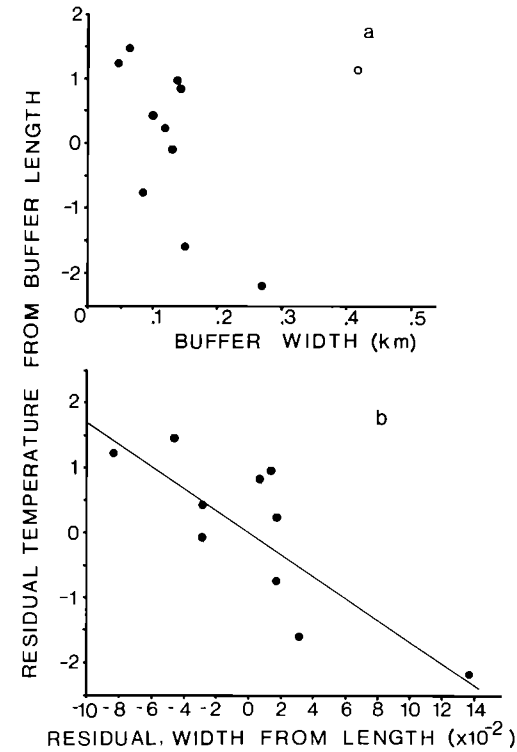

Figure 8. Relationship between the residual of temperature (C) from buffer strip length (see Fig. 7) and buffer strip width (a) and the residual of buffer strip width from length of buffer strip (b). The open circle in (a) represents Galt Creek, which is omitted in 8b.

maximum temperature to the length of the buffer strip (Fig. 7). The least squares fit was

$$y = 28.87 - 6.565x_l^{0.333} \qquad (1)$$

where y = trimean weekly maximum temperature, and x_l = length (kilometers) of buffer strip upstream of the site. Equation 1 explained 77.0% of the variation in weekly maximum temperature.

The residual of temperature from length appeared to be related to buffer strip width (Fig. 8a), but with one outlying data point. This outlier, Galt Creek, is very wide and shallow immediately upstream of the study site and flows east to west, so is exposed to direct insolation during most of the summer despite its wide, forested buffer strip. Therefore, Galt Creek was deleted before further analysis of the effects of buffer strip width.

Next, the correlation between length and width

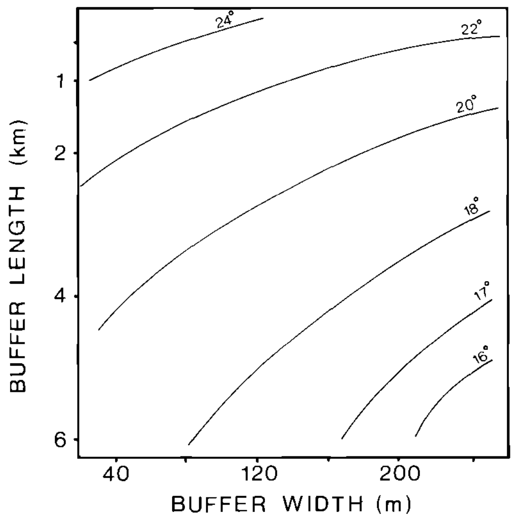

Figure 9. Predicted trimean weekly maximum temperatures (C) for streams with buffer strips of varying length and width.

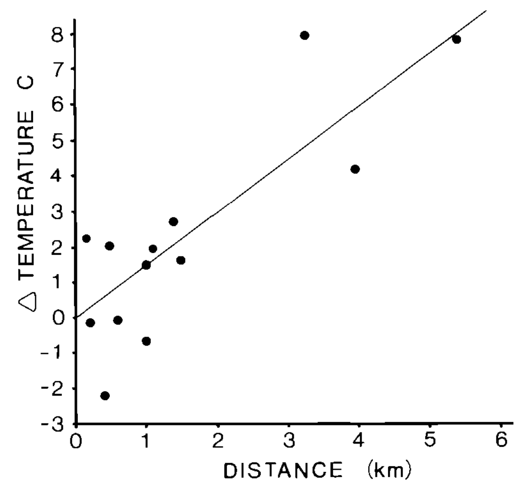

Figure 10. Relationship between distance from a sampling site to an upstream buffer strip, and the difference between the observed temperature at the site and that calculated for the stream at the point of emergence from the buffer strip.

was removed by regressing width on length and taking the residual of width from length. Length and width were not significantly correlated (r = 0.286). The residual of temperature from length was then regressed on the residual of width from length, and this relationship (Fig. 8b) was added to Equation 1 to produce:

$$y = 29.87 - 5.757x_1^{0.333} - 15.42x_2 \quad (2)$$

where x_1 = buffer strip length in kilometers, and x_2 = buffer width in kilometers. Equation 2 accounted for 90.0% of the variation in trimean weekly maximum temperature in the 10 streams. The form of the equation is illustrated in Fig. 9.

This equation obviously is unrealistic in that temperature decreases linearly with increasing buffer strip width even though temperature actually would reach asymptotic limits at both extremes. However, there is little justification in the data for a nonlinear fit (Fig. 8b). Caution should be used in applying the equation beyond the range of the data employed.

Finally, we examined 12 other streams with buffer strips upstream of the sampling site to estimate the rate at which streams warm up after leaving a forested zone, and to validate our multiple-regression equation on a second data set.

Equation 2 was used to predict the temperatures of the 12 streams as they left the upstream buffer strips, these temperatures were subtracted from those observed at the sampling sites, and the differences compared with the distance between the sampling site and the lower edge of the buffer strip (Fig. 10).

The least squares fit passed very close to the origin, verifying the multiple regression employing buffer strip length and width. The residual variation was greater than for the original data set. The slope of the line is an estimate of the warming rate of a stream more or less completely exposed to insolation—1.487 C/km.

Adding the distance upstream to a buffer strip (x_3) as a new independent variable to the multiple regression produced

$$y = 29.87 - 6.565x_1^{0.333} - 15.42x_2 + 1.49x_3$$

which accounted for 74.3% of the variation in trimean weekly maximum temperature for the combined data sets with 22 streams.

Discussion

Creaser (1930) and Ricker (1934) cited temperature as the major factor in the maintainance of self-sustaining populations of brook trout and our observations further confirm this. All but one of the 40 streams studied which had typical weekly maximum temperatures less than 22 C supported self-sustaining trout populations; warmer streams had, at best, marginal trout populations. Trout streams also tended to have stable flow regimes and low concentrations of fine suspended solids, but these attributes were shared with many nontrout streams. Neither gradient nor size distinguished trout streams from other streams.

Variations in the distinguishing environmental factors (temperature, stability of flow, and suspended solids) were all at least partially influenced by the presence of forested (i.e., a complete canopy of deciduous or coniferous vegetation) riparian buffer strips. Our distinction between forested and nonforested riparian zones was crude but did account for most of the observed variation in the trimean weekly maximum temperature. As pointed out by Brown and Krygier (1970), the most important cause of high stream temperatures is direct insolation resulting from the absence of shading by a forest canopy. Other factors such as steep valley walls and the orientation of the stream to the summer sun also may be important locally, as seen at Galt Creek.

We feel that our empirical approach to the estimation of the required size of buffer strips to maintain trout populations in southern Ontario streams has yielded good predictions for length. Our estimate of the effect of width is surprising, especially in that a linear effect apparently continues some distance from the stream.This may be because areas of riparian forest in southern Ontario rarely occur as narrow tracts along streams but rather as irregularly shaped woodlots, and these are rarely centered on the stream. Thus, the effective buffer strip width over much of the length of a forested stream segment may be considerably less than the average width of the buffer strip (i.e., A/2L). Brazier and Brown (1973) found that canopy density along the path of incoming solar radiation in Oregon best described the shading capacity of a buffer strip and suggested that such strips need only be wide enough to include trees contributing to canopy cover. If we extrapolate somewhat beyond the limits of our observations, our multiple-regression equation for predicting temperatures from width and lengths of buffer strips estimates that an unbroken buffer extending 3 km upstream of a site need only be 10 m wide to produce a maximum weekly temperature of less than 22 C. Such an extrapolation is risky because the equation is based on the linear portion of an asymptotic relationship. If, as in Oregon streams, blockage of direct insolation by foliage is of primary importance, the minimum significant buffer width for a narrow stream covered by tall, dense vegetation actually may be less than 10 m. Alternatively, other factors acting over greater distances from the stream may be important. Hewlett and Fortson (1982) suggested that both soil and groundwater temperatures may be increased, thereby leading to a rise in stream temperature, because of clearcutting even if a buffer strip is left in place. Whether or not this is due to soil warming by direct insolation or an effect on local microclimate remains to be determined.

Minimum buffer width depends on the age and species composition of the riparian vegetation and its resulting height and foliage density. As illustrated by Galt Creek, wider streams require taller trees. Final refinement of estimates of rates of cooling (or warming) of streams entering (or leaving) buffer strips would have to consider such factors as total discharge, gradient, and groundwater discharge because cooling (or warming) rates are a function of the time during which a given mass of water is shaded from (or exposed to) sunlight and the rate of dilution by cooler groundwater. This becomes a complex and perhaps entirely local problem but certainly merits further study. While measurement of groundwater discharge was beyond the scope of this study, the similar daily minimum temperatures in most of our streams suggests that groundwater discharge may differ very little, at least within a given geographical area. Our empirical approach has provided conservative estimates of buffer strip dimensions that should apply to most, if not all, of agricultural southern Ontario and other areas with similar climates.

The ideal temperature regime for trout populations varies somewhat with the species. The upper limit of the optimum temperature range for brook trout, 20 C (Power 1980), is lower than that for rainbow trout (21 C) or brown trout (23.9 C) (Scott and Crossman 1973). Lethal temperatures are several degrees higher for each species. Interestingly, the mean July temperatures for 12 of our study streams were less than 19 C, 22 were less than 21 C, and all were less than 24 C, yet trout were observed in only 12 streams. This was probably due to the diurnal patterns of temperature fluctuation. As pointed out by Lee and Samuel (1976), unshaded streams reach their maximum temperature earlier in the day than do shaded streams, but both have similar minimum temperatures at night. Thus, while mean temperatures calculated from maximum/minimum observations may not be greatly different, the daily duration of higher temperatures in unshaded streams is much greater than in shaded ones. This lengthening of the warm period may not necessarily be directly lethal to trout but certainly appears to limit their success.

The mechanism by which sublethal temperatures limit trout populations in southern Ontario streams is not clear, but may be related to increased competition from other species. In southern Ontario streams, increasing temperature allows coexistence of more species of fish, especially cyprinids. In western North America, clearcutting rarely seems to result in the complete elimination of trout from the affected streams, although changes in population structure and standing stocks have been noted (e.g., Elser 1968; Meehan et al. 1969; Chapman and Knudsen 1980; Murphy and Hall 1981). Such changes usually are short-term (a few years in most cases) and potential competitors such as *Semotilus atromaculatus* and *Catastomus commersoni* are very rare or do not occur in the area (Scott and Crossman 1973). In contrast, land use along our study streams has been virtually unchanged for nearly a century—sufficient time for invasion and establishment of many species of warmwater fish. Over such a period of time, subtle changes in the population biology of trout species due to increased stream temperatures may have been augmented, or even completely overshadowed, by competition with these more recently established species.

Ricker (1934) felt that maximum temperatures of 24 C set the upper limit for self-sustaining trout populations in southern Ontario streams. To relate this observation to our data, we examined the relationship between the trimean weekly maximum temperature and overall maximum temperatures. A regression indicated that a trimean weekly maximum of 22 C corresponds to an overall maximum of 25.6 C, very close to the short-term lethal temperature for trout species found in southern Ontario (Scott and Crossman 1973; Power 1980).

Other factors, especially suspended solids and fluctuations in discharge, appear to have less influence on the presence or absence of trout but should not be ignored. More favourable conditions with respect to both of these factors would result from the establishment of riparian buffer strips. Our observations suggest that the length of a buffer strip needed to achieve significant improvement might be less for suspended solids, and greater for discharge, than for temperature control. The link between pasture and high concentrations of suspended solids indicates that preventing the access to streams by cattle would reduce sediment loads substantially (see also Cope 1979) and improve overall habitat quality (Keller and Burnham 1982). Our only cool-water, nontrout stream (West Credit) was heavily grazed immediately upstream of the study site.

In conclusion, our results confirm that temperature is the most significant factor determining the presence or absence of resident trout in small southern Ontario streams. Control of temperature, and to a lesser extent turbidity and stability of discharge, can be achieved through establishment or maintenance of forested riparian buffer strips. We conclude that the necessary dimensions for buffer strips in a particular area can be determined empirically.

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