FACTORS AFFECTING LARVAL BLACK-FLY MOVEMENT AND DISTRIBUTION (DIPTERA: SIMULIIDAE)

DRIFT OF BLACK-FLY LARVAE AND THE INFLUENCE OF WATER-VELOCITY, SUBSTRATE ROUGHNESS AND INCIDENT LIGHT INTENSITY ON THEIR MICRODISTRIBUTION (DIPTERA: SIMULIIDAE)

by

CARLOS JACINTO WONG LIN-KI, B.Sc.

A Thesis
Submitted to the Faculty of Graduate Studies
in Partial Fulfilment of the requirements
for the Degree
Master of Sciences

McMaster University

July, 1975.

MASTER OF SCIENCE (1975)
(Department of Biology)

MCMASTER UNIVERSITY
Hamilton, Ontario

TITLE: Drift of Black-fly Larvae and the Influence of Water-velocity, substrate Roughness and Incident Light Intensity on their Microdistribution (Diptera: Simuliidae)

AUTHOR: Carlos Jacinto Wong Lin-ki, B.Sc. (Notre Dame University)

SUPERVISOR: Professor D.M. Davies

NUMBER OF PAGES: xx, 289

SCOPE AND CONTENTS:

Part of this study was designed to examine diurnal drift of blackfly larvae of different species and stages. Larvae drifted more during the night, especially just after evening twilight. A sudden increase in water velocity also initiated larval drift. The re-establishment of drifting larvae was greater on rough rather than smooth surfaces but was not influenced by substrate colour.

Experiments were conducted to determine and compare the high and low water-velocity thresholds for larvae of different species and stages from different habitats. High current thresholds were those above which the larvae would be torn from the substrate, whereas low thresholds were those below which larvae ceased to filter feed statically but began to crawl about.

The effect of different incident light intensities on micro-distribution of black-fly larvae was explored in artificial troughs using a graded series of plastic filters.

DEDICATED

TO

MY BELOVED

PARENTS

CON TODO CARIÑO

DEDICO

ESTA TESIS

A MIS

QUERIDOS PADRES

ACKNOWLEDGEMENTS

I take this opportunity to express my deepest gratitude and thanks to my Supervisor, Professor D.M. Davies, for suggesting the topic of research, for his patience, guidance, invaluable assistance, and encouragement without which this work could never have been completed. The interest and ideas contributed by many persons of McMaster University and Drs. P.D.M. Macdonald and Dr. J. Vlachopoulos of the Departments of Applied Mathematic and Chemical Engineering respectively were greatly appreciated.

I am indebted to Mrs. Helen Györkös for her technical assistance and introducing me to the black-fly larval identification, Mrs. Robin Davies for helping with identification of the collections during the summer of 1973 and 1974, Mr. Robert Gillies for help in building the experimental troughs in 1974, Mssrs. Zahirali Lavji and Norbert Maerz for part time field assistance during the summer of 1973 and 1974, and especially to Mr. Gregory Trott for his invaluable field assistance during these two summers.

Laboratory facilities in the field were generously provided in Algonquin Park by the Ministry of Natural Resources, and special thanks to Mr. Owen William and Robert Stiver.

Also I would like to thank Miss Jocelyn Voortman for her patient typing of the manuscript.

Financial support for this study was provided by Ontario Graduate Fellowships and Teaching Assistantships from McMaster University and funds made available by Dr. D.M. Davies from his National Research Council of Canada grant were greatly appreciated.

TABLE OF CONTENTS

	Page
INTRODUCTION	1
MATERIALS AND METHODS	6
1. Description of Experimental and Collection Sites	6
A) North Madawaska River	6
B) Bog Outlet Stream	8
C) Costello Creek	8
D) Ragged Falls, Oxtongue River	8
E) Marsh's Falls, Oxtongue River	8
2. Collecting Methods for Simuliid Larvae	9
3. Measurements of Environmental Conditions	11
4. Experiments on Water-Velocity Thresholds	12
A) The Drum Experiments	12
B) Experiments in Wooden Troughs	18
5. Experiments on Larval Substrate Preference and Drift	22
A) Flat Plate	23
B) Cone Experiments	25
i) Diurnal Drift of Larvae	25
ii) Effect of Depth on Larval Drift	27
iii) Effect of Coloured Cones	27
C) Surface Roughness and Accumulation of Drifting Larvae	28
6. Experiments with Different Levels of Incident Light	30

TABLE OF CONTENTS (CONT'D)

Page

RESULTS 36

1. Experiments on Water-Velocity Thresholds. 36

A) Introduction. 36

B) Drum Experiments. 36

a) High Water Velocities 37

i) Effect of Larval Stage. 39

ii) Species Differences 40

iii) Same Species in Different Streams 41

b) Low Water Velocities 73

i) Effect of Larval Stage. 75

ii) Species Differences 76

iii) Same Species in Different Streams 77

c) Experiments in Wooden Troughs 93

2. Larval Substrate Preference and Drift 104

A) Flat Plate Experiments. 104

B) Cone Experiments. 110

i) Diurnal Drift of Larvae 110

ii) Effect of Depths on Larval Drift. 152

iii) Effect of Colour on the Accumulation of Drifting Larvae. 167

C) Accumulation of Drifting Larvae in Relation to Substrate Roughness 175

3. Experiments with Different Levels of Incident Light 189

DISCUSSION. 213

1. Influence of Water Velocity on Larval Drift and Distribution. . . 213

TABLE OF CONTENTS (CONT'D)

Page

A) High Water-Velocity Thresholds. 215

i) Larvae from Different Habitats 215

ii) Different Larval Stages of the Same Species. 215

iii) Different Species from the Same Habitat. 217

iv) Same Species from Different Habitats 217

B) Effect of Current in Wooden Troughs 221

C) Low Water-Velocity Thresholds 222

i) Different Larval Stages in the Same Species. 222

ii) Different Species from Same Habitat and Same Species from Different Habitats 222

2. Diurnal Drift and Re-establishment. 225

A) Use of Cones. 225

B) General Larval Drift of Simuliids and Other Aquatic Insects . . . 225

C) Diurnal Larval Drift of Simuliids and Other Aquatic Insects 226

D) Simuliid Larval Drift at Different Depths 234

E) Effect of Changing Water Velocity on Larval Drift 236

F) Influence of Substrate Roughness on Re-establishment of Drifting Simuliid Larvae 238

G) Differential Accumulation of Drifting Simuliid Larvae along Flat Surfaces 239

H) Effect of Substrate Colour on Re-establishment of Drifting Simuliid Larvae 240

I) Possible Influence of Other Invertebrates on Simuliid Larval Drift. 241

3. Influence of Incident Light Intensity on Microdistribution of Simuliid Larvae 244

SUMMARY 247

REFERENCES 249

APPENDIX 276

LIST OF TABLES

Table		Page
1	Reproducibility of paddle revolutions per minute at two tachometer settings.	17
2	Dimensions of wooden troughs used in simuliid larval experiments in 1973 and 1974.	20
3	Comparison of light transmission of the filters in foot candles.	34
4	Summary of the conditions for the experiments in 1973 with High water velocities in the cylindrical drum.	42
5a-c	Range of water velocities across each ring at a given tachometer reading for 1973 experiments on water velocity thresholds with larvae in the cylindrical drum.	
	a) Ragged Falls	43
	b) Costello Creek	44
	c) Bog Outlet Stream	45
6	Means of percentages (with standard errors) of larvae remaining after certain time in different range of water velocity during the 1973 drum experiments.	46
7	Number and percentage of immature and mature larvae (and pupae) of different species at the end of 1973 experiments in the cylindrical drum.	47
8	Number of larvae in different length classes and maturity classes in the cylindrical drum from June to August 1974, in tests for upper and lower water velocity thresholds.	276 (in append
9	Summary of the conditions for the experiments in 1974 with high and low water velocities in the cylindrical drum.	280 (in append
10	Means of percentages (with standard errors) of larvae remaining after a certain time in different ranges of high and low water velocity during the 1974 drum experiments.	48
11	Number and mean length of larvae in each stage grouping used in the cylindrical drum experiments testing upper and lower velocity threshold from June to August 1974.	51
12	Means of percentages (with standard errors) of larvae remaining after a certain time in different ranges of low water velocity during the 1974 drum experiments.	78

Table		Page
13	The water velocity calculated for different positions down the middle of each of the three long troughs used in the 1973 experiments in Costello Creek.	96
14 .	Method of calculating the water velocity in wooden troughs	284 (in append
15	Distribution of larval of S. venustum/verecundum and S. vittatum in the 3 troughs (T_{18}, T_{19}, T_{20}) at the end of the 1973 experiments on the influence of water velocity on larval movements.	97
16.	Accumulation of larvae on the flat metal plate in the North Madawaska River.	106
17	The places and dates for the 1974 cone experiments on diurnal drift of simuliid larvae.	116
18	Times of sunrise, sunset, moonrise and moonset and periods (in hr) of daylight and moonlight in 1974 at the Wildlife Research Station, Algonquin Park, Ontario.	117
19	Numbers of different stages and species of simuliid larvae involved in experiments on diurnal drift in 1974.	118
20	Species and average length (in mm) of simuliid larvae involved in cone experiments on diurnal drift.	119
21	Lengths of larvae in the streams during cone experiments on diurnal larval drift in 1974	120
22	The total number of larvae of S. tuberosum A drifting in the North Madawaska River at different times of a 24-hr period during each experiment during 1974.	121
23	The number and percentage of larvae in each of four length classes for each of four 2-hr intervals, spaced over a 24-hr period, for each cone experiment. For the North Madawaska River the larvae are S. tuberosum A and for the Bog Outlet Stream S. venustum/verecundum.	122
24	The number of larvae of S. tuberosum A in the North Madawaska River in all experiments in 1974 are combined for each length class at each of the four 2-hr time intervals (9-11 am, 3-5 pm, 9-11 pm, 3-5 am) and the percentage calculated .	123

Table		Page
25	The average length of drifting larvae of all species which accumulated on cones at different times of the day (9-11 am, 3-5 pm, 9-11 pm, 3-5 pm)	124
26	Conditions and procedure during experiments on measuring larval drift at different depths in 1974.	154
27-30	Accumulation of drifting larvae on 3 pairs of cones at two different depths (see Table 26).	
	Vertical separation of pairs	
	27 2.5 cm (Experiment 1)	155
	28 4.5 cm (Experiment 2)	156
	29 6.25 cm (Experiment 3)	157
	30 8.25 cm (Experiment 4)	158
31	The effect of increasing vertical distance between cones on the relative percentages of drifting larvae accumulating on the upper and lower cones.	159
32	Comparison of larvae drifting from 8 am to 8 pm and from 8 pm to 8 am.	160
33	Number of larvae of each length class for each maturity category in each cone experiment for testing the effect of depths on accumulation of drifting larvae in July and August 1974 in the North Madawaska River.	285 (in appendix
34	Number of larvae by species in each maturity category on each cone during the July-August 1974 cone experiments for testing the effect of depth on the accumulation of drifting larvae in the North Madawaska River.	161
35-40	Number and percentage of larvae accumulating on three coloured cones (medium green, black, white) or four coloured cones (light blue, light green, medium gray, pink) in 1973, and 3 coloured cones (dark red, light blue, medium green) in 1974, together with the "T"-test of significance.	
	35 North Madawaska River from July 23-August 1, 1973 (3 colours	169

Table			page
	36	North Madawaska River from July 23–August 1 1973 (4 colours)	170
	37	Bog Outlet Stream from August 4-13, 1973 (3 colours)	171
	38	Bog Outlet Stream from August 4-13, 1973 (4 colours)	172
	39	North Madawaska River from July 30–August 4, 1974 (3 colours)	173
	40	Bog Outlet Stream from July 10-21, 1974 (3 colours)	174
41	The average water depth at different positions along each trough during the experiments on accumulation of drifting larvae on different surfaces (with standard errors).		176
42-44	The results of two experiments comparing the differential larval accumulation in three artificial troughs tested in pairs a) Initial position, b) reverse position.		
	42a-b	Smooth (control) and papillated (spike) surfaces	177
	43a-b	Papillated (spike) and ridged (stripe) surfaces	179
	44a-b	Smooth (control) and ridged (stripe) surfaces	181
45	Preliminary experiments in 1973 comparing the influence of various intensities of incident light during sunny days on the distribution of simuliid larvae in equal areas of a wooden trough placed in Costello Creek.		194
46a-c	The change in number of larvae in the middle of an area of a trough with different covers (or uncovered) in response to incident light.		
	a)	In 32-64 f.c. (overcast)	195
	b)	In 64-125 f.c. (cloudy)	196
	c)	In 125-250^{+} f.c. (sunny)	197

LIST OF TABLES (cont'd)

Table		Page
47a–c	The change in the percentage of larvae in the middle of an area of a trough with different covers (or uncovered) in response to incident light.	
	a) In 32–64 f.c.	198
	b) In 65–125 f.c.	199
	c) In 125–250$^+$ f.c.	200
48	Summary of comparison of larval preference in the middle area of a trough for different pairs of incident light conditions.	201
49a–b	The change in number of larvae in the middle and the sides of an area of a trough with different covers (or uncovered) in response to incident light.	
	a) 32–64 f.c. (overcast)	202
	b) 125–250$^+$ f.c. (sunny)	203
50a–b	The change in the percentage of larvae in the middle and the side of an area of a trough with different covers (or uncovered) in response to incident light.	
	a) 32–64 f.c.	204
	b) 125–250$^+$ f.c.	205
51	Summary of comparison of larval preference in the middle and the side areas of a trough for different pairs of incident light conditions.	207
52	Number of rows and number of hooks per row on both the proleg and caudal end of different instars of larval <u>Austrosimulium tillyardianum</u>.	219
53	Measurements of the number of hooks per row and the number of rows on the caudal end of larvae for species used in the present study (or closely related ones).	220
54	A comparison of the times of diurnal drift peaks in black fly larvae as reported by different authors.	229

LIST OF TABLES (cont'd)

Table		Page
55	Summary of reports in the literature concerning the optimum and maximum water depths at which simuliid larvae are found.	235

LIST OF FIGURES

Figure		Page
1	Map of the area surrounding the Wildlife Research Station of the Ministry of Natural Resources, Algonquin Park, Ontario, Canada.	7
2	Larval collection site at Ragged Falls.	10
3	Diagram of pyroheliograph	289 (in appendix)
4	Diagram of rotating paddle in drum.	13
5	Large troughs in stream in 1973.	19
6	Illumination troughs with wooden sides used in 1973.	19
7	Oblique view of flat plate in stream with worker.	24
8	Close-up view of marked-upper surface of flat plate.	24
9a,b	Metal cone apparatus for studying larval drift.	
	a) Metal dexion support	26
	b) Cone	26
10a-c	Patterns of rough plastic surfaces used in larval drift experiments.	
	a) Top view of spike surface	29
	b) Cross-sectional view of spike surface	29
	c) Longitudinal section of ridged surface	29
11	Illumination trough with clear sides used in 1974.	33
12	The predicted (calculated) and actual (measured) water velocities at the periphery of the drum at low paddle speeds.	52
13	The predicted (calculated) and Actual (measured) water velocities at the periphery of the drum at high paddle speeds.	53
14-16	Ability of larvae to withstand different water velocities in a cylindrical drum over a period of 12 hours.	
	14 Larvae from Ragged Falls	54
	15 Larvae from Costello Creek	55
	16 Larvae from Bog Outlet Stream	56

LIST OF FIGURES (cont'd)

Figure		Page
17	The ability of larvae from Ragged Falls, Costello Creek, Bog Outlet Stream to withstand high water velocities, in 1973.	57
18a-c	The ability of larvae of *S. longistylatum* from Ragged Falls to withstand different water velocities in a cylindrical drum.	
	a) Large larvae	58
	b) Very small larvae	59
	c) Small larvae	60
19a-c	The ability of larvae of *S. decorum* from North Madawaska River to withstand different water velocities in a cylindrical drum.	
	a) Large larvae	61
	b) Small larvae	62
	c) Mature larvae	63
20a-c	The ability of large larvae (mainly immature) of different species from Ragged Falls to withstand different water velocities in a cylindrical drum.	
	a) *S. longistylatum*	64
	b) *S. tuberosum* A	65
	c) *S. tuberosum* B	66
21a,b	The ability of large larvae (mainly immature) of different species from North Madawaska River to withstand different water velocities in a cylindrical drum.	
	a) *S. decorum*	
	b) *S. tuberosum* A	
22a,b	The ability of large larvae (mainly immature) of *S. tuberosum* A from two different streams to withstand different water velocities in a cylindrical drum.	
	a) Ragged Falls	69
	B) North Madawaska River	70
23a,b	The ability of large larvae (mainly immature) of *S. venustum/verecundum* from two different streams to withstand different water velocities in a cylindrical drum.	
	a) Costello Creek	71
	b) Bog Outlet Stream	72
24a-c	The effect of low water velocities in a cylindrical drum in 1973 on immigration or emigration of *S. venustum/verecundum* collected from Costello Creek. At paddle speeds:	
	a) 9.19 r.p.m.	80
	b) 10.25 r.p.m.	81
	c) 24.38 r.p.m.	82

Figure		Page
25a–d	The migration of large larvae of S. longistylatum, collected from Ragged Falls, at different low water velocities in a cylindrical drum.	
	a) Large larvae	83
	b) Large larvae	84
	c) Mature larvae	85
	d) Very small larvae	86
26a–c.	The migration of larvae of S. decorum, collected from North Madawaska River, at different low water velocities in a cylindrical drum.	
	a) Large larvae	87
	b) Mature larvae	88
	c) Small larvae	89
27a–b	The migration of larvae, collected from Ragged Falls, at different low water velocities in a cylindrical drum.	
	a) S. tuberosum A	90
	b) S. tuberosum B	91
28	The migration of larvae S. tuberosum A, collected from North Madawaska River, at different low water velocities in a cylindrical drum.	92
29–31	The percentage change in the larval abundance in different sections: central section ($^{M}2$), lateral section ($^{M}1$ and $^{M}2$) along edge angle ($^{C}1$ and $^{C}2$) of a smooth bottomed, wooden trough placed in Costello Creek.	
	29 Widely divergent trough ($^{T}18$)	98
	30 Narrowly divergent in (T_{19})	99
	31 Paralled sided in (T_{20})	100
32	The percentage change in the abundance of simuliid larvae in different sections (upper, middle and lower third) of a smooth bottomed, parallel-sided trough (T_{20}), placed in Costello Creek.	101
33	The larval accumulation in different sections (M_2 central, M_1 and M_3 lateral sections, C_1 and C_2 along edged total) with time in a parallel-sided wooden trough (T_{23}) with papillated (spike bottom) placed in Costello Creek.	102

LIST OF FIGURES (cont'd)

Figure		Page
34	The distribution of larvae (by thirds) in a parallel-sided wooden trough (T_{23}) with a papillated bottom in Costello Creek.	103
35	Accumulation of simuliid larvae on long flat plate in the North Madawaska River from July 6-13, 1973 in relation to changing water velocity.	108
36	Accumulation of drifting of larvae on each quarter on the flat plate from July 6-13, 1973 in the North Madawaska River.	109
37a-b	Change in accumulation of drifting larvae during day and night on 3 separate cones in two streams in 1973.	
	a) North Madawaska River	125
	b) Bog Outlet Stream	126
38-42	Number of drifting larvae of all species accumulating over a 24-hour period assessed by 2-hour collections or during the night over different periods by hourly collections in the summer of 1974 in the North Madawaska River and Bog Outlet Stream.	
	38 North Madawaska River from June 18-22 (2-hourly)	127
	39a-b North Madawaska River from June 24-27	
	a) 2-hourly	128
	b) hourly	129
	40a-b Bog Outlet Stream from June 25-27	
	a) 2-hourly	130
	b) hourly	131
	41a-b North Madawaska River from July 22-27	
	a) 2-hourly	132
	b) hourly	133
	42a-b North Madawaska River from August 12-16	
	a) 2-hourly	134
	b) hourly	135
43a-e	Drifting larvae of Simulium species accumulating on cone every 2 hours during day and night from June 18-22 in the North Madawaska River.	
	a) S. tuberosum A	136
	b) S. venustum/verecundum	137
	c) S. vittatum	138
	d) S. decorum	139
	e) S. tuberosum A mature larvae	140

LIST OF FIGURES (cont'd)

Figure		Page
44a-d	Drifting of larvae of *Simulium* species accumulating on cones every 2 hours during day and night from June 24-27 in the North Madawaska River.	
	a) *S. tuberosum* A	141
	b) *S. venustum/verecundum*	142
	c) *S. vittatum*	143
	d) *S. tuberosum* A mature larvae	144
45a-d	Drifting of *Simulium* species accumulating on cones every 2 hours during day and night from June 25-27 in the Bog Outlet Stream.	
	a) *S. venustum/verecundum*	145
	b) *S. tuberosum* A	146
	c) *S. vittatum*	146
	d) *S. venustum/verecundum* mature	146
46	Of all the last and penultimate larval stages the percentage of those drifting with large white histoblasts that were counted at four different times during a 24-hr period are shown for the summer of 1974.	147
47	Of all the last and penultimate larval stages, the percentage of those drifting with full size dark histoblasts (mature) that were counted at four different times during a 24-hr period are shown for the 1974 summer.	148
48a-d	For *S. tuberosum* A the percentage of immature larvae of different lengths drifting.	
	a) 0-1.5 mm	149
	b) 1.5-3 mm	149
	c) 3-4.5 mm	150
	d) 4-5.6 mm	150
49	Changes in the average length of drifting larvae of all species accumulating on cones in different experiments in 1974 in the North Madawaska River and Bog Outlet Stream.	151
50	Effect of vertical distance between cones on the percentage difference in larval accumulation on the upper cones and lower cones.	162

LIST OF FIGURES (cont'd)

Figure		Page
51-52	Number of drifting larvae of all species accumulating at 2 different depths over 24-hr period assessed by 2-hourly collections during the night as assessed hourly in the North Madawaska River from 12-16 August.	
	51a Upper cone (2-hourly)	163
	51b Upper cone (hourly)	164
	52a Lower cone (2-hourly)	165
	52b Lower cone (hourly)	166
53-55	The larval accumulation with time in three troughs tested in pairs. a) indicates initial position of the troughs b) indicates reversed position of the troughs.	
	53 Smooth surface (control) and papillated surface (spike)	183
	54 Papillated surface (spike) and ridged surface (stripe)	184
	55 Ridged surface (stripe) and smooth surface (control)	185
56-58	Final distribution of larvae by quarters (each 30 cm) along the length of the 3 troughs tested in pairs.	
	56 Smooth (control) and papillated (spike) bottoms	186
	57 Papillated (spike) and ridged (stripe) bottoms	187
	58 Smooth (control) and ridged (stripe) bottoms	188
59a-f	Experiments on the effect of different incident illumination on larval numbers in the centre of certain areas of the troughs under sunny conditions (125-250$^+$ f.c.)	
	a) T (uncovered)	209
	b) G_1 (greys with decreasing transmission)	209
	c) G_2 (greys with decreasing transmission)	210
	d) G_{1+2} (greys with decreasing transmission)	210
	e) G_3 (greys with decreasing transmission)	211
	F) B (black opaque)	211
60a-b	The relative influence of different levels of incident light in causing simuliid larvae to move into and out of equal areas of clear plastic-sided wooden troughs placed in Costello Creek in 1975.	
	a) Overcast days (32-64 f.c.)	212
	b) Sunny days (125-250$^+$ f.c.)	212

INTRODUCTION

The family Simuliidae is worldwide in distribution and it includes small insects called blackflies, or sometimesbuffalo-gnats because the adults are humpbacked. In Canada, adult Simuliidae appear in large swarms during the late spring and early summer causing considerable annoyance to livestock and man by their vicious bites, at times making field work almost impossible. The Simuliidae in certain tropical regions are known to transmit Onchocerca volvulus Leuckart to humans (James & Harwood 1969), but in North America are only known to transmit pathogens to animals, mainly birds.

As in other bloodsucking nematocerous flies only the females feed on blood, which serves as nourishment for development of the eggs. These are laid freely into the water while the female is flying, resting at the water line on substrate lapped by water, or under water (Davies and Peterson 1956). Females of several species fly upstream to oviposit at the outlet of a lake or pond, or at a small rapids (Müller 1954 in Waters 1972; Roos 1957).

The larvae, which are filter feeders, live only in running water, near the sites where the eggs are laid. They are more abundant at the outlet of a lake or pond, where there is a greater abundance of suspended food that they filter from the water by means of their head fans. They are fastened to rocks or plants by concentric circles of hooklets at the caudal end. The hooklets firmly grip a pad of salivary gum, first secreted by the mouth of the larvae.

It is almost universal and most authors agree that most simuliid larvae prefer the fastest flow in the stream (Pentelow 1935; Vargas 1945; Radzivilovskaya 1950; Dalmat 1955; Phillipson 1956; Peterson 1950; Rubtzov 1956, 1962; Carlsson 1962, 1967; Harrod 1965; Maitland and Penney 1967;

Zahar 1951), especially where the current is laminar (Grenier 1949; Hocking and Pickering 1954; Maitland and Penney 1967) but never in places where the water current strikes against the surface (Radzivilovskaya 1950; Zahar 1951). On the other hand, Rubtzov (1940) in Zahar (1951) found denser colonies in waters highly charged with air bubbles which are necessary for respiration.

There are different views concerning the importance of current for the larvae. Certain workers hold that O_2 supply is the main reason for larval preference of a certain current speed, a supply produced by the agitation of the water (Strong et al 1934; Radzivilovskaya 1950; Phillipson 1956), but Zahar (1951) found an insignificant difference in the amount of O_2 saturation between fast and slow current. Also Phillipson (1956) found that larvae move independently of O_2 at concentrations above 50% saturation. In addition, it is considered that the proper current is the most important condition for normal larval development (Phillipson 1956; Ussova 1961; Colbo 1974). Zahar (1951) suggested that current is important in the feeding process of filter-feeding simuliid larvae.

Of great importance for the control of larvae will be the knowledge of the high and low water-velocity thresholds for larvae of different species and stages. There are only three reports with very limited laboratory data on the high and low water-velocity thresholds of black-fly larva (Phillipson 1956, 1957; Carlsson 1962) and none of these differentiated the thresholds for different stages of larvae.

Rubtzov (1962) states that most simuliid larvae complete their development where they hatch and Ussova (1961) states that under normal circumstances they spend most of their life without migrating. D.M. Wood (in Peterson and Peterson 1962, p. 73-74) found larvae in an artificial stream tended to stay in one place unless crowded. This differs from certain other workers, namely Colbo (1974), who found that first stage larvae of species, that hatched from eggs recently exposed by flooding after being buried in mud, did migrate to attach to a firm substrate downstream. D.G. Peterson (in Peterson and Peterson 1962, p. 74) observed the same downstream migration of newly hatched larvae. If conditions change, larval migration or drift may be initiated. Migration occurs after a fluctuation in water level or an increase in turbidity following a rain (Rubtzov 1962, 1964; Ussova 1961). Slowly passing a shadow over larvae of certain species will cause them to drift (J.R. Anderson and K.M. Sommerman in Peterson and Peterson 1962, p. 70). The change in illumination during the day and night and contact with other organisms are said to initiate larval drift (Rubtzov 1962, 1964). Ussova (1961) suggests that short migration occurs when larvae are searching for a place with better illumination, optimum current speed, less turbidity or higher O_2 level.

The taxa of the stream insects that are most important quantitatively in the drift are: Ephemeroptera (mayflies), Simuliidae (Diptera), Trichoptera (caddisflies), Plecoptera (stoneflies), apparently in that order (Waters 1969b). Other than insects, amphipods of the genus Gammarus are often in the drift. Diurnal drift pattern of aquatic insects was first reported by Tanaka (1960), since then much work has been done which has been summarized (Bishop and Hynes 1969a; Waters 1969a,b, 1972), but more recent information has appeared (Radford & Hartland-Rowe 1971; Clifford 1972 a,b; Steine 1972).

Most authors studying diurnal drift found that Ephemeroptera, Plecoptera and some Trichoptera became more active after sunset. As early as 1927, Hubault reported such insects foraging on top of rocks at night when negative phototaxis no longer operated (during the day they were found beneath rocks). A review of the literature is found in Elliot (1967 a,c; 1972c), Bishop & Hynes (1969a) and Hynes (1970b).

The main reason for these insects being more active at night on both upper and lower surfaces of stones, with maximum activity just after sunset was to feed (Elliot 1972c). Elliot (1969b) after examining and dissecting the digestive tracts of Trichoptera concluded that larvae fed chiefly at night and most of the food was quickly digested during the day. Foraging at night evolved because of its selective value for maximum protection against predators (Madsen 1969; Chaston 1969b; Waters 1972). This added exposure at night apparently increases the probability of dislodgement by water currents. Herbivores seek algae on top of stones, while predators follow in response to their prey. In addition physical contact between individuals may result in some swimming up into the water (McLay 1968) and the detachment will depend upon the strength of the current, density of the nymphs or larvae and the jostling between them (Elliot 1967c). It has been suggested that the densities of detached animals in the drift reflects both the number of animals moving over the exposed parts of stones and aquatic plants, and the extent of competition between the animals for food and space (Elliot 1967a).

In the literature there are only a few scattered reports on the diurnal drift of black-fly larvae and all have been included in the discussion of drift with other organisms.

Light appears to be a very important factor affecting the migrationof aquatic insects, but there is only one experimental study on the influence of incident light on the movement of black-fly larvae (Davies, 1949). Most other reports are more qualitative observations in the field; furthermore the conclusions reached do not always agree.

The objectives of this research on black-fly larvae were three-fold:

1) To determine the upper and lower water-velocity thresholds of different species and stages from different streams

2) To examine larval drift and larval re-establishment under different conditions as follows:

a) the day-night effect

b) sudden increase in water velocity

c) water depth

d) substrate roughness

e) substrate colour

3) To determine larval preferences for different levels of incident light.

MATERIALS AND METHODS

1. Description of Experimental and Collection Sites

The research was conducted from June to August in 1973 and 1974 mainly at the Wildlife Research Station of the Ontario Ministry of Natural Resources, located at mile 20 on highway 60 in the upper Madawaska valley, Algonquin Park, Ontario (45^{o} 35'N, 78^{o} 30'W). Algonquin Park, with an area of 7536 km^2, lies between Georgian Bay and the Ottawa River in a transitional zone between the southern deciduous and northern coniferous forests and contains many lakes, rivers and creeks with rapids and falls, providing an ideal locale for the study of black-flies and other lotic fauna.

Experimental stations were established on three streams at or close to the outlet of lakes where simuliid larval populations were adequate (or could be maintained), where there was sufficient flow of water, and where the water depth was suitable for the deployment of apparatus. These stations were chosen also for their accessability by car, as observations had often to be made frequently and time was at a premium. In addition, other sites were selected for the collection of larvae of certain species for experimental use. All these sites are described below.

a) North Madawaska River

This is fairly shallow river, up to 1 m deep at the beginning of summer and no more than 10 m in width, which drains Lake Sasajewun, a relatively shallow body of water of ca. 16 ha. (Figure 1). The lake outflow is controlled by a man-made dam and is fast-flowing for the first 40 m with a rocky bottom. After a small pond the stream winds through banks of speckled alder *Alnus rugosa* var. *americana* (Regel), for 3-4.5 km.

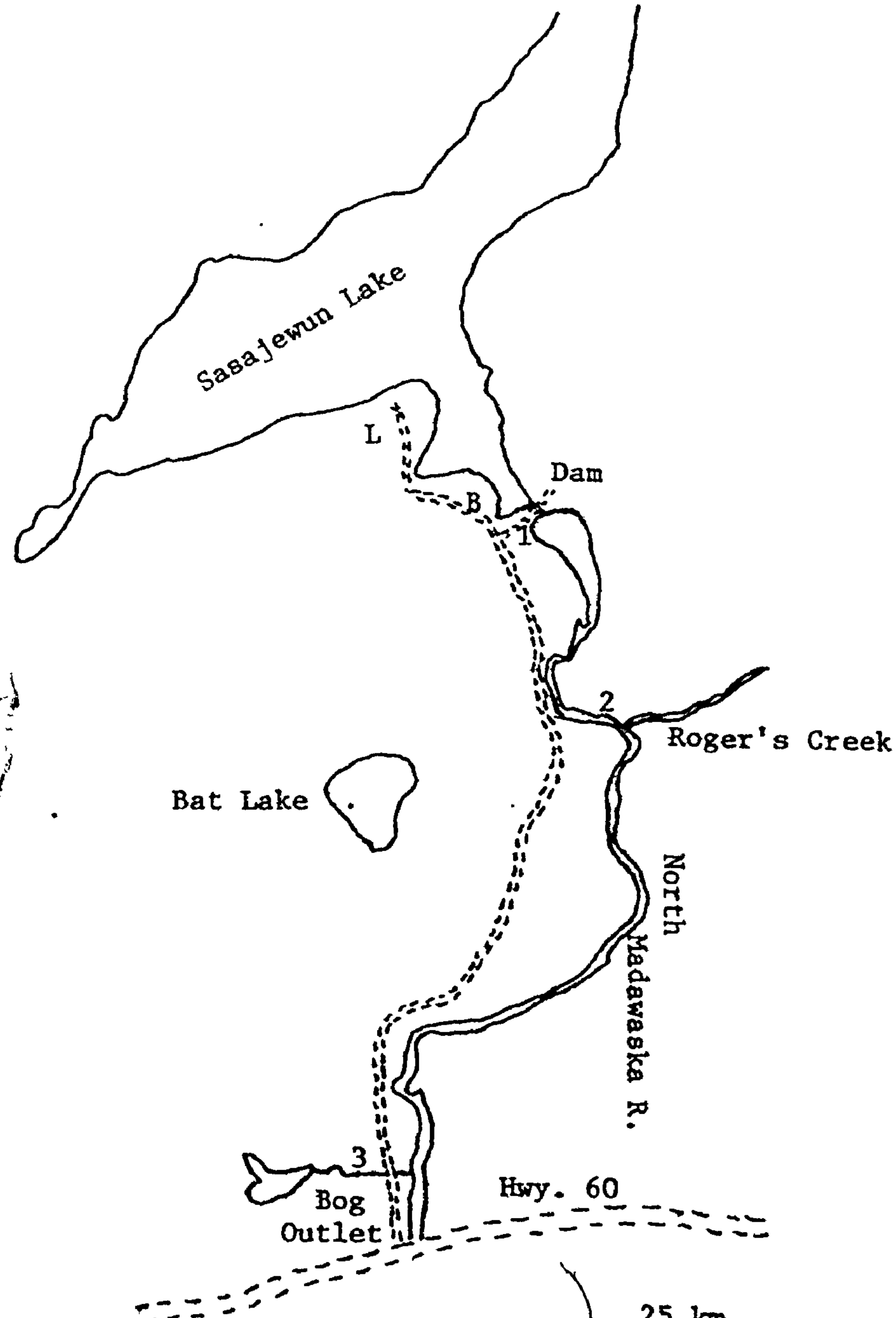
Figure 1. Map of the area surrounding the Wildlife Research Station of the Ministry of Natural Resources, Algonquin Park, Ontario, Canada.

L = Laboratory

B = Small screen shed (1973 drum experiment, position of pyroheliograph on open beach).

Experimental Sites

1. Cone experiment at Madawaska River
2. Flat plate experiment
3. Cone experiment at Bog Outlet Stream


Sasajewun Lake
L
Dam
B
1
2
Roger's Creek
Bat Lake
North
Madawaska R.
3
Bog
Outlet
Hwy. 60
.25 km.

b) Bog Outlet Stream

This is a shallow stream 30 cm deep and 1.5 m wide, draining a small bog lake of *ca.* 2 ha. (Figure 1). It flows over a disused beaver dam and through swampy terrain for 70 m before reaching the side road to the Research Station and after a further 30 m, it empties into the North Madawaska River. It is flanked along its upper half by speckled alder and increasingly farther down by grasses, such as reed meadow grass, *Glyceria* spp. The latter with bur-reed (*Sparganium eurycarpum* Englemann) and cattail (*Typha latifolia* L.) provided trailing leaves and emergent vegetation to which simuliid larvae attached.

c) Costello Creek

This stream is located 18 km east of the Research Station along Highway 60, and drains the shallow northeast end of Costello Lake, which has an area of about 20 ha. The stream is swift, flowing over rocks near the lake and is up to 6 m in width: below it narrows to 2–3 m and winds for 6 km beside the 3 km road to Lake Opeongo. In parts of the first rapids are bur-reed, cattail and meadow grasses which trail into the water and serve as a substrate for simuliid larvae, but this area is open with little shade.

d) Ragged Falls, Oxtongue River

This site is 42 km west of the Research Station (9.5 km west of the Park west gate). The falls and rapids stretch for 70 m dropping at an angle of ca. 40^{o} with an extremely fast flow, over huge boulders and smooth granitic bedrock.

e) Marsh's Falls, Oxtongue River

This is located ca. 3.2 km east from Highway 60 along Highway 35 or about 51 km southwest of the Research Station. The first 10 m drop of the falls is steep with an extremely fast flow over permanent bedrock. Thereafter the slope is more moderate for 50 m with boulders until a large pond-like widening in the river is reached.

2. Collecting Methods for Simuliid Larvae

Larvae were collected from four different sites for the drum experiments (described below). In smaller streams, such as the Bog Outlet Stream and Costello Creek, larvae were obtained mainly by gathering the leaves of cattail, bur-reed and grasses trailing in the water and then washing the larvae from them into pails. In the Madawaska River larvae were collected just below the Sasajewun Lake Dam, being scraped with small plastic containers from the cement chute and from rocks and logs below it. At Ragged Falls and Marsh's Falls larvae were scraped from the rocks using kitchen sieves attached to 1.2 m poles. In 1973 at Ragged Falls, collections were made with difficulty in the rapids above the main falls and in 1974 from a swift flow between two rocks in the falls, where a big fallen pine tree spanned a narrows, its submerged needled branches with accumulated debris becoming covered with larvae, and thus also diverted part of the main flow over a large rock (Figure 2). Larvae were more easily collected from the branches and rock than elsewhere with the careful use of forceps. At times the water level was found to fluctuate as much as 60 cm in two days at Marsh's Falls.

Collected larvae and often substrate were transferred to 10-litre plastic pails which, on return to the laboratory, were partly immersed in Lake Sasajewun to keep them cool, and air from an air pump was bubbled through the water in the pails.

Figure 2. Larvae collection at Ragged Falls.

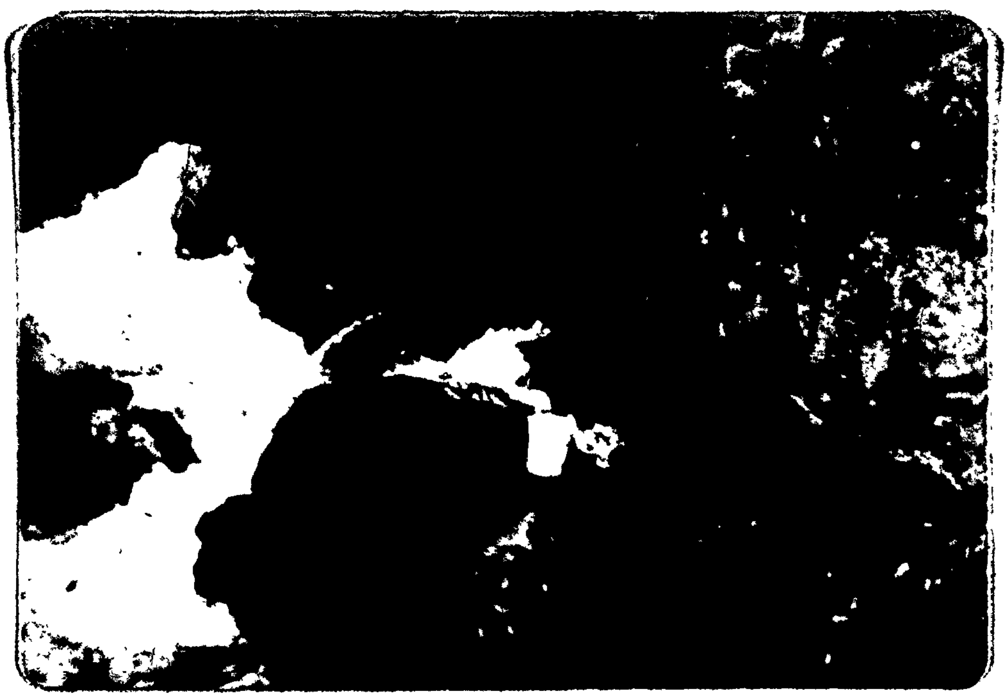


Figure 2.

In 1974, larvae from the Bog Outlet Stream or Costello Creek were used also for both the light and current experiments in wooden troughs (see below).

For the drum experiments in 1974, larvae immediately after collection were examined in the laboratory and divided roughly into species and stages. The stages were of three categories:

a) Immature larvae (usually stage 2 to the penultimate stage) with no pupal respiratory gill histoblast to those with a pale, less than full-sized histoblast.

b) Immature larvae (final instar) with full-sized but pale pupal respiratory gill histoblast.

c) Mature larvae (pharate pupa) with dark pupal respiratory gill histoblasts (ready to spin cocoon).

After each drum experiment larvae were preserved in 95% ethanol for confirmation of identification and for measurements. The length of every larva are measured to the highest 5 mm and the average lengths for each experimental sample was calculated.

After most of the other types of experiments, all larvae, or samples of them, (and any pupae that had formed) were preserved in vials of 95% ethanol for later identification and measurement.

3. Measurement of Environmental Conditions

The total solar radiation was measured continuously in langleys with a pyroheliograph (Belfort Instrument Co., Baltimore, U.S.A.) which was placed in an open area on the shore of Lake Sasajewun (see Figure 3 in appendix). The incident light intensity at the experimental site at particular times was measured with a Sikonic Studio exposure meter (Model 5) from Brockway Camera Corp., New York. This was done by pointing the meter directly up at the sky. Rainfall was measured with a standard funnel-type rain gauge. Water temperature was measured with a hand thermometer at certain times. Water velocity was assessed by floating a small piece of leaf down a measured distance and recording the time with a stop watch. In most cases several readings were averaged. Water velocity was also measured with a "L"-shaped, glass pitot-tube manometer. The times of sunrise, sunset, moonrise and moonset were calculated for the Wildlife Research Station using readings provided by the Atmospheric Environment Service for three surrounding localities (Walters, 1974). All times are Eastern Daylight Time.

4. Experiments on Water-Velocity Thresholds

Experimental methods were designed to determine two velocity thresholds for each larval population:

1. A high threshold above which larvae could no longer remain attached.
2. A low threshold below which larvae began to crawl about.

a) The Drum Experiments

Most of the analyses on high water-velocity thresholds and all of those on low water-velocity thresholds were conducted in a cylindrical, white-painted metal drum, 56.51 cm in diameter, which was cut down to a height of 27.94 cm (Figure 4). On the bottom 7 concentric circles were drawn in waterproof ink, each ring having a diameter 4 cm larger than the next inner ring. These rings were numbered 1 to 7 from the centre outward.

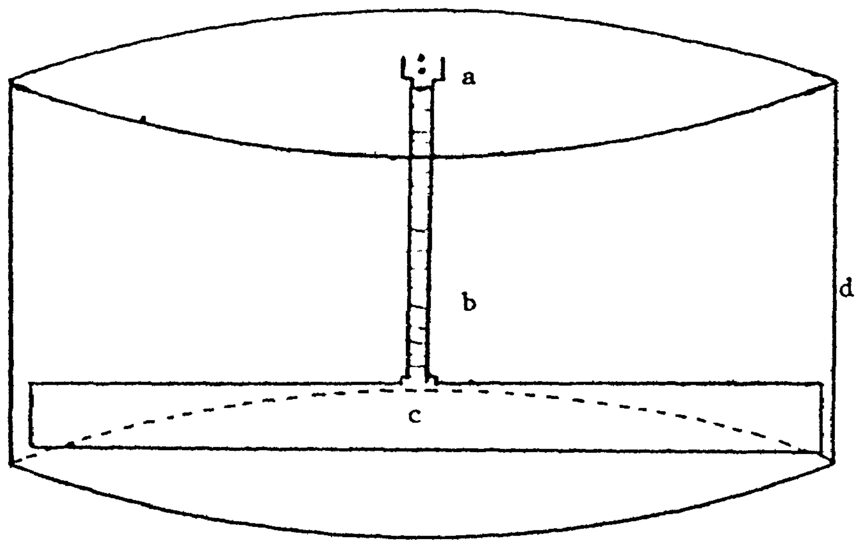
Figure 4. Diagram of rotating paddle in drum (for dimensions see text).

a) Connection to motor

b) Shaft

c) paddle

d) drum


a
b
c
d

The change in position of the larvae could be determined by counting the number of larvae in certain rings periodically during the experiments. The range of water velocities and the average value in each ring were calculated, the velocities being faster towards the periphery of the cylinder.

The water in the drum was circulated by a motor-driven paddle. The motor was bolted to a sturdy wooden board that straddled the top of the drum. A stainless steel rod (0.64 cm diam.) fastened to the motor shaft, passed through a hole in the board and was bolted through the centre of a wooden paddle (54.61 cm long X 6.99 cm wide X 4.45 cm thick) which reached 5 cm from the bottom of the drum. (Figure 4). The paddle was painted with white, waterproof, non-toxic, enamel (Impervo High Gloss no. 13301 of Benjamin Moore & Co.). The Dynamatic-adjustospeed motor (model no. M2-410000-5041-QK) was ½ h.p. with a range of speeds from 50-1600 rpm. To the motor was attached a gear reducer (model no. BGGV from Morse Chain Division, Toronto) having a ratio of 5:1 and 0.80 h.p. and a maximum speed of 750 rpm. The speed of the motor was controlled with a Dynamatic Variable Speed tachometer calibrated from 0-100, which allowed a wide range of speeds. The motor was powerful enough that rotating the paddle in the water made no difference in the rpm. In any case, the motor was never used at full speed as the highest tachometer reading reached was 30 (1/3 of its total power).

Differently shaped paddles were tested before the one described was selected, as it gave the most uniform water velocity at both high and low speeds. The water depth during experiments was between 6 to 8 cm. At the beginning of an experiment, larvae, collected from the habitats mentioned above, were transferred from the storage container to the bottom of the drum by means of a medicine dropper. Using a dropper instead of forceps minimized damage to the larvae. They could be moved to approoriate rings by squirting them with water from the dropper. When studying high velocity thresholds, approximately equal numbers of larvae were placed in the three outermost rings (5, 6 and 7). When studying low velocity thresholds, larvae were distributed in the three innermost rings (1, 2 and 3). The subsequent counts of larvae in each ring, made periodicallv during an experiment, were expressed as a percentage of the original number at time zero.

Once most of the larvae were attached to the bottom and counted in each ring, the paddle was revolved at gradually increasing speeds until the desired water velocity was obtained. After specified times the number of larvae in each ring was counted to observe any change. With high speeds, the water was too turbulent to see the larvae, so that the paddle had to be slowed sufficiently for a few seconds, so that larvae could be clearly seen and counts made. During this time the larvae did not move and even retained the bent condition characteristically found in a strong current.

In preliminary experiments the paddle was slowed and speeded quickly, before and after each count respectively, but it was found that the larvae were disturbed by these rapid changes and tended to migrate or become detached more readily than when the paddle speed was changed more gradually. Therefore in subsequent experiments the paddle was slowed over 15-20 seconds and speeded again over 30-60 seconds. In this way the larvae seemed little or not at all, affected by the count periods. However, if the paddle stopped completely, larvae immediately began to move about.

In order to ensure that the tachometer readings could be lowered and raised with reasonable precision a series of 10 trials were done at two readings 14 and 24 (Table I). It is seen that the tachometer can be returned to close to its original setting after lowering to make larval counts. Calibration of tachometer readings with paddle revolutions were done three times, at the beginning of experiments in 1973, following the repair of the motor after breakdown in mid summer 1973, and in early 1974 after the motor and gears were cleaned.

In 1973 the drum experiments were conducted within a small screened shed, 15 m from Lake Sasajewun, and before each experiment the drum was cleaned and fresh water used. At the end of each experiment the larvae were placed back in the pail which was kept cool by being partially submerged in the lake and supplied with bubbles from an electric air pump. At the end of each test any sickly or dead larvae, and any pupae, were preserved in 95% ethanol for later identification. For an experiment in late summer, larvae were collected from the Bog Outlet Stream on 10 and 17 September and brought back to McMaster University where they were kept at 8°C in a container through which air was bubbled. Larvae needed for each test were brought to the laboratory, and allowed to adapt overnight as the aerated water rose to 20°C.

In 1974 the drum experiments were done in a laboratory building where the temperature remained fairly cool all day so that the larvae could be left in the drum between experiments. The water was changed at least once every two days and the drum carefully cleaned. The fresh water was taken directly from the lake to avoid any possible effects of heavy metal ions from tap water.

Table 1

REPRODUCIBILITY OF PADDLE REVOLUTIONS PER MINUTE AT TWO TACHOMETER SETTINGS

Tachometer setting	Number of Trial 1	2	3	4	5	6	7	8	9	10
14	52.75	53.00	53.25	53.50	54.25	54.00	53.75	54.00	54.25	54.00
24	88.00	88.50	88.00	88.00	87.50	88.00	88.25	88.50	88.00	88.75

b) Experiments in Wooden Troughs

These experiments, to determine high, water-velocity thresholds, were done in 1973 at Costello creek and the following wooden troughs placed in the natural stream were used (Figure 5, 6 and Table 2):

2 long half-divergent troughs,

1 long parallel-sided trough,

3 short half-divergent troughs.

The sides of these wooden troughs were held to their bottoms with screws and waterproof glue. The long divergent troughs were tapered at an angle of less than 8° to minimize turbulence (Streeter, 1971). A straight, parallel-side trough was joined to the narrow upstream end of each divergent trough to face the incoming current in order to minimize turbulence and eddies. These two sections of trough were held together by iron straps (30 cm x 2.5 cm x 0.3 cm) with holes drilled in them so that two could be screwed to the outer surface of each side. The cracks were filled with putty. After this, the trough unit was painted black on the outside and white on the inside using the same white, waterproof, non-toxic enamel that was applied to the "drum" paddle (see above). Also iron straps of appropriate length were screwed across the top of the two sides at each end and in the middle to reduce warping of the wooden sides in the water. In 1974 only two long straight troughs were used, as they were considered to give the widest range of water velocities along their length.

Cross lines were drawn with waterproof ink at 10 cm intervals along the length of each trough and two evenly spaced longitudinal lines divided the trough into sections designated M_1, M_2 and M_3. Larvae were counted in the three "M" zones for every 10 cm strip and in addition larvae

Figure 5. 1973 Large troughs in stream.

Figure 6. 1973 Illumination troughs with wooden sides.

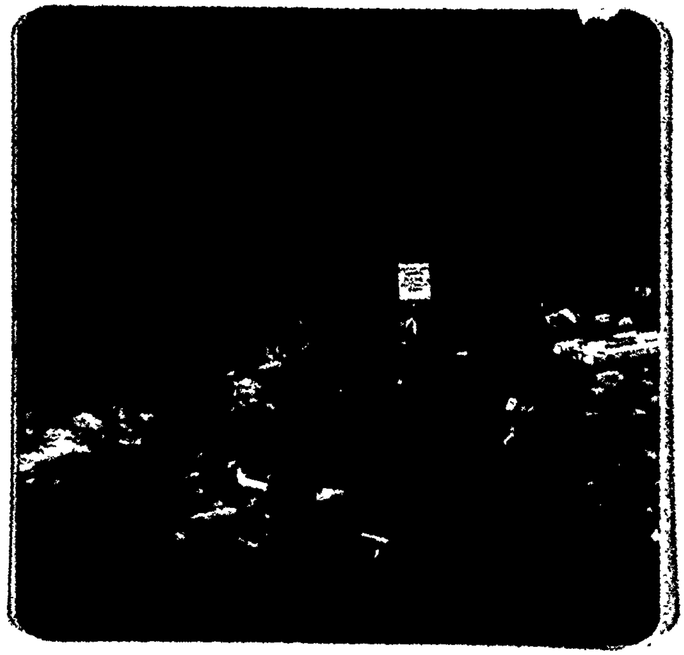


Figure 5.

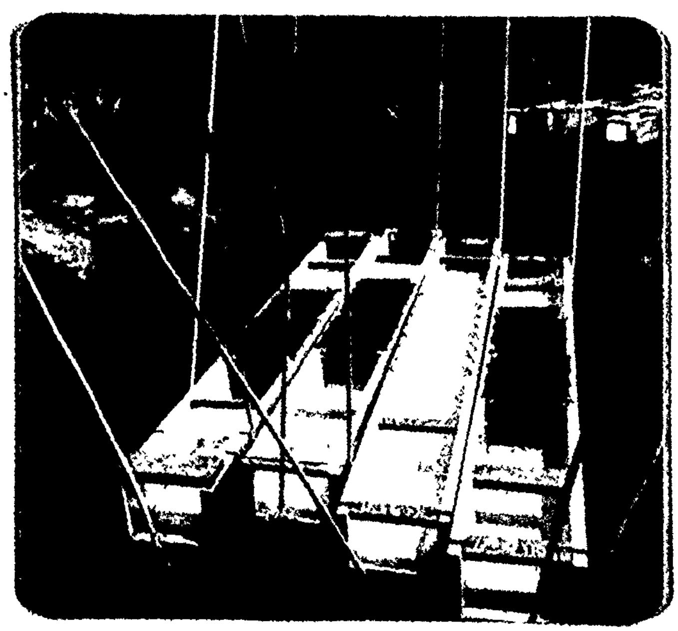


Figure 6.

Table 2

Dimensions of wooden troughs used in simuliid larval experiments in 1973 and 1974

(in cm)

Trough	Length			Width (inside)			Depth (inside)
	Total	Straight section	Tapered section	Straight section	Centre of taper	Widest section	
Long rectangular[1]	246.70	246.70	-	27.94	-	-	12.54
Long, wide, half-tapered	275.59	65.41	210.19	9.21	18.42	28.26	12.54
Long, narrow, half-tapered	309.88	65.40	244.48	4.60	15.24	27.46	13.02
Short, wide, half-tapered	157.80	77.47	89.22	16.51	20.32	30.16	13.18
Short, medium, half-tapered	158.43	78.11	80.33	8.26	19.53	27.62	13.65
Short, narrow, half-tapered	158.75	78.74	80.01	4.60	11.75	17.78	13.18
Short rectangular[3]	151.77	151.77	-	14.61	-	-	10.95
Short rectangular with clear[2,3] plastic side	152.40	152.40	-	13.34	-	-	11.43

[1] Used also in 1974
[2] Used only in 1974
[3] for illumination

right at the edge angle were counted separately; hence there were five counts for each 10 cm strip down the trough.

Each trough was set in the shallow stream parallel with the flow and adjusted so that a uniform depth of water flowed through the wooden trough. Water depth was measured with a metric ruler at both ends and in the middle at two point across the trough. Sometimes because of a change in water level the flow would be altered in the trough so that one side had deeper water. The level of the trough was then adjusted with small rocks underneath to regain the original uniform flow. At first such adjustments were made only at the start of an experiment but later, especially in 1974, they were made, if necessary, during an experiment at the time of a larval count. Occassionally later in the summer as the water level diminished, the creek beside the trough had to be dammed to divert sufficient water for the experiments.

At the start of an experiment, reeds and grasses covered with larvae were shaken over the trough until many larvae dropped in; then a little water was washed back and forth in the trough, until larvae became attached. Then first the upstream end of the trough was lowered to the stream bed after which the downstream end was slowly lowered to the stream bed so that the flow in the trough increased only gradually. After a 15-min period to allow the larval population to stabilize the initial count was made. In order to see the larvae through the irregular water surface, a piece of transparent plexiglass was held across the trough at an angle to the water surface, above the strip to be counted, so that the larvae could be seen. Subsequent counts were made periodically one to three times a day for several days. After each experiment the bottom of the trough was washed to remove a slimy film that seemed otherwise to interfere with larval movement. At the end of an experiment, the trough was lifted from the stream and placed on two rocks on the bank. Then the larvae and any pupae were placed in vials of 95% ethanol for later identification.

In early experiments it was noticed that in sunlight the larvae accumulated in the shadows from the metal straps and the sides. In subsequent experiments the entire trough was covered with several 30-cm strips of black tar paper attached with staples. Strips of paper were lifted in sequence at the time that the larvae were counted and the water velocity and water depths at different places in the trough were measured.

Water velocity in the trough was measured in two ways. One measure was the time taken by a small floating object to traverse certain lengths of the trough as measured by a stop watch. Usually 5-10 measurements were averaged. Occasionally, in addition, measurements were made with a pitot tube manometer at certain places in the trough.

An attempt to make the flow more laminar, by placing a series of different mesh-sized screens in front of the trough, was frustrated by the rapid clogging by debris.

5. Experiments on Larval Substrate Preference and Drift

In the natural stream, it has been observed that insect larvae, including black-fly larvae, often lose their hold on the substrate and drift downstream. Thus it is possible to place objects in the stream, even suspended into the water (not touching the bottom), and have almost a pure population of black-fly larva accumulate on them in short periods of time. This is because the black-fly larvae can produce salivary gum and drift downstreams on threads of this gum which is also used to attach to objects.

a) Flat Plate

An experiment was planned to examine the distribution of larvae on a long flat surface held horizontally in the stream under changing conditions. A straight smooth-flowing stretch of the North Madawaska river was selected at a point 250 m below Lake Sasajewun dam where the water depth was ca 90 cm (Figure 1). A thin galvanized iron plate was made with the following dimensions: length 182.22 cm, width 45.72, cm thickness 0.125 cm, the side edges being bent down at 90^{o} to form flanges 1.91 cm wide to provide more rigidity. Three iron rods (1.91 cm in diam.) were soldered across the bottom of the plate: one in the centre and the other two at 15.24 cm from each end. Each rod projected 15.24 cm beyond each side of the plate and had a cylindrical metal tube (7.62 cm long and 2.70 cm in diam.) soldered at right angles to its end (Figure 7,8). Through each metal tube could be fitted a vertical iron rod (122 cm long and 2.54 cm in diam.) with a pointed end which was driven into the stream bed. The plate was made horizontal at 5-12 cm below the water surface and then two screws in each tube were tightened to hold firmly to the vertical rods. The plate had previously been painted with the white, waterproof, non-toxic enamel used on the "drum" paddles (see above). Cross lines were drawn with black waterproof ink at 5-cm intervals along the plate, as well as three equally spaced longitudinal lines (Figure 8).

The plate was placed in the stream one week before starting the experiment, and after this interval, some of the accumulated larvae, especially on the upstream half of the plate, were removed to approximate an even distribution of the remaining larvae. Larvae were counted 1 to 4 times daily, at which time 10 measurements of water velocity were made as with the troughs (see above), and the water depth at three points across the

Figure 7, 8. Two Views of Flat Plate.

Figure 7. Oblique view of flat plate in stream with worker.

Figure 8. Close up view of marked upper surface.

Figure 7.

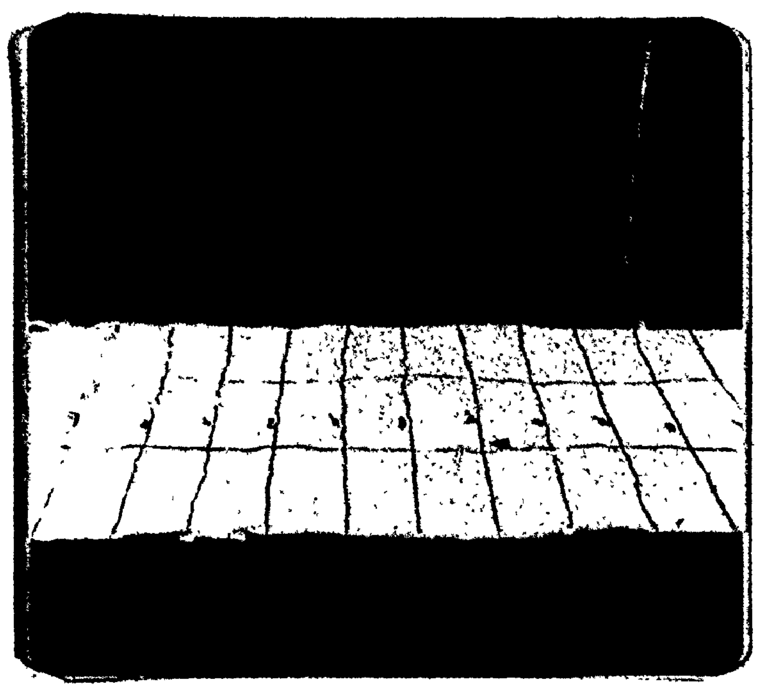


Figure 8.

centre and also across the two ends was measured which also insured that the plate was still parallel with the water surface. The light intensity, water temperature and other general meteorological conditions were recorded. During this experiment one drop log was removed from Lake Sasajewun Dam to determine the effect of this change in water velocity and water depth on the larvae.

b) Cone Experiments

Stainless steel cones (21.59 cm long, 8.89 cm widest diam. and 0.079 cm sheet thickness) were welded to a U-shaped stainless steel plate (3.81 cm in the middle and 5.08 cm for each end). A bolt through the centre of the plate fastened the cone to a vertical piece of white-painted, right-angled metal Dexion (3.81 cm wide per side and 0.159 cm thick) that was sharpened at one end for penetrating the stream bed (Figure 9a,b). The pointed end of the cone faced exactly upstream and removable plastic cones were fitted over the metal cones and held in place by the current. In 1973 plastic of two different textures (one smooth and one with minute ridges) and several colours were used. For each experiment only one texture was used and in 1974 all experiments were done with smooth plastic. The plastic was cut and then glued into cones using in 1973 fish-tank cement which lasted only a few days, so that in 1974 epoxy glue was used with more permanence.

(i) Diurnal Drift of Larvae

Three cones were anchored in a line across the Bog Outlet Stream, 10 m upstream from the sideroad and in the North Madawaska River, 40 m below Lake Sasajewun dam. The white cone covers were removed at 1 or 2 hr intervals and placed in 500 ml, stacking plastic containers. Soon thereafter in the

Figure 9a,b. Metal cone apparatus for studying larval drift. One or two metal cones, one above the other, can be bolted to the Metal Dexion which support which is driven into the stream bed.

9a. a. Metal Dexion support

9b a. Cone

b. U-shaped plate

c. bolt

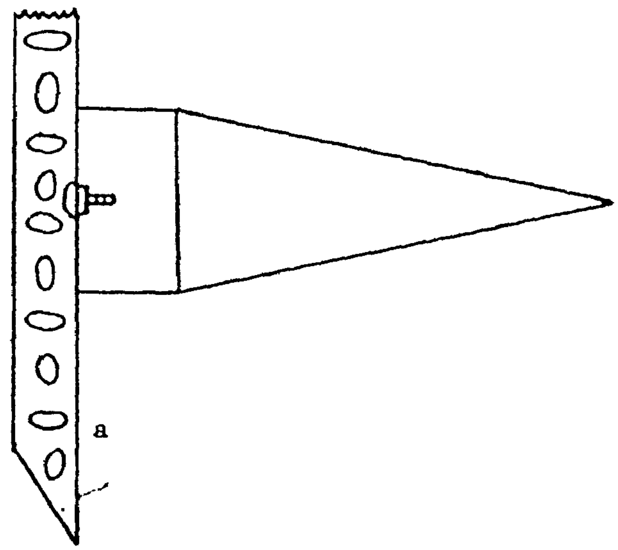


Figure 9a

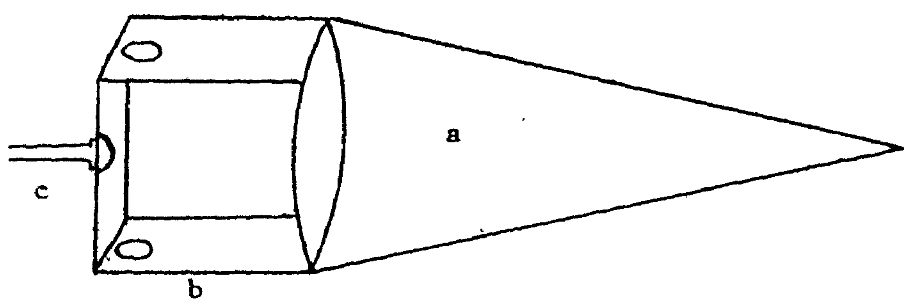


Figure 9b

laboratory the attached larvae and occasional pupae were removed and preserved in 95% ethanol and later identified and counted. In removing a cone cover from the metal cone, it was slid forward against the current and lifted straight out of the water in one continuous movement. New cone covers immediately replaced the old. This method takes only a few seconds so that up to 6 cone covers could be replaced in 2-3 min. Light measurements were taken and other meteorological conditions were noted as discussed earlier.

(ii) Effect of Depth on Larval Drift

Two cones, one above the other, were placed in the North Madawaska River, 40 m below Lake Sasajewun dam. The top cone was set at two different depths below the water surface, the lower cone being at four different distances below it in separate experiments. Four experiments were run and in the first three experiments three pairs of upper and lower cones were placed across the river in the fastest part. In experiment 4 only one pair of cones was used. The white cover cones with accumulated larvae were replaced at intervals during the experiments (see Results).

(iii) Effect of Coloured Cones

Experiments were conducted in the summers of 1973 and 1974 at two sites, one in the North Madawaska River about 40 m below Lake Sasajewun dam and the Bog Outlet Stream 60 m below the beaver dam. In 1973 plastic cover cones of seven colours were used. The cones were arranged in two lines across the stream at each site; the colour cones in the first row being white, black and medium green and in the second, medium grey (transparent plastic over dull stainless steel), light blue, light green, and light red (pink). The cones in the first row were positioned so that each was upstream of the centre of the space between two cones of the downstream row. Two experimental periods were used each day: 9 am to 5 pm (the highest light intensity) and 9:15 pm to 5:15 am (darkness as checked by the pyroheliometer), and cone covers were changed at the end of each period. Once a day the position of the colours was changed cyclically within each row to reduce bias. The cones were placed in the fastest part of the stream. In the North Madawaska River the cones were 31.5 to 36 cm apart and the rows were 55 to 57.5 cm apart. The cones were 13-16 cm below the water surface. In the Bog Outlet Stream, the cones were 21 to 31 cm apart and the rows were ca 50 cm apart. The cones were 12.5 cm below the surface on August 4 but only 5.5 cm below the surface on August 7. The water velocity during the experiments at each site was averaged.

In 1974, plastic cones of only three colours across the spectrum were used, namely light blue (as in 1973), medium green (as in 1973) and dark red. Experiments were run at the two sites used in 1973 but only during daylight from 8 am to 6 pm (highest light intensity) and the colours were changed cyclically each day as before.

c) Surface Roughness and Accumulation of Drifting Larvae

Two roughened transparent plastic surfaces were compared with the smooth white painted surface as a control. One sheet of plastic (1.5 mm thick) had nipples or "spikes" (height 5 mm, width at tip 1.1 mm and at base 2.5 mm) which had a tip to tip spacing between 24-29 mm (Figure 10a,b). The other sheet had parallel cross-ridges (height 0.4 mm) with a crest to crest distance of 4.1 to 4.5 mm (Figure 10c). The heights and thickness were measured with a vernier caliper. These sheets were cut to fit the drum but could not be attached and detached readily. Therefore such sheeting was cut to fit the short, re 10. Patterns of Rough plastic surfaces used in larval drift experiments.

a) Top fiew of "spike" surface showing spacing of plastic points.

b) Cross-sectional view of spike surface showing shape of spikes

c) Longitudinal section of ridged surface showing shape of ridges.

* All measurements in mm.

Figure 10a

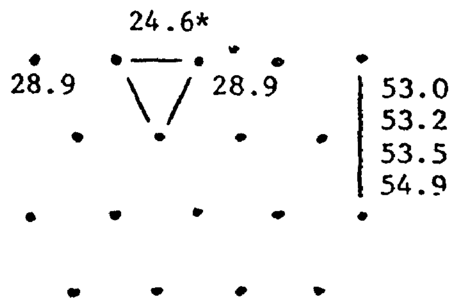


Figure 10b

Figure 10c

parallel-sided troughs and stapled in closely to the bottom and up each side. For each experiment in 1973 two troughs (also used for the 1973 illumination experiments) were placed side by side in Costello creek and tar paper strips placed over the troughs (see description of method in 4b). All pairs of the three surfaces (smooth, ridged and spikes) were tested and to avoid position effect the troughs were interchanged after each experiment and a second experiment run for the same period of time. No larvae were put in the troughs but allowed to accumulate by immigration from upstream and counts were made at least once a day. The troughs were marked with cross lines at 10-cm intervals and lengthwise by a midline, and counts were made in each half of a 10-cm interval but larvae along the edges were counted separately. No counts were made in the first 10 cm of the trough as the accumulated larvae were too dense to count accurately in a reasonable time. At the time of each larval count 10 measurements of water velocity were made with a small floating object and a stop watch, and the water depth at each end and in the middle of the 60-cm trough were recorded. In 1974, an attempt to find suitable waterproof surfaces in a graded series of roughnesses was unsuccessful.

6. Experiments With Different Levels of Incident Light

Simuliid larvae were tested for their migration to or from two equal areas in a trough, each area having a different level of incident light.

In 1973, 8 wooden troughs were made using dressed, seasoned birch boards (1.91 cm thick). The inner bottom surface of each trough was 151.77 cm long and 14.61 cm wide and the wooden sides had an inner height of 10.95 cm (Figure 6). The troughs were held in place in Costello Creek by sharpened metal rods driven into the stream bed. The inside of the troughs was painted with the white, waterproof, non-toxic enamel used for the paddle in the drum experiments. Four black lines were drawn across the bottom of the trough, 22.86 cm apart, and a central longitudinal line down the length of the trough.

Covers were cut from acrylic plastic sheets* (3.1 mm thick) with different light transmissions (Table 3). These were given symbols as follows: clear (T), grey Rohaglass® 1824 (G_1), grey Rohaglass 1826 (G_2), grey Rohaglass 1825 (G_3) and black opaque (B). Each cover was 22.86 cm long and 19.05 cm wide so that it rested on the wooden edges of the trough. It was held in place by L-shaped nails in the wood that could be rotated for release of the cover. Near the ends of each cover, two holes were drilled so that another piece of the same plastic (10.16 cm long) could be hung vertically at each end. Near the top of each of these side pieces, 3 pairs of holes, 1.2 cm apart, were drilled; thus these side pieces could be tied to the top cover so that they could be at different heights just above the water level as the volume of the water in the trough varied.

The trough was made as level as possible by testing the water level in different parts of the trough. Larvae were then introduced into the trough and fairly evenly distributed in that section being used for

---

* Crystaplex Plastics Ltd., Mississauga, Ontario.

the experiment. After 2-5 min an initial count was made. The final count in each trough area was made around 2:15 - 2:45 pm when the sun was near its highest point. At the time of larval counts, the water level at each end of the trough was recorded, 5-10 measurements of water velocity (with a small floating object) were averaged and the incident light measured with the light meter. Some idea of the changing incident light (change in cloud cover) was afforded by the continuously recording pyroheliograph.

Because the wooden sides of the 1973 troughs cast shadows that obscured the results, new troughs with clear acrylic plastic sides were made for the 1974 experiments. These troughs had a dressed wooden bottom (1.91 cm thick) painted white, 152.4 cm long and 13.34 cm inner width, and plastic sides with 11.43 cm inner height (Figure 11). Black lines were drawn across the trough bottom, 15.24 cm apart, as well as a central longitudinal line. The plastic covers were 15.24 cm long and 16.61 cm wide. The covers, in addition to the vertical pieces at each end, now needed side pieces that controlled the light entering through the clear plastic walls of the trough. These side pieces (11.75 cm high) were glued to the edges of the top covers forming an inverted "U". Rather than using a clear plastic cover, the control area was left coverless. One additional grey cover was made, combining grey Rohaglass 1824 and 1826 (G_{1+2}); in this way there was a continuous series, each cover having twice the light transmission of the darker filter below it in the series (Table 3). Usually 6 troughs were in operation at one time, each pair using the same two filters (or clear area) but in reverse order. As in 1973 larvae were distributed in the troughs at 8-9:30 am and shortly thereafter an initial count in each

Figure 11. 1974 Illumination troughs with clear sides.

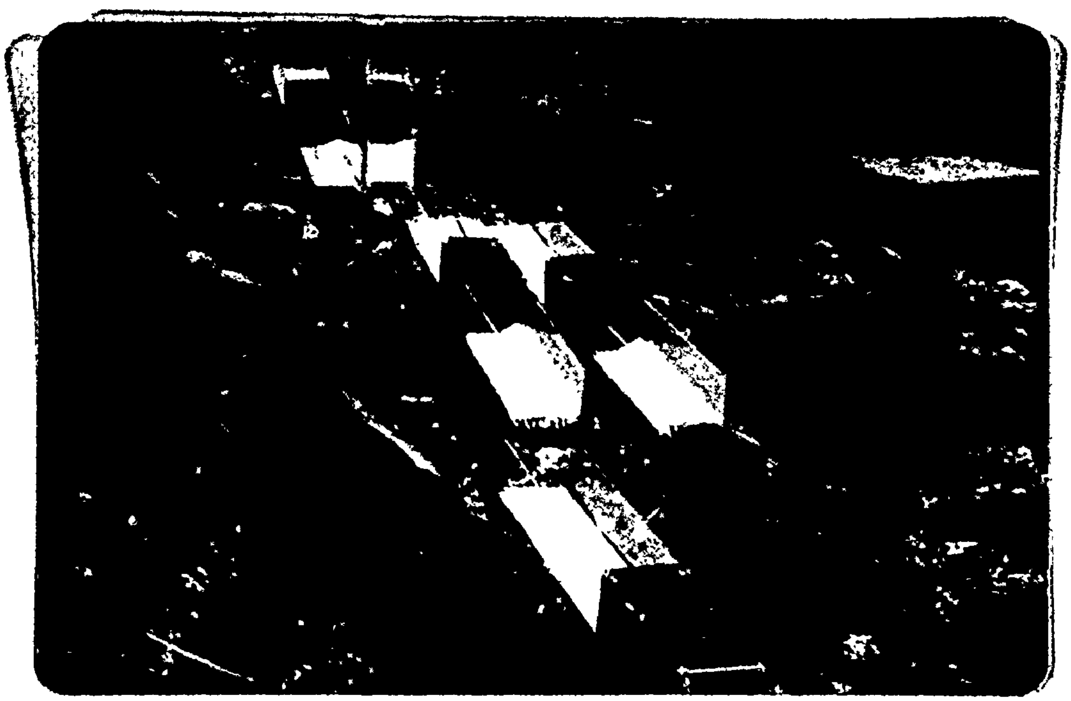


Figure 11.

Table 3

Comparison of Light Transmission of the Filters in Foot-candles (black = 0 f.c.)

Rohaglass No.	1825	1826+1824	1826	1824	uncovered
Symbol	G_3	G_{1+2}	G_2	G_1	T
Foot-Candles	16	32	64	125	250

area was made and the final count was made between 2:15-2:45 pm, when the sunlight fell most vertically on the troughs. As in 1973 at the time of the larval counts, the light intensity, water velocity and water level were recorded. After each experiment the larvae were preserved in vials of 95% ethanol for later identification and measurement. Later a sample of 2 vials from a maximum of 6 daily vials were randomly selected for every third day, identified and measured.

RESULTS

1. Experiments on Water-Velocity Thresholds

A. Introduction

It was observed in the natural stream, in the wooden trough and in the drum with rotating water that, when in slow water velocities, the larvae would be in an almost upright position attached by their anal ring of hooks to a pad of secreted salivary gum. As the water velocity increased, the larvae became closer and closer to a horizontal position with the substrate, their heads pointing downstream. In extremely rapid currents a larva was seen to bend its head upstream in order to secrete a second pad of salivary gum to which the proleg ring of hooks could be affixed affording the larvae a double anchorage. It was also noticed that above a certain low current threshold the larvae remained usually in position during increasing water velocity until they were torn loose by an extremely rapid current. Often at these times the larvae would drift downstream on a thread of salivary gum and might be able to reattach to a favourable spot downstream. On the other hand, if the current dropped below a certain threshold, larvae began to crawl around in all directions until reaching a region of current above the threshold where they once more took a more permanent position.

B. Drum Experiments

The tachometer readings were converted empirically into revolutions per minute (rpm) by counting the revolutions of the paddle and averaging two to three trials at each tachometer reading. These tachometer values could be set with considerable precision (see Table 1 in Materials and Methods). The measured maximum current velocity at any position along the radius of the drum from the centre (with zero velocity) to the periphery was calculated by the formula $\frac{2\Pi r \times rpm}{60}$ where r = the distance from the centre of the drum to the outer periphery of each of the 4-cm concentric rings. The velocity at the periphery of the drum was also tested empirically from 0-1 cm above the bottom using a Kent Miniflo micropropeller probe (Type 265), and the results when compared with the calculated values at the periphery (Figure 12, 13) were lower, as expected, because they were approaching the boundary layer.

Larvae were initially placed on the drum bottom in certain of the concentric rings at the beginning of each experiment. Changes in larval number in each ring were expressed as percentages of the initial number at time zero.

a) High Water Velocities

In 1973 the following tests were run to determine the upper current thresholds for larvae from three different locations: from Ragged Falls - 4, from Costello Creek - 10, and from the Bog Outlet Stream - 8. The date and duration of each experiment, velocities for the outer periphery of each ring and the number of larvae in each ring periodically during the experiment are shown in Table 4. Table 5 shows the actual water velocities included in 30 cm/sec velocity ranges for each tachometer reading for different experiments in 1973. The data were pooled for each of the larval populations and were plotted on the graphs below, and standard errors were calculated (Table 6). The samples from each location were identified and separated into 3 stages: immature and mature larvae and pupae (Table 7).

The larvae from Ragged Falls were all Simulium (Shewellomyia) longistylatum Shewell (with possibly a few of the closely related S. (Sh.)

pictipes Hagen intermixed).

Ragged Falls had an extremely rapid current and some of the larvae from there were able to withstand 260-290 cm/sec. Thus, 90-100% of the larvae remained in this current for up to 12 hr. Below this speed larvae appeared to move and become dislodged (Figure 14).

The larvae from Costello Creek were over 60% Simulium (Psilozia) vittatum Zetterstedt (Table 7). The current in Costello Creek, just below Costello Lake, was moderate in 1973 due to high rainfall and thus high water levels. Most larvae (85%) showed little detachment in currents below 140 cm/sec after 2 hr. From 140-230 cm/sec roughly 50-65% remained after 2 hr whereas above 230 cm/sec only 2-16% remained for 2 hr (Figure 15).

The larvae from the Bog Outlet Stream were tested back in Hamilton after a 4-hr drive from Algonquin Park at the end of the summer (see Materials and Methods). Although kept relatively cool during transport and then being stored in cool room at 8°C, until the experiments, they may have been somewhat weaker than if they had been tested in Algonquin Park. These larvae were probably mostly Simulium (Simulium) verecundum Stone and Jamnback, with possibly some S. (S) venustum Say intermixed, but it is difficult to separate the larvae of these two species. These larvae were frequently torn away when the water velocity in the drum exceeded 110 cm/sec. After 2 hr only 8-40% remained, the percentage decreasing with increasing velocity (except for the range 260-290 cm/sec which is unexplained) (Figure 16).

Larvae from the Bog Outlet Stream, comprising mostly S. (S) venustum-verecundum, were tested again in 1974 for their upper current thresholds. The results differed markedly from those in 1973, indicating that the transport and holding of the larvae had weakened them. In 1974, 83% of the larvae withstood velocities of up to 230 cm/sec for 8 hr. At 230-260 cm/sec, 45% remained after 2 hr but only 15% at 260-290 cm/sec for 2 hr (Figure 23b). The differences in response of larvae of different species from the three above locations are summarized in Figure 17.

In 1974 it was decided to concentrate on experiments which compared the upper current velocity thresholds of different species and also of different stages from one habitat, as well as the same species and size-range from different habitats.

With the many living larvae needed for the experiments it was possible to select species and stages only in a rough way. However, after the experiments were completed, samples of the larvae were then identified, their lengths measured and the larvae divided into 3 categories: immature (IM), penultimate and last stage with large white pupal respiratory histoblasts (IMLH) and mature larvae (MAT) (Table 8 in appendix). The paddle velocities, number of larvae and water velocities in every ring, date and length (in hours) of experiment, species and sizes of larvae and locality are given in Table 9 (see appendix). In 1974 only a few selected high current velocities were tested. To strengthen the data, experiments were repeated using the same series of velocity ranges, and the percentage of larvae remaining after certain time intervals in each experiment were pooled and plotted in graphs below and the standard errors calculated (Table 10). These data, for the larval numbers at every 30 cm/sec velocity interval, were plotted against time in hours.

i) Effect of Larval Stage

Larvae of different developmental stages of one species from one habitat were compared in a series of experiments. The number of larvae in each stage grouping tested and the average length of the larvae in each size range are indicated in Table 11.

From Ragged Falls, tests were run on large, small and very small larvae of S. longistylatum. In figure 18a it is seen that with large larvae, even at 290-305 cm/sec almost 94% remained after 2 hr and 87% after 8 hr. For very small larvae (mostly stage II), 58% withstood currents of 200-230 cm/sec for 8 hr, but only 25-66% currents of 200-305 for 2 hr and 10-58% for 8 hr (Figure 18b). Small larvae of this species (including 14% S. tuberosum A) were intermediate in their ability to withstand high velocities, i.e. at 230-305 cm/sec 73-75% for 2 hr and 46-75% after 8 hr (Figure 18c).

From the North Madawaska River below Lake Sasajewun Dam, three sizes of Simulium (Simulium) decorum Walker were selected for testing (Figure 19a large and Figure 19b small). Over 75% of the large larvae withstood for 2 hr speeds of 170-260 cm/sec, 70% speeds of 260-290 cm/sec but only about 28% speeds of 290-305 cm/sec (Figure 19a). The small larvae seemed more resistant. As well as over 76% withstanding 170-260 cm/sec for 2 hr, and 71-90% for 8 hr, over 90% withstood 260-305 cm/sec for 8 hr (Figure 19b). With mature larvae (with dark histoblasts) after 2 hr 65-95% of the population withstood velocities of 170-290 cm/sec for 2 hr and 54-78% for 8 hr, while only 42% withstood 290-320 cm/sec for 8 hr (Figure 19c).

ii) Species Differences

At Ragged Falls there were two and possibly three species, S. longistylatum and two probable sibling species of S(S.) tuberosum Lundstrøm which we shall call A and B. Slightly higher velocities (up to 317 cm/sec) were used in these experiments compared to those in the previous section. As in the previous section, large larvae of S. longistylatum are able to withstand high water velocities; more than 84% withstood currents of 200-320 cm/sec for 2 hr and 78-83% for 8 hr (Figure 20a). For S. tuberosum A, 79-99% of large larvae resisted for 2 hr currents of 200-320 cm/sec, 99% currents of 200-230 cm/sec, 90% currents of 230-260 cm/sec, 86% currents of 260-290 cm/sec and 78% currents of 290-320 cm/sec. However after 8 hr only 72-99% remained in currents of 200-320 cm/sec with numbers decreasing as velocity increased (Figure 20b). With large larvae of S. tuberosum B (Figure 20c), it is seen that over 80% could resist velocities of 200-320 cm/sec for 2 hr and over 78% for 8 hr.

In the North Madawaska River, experiments with two species were run, i.e. S. decorum (Figure 21a) and S. tuberosum A (Figure 21b). With large larvae of S. decorum, over 75% could withstand velocities of 170-260 cm/sec for 2 hrs and over 73% for 8 hr, and 69.5% could withstand 260-290 cm/sec for 2 hr and only 46% for 8 hr, whereas only 27.5% could resist 290-305 cm/sec after 2 hr and 24% after 8 hr (Figure 21a). With large larvae of S. tuberosum A 85.5-92% resisted speeds ranging from 170-305 cm/sec for 8 hr (Figure 21b).

(iii) Same Species in Different Streams

Large larvae of S. tuberosum A occurred both in the Oxtongue River at Ragged Falls and in the North Madawaska River in the rapids just below Lake Sasajewun Dam. 79-99% of these larvae from Ragged Falls resisted

Table 4

A summary of the conditions for the experiments in 1973 with high water velocities in the cylindrical drum. All experiments run for 12 hours

Place and date	Initial no. of larvae 5*	6	7	Water Velocity at outer edge of each ring 4*	5	6	7
Ragged Falls							
August 10	17	39	27	140.32	175.41	210.49	245.57
11	22	46	19	133.20	166.50	199.81	233.11
12	23	36	26	133.70	166.50	199.81	233.11
13	15	28	25	133.20	166.50	199.81	233.11
14	21	24	10	152.95	190.01	228.08	266.09
15	11	18	9	29.87	37.34	44.81	52.28
Costello Creek							
August 23	27	30	27	18.43	23.04	22.65	32.25
25	23	20	18	40.83	51.04	61.25	71.46
26	24	13	23	29.52	36.90	44.28	51.66
27	28	19	17	15.40	19.25	23.10	26.95
Bog Outlet Stream							
Sept. 11	29	39	31	153.31	191.64	229.96	268.29
12	21	19	26	139.91	174.88	209.86	244.84
13	15	20	19	127.76	159.70	191.64	223.58
14	11	20	11	116.03	145.04	174.04	203.05
17	15	37	38	105.98	132.47	158.97	185.46
18	4	16	9	40.42	50.53	53.20	85.40

* ring number

Table 5

Range of water velocities across each ring at a given tachometer reading for 1973 experiments on water velocity thresholds with larvae in the cylindrical drum. Ring number in brackets.

A. Larvae from Ragged Falls

Velocity Range (cm/sec)	Tachometer Reading 11	27	29	30
20–50	(5) 29.9–37.3			
	(6) 37.3–44.8			
50–80	(7) 44.8–52.3			
140–170		(5) 133.2–166.5		
170–200		(6) 166.5–199.8	(5) 140.3–175.4	(5) 152.1–190.0
200–230			(6) 175.4–210.5	(6) 190.0–228.1
230–260		(7) 199.8–233.1	(5) 210.5–245.6	
260–290				(7) 228.1–266.1

Table 5 (cont'd)

B. Larvae from Costello Creek

elocity Range (cm/sec)	Tachometer Reading 12	14	16	18	20	22	24	26	28
0-50	(5) 27.6-34.5								
	(6) 34.5-41.4								
	(7) 41.4-48.4								
50-80		(5) 51.9-64.9							
		(6) 64.9-77.9							
		(7) 77.9-90.9	(5) 68.7-85.9	(5) 82.1-102.6					
			(6) 85.9-103.0						
110-140			(7) 103.0-120.2	(6) 102.6-123.1	(5) 96.3-120.4	(5) 107.6-134.0			
140-170				(7) 123.1-143.6	(6) 120.4-144.4	(6) 134.0-160.8	(5) 119.6-149.7		
					(7) 144.4-168.5				
170-200						(7) 170.8-187.6	(6) 149.7-179.6	(5) 137.3-171.7	
200-230							(7) 179.6-209.5	(6) 171.7-206.0	(5) 158.3-197.8
230-260								(7) 206.0-240.3	(6) 197.8-237.4
260-290									(7) 237.4-277.0

Table 5 (cont'd)

C. Larvae from Bog Outlet Stream

Velocity Range (cm/sec)	Tachometer Reading 12	23	24	26	28	30
50-80	(5) 40.4-50.5					
	(6) 50.5-73.2					
80-110	(7) 73.2-85.4					
110-140		(5) 106.0-132.5				
140-170		(6) 132.5-159.0	(5) 116.0-145.0	(5) 127.8-159.7		
170-200		(7) 159.0-185.5	(6) 145.0-174.0	(6) 159.7-191.6	(5) 139.9-174.9	(50 153.3-191.6
200-230			(7) 174.0-203.1	(7) 191.6-223.6	(6) 174.9-209.9	(6) 191.6-230.0
230-260					(7) 209.9-249.9	
260-290						(7) 230.0-268.3

Table 6

Means of percentages (with standard errors) of larvae remaining after certain time in different range of water velocity during the 1973 drum experiments corresponding to test figures.

* only one experiment instead of the usual two or more.

		Time (hours)					
		2		8		12	
Water Velocity cm/sec	Figure in text	Mean	SE±	Mean	SE±	Mean	SE±
	Ragged Falls						
20-50	14	102.78	2.78	101.01	10.10	99.25	17.43
110-140		*111.11		77.78		77.78	
140-170		86.66	0.30	86.76	4.15	67.20	23.72
170-200		65.83	4.84	52.59	6.17	10.83	5.41
200-230		95.03	7.53	77.41	14.91	70.19	11.86
230-260		78.58	11.92	45.71	4.08	6.63	3.83
260-290		*100.00		90.00		100.00	
	Costello Creek						
20-50	15	88.44	8.86	12.49	7.21	11.08	6.40
50-80		87.50	2.30	77.94	6.50	77.94	6.50
80-110		85.35	8.05	73.64	10.44	67.25	9.32
110-140		95.56	2.62	86.38	5.21	84.11	6.12
140-170		65.30	8.95	46.36	9.36	42.95	8.92
170-200		49.80	14.19	23.77	10.70	11.43	2.28
200-230		47.97	11.04	27.17	16.35	8.93	5.80
230-260		15.98	7.28	0.80	0.80	0	0
*260-290		*11.24		0.53		0	
	Bog Outlet Stream						
50-80	16	118.75	31.25	112.5	53.03	55.39	39.17
*80-110		*77.78		66.67			66.67
*110-140		*33.33		13.33		6.67	
140-170		40.59	8.05	13.12	7.09	13.12	7.09
170-200		39.87	7.79	11.39	2.24	8.12	2.20
200-230		21.45	3.29	1.32	1.32	1.32	1.32
*230-260		*7.69		3.85		0	
*260-290		*22.58		3.23		0	

Table 7

Number and percentage of immature and mature larvae (and pupae) of different species at the end of 1973 experiments, in the cylindrical drum testing larvae from three streams for upper and lower water velocity thresholds.

Species	Larvae Immature		Larvae Mature		Pupae		
Place and date	#	%	#	%	#	%	Total
Costello Creek (June 8-23)							
S. venustum/verecundum	36	11.36	55	17.35	4	1.26	29.97
S. vittatum	117	36.91	80	25.24			62.15
S. tuberosum A	1	.32					.32
S. decorum	2	.63	3	.95			1.58
S. latipes	13	4.10	4	1.26			5.36
S. croxtoni	2	.63					.63
Bog Outlet (August 24-September 2)							
S. venustum/verecundum	154	91.12	11	6.51			97.63
S. vittatum	2	1.18	2	1.18			2.37
Ragged Falls (August 10-15)							
S. longistylatum	129	87.55	18	12.24			100.

Table 10

Means of percentages (with standard errors) of larvae remaining after a certain time in different ranges of high water velocity during the 1974 drum experiments corresponding to test figures, Long = S. longistylatum, Dec = S. decorum, Tub A and B, = S. tuberosum A and B, V/V = S. venustum/verecundum. L = large, M = mature, S - small, VS = very small, RF = Ragged Falls, MR - North Madawaska River CC = Costello Creek, BO = Bog Outlet Stream

* only one experiment instead of the usual two or more

Species	Larval stage	Place	Figure	Velocity range cm/sec	Means and Standard error at certain times (in hours) 2 Mean %	2 SE±	8 Mean %	8 SE±
Long	L	RF	18a	*200-230	90.0		80.0	
				*230-260	105.5		83.3	
				260-290	91.2	8.80	78.9	7.55
				*290-305	93.8		100.0	
Long	VS	RF	18b	*200-230	56.3		56.3	
				*230-260	25.0		10.0	
				260-290	66.5	8.30	25.2	23.6
				*290-305	45.5		18.0	
Long	S	RF	18c	*200-230	100.0		105.0	
				*230-260	73.9		47.8	
				260-290	75.4	6.70	66.3	1.85
				*290-305	75.0		75.0	
Dec	L	MR	19	170-200	100.0	11.45	77.5	14.05
				200-230	75.2	15.80	73.8	9.45
				*230-260	100.0		93.8	
				260-290	69.5	5.98	46.2	9.62
				*290-305	78.6		23.8	
Dec	S	MR	19b	170-200	76.3	11.75	70.6	7.85
				200-230	90.6	2.80	81.4	18.05
				*230-260	100.0		100.0	
				260-290	106.2	6.91	90.0	5.23
				*290-305	93.3		100.0	
Dec	M	MR	19c	170-200	71.3	2.35	78.3	11.50
				200-230	67.1	0.85	57.8	14.65
				*230-260	95.0		70.0	
				260-290	65.3	6.83	53.7	8.78
				*290-305	36.7		42.9	

Table 10 cont'd

Species	Larval Stage	Place	Figure	Velocity range cm/sec	Means and Standard error at certain times (in hours) 2 Mean %	2 SE±	8 Mean %	8 SE±
Long	L	RF	20a	200-230	90.2	20.25	80.9	10.70
				*230-260	105.6		83.3	
				260-290	87.1	5.48	79.1	4.89
				290-320	84.5	9.15	78.1	9.35
Tub A	L	RF	20b	200-230	99.2	5.30	98.7	27.45
				*230-260	90.0		80.0	
				260-290	85.7	1.66	82.6	7.05
				290-320	78.6	3.25	72.5	5.95
Tub B	L	RF	20c	200-230	90.3	3.10	87.2	3.10
				*230-260	105.5		100.0	
				260-290	81.7	10.64	77.8	13.71
				290-320	83.2	11.35	80.1	13.71
Dec	L	MR	21a	170-200	100.0	11.45	77.5	14.05
				200-230	75.1	15.80	73.7	9.45
				*230-260	100		93.8	
				260-290	69.6	5.98	46.2	9.62
				*290-320	27.5		24.1	
Tub A	L	MR	21b	170-200	110.1	2.45	94.0	5.45
				200-230	93.4	5.50	89.0	7.85
				*230-260	96.9		96.8	
				260-290	102.0	2.16	97.0	2.63
				*290-320	77.2		86.4	
Tub A	L	RF	22a	200-230	99.3	5.30	99.3	5.30
				*230-260	90.0	-	90.0	
				260-290	85.6	1.66	82.7	7.05
				290-320	78.8	3.25	72.6	5.95
Tub A	L	MR	22b	200-230	25.8	9.10	89.2	8.75
				*230-260	96.8		96.8	
				260-290	102.2	2.47	96.7	3.03
				290-320	81.0	3.85	85.5	5.45
V/V	L	CC	23	*110-140	100.0		102.9	
				140-170	100.0	0.00	98.3	1.35
				170-200	98.2	8.09	86.5	5.91
				*200-230	77.4		71.0	
				230-260	49.0	10.40	21.4	11.8
				*260-290	30.3		12.1	

Table 10 cont'd

Species	Larval stage	Place	Figure	Velocity range cm/sec	Means and Standard error at certain times (in hours) 2 Mean %	2 SE±	8 Mean %	8 SE±
V/V	L	BO	23b	*110-140	94.1		102.9	
				140-170	100.1	3.25	103.3	0.65
				170-200	93.3	3.22	83.2	0.61
				*200-230	87.0		82.6	
				230-260	45.7	11.15	28.1	13.15
				*260-290	20.0		6.7	

Table 11

Number and mean length of larvae in each stage grouping used in the cylindrical-drum experiments testing upper and lower water velocity threshold from June to August 1974. Note: RF = Ragged Falls, NMR - North Madawaska River, BOS = Bog Outlet Stream, CC = Costello Creek, L - *S. longistylatum*, T_A and T_B = *S. tuberosum A and B*, D = *S. decorum*, V/V = *S. venustum/verecundum*, VIT = *S. vittatum*, U = *undetermined*.

Date	Place	Species	Maturity: IM Total no. of larvae	IM Average length (mm)	IMLH Total no. of larvae	IMLH Average length (mm)	MAT Total no. of larvae	MAT Average length (mm)
13-22 VI	RF	L	44	8.20	6	9.83	9	8.94
12-14 VII	RF	L	50	6.70				
16-19 VII	RF	L	8	3.81				
20-23 VII	RF	L	29	3.40				
25-28 VII	RF	L	4	3.50				
29-31 VII	RF	L	112	4.52				
		T_A	18	2.89				
3-4 VIII	NMR	D	35	6.73	23	7.35	34	8.16
		T_A	1	4.50				
		VIT	1	3.50				
		U	65	7.15				
5-6	NMR	E	12	7.58	6	7.83	15	7.78
7-11 VIII	NMR	D	57	5.20				
		T_A	7	4.43	1	5.00		
12-14 VIII	RF	T_B	23	4.20			23	5.04
14-16 VIII	NMR	T_A	4	3.88	10	4.90	39	5.06
		U	2	4.00				
16-17 VIII	RF	L	45	7.70				
		U	2	4.50				
18-20 VIII	RF	T_B	16	5.76	12	3.83	8	4.31
20-21 VIII	CC	V/V	61	4.57	19	5.29	27	5.30
		U	1	4.00				
21-22 VIII	BOS	V/V	118	5.53	6	5.33	1	5.05
22-23 VIII	NMR	D	138	4.80				

Figure 12. The predicted (calculated) O---------O and actual (measured) ●———● water velocities (Y in cm/sec) at the periphery of the drum at low paddle speeds (X in rpm). Equations: Predicted Y = 0.0063819+2.9326X and measured Y = -5.3277+1.9752X.

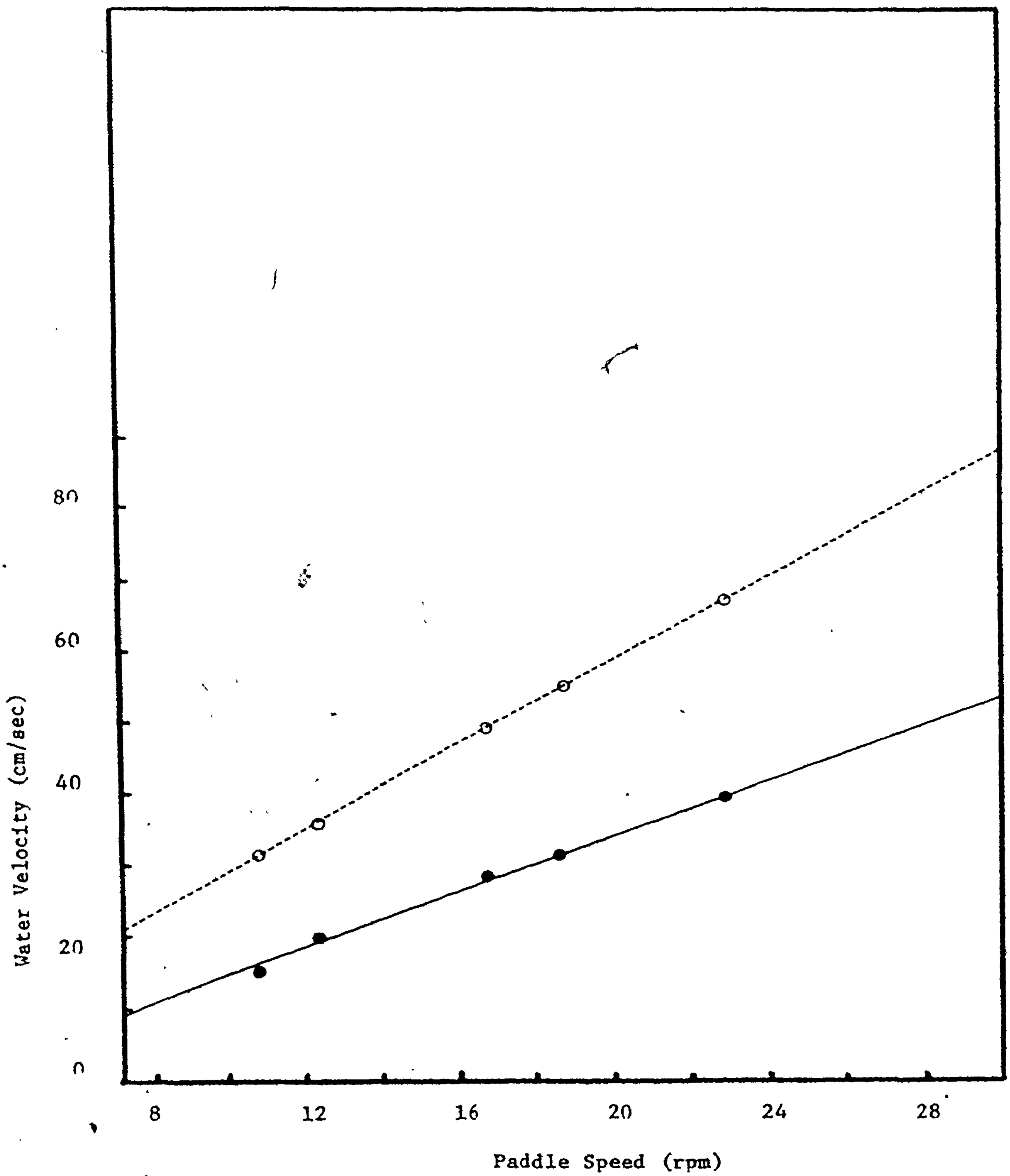

80
60
40
20
0
Water Velocity (cm/sec)
8
12
16
20
24
28
Paddle Speed (rpm)

Figure 13. The predicted (calculated) o-------o and actual (measured) ●———● water velocities (Y in cm/sec) at the periphery of the drum at high paddle speeds (X in rpm). Equations: Predicted Y = 0.0000897+2.93241X and measured Y= 0.93757+1.8566X

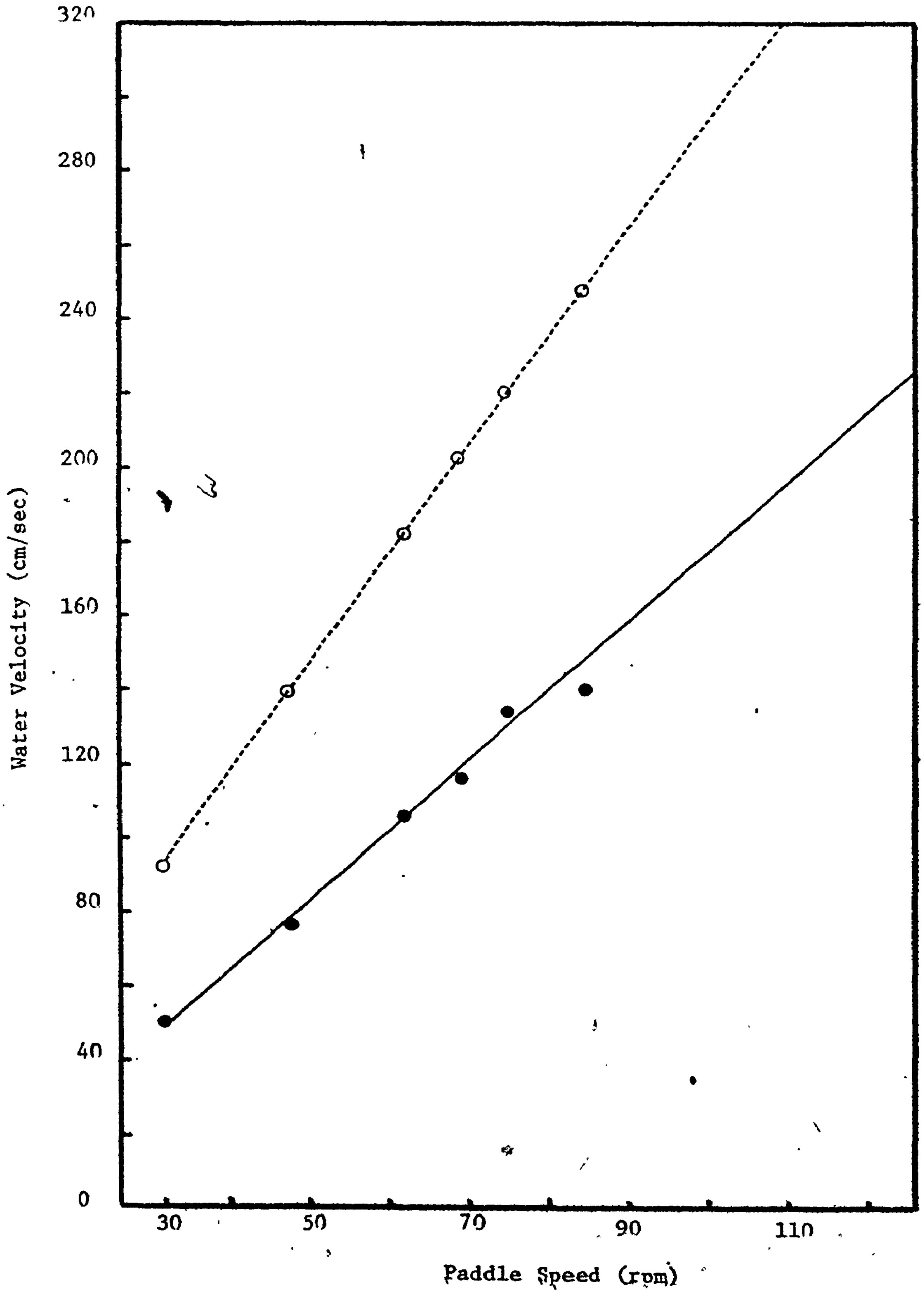

320
280
240
200
160
120
80
40
0
Water Velocity (cm/sec)
30
50
70
90
110
Paddle Speed (rpm)

Figure 14 . The ability of larvae from Ragged Falls in 1973 to withstand different water velocities in a cylindrical drum over a period of 12 hours. The number of experiments for each velocity range are shown at the right of each symbol.

▲ ———————— ▲	2	20-50 cm/sec
△ - - - - - - - △	1	50-80 cm/sec
● ——————●	1	140-170 cm/sec
○ ············ ○	3	170-200 cm/sec
▼ ———————— ▼	2	200-230 cm/sec
▽ - - - - - - ▽	3	230-260 cm/sec
◆ ———————— ◆	1	260-290 cm/sec

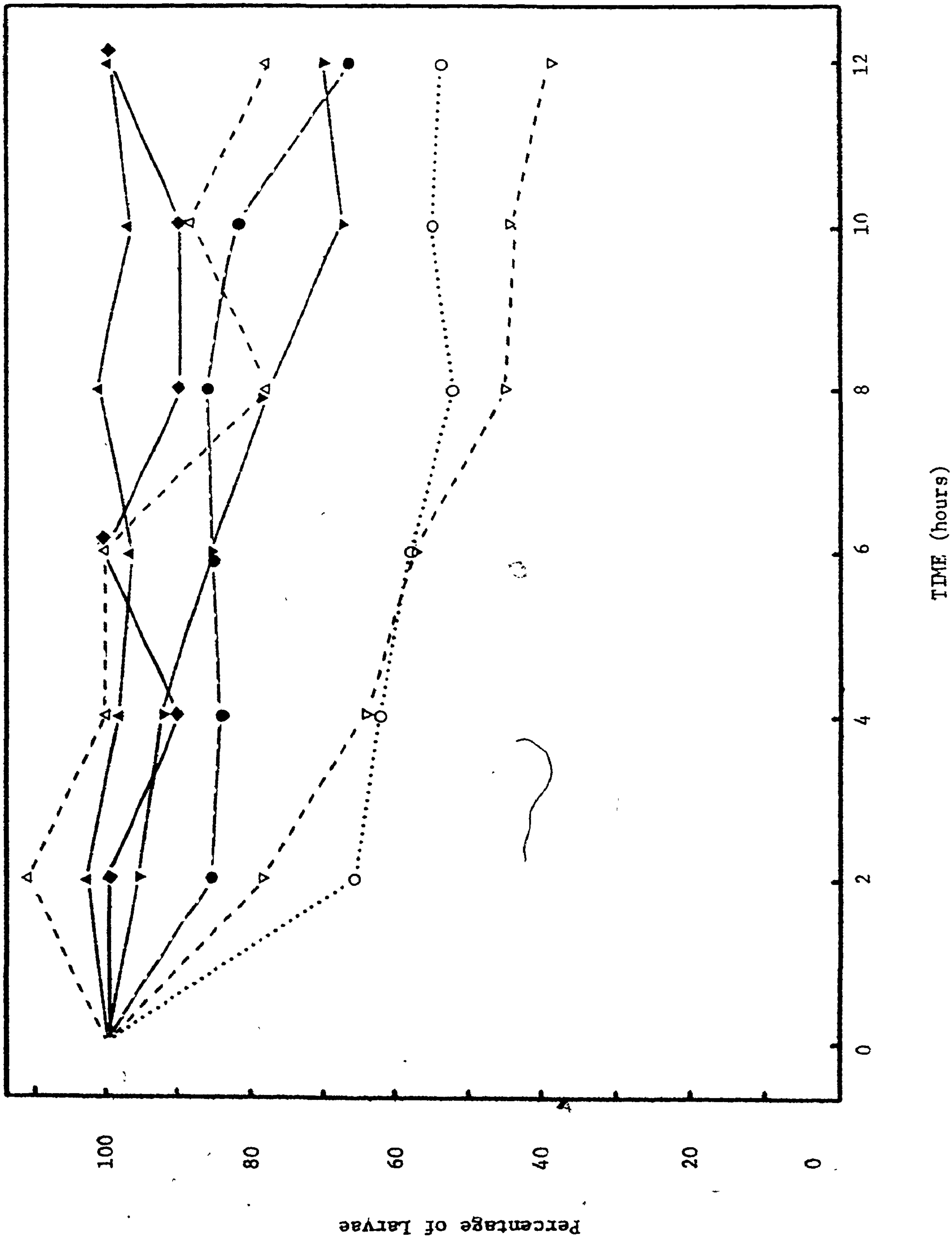

TIME (hours)
0
2
4
6
8
10
12
Percentage of Larvae
0
20
40
60
80
100

Figure 15. The ability of larvae from Costello Creek in 1973 to withstand different water velocities in a cylindrical drum over a period of 12 hours. The number of experiments for each velocity range are shown at the right of each symbol.

▲———▲	3	20–50 cm/sec
△ - - - - - - - △	2	50–80 cm/sec
■———■	4	80–110 cm/sec
□ -------------- □	4	110–140 cm/sec
● —— —— —— ●	5	140–170 cm/sec
○ ·············· ○	3	170–200 cm/sec
▼———▼	3	200–230 cm/sec
▽ - - - - - - - ▽	2	230–260 cm/sec
◆———◆	1	260–290 cm/sec

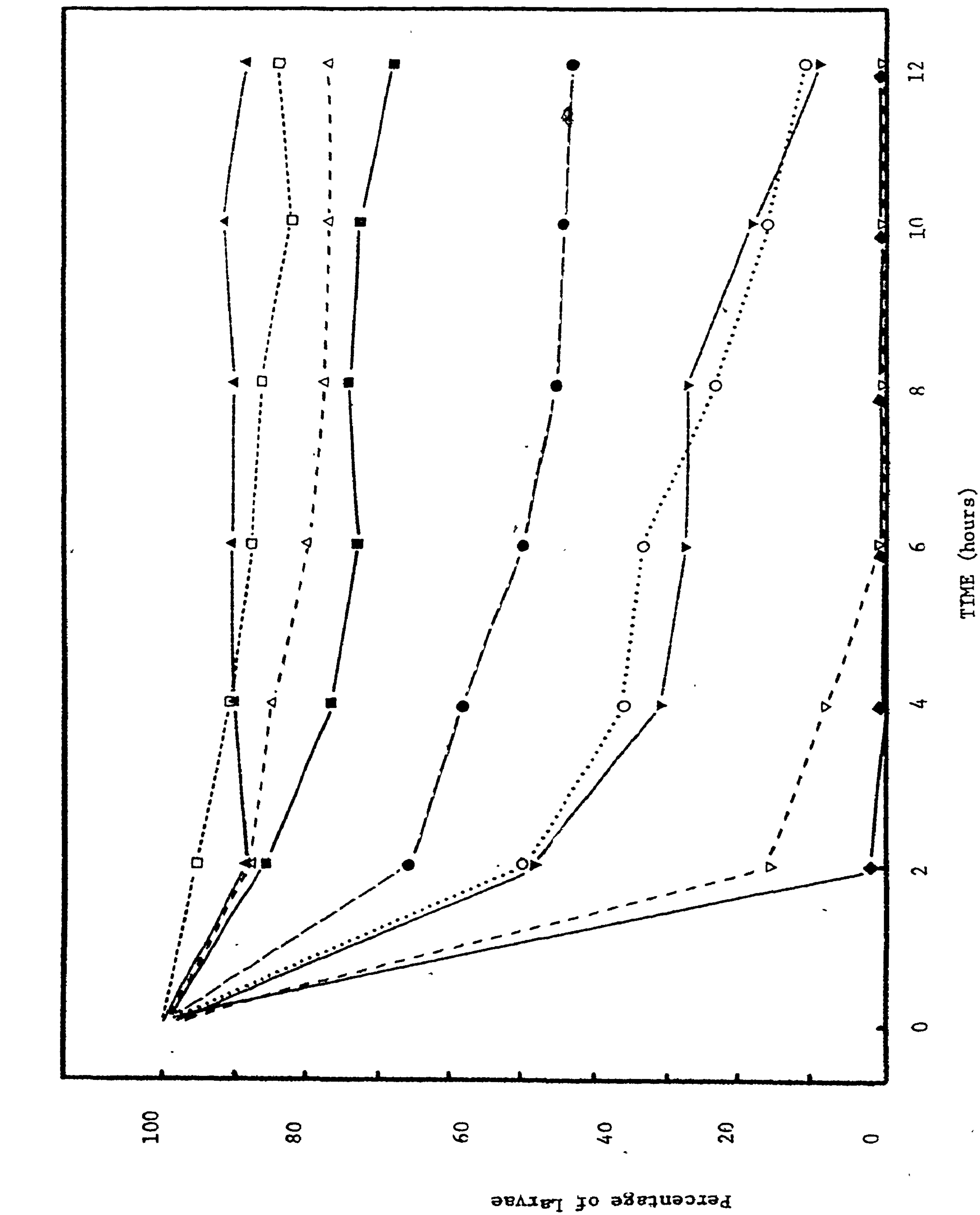

Percentage of Larvae
100
80
60
40
20
0
TIME (hours)
0
2
4
6
8
10
12

Figure 16. The ability of larvae from Bog Outlet Stream in 1973 to withstand different water velocities in a cylindrical drum over a period of 12 hours. The number of experiments for each velocity range are shown at the right of each symbol.

△ - - - - - - - △	2	50-80 cm/sec
■ ——————— ■	1	80-110 cm/sec
□ ··············· □	1	110-140 cm/sec
● — — — — — ●	3	140-170 cm/sec
○ ············· ○	6	170-200 cm/sec
▼ ——————— ▼	5	200-230 cm/sec
▽ - - - - - - ▽	1	230-260 cm/sec
◆ ——————— ◆	1	260-290 cm/sec

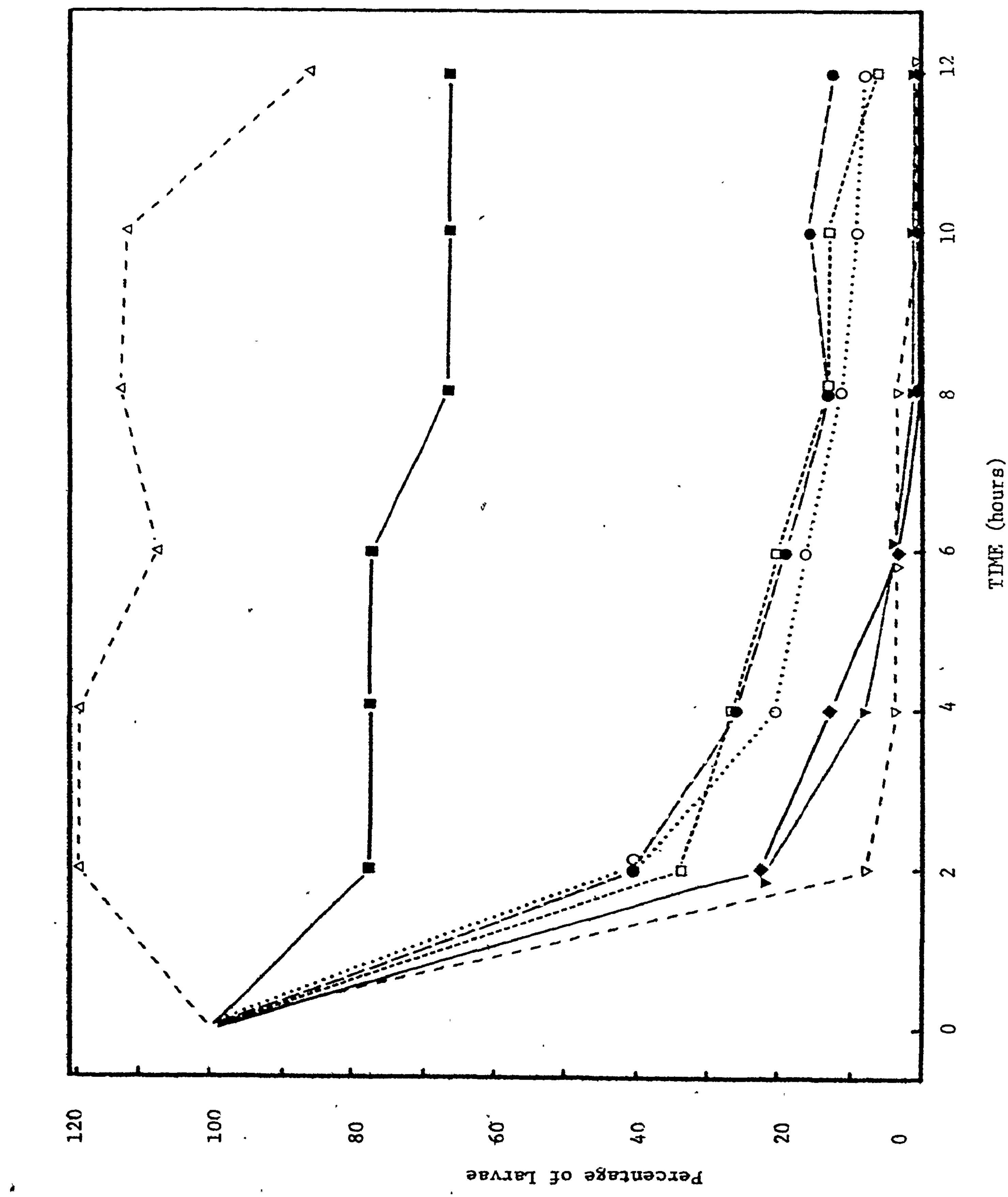

Percentage of Larvae
0
20
40
60
80
100
120
TIME (hours)
0
2
4
6
8
10
12

Figure 17. The ability of larvae from 3 different streams in 1973 to withstand high water velocities. Only results from experiments in which tests were run for similar water velocities (i.e. 50-80 cm/sec and 140-290 cm/sec) are combined.

▲ --------------▲ Ragged Falls

■ ———————— ■ Costello Creek

● - - - - - - ● Bog Outlet Stream

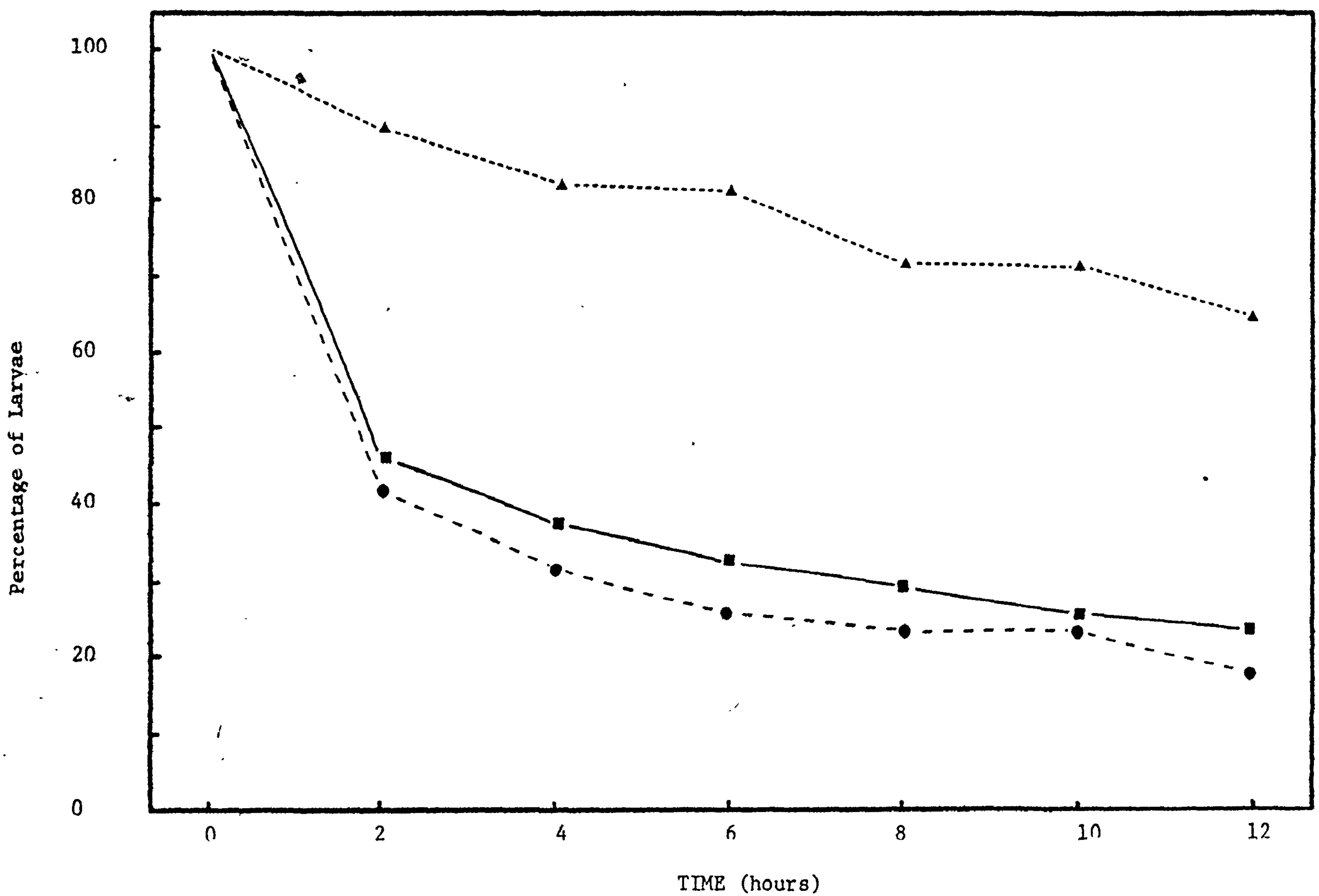

Percentage of Larvae
100
80
60
40
20
0
0
2
4
6
8
10
12
TIME (hours)

Figure 18 a–c. The ability of larvae of <u>S</u>. <u>longistylatum</u> from Ragged Falls to withstand different water velocities in a cylindrical drum. Results of only those experiments in 1974 with tachometer readings of 26 and 28 were averaged.

□ -------------- □	200–230 cm/sec
● — — — — — — ●	230–260 cm/sec
○ ············· ○	260–290 cm/sec
▲ ———————— ▲	290–305 cm/sec

a) Large larvae

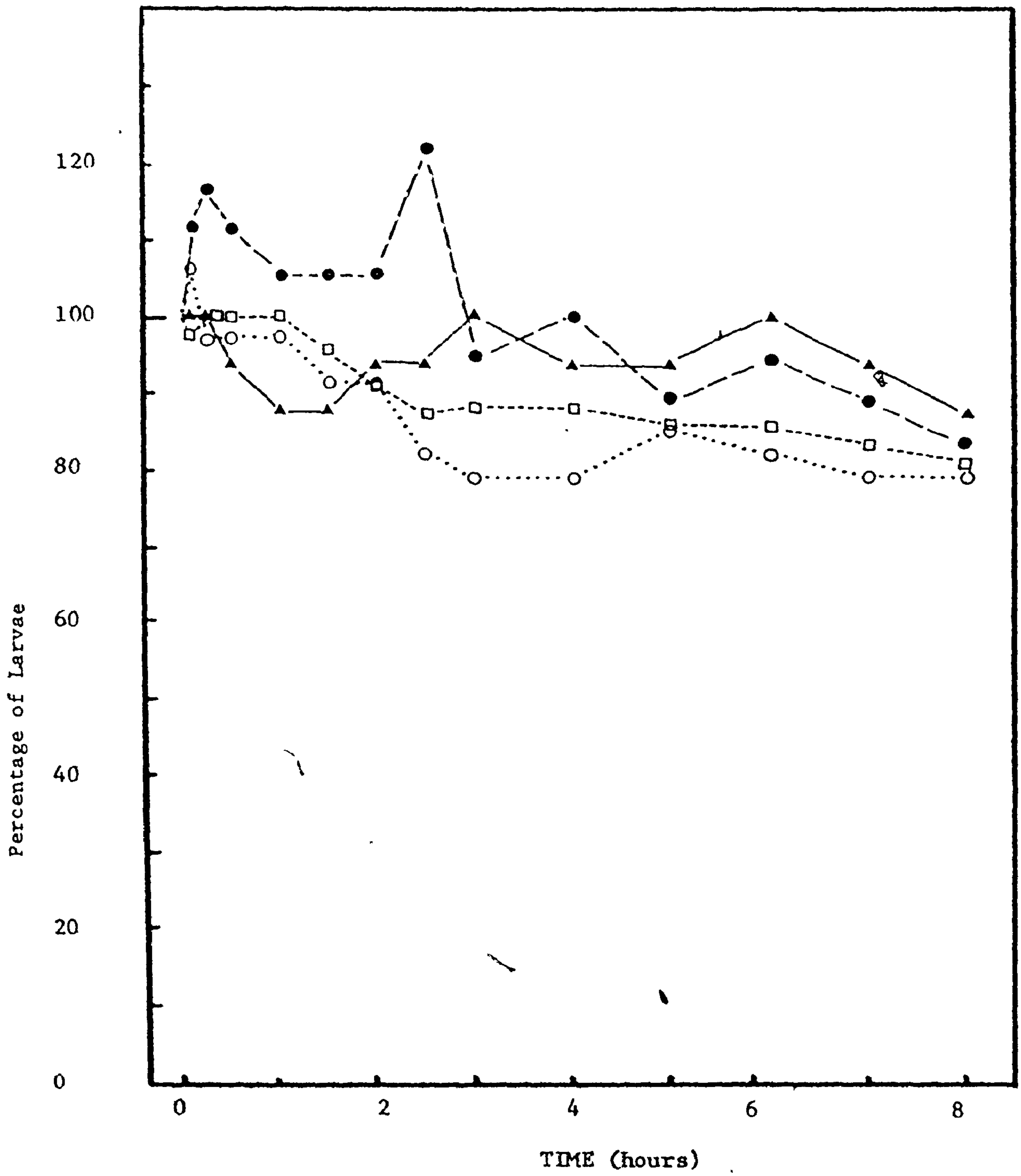
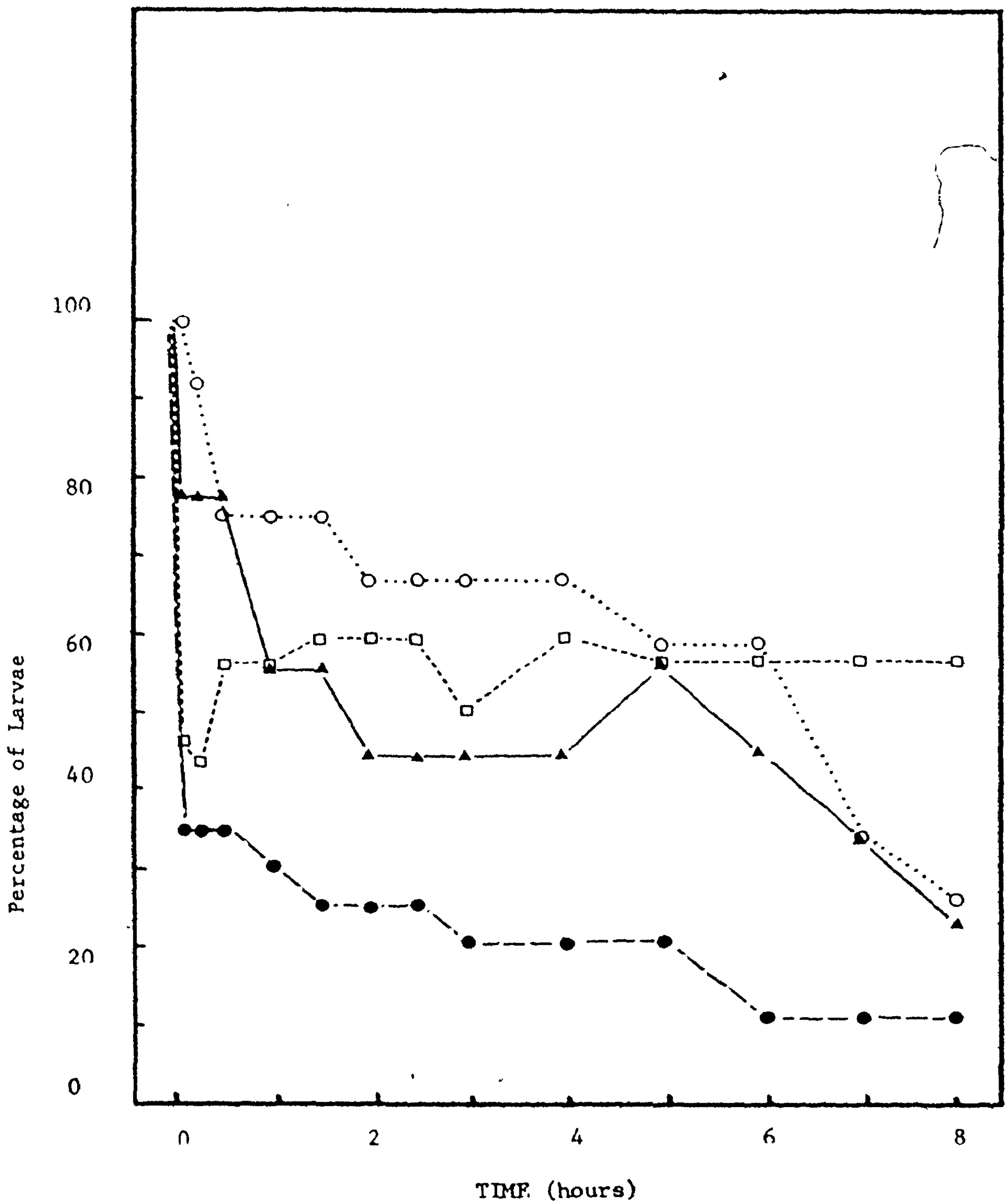

120
100
80
60
40
20
0
Percentage of Larvae
0
2
4
6
8
TIME (hours)

Figure 18 a-c. (cont'd)

b) Very small larvae


100
80
60
40
20
0
Percentage of Larvae
0
2
4
6
8
TIMF (hours)