# AN ECOLOGICAL STUDY OF THE TADPOLE MADTOM *NOTURUS GYRINUS* (MITCHELL), WITH SPECIAL REFERENCE TO MOVEMENTS AND POPULATION FLUCTUATIONS

A Thesis

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ABSTRACT

Movements and population fluctuations of the tadpole madtom, Noturus gyrinus, in the Rat River, Manitoba were investigated during two consecutive summer sampling periods. Madtoms were found exclusively in aquatic vegetation, and the scarcity of this type of habitat in the Rat River apparently restricted both movements and distribution. Population levels were greatly decreased by drought in 1967 which caused severe habitat dessication in the late summer, resulting in heavy mortality of young-of-year and adults. This mortality was reflected by low 1968 population levels. Minor fluctuations in population levels within each sampling period were probably a reflection of short-distance movements in the vicinity of each sampling station and possibly from sampling error. Laboratory and field fin-clipping experiments did not reveal adverse effects on any specimens from the marking method.

Madtoms apparently overwinter in the Rat River near their summer habitat. Specimens held in the laboratory were able to tolerate water temperatures approaching $0^{\circ}C$. with no apparent adverse effects.

Main food items in madtom stomachs examined were Hyalella azteca and mature and immature insects, chiefly chironomid larvae and other dipterans. In the laboratory no feeding occurred at water temperatures of less than $3.5^{\circ}C$.

There was no evidence of predation on N. gyrinus

in either laboratory or field situations. A toxin associated with its pectoral and dorsal spines, when injected into *Stizostedium canadense*, *Salmo gairdneri* and *Esox lucius* incapacitated them almost immediately. This toxin was probably an effective defence mechanism.

# ACKNOWLEDGMENTS

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# INTRODUCTION

The tadpole madtom, *Noturus gyrinus* (Mitchell), is a small species of freshwater catfish, rarely exceeding 100 mm. in total length. It is best distinguished from other members of the genus *Noturus* in the fewer rays of its paired fins, broad lateral extension of its premaxillary tooth patch, wide caudal fin, and lack of serrae or barbs on the posterior edge of its pectoral spines (Taylor, 1956).

The species is generally found in slow-moving waters of rivers or lakes in regions of heavy growth of aquatic vegetation. In Manitoba, collection records are generally confined to southern regions of the province. It has been collected infrequently from the Assiniboine and Red Rivers as well as from tributaries of the Red, primarily the Sale and Rat Rivers. One collection record for central Lake Winnipeg was reported (Keleher, 1952).

The purpose of this study was to investigate some aspects of the ecology of *N. gyrinus*. The primary goals were to determine if any movements or migrations occur within the study area, since the Rat River distribution appeared to be localized (Stewart, per. comm.), and to determine population levels and fluctuations during the two summer sampling periods. Secondary considerations investigated were food habits, breeding habits and life history, predation, and effects of toxin. Little published data are available on these aspects of tadpole madtom biology, with the exception of food habits.

## LITERATURE REVIEW

Taylor (1956) gives a synonomy of Noturus gyrinus and compiled a bibliography of the species to that date in his primarily systematic review and revision of the species Noturus.

### Fin-clipping for Determination of Movements and Population Levels. Its Effects on Fishes

Fin-clipping has been used extensively as a method of marking in experiments to determine both movements and population sizes of fishes. Ball (1944) used this method of marking in a study of movements of several fish species, including the yellow bullhead (Ictalurus natalis) in Third Sister Lake, Michigan. In a check of the fin-clipping method of marking for estimating fish population sizes of Lake Senachwine, Illinois, Krumholz (1944) found that the estimate obtained from netting and fin-clipping operations was very close to that obtained from poisoning the lake.

Some disadvantages to fin-clipping exist. Ricker (1949) showed that survival rate of fingerling largemouth bass (Micropterus salmoides) decreased as a result of fin-clipping. This effect was more evident if two or more fins were removed in this species and in the yellow perch (Perca flavescens). Shetter (1951) found that removal of pectoral fins in fingerling lake trout (Salvelinus namaycush) resulted in higher mortality. Another disadvantage of fin-clipping, as with other marking methods, is the possibility of behavioural differences resulting from handling and marking procedures, which may be difficult to detect. Gerking (1950) cautioned against overlooking the possibility that fin-clipping affects movements or migrations from one area to another. One further disadvantage is that movements of individual fish cannot be tracked as they can with marks such as the numbered Peterson tag.

However, the disadvantages of fin-clipping are outweighed by the advantages. Generally there is low mortality. Ricker (1949) states that it has no immediately fatal effects upon either large or small fishes of the kinds most frequently used in marking experiments, chiefly salmonids and centrachids. The fin-clipping procedure is simple, and marked recaptures are easily identifiable. Ball (1944) found that even in cases where fin regeneration had occurred in recaptures, it was recognizeable by malformation of the regenerated fin. Ricker (1958) claimed that pectoral fins of several species, including ictalurids, did not regenerate at all, and pelvic fins only rarely when clipped at the base. In addition, fin-clipping leaves no external projections (such as disk tags) which could impede movement in a stream or become entangled with vegetation.

Movements in Streams and Lakes

Several experiments have indicated limited or restricted movements of stream fishes.

Gerking (1950) stated that if a fish population is stable, it must be able to withstand environmental stress without disrupting its composition. He then presented a strong case for stability of location of a stream fish population [golden redhorse sucker (*Moxostoma erythrurum*), hog sucker (*Hypentelium nigricans*) spotted sucker (*Minytrema melanops*), longear sunfish (*Lepomis megalotis*) green sunfish (*L. cyanellis*), rock bass (*Ambloplites rupestris*), spotted bass (*Micropterus punctulatus*), and smallmouth bass (*M. dolomieui*)] by showing that seventy-five per cent of the fish were found in their original location following an unusually violent summer flash flood which increased the normal flow of the river by more than three-fold.

Crossman (1956) demonstrated from recapture data that muskellunge (*Esox masquinongy*) moved very little in the summer, since numerous fish were caught several times at the site of marking, and very few fish were caught in the summer at a site other than where marked in Nogies Creek, Ontario.

Funk's (1955) study of movements of stream fishes in Missouri showed that all species studied had high proportions of sedentary individuals in the summer, including the channel catfish (*Ictalurus punctatus*), flathead catfish (*Pilodictis olivaris*), and yellow bullhead (*Ictalurus natalis*). He pointed out, however, that if most of the sampling is done in limited areas near release sites a strong bias in favor of restricted movements is introduced, and that all water accessible to the fish should be sampled with equal intensity.

Ball (1944) and Shoemaker (1952) found that a large percentage of yellow bullheads (I. natalis) were recaptured in the same sites as tagged; Ball recaptured some tagged individuals several times in the same area, in Third Sister Lake, Michigan and used this is a criterion of a tendency to remain in a limited area for considerable periods of time.

Holton (1953) compared number of recaptures to total sample size (percent recapture or recapture rate) for each individual inventory as an indication of population stability, or extent to which trout remained in one area in a small Montana creek.

McCleave (1964) stated that recapture of many marked sculpins within a restricted area would demonstrate limited movement. Both McCleave and Holton reported a decrease in rate of recapture from census to census. McCleave attributed this decrease to mortality from shocking procedures.

In all marking experiments, the method of capture, handling, and identifying the fish may affect subsequent behaviour of the fish (Gerking, 1959). Stefanich (1952) stated that disturbance of fish at time of sampling and marking may cause the fish to move out of the section sampled, and mortality resulting from handling and marking may reduce total numbers.

## Population Sizes (Levels of Abundance)

Several assumptions must be made in using mark-recapture data for population inventories such as the Peterson and Schumacher estimates, and the Schnabel multiple census (Ricker, 1958).

DeLury (1958) stated that the assumptions which must be made for both Schumacher and Schnabel census are:

(i) that the population does not change in size during the sampling i.e. mortality and recruitment negligible, and all samples returned to the population.

(ii) that animals are sampled at random from the population.

Bailey (1952) added to these the assumptions that marked and unmarked animals have the same likelihood of being caught.

Thus three possible sources of error in marking experiments are that

(1) the population estimate will be too high if a number of marked fish die (or move) as a result of marking.

(2) the population estimate will be too low if marked fish are more likely to be caught than unmarked fish (DeLury, 1947).

(3) population estimate too high if both marked and unmarked die or leave area at random.

DeLury (1947) stated that population estimates based on recapture of marked fish have very large sampling errors, since each estimate is based on a very small number of recaptures.

Harrison (1953) found tagging to be of little value in making stream inventories of the channel catfish *Ictalurus lacustris* since returns were only about 3.5 per cent of marks.

Catch per unit effort, or C/f, is defined as the catch of fish, in numbers or in weight, taken by a defined unit of fishing effort (Ricker, 1958). DeLury defined C/f for a given time period (t) as number of fish caught, c(t), divided by number of seine hauls, e(t). His assumptions were that catchability is constant and that the population is either constant, gradually lowering due to natural mortality, or becoming greater due to recruitment.

C/f should indicate relative abundance of fish, but may be somewhat distorted by several factors. These include changes in catchability of the fish from year to year due to differences in their distribution or behaviour, variations in deployment of the fishing apparatus, or its variable effectiveness because of weather conditions (Ricker, 1958).

Taylor (1956) noted that *Noturus gyrinus* is particularly abundant in lakes and their outlets, sloughs, ponds, quiet backwaters and in the oxbows and base-level outlets of streams. Their apparent preference for weedy habitats has been reported by Bailey (1938), Dymond (1947), Evermann and Clark (1920), Hankinson(1908), Hubbs and Lagler (1964), and

Raney (1950). Hay (1894) reported finding the species under stones and logs in streams.

There have been several studies of food habits of N. gyrinus: Evermann and Clark (1920), Forbes (1888), Hankinson(1908), Pearse (1915, 1918), and Sibley (1932). Food items consisted chiefly of both larval and adult insects and crustaceans, occasional small fish, and small amounts of vegetable fibre and algae.

Noturus gyrinus has been variously described as spawning from May to July. Very few observations of egg clusters have been reported. Brief notes on breeding habits recorded by Bailey (1938), Evermann and Clark (1920), Forbes and Richardson (1909), Hankinson(1908), Raney (1950, Richardson (1913), and Wright and Allen as cited in Adams and Hankinson(1928) are summarized in Table I.

Little information is available on the life history of N. gyrinus other than the preceeding on spawning, habitat, and food. Evermann and Clark (1920) reported capturing the species during winter raking operations in Chara beds of an Indiana lake. One species of catfish, the brown bullhead (Ictalurus nebulosus) was observed buried in the substrate under laboratory water temperatures of 0-18°C. (Loeb, 1963).

From vertebral ring counts and length-frequency data, Hooper (1949) found three distinct size and age groups of N. gyrinus in Demming Lake, Minnesota, from a large sample

TABLE I: Observations of breeding habits of N. gyrinus.

| AUTHOR | LOCATION | Stated Spawning Time | Actual Nest Obser-vations | REMARKS |
|---|---|---|---|---|
| Bailey (1938) | New Hampshire | -- | June 14 | 86 mm. ♂ guarding 117 eggs in beer can; eggs adhering to one another in compact mass; eggs 3.5 mm. diameter. |
| Evermann & Clark (1920) | Lake Maxin-kuckee, Indiana | June & July | -- | May 18 = ♀ distended with 50 eggs. July 10 = ♀ distended with 93 eggs. All others in July spent or immature. |
| Forbes & Richard-son (1909) | Illinois | May (probably) | -- | ♂'s & ♀'s taken June 8 already spent. |
| Hankinson (1908) | Southern Michigan | -- | June 26 | 2 3/8" long specimen guarding cluster of eggs in old tin can. |
| Raney (1950) | Virginia | late June | | Eggs are laid in late June in a clump under a stone or board, and in old tin cans. |
| Richard-son (1913) | Illinois | | -- | July 1, 1910; ♀ full of nearly ripe eggs. |
| Wright & Allen (1913) as cited in Adams & Hankinson (1928) | Ithaca, N.Y. | May - July 1 | -- | Nest under boards, in cans, under crockery. |

collected August 15, 1945. The groups were as follows: Year 0 young-of-year (15-35 mm.), I (43-85 mm.) and II (78-104 mm.). No growth studies have been undertaken on *N. gyrinus*. However, a study of the margined madtom (*N. insignis*), a slightly larger species than *N. gyrinus*, revealed that most growth takes place between June and September (Clugston and Cooper, 1960).

Few instances of natural predation on *N. gyrinus* have been reported; predation by rock bass (*Ambloplites rupestris*) reported by Evermann and Clark (1920), and one instance of predation by a snake, found near a fish rearing station with a 3.25" madtom in its stomach (Lagler and Salyer, 1945). Adams and Hankinson (1928) reported that *N. gyrinus* was valuable as bass bait in Lake Oneida, New York, due to its tenacity for life. Bean (1903) stated that it was in great demand for hook and line fishing, "especially in the capture of black bass (*Micropterus sp.*) for which it is one of the best baits known."

The tadpole madtom possesses poison glands at the base of its dorsal and pectoral spines, and has frequently been reported as producing a painful sting when the fish is handled. Reed (1907) described the histology and mechanics of operation of these glands. He termed the sting produced by injury from a pectoral or dorsal spine as like that of a bee, while Evermann (M.S.) as cited in Reed (1907) described it as "like that which would result from a severe nettle sting." No information pertaining to toxic effects on organisms other than man has been reported in the literature.

MATERIALS AND METHODS

## Physical Descriptions

### A. Description of Rat River Drainage Area

The Rat River, a tributary of the Red, drains 460 square miles of south-eastern Manitoba. The physiography ranges from swamp and sand plain at its south-east extremity to level lacustrine plain toward its convergence with the Red River. During its meandering course of 104 km. (65 miles) the average gradient is about seven feet per mile. The river bed composition varies greatly. The upper two-thirds include boulder, rubble, and gravel sections, associated with steep gradients where the stream descends strand lines of Glacial Lake Agassiz, as well as sand-silt sections. A transition to clay and silt substrate occurs on the lacustrine plain. No part of the Rat River watershed drains the Precambrian shield.

### B. Description of Study Area

The section of the Rat River chosen for study was situated 64 km. (40 miles) south-east of Winnipeg near the town of St. Malo. The study section was 72 km. (45 miles) from the source of the river and 32 km. (20 miles) from its convergence with the Red River. Physiographically it is in the transition zone between gently undulating till plain and level lacustrine plain. Natural terrestrial vegetation consists of wooded grassland near tall grass prairie; chiefly sandbar willow (*Salix interior*) and peach leaf willow

(S. amygdaloides) border the river.

Immediately upstream from the study area a dam was located, creating a reservoir approximately 0.7 square kilometers lying in the region of the original Rat River bed. The study section was situated on a 2.4 km. long section of the river with substrate ranging from silt and sand to sand and gravel in the main channel. Side channels were heavily silted. Approximately 160 meters downstream from the study area there was an abrupt change to clay and silt substrate at the border of the lacustrine plain.

(a) Physical Data

Data on St. Malo reservoir levels and Rat River water levels and discharge rates for 1967 and 1968 were obtained from the Federal Department of Energy, Mines and Resources, Inland Waters Branch. In addition, water levels and temperatures were recorded daily at three separate sampling areas during the 1968 sampling period. Fig. 1 compares rate of discharge of the Rat River for 1967 and 1968, indicating fluctuations between the two years. Readings were taken 1.1 km. below the St. Malo dam. Fig. 2 shows Rat River water level and temperature data for 1968 only. Plates 1 to 4 illustrate differences in water levels and flow rates for 1967 and 1968 at four sampling stations.

Fig. 1: Rate of discharge of Rat River, 1967 - 1968

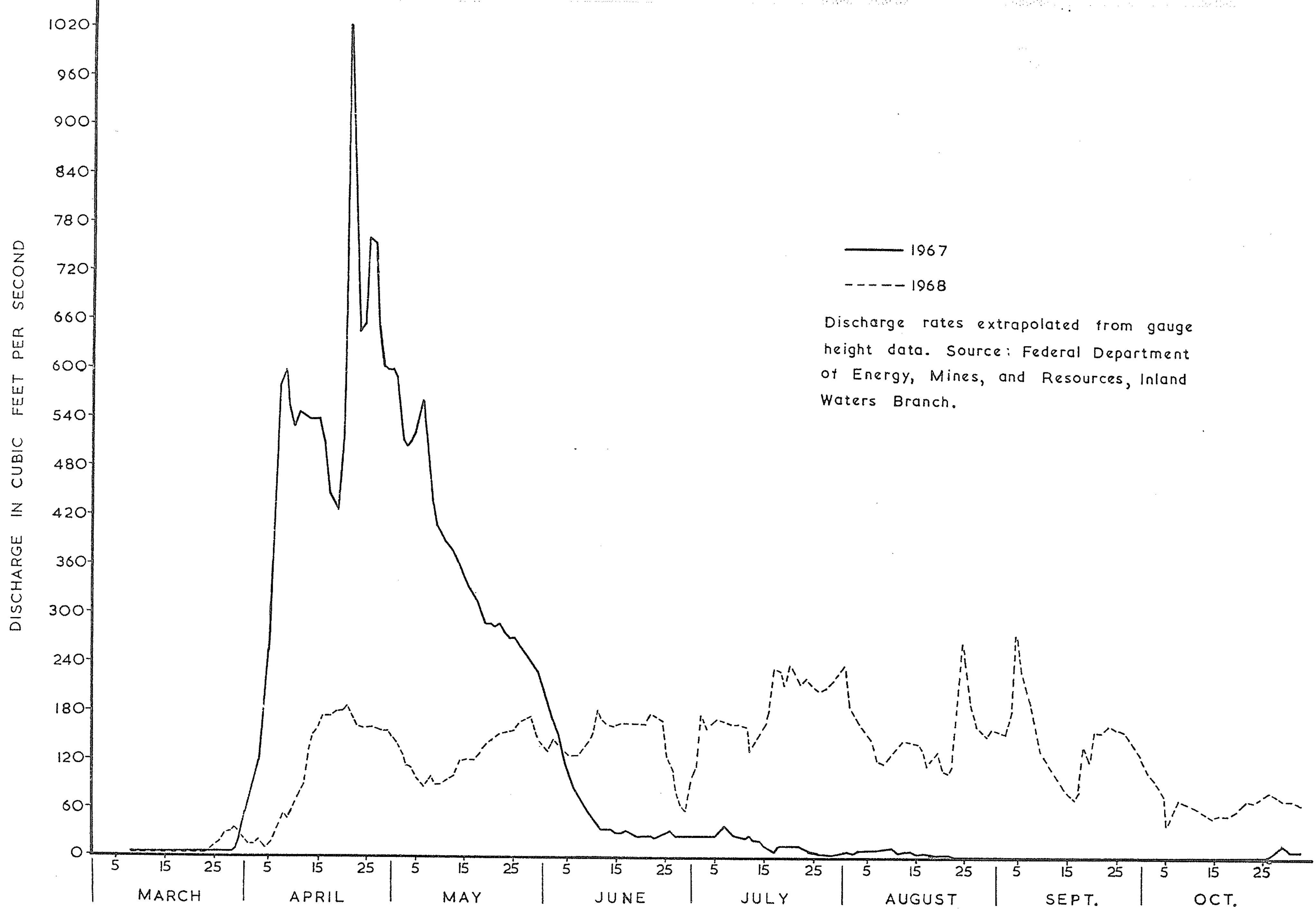
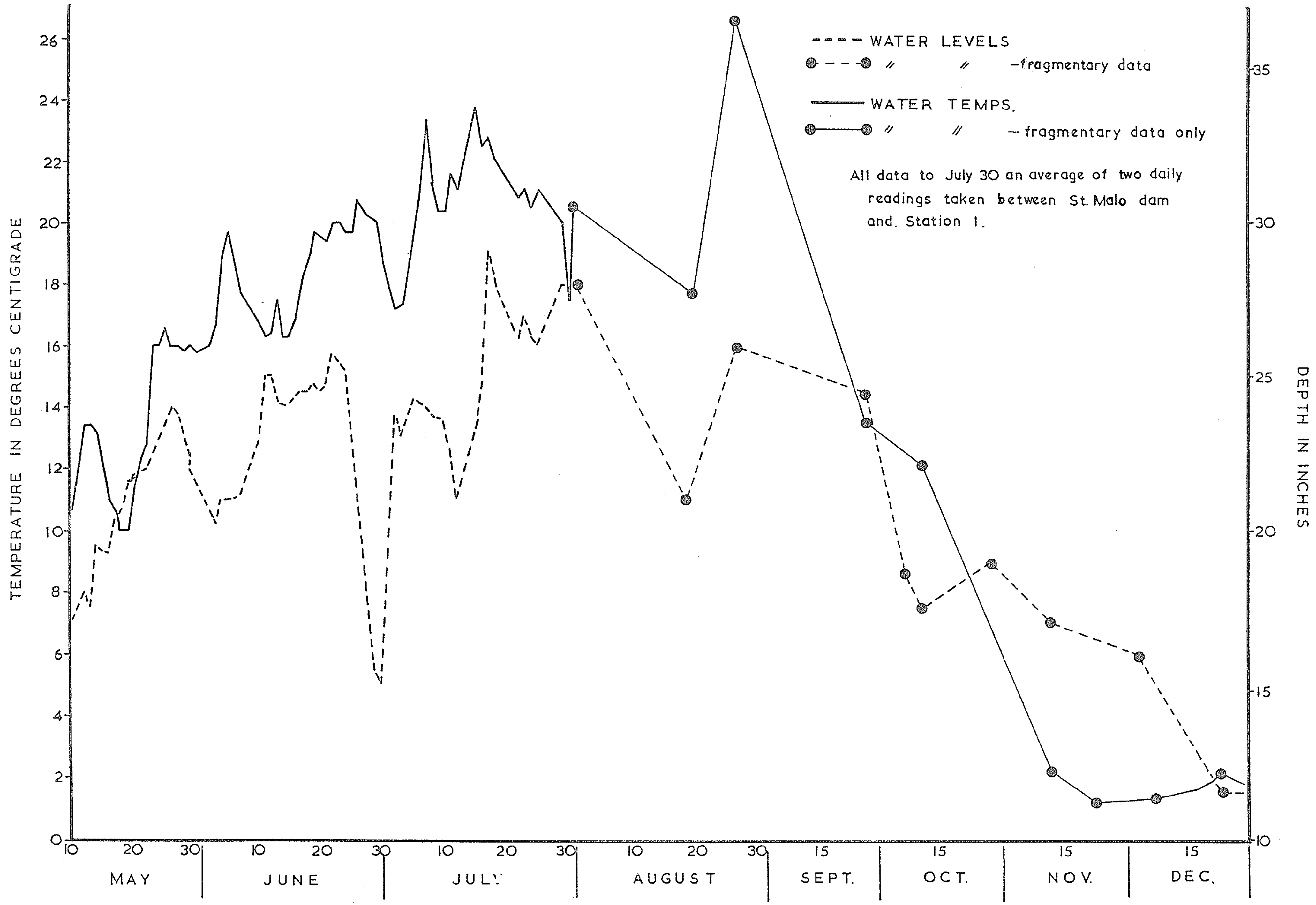

DISCHARGE IN CUBIC FEET PER SECOND
1020
960
900
840
780
720
660
600
540
480
420
360
300
240
180
120
60
0
5
15
25
MARCH
APRIL
MAY
JUNE
JULY
AUGUST
SEPT.
OCT.
1967
1968
Discharge rates extrapolated from gauge height data. Source: Federal Department of Energy, Mines, and Resources, Inland Waters Branch.

Fig. 2: Water temperatures and levels of Rat River, 1968



WATER LEVELS
" " -fragmentary data
WATER TEMPS.
" " -fragmentary data only
All data to July 30 an average of two daily readings taken between St. Malo dam and Station 1.
TEMPERATURE IN DEGREES CENTIGRADE
DEPTH IN INCHES
MAY
JUNE
JULY
AUGUST
SEPT.
OCT.
NOV.
DEC.

The following plates illustrate differences in levels and flow rates between the 1967 and 1968 sampling periods. Photos were taken as river levels approached their lowest values for each sampling periods (see Fig. 1 and 2).

Plates 1 and 2 show Rat River stations 1 and 2, taken from St. Malo dam.

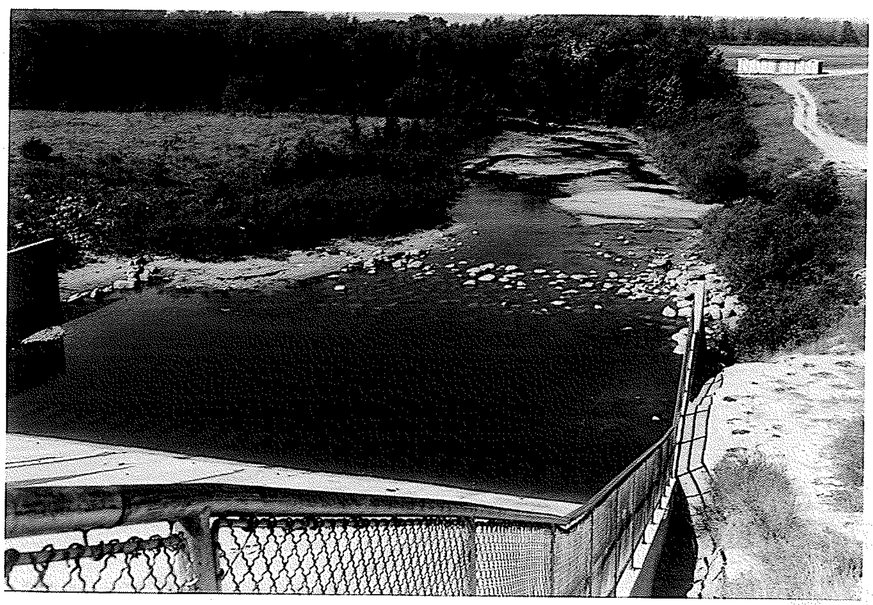


Plate 1: September 8, 1967. River flow ceased. Most of Station 1 (large sandbar on right) obliterated except for ditch extending off to right from sandbar. Station 2 is shown in far background, right side of river.

Plate 2: Stations 1 and 2, July 1, 1968. Water level approximately 12.5 cm. below mean for May - September 1968. Lowest water level of sampling was approximately 6 cm. lower than shown, on June 30, 1968.

Plates 3 and 4 show stations 4(a) (foreground, vegetation on both sides of river, extending up to second large rock in centre of riverbed) and station 4(b) (in background, beyond large rocks); taken from Hwy. 59 bridge.

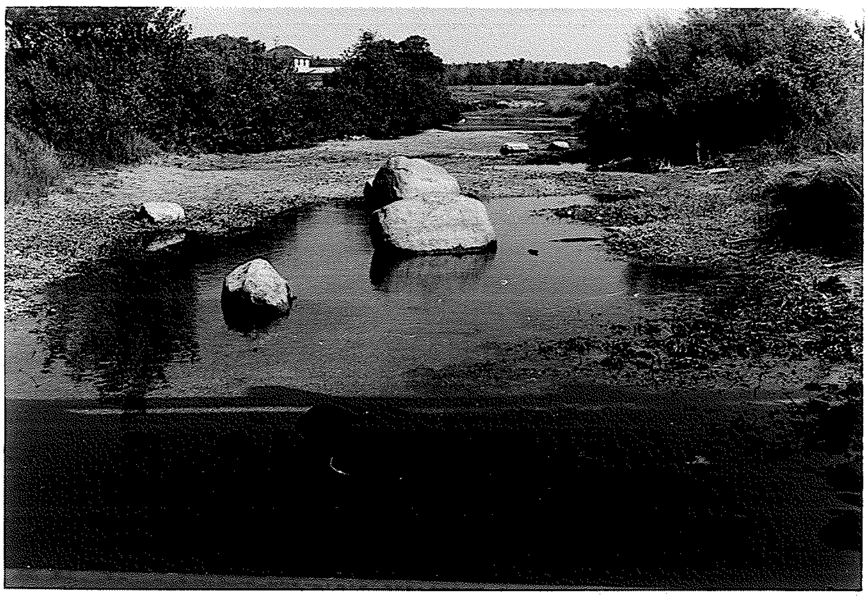


Plate 3: Stations 4(a) and 4(b), September 8, 1967. Note dessicated vegetation on both sides of river, former madtom habitat. Station 4(b) lay between second large rock in foreground and the two smaller rocks in background. Note also this section of river was at this time completely cut off from upstream sections due to low water level.

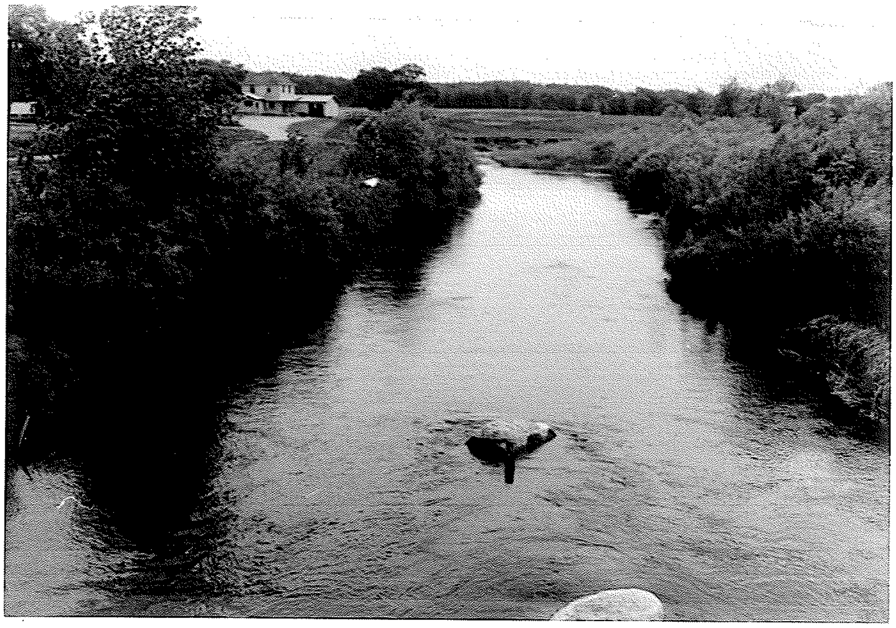


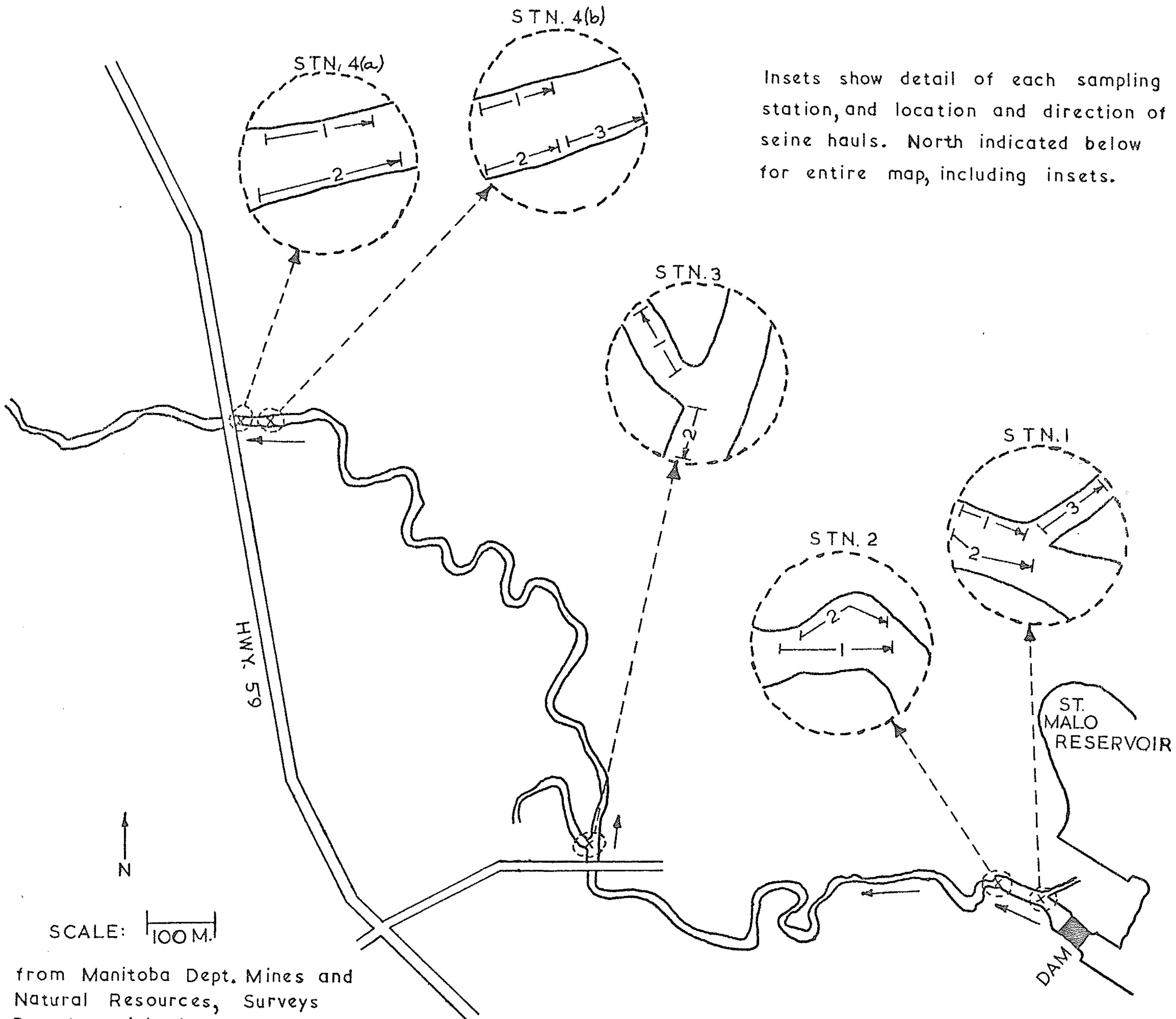
Plate 4: July 1, 1968. Stake at lower left shows upstream boundary of station 4(a). Stake in front of centre rock was water level gauge.

(b) Station Descriptions

Five sampling stations were established between the St. Malo reservoir dam and Provincial Highway No. 59, a distance of 2.4 km. (1.5 miles) of river, in areas where madtoms were most abundant i.e. in regions of dense aquatic vegetation (see Fig. 3).

Station 1, situated 30 meters downstream from the reservoir dam, consisted of a sandbar in the main channel surrounded by a moderate growth of *Vallisneria*

Fig. 3: Rat River sampling stations. Insets show detail of each station and seine haul.




from Manitoba Dept. Mines and Natural Resources, Surveys Branch aerial photograph.

*americana* (tapegrass), and a ditch containing thick growth of *Elodea canadensis* (common waterweed). The ditch, branching off for 30 meters to the north, was considerably deeper than the main channel, exceeding 1 meter in depth in some places during the summer. This could conceivably serve as a refuge area for fish during times of environmental stress such as flood, drought, and heavy icing.

Station 2, 52 meters downstream from Station 1, similarly had a nearby deep pool which could have been a refuge area. This sampling area had a sandy substrate in the middle of the main channel with a moderate growth of tapegrass, and a muddy substrate on the north side, with moderate growth of common waterweed.

Station 3 was located 1030 meters (.64 miles) from Station 2, near the junction of the main channel and an oxbow. At the junction was a deep, heavily vegetated pool, again a possible refuge area during times of climatic stress. The mud and silt substrate of the oxbow contained sparse growth of pond weed (*Potomageton sp.*) while sparse *Elodea* occupied the oxbow side of the main channel.

Stations 4(a) and 4(b) were situated 1234 meters (.77 miles) from Station 3, immediately upstream from the

Provincial Highway 59 bridge across the river. These stations were in close proximity, their limits being only 6 meters apart. Vegetation was chiefly sparse Potomageton, with some bar reed (Sparganium angustifolium). The vegetated areas of both stations were in shallower water than the previous three stations, and were therefore more susceptible to dessication during times of drought. No appreciable overhanging terrestial cover flora was present. In addition, there were no potential refuge areas available nearby.

Fishes other than Noturus gyrinus indiginous to the study area included young-of-year northern pike (Esox lucius), Johnny darter (Etheostoma nigrum), blackside darter (Percina maculata), mudminnows (Umbra limi), and young white suckers (Catostomus commersoni).

## Sampling and Marking Procedures

(A) Seining: Sampling of fish was carried out at regular intervals of time using a 3 meter length, 3/16" (5 mm.) mesh nylon, two-man seine. The net was pulled through defined areas of aquatic vegetation at each sampling station (see Fig. 3) at all times against the current and with the lead line kept as close to the bottom as possible. At some times during the 1968 sampling period, a one-man, 1.5 meters seine was used, at which time care was taken to cover the same area as the 3 meters seine (i.e. two 1.5 meters seine hauls = one 3 meters seine haul). In instances where habitat was being damaged by the seining operations, different hauls at each station were carried out on a rotational basis to lessen the number of times each defined area was seined per time interval. Generally, each area was seined twice a week in 1967, once a week in 1968, except where excessive habitat destruction was occurring. Table II describes seine hauls for each sampling station.

(B) Marking of Fish:

(a) Procedure: Fin-clipping procedure involved clipping off a fin or combination of fins with a scalpel as close to the body as possible. In the case of pectoral and dorsal fins, spines were also cut off. No anaesthetic was used. A different fin or combination of fins was cut off at each sampling station, and was consistent over the two sampling seasons. The fin clips utilized and numbers of fish marked are shown in Table III.

(b) Effects of Fin-Clipping

A total of 24 marked and unmarked tadpole madtoms were held together for extended periods of time for

TABLE II: Seine haul descriptions

| Stn. No. | Seine Haul # | Seine Haul Lgth (M). | Aquatic Vegetation | Substrate Type |
|---|---|---|---|---|
| 1[1] | 1-main channel | 9.15 M | Vallisneria around sand bar (main channel) | Sand |
| | 2-main channel | 9.15 | Vallisneria around sand bar (main channel) | |
| | 3-ditch | 9.15 | Elodea, (thick); ditch | Mud |
| 2 | 1 | 18.30 | Vallisneria; middle main channel | Mud and Sand |
| | 2 | 21.34 | Elodea; N. side main channel | |
| 3 | 1 | 14.33 | Potomageton (sparse); oxbow | Mud and Sand |
| | 2 | 12.20 | Elodea (sparse); S. side, main channel | Sand |
| 4(a) | 1 | 11.28 | N. side, main channel (Sparganium augustifolium, Potomageton) | Sand and Gravel |
| | 2 | 15.24 | S. side, main channel (Sparganium augustifolium, Potomageton) | |
| 4(b)[2] | 1 | 9.15 | N. side; Sparganium (sparse) | Sand and Gravel |
| | 2 | 11.28 | S. side; Potomageton | |
| | 3 | 12.50 | S. side | |

[1]Prominant cover flora at Stations 1, 2, and 3 is Salix interior - sandbar willow, Salix amygdaloides - peach leaf willow.

[2]1967 only.

TABLE III: Fin clipped totals - 1967 and 1968

| | | 1967 | | 1968 | |
|---|---|---|---|---|---|
| Stn. No. | Fin Clip | Adult | Young-of-year | Adult | Young-of-year |
| 1 | Anal | 186 | 23 | 5 | 0 |
| 2 | Dorsal | 139 | 19 | 31 | 0 |
| 3 | Dorsal and Anal | 99 | 12 | 29 | 0 |
| 4(a) | Left Pectoral | 112 | 13 | 10 | 0 |
| 4(b) | Right Pectoral | 82 | 10 | 0 | 0 |
| TOTALS | | 618 | 77 | 75 | 0 |

observations of effects of fin-clipping; 12 were held in a laboratory aquarium for 19 months and 12 were held in minnow traps secured in midstream of the Rat River for a period of five weeks.

(i) Laboratory: The marks used on the laboratory specimens were the following: 3- dorsal and anal fins clipped

3 - left pectoral and anal fins clipped

3 - dorsal, anal, and left pectoral fins clipped

3 - controls (no clips)

These fish were placed in an aquarium with vegetation, kept at room temperatures (11 to 20°C range) and observed periodically from August 7, 1967 to February 12, 1969 for effects of fin-clipping and for incidence of regeneration of clipped fins.

(ii) Field: Twelve madtoms were held in two plastic minnow traps anchored on the bottom in midstream of the Rat River near stations 1 and 2 for five weeks (October 6 to November 13, 1968). Trap #1 was located in midstream near station 1 in 0.5 meters depth of water. Six madtoms were placed in the trap. Three were marked (two left pectoral and dorsal, one anal and dorsal fins clipped) and three were unmarked.

Trap #2 was situated 4 meters upstream from station 2. Six madtoms, three marked (two left pectoral and anal, one anal and dorsal fins clipped) and three unmarked, were placed in the trap.

Water temperatures ranged from 12°C to 2°C and current was approximately two to three feet per second. Bottom cover was chiefly green algae; traps were camouflaged with algae and *Elodea*. Traps were examined twice during the five week period.

(C) Sampling Data Recorded

For each seine haul, the following data were recorded for *Noturus gyrinus*:

(a) total number of madtoms captured on sample day t [Ct]

(b) number of previously marked fish recaptured [Rt]

(c) number of fish marked on day t [Mn]

(d) total number of marked fish at large [Mt]

(e) total length (snout-end of tail) for all madtoms seined (1968 only)

All madtoms seined were returned to the same area from which they were captured.

## Treatment of Mark-Recapture Data

### A. Movements

Rate of recapture, used as a criterion of extent of movement of fish, was calculated by dividing sample size Ct by recaptures Rt for each sampling day. Average rate of recapture was determined for each sampling station. If the population is stable i.e. very limited movement occurring, then rate of recapture should increase throughout the sampling period, since the numbers of marked individuals at large increase with each productive seining operation. However, mortality of marked individuals, emigration of marked fish out of the sampling area, or immigration of unmarked fish into the sampling area are all possible factors that would tend to lower the expected increase in rate of recapture.

Since different fin clips were utilized at each sampling station, any evidence of movements could be traced by examination of fins of fish seined at each station and from areas between stations. Movements occurring both within each sampling seasons and between the two sampling seasons could then be determined.

Since no systematic sampling was practical during the winter months due to ice conditions on the river, the possibility existed that madtoms migrated elsewhere for overwintering. In order to test the assumption that madtoms do not migrate for this purpose, a series of laboratory and field overwintering experiments were carried out. The objects were to determine extent of tolerance of N. gyrinus to extremely cold water temperatures in the laboratory, and to determine if they overwinter in their Rat River habitat, either on or buried in the substrate.

In the laboratory, seven N. gyrinus: 1 - 1967 adult (yr. II), 2 - 1967 young (Yr. I), 3 - 1968 adults (yr. I or II), and 1 - 1969 adult (yr. I) were acclimatized to a water temperature of 3.5°C. for varying amounts of time up to 40 days in a 5 gallon aquarium with fine sand substrate. For further cooling down to approximate winter water temperatures (0 to 1°C) the aquarium was partially immersed in a 175 liter "Instant Ocean" aquarium equipped with a water circulation system and cooling unit with thermostat, and containing a salt-water solution to prevent freezing of the system. Observations of madtoms living under simulated winter conditions of water temperature (0.25 to 0.75°C) and photoperiod (ranging from 8 hrs. light - 16 hrs. darkness to 10 hrs. light - 14 hrs. darkness) were made at least twice daily for a period of 33 days. On the seventeenth day, 7 live Gammarus sp. were introduced into the aquarium as food. Extensive icing was evident in the bottom of the aquarium on the last 10 days of the experiment, but at least one quarter of the substrate surface area was ice-free at all times.

In order to observe madtoms overwintering in the Rat River a 4.9 meter circumference fish containment area (5 mm. mesh hardware cloth supported by 1.3 cm. diameter reinforcing rods) was set up in the Rat River near Station 2 on November 17, 1968. Seven madtoms (3 fin-clipped, 4 unmarked) were placed in the trap and the area was checked in December and March for evidence of survival. Substrate consisted of fine sand, sticks, vegetative debris, and algae. Water temperatures were 2.2°C in November and 1.5°C in mid-March (probably lower in December, January, and February). Water depth was approximately 0.5 meters.

B. Populations (Levels and Fluctuations)

Population estimates were calculated for each sampling station using the Schnabel multiple census technique

(Ricker, 1958) whereby

$$\text{Total Population } \hat{N} = \frac{\sum [Ct\ M(t-1)]}{\sum Rt}$$

where $Ct$ = total sample on day t

$M(t-1)$ = total number of previously marked fish at large

$Rt$ = number of recaptures in sample C

A 95% confidence interval was calculated for the population estimate at each sampling station.

All mark-recapture data were converted to catch per unit effort, expressed as average number of madtoms captured per 15 meter$^2$ area seined, generally a weekly average. This arbitrarily set area of 15 meters$^2$ was based on the average width of the seine when functioning of 2.5 meters X arbitrary haul length of 6 meters = 15 $M^2$. All seine haul data was converted to this common area since haul lengths varied from station to station. The formula used was:

$$\text{Number of adult madtoms}/15\ M^2 \text{ (Catch per Unit Effort) or } C/f = \frac{\text{No. of madtoms in seine haul (Ct)}}{\text{Total seine haul length}/6 \text{ Meters}}$$

$$= \frac{Ct \times 6}{\text{Total seine haul length}}$$

Using this formula, catch per unit effort, used as an index of abundance, could be effectively compared at the different sampling stations. Where weekly means were calculated on the basis of two individual sampling days, coefficients of variation were calculated for the means. Young-of-year *N. gyrinus* were not included in population estimates or C/f data, so recruitment problems were negligible. However, approximate abundance of young-of-year was recorded.

## Other Biological Considerations

### A. Food Habits

Stomachs of 61 *N. gyrinus* collected from the Rat River (June, 1967 and July, 1968) and from St. Malo Reservoir (July, 1968) were dissected and contents analysed. All recognizeable food items were counted and percentage of stomachs containing each type of food item was recorded.

### B. Breeding Habits

The only recorded evidence of spawning in *N. gyrinus* has been the observations by Bailey (1938) and Hankinson (1908) of adult madtoms guarding egg clusters in old tin cans. Six pipes, 45 cm. long by 4 cm. diameter, were placed in heavy aquatic vegetation at stations 1, 2, 3, and 4(a) in June 1969 in an effort to capture and observe spawning madtoms.

### C. Age Classes

An attempt was made to age preserved madtoms by the vertebral ring method of Hooper (1949).

Specimens captured in September, 1967 and June, 1968 were measured (total length); length-frequency graphs were constructed to determine size distribution and year classes.

D. Predation

During July of 1968, a large number of Northern pike (*Esox lucius*) ranging in size from 12 to 17.5 cm. were seined in madtom habitat, in association with tadpole madtoms. The possibility of young northern pike acting as predators on madtoms was investigated.

Forty young northern pike seined in madtom habitat were killed, the stomachs removed, and contents recorded. In addition, several fish indiginous to the Rat River, namely Johnny darters (*Etheostoma nigrum*), blackside darters (*Percina maculatus*), mudminnows (*Umbra limi*), and young white suckers (*Catostomus commersoni*), together with young northern pike (*Esox lucius*) and tadpole madtoms (*Noturus gyrinus*) were held together in a laboratory aquarium and deprived of food for one month. Any observations of occurrence of predation were recorded.

E. Effects of Toxin

The effects of toxin from madtom spines on man has often been described as extremely painful; (Reed, 1907; Evermann, as cited in Reed, 1907). However, no records of its effects on other fishes were evident in the literature. Spines of live madtoms were injected into the lateral musculature of various fishes - the northern pike (*Esox lucius*), sauger (*Stizostedium canadense*), and rainbow trout fry (*Salmo gairdneri*) and any observed effects were noted.

## RESULTS

### Effects of Fin-Clipping

#### (i) Laboratory Observations

No detrimental effects, either immediate or long-term were observed on madtoms fin-clipped and held in a laboratory aquarium. Swimming ability did not appear to be impaired, even immediately after placing the clipped fish back into the aquarium. No fungus developed, and no mortality of marked fish occurred between August 7, 1967 and February 12, 1969, the entire observation period.

Some regeneration of clipped fins was observed 21 days after initial clipping in the laboratory. Regeneration of some dorsal and anal fins was complete within seventy days of clipping. However, a distinct demarcation line persisted where the cut had been made, and regenerated parts were in all instances a lighter color than the original fin. No regeneration of dorsal spines occurred, but in two cases pectoral spines appeared to regenerate. Pectoral fins regenerated more slowly than anal or dorsal fins. In two large madtoms (80 to 90 mm.) very little regeneration occurred. In both fish there was no evidence of dorsal fin regeneration during the nineteen months of observations. Fin clips on all madtoms were evident at the end of the observation time. There was a trend toward faster fin regeneration in the smaller fishes.

#### (ii) Field Observations

After being held for five weeks in minnow traps in the Rat River, neither the fin-clipped specimens nor controls showed any harmful effects. All but one unmarked madtom escaped from trap 2.

Movements

(a) Rate of Recapture

Recapture rate, expressed as a percentage $\left(\frac{Rt}{Ct}\right)$ was used as an indication of population stability (Holton, 1953), whereby high recapture rate indicates highly stable population. Recapture data for each inventory, summarized in Tables IV and V, showed an increase in recapture rate during the first month of sampling in 1967, followed by a general decrease. This decrease can be a result of marked fish dropping out of the population through emigration or mortality, or of unmarked fish immigrating into the sampling areas. Highest average rates of recaptures in 1967 occurred at stations 1 (37.5%) and 3 (35.5%) while the lowest was at station 4(a) (12.5%). Rates of recapture for 1968 were much lower than 1967 at all stations.

(b) 1967 Sampling Season

A total of 618 tadpole madtoms were fin-clipped in the 13-week sampling period, June through September. During this time, only five marked fish were recaptured at sites other than where they were marked and released (Fig. 4). One fish had moved a distance of 2.1 km. (1.4 miles), another 52

TABLE IV: Rate of recapture 1967 $\frac{\text{Recapture (Rt)}}{\text{Total sample (Ct)}} = \%$

| Date | Coll. No. | Stn. No. 1 Rt/Ct | % | Stn. No. 2 Rt/Ct | % | Stn. No. 3 Rt/Ct | % | Stn. No. 4(a) Rt/Ct | % | Stn. No. 4(b) Rt/Ct | % |
|---|---|---|---|---|---|---|---|---|---|---|---|
| June 26 | 1 | 0/22 | 0 | 0/6 | 0 | --- | | --- | | --- | |
| 26 | 2 | 12/36 | 33.3 | --- | | --- | | --- | | 0/11 | 0 |
| 29 | 3 | 13/34 | 38.2 | 2/15 | 13.3 | 0/13 | 0 | --- | | --- | |
| July 4 | 4 | 12/25 | 48.0 | 1/9 | 11.1 | 3/15 | 20.0 | 0/1 | 0 | 1/6 | 16.6 |
| 6 | 5 | 18/34 | 52.9 | 4/15 | 26.6 | 5/11 | 45.4 | 1/4 | 25.0 | 2/11 | 18.1 |
| 11 | 6 | 14/20 | 70.0 | 2/28 | 7.1 | 4/13 | 30.7 | 0/1 | 0 | 0/2 | 0 |
| 14 | 7 | --- | | --- | | --- | | --- | | --- | |
| 18 | 8 | 9/18 | 50.0 | 3/11 | 27.2 | 7/10 | 70 | 1/5 | 20 | --- | |
| 21 | 9 | 6/12 | 50.0 | 0/9 | 0 | 1/3 | 33.3 | 0/12 | 0 | 2/11 | 18.1 |
| 25 | 10 | 1/5 | 20.0 | 3/10 | 30.0 | 3/5 | 60.0 | 5/13 | 38.4 | 12/26 | 46.1 |
| 28 | 11 | 7/13 | 53.8 | 2/10 | 20 | 4/6 | 30.7 | 5/13 | 38.4 | 3/10 | 30.0 |
| Aug. 1 | 12 | 4/10 | 40.0 | 3/10 | 30 | 1/8 | 12.5 | 0/8 | 0 | 3/9 | 33.3 |
| 8 | 13 | 5/21 | 23.8 | 0/12 | 0 | 5/10 | 50.0 | 3/25 | 12.0 | 4/13 | 30.7 |
| 11 | 14 | 3/13 | 23.0 | 2/6 | 33.3 | 2/2 | 100 | 5/18 | 27.7 | 2/6 | 33.3 |
| 14 | 15 | --- | | --- | | --- | | --- | | --- | |
| 15 | 16 | 4/10 | 40.0 | 0/4 | 0 | 1/3 | 33.3 | 2/18 | 11.1 | 0/5 | 0 |
| 18 | 17 | 4/6 | 66.6 | 3/3 | 100 | 1/5 | 20.0 | 0/6 | 0 | 0/1 | 0 |
| 22 | 18 | 3/9 | 33.3 | 1/12 | 8.3 | 3/10 | 30.0 | 0/4 | 0 | 0/0 | -- |
| 25 | 19 | 3/10 | 30.0 | 1/3 | 33.3 | 8/12 | 66.6 | 1/6 | 16.6 | 0/0 | -- |
| 29 | 20 | 1/3 | 33.3 | 1/3 | 33.3 | 1/7 | 16.6 | 0/0 | -- | 0/0 | -- |
| Sept. 5 | 21 | 0/3 | 0 | 0/0 | -- | 0/8 | 0 | 0/0 | --- | 0/0 | -- |
| 12 | 22 | 0/2 | 0 | 1/1 | 100 | 2/9 | 22.2 | 0/1 | 0 | 0/0 | -- |
| 18 | 23 | 2/2 | 100 | 0/1 | 0 | 0/0 | -- | 0/0 | -- | 0/0 | -- |
| Average rate of recapture | | | 37.5% | | 25.0% | | 35.5% | | 12.5% | | 19.0% |

Average rates computed using only collections where total sample was one or more madtoms.

All percentage values indicate numbers of madtoms recaptured in same area in which marked.

$\bar{x} = 26\%$

TABLE V: Rate of recapture $\frac{Rt}{Ct}$ for 1968 marks only

| Date | Coll. No. | Stn. No.1 | | Stn. No.2 | | Stn. No.3 | | Stn. No. 4(a) | | Stn. No. 4(b) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Rt/Ct | % | Rt/Ct | % | Rt/Ct | % | Rt/Ct | % | Rt/Ct | % |
| May 21 | 1 | 0/2 | 0 | 0/0 | 0 | --- | | --- | | No specimens captured in 1968 | |
| 29 | 2 | 0/0 | - | --- | | --- | | --- | | | |
| 31 | 3 | 0/1 | 0 | 0/9 | 0 | --- | | --- | | | |
| June 3 | 4 | 0/0 | - | 1/10 | 10 | 0/4 | 0 | 0/3 | 0 | | |
| 6 | 5 | 0/1 | 0 | 0/3 | 0 | 0/2 | 0 | 0/0 | - | | |
| 11-12 | 6 | 0/0 | - | 1/2 | 50 | 1/4 | 25 | 0/0 | - | | |
| 13-14 | 7 | 0/0 | - | 1/2 | 50 | 0/2 | 0 | 0/0 | - | | |
| 17-18 | 8 | 0/0 | - | 0/3 | 0 | 1/6 | 16.6 | 0/3 | 0 | | |
| 19-20 | 9 | 0/0 | - | 0/1 | 0 | 0/6 | 0 | 0/1 | 0 | | |
| 24 | 10 | 0/0 | - | 0/1 | 0 | 0/2 | 0 | 0/3 | 0 | | |
| 26-27 | 11 | 0/1 | 0 | 0/2 | 0 | 0/1 | 0 | 0/0 | - | | |
| July 2 | 12 | 0/1 | 0 | 0/0 | - | 0/0 | - | 0/0 | - | | |
| 8-9 | 13 | 0/0 | - | 0/0 | - | 0/4 | 0 | 0/0 | - | | |
| 16-18 | 14 | 1/2 | 50 | 0/0 | - | 0/6 | 0 | 0/0 | - | | |
| 22-24 | 15 | - | - | 0/2 | 0 | 0/3 | 0 | --- | | | |
| 31 | 16 | 0/0 | - | - | - | 0/0 | - | 0/0 | - | | |
| Aug. 9 | 17 | 0/3 | 0 | 0/0 | - | 0/2 | 0 | --- | | | |
| 26 | 18 | 0/0 | - | 0/0 | - | 0/0 | - | --- | | | |
| Average rate of recapture | | | 7.0% | | 10.0% | | 3.5% | | 0.0% | | |

Ct & Rt includes 1968 marks only $\bar{x} = 5\%$

meters, and three moved about 9 meters each.

Further evidence of species localization was indicated by the results of seine hauls made at locations other than the established sampling stations. Seining in aquatic vegetation between stations 1 and 2 in late July and mid-August yielded five and 31 madtoms respectively, none of which had been fin-clipped. Nineteen of the latter were tagged with white thread attached through dorsal musculature and released. Six of these were recaptured at station 1 within 22 days. It is presumed that the other tagged fish remained where they were released.

There were 77 young-of-year madtoms fin-clipped in 1967. None were recaptured other than at the site where marked.

(c) 1968 Sampling Season

During the 12-week sampling period, May through August, 75 adult madtoms were marked. None were recaptured at a site other than where they were first collected, fin-clipped, and released. Seining between stations 1 and 2 in early August yielded 23 adults and 2 young-of-year, and in late September 15 adults. None of these fish had been marked.

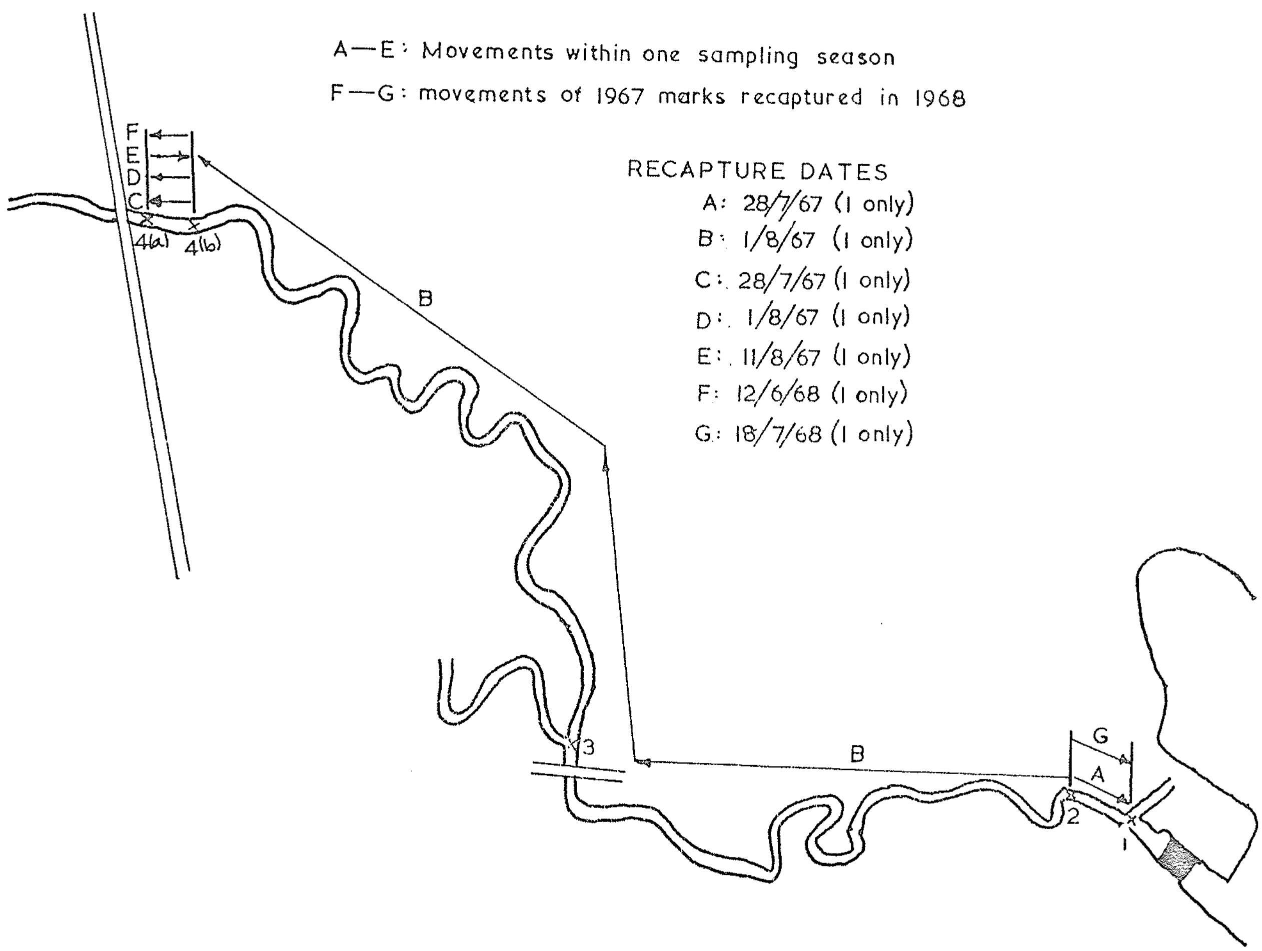
Of all the fish collected at the sampling stations in 1968, 11 were marked in 1967, representing only 1.4 per cent of the total marked in 1967. Included were both young-of-year and adults marked in the first year. These observations are summarized in Table VI and illustrated in Fig. 4.

TABLE VI: Subsequent year recaptures of marked N. gyrinus, Rat River, 1967 - 1968.

| Recapture Date | 1967 Marking Location | 1968 Recapture Location | No. 1967 Recaps. | Mark | Probable Age in 1968 |
|---|---|---|---|---|---|
| 21/5/68 | Stn. 2 | Stn. 2 | 1 | Dorsal clip | Year II (recaptured again 31/5/68) |
| 29/5/68 | Stn. 2 | Stn. 2 | 3 | Dorsal clips | Year I i.e. 1967 young-of-year |
| | | | | (Recaptured again 31/5/68) | |
| 31/5/68 | Stn. 2 | Stn. 2 | 2 | Dorsal | Year I - 52 mm. |
| | | | | Dorsal | Year II - 66 mm. |
| | | | | (Recaptured again 6/6/68) | |
| *12/6/68 See Fig. 4(f) | Stn. 4(b) | Stn. 4(a) | 1 | Left pectoral clip | Year II - 72 mm. (Movement of 9 meters approx.) |
| 14/6/68 | Stn. 3 | Stn. 3 (side channel) | 1 | Dorsal & anal clip | Year II - 83 mm. |
| 18/6/68 | Stn. 3 | Stn. 3 (side channel) | 1 | Dorsal & anal clip | Year I - 55 mm. (recaptured again 20/6/68) |
| 19/6/68 | Stn. 2 | Stn. 2 | 1 | Dorsal clip | Year I (?) - 58 mm. |
| *18/7/68 See Fig. 4(g) | Stn. 2 | Stn. 1 (ditch) | 1 | Dorsal clip | Year II - 74 mm. |
| | | | | Movement of approx. 52 M. (into refuge?) | |
| | | Total | 11 | | |

*Movement between stations occurred.

Fig. 4: Movements of marked *Noturus gyrinus* in the Rat River within each sampling period and between 1967 and 1968, with recapture dates of all marked fish showing movement.


A—E: Movements within one sampling season
F—G: movements of 1967 marks recaptured in 1968
RECAPTURE DATES
A: 28/7/67 (1 only)
B: 1/8/67 (1 only)
C: 28/7/67 (1 only)
D: 1/8/67 (1 only)
E: 11/8/67 (1 only)
F: 12/6/68 (1 only)
G: 18/7/68 (1 only)
F
E
D
C
4(a)
4(b)
B
3
B
G
A
2
1

(d) Overwintering Observations

When the aquarium containing fish acclimated to $3.5^{\circ}C$ was immersed in the "Instant Ocean" for further cooling to between 0.25 and $0.75^{\circ}C$, the fish exercised a group digging reaction in one corner of the aquarium. This same behaviour was observed when fish were held at room temperature, ($13^{\circ}C$) and may be the result of general disturbance rather than of exposure to cold temperatures.

During the 33 day observation period when the fish were held at 0.25 to $0.75^{\circ}C$ water temperatures, they were occasionally active but spent most of their time huddled together on the bottom. No fishes attempted to bury themselves in the substrate. When ice formed on the bottom materials of the aquarium the fish lay motionless but responded to prodding. One madtom, captured in the Rat River a month prior to placing it in the aquarium, exhibited more activity than the rest, which had been collected in the summer of 1967 and 1968. As water temperatures increased to room temperature of $13^{\circ}C$ the fish became progressively more active.

None of the seven *Gammarus sp*. placed in the aquarium was eaten by madtoms while the water was coldest. When the water temperature rose to $3.5^{\circ}C$ all the amphipods were eaten in one day.

Some of the field experiments on the overwintering behaviour of tadpole madtoms were inconclusive. All fish placed in the trap on November 17, 1968 were still there on

December 2, 1968, but on December 21, 1968 when water temperature was 2.2°C only one dead fish was found in the trap. On March 9, 1969 the water temperature was 1.5°C and no fish were found in the trap either by seining or digging up the substrate. On March 16, 1969 one fish was collected in vegetative debris near the trap. Seining in detritus near station 1 yielded one tadpole madtom on February 7, 1970.

## Populations

### A. Estimates of Abundance

Population estimates derived by the Schnabel census method are summarized in Appendix II. Confidence limits were established using reciprocals and "t" values as outlined by Ricker (1958). With the exception of station 3, the estimated madtom population levels were much higher in 1967 than in 1968.

### B. Relative Abundance and Fluctuations

Relative abundance and fluctuations in population levels at all sampling stations in 1967 and 1968 are expressed in terms of catch per unit of effort, C/f. Complete tables of C/f data are placed in Appendix I. Coefficient of variation, CV., where CV. = $\frac{s}{\bar{x}} \cdot 100$, was calculated for weekly samples when number of samples was greater than one. A much smaller proportion of 1968 data was subject to calculation of C.V.

The 1968 C/f for all sampling stations was consistently lower than in 1967 (Figs. 5 to 9). At stations 1 and 2 (Figs. 5 and 6) it generally dropped as sampling period progressed during both years. The 1967 C/f for stations 4(a) and 4(b) (Figs. 8 and 9) exhibited like patterns, peaking in mid-summer, then rapidly declining. The fluctuation pattern at station 3, (Fig. 7) was unlike all other sampling stations during both 1967 and 1968. A comparison of C/f for all sampling stations in 1967 and 1968 is shown in Figs. 10 and 11 respectively.

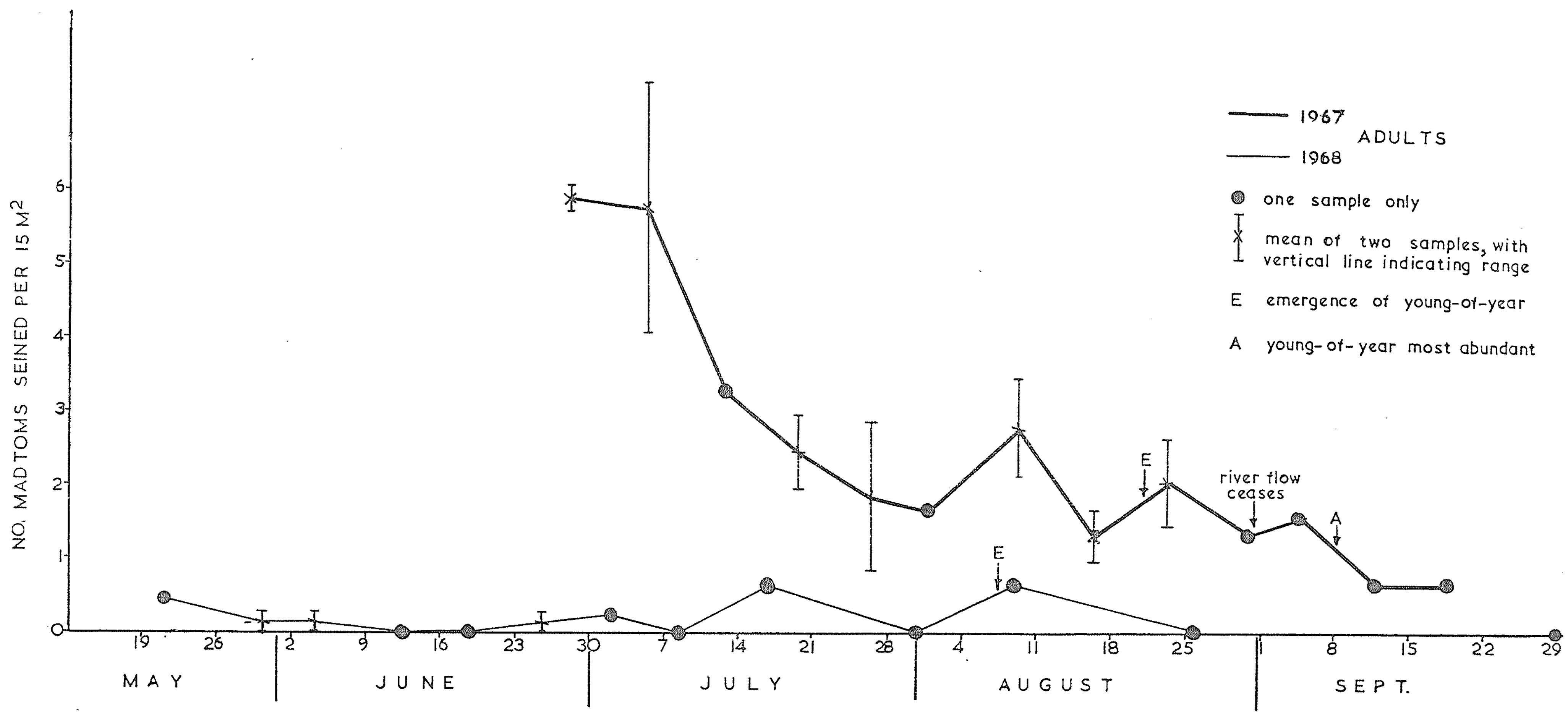
Other Biological Considerations

A. Food Habits

The stomach contents of 61 tadpole madtoms collected from both the Rat River and St. Malo reservoir in June and July, 1967 and 1968, are summarized in Table VII. Major food items were crustaceans and insects, the prominent forms being *Hyalella azteca* and chironomids respectively. Some strong similarities exist in the food items of river madtoms over the two successive years, notably in the percentage of stomachs containing crustaceans (43.5 and 42.1 per cent respectively). In both years a higher proportion of Rat River madtom stomachs held insects than crustaceans (52.2 and 68.4 per cent respectively), but the 1967 sample had a higher incidence of dipterans than in 1968.

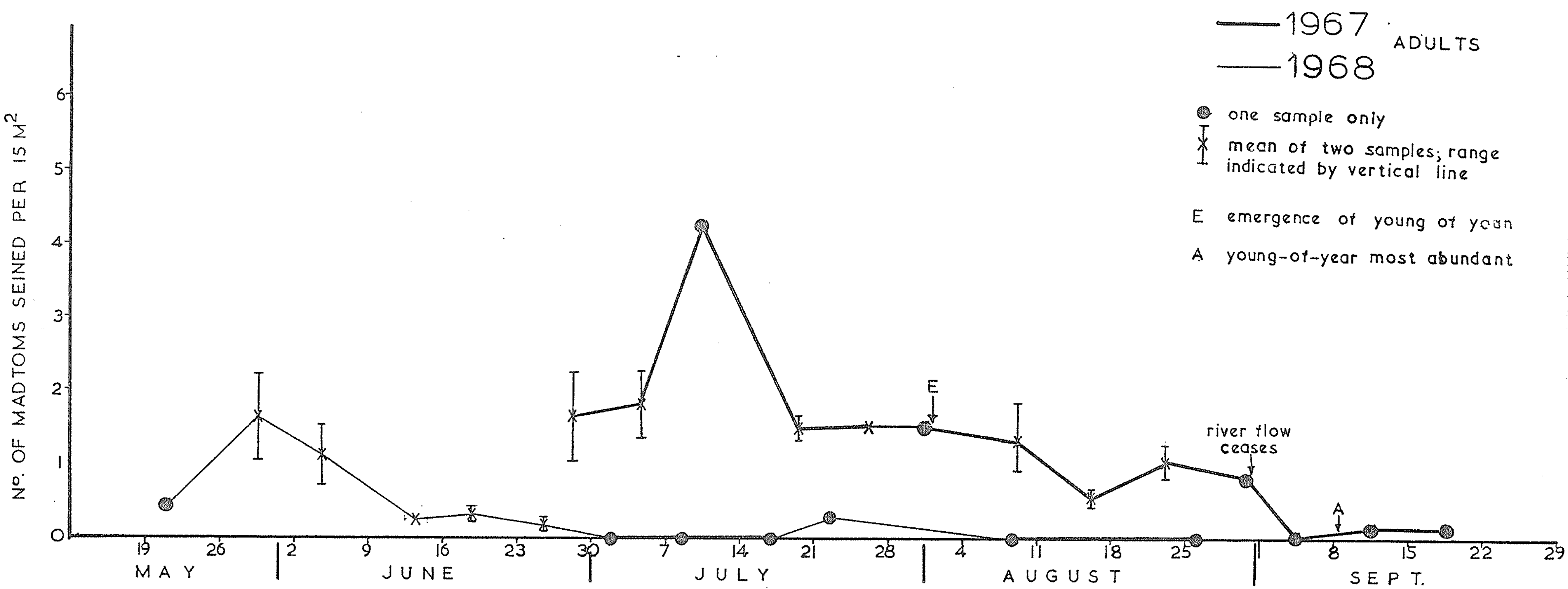
Differences in food items between river and reservoir fish samples were considerable. Insect material was lacking in reservoir fish stomachs, but they contained a greater amount

Fig. 5: Catch per unit effort - Station 1, 1967-1968.



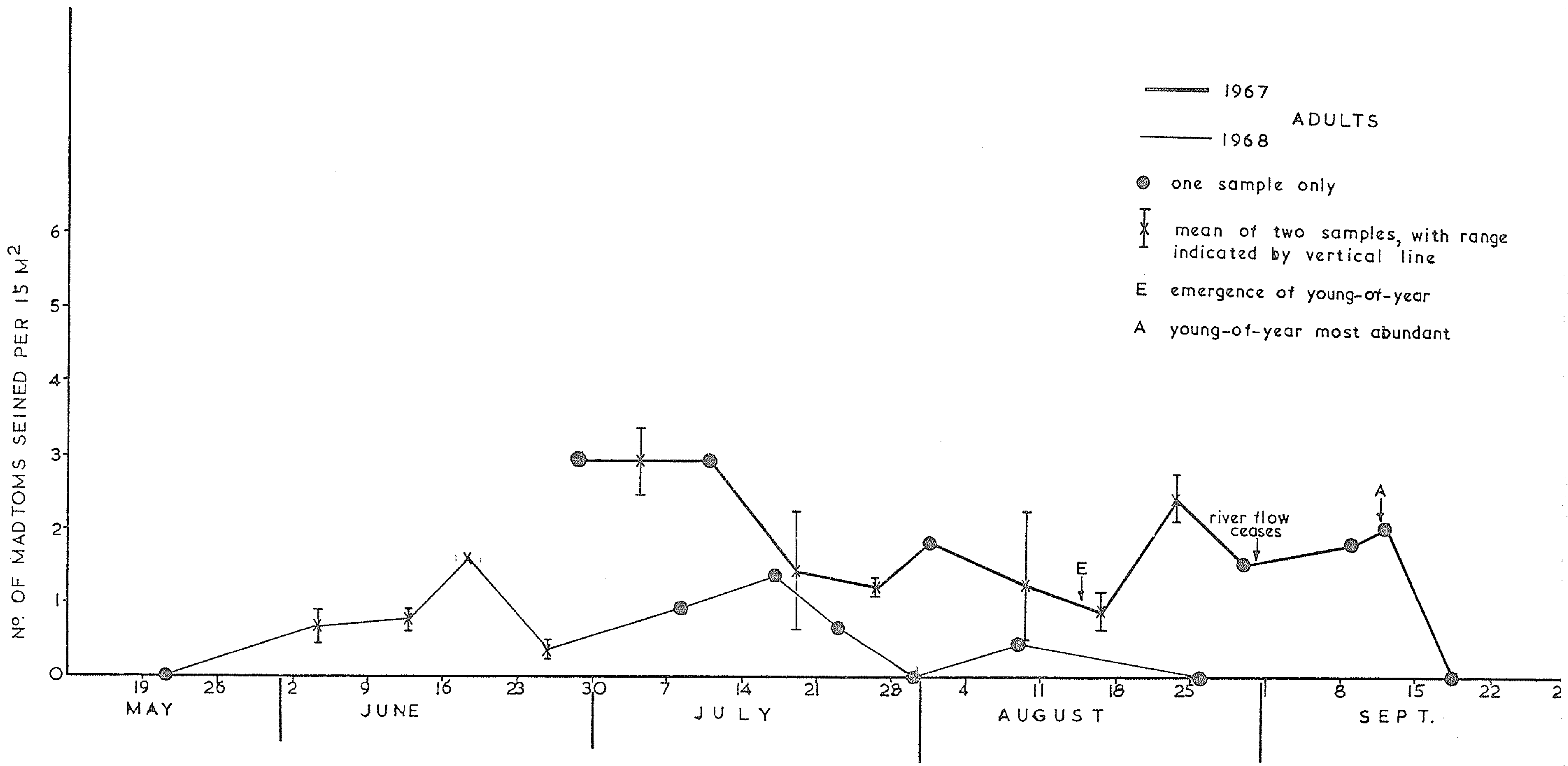
NO. MADTOMS SEINED PER 15 M²
0
1
2
3
4
5
6
19
26
2
9
16
23
30
7
14
21
28
4
11
18
25
1
8
15
22
29
MAY
JUNE
JULY
AUGUST
SEPT.
1967
1968
ADULTS
one sample only
mean of two samples, with vertical line indicating range
E emergence of young-of-year
A young-of-year most abundant
E
E
river flow ceases
A

Fig. 6: Catch per unit effort - Station 2, 1967-1968.



No. OF MADTOMS SEINED PER 15 M²
0
1
2
3
4
5
6
19
26
2
9
16
23
30
7
14
21
28
4
11
18
25
1
8
15
22
29
MAY
JUNE
JULY
AUGUST
SEPT.
1967
1968
ADULTS
one sample only
mean of two samples; range indicated by vertical line
E emergence of young of year
A young-of-year most abundant
E
A
river flow ceases

Fig. 7: Catch per unit effort - Station 3, 1967-1968.



1967
1968
ADULTS
one sample only
mean of two samples, with range indicated by vertical line
E emergence of young-of-year
A young-of-year most abundant
river flow ceases
E
A
Nº. OF MADTOMS SEINED PER 15 M²
0
1
2
3
4
5
6
19
26
2
9
16
23
30
7
14
21
28
4
11
18
25
1
8
15
22
2
MAY
JUNE
JULY
AUGUST
SEPT.

Fig. 8: Catch per unit effort, Station 4(a), 1967-1968.

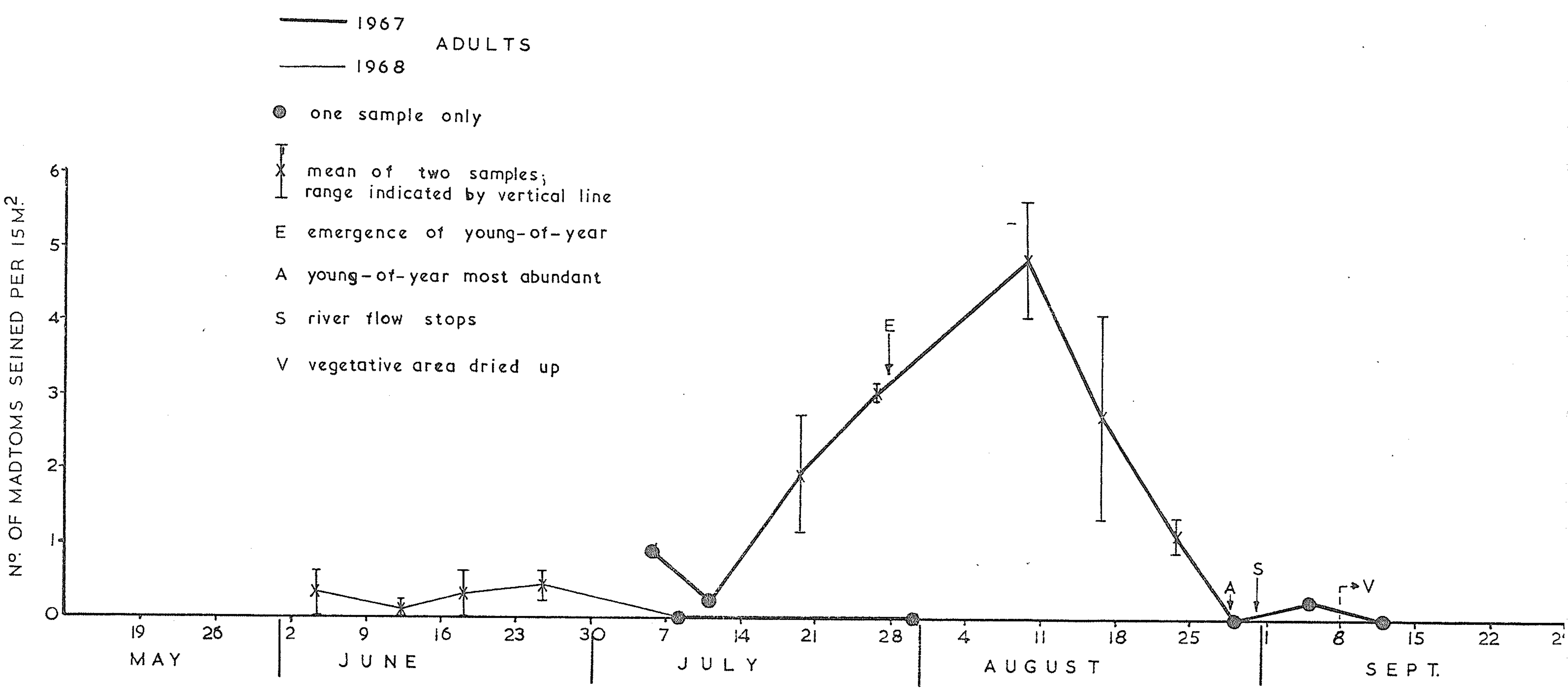
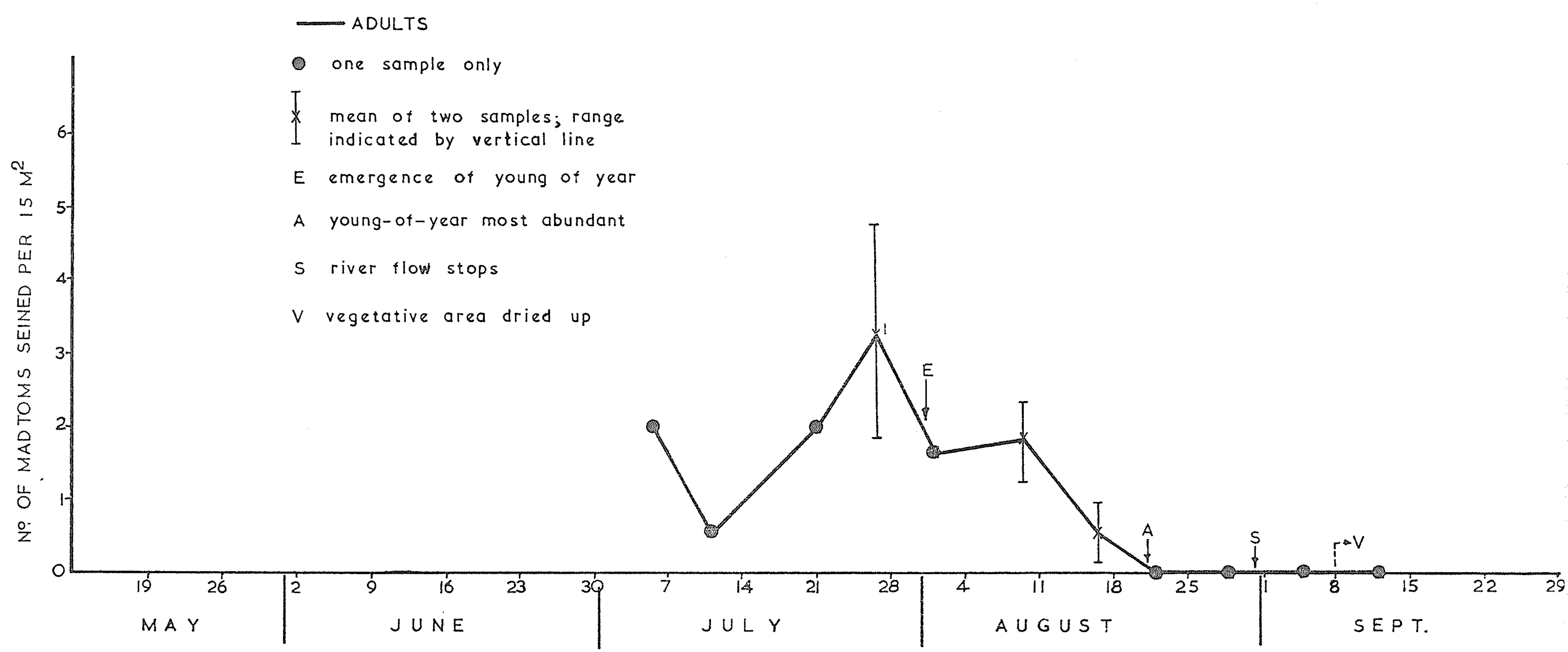

1967
1968
ADULTS
one sample only
mean of two samples;
range indicated by vertical line
E emergence of young-of-year
A young-of-year most abundant
S river flow stops
V vegetative area dried up
Nº OF MADTOMS SEINED PER 15 M²
0
1
2
3
4
5
6
19
26
2
9
16
23
30
7
14
21
28
4
11
18
25
1
8
15
22
MAY
JUNE
JULY
AUGUST
SEPT.
E
A
S
V

Fig. 9: Catch per unit effort - Station 4(b), 1967-1968.

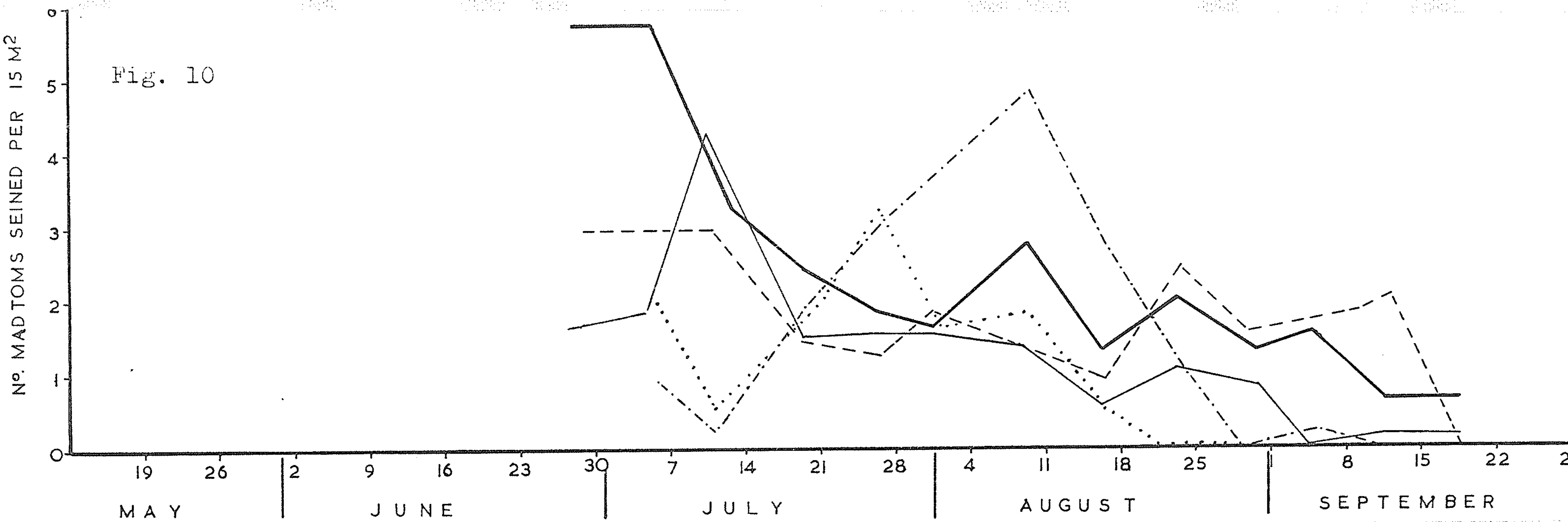


ADULTS
one sample only
mean of two samples; range indicated by vertical line
E emergence of young of year
A young-of-year most abundant
S river flow stops
V vegetative area dried up
No. OF MADTOMS SEINED PER 15 M²
0
1
2
3
4
5
6
19
26
2
9
16
23
30
7
14
21
28
4
11
18
25
1
8
15
22
29
MAY
JUNE
JULY
AUGUST
SEPT.
E
A
S
V

Fig. 10: Catch per unit effort at all sampling stations - 1967 (using weekly means).

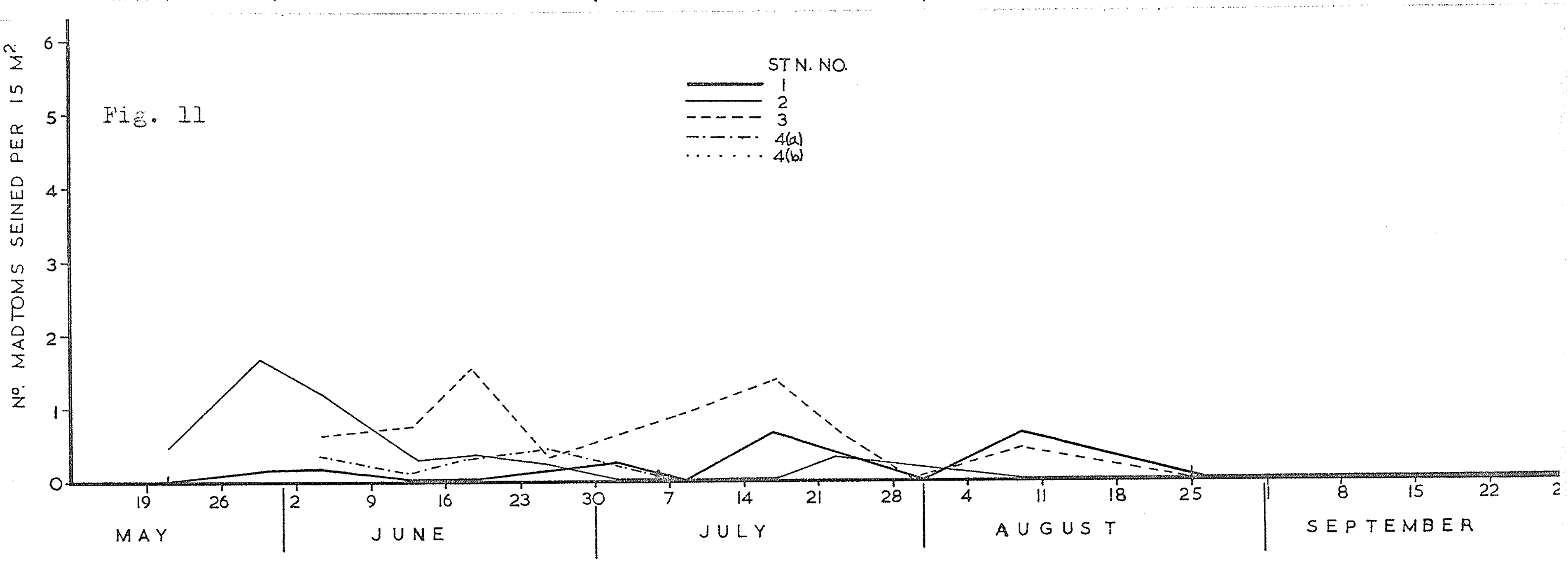
Fig. 11: Catch per unit effort at all sampling stations - 1968 (using weekly mean).

Fig. 10



Nº. MADTOMS SEINED PER 15 M²
0
1
2
3
4
5
6
19
26
2
9
16
23
30
7
14
21
28
4
11
18
25
1
8
15
22
29
MAY
JUNE
JULY
AUGUST
SEPTEMBER


Fig. 11



Nº. MADTOMS SEINED PER 15 M²
STN. NO.
1
2
3
4(a)
4(b)
0
1
2
3
4
5
6
19
26
2
9
16
23
30
7
14
21
28
4
11
18
25
1
8
15
22
29
MAY
JUNE
JULY
AUGUST
SEPTEMBER

of Hyalella azteca than river samples. Evidence of parasitism by nematodes and trematodes was found only in 1968 Rat River samples. Vegetable material may have been ingested incidentally while browsing for other food items. The percentage of empty stomachs was consistent for both river and reservoir samples.

The main method of feeding observed in the laboratory was browsing on the substrate. Some feeding at the surface occurred when food was first introduced into aquaria. Tadpole madtoms withstood extended periods of time without food in cold water in the laboratory, with no obvious detrimental effects.

B. Breeding Habits

Attempts to observe spawning behaviour or egg clusters proved fruitless during both the 1967 and 1968 sampling periods. See Table I for observations of breeding in N. gyrinus recorded in the literature.

C. Age Classes

Aging attempts by the vertebral ring method (Hooper, 1949) and by otolith readings were unsuccessful, probably due to length of time specimens had been preserved in formaldehyde before aging was attempted. As a result, age class determination was based on limited length-frequency data and by extrapolation from Hooper's (1949) aging data.

TABLE VII: Stomach contents of *Noturus gyrinus*, 1967 and 1968

| Food Items | 1967 Rat River–23 samples 1 | 2 | 3 | 1968 Rat River–19 samples 1 | 2 | 3 | 1968 St. Malo–19 samples 1 Res. | 2 | 3 |
|---|---|---|---|---|---|---|---|---|---|
| CRUSTACEA | 37 | 10 | 43.5 | 10 | 8 | 42.1 | 36 | 11 | 57.9 |
| Amphipoda: *Hyalella azteca* | 27 | 6 | 26.1 | 4 | 2 | 10.5 | 34 | 9 | 47.3 |
| *Gammarus sp.* | 1 | 1 | 4.3 | 0 | 0 | 0 | 0 | 0 | 0 |
| Cladocera: *Daphnia pulex* | 8 | 2 | 8.7 | 6 | 2 | 10.5 | 1 | 2 | 10.5 |
| Clad. larvae | 1 | 1 | 4.3 | 0 | 0 | 0 | 0 | 0 | 0 |
| Decapoda: *Orconectes virilis* | 0 | 0 | 0 | 0 | 0 | 0 | 1[claw] | 1 | 5.3 |
| INSECTA | 30 | 12 | 52.2(i) | 5 | 13 | 68.4 | 1 | 1 | 5.3 |
| Diptera: chironomids | 9 | 4 | 17.4 | 3 | 3 | 15.8 | 0 | 0 | 0 |
| Other dipterans | 19 | 8 | 34.8 | 1 | 1 | 5.3 | 0 | 0 | 0 |
| Coleoptera: Dytiscids | 0 | 0 | 0 | ?(ii) | 2 | 10.5 | 0 | 0 | 0 |
| Other coleopterans | 1 | 1 | 4.3 | 1 | 1 | 5.3 | 0 | 0 | 0 |
| Ephemoptera: may-flies | 1 | 1 | 4.3 | 0 | 0 | 0 | 0 | 0 | 0 |
| VERTEBRATES (FISH) | | | | | | | | | |
| Darter (*Etheostoma nigrum*) | 1) | 2 | 8.7 | 0 | 0 | 0 | 0 | 0 | 0 |
| Sucker (*Catostomus commersoni*) | 1) | | | | | | | | |
| MISCELLANEOUS | | | | | | | | | |
| Parasites: Nematodes | 0 | 0 | 0 | 9 | 4 | 21.1 | 0 | 0 | 0 |
| Trematodes | 0 | 0 | 0 | 2 | 1 | 5.3 | 0 | 0 | 0 |
| Vegetable Material | - | 4 | 17.4 | - | 4 | 21.1 | - | 1 | 5.3 |
| Empty | - | 7 | 30.4 | - | 5 | 26.3 | - | 5 | 26.3 |

1. Total number food items.
2. Number stomachs containing food items.
3. Percentage of stomachs containing food items.

(i) Includes fragments of unidentified insects.

(ii) Fragments only.

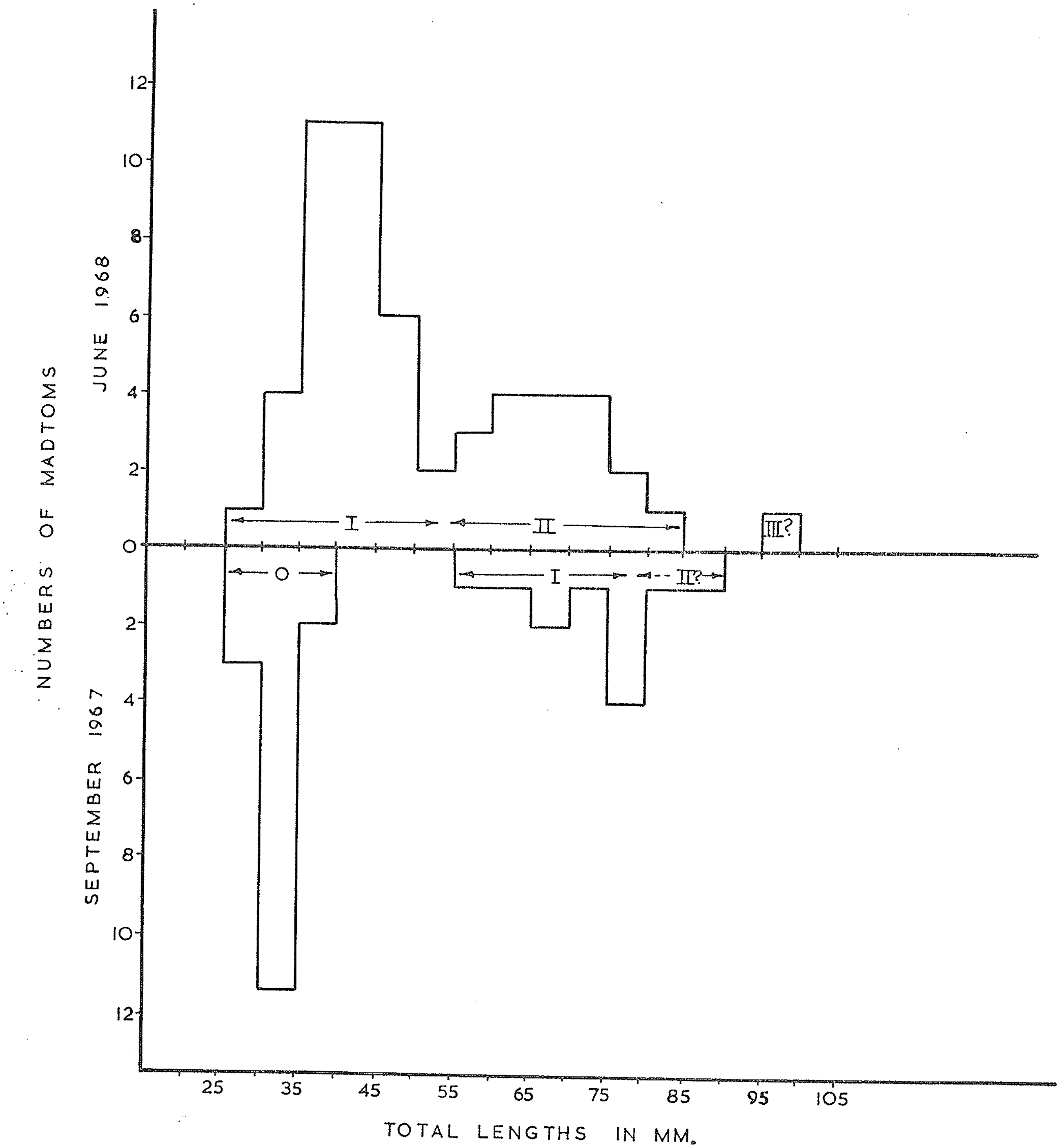
Figure 12 shows length-frequency data for N. gyrinus specimens captured in September, 1967 and June, 1968. Therefore, the data can be considered as a comparison of spring and fall fish lengths between two successive years. Three distinct age groups are evident.

Young-of-year madtoms (Year 0) which emerged in early August were easily recognized by their smaller size (size range 28 to 40 mm.; mode of 33 mm.). The Year 0 group is distinct in Fig. 12 (September, 1967 captures).

Year I N. gyrinus captured in June, 1968 (range of 28 to 50 mm.; mode of 40 mm.) were a second distinct group. This size group would be the previous year's young-of-year, and therefore indicates very little growth during the months of September through June. It can be extropolated that Year I adults grow considerably between June (mode 40 mm.) and September (mode 77 mm.).

Another fairly distinct size group in 1968 (range of 56 to 85 mm.) probably consists of Year II adults. The number of madtoms of length greater than 85 mm. was limited in both 1967 and 1968, particularly towards the end of the sampling periods (maximum recorded length of Rat River specimens was 108 mm.) These may be regarded as large Year II adults or possibly older. Gravid females captured June 29, 1967 and July 16, 1968 ranged in length from 79 to 93 mm. Therefore it is probably that sexual maturity, in females at

Fig. 12: Length-frequency data for *Noturus gyrinus* in two consecutive years. Probable year classes are indicated by Roman numerals. All data in class intervals of 5 mm. (26 - 30, 31 - 35 etc.).



NUMBERS OF MADTOMS
JUNE 1968
SEPTEMBER 1967
12
10
8
6
4
2
0
2
4
6
8
10
12
I
II
III?
O
I
II?
25
35
45
55
65
75
85
95
105
TOTAL LENGTHS IN MM.

least, is not reached until Year II. Mortality following spawning is also indicated by catch per unit effort data.

D. Predators

Stomach analysis of the 40 young northern pike (*Esox lucius*) which were seined in madtom habitat yielded a great variety of food items. These included insects (both larvae and adults), amphipods, young crayfish (*Orconectes virilis*), mudminnows (*Umbra limi*), young white suckers (*Catostomus commersoni*), and one 70 mm. tadpole (*Rana pipiens*). However, no tadpole madtoms (*N. gyrinus*) were found in the stomachs.

Young northern pike (*Esox lucius*) were held and starved in laboratory aquaria along with several indiginous Rat River fishes, including madtoms. The *E. lucius* specimens devoured all the other fish except the madtoms within two weeks, then reverted to cannibalism until only one pike remained. This one pike lived with both fin-clipped and unmarked madtoms in the same aquarium for five weeks with no incidence of predation on the adults. However, one young-of-year *N. gyrinus* in the same aquarium disappeared, presumably devoured by the pike.

E. Defence

The typical defence posture exhibited by *N. gyrinus* when handled was arching of the back and erection of the dorsal and pectoral spines. Thus spines pointed out in three directions. Effects of toxin directly injected from pectoral spines of live N. gyrinus into lateral musculature of other fish are summarized below.

A sauger (Stizostedium canadense) exhibited slowed responses to prodding with a stick; full recovery occurred within five hours. A rainbow trout fry (Salmo gairdneri) turned on its side for a few minutes immediately following injection. Its evasive responses to gentle prodding were slowed for about one hour; full recovery took place within five hours. The Northern pike (Esox lucius) of 30 cm. length was most severely affected by injection of madtom toxin. It exhibited laboured respiratory movements and turned belly-up after 15 minutes. Full recovery took twelve hours.

## DISCUSSION

### Movements

Mark-recapture data indicated that movements of tadpole madtoms were limited, both within each sampling season and between sampling seasons. The only recorded instance of extensive movement during the two summer sampling periods was that of 2.2 km (1.4 miles) by one specimen during the summer of 1967 (Fig. 4). Most frequent movement in 1967 was between station 4(b) and 4(a), a distance of about 9 meters, by three adult madtoms. There was no recorded movement of madtoms between stations during the 1968 sampling period. In addition, there was no evidence of movements of marked young-of-year madtoms during either 1967 or 1968 sampling periods.

Seining in the area of the Rat River between stations 1 and 2 in both 1967 and 1968 yielded no marked fish from either station, indicating that madtoms were not emigrating from the sampling stations into this area. However, six of nineteen fish seined in this area, specially marked with thread tag, and returned to the same area in 1967 were recaptured at station 1, suggesting immigration from this between-station area upstream into station 1. The fact that sample size (Ct) did not drastically increase at station 1 or 2 during sampling period (Appendix I) further suggests that immigration into these two sampling stations was not widespread. The relatively high recapture rates at these two stations in 1967 (Table IV) supports this contention, since immigration of unmarked fish into the sampling stations would tend to increase sample size but lower rate of recapture. Mark-recapture data of 1968 indicated neither immigration or emigration in this area of the Rat River. Conversely, at stations 4(a) and 4(b) during the 1967 sampling period, the adult population levels increased sharply before emergence of young-of-year (Figs. 8 and 9). The lower rate of recapture at these sites, particularly station 4(a) (Table IV) may indicate a more extensive movement of madtoms into these preferred habitats from immediately surrounding vegetation.

Of the eleven 1967 fin-clipped madtoms recaptured in 1968 (1.4 per cent of the 1967 marked total), two had moved from one station to another, distances of nine meters and 52 meters respectively (Table VI and Fig. 4). The remainder were captured at their 1967 marking site. These data suggest that madtoms may occupy the same habitat during both summer and winter. The isolation of stations 4(a) and 4(b) by low water levels in the fall of 1967 (Plate 3) may have confined the surviving madtoms to these areas for the winter. The capture of N. gyrinus specimens in vegetative detritus of the Rat River on March 16, 1969 and February 7, 1970 near stations 2 and 1 respectively supports the contention that madtoms overwinter in the vicinity of their summer habitat.

The laboratory observations give some indication of the manner in which tadpole madtoms respond to a winter environment. At temperatures below 3.5°C these animals may enter a state of torpor which enables them to endure the sometimes adverse winter conditions. Temperatures increasing from 3.5°C probably stimulate the fish to resume normal activities.

Using mark-recapture data primarily from set sampling stations established in the most apparently favourable habitat may lead to an inherent bias in favor of restricted movement (Funk, 1955). However, sampling the entire section of Rat River between the St. Malo dam and Highway 59 (Fig. 4) indicated a lack of both madtoms and suitable madtom habitat except at the regular sampling stations and the area between stations 1 and 2. Therefore this particular stream situation did not lend itself well to selection of sampling sites at random, which in other stream environments would possibly reduce the probability of biased data.

## Factors Affecting Movements

Several factors may have contributed to restricted movements of madtoms. First, they were found exclusively in heavy aquatic vegetation, obviously their preferred habitat. In the Rat River study area, the patches of aquatic vegetation were as a rule separated by large areas of little or no vegetation which may have acted as barriers to ventures into other suitable habitats. Even where there was a continuous bed of vegetation as between stations 1 and 2, there was little evidence of movement between stations, indicating that even where physical barriers to movements did not exist, movement did not occur in any significant amounts.

This extremely sedentary mode of life could not be attributed to territoriality, since laboratory specimens made no effort to establish and defend a territory, but instead tended to group together in any corner of the aquarium.

Predation as a factor in the madtoms' adherance to a sedentary existence in aquatic vegetation cannot be entirely discounted. However, stomach analysis and laboratory observations revealed that the northern pike (Esox lucius), a predator of most Rat River fish species, was not a predator on tadpole madtoms, even in aquaria with no vegetation. In fact, the effects of madtom toxin were more severe on the northern pike, apparently affecting the respiratory function, than on sauger (Stizostedium canadense) or the much smaller rainbow trout fry (Salmo gairdneri), neither of which are indiginous to the Rat River. No other fish of large enough size or numbers to be considered a threat as predators were found in N. gyrinus habitat or elsewhere in the study area. Neither predatory birds nor terrestrial animals were common near the Rat River study area. Also, the defence posture of N. gyrinus would appear to effectively thwart predation attempts. Therefore predation cannot be regarded as an important factor in the restricted movement (or decreased numbers) of tadpole madtoms.

Food supply may be an important factor restricting N. gyrinus to aquatic vegetation. Hyalella azteca (Saussure), the greatest single food source in the diet of tadpole madtoms examined in 1967 and 1968 (Table VII) is primarily a benthic animal, preferring Potomageton (pond weed) in shallow waters (Biette, M.S.). This plant was found in beds of aquatic vegetation at 3 of the 5 sampling stations in the Rat River. Vegetable fibres were present in almost 20 percent of river madtoms examined. Therefore it is probable that madtoms are restricted to aquatic vegetation since it provides habitat for their chief food supply, Hyalella. While vegetation may serve as part of the diet, it is possible that it is ingested incidentally during browsing.

## Populations

The two methods used to obtain information in regards to population levels (Schnabel census) and relative abundance and fluctuations (catch per unit effort) both required certain assumptions, discussed in the literature review.

The data indicate that population decreased in size during sampling, particularly in 1967. Therefore the main assumption for the Schnabel census, that the population does not change in size during sampling, was not satisfied. This fact alone renders the Schnabel estimates ambiguous.

During both sampling periods all previously unmarked madtoms seined were subsequently marked and returned to the population. Because of the evidence of limited movement, it is assumed that most N. gyrinus at each station were sampled at some time during each sampling period. Therefore the total numbers of 618 madtom adults marked in 1967 and 75 in 1968 indicate actual abundance for each year. The problem of recruitment within each sampling period distorting these totals was eliminated since young-of-year were easily differentiated from adults on the basis of size, and were not included in marked totals.

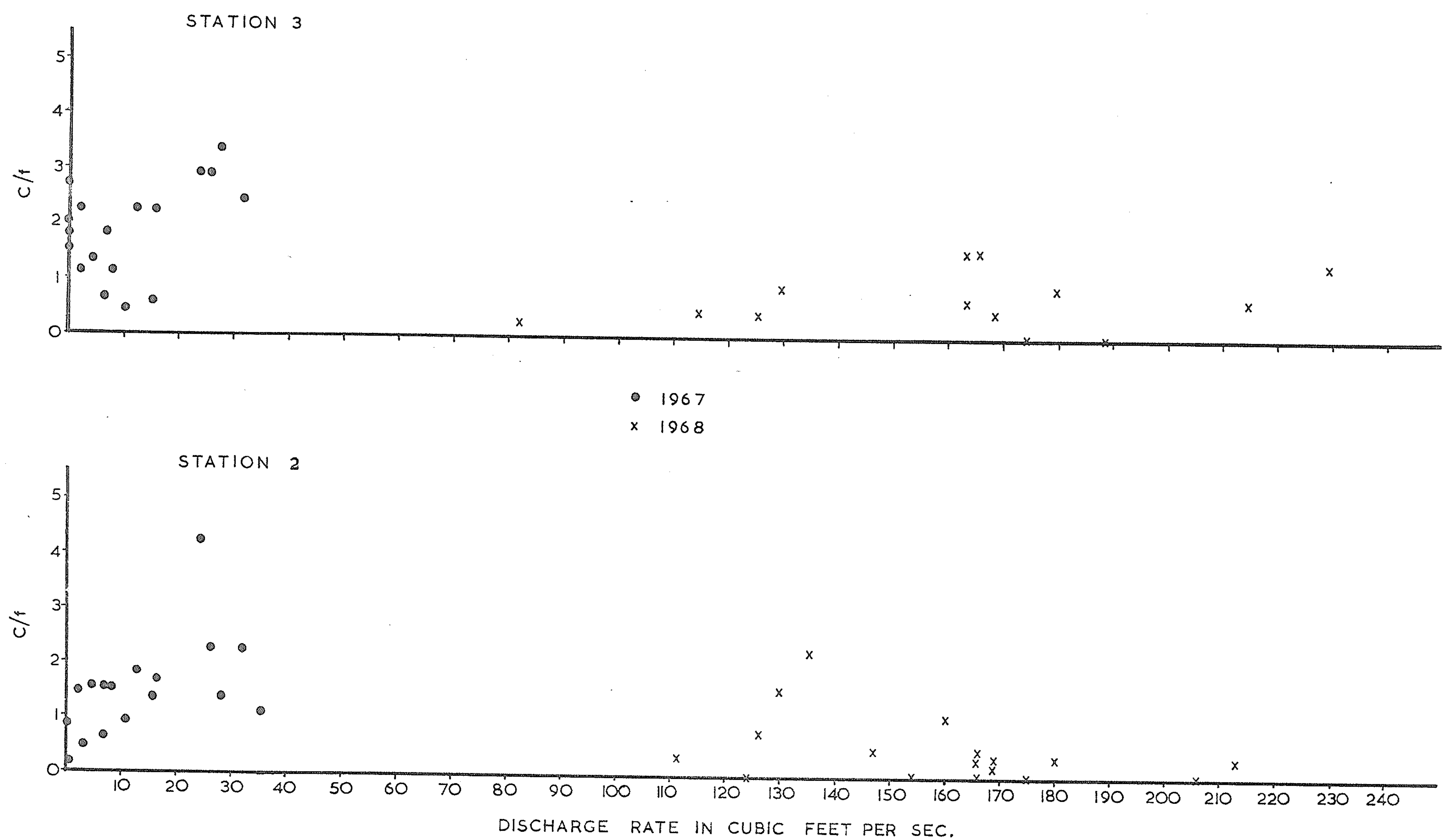
The catch per unit effort (C/f) method for determining relative abundance and fluctuations in population size is advantageous in that data are not distorted by changes in population levels, small sample size or small recapture rate. The main assumption for C/f data is that catchability is constant. Year to year changes in catchability are commonly caused by differences in distribution or behaviour of the fish, or variable effectiveness of the fishing gear because of weather conditions (Ricker, 1958). Mark-recapture data indicated very limited movements and restriction to heavy aquatic vegetation. Therefore distribution of N. gyrinus probably remained constant over the two year study period. Effects of repeated capture and release on the behaviour of madtoms were impossible to determine in the natural stream situation, but laboratory observations did not reveal any aberrant behaviour following handling and marking procedures. Since discharge rates were much greater during the 1968 sampling period than during 1967 (Fig. 1), it is possible that efficiency of the seining operations varied between the two years. No correlation between C/f data and discharge rate is evident, however (Fig. 13), so the possibility of changes in effectiveness of the fishing gear is not strong.

Catch per unit effort data for both 1967 and 1968 indicates considerable fluctuations in population levels, both within each sampling period as well as between 1967 and 1968. The following interprets in detail station-by-station results of catch per unit effort data, which are presented in graphs (Figs. 5 - 9).

Station No. 1 (Fig. 5)

The 1967 catch per unit effort indicates a marked initial drop in population during July, probably a result of intensive seining causing some habitat destruction, leading to some dispersal of madtoms into less disturbed habitat further up the adjacent ditch. Decrease in population level during August was less marked. This was possibly due in part to some immigration of madtoms into station 1 from the vegetated area between stations 1 and 2. The decrease in population was again more evident in September, probably due to environmental stress in the form of low water levels in the sampling areas

Fig. 13: Correlation of catch (C/f) with Rat River discharge rate at stations 2 and 3, 1967 - 1968.


STATION 3
C/f
5
4
3
2
1
0
1967
1968
STATION 2
C/f
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
160
170
180
190
200
210
220
230
240
DISCHARGE RATE IN CUBIC FEET PER SEC.

forcing emigration of madtoms from station 1 into the deeper waters of the heavily vegetated ditch, which served as a refuge area.

Population levels were drastically lower than 1967 levels at station 1 throughout the entire 1968 sampling period. Sample sizes in 1968 were too small to show any definite population trends at the station. No adult madtoms were seined after August 9, 1968.

Young-of-year madtoms were first observed here on August 22, 1967. No young were seined in 1968 at station 1, but two were seined between stations 1 and 2 on August 9.

Station No. 2 (Fig. 6)

With the exception of one unexplainably high catch on July 11, the 1967 population levelled off just prior to first observed emergence of young-of-year on August 1. This was followed by a general slow decrease in population level during August, with a marked decrease after river flow ceased on August 29.

Catch per unit effort of 1968, while much lower than that of 1967, shows some similarity in that it had one unexplained increase in population level at the beginning of the sampling period, followed by a general decline. In 1968, however, this decline reached zero by July 2 while in 1967 it did not reach zero population until September 5. No young-of-year were observed or seined at station 2 during 1968. It should be noted that in the area between stations 1 and 2, 23 adults and 2 young-of-year were seined on August 9, 1968, and a further 15 adults seined in the same area on September 27, 1968; indicating some recovery of the population.

Station No. 3 (Fig. 7)

This sampling station exhibited the greatest population fluctuations during both 1967 and 1968 sampling periods. Little explanation can be offered for the seemingly erratic fluctuations. It should be noted, however, that 1968 population levels, as with the previous two stations, were consistently lower than 1967 levels.

It may be hypothesized that in 1967 the initial decrease in population during July was the result of disturbed habitat by seining operations, leading to emigration of madtoms into the nearby deep pool which may have served as a refuge area. The increase in late August may be a reflection of increased food resources in the aquatic vegetation causing a greater density of madtoms in the sampling areas. The final decrease in 1967 population during September probably reflected both post-spawning mortality and emigration from the sampling area back into the refuge area because of environmental stress i.e. low water levels in areas of aquatic vegetation after the river flow ceased. Young-of-year were first seined on August 15, 1967.

Less explanation can be offered for the 1968 population fluctuations. No correlation exists between catch per unit effort at station 3 and Rat River flow rate data (Fig. 13); therefore fluctuations here cannot be explained on the basis of differences in efficiency of operation of the seine net in different flow rates and water levels of the river. The only basic trend obvious from 1968 population fluctuations at station 3 is that it drops off to zero by August 25, three weeks earlier than it did in 1967. No young-of-year madtoms were seined here during the 1968 sampling period.

<u>Stations No. 4(a) and 4(b)</u> (Figs. 8 and 9)

Both stations were similar in many respects, the sparse vegetative areas being in shallow water with no appreciable cover flora, and no readily available refuge areas or preferred habitat to which madtoms could migrate, unlike the previous three sampling stations. Catch per unit effort data were quite similar at both stations in 1967. Both exhibited a slight initial drop in population, probably due to disturbance of habitat resulting in some dispersal of madtoms into surrounding areas. This was followed by an increase in abundance of adults, probably by immigration from immediately surrounding areas, particularly at station 4(a), reflected by its large sample size but low rate of recapture during early August. At this same time, station 4(b) had a considerably higher rate of recapture and there was some evidence of a migration of madtoms from 4(b) to 4(a) (Fig. 4). During the latter part of August, 1967, adult populations dropped sharply at both sampling stations while at the same time young-of-year madtoms were becoming increasingly abundant. This decrease in adult populations corresponded with a steady drop in river level with resulting dessication of the aquatic vegetation serving as habitat. This probably accounts for the migration of some adults from station 4(b) to 4(a), since habitat of the latter lay in slightly deeper water and was therefore not as susceptible to dessication. The 1967 adult populations at both stations approached zero at the same time that young-of-year madtoms were most abundant at the end of August. River flow ceased entirely August 29, and by September 8 the entire vegetative area of station 4(b) was dried up with only a small fraction at 4(a) remaining under water (Plate 3).

The low population level at station 4(a) and complete absence of madtoms at 4(b) during 1968 reflects the severe mortality of 1967 young-of-year and adults caused by dessication of their habitat. From a total of 194 adults and 23 young-of-year fin-clipped at these two stations during 1967, only one was recaptured in 1968. These data support the contention that heavy mortality occurred in 1967. Shetter (1951) found that removal of pectoral fins of fingerling lake trout resulted in higher mortality. The fact that recapture rate within sampling periods was lower at stations 4(a) and 4(b), where pectoral clips were used, than at the other sampling stations may indicate higher mortality due to pectoral fin-clipping. However, it may also be attributed to greater degree of immigration into these two stations.

Absence of 1967 recaptures in 1968 was evidenced in the entire Rat River study area. Only 1.4 per cent of all madtoms marked in 1967 (both adults and young-of-year) were recaptured in 1968. This appears to be chiefly the result of environmental stress in the form of drought causing excessive mortality to the 1967 tadpole madtom population during the latter part of August and throughout September, 1967.

Another factor which must be considered in conjunction with population differences is efficiency of the seining operations in 1968. It was impossible to seine as quickly in the faster currents and higher water levels of 1968, therefore the efficiency of the seine net may have decreased. However, no correlation exists between 1968 water level/flow rate data and catch per unit effort in that sampling period (Figs. 1, 2, and 13).

The possibility that madtoms may have sought refuge from the fast current in 1968 by migrating into deeper pools (such as the ditch at station 1, and deep pools adjacent to stations 2 and 3), was not substantiated because of the inaccessability of these areas to sampling by either seining or electro-fishing techniques.

The foregoing indicates a close relationship between movements and population fluctuations. The fact that madtoms exhibited very restricted movement resulted in little reinvasion into areas which were severely depopulated from 1967 mortality. This was particularly evident at stations 1 and 2, where populations remained very low throughout 1968 although they were fairly abundant in the vegetated area between the two stations towards the end of the 1968 sampling period. Thus once populations were reduced by environmental stress in 1967, data of 1968 indicate very slow on complete lack of recovery of populations in the areas most severely depopulated.

Most of the minor fluctuations in populations within each sampling period were probably a result of both sampling error and short distance movements, including some immigration into preferred habitats for breeding and emigration out of sampling areas into refuge area due to disturbance from seining and during times of environmental stress, as occurred in 1967. The major downward fluctuations were a result of mortality, both natural and from the above-mentioned environmental stresses.

Different environments within the study area produced noticeably different trends in population fluctuations, again related to movements. For example, at stations 1 and 2 with their nearby refuge areas, the population levels generally decreased rapidly at first, then more slowly later in the sampling period. This was a reflection of rapid initial dispersal into refuge areas, followed by mortality and some emigration out of the stations as the river dried up. Stations 4(a) and 4(b), on the other hand, lacked refuge areas and had shallower vegetated areas. Here population generally increased during the first half of the 1967 sampling period, probably due to a concentration of madtoms in the most preferred habitat for breeding and survival of young. The later decrease to zero population was due to heavy mortality as their habitat quickly dried up and the vegetated areas became isolated from the rest of the river, thus cutting the fish off from any potential refuge elsewhere. The great fluctuations in populations at station 3 during both 1967 and 1968 were probably a reflection of movements in and out of the immediately accessible deep and heavily vegetated pool adjacent to both the main and side channels of this sampling area.

Fluctuations in populations as shown by catch per unit effort data if real were probably the result of limited movements in the vicinity of each station, as well as from mortality, both natural and stress-induced.

## SUMMARY

1. The tadpole madtom, *Noturus gyrinus*, was found exclusively in aquatic vegetation in the Rat River, Manitoba.

2. Movements of both adult and young-of-year tadpole madtoms during the summer are very restricted and over the winter negligible.

3. *N. gyrinus* apparently overwinter in vegetative detritus in the Rat River in the vicinity of their summer habitat. In the laboratory, madtoms tolerated water temperatures approaching 0°C with no obvious detrimental effects; there was no effort to burrow into the substrate at these low temperatures.

4. Population levels dropped drastically between 1967 and 1968 sampling periods. This was probably the result of severe drought during the late summer and early autumn of 1967 causing heavy mortality to both adult and young-of-year madtoms. Young-of-year were particularly affected since they emerged as habitat was being dessicated because of low water levels. Mortality of the latter was probably the chief cause of low 1968 population levels. Sampling difficulties due to high water levels and velocities in 1968 may have been a minor contributing factor to the lower 1968 catch per unit effort.

5. Fluctuations in population levels within each sampling period were probably caused by a combination of

factors, chiefly restricted movements in the vicinity of each sampling station and mortality, both natural and as a result of unfavorable environmental conditions in 1967.

6. Fin-clipping was a satisfactory marking method for the two year study period. It had no observable detrimental effects on the tadpole madtom.

7. Main food items of tadpole madtoms in the Rat River and reservoir were the amphipod *Hyalella azteca* and insects, chiefly dipterans, the former being the chief item. Since the preferred habitat of *Hyalella* is aquatic vegetation, particularly *Potomageton* in shallow waters, it is probably that this food item is a factor limiting madtoms to a hydrophytic habitat. No feeding was observed in the laboratory at water temperatures of less than 3.5$^{o}$C.

8. From length-frequency data there appear to be at least three distinct age classes of *N. gyrinus*.

9. No observations of predation on *N. gyrinus* by other fish, birds, or land vertebrates, was observed. The most abundant potential predator, the northern pike (*Esox lucius*) displayed a severe reaction to madtom venom injected directly into its lateral musculature. The defence posture, venomous spines, and cryptophyllic behaviour of madtoms probably rendered them immune to serious predation.

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APPENDIX I: Tables A – I. Summary of collection records for all sampling stations, 1967 and 1968 sampling periods, standard deviations and CV for weekly C/f data given where applicable.
Unweighted Schnabel estimates are indicated.

TABLE A: Station No. 1 - 1967 data

| Coll. No. | Date | Number Marked Mn | Marked Total Mt | Number Recaps. Rt | Total Sample Ct | M(t-1)Ct | Total Lgth. of Seine Hauls (meters) | No. Madtoms per $15M^2$ $\frac{Ct \times 6}{\text{seine haul lgth.}}$ | Weekly Ave. No. Madtoms per $15M^2$ | Standard Deviation | Coeff. variation $s/\bar{x}$ . 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 67/1/1 | June 26 | 22 | 22 | 0 | 22 | 0 | | | | | |
| 2 | 26 | 24 | 46 | 12 | 36 | 792 | 36.6m. | 5.90 | 5.83 | 0.0989 | 1.69% |
| 3 | 29 | 21 | 67 | 13 | 34 | 1564 | 36.6 | 5.76 | | | |
| 4 | July 4 | 13 | 80 | 12 | 25 | 1675 | 36.6 | 4.09 | 5.76 | 2.3617 | 40.97% |
| 5 | 6 | 16 | 96 | 18 | 34 | 2720 | 27.45 | 7.43 | | | |
| 6 | 11 | 6 | 102 | 14 | 20 | 1920 | 36.6 | 3.28 | 3.28 | | |
| 7 | 14 | --- | --- | --- | --- | --- | --- | | | | |
| 8 | 18 | 9 | 111 | 9 | 18 | 1836 | 36.6 | 2.95 | 2.46 | 0.6929 | 28.16% |
| 9 | 21 | 6 | 117 | 6 | 12 | 1332 | 36.6 | 1.97 | | | |
| 10 | 25 | 4 | 121 | 1 | 5 | 585 | 36.6 | 0.82 | 1.83 | 1.4283 | 78.14% |
| 11 | 28 | 6 | 127 | 7 | 13 | 1573 | 27.45 | 2.84 | | | |
| 12 | Aug. 1 | 6 | 133 | 4 | 10 | 1270 | 36.6 | 1.64 | 1.64 | | |
| 13 | 8 | 16 | 149 | 5 | 21 | 2793 | 36.6 | 3.44 | 2.79 | 0.9263 | 33.26% |
| 14 | 11 | 10 | 159 | 3 | 13 | 1937 | 36.6 | 2.13 | | | |
| 16 | 15 | 6 | 165 | 4 | 10 | 1590 | 36.6 | 1.64 | 1.31 | 0.4666 | 35.61% |
| 17 | 18 | 2 | 167 | 4 | 6 | 990 | 36.6 | 0.98 | | | |
| 18 | 22 | 6 | 173 | 3 | 9 | 1503 | 36.6 | 1.48 | 2.05 | 0.8061 | 39.32% |
| 19 | 25 | 7 | 180 | 3 | 10(12)* | 1730 | 27.45 | 2.62 | | | |
| 20 | 29 | 2 | 182 | 1 | 3(4) | 540 | 18.3 | 1.31 | 1.31 | | |
| 21 | Sept. 5 | 3 | 185 | 0 | 3(7) | 546 | 27.45 | 1.53 | 1.53 | | |
| 22 | 12 | 1 | 186 | 0 | 2 | 370 | 18.3 | 0.66 | 0.66 | | |
| 23 | 18 | 0 | 186 | 2 | 2 | 372 | 36.6 | 0.66 | 0.66 | | |
| Totals | | 186 | | 121 | 313 | 27638 | | | $\bar{x}$ = 2.52 | | $CV_{\bar{x}}$ = 36.74 |

df = 20 $\qquad \hat{N} = \frac{\sum M(t-1)Ct}{\sum Rt} = \frac{27638}{121} = 228.4$ (direct unweighted Schnabel census)

*Numbers in brackets indicate total sample, including madtoms tagged between stations 1 and 2 which migrated into station 1 and were used in catch per unit effort calculations but not in population estimates.

TABLE B: Station No. 2 - 1967 data

| Coll. No. | Date | Number Marked Mn | Marked Total Mt | Number Recaps. Rt | Total Sample Ct | M(t-1)Ct | Total Lgth. of Seine Hauls (meters) | No. Madtoms per $15M^2$ $\frac{Ct \times 6}{\text{seine haul lgth.}}$ | Weekly Ave. No. Madtoms per $15M^2$ | Standard Deviation(s) | Coeff. variatio $s/\bar{x}$ . 1C |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 67/1/2 | June 26 | 6 | 6 | 0 | 6(7) | 0 | 39.64 | 1.06 | | | |
| 2 | 26 | - | - | - | ---- | - | ------ | ---- | 1.67 | 0.8556 | 51.38% |
| 3 | 29 | 13 | 19 | 2 | 15 | 90 | 39.64 | 2.27 | | | |
| 4 | July 4 | 8 | 27 | 1 | 9 | 171 | 39.64 | 1.36 | 1.82 | 0.6435 | 35.45% |
| 5 | 6 | 11 | 38 | 4 | 15 | 405 | 39.64 | 2.27 | | | |
| 6 | 11 | 26 | 64 | 2 | 28 | 1064 | 39.64 | 4.24 | 4.24 | | |
| 8 | 18 | 8 | 72 | 3 | 11 | 704 | 39.64 | 1.66 | 1.51 | 0.2121 | 14.04% |
| 9 | 21 | 9 | 81 | 0 | 9 | 648 | 39.64 | 1.36 | | | |
| 10 | 25 | 7 | 88 | 3 | 10 | 810 | 39.64 | 1.51 | 1.51 | 0.00 | 0.00% |
| 11 | 28 | 8 | 96 | 2 | 10 | 880 | 39.64 | 1.51 | | | |
| 12 | Aug. 1 | 7 | 103 | 3 | 10 | 960 | 39.64 | 1.51 | 1.51 | | |
| 13 | 8 | 12 | 115 | 0 | 12 | 1236 | 39.64 | 1.82 | 1.37 | 0.6435 | 47.14% |
| 14 | 11 | 4 | 119 | 2 | 6 | 690 | 39.64 | 0.91 | | | |
| 16 | 15 | 4 | 123 | 0 | 4 | 476 | 39.64 | 0.61 | 0.53 | 0.1131 | 21.33% |
| 17 | 18 | 0 | 123 | 3 | 3 | 369 | 39.64 | 0.45 | | | |
| 18 | 22 | 11 | 134 | 1 | 12 | 1476 | 48.79 | 1.48 | 1.16 | 0.4525 | 39.00% |
| 19 | 25 | 2 | 136 | 1 | 3 | 402 | 21.34 | 0.84 | | | |
| 20 | 29 | 2 | 138 | 1 | 3 | 408 | 21.34 | 0.84 | 0.84 | | |
| 21 | Sept. 5 | 0 | 138 | 0 | 0 | --- | 39.64 | 0 | | | |
| 22 | 12 | 0 | 138 | 1 | 1 | 138 | 39.64 | 0.15 | 0.15 | | |
| 23 | 18 | 1 | 139 | 0 | 1 | 138 | 39.64 | 0.15 | 0.15 | | |
| Totals | | 139 | | 29 | | 11065 | | | $\bar{x}$ = 1.29 | | $CV_{\bar{x}}$ = 29.762 |

df = 19 unweighted $\hat{N} = \frac{11065}{29} = 381.5$

TABLE C: Station No. 3 - 1967 data

| Coll. No. | Date | Number Marked Mn | Marked Total Mt | Number Recaps. Rt | Total Sample Ct | M(t-1)Ct | Total Length of Seine Hauls (meters) | No. Madtoms per $15M^2$ $\frac{Ct \times 6}{\text{seine haul lgth.}}$ | Weekly Ave. No. Madtoms per $15M^2$ | Standard Deviation(s) | Coeff. variation $s/\bar{x} \cdot 100$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 67/3/3 | June 29 | 13 | 13 | 0 | 13 | 0 | 26.53 | 2.94 | 2.94 | | |
| 67/4/3 | July 4 | 12 | 25 | 3 | 15 | 195 | " | 3.39 | 2.94 | 0.6363 | 21.64% |
| 5 | 6 | 6 | 31 | 5 | 11 | 275 | " | 2.49 | | | |
| 6 | 11 | 9 | 40 | 4 | 13 | 403 | " | 2.94 | 2.94 | | |
| 8 | 18 | 3 | 43 | 7 | 10 | 400 | " | 2.26 | 1.47 | 1.1172 | 76.00% |
| 9 | 21 | 2 | 45 | 1 | 3 | 129 | " | 0.68 | | | |
| 10 | 25 | 2 | 47 | 3 | 5 | 225 | " | 1.13 | 1.25 | 0.1627 | 13.06% |
| 11 | 28 | 2 | 49 | 4 | 6 | 282 | " | 1.36 | | | |
| 12 | Aug. 1 | 7 | 56 | 1 | 8 | 392 | " | 1.81 | 1.81 | | |
| 13 | 8 | 5 | 61 | 5 | 10 | 560 | " | 2.26 | 1.36 | 1.2798 | 94.45% |
| 14 | 11 | 0 | 61 | 2 | 2 | 122 | " | 0.45 | | | |
| 16 | 15 | 2 | 63 | 1 | 3 | 183 | " | 0.68 | 0.91 | 0.3182 | 35.16% |
| 17 | 18 | 4 | 67 | 1 | 5 | 315 | " | 1.13 | | | |
| 18 | 22 | 7 | 74 | 3 | 10 | 670 | " | 2.26 | 2.49 | 0.3182 | 12.80% |
| 19 | 25 | 4 | 78 | 8 | 12 | 888 | " | 2.71 | | | |
| 20 | 29 | 6 | 84 | 1 | 7 | 546 | " | 1.58 | 1.58 | | |
| 21 | Sept. 9 | 8 | 92 | 0 | 8 | 672 | " | 1.81 | 1.81 | | |
| 22 | 12 | 7 | 99 | 2 | 9 | 828 | " | 2.04 | 2.04 | | |
| 23 | 18 | 0 | 99 | 0 | 0 | --- | " | 0 | 0 | | |
| Totals | | 99 | | 51 | | 7085 | | | $\bar{x} = 1.79$ | | $CV_{\bar{x}} = 42.18$ |

df = 18 unweighted $\hat{N} = \frac{7085}{51} = 139$

TABLE D: Station No. 4(a) - 1967 data

| Coll. No. | Date | Number Marked Mn | Marked Total Mt | Number Recaps. Rt | Total Sample Ct | M(t-1)Ct | Total Length of Seine Hauls (meters) | No. Madtoms per $15M^2$ Ct x 6 / seine haul lgth. | Weekly Ave. No. Madtoms per $15M^2$ | Standard Deviation(s) | Coeff. variatio $s/\bar{x}$ . 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 67/4/4(a) | July 4 | 1 | 1 | 0 | 1 | 0 | 26.52 | ---- | ---- | | |
| 5 | 6 | 3 | 4 | 1 | 4 | 4 | " | 0.90 | 0.90 | | |
| 6 | 11 | 1 | 5 | 0 | 1 | 4 | " | 0.23 | 0.23 | | |
| 8 | 18 | 4 | 9 | 1 | 5 | 25 | " | 1.13 | | | |
| 9 | 21 | 12 | 21 | 0 | 12 | 108 | " | 2.71 | 1.92 | 1.1172 | 58.18% |
| 10 | 25 | 8 | 29 | 5 | 13 | 273 | " | 2.94 | | | |
| 11 | 28 | 8 | 37 | 5 | 13(14)* | 377 | " | 3.17 | 3.06 | 0.1627 | 5.32% |
| 12 | Aug. 1 | 8 | 45 | 0 | 8(10) | 296 | " | 2.26 | 2.26 | | |
| 13 | 8 | 22 | 67 | 3 | 25 | 1125 | " | 5.66 | | | |
| 14 | 11 | 13 | 80 | 5 | 18 | 1206 | " | 4.07 | 4.87 | 1.1243 | 23.10% |
| 16 | 15 | 16 | 96 | 2 | 18 | 1440 | " | 4.07 | | | |
| 17 | 18 | 6 | 102 | 0 | 6 | 576 | " | 1.36 | 2.73 | 1.9162 | 70.57% |
| 18 | 22 | 4 | 106 | 0 | 4 | 408 | " | 0.90 | | | |
| 19 | 25 | 5 | 111 | 1 | 6 | 636 | " | 1.36 | 1.13 | 0.3252 | 28.77% |
| 20 | 29 | 0 | 111 | 0 | 0 | ---- | " | 0 | 0 | | |
| 21 | Sept. 5 | 1 | 112 | 0 | 1 | 111 | " | 0.23 | 0.23 | | |
| 22 | 12 | 0 | 112 | 0 | 0 | ---- | " | 0 | 0 | | |
| Totals | | 112 | | 23 | | 6589 | | | $\bar{x}$ = 2.19 | | $CV_{\bar{x}}$ = 37.188 |

df = 16 unweighted $\hat{N} = \frac{6589}{23} = 286.5$

*Numbers in brackets include marks from other stations, used in catch per unit effort calculations but not in population estimates.

TABLE E: Station No. 4(b) - 1967 data

| Coll. No. | Date | Number Marked Mn | Marked Total Mt | Number Recaps. Rt | Total Sample Ct | M(t-1)Ct | Total Lgth. of Seine Hauls | No. Madtoms per $15M^2$ | Weekly Ave. No. Madtoms per $15M^2$ | Standard Deviation(s) | Coeff. variation $s/\bar{x} \cdot 100$ |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | | | $\frac{Ct \times 6}{\text{seine haul lgth.}}$ | | | |
| 67/2/4(b) | June 26 | 11 | 11 | 0 | 11 | 0 | ? | --- | | | |
| 67/4/4(b) | July 4 | 5 | 16 | 1 | 6 | 66 | ? | --- | | | |
| 5 | 6 | 9 | 25 | 2 | 11 | 176 | 32.93m | 2.00 | 2.00 | | |
| 6 | 11 | 2 | 27 | 0 | 2 | 50 | 20.43 | 0.59 | 0.59 | | |
| 9 | 21 | 9 | 36 | 2 | 11 | 297 | 32.93 | 2.00 | 2.00 | | |
| 10 | 25 | 14 | 50 | 12 | 26 | 936 | " | 4.74 | 3.28 | 2.0647 | 62.94% |
| 11 | 28 | 7 | 57 | 3 | 10 | 500 | " | 1.82 | | | |
| 12 | Aug. 1 | 6 | 63 | 3 | 9 | 513 | " | 1.64 | 1.64 | | |
| 13 | 8 | 9 | 72 | 4 | 13 | 819 | " | 2.37 | 1.83 | 0.7707 | 42.23% |
| 14 | 11 | 4 | 76 | 2 | 6(7)* | 432 | " | 1.28 | | | |
| 16 | 15 | 5 | 81 | 0 | 5 | 380 | " | 0.91 | 0.55 | 0.5162 | 94.71% |
| 17 | 18 | 1 | 82 | 0 | 1 | 81 | " | 0.18 | | | |
| 18 | 22 | 0 | 82 | 0 | 0 | --- | " | 0 | 0 | 0.00 | 0.00 |
| 19 | 25 | 0 | 82 | 0 | 0 | --- | " | 0 | | | |
| 20 | 29 | 0 | 82 | 0 | 0 | --- | " | 0 | 0 | | |
| 21 | Sept. 5 | 0 | 82 | 0 | 0 | --- | " | 0 | 0 | | |
| 22 | 12 | 0 | 82 | 0 | 0 | --- | " | 0 | 0 | | |
| Totals | | 82 | | 29 | | 4250 | | | $\bar{x} = 1.17$ | | $CV_{\bar{x}} = 49.970$ |

df = 16 unweighted $\hat{N} = \frac{4250}{29} = 146.5$

*One station 4(a) mark not included in population estimates but used in catch per unit effort calculations.

TABLE F: Station No. 1 - 1968 data

| Coll. No. | Date | Number Marked Mn | Marked Total Mt | Number Recaps. Rt | Total Sample Ct | M(t-1)Ct | Total Lgth. of Seine Hauls (meters) | No. Madtoms per 15M² ($\frac{Ct \times 6}{\text{seine haul lgth.}}$) | Weekly Ave. No. Madtoms per 15M² |
|---|---|---|---|---|---|---|---|---|---|
| 68/1/1 | May 21 | 0 | 0 | 0 | 2 | - | 27.45 | 0.44 | 0.44 |
| 2 | 29 | 0 | 0 | 0 | 0 | - | " | 0 | 0.11 |
| 3 | 31 | 1 | 1 | 0 | 1 | - | " | 0.22 | |
| 4 | June 3 | 0 | 1 | 0 | 0 | - | " | 0 | 0.11 |
| 5 | 6 | 1 | 2 | 0 | 1 | 1 | " | 0.22 | |
| 6 | 11-12 | 0 | 2 | 0 | 0 | - | " | 0 | 0 |
| 7 | 13-14 | 0 | 2 | 0 | 0 | - | " | 0 | |
| 8 | 17-18 | 0 | 2 | 0 | 0 | - | " | 0 | 0 |
| 9 | 19-20 | 0 | 2 | 0 | 0 | - | " | 0 | |
| 10 | 24 | 0 | 2 | 0 | 0 | - | " | 0 | 0.11 |
| 11 | 26-27 | 1 | 3 | 0 | 1 | 2 | " | 0.22 | |
| 12 | July 2 | 1 | 4 | 0 | 1 | 3 | " | 0.22 | 0.22 |
| 13 | 8-9 | 0 | 4 | 0 | 0 | - | " | 0 | 0 |
| 14 | 16-18 | 1 | 5 | 1 | 2*(3) | 8 | " | 0.66 | 0.66 |
| [1] 15 | - | - | - | - | - | - | - | - | - |
| 16 | 31 | 0 | 5 | 0 | 0 | - | " | 0 | 0 |
| 17 | Aug. 9 | 0 | 5 | 0 | 3 | 15 | " | 0.66 | 0.66 |
| 18 | 26 | 0 | 5 | 0 | 0 | - | " | 0 | 0 |
| 19 | Sept. 27 | 0 | 5 | 0 | 0 | - | " | 0 | 0 |
| Totals | | 5 | | 1 | | 29 | | | |

df = 17 unweighted $\hat{N} = \frac{29}{1} = 29$

*Ct for population estimates does not include one 1967 recapture from station 2.

[1]No madtoms marked after Collection 14 (July 16).

TABLE G: Station No. 2 - 1968 data

| Coll. no. | Date | Number Marked Mn | Marked Total Mt | Number Recaps. Rt | Total Sample Ct | M(t-1)Ct | Total Lgth. of Seine Hauls (meters) | No. Madtoms per $15M^2$ Ct x 6 / seine haul lgth. | Weekly Ave. No. Madtoms per $15M^2$ | Standard Deviation(s) | Coeff. variation s/$\bar{x}$ . 100 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 68/1/1 | May 21 | 0 [1] | 1 | 1 * | 3 | --- | 39.64 | 0.45 | 0.45 | | |
| 2 | 29 | 0 [1] | 4 | 3 * | 7 | | " | 1.06 | 1.67 | 0.8556 | 51.38% |
| 3 | 31 | 9 | 15 | 6 * | 15 | 60 | " | 2.27 | | | |
| 4 | June 3 | 9 | 24 | 1 | 10 | 150 | " | 1.51 | 1.14 | 0.5303 | 46.72% |
| 5 | 6 | 3 | 27 | 2 * | 5 | 120 | " | 0.76 | | | |
| 6 | 11-12 | 1 | 28 | 1 | 2 | 54 | " | 0.30 | 0.30 | 0.00 | 0.00% |
| 7 | 13-14 | 1 | 29 | 1 | 2 | 56 | " | 0.30 | | | |
| 8 | 17-18 | 3 | 32 | 0 | 3 | 87 | " | 0.45 | 0.38 | 0.1063 | 28.34% |
| 9 | 19-20 | 1 | 33 | 1 * | 2 | 64 | " | 0.30 | | | |
| 10 | 24 | 1 | 34 | 0 | 1 | 33 | " | 0.15 | 0.23 | 0.1061 | 47.16% |
| 11 | 26-27 | 2 | 36 | 0 | 2 | 68 | " | 0.30 | | | |
| 12 | July 2 | 0 | 36 | 0 | 0 | 0 | " | 0 | 0 | | |
| 13 | 8-9 | 0 | 36 | 0 | 0 | 0 | " | 0 | 0 | | |
| 14 | 16-18 | 0 | 36 | 0 | 0 | 0 | " | 0 | 0 | | |
| 15 | 22 | 1 | 37 | 0 | 2 | 72 | " | 0.30 | 0.30 | | |
| 16 | 31 | - | --- | - | - | --- | | | | | |
| 17 | Aug. 9 | 0 | 37 | 0 | 0 | 0 | " | 0 | 0 | | |
| 18 | 26 | 0 | 37 | 0 | 0 | 0 | " | 0 | 0 | | |
| Totals | | 31 | | 16 | | 764 | | | $\bar{x}$ =0.48 | | $CV_{\bar{x}}$ = 34.72 |

df = 16 unweighted $\hat{N} = \frac{764}{16} = 47.75$

[1]All unmarked fish returned without fin-clipping on these two sampling days.

NOTE: 1967 clips recaptured in 1968 are included in population estimates. (Rt and Mt).

*indicates 1967 marks.

TABLE H: Station No. 3 - 1968 data

| Coll. No. | Date | Number Marked Mn | Marked Total Mt | Number Recaps. Rt | Total Sample Ct | M(t-1)Ct | Total Lgth. of Seine Hauls (meters) | No. Madtoms per 15M² $\frac{Ct \times 6}{\text{seine haul lgth.}}$ | Weekly Ave. No. Madtoms per 15M² | Standard Deviation(s) | Coeff. variatio s/$\bar{x}$ . 10 |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 68/1/3 | May 21 | 0 | 0 | 0 | 0 | --- | 26.53 | 0 | 0 | | |
| 2 | 29 | - | - | - | - | --- | " | - | | | |
| 3 | 31 | - | - | - | - | --- | " | - | | | |
| 4 | June 3 | 4 | 4 | 0 | 4 | --- | " | 0.90 | | | |
| 5 | 6 | 2 | 6 | 0 | 2 | 8 | " | 0.45 | 0.68 | 0.3182 | 47.14% |
| 6 | 11-12 | 3 | 9 | 1 | 4 | 24 | " | 0.90 | | | |
| 7 | 13-14 | 2 | 12 | 1*(1) | 3 | 27 | " | 0.68 | 0.79 | 0.1555 | 19.68% |
| 8 | 17-18 | 5 | 18 | 2*(1) | 7 | 84 | " | 1.58 | | | |
| 9 | 19-20 | 6 | 24 | 1*(1) | 7 | 126 | " | 1.58 | 1.58 | 0.00 | 0.00% |
| 10 | 24 | 2 | 26 | 0 | 2 | 48 | " | 0.45 | | | |
| 11 | 26-27 | 1 | 27 | 0 | 1 | 26 | " | 0.23 | 0.34 | 0.1555 | 45.73% |
| 12 | July 2 | 0 | 27 | 0 | 0 | -- | " | 0 | 0 | | |
| 13 | 8-9 | 4 | 31 | 0 | 4 | 108 | " | 0.90 | 0.90 | | |
| 14 | 16-18 | 0 | 31 | 0 | 6[1] | 186 | " | 1.36 | 1.36 | | |
| 15 | 22-24 | 0 | 31 | 0 | 3 | 93 | " | 0.68 | 0.68 | | |
| 16 | 31 | 0 | 31 | 0 | 0 | -- | " | 0 | 0 | | |
| 17 | Aug. 9 | 0 | 31 | 0 | 2 | 62 | " | 0.45 | 0.45 | | |
| 18 | 26 | 0 | 31 | 0 | 0 | -- | " | 0 | 0 | | |
| Totals | | 29 | | 5 | | 792 | | | $\bar{x}$ =0.635 | | $CV_{\bar{x}}$ = 28.13 |

df = 15 unweighted $\hat{N} = \frac{792}{5} = 158.4$

[1]No marking after July 9.

*Indicates 1967 station 3 recapture; number of 1967 marks in brackets.

TABLE I: Station 4(a) - 1968 data

| Coll. No. | Date | Number Marked Mn | Marked Total Mt | Number Recaps. Rt | Total Sample Ct | M(t-1)Ct | Total Lgth. of Seine Hauls (meters) | No. Madtoms per $15M^2$ $\frac{Ct \times 6}{\text{seine haul lgth.}}$ | Weekly Ave. No. Madtoms per $15M^2$ |
|---|---|---|---|---|---|---|---|---|---|
| 68/1/4(a) | May 21 | - | - | - | - | - | --- | --- | |
| 2 | 29 | - | - | - | - | - | --- | --- | |
| 3 | 31 | - | - | - | - | - | --- | --- | |
| 4 | June 3 | 3 | 3 | 0 | 3 | - | 26.52 | 0.68 | 0.34 |
| 5 | 6 | 0 | 3 | 0 | 0 | - | " | 0 | |
| 6 | 11-12 | 0 | 4 | 1 | 1* | 3 | " | 0.23 | 0.13 |
| 7 | 13-14 | 0 | 4 | 0 | 0 | - | " | 0 | |
| 8 | 17-18 | 3 | 7 | 0 | 3 | 12 | " | 0.68 | 0.34 |
| 9 | 19-20 | 0 | 7 | 0 | 0 | - | " | 0 | |
| 10 | 24 | 1 | 8 | 0 | 1 | 7 | " | 0.23 | 0.46 |
| 11 | 26-27 | 3 | 11 | 0 | 3 | 24 | " | 0.68 | |
| 12 | July 2 | 0 | 11 | 0 | 0 | - | " | 0 | 0 |
| 13 | 8-9 | 0 | 11 | 0 | 0 | - | " | 0 | 0 |
| 14 | 16-18 | 0 | 11 | 0 | 0 | - | " | 0 | 0 |
| 15 | 22-24 | - | - | - | - | - | " | - | |
| 16 | 31 | 0 | 11 | 0 | 0 | - | " | 0 | |
| Totals | | 10 | | 1 | | 46 | $\bar{\bar{x}} = 0.25$ | | |

df = 11 unweighted $\hat{N} = \frac{46}{1} = 46$

*Indicates 1967 station 4(a) clip.

APPENDIX II: Population estimates by the Schnabel census method, 1967 - 1968.
95% confidence intervals established by calculating $\widehat{1/N} \pm$ Est. S. E. and obtaining reciprocal values in table of reciprocals.

APPENDIX II: Schnabel Population Estimates

1967

| Stn. No. | Total Marked $\Sigma Mn$ | Total Recaps. $\Sigma Rt$ | $\Sigma(Ct\ Mt)$ | Est. Pop. $\left[\hat{N} = \frac{\Sigma(Ct\ Mt)}{\Sigma Rt}\right]$ | Reciprocal $\hat{1/N} = \frac{\Sigma Rt}{\Sigma(Ct\ Mt)}$ | $\sqrt{V \frac{\hat{1}}{N}}$ x t value (.025,df)= $\sqrt{\frac{\Sigma Rt}{(\Sigma Ct\ Mt)^2}}$ | Estimated S.E. | 95% C.I. |
|---|---|---|---|---|---|---|---|---|
| 1 | 186 | 121 | 27638 | 228 | $\frac{121}{27638}$ = .004378 | .000338 x 2.086 = | ± .000830 | 192-282 |
| 2 | 139 | 29 | 11065 | 382 | $\frac{29}{11065}$ = .002620 | .000486 x 2.093 = | ± .001017 | 275-624 |
| 3 | 99 | 51 | 7085 | 139 | $\frac{51}{7085}$ = .007198 | .001007 x 2.101 = | ± .002115 | 107-197 |
| 4(a) | 112 | 23 | 6589 | 287 | $\frac{23}{6589}$ = .003490 | .000727 x 2.120 = | ± .001541 | 199-513 |
| 4(b) | 82 | 29 | 4250 | 147 | $\frac{29}{4250}$ = .006823 | .001267 x 2.120 = | ± .002686 | 105-242 |
| Total | 618 | | | 1183 | | | | |

1968

| Stn. No. | Total Marked $\Sigma Mn$ | Total Recaps. $\Sigma Rt$ | $\Sigma(Ct\ Mt)$ | Est. Pop. | Reciprocal | $\sqrt{V \frac{\hat{1}}{N}}$ x t value (.025,df)= | Estimated S.E. | 95% C.I. |
|---|---|---|---|---|---|---|---|---|
| 1 | 5 | 1 | 29 | 29 | $\frac{1}{29}$ = .034482 | .034482 x 2.110 = | ± .072757 | 9 - greater than tabl value |
| 2 | 31 | 16 | 764 | 48 | $\frac{16}{764}$ = .020942 | .005235 x 2.120 = | ± .011098 | 3-102 |
| 3 | 29 | 5 | 792 | 158 | $\frac{5}{792}$ = .006313 | .002823 x 2.131 = | ± .006015 | 81-3356 |
| 4(a) | 10 | 1 | 46 | 46 | $\frac{1}{46}$ = .021739 | .021739 x 2.201 = | ± .047847 | 14- greater than table value |
| 4(b) | 0 | 0 | --- | --- | | | | |
| Totals | 75 | | | 281 | | | | |

95% confidence intervals established by calculating $\hat{1/N}$ ± Est. S. E. and obtaining reciprocal values in table of reciprocals.