Canadian Technical Report of
Fisheries and Aquatic Sciences 989

August 1981

GROWTH, SURVIVAL AND DISTRIBUTION OF *Gammarus lacustris* (CRUSTACEA - AMPHIPODA) STOCKED INTO PONDS

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This is the 132nd Technical Report
from the Western Region, Winnipeg

ERRATA SHEET

Mathias, J.A., and M. Papst. 1981. Growth, survival and distribution of *Gammarus lacustris* (Crustacea - Amphipoda) stocked into ~~lakes~~ ponds. Can. Tech. Rep. Fish. Aquat. Sci. 989: iv + 11 p.

The correct figure captions should read:

Figure 1. Fish pond designed for amphipod-trout food chain. Zone A is shallow, a refuge and production habitat for *G. lacustris*, Zone C is deeper, a cool-water habitat for *Salmo gairdneri*. Zones Band D are shallow pond margins.

Figure 2. Frequency distribution of *Gammarus lacustris* brood size. Mean, standard error and sample size are indicated. A. Pond population, June 2 and June 18 combined; B. Lake 100 population, May 30 and June 4, 13 and 16 combined.

Figure 3. Proportion of female *Gammarus lacustris* with broods, as a percentage of adult population (solid circles) and as percentage of female population (open triangles). Numbers in brackets indicate the percentage of broods which have developed to the juvenile stage. Sample sizes are indicated at top of graphs. A. Pond population. B. Lake 100 population.

Figure 4. Growth rate of adult and juvenile *Gammarus lacustris* in the pond (solid circles) and in Lake 100 (open triangles). Vertical lines indicate 95% confidence limits.

Figure 5. Mortality of *Gammarus Zacustris* in the pond. A. Eggs plus juveniles. Open circle, estimated egg density, solid circle, observed egg density; solid squares, observed juvenile densities. 8. Adults. Open circles, estimated adult densities; solid squares, observed adult densities. Percentage values are calculated mortality rates in percent per day.

Figure 6. Density of *Gammarus lacustris* adults (shaded bars) and juveniles (open bars) found in the four sampling zones. Note different scale for juveniles and adults. The relative area of each zone is shown as a percentage.

Cat. no. Fs 97-6/989 ISSN 0706-6457

Correct citation for this publication:

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ABSTRACT

Mathias, J.A., and M. Papst. 1981. Growth, survival and distribution of *Gammarus lacustris* (Crustacea - Amphipoda) stocked into ~~lakes~~ ponds. Can. Tech. Rep. Fish. Aquat. Sci. 989: iv + 11 p.

Gammarus lacustris was stocked at a density of 411 animals m^{-2} into a 1.8 ha pond with no fish predators. A high mortality rate of 8% da^{-1} was attributed to invertebrate predation. Growth rates and brood sizes of the stocked amphipods were similar to those of the parent population. Sex ratio, body size and reproductive stage of adult *G. lacustris* were biased by the harvest method and therefore differed between the stocked and parent populations. Stocking of *G. lacustris* into ponds as a food organism for fish is feasible if invertebrate predators can be controlled.

Key words: invertebrates; amphipods; growth; survival; stocking; pond; *Gammarus*.

RESUME

Mathias, J.A., and M. Papst. 1981. Growth, survival and distribution of *Gammarus lacustris* (Crustacea - Amphipoda) stocked into ~~lakes~~ ponds. Can. Tech. Rep. Fish. Aquat. Sci. 989: iv + 11 p.

L'experience a consiste à peupler de *Gammarus lacustris* un étang de 1.8 ha, à une densite de 411 gammares par m^2. L'etang ne contenait aucun poisson predateur. Le taux élevé de mortalite (8% par jour) a été attribue à l'action d'invertebres predateurs. La vitesse de croissance des gammares experimentaux et le nombre de petits de leurs femelles, ressemblent à ceux de la population cousine temoin. Les donnees sur la repartition sexuelle, la taille et le stade de reproduction chez le gammare adulte ont été faussées par la methode de recolte et, en consequence, different de celles relatives à la population temoin. Peupler les etangs de *Gammarus lacustris* pour les faire servir d'aliment aux poissons est donc faisable, à condition que l'on contrôle les invertébrés predateurs.

Mots-clés: invertebres; amphipodes; croissance; survie; peupler; etang; *Gammarus*.

INTRODUCTION

The amphipod *Gammarus lacustris lacustris* Sars is commonly found in lakes and ponds throughout the Hudson Bay drainage basin. It attains densities of up to 7000 per m^2 in small lakes on the Canadian prairies where there are no fish predators (Mathias, unpublished data). Johnson et al. (1970) suggested that *G. lacustris* production in these prairie lakes could form the basis for the free-ranging (extensive) culture of rainbow trout. Thousands of pothole lakes have since been used for trout culture. and several studies of trout food habits in these lakes have shown that *G. lacustris* makes up about 30% of the diet of larger trout (over 50 grams) in lakes where forage fish are not available as a food (Table 1). In some lakes, 40% to 70% of the stomach contents were composed of *G. lacustris*.

An alternative strategy for the use of *G. lacustris* would be to harvest them live (Mathias et al., MS) and either feed them live to trout under intensive culture. or use them as feed ingredient to replace more costly marine sources of animal protein (Lombard North Group 1973). The nutritional quality of *G. lacustris* as a fish food has been documented by Driver et al. (1974) and Kelso (1973), and high feed conversion efficiencies of rainbow trout, *Salmo gairdneri*, fed on live *G. lacustris* have been demonstrated by Mathias et a1. (in press).

The present paper addresses another strategy; that of stocking *G. lacustris* into special Ilbenthic production" fish ponds where they would establish reproducing populations and form the basis for the semi-intensive culture of rainbow trout. Ponds were designed to contain two distinct habitats; a large, central shallow-water area primarily for amphipods, and a surrounding deeper-water habitat primarily for trout. We hypothesized that the gammarids would colonize the central part of the pond, and as their population increased, move out into the trout habitat where they would be exposed to predation. Here we examine the growth, survival and distribution of *G. lacustris* stocked for the first year into the ponds in the absence of predatory fish.

METHOOS

The artificial pond is shOl;n in Fig. 1. Its surface area is 1.8 ha. The center of the pond (zone A) is at ground level and consists of productive prairie loam. The excavated portion of the pond (zones 8-D) is 2.8 m deep and is designed to be a cool-water refuge for a trout population. Its soils are clay and much less productive than surface soils. Prior to 1979, the pond had been drained during the winter to eliminate fish predators such as sticklebacks (*Culea inconstans* Kirtland) and fathead minnows (*PimephaZee promelas* Rafinesque). Ouring the summer of 1979, the pond was filled to a water depth of 30-40 em over the central area. This zone (zone A, Fig. 1) was covered by partially submerged terrestrial grasses which died off slowly during the summer. Aquatic vegetation in the littoral zones 8 and 0 extended only 2-2.5 m into the pond. *Potamogeton pectinatus* and *Myriophyllum exalbescens* were the dominant species. The pond bottom (zone C) was bare, with scattered patches of *Chara* sp. In the spring of 1979, a large number of sweep samples taken with fine-mesh dip net in zones A, B, C, and 0 of the pond produced only two *G. lacustris* adults and several *Hyalella a2teca*.

An estimated 7.6 x 10^6 *G. lacustris* (mean density, 411 individuals m^{-2}). were stocked into the pond between May 16 and June 14, 1979. The animals were harvested (see Mathias et a1. MS for methods) one to three days prior to stocking from lake 100 near Erickson, Manitoba (see Sarica 1975 and Sunde and Barica (1975) for lake description), held overnight in floating cages. They were then transported 400 km to the Rockwood Fish Hatchery and jettisoned through a fire hose into the pond. The amphipods were not damaged by the harvest or the transport technique (Mathias et a1. in press).

Quantitative core samples were taken from the pond three times during the summer to measure amphipod density, growth rate and distribution. The sampling was stratified into four zones (A, 8, C and 0, Fig. 1). Samples were allocated in the following way: zone A (54% of pond area), 32 cores; zone B (2.7% of pond area), 8 cores; zone D (3.4% of pond area), 8 cores. The cores wer.e a 10.2 cm diameter steel tube which could be pushed into the sediment by hand and used in water depths up to 1 m. In zone C (39.8% of pond area) which was deeper, 24 samples were taken with a multiple corer (Hamilton et al. 1970) which contained three, 5.1 cm diameter cores. The pond was divided into B equal sections and samples from each zone (A-D) Were allocated equally into the sections and pooled before analysis. Benthic sweep samples were taken from the pond with a fine-mesh dip net on June 2 and 18 to monitor reproductive condition and growth of adults.

A series of similar sweep samples were also taken from shallow water in lake 100 throughout the summer to compare the lake population and the stocked population of *G. lacustris*. Growth, sex ratio, population size structure and brood sizes were measured. Growth was measured as change in the head length, but expressed in terms of dry weight according to the following relationship: (log dry weight, mg) = 3.846 (log head length, mm) - 0.019, (r^2 = 0.98). The natural logarithm of dry weight was regressed against time in days, and the slope of the lines, multiplied by 100, taken as the size-specific growth rate in % dry body weight per day. Mortality was measured as 100 (In Nt - In No)/t, (where Nt and No are population densities at time t and time o. t days apart), and expressed as % of the population per day.

To assess the density of invertebrate predators in the pond, 3 quantitative sweep samples were taken on June 2. A fine-mesh dip net was used to sweep 1 m^2 areas of the pond bottom. The sediment, vegetation, and water column was swept repeatedly in each location.

RESULTS

REPRODUCTION

The average number of eggs carried by *G. lacustris* females during the first two weeks of June was similar in the pond and in lake 100 (Fig. 2), indicating that the stocking procedure did not interfere with the broods ($p<0.05$). However, brood sizes declined slightly with time. In the pond, the average brood size between June 2 and June 18, 16.2 eggs/female, was significantly smaller (t-test, $p<0.05$) than that on May 25 (20.2 eggs/female; Mathias et a1. MS). Similarly, in lake 100, the average brood size decreased between June 4 and June 16, although the difference was not statistically significant.

The variance of the brood size in the pond was not significantly different from that in lake 100 (Fig. 2; 2-tai1ed F ratio test).

The timing of the hatching of *G. laaustris* eggs can be characterized by the date on which 50% of broods are composed of juveniles. In lake 100, 50% of the eggs had hatched by June 14 (Fic. 38), while in the pond eggs hatched on about June 25 (Fig. 3A). Similarly, the timing of brood release in *G. lacustris* can be expressed as the date on which 50% of females have released their broods. In lake 100, brood release occurred on about June 16 (Fig. 28) while in the pond it occurred about 13 days later (Fig. 2A).

GROWTH

The growth rate of adult *G. lacustris* (0.3% dry weight day-I) in the fish pond and in lake 100 was similar (Fig. 4). A size-selective bias of the harvest procedure (Mathias et a1. MS) is reflected in the larger mean size of adults in the fish pond at all times during the summer.

The growth curves of juveniles in the fish pond and lake 100 were different (Fig. 4). In lake 100, the average growth rate (7 sampling dates) was 4.6% dry weight day-I. The apparent lag during the first week was presumably an artifact caused by continued recruitment of small animals into the population until June 25. In the fish pond, the early rapid increase in average weight probably resulted from a combination of high growth rates as well as size-selective predation by dytisicids, causing a bias toward the larger juveniles. Growth rates would have to be 16%-22% dry weight day-l to account for the apparent size increase between June 18 and 27. These are higher than any published values for amphipods. The smaller size variation of juveniles in the pond on June 27 and July 19 compared with that in lake 100 is consistent with the hypothesis of size-selective predation. (The large variance on June 18 resulted from a small sample size of 4 animals).

MORTALITY

Mortality of *G. lacustris* in the pond was high. The first quantitative sample taken on June 27 revealed that only 42 adults m-Z remained of the estimated 411 animals m-Z which had been stocked between May 17 and June 14. A mortality rate was estimated for the stocking period by fitting various mortality values to the density of animals stocked (indicated by the vertical lines in Fig. 58) and the measured adult density on June 27. A constant mortality rate of 8% day-' fit the data well (curved line, Fig. 58). The adult mortality rate decreased to 4.7% day-l between June 27 and July 19, and was negligible after that.

A high mortality rate was also characteristic of juveniles. A mortality rate of 7.7% day-I fitted the decline in the egg-p1us-juvenile density shown in Fig. SA. Egg density and juvenile density were combined for this estimate because eggs were hatching into juveniles during the period June 18-Ju1y 19 (Fig. 3A). The June 18 egg density (arrow, Fig. SA) is based on 100 adults m-Z (Fig. 5B) x Bl.5% of adults carrying broods (Fig. 4A) x 16 eggs per brood (Fig. 2A). There were no juveniles on June 18. On June 27 there were 643 juveniles m-Z in the pond popUlation (solid square, Fig. SA) plus an estimated 255 eggs m-Z. The density of eggs was estimated from the measured adult density, 42 m^{-2} (Fig. 5B), x 38% of adults carrying broods (Fig. 3A) x 16 individuals per brood. The July 19 and August 14 values are observed juvenile densities. From June IB to June 27, the B% mortality rate of adults would also apply to their broods, but from June 27 to August 19 juveniles became free swimming. An overall egg-p1us-juveni1e mortality rate of 7.7% day-I therefore suggests that the mortality rate of juveniles alone would be slightly lower than 7.7% day-I.

DISTRIBUTION

The density of *G. lacustris* in zones A, B, C and 0 of the pond is shown in Fig. 6. Two weeks after stocking (June 27), adult densities were highest in zones C and D and lowest in zone A. The distribution of juveniles on June 27 tended to reflect that of adults, except that juveniles were over-represented in zone A and under-represented in zone C. In later samples (July 19-August 14), adults moved away (or were eliminated) from zone D and moved centrally into zones A, Band C. Like adults. juveniles also moved into the pond center (zones A and B), but they avoided deep water (zone C), and their density remained relatively high in zone D.

The relative number of *G. lacustris* in each zone of the pond can be calculated by multiplying the density in each zone by the relative area of the zone.

PREDATORS

The average densities of *G. lacustris* and predators of *G. lacustris* found;n the pond on June 2 were as follows:

Group	Common Name	$\bar{X}$ no. m^{-2}
G. lacustris		102
Dytiscid ,arvae	(predaceous diving beetle)	21
Oytiscid adults		35
Notonectids	(back swimmers)	1
Zygoptera nymphs	(damselflies)	1

The sweep samples gave reasonable estimates of invertebrate densities since the amph;pod density agreed fairly well with the June 2 estimate from Fig. 58 (ca. 130 individuals m^{-2}).

Oytiscid larvae held in the laboratory consumed 2-4 adult *G. lacustris* per day, depending on size, when fed no other food.

DISCUSSION

REPRODIICTION

The harvest. transport and stocking procedures had no effect on the average number of eggs carried by female *G. lacustris* (Fig. 2), and recruitment of juveniles in the stocked population was unimpaired. The ratio of the density of juveniles in the pond to the mean density of adults,after completion of recruitment on July 19, was about 9 juveniles/adult. This is lower than the 12.8 juveniles/adult expected if each female on June 15 (females were 80% of the adult population; Fig. 3A) released 16 juveniles. but it compares well with other field studies. In 3 pothole lakes we have studied, the post-recruitment ratio of juveniles/adults ranged from 5-7 (Mathias. unpUblished data).

The slight decrease in brood size which was noted in the pond between May 25 and June 2-18 suggests that there is a tendency for eggs to be lost during the brooding period.

Gammarus lacustris in the pond released their broods about 13 days later than those in lakes 100. Presumably, eggs carried by femal es in the pond were at an earlier stage of development than those in lake 100. Water temperature was not a factor because the pond was about 2 C warmer than 100 (Mathias. unpublished data), and this would have accelerated the rate of egg development and advanced the time of brood release.

The amphipods were transferred from lake 100 to the pond continuously from May 17 until June 14 (Fig. 5), so that if there were no bias in the harvested population, females in lake 100 carrying advanced eggs or juveniles (i.e.• on June 13. Fig. 38) should have appeared in the pond with juveni·le broods on June 16 and contributed to earlier brood release. Presumably female *G. lacustris* which were captured from the harvest net in lake 100 were -in an earl ier stage of egg production, on average, than those sampled from the lake 100 population with a dip net. Reasons for this sort of bias are unclear, although the harvesting procedure is selective for other characteristics of *G. lacustris*, such as the sex ratio and size (Fig. 4 and Mathias et al. in press).

GROWTH

The growth rate of *G. lacustris* adul ts in the pond and in lake 100 is characteristic of other prairie lakes we have studied (Mathias, unpublished data). In other lakes. however, adults which have overwintered generally weigh more in the spring (approximately 7-10 mg dry weight) than animals in lake 100 and the pond. We attribute the smaller average adUlt size in lake 100 to crowding, since densities there appear higher than in other lake studies (Mathias, personal observation). The growth rate of juveniles in the pond (Fig. 4) is difficult to assess because the high juvenile mortality occurring from June 18 to July 19 (Fig. SA) probably removed smaller animals from the juvenile size distributions of June 27 and July 19, inflating the apparent growth rate. Nevertheless, the size attained by juveniles on August 13 indicates that growth in the pond is adequate to produce sexually mature adults by the following spring.

MORTALITY

The high mortal ity rate of *G. lacustl'is* juveniles in the pond is consistent with rates measured in prairie lakes (t.lathias, unpublished data). However, the period of highest mortality in natural lakes is generally shorter (10-14 days) than that observed in the pond (Fig. 5A). resulting in survival of a much larger fraction of the new cohort. The adult mortal ity rate of B% day -, in the pond was extremely high compared to rates of about 1% per day measured in natural ponds without fish (Mathias, unpubl ished data). It does compare, however, with rates of 8-10% day-l in prairie lakes where rainbow trout fingerlings have been stocked at high densities (0.5 fish m^{-2}). In the pond. where no fish were present. the mortality was attributed largely to invertebrate predation.

The ratio of the densities of all invertebrate predators to *G. lacustris* (0.56:1) in the pond was extremely high. The density of dytiscid larvae alone was easily sufficient to account for *G. lacustris* mortality during this period. At the maximum amphipod density of 200 m^{-2} (Fig. 5B). a mortality rate of 8% day^{-1} would imply a death rate of 16 adults m^{-2}, day^{-1}. The dytiscid larvae, at a density of 21 m^{-2} would have to consume less than one amphipod day-l to generate the observed mortality, whereas in the laboratory dytiscid larvae were capable of consuming an average of 2-4 *G. lacustris* day^{-1}.

DISTRIBUTION

The pond (Fig. 1) was designed to provide two habitats; a shallo\'/, warm-water area (zone A) for production of benthic invertebrates, and a deep-water area (zone C) for trout. It was hypothesized that juvenile *G. lacustris* would prefer the warm-water refuge where their growth would contribute to population production.

whereas the more active adults would move into deeper water and become vulnerable to trout predation. The habitat distribution of *G. lacustris* in the pond is compatible with this concept of a two-step amphipod-trout food chain. By mid August when pond-cultured trout begin to accumulate most of their body weight, 40% of adult amphipods were found in the trout habitat (zone C). Approximately 50% were found in the central production zone. At the same time, over 80% of juveniles were found in the production zone (A) and none in the trout habitat. At this time the It-year old adults are expendable in terms of population increase while the smaller juveniles will form the next season1s breeding stocks. The distribution pattern of *G. lacustris* in the pond could probably be improved further by stocking the amphipods directly into zone A rather than into zone D.

The central problem with stocking *G. lacustris* into ponds is the high mortality caused by invertebrate predators. Predator control must be initiated prior to stocking. A technique for controlling dytiscids and notonectids, used commonly by pond managers rearing bass fry, is to spray the water with an oil mixture (1 part cod-liver oil: 2-3 parts gasoline). The technique reportedly does not harm fish fry or crustaceans (Brown 1940; Kingsbury 1936). If predators can be controlled, the introduction of *G. lacustris* into ponds as a forage organism for fish appears feasible.

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Table 1. Percentage of *G. lacustris* by weight (by volume for N. Dakota lakes) in stomachs of rainbow trout, *Salmo gairdneri*. All trout were larger than 50 g and taken from lakes where forage fish were absent. N is the number of fish stomachs examined.

Region	Lake	Year	*G. lacustris*	N
Erickson, Manitoba	721[a]	1973	10.2	30
	721[a]	1974	19.3	24
	885[b]	1976	39.9	97
	255[b]	1976	33.6	119
North Dakota[c]	II	1971	73.9	18
	III	1971	16.7	18
	II	1972	9.7	22
	IV	1972	59.0	13
		Mean	32.8	

a Data from Bernard and Holmstrom (1978).

b Data from Tavarutmaneegul (1978).

c Data from Meyers (1973).

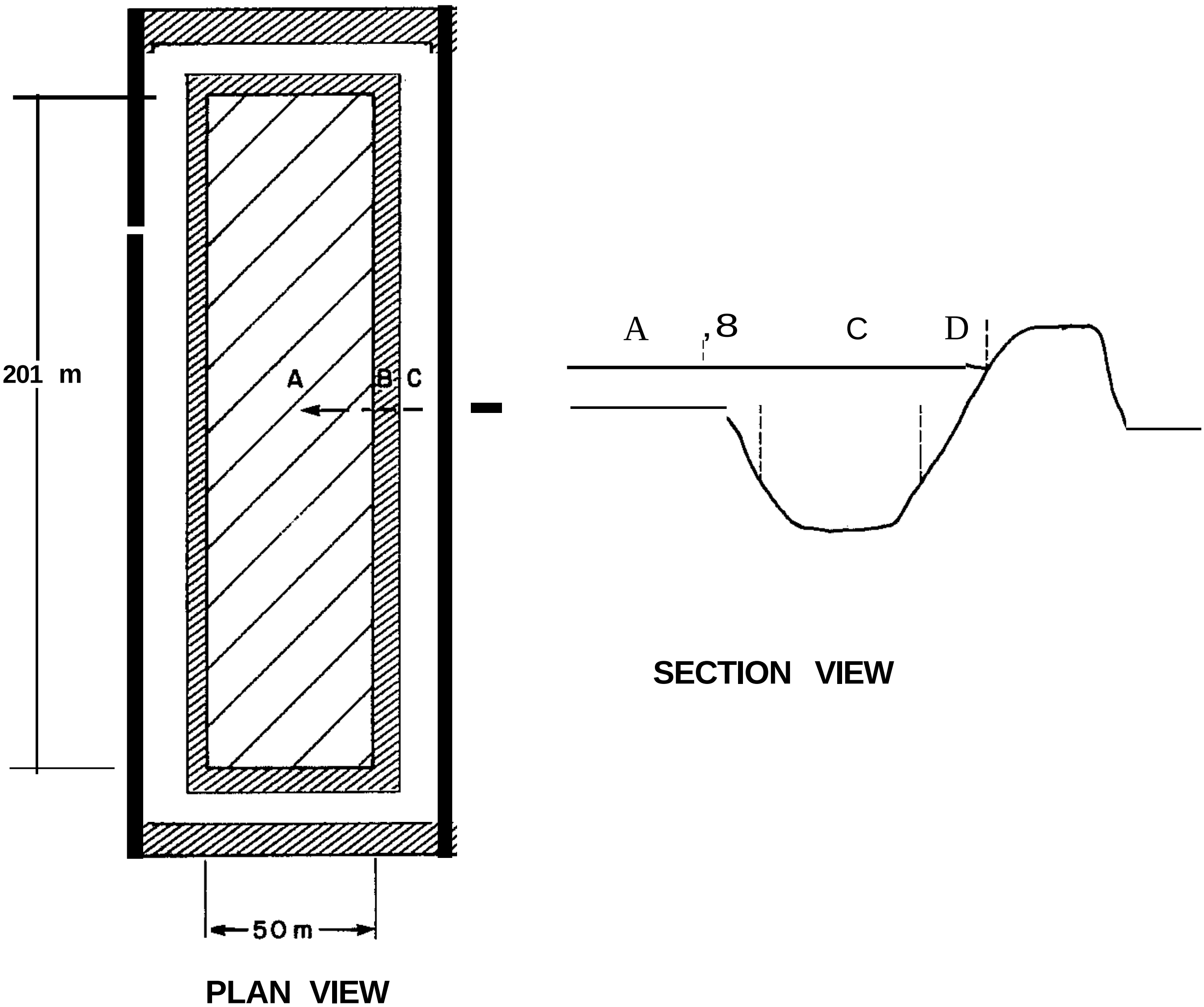

Fig. 1. Fish pond designed for amphipod-trout food chain.

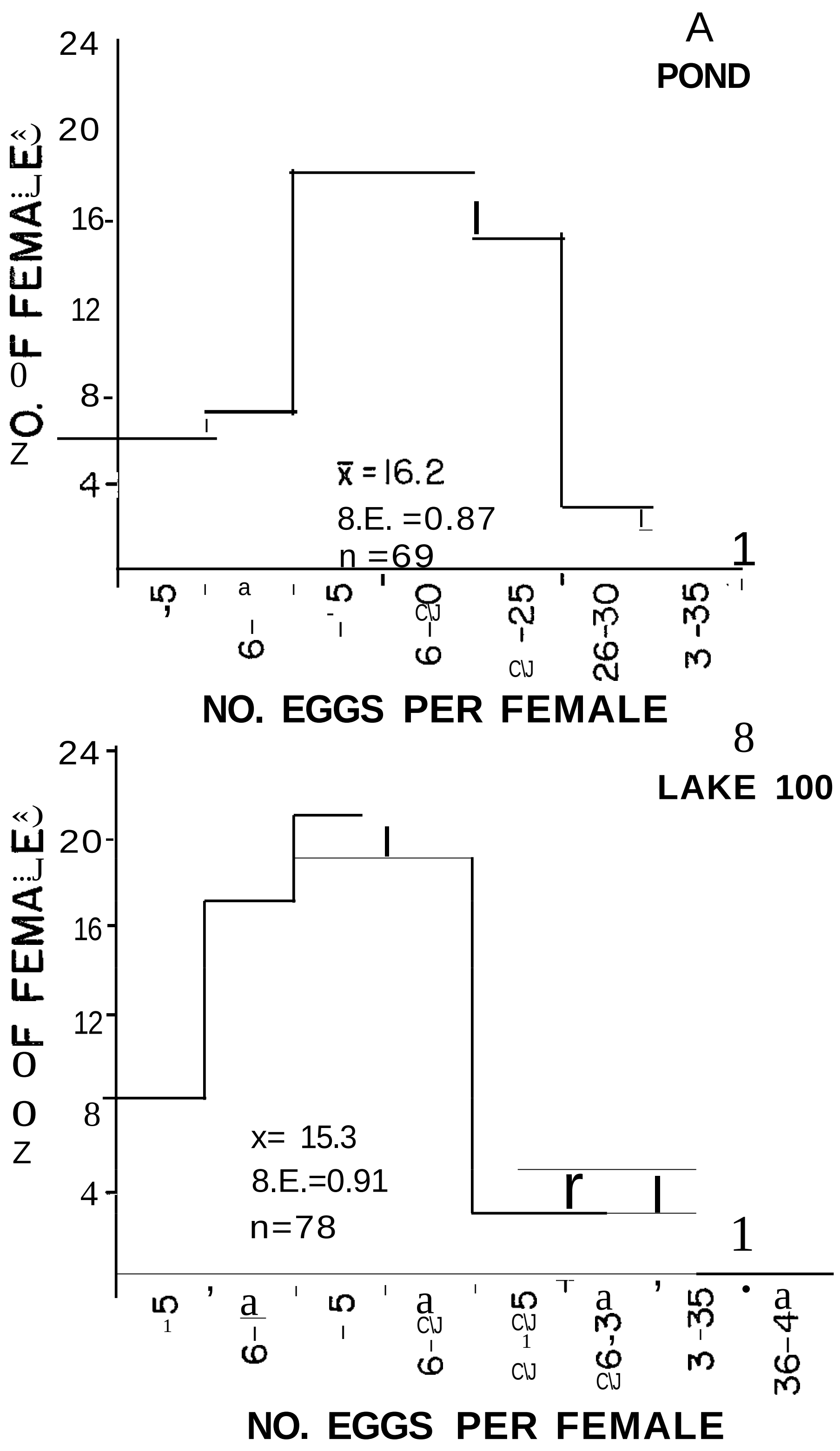

Fig. 2. Frequency distribution of *Gammarus lacustris* brood size.

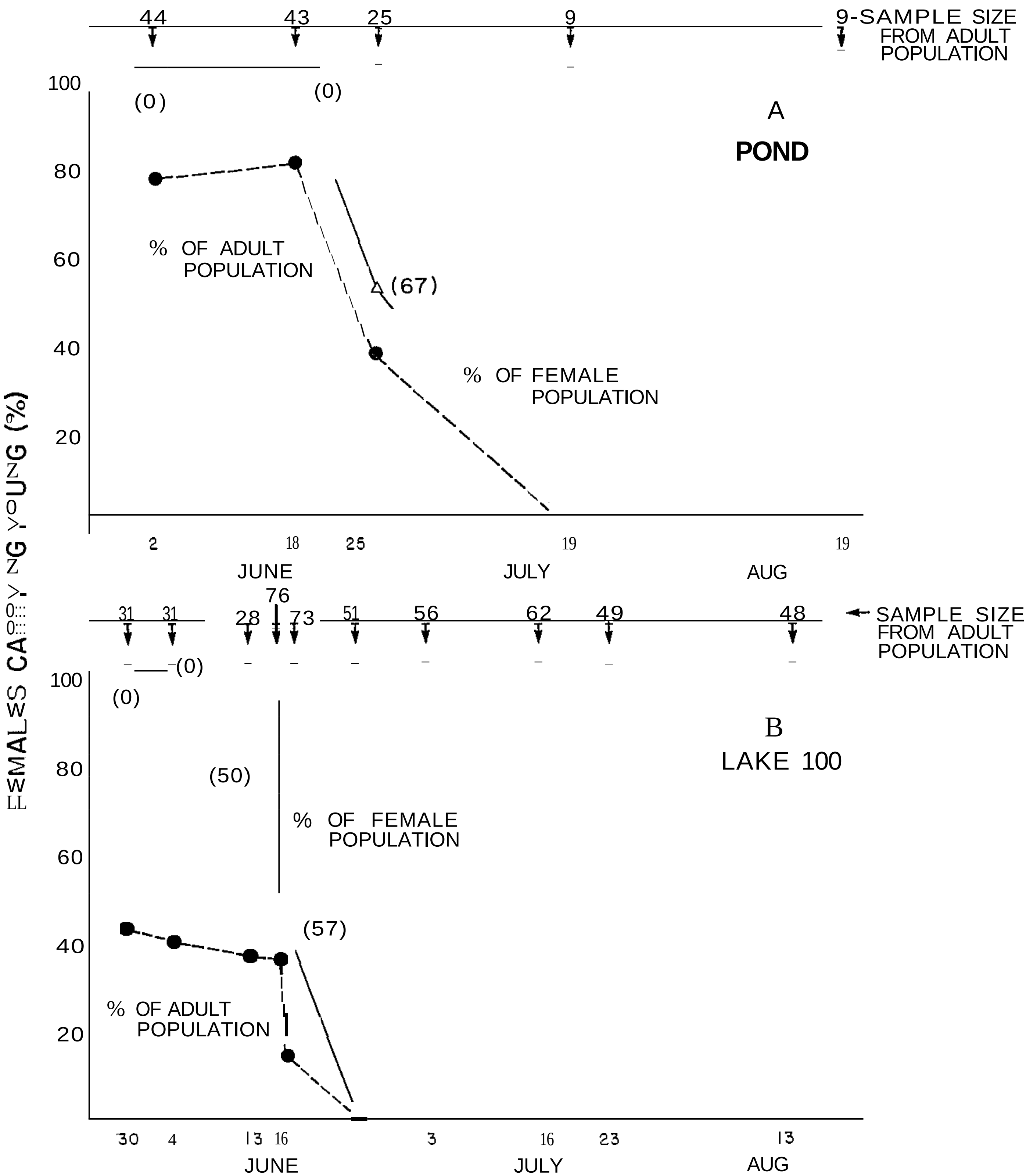

Fig. 3. Proportion of female *Gammarus lacustris* with broods.

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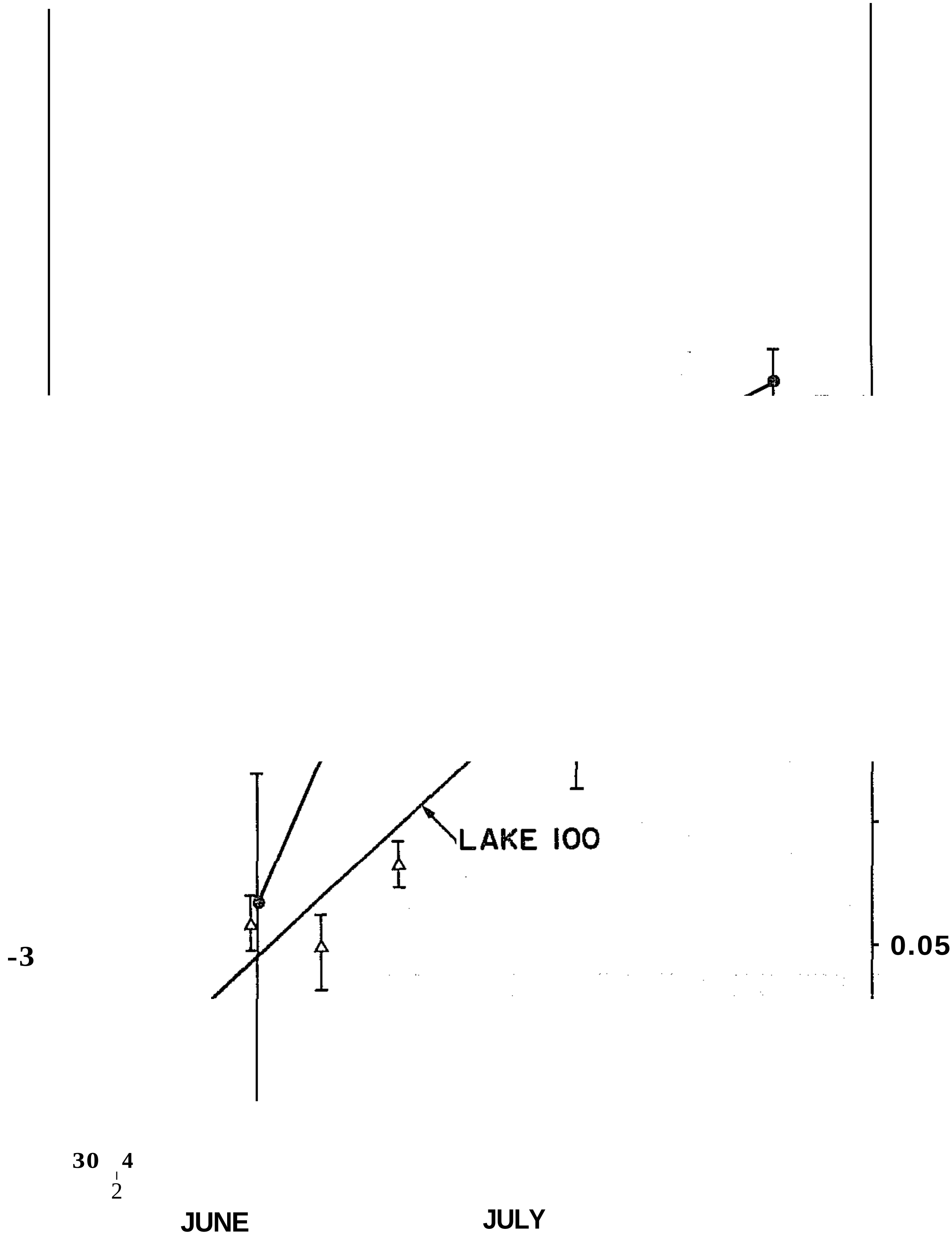

Fig. **4.** Growth rate of adult and juvenile *Gammarus lacustris*.

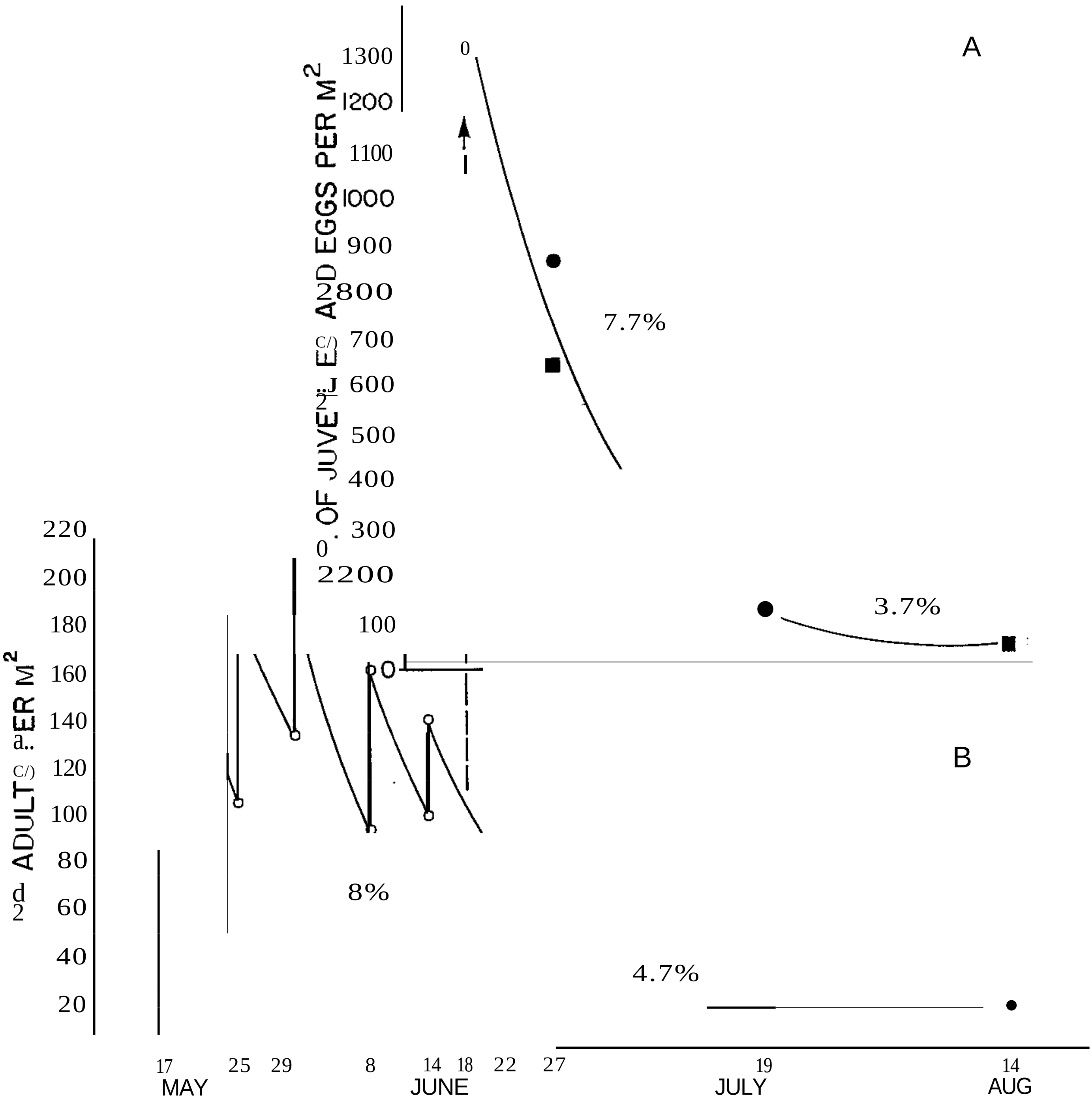

Fig. 5. Mortality of *Gammarus lacustris* in the pond.

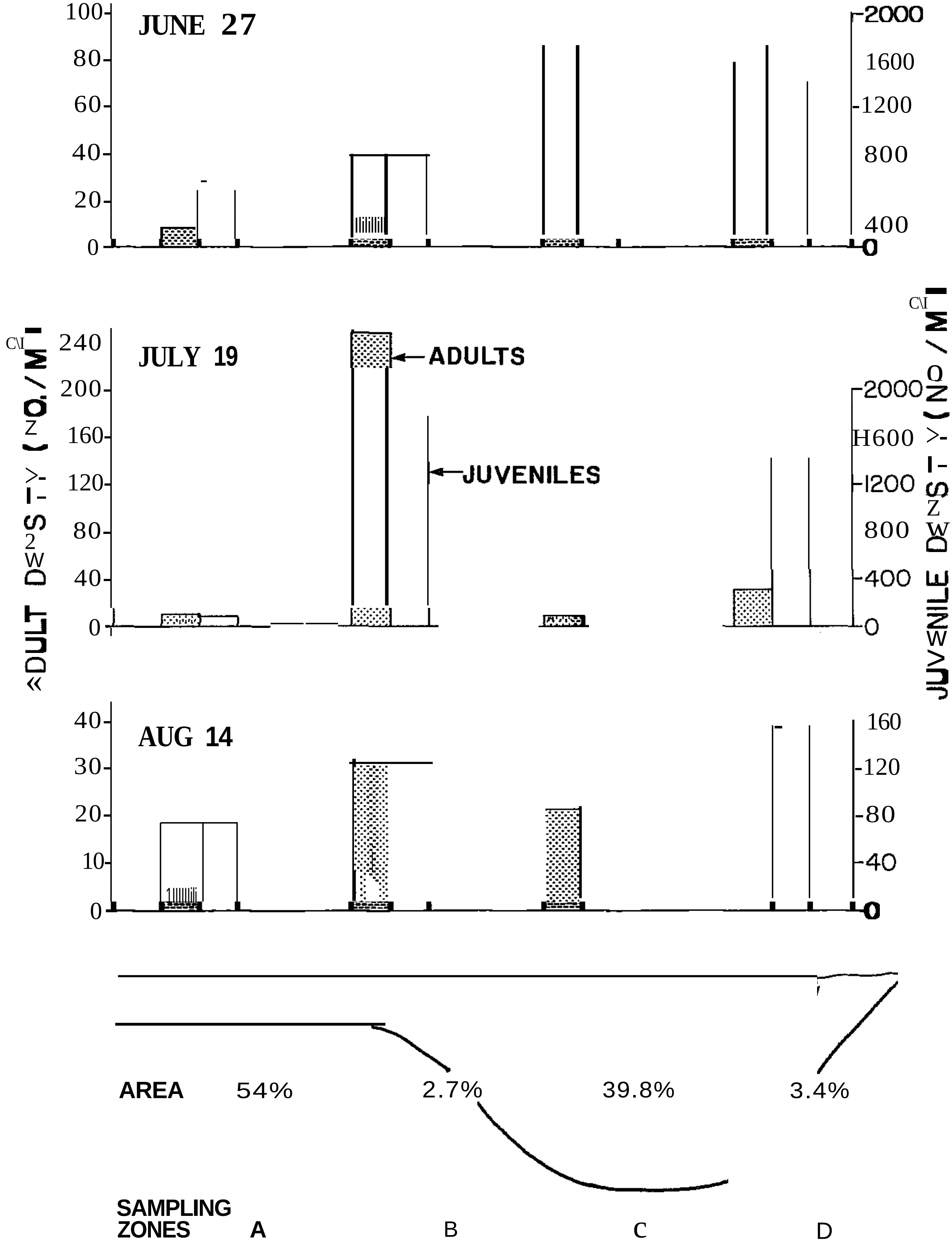

Fig. 6. Density of *Gammarus lacustris*.