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HABITAT AVAILABILITY, REPRODUCTION AND POPULATION DYNAMICS OF THE FRESH WATER BLENNY *SALARIA FLUVIATILIS* (ASSO, 1801) IN LAKE KINNERET, ISRAEL

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Abstract: The present study investigates the relationship between water level fluctuation and population structure and dynamics of the blenny *Salaria fluviatilis* (Asso, 1801) (Blenniidae) in Lake Kinneret, Israel. Except for a short pelagic phase of the larvae (ca 6 weeks), the fish spends its life in the littoral region where it feeds and breeds.

Breeding extends throughout the year and peaks from early spring (March) to mid summer (July). The blenny spawns on rocks of medium size (stone surface area of ca 500 cm2) and thus we suspect that its breeding success is affected by water level fluctuation that determines availability of rocky habitats. Highest breeding success is expected to occur when the lake level is high and rocky habitats are plentiful. The number of eggs in a nest of *S. fluviatilis* in Lake Kinneret varies from 500 to 8000 eggs, corresponding to 2 - 30 spawns, respectively.

The blenny shows size related habitat partition. Smaller fish are more abundant in habitats of small stones and cobbles, whereas, the larger fish are found mostly in habitats of large stones and boulders. We attribute this habitat segregation to predation avoidance behavior.

The relative importance of *S. fluviatilis* in the littoral zone fish assemblage (numerically and in biomass) is inversely related to water level. The blenny is the most prevalent fish in the rocky littoral in years of low lake levels, when rocky habitats are in short supply. Diversion of water for human use increases water fluctuation of Lake Kinneret. Such action interferes with the needs of fish and other organisms that depend on rocky littoral resources. For the blenny low lake levels mean greater competition for shelters and fewer suitable spawning niches. Moreover, it limits the options of segregation between small and large blennies, forcing greater interaction between them, including cannibalism. Recent consecutive drought years, that exacerbate water shortage, forces management of Lake Kinneret under wide water level fluctuations. This in turn, reduces the fitness of *S. fluviatilis*.

Key words: *Salaria fluviatilis*; Blenniidae; Fish biology; Lake Kinneret; Water level fluctuation; Human impact.
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Introduction

Water bodies in semi-arid and in dry-tropical regions with distinct wet and dry seasons, exhibit seasonal changes in water level. Global climate changes extend this phenomenon to water bodies in previously mesic regions. Fluctuations of water level unrelated to climatic conditions also occur in regulated water bodies such as hydroelectric and irrigation reservoirs (e.g., Hellsten et al., 1996; Dimalexis and Pyrovetsi, 1997).

In many lakes littoral structure and complexity follow plant life cycle, and organisms depending on these resources are forced to synchronize with the “window of opportunity” provided by macrophyte growth (Gasith and Gafny, 1998). In some lakes, such as Lake Kinneret, rocky formation is the major source of structural complexity of littoral habitats. Unlike plants, rocky structures are more stable and allow more temporal leeway in resource utilization (Gasith and Gafny, 1998). The availability of both biotic and abiotic littoral structures can be markedly modified by water level fluctuations (Gasith and Gafny, 1990). Whether natural or man-made, water level fluctuations can act as a major source of ecological variance in aquatic ecosystems, among other by the influence of the water level on the availability of structured habitats, for example, in the littoral zone of a lake (Gasith et al., 2000). Rising and falling of a lake level, temporarily inundates and exposes near shore areas. This enhances shore erosion (Coops et al., 1999), often restricting establishment of macrophytes in the littoral zone (Gafny and Gasith, 2000) and changes the availability of wetted rocky areas. Thereby, water level fluctuation limits the availability of cover and food for predators and grazers (Gasith and Gafny, 1998; Meerhoff et al., 2003). Changes in habitat availability in the littoral zone can influence breeding success and survival of fishes thereby affecting population size and age structure (Cohen and Radomski, 1993). These effects are expected to be most pronounced in species that depend on littoral resources for most of their life cycle.

Salaria fluviatilis (Asso, 1801) is a freshwater fish, a single representative of the marine family Blenniidae in the circum Mediterranean freshwater basins, which typically inhabits near shore rocky habitats (Breder and Rosen, 1966; Côté et al. 1999; Vinyoles and De Sostoa, 2007). Zander (1972) and Perdices et al. (2000) suggested that this species is a descendant of an ancestor species closely related to the marine species *Salaria pavo* (Risso, 1810) which is common in shallow, littoral regions of the Mediterranean sea. Kosswig (1967) links this species to the fish fauna of an ancient Tethys sea. *S. fluviatilis* is known from streams and lakes throughout the Mediterranean basin (with the exception of Egypt, Libya, Tunis and the Black Sea basin, Wickler, 1957; Zander, 1972; Perdices et al., 2000). This blenny has been recorded only once in the coastal streams of Israel (Goren, 1983), presently it is known only in Lake Kinneret and in streams that drain into this lake.

We studied habitat utilization, reproduction, and population dynamics of *Salaria fluviatilis* in Lake Kinneret. In this lake this blenny spends most of its life exclusively in the littoral zone, a region that undergoes large water level fluctuations associated with marked changes in habitat structure.

Materials and Methods

Study site:

Lake Kinneret is a warm (13-30°C) monomictic, oligohaline (~ 220-350 mg Cl-1) slightly eutrophic lake (primary production ~ 1,200-2,300 mg Cm-2d-1, Berman et al., 1995). The lake is ca. 210 m below sea level (BSL), located in northern Israel (Serruya, 1978). It cover an area of ca. 170 km2, with a maximum depth of ca. 43 m. The lake is relatively regular (shore development index of 1.16) and shoreline length is ca. 53 km (Serruya, 1978). The lake level naturally oscillates between 209 to 211 m BSL. Since the early 1930s the lake level has been artificially regulated and water level fluctuations have more than doubled (Serruya, 1978; Gasith and Gafny, 1990; Humbright et al., 1994).

Submerged macrophytes are rare in Lake Kinneret and structured habitats are provided mostly by rocky formations of stones of different sizes (maximum linear dimension: pebbles <5 cm, small cobbles 5-10 cm, large cobbles 10-20 cm, small boulders 20-35 and large boulders >35 cm, Gasith et al., 2000). Fall of the lake level reduces the proportion of rocky shores increasing the proportion of sandy and vegetated ones (Gasith and Gafny, 1990, 1998).

During 1991-1992 the biology and population dynamics of the blenny was investigated at two rocky sites, ca. 300m apart on the eastern side of the lake. The rocky substrate in these sites extends ca. 45-50 m lake-ward and is totally submerged when the lake is at its maximum level (209 BSL). At

At one site (Gofra south, St. E20/21 Fig.1) the rocky substrate is relatively diverse (Table 1), correspondingly, stone surface area is provided by small cobbles (22%), large cobbles and small boulders (33 and 10%, respectively) and large boulders (35%). Here on this site is referred to as the boulder site. Rocks in the other site (Gofra north, St. E21 Fig. 1) are smaller, and stone surface area is provided by small and large cobbles (18 and 82%, respectively). Correspondingly, stone diversity index (Shanon- Weiner) in the latter site is about 40% lower. Here on this site is referred to as the cobble site. Within each site, stone size, diversity and density remain relatively unchanged under different lake levels (Table 1).

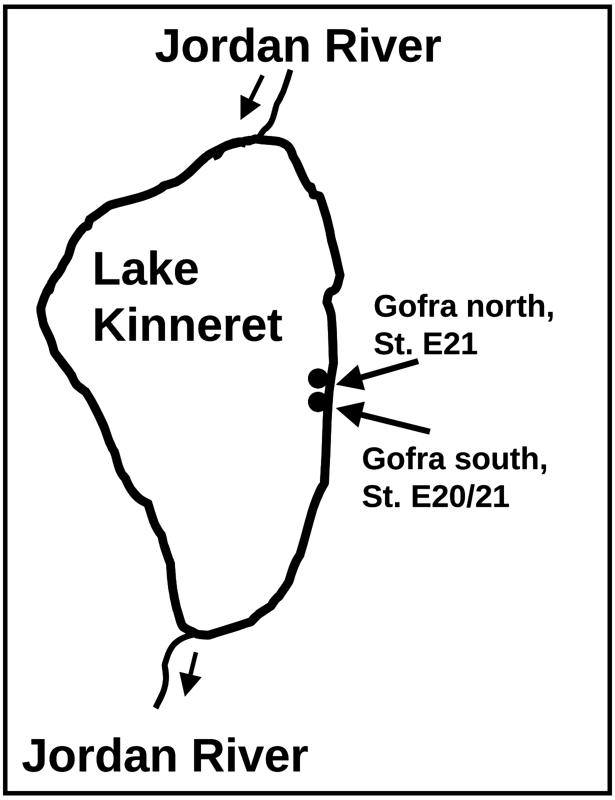

Figure 1. Map of Lake Kinneret, study sites are shown.

The density and biomass of *S. fluviatilis* in the shallow littoral zone (up to 1 m depth) were determined by sampling a known area of about 100m^2 enclosed by a small mesh (2mm) net. The fish in the enclosed area were electro-fished (7 kW, 300/500 volt, EFKO - Gmbh D-7970 electro-shocker). The fishing effort in a site was divided into three consecutive sessions, half-hour each, interrupted by 10-15 minute pause. This procedure was adopted after electro-fishing for 4 half hour sessions indicated that >85% of the fish were collected in the first hour and a half. On four occasions sampling was duplicated at one or the other site. Similarity (Goren, 1979) between duplicate samples was > 80%. The fish collected were sorted to species and preserved (6% naturalized formalin). We measured the blennies' total length (±1 mm), and blot-dry and oven dry (4 days, 70°C) weights (±0.1g). Drying at 70°C for 4 days was found satisfactory; additional drying at 100°C for 24 hours resulted in additional weight loss of no more than 1%. The weight ratio of freshly blot-dry fish to that of blot-dry of fish that were preserved for 2 weeks was 0.89 ± 0.038 (n=19) and that of dry to wet weight was 0.26 ± 0.04 (n=19).

Based on frequency of size distribution of a sample of 197 fish collected in April (Figure 2) the blenny population was divided into the following five size groups: postlarvae (<27 mm), small (28-42 mm), medium (43-54 mm), medium-large (55-69 mm), and large (>70 mm).

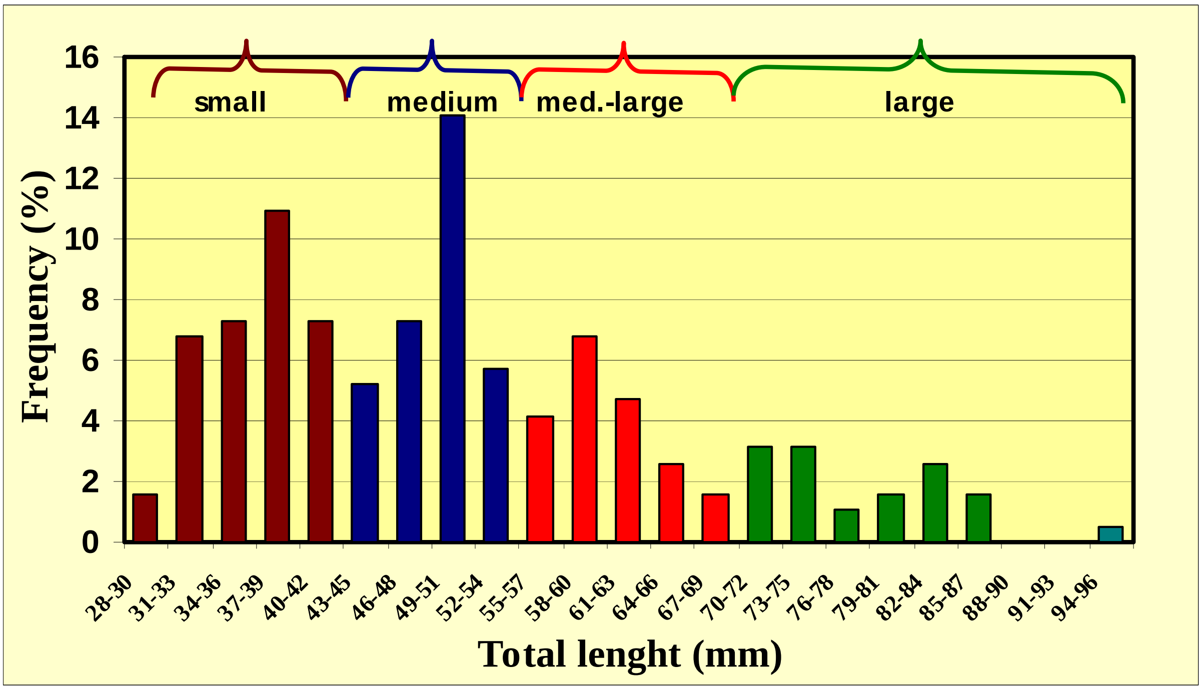

Figure 2. Fish size distribution and size groups (n= 197 fish)

Reproduction period and breeding intensity were determined by the frequency of occurrence of spawns. On each sampling date, we examined for nests on thirty large cobbles and small boulders (10-35 cm in length), randomly picked in the shallow littoral zone (depth <2m) at site E21. Additional information was obtained by examining other rocky sites around the lake (n= 30 rocks in each site). We recorded the number of spawns on each stone, measured the area they occupy (by tracing the nest limits on a plastic sheet), and counted the number of eggs in an area of cm^2. We found that the average egg density was 50 per cm^2 (±15, n=8). We estimated the total number of eggs per nest by multiplying the average egg density by the total area of the nest.

We determined the size of stones favored for spawning by the blenny by recording the frequency of spawns found on randomly collected cobbles and boulders (n=41) in the shallow littoral zone. We expressed stone size by the relevant spawning area that we estimated by the length and width of stone bottom that was lifted above the sediment. We recorded breeding behavior under laboratory conditions in aquaria (60X30X25cm) filled with lake water and rocks. Adult blennies were collected in February and April. The fish were kept at room temperature (21-23°C) and fed with Daphnia.

Results

Habitat structure

Adult Salaria were found exclusively in rocky sites whereas post-larvae were occasionally found also in sandy habitats. On December 1990 Lake Kinneret water level was extremely low (212.95 m BSL) and large areas of the shallow littoral zone were exposed. The following winter (1991) was relatively dry and the lake level rose by only about one meter. Only 30% or less of the rocky littoral at both study sites was under water during that year (Figure 3). The subsequent winter (1992) was extremely rainy, causing the lake level to rise by ca. 4 m within five months. Consequently, 90% or more of the rocky littoral remained underwater throughout the following summer and fall (Figure. 3).

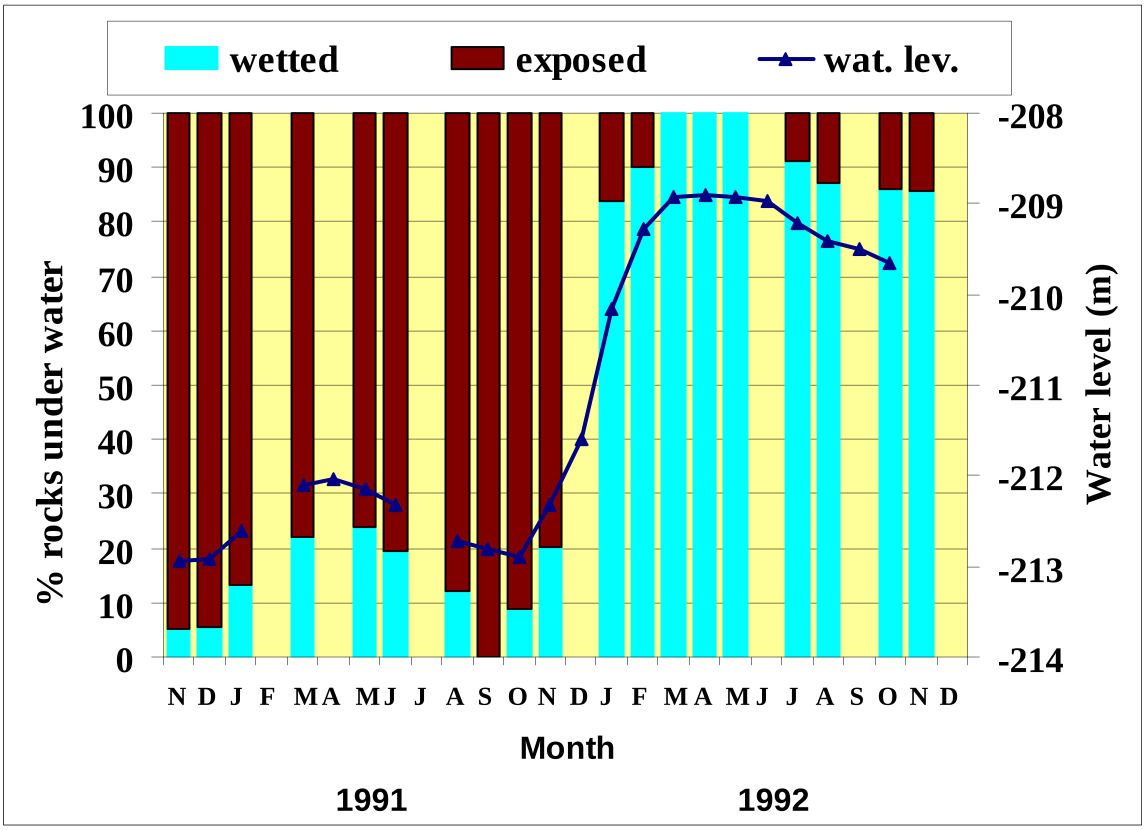

Figure 3. Relationship between water level (meter below sea level) and the proportion of wetted rocky littoral at the study sites.

Reproduction

Adult fish collected in February spawned in the laboratory in April (at 21-23°C). Adults collected in April spawned within 36 hours of transfer to the laboratory. These fish also spawned later, in December and January. Spawning (probably by different females) usually lasted for several days. In the laboratory the eggs were laid on the sides and underside of the rocks. We observed guarding behavior by a territorial male that was moving back and forth over the eggs. Embryonic development lasted for 11-13 days. Removal of a guarding male for one day resulted in rapid infection of the eggs by a fungus *(Saprolegnia*) and ultimately lead to embryos mortality.

In the lake we found spawns throughout the year. The temperature in the lake varied between ca 14°C in winter to 31°C in summer (Figure 4). In 1991 spawns were most abundant in spring (March to May, Fig. 4). The eggs were always found on the underside of the rocks, most frequently on small boulders with bottom area of ca 500 cm2 (Figure 5). Egg numbers per nest varied greatly from a minimum <500 (August, October) to a maximum of ca 8000 (April, Table 2). Different stages of embryonic development within a nest indicated that the eggs were laid at different times (Figure 6).

Population structure and dynamics

The smallest fish found in the shallow littoral zone were post-larvae (16-27mm). In June 1992, we observed large schools of post-larvae swimming along the shoreline in water 5-15cm deep. Preliminary otoliths analysis (R. Eckmann, University of Konstanz) revealed daily growth rings with an abrupt growth change after a period of 4-6 weeks. This change may be associated with the shift from a pelagic larval stage to that of a littoral, benthic, post larval stage.

Table 1. Mean stone density (±SD) and stone size diversity (Shanon-Weiner index) at the study sites, under different lake levels.

Water Level m below sea level	E21 (Gofra north)		E20/21 (Gofra south)	
	Stone density No./ m^2 (±SD)	**Size diversity index**	**Stone density No./ m^2 (±SD)**	**Size diver-sity index**
209.5	140.5 (± 10.1)	0.275	71 (± 9.4)	0.498
211	117 (± 9.3)	0.289	70 (± 11.5)	0.497
212.5	105 (± 8.8)	0.276	68 (± 2.9)	0.436

Table 2. Spawn size (median and range of egg number per nest) of *S. fluviatilis* in Lake Kinneret (1991).

Month	Median	Minimum	Maximum	No. of spawns
March	2275	1320	3230	9
April	3400	980	8030	11
May	2920	700	4120	8
June	2370	1350	3150	6
July	3855	2290	5950	8
August	1110	530	1280	5
October	780	560	1250	5

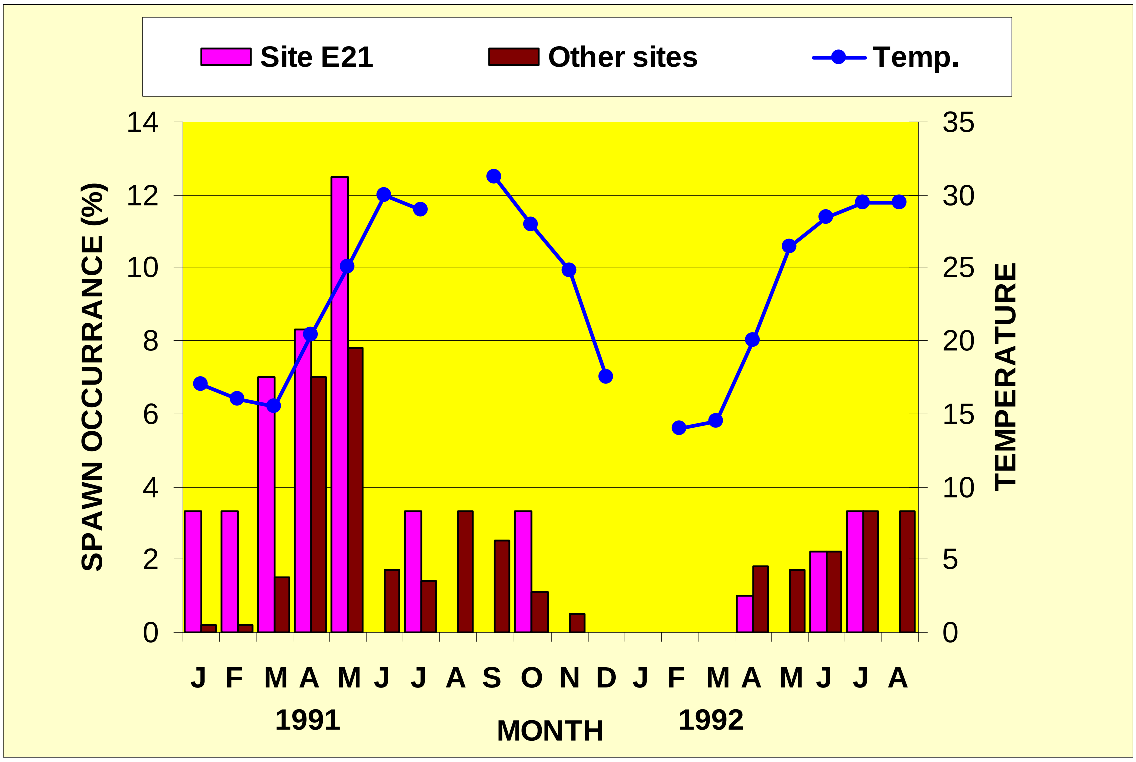

Figure 4. Temperature fluctuation and proportion of spawns of *S. fluviatilis* recorded at different sites in the littoral zone of Lake Kinneret, 1991-1992 (30 stones at each site).

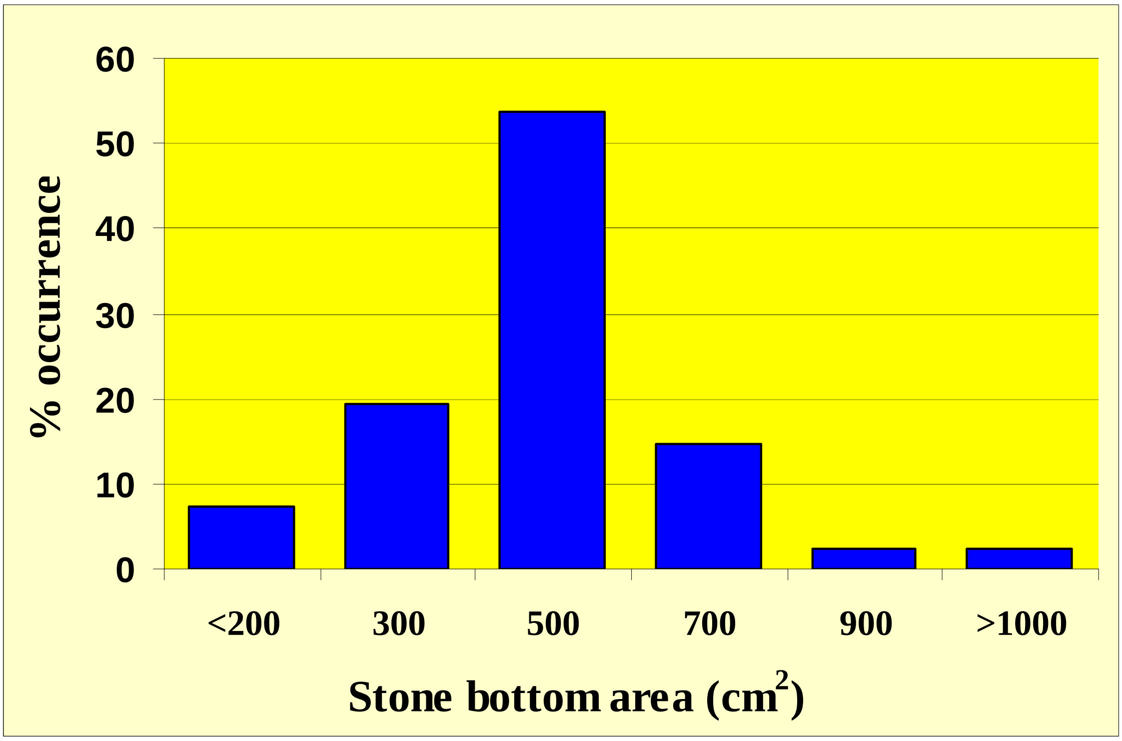

Figure 5. Relationship between spawn frequency and stone size.

Figure 6. Different stages of embryonic development within a nest of *S. fluviatilis.*

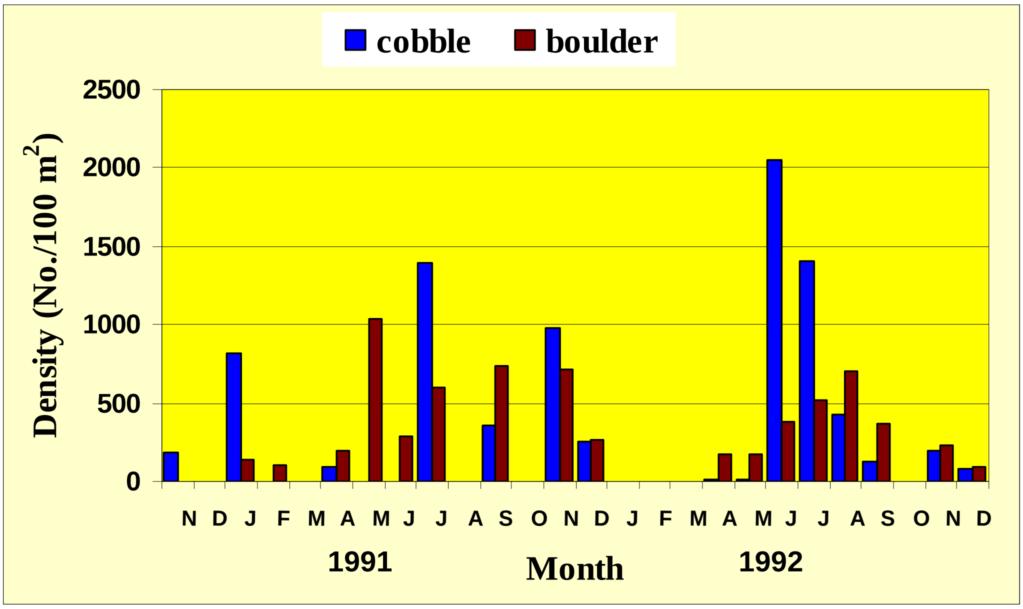

Figure 7. Comparison of blenny density at the "cobble" and "boulder" sites (E21, Gofra north and E20/21, Gofra south, respectively) during low (1991) and high (1992) lake levels.

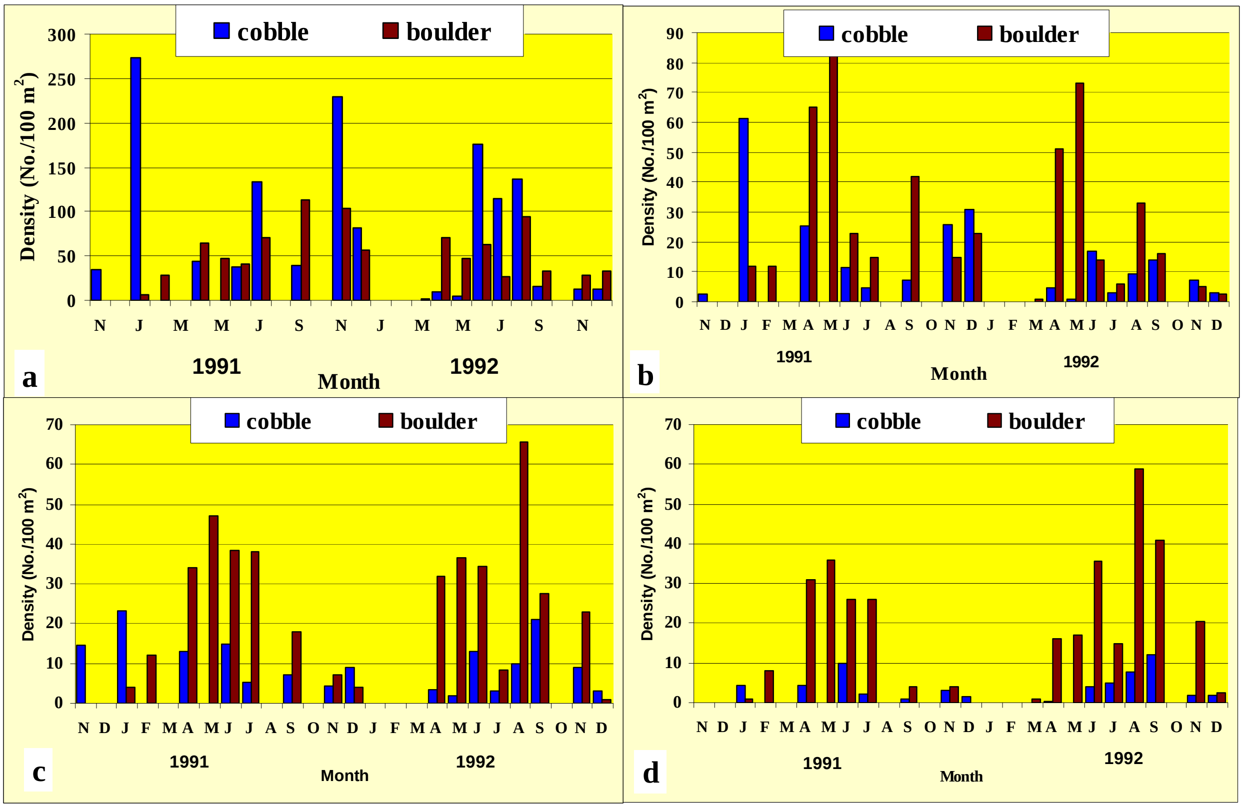

Figure 8. Relationship between blenny group size and density at the "cobble" and "boulder" sites (E21, Gofra north and E20/21, Gofra south, respectively) during low (1991) and high (1992) lake levels (a. small: 28-43mm; b. medium:44-55mm; c. medium-large: 56-67mm; d. large >68mm).

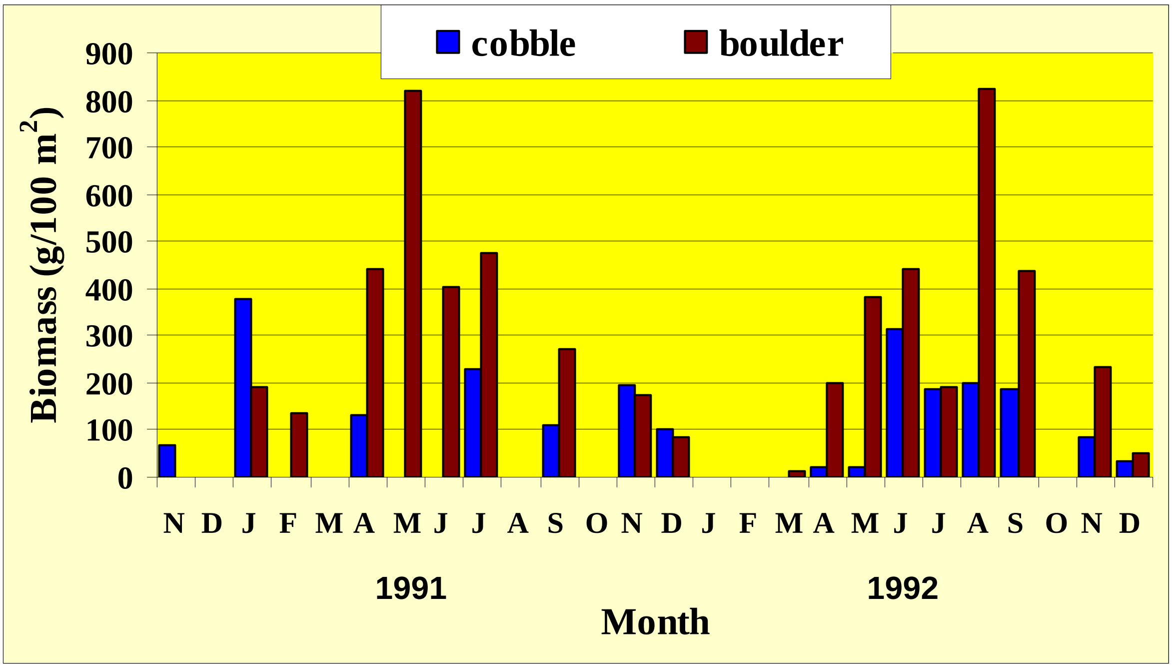

Figure 9. Comparison of blenny biomass at the cobble and boulder sites during low (1991) and high (1992) lake levels.

The blenny was numerically the single most important fish at both the cobble and the boulder sites (45% or higher of the fish assemblage). Its density and size varied both temporally and with habitat structure; density at both the cobble and boulder sites was lowest in winter or early spring (<200 fish per $100m^2$) and 3-10 fold higher in late spring and/or summer (Fig. 7). We failed to find the blennies at both sites when the lake level rapidly rose, (winter 1992; Fig. 6).

For 8 months, from late spring (May) through early winter (December) post-larvae (<27mm) comprised 50-90% of the blenny population, both at the cobble and the boulder sites. Difference in distribution of the blennies at the two sites became apparent as the fish grew. The density of small blennies was higher at the cobble than at the boulder site during summer and fall (Fig. 8a). The density pattern was reversed (higher density at the boulder site) as the fish grew in size (44-55mm, Fig. 8b), and was most apparent in fish larger than 56 mm (Fig. 8c,d).

The relationship between the blenny's wet weight and length in Lake Kinneret is expressed by the equation: W = 0.000015TL 2.98 (n= 1307, r= 0.97), where W= blot dry wet-weight (g); TL = total length (mm). Blenny's biomass (blot dry wet weight) was generally highest during late spring and summer (Fig. 9). In both the cobble and boulder sites it comprised <50% of the total fish biomass. Blenny's biomass at the boulder site was markedly higher than at the cobble site (maximum biomass ca 800 and 400 g per $100m^2$, respectively). In 1991, when the lake level was low, the highest blenny biomass at the boulder site was recorded in late spring, whereas in the following year when the lake level was high, its highest biomass at this site was recorded in summer (Fig. 9).

Blennies larger than 56mm, which comprised 27 and 42% of the population at the boulder site in 1991 and 1992, contributed 60 and 75% of the fish biomass, respectively. At the cobble site, this size group made only up 9 and 16% of the population in 1991 and 1992 and contributed 30 and 50% of the biomass, respectively.

Discussion

Salaria fluviatilis is a small fish, numerically important in the rocky littoral of Lake Kinneret (> 80% of the fish population, Gasith et al., 2000). Except for a short pelagic phase of the larvae (ca. 6 weeks), the fish spends its entire life in the littoral region, where it feeds and breeds throughout the year. Peak breeding is in early spring (March) to mid summer (July). A shorter reproduction period (May-July) was reported for *S. fluviatilis* in eastern Spain (Freeman et al., 1990) and from May to August in a Mediterranean stream in north-east Spain (Vinyoles and De Sostoa, 2007). A short breeding period was reported also for the related marine blennies (Zander, 1986; Patzner et al., 1986; Lahnsteiner and Patzner, 1990). The protracted breeding period in Lake Kinneret is probably associated with the lake's higher temperature regime (ca 14 to 30ºC). Neat et al. (2003) who studied the reproduction of this species at three different sites (Lake Kournas, Crete, Greece; Fango River, North-West Corsica, France; Lake Garda, Italy) found that the fish spawn at temperatures of 18 to 21ºC. Lengkeek and Didderen (2006) who also studied the reproduction of *S. fluviatilis* in the Fango River reported that during the breeding season midday water temperature ranged from 15 to 26 ºC.

Seasonal imbalance between water input (runoff and rainfall) and water output (outflow, evaporation and diversion of water for human use) cause marked fluctuation of water level in Lake Kinneret (over 4m). As a result, large areas of littoral zone are periodically exposed and inundated. This in turn causes variation in the availability of rocky formation (Gasith et al., 2000), an important source of structural complexity in littoral zones (Gasith and

Gafny, 1990, 1998; Beauchamp et al., 1994). The blenny like other littoral species uses rocky habitat for cover and breeding. Highest breeding success of fish is expected when the lake level is high and rocky habitats are plentiful. Indeed highest richness, density and biomass of fish were reported in the littoral zone of Lake Kinneret under high lake levels (Gasith et al., 2000).

As evident by the presence of embryos at different developmental stages, nests of *S. fluviatilis* consists of multiple spawns possibly by different females (harem spawning). We cannot exclude the possibility that multiple spawning females (Vinyoles and De Sostoa, 2007) repeatedly contribute to a single nest. Egg number in a nest varies from 500 to 8000 eggs, corresponding to 2 - 30 spawns, respectively (based on an average of 200-300 eggs per spawn, Wickler, 1957). At a temperature range of 21-23ºC embryonic development lasts less than two weeks. This period of embryo development is similar to that reported by Lengkeek and Didderen (2006; 14 days at water temperature of 18 ºC).

Males have been observed moving back and forth over the eggs. This behavior may be associated with protection of the eggs from fungal infection, possibly by smearing antibiotic material over the eggs. Soon after hatching the larvae migrate from the littoral to the pelagic zone (Goren, unpublished data). Four to six weeks later the post-larvae migrate back to the littoral zone. They move in large schools along the shoreline, in search of suitable habitat, mostly rocks. Schooling in very shallow water protects the post-larvae from predators, including cannibalism by larger blennies (observed in this study).

The blenny exhibits size-related habitat segregation. The smaller fish are more prevalent in rocky habitats of small stones and cobbles, whereas the larger fish are found mostly in habitats of large stones and boulders. Such habitat segregation can reduce cannibalism.

The density of large blennies (>56 mm) in the shallow rocky littoral (<2m), increases in spring and early summer (March-June), a time of peak breeding. The density of post-larvae peaks in habitats of small stones two to three months later (June and July).

The importance of *S. fluviatilis* in the littoral zone fish assemblage (numerically and in biomass) varies with changes in the availability of rocky habitats, caused by fluctuations in lake level. The blenny is the most prevalent fish in the rocky littoral in years of low lake levels, when rocky habitats are in short supply. Its small size (< 12 cm) enables this fish to use niches of small rocks, which are unsuitable for larger fish (Gasith et al., 2000). In contrast, under high lake levels, the blenny is numerically more important in habitats of large stones, particularly during the breeding period.

Lake Kinneret is a main source of drinking water in Israel. Diversion of water from the lake for human use increases the amplitude of water level fluctuation, adversely affecting fish and other organisms that depend on rocky littoral resources for their livelihood. For the blenny, low lake levels mean fewer suitable spawning niches and greater competition for shelter. Under these conditions, size-related habitat segregation of the blennies is denied, forcing greater interaction (including cannibalism) between the small fish and the larger ones. Five consecutive drought years experienced recently in Israel drastically reduced the availability of rocky formation in the littoral zone of Lake Kinneret. We expect that this extreme drawdown in lake level significantly reduced *S. fluviatilis* population.

Acknowledgments

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