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OCCURRENCE OF A NEW PONTO-CASPIAN INVASIVE SPECIES, *CORDYLOPHORA CASPIA* (PALLAS, 1771) (HYDROZOA: CLAVIDAE) IN LAKE BALATON (HUNGARY)

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Cordylophora caspia, a new Ponto-Caspian invasive species was found in Lake Balaton in August 2001. The aim of this study was to survey the distribution, abundance and life cycle of this species in Lake Balaton and to investigate its possible route of invasion. In Lake Balaton different substrata (stones, water lilies, reeds) were examined at several stations. Life cycle studies of *C. caspia* were done on specimens sampled at Tihany peninsula station. Colonies of *C. caspia* occurred at most sampling stations in Lake Balaton together with other invasive Ponto-Caspian invertebrates (e.g. the mussel *Dreissena polymorpha* and the amphipod *Chelicorophium curvispinum*). Colonies of *C. caspia* form menont stadia from December through April. Reproduction starts in May and lasts until November, the density ranged between 6.44 to 25.78 ind. cm^{-2} of stone substrata. Lake Balaton is connected to Danube River via the Sió canal. Stones from the littoral zone of the Danube River were sampled in 2003, from Dunaföldvár to Mohács, to ascertain whether this waterway might be the source of the introduction of *C. caspia* to Lake Balaton. No individuals of *C. caspia* were found at any of the Danube stations.

Key words: *Cordylophora caspia*, life cycle, stony littoral zone, Lake Balaton, invasive species

INTRODUCTION

Since its original description from the Caspian Sea, *Cordylophora caspia* (PALLAS, 1771) has been found from boreal to subtropical areas (ARNDT 1984, BIJ DE VAATE *et al*. 2002). It is possible that this species is dispersing around the globe via ships and birds. It occurs mainly in brackish water, but because it is euryhaline, can live in freshwater wherever it finds solid substrates. The length of individuals, the number of tentacles and the degree of branching are related to the ecological requirements of this species (KESSELYÁK 1943, ARNDT 1984, FOLINO 2000). On the basis of branching, hydrozoan polyps can be classified as first, secondary, tertiary or quaternary polyps. *C. caspia* reproduces sexually and asexually. Individuals have no medusa stadia. Spermatozoa and eggs are formed in gonophores of unisexual colonies and fertilization occurs in the female gonophore, where the planula larvae develop. Planula larvae leave the gonophores and form new colonies. Budding and stolonization are the methods of asexual reproduction, and because of efficient regeneration ability, can form a new colony from any part of an old colony. The colonies form overwintering formulae (menont stadia devoiding polyps) which withdraw in the roots. In spring polyps develop from the roots, gonophores develop on the polyps. *C. caspia* fills the niche of benthic colonial predator, as this hydroid preys on larval insects (SMITH *et al*. 2002). It can also colonize artificial substrates (DEAN & BELLIS 1975).

Lake Balaton, the largest lake in central Europe, concerning it surface (length: 78 km, average width: 7.6 km, surface: 596 km^2, mean depth: 3.25 m), is connected with the Danube river via a canal (the Sió), through which substantial invasions by *Chelicorophium curvispinum* (G. O. SARS, 1895) and *Dreissena polymorpha* (PALLAS, 1771) occurred in the 1930s (SEBESTYÉN 1938). Since then the above invaders have become relatively less dominant in the littoral zone as other invaders (e. g. amphipod *Dikerogammarus* species) have appeared in the lake (MUSKÓ & BAKÓ 2005, MUSKÓ *et al.* 2007). The lake was eutrophic until 1995 after which, due to former serious effort to reduce nutrients in the lake, its condition has improved. The trophic status of the lake has improved even though the westernmost basin (Keszthely) is still more eutrophic.

This species was reported initially in Hungary near the city Szeged at the confluence of the Rivers Tisza and Maros where it occurs on the lower surface of stones (KESSELYÁK 1943). More recently (August 2001) this species was found in Lake Balaton at Tihany, in front of the Balaton Limnological Research Institute by us.

The aim of this study was to survey the distribution, abundance and life cycle of this species in Lake Balaton and to investigate its possible route of invasion.

MATERIALS AND METHODS

In Lake Balaton the northern shoreline sites (Keszthely, Szigliget, Badacsony, Tihany and Balatonalmádi) were sampled 3rd June and 2nd September 2003. In August samples were taken at the southern shoreline stations at Fonyód, Szántód, Szabadi-Sóstó (17, Fig. 1) as well as at several points of the Tihany peninsula (20, Fig. 1). Samples from rock surfaces were also taken from Danube River sites (Dunaföldvár, Paks and Mohács, Fig. 1) 5th April 2003, in order to determine if the river is the source of *C. caspia* which may have entered Lake Balaton via the Sió canal. This canal flows from Lake Balaton at Siófok (Lake Balaton) and into the River Danube between Paks and Mohács.

Substrates other than stones (ROOS 1979) were also surveyed in Lake Balaton: water lilies in Bozsai Bay at Tihany peninsula and the stems of reeds at several places of reedy zone (Fig. 1*d*, sited) in order to compare with stony substrates. Colonies of *C. caspia* were scraped from determined surface of stones (three replicas where it was possible) and stored in 70% ethanol. The abundance of individuals in each colony and the number of branches, gonophores and tentacles were determined for each colony along with individual body length.

Water quality parameters of Lake Balaton (pH, conductivity, turbidity, O_2 concentration and temperature) were measured using a Horiba U-10 water chequer (3rd June and 2nd, 3th September).

In order to study the life cycle, animals were collected regularly in front of the Institute at Tihany in 2003 (Fig. 1, Site c). To study the growth and development in laboratory, collections were made in May and July 2003 also at Tihany, stored in thermostat at 20 °C with natural light. The development and settling of animals was recorded daily. Some individuals were placed in aquaria at room temperature in September 2004 to study the development of the menont stadia.

All data are expressed as mean ± standard deviation. Correlations between length, number of branching, number of heads and number of gonophores were tested using Excel program. In order to study the similarity of the colonies at the different sampling stations and period cluster analysis was used (Syntax 2000 software, PODANI 1997).

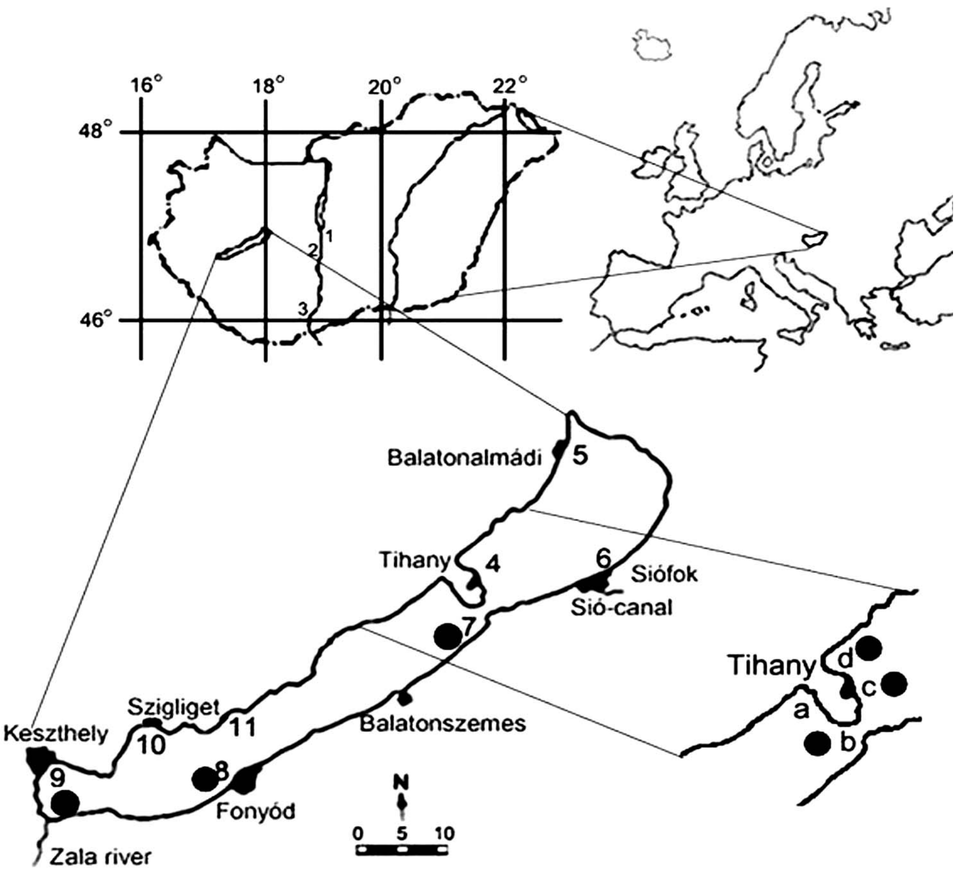

Fig. 1. Localization of sampling stations in Hungary, in Lake Balaton and around Tihany-peninsula. • Stations where *C. caspia* were found. 1 = Dunaföldvár, 2 = Paks, 3 = Mohács, 4 = Tihany, 5 = Balatonalmádi, 6 = Szabadi-Sóstó, 7 = Szántód, 8 = Fonyód, 9 = Keszthely, 10 = Szigliget, 11 = Badacsony. Around Tihany peninsula a = Sajkód, b = Tihany-ferry, c = in front of Balaton Limnological Research Institute, d = Gödrös. Scale: 10 km for Lake Balaton

RESULTS

The hydrozoan species *C. caspia*, after invading Lake Balaton, has spread rapidly throughout the lake in the littoral zone along the northern and southern shores. Mainly found living on stones, colonies have also been seen on reeds. No colonies of this species were found in the Danube, so it is unlikely that the river is the mean of transport of this invasive species to the lake.

On the northern shoreline of Lake Balaton, *C. caspia* colonies were found in Tihany and Keszthely. At the latter station presence of colonies was so rare, that after surveying about thirty stones only one colony was found. On the southern shoreline at the harbour in front of Fonyód and Szántód many colonies were found. At the Tihany peninsula, apart from the front of the Institute, at Gödrös and at Tihany-ferry some colonies were found after surveying 20–30 stones. Moreover, at Tihany-ferry some colonies were also found in the reedy zone. Colonies of *C. caspia* were found in wave-exposed sites with good oxygen supply, at a depth, where the stones were not yet sunk in the mud; this depth varied at the different stations. Colonies grew on the lower or lateral surface of the stones. In the vicinity of the colonies other Ponto-Caspian species were always found: the mussel *Dreissena polymorpha* (PALLAS, 1771), the amphipods *Chelicorophium curvispinum* (G. O. SARS, 1895) and *Dikerogammarus* spp. and the isopod *Jaera istri* VEUILLE, 1979. Other invertebrates were also associated with *C. caspia* namely various species of freshwater sponge (Porifera) and chironomid larvae and the hydra *Hydra oligactis* (PALLAS, 1766). The branches of *C. caspia* served, also, as substrata for ciliates and diatoms.

The pH ranged between 8.00 and 8.47, the conductivity (mS cm^{-1}) between 0.74 and 0.79, the turbidity (NTU) between 22 and 584, the O_2 concentration (mg l^{-1}) between 6.38 and 11.07, and the temperature (°C) between 18.8 and 28.8 (Table 1).

There were no considerable differences in the number of tentacles and mean length of the animals along the longitudinal axis of Lake Balaton, but the density (ind cm^{-2} stone surface) was higher at Keszthely and Fonyód than at other sites (Table 2). Seasonal differences in animal density were recorded as higher at the end of summer than at the beginning of this season. The mean number of branches on each individual was greater near the northern shoreline than near southern shoreline (Table 1). Gonophores were found in June at Keszthely and Tihany. At the end of August and at the beginning of September gonophores were found at Szántód and Tihany-ferry, their abundance here was similar to that seen in June at the former two sites. In front of Balaton Institute (Tihany, Fig. 1 Site c) gonophores were found as late as November. There were large differences in the length among animals near Tihany peninsula: At Gödrös (Fig. 1 Site d) animals had length of 1–2

Table 1. Measured water parameters (in 2003) at different sites (Almádi = Balatonalmádi, NTU = nephelometric turbidity unit).

Date (day, month)	Locality	pH	Conductivity ($mS\ cm^{-1}$)	Turbidity (NTU)	O_2 concentration (mgl^{-1})	Temperature (ºC)
03. 06.	Keszthely	8.43±0.03	0.76±0.0	183±23	9.15±0.06	24.0±0.0
03. 06.	Szigliget	8.15±0.03	0.76±0.0	230±10	8.25±0.14	25.1±0.0
03. 06.	Badacsony	8.39±0.02	0.76±0.0	23± 1	11.06±0.11	25.4±0.0
03. 06.	Tihany	8.32±0.10	0.76±0.0	22± 1	8.84±0.14	25.2±0.0
03. 06.	Almádi	8.41±0.03	0.76±0.0	512±95	11.07±0.31	28.8±0.1
02. 09.	Keszthely	8.00±0.01	0.76±0.0	139± 5	6.38±0.08	20.3±0.0
02. 09.	Szigliget	8.23±0.02	0.74±0.0	132±11	10.14±0.15	19.5±0.1
02. 09.	Tihany	8.21±0.01	0.78±0.0	50±22	10.11±0.05	21.1±0.0
02. 09.	Almádi	8.19±0.02	0.74±0.1	35±13	9.8±0.08	20.1±0.1
02. 09.	Fonyód	8.47±0.02	0.76±0.0	155±23	9.28±0.06	20.7±0.1
02. 09.	Szántód	8.20±0.00	0.77±0.0	117±34	8.37±0.16	20.9±0.0
02. 09.	Sóstó	8.31±0.01	0.79±0.0	73± 8	9.48±0.16	18.8±0.1
03. 09.	Sajkod	8.40±0.03	0.75±0.0	157±19	10.79±0.20	19.7±0.1
03. 09.	Gödrös	8.10±0.03	0.78±0.0	584±17	9.01±0.04	18.9±0.0
03. 09.	Tihany rév	8.08±0.03	0.78±0.0	105±11	8.51±0.07	19.2±0.0

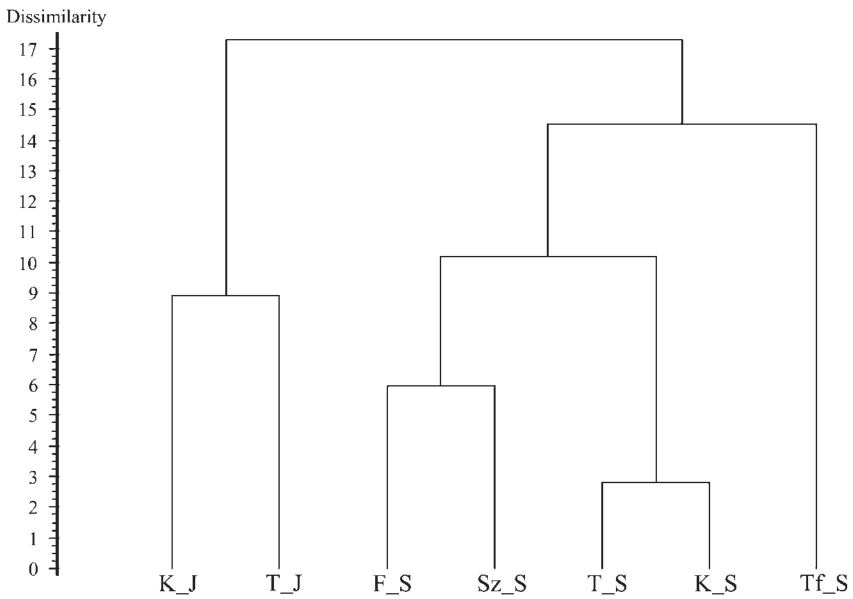

Fig. 2. Result of cluster analysis of all measured and calculated parameters. F = Fonyód, K = Keszthely, Sz = Szántód, T = Tihany, Tf = Tihany, ferry; J = June, S = September

Table 2. Sampling localities and comparison of the features of *C. caspia* colonies (average ± S. D. = standard deviation)

Locality	Keszthely	Tihany	Keszthely	Tihany	Fonyód	Szántód	Tihany ferry
Date (day, month)	06.03.	06.03.	09.02.	08.26.	08.17.	08.17.	08.20.
Density (ind. cm^{-2})	6.44**	6.38±3.26	25.78**	13.19±10.92	20.89±3.34	14.16±2.61	18.83±7.15
Length (mm) (min.–max.)	2.5–14.0	0–13.0	5.5–14.5	4.5–16.0	1–17.0	2–16.6	1–34.0
Length (mm) (average±S.D.)	7.38±2.79	5.72±1.31	9.68±2.65	9.89±3.39	9.13±4.0	8.02±3.48	20.42±8.71
Number of branching ind^{-1} (min.–max.)	0–6	0–10	2–27	0–56	0–22	0–37	0–36
Number of branching ind^{-1} (average±S.D.)	2.43±1.56	2.12±1.56	11.14±6.58	11.47±13.14	8.7±6.05	7.58±7.62	15.97±10.24
Number of gonophores ind^{-1} (min.–max.)	0–5	0–3	0	*	0	0–13	0–17
Number of gonophores ind^{-1} (average±S.D).	1.24±1.22	0.69±0.76	0	*	0	1.83±2.69	2.37±3.92
Percent of individuals with gonophores (%)	67.24	54.17	0	0	0	63.50	56.70
Hydra of first order (%)	15.50	27.35	0	4.80	10.60	5.80	6.70
Hydra of second order (%)	84.50	68.40	13.64	33.30	21.30	48.10	33.33
Hydra of third order (%)	0	4.25	44.45	38.10	59.60	40.40	60
Hydra of fourth order (%)	0	0	40.90	23.80	8.50	5.70	0
Number of tentacles ind^{-1}	15±3	13±2	12±2	14±1	12±1	16±1	16±2

*Gonophores were found sporadically

**Animals were found very rarely

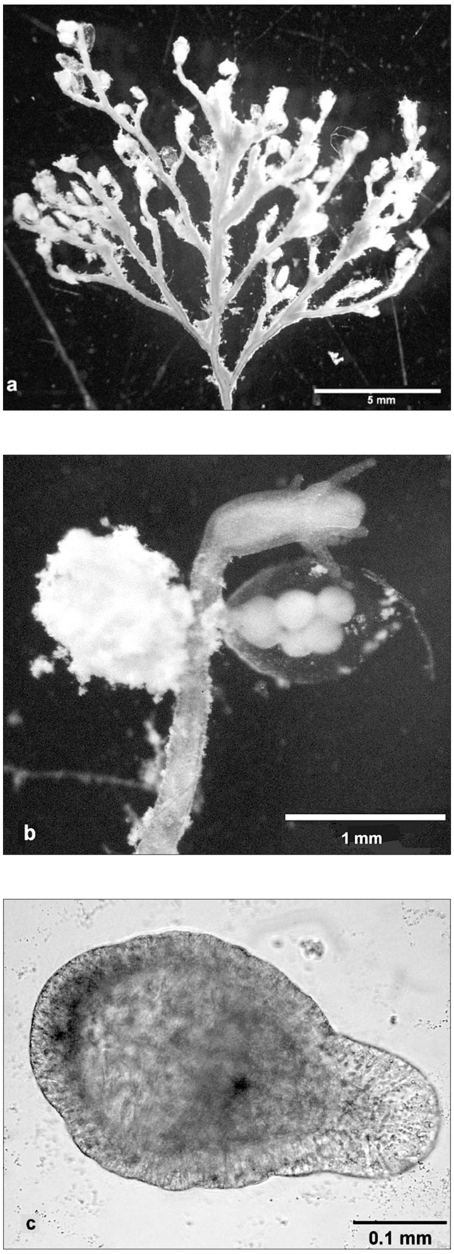

Fig. 3. Photomicrographs of a = part of a colony (preserved in 70% ethanol), b = female polyp with gonophores containing eggs (living) c = planula larva (living)

mm while at Tihany-ferry (Fig. 1 Site b) lengths of 3 cm were frequently found. Colonies at Tihany-ferry were not only larger but also their density and branching were greater when compared to other stations (Table 1). Although branching (number of branches per colony) was more pronounced at Tihany-ferry, branches were shorter in length.

According to the results of cluster analysis, the samples taken from Tihany and Keszthely (end of summer) were similar to each other (northern shoreline), and different from that of the southern shoreline (Fig. 2). The samples in June were different from those from the end of summer. There were close linear correlations between length and branching at all stations, except for Keszthely (Table 3). If all the data for Lake Balaton were pooled concerning, the linear correlation between length and branching was also close ($R^2 = 0.6014$). No close correlations occurred between the length and number of gonophores (R^2 ranged between 0.0165 and 0.4265) and between the length and number of heads (R^2 ranged between 0.0371 and 0.3301). The colonies were significantly larger at Tihany--ferry than at other stations around the Tihany peninsula ($p = 0.000$).

The development and growth of colonies was observed at Tihany (in front of the Institute) and at Keszthely. The density of individuals considerably increased by the end of summer as compared to June (Table 2). While the

Table 3. Correlation equations between different data of *C. caspia*, and the correlation coefficients. Bold: close correlations

Station and Month	Lenght (mm) – number of branching	Length (mm) – number of gonophores	Length (mm) – number of heads
Tihany, June	y = 0.628x–1.348 **R^2 = 0.512**	y = 0.051x+0.450 R^2 = 0.017	y = 0.117x+0.397 R^2 = 0.037
Tihany, August	y = 2.989x–18.07 **R^2 = 0.596**	No data	No data
Tihany-ferry, August	y = 0.934x–3.112 **R^2 = 0.631**	y = 0.176x–1.228 R^2 = 0.153	No data
Szántód, August	y = 1.790x–6.780 **R^2 = 0.667**	y = 0.431x–1.628 R^2 = 0.309	No data
Fonyód, August	y = 1.259x–2.800 **R^2 = 0.692**	No data	No data
Keszthely, June	No data	y = 0.302x–0.906 R^2 = 0.427	y = 0.385x–0.158 R^2 = 0.330
Keszthely, September	y = 1.334x–1.779 R^2 = 0.288	No data	No data
Pooled data	y = 1.062–2.684 **R^2 = 0.601**	y = 0.124x–0.136 R^2 = 0.135	y = 0.364x–0.479 R^2 = 0.314

number of branches per colony had increased by fivefold by the end of summer, mean lengths were not significantly different. Almost exclusively, colonies showing first- or second order branching occurred in June, while at the end of summer colonies showing third and fourth order branching dominated (Fig. 3*a*). There was no seasonal difference in the number of tentacles on the polyps. Persistent, overwintering formulae were found on the stones in April (water temperature: 9 °C). Polyps appeared in late April (water temperature: 15 °C) after overwintering as menont stadia and developed gonophores by late May (water temperature: 18 °C). Gonophores were also observed in late September (water temperature: 21 °C) until November but in small numbers. In the laboratory the formation of eggs in the gonophores (Fig. 3*b*) and the hatching of planula larvae (Fig. 3*c*) were observed along with stolonisation. One polyp from the root was removed and formed a new root on which polyps appeared after several days. In aquaria, at room temperature, menont stadia were observed from November until the end of January with polyps appearing in early February.

DISCUSSION

Since no individuals of *C. caspia* were found in the Danube river, it is hypothesized that the invasion could have occurred by transport on birds. The appearance of *C. caspia* in Lake Balaton may be exacerbated by an increase in salinity (VIRÁG 1998), especially the increase of sodium ion concentration (VIRÁG 1998 and the data of Central Danubian Environmental Inspectorship in 2003: Na^+: 37–45 mg l^{-1}). That *C. caspia* may also thrive in the eutrophicated aquatic environments is well documented (ARNDT 1984, BIJ DE VAATE *et al.* 2002). The nutrient load of Lake Balaton has decreased in recent years however eutrophication is still significant especially in the western part, in Keszthely and Szigliget. The appearance of *C. caspia* in the mesotrophic Siófok basin may be a late response to the eutrophication. The measured water quality parameters do not seem to interact with *C. caspia* distribution and abundance, because there were no large differences between the stations where this species was found and the stations where it was not found. According to literature data, there is no dominant factor, which would explain the occurrence of this species. The appearance of *C. caspia* in Lake Balaton may be due to a complex interaction of abiotic and biotic factors (ROOS 1979).

The number of tentacles on *C. caspia* polyps in Lake Balaton (12–16), is considerably lower when compared to similar work done on this species in the Connecticut River (17–24) (SMITH *et al.* 2002).

Menont stadia were observed from December until April. Reproduction starts in April, and lasts until November. The existence of menont stadium in the laboratory, at room temperature, suggests endogenous circumannual rhythms of growth as in other marine benthic hydroids (see GILLI & HUGHES 1995). The increased density of polyps at the end of summer as compared to June can be explained by both sexual and asexual reproduction. Animals reproduce mainly sexually at the beginning of the summer, and their main growth period is in August. This was found to be true in other studies (ROOS 1979, GILLI & HUGHES 1995).

The differences in growing and branching can not be explained by the water quality parameters measured. FULTON (1962) established, on the basis of laboratory studies, that *C. caspia* is insensitive to pH, temperature, light intensity and oxygen supply Differences in growth and branching may be explained by biological (competition, predator-prey relationships) rather than physical/chemical relationships. Further studies are necessary to clear these relationships. The biotope and niche of *C. caspia* in Lake Balaton is similar to other regions (KESSELYÁK 1943, ZEVINA 1961, ZEVINA *et al*. 1963, ROOS 1979). Ponto-Caspian species seem to respond to similar condition regardless of geographic location.

C. caspia is euryhaline and its appearance in Lake Balaton may be because of its opportunistic and broad environmental niche rather than its preference for eutrophic waters. It thrives in – non – eutrophic environments as well.

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