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# POPULATIONS OF TWO PREDATORY CLADOCERANS IN THE VISTULA LAGOON – THE NATIVE *LEPTODORA KINDTII* AND THE NON-INDIGENOUS *CERCOPAGIS PENGOI*

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## Abstract

The distribution and population structure of two predatory cladocerans – the native *Leptodora kindtii* (Focke, 1844) and the non-indigenous *Cercopagis pengoi* (Ostroumov, 1891), were studied in the Vistula Lagoon (Baltic Sea) during the 1996-2000 period. A species of Ponto-Caspian origin, *C. pengoi* was introduced to the lagoon by sea currents in August 1999. Prior to this, *L. kindtii* was not recorded every year in the study area. In 1999 and 2000, both *Leptodora* and *Cercopagis* were recorded in the lagoon. Since the *C. pengoi* invasion, the area of *L. kindtii* occurrence has increased in the direction of the more saline part, although high densities occurred only in the freshwater regions. *C. pengoi* occurred throughout the lagoon. The population of *C. pengoi* was represented by individuals from 0.8 to 2.75 mm in length and consisted of juveniles, males, and parthenogenetic (with 6-15 eggs) and gamogenetic (with 1-2 resting eggs) females. No changes in the structure of the *L. kindtii* population, such as the appearance of sexual generation, were noted.

## INTRODUCTION

The salinity gradient and the high anthropogenic load of commercial and recreational activity have the greatest influence on the Vistula Lagoon ecosystem. This basin is important for fishery, as it is a spawning and feeding area for several commercial fish species, including herring *Clupea harengus membras* L.

The zooplankton of the Vistula Lagoon is represented by 51 species (Rotatoria – 27, Cladocera – 10, Copepoda – 14) (Naumenko 2004). The specific hydrology of the lagoon, which includes shallow depths, salinity gradient fluctuation, strong wind-wave mixing, and low velocity of suspended matter sedimentation, does not permit the mass development of but a few species. Only *Eurytemora affinis* (Poppe) is able to be a dominant species in the lagoon (more than 50% in term of biomass). As regards feeding mode, phytophagous and omnivorous species prevail (77% and 20%, respectively), and the share of zoophagous species is very insignificant (Naumenko 2000). Two species of Cladocera – the native *Leptodora kindtii* (Focke 1844) and the non-indigenous *Cercopagis pengoi* (Ostroumov 1891) play the most important role among the predatory zooplankton of the Vistula Lagoon.

*C. pengoi* is a species of Ponto-Caspian origin. It was first recorded in the Baltic Sea in the Gulf of Riga in 1992 (Ojaveer and Lumberg 1995). The rapid colonization of the Baltic by *Cercopagis* followed (Gorokhova *et al*. 2000). In August 1999, the species was recorded in the Vistula Lagoon for the first time (Polunina 2000). The character of its distribution against the background of water temperature and salinity in the area led to the conclusion that the species was introduced to the lagoon by sea currents in early August (Naumenko and Polunina 2000).

*L. kindtii* has been recorded in the Vistula Lagoon since the 1940s by various authors (Schmidt-Ries 1940). According to earlier data (Naumenko 1999) confirmed by the present study, this native species is not noted in the Russian part of the Vistula Lagoon every year despite the fact that it was present in the Pergola River, which flows into the lagoon. This does not mean that the species does not form a self-reproducing population in the Vistula Lagoon. There have been observations (*e.g.*, Krylov 1984), that predatory cladocerans are able to live in water bodies for a long time at very low abundances, maintaining a so-called “hidden existence”, in which case they are not caught during standard hydrobiological surveys.

The possibility of a species becoming naturalized in a new community does not only depend on the peculiarities of its biology, but also on factors in the recipient community. After invasion, a species either needs to be able to find an empty niche or successfully compete for an occupied one (Berg *et al.* 1988). The vulnerability of the ecosystem to the invasion of one or another species is defined considerably by the complex of biotic relations – by predatory pressure and the presence of competition with biologically and ecologically similar species (Pavlov *et al*. 2001).

The aim this study is to perform a comparative analysis of two predatory cladoceran populations, the non-indigenous *C. pengoi* and the native *L. kindtii*, in the Vistula Lagoon.

## AREA OF STUDY

The area of investigation covered the Russian part of the Vistula Lagoon, including the Primorskaja Bight and the Kaliningrad Marine Channel (KMC). The Vistula Lagoon is a typical semi-enclosed shallow coastal basin in the southeastern Baltic with low salinity (about 3-5 PSU) and a soft bottom. The average depth is 2.7 m (max. 5.2 m), the total area is 861 $km^2$, of which 473 $km^2$ belong to the Russian Federation (Solovyohv 1971). Hydrological conditions are controlled mainly by water-exchange through the Baltijsk Strait and Pregola River run-off.

The Primorskaja Bight is situated in the northern part of the lagoon, and its depth is about 2-3 m. The KMC, 20 km in length and 9-11 m in depth, connects the mouth of the River Pregola with the Baltijsk Strait.

## MATERIAL AND METHODS

Samples were collected at 15 stations - 9 in the open part of the lagoon, 1 in the Primorskaja Bight, and 6 in the KMC.

During the 1996-2000 period, 180 zooplankton samples were collected and treated. The samples were taken by vertical hauls from the bottom to the surface with a Juday plankton net (opening diameter 14 cm; mesh size 100 μm) and preserved in 4 % formalin.

As *C. pengoi* was recorded in the lagoon only once in 1999, the seasonal dynamics of changes in its population structure could be followed based on data collected from April to September 2000. Sampling intervals of 10-25 days were applied. All the *Cercopagis* individuals were divided into four groups: 1) juveniles – with one pair of caudal spines, without eggs, 2) parthenogenetic females (P) with 1-3 pairs of caudal spines, 3) gamogenetic females (G) with 2-3 pairs of caudal spines, and 4) males with 1-3 pairs of caudal spines. The number of eggs in the marsupium was counted.

Data on water temperature and salinity were obtained with a Hydronaut sensor.

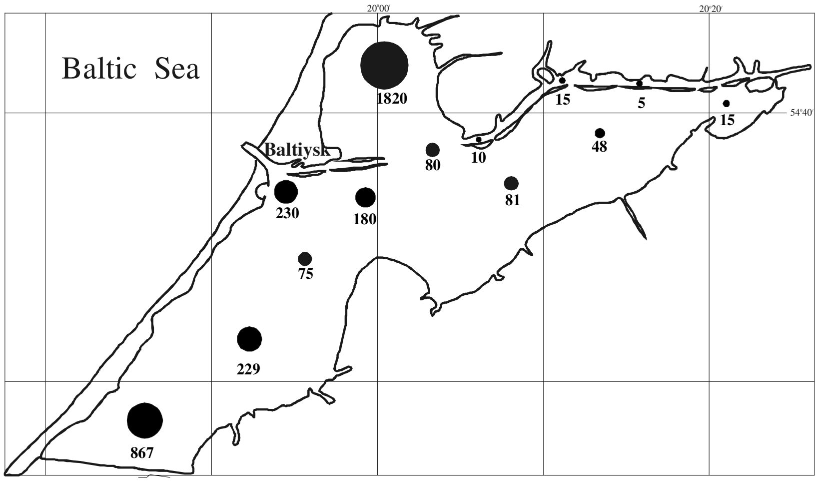


**Fig. 1.** Distribution of *Cercopagis pengoi* in the Vistula Lagoon in 2000.

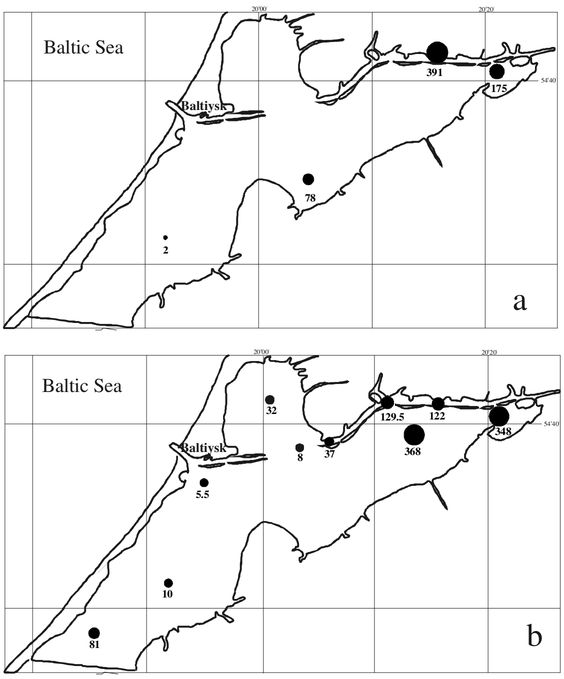


**Fig. 2.** Distribution of *Leptodora kindtii* in the Vistula Lagoon, a – 1996-1999, b – 2000.

## RESULTS

### Spatial and temporal distribution patterns

In 2000, *C. pengoi* was recorded almost everywhere, including parts of the study area from which it had been absent in August 1999. Its density increased as the salinity gradient increased. The highest species abundance was observed at the station where it was present in 1999 (Fig. 1).

*C. pengoi* abundance was higher in 2000 than in 1999. The highest abundance (to about 7000 ind. $m^{-3}$) during the study period was recorded in the Primorskaja Bight. In the part of the lagoon with fresh water (the mouth of the Pregola River), the average abundance of this non-indigenous cladoceran did not exceed 30 ind. $m^{-3}$.

In 1996-1999, *L. kindtii* occurred in parts of the Vistula Lagoon with fresh water, and only there could it sometimes reach a high density (maximum 1900 ind. $m^{-3}$) (Fig. 2a). In 2000, (the first year after the invasion of *C. pengoi*), *Leptodora* also occurred in more saline parts of the lagoon, and the density of this native cladoceran was higher than it had been in previous years (Fig. 2 b).

In spring 2000, *Cercopagis* appeared in the lagoon's zooplankton as early as in the middle of May (earlier than it usually does in its native area of distribution and in the Gulf of Finland) due to the early water warming to temperatures of up to 17.5°C. It was, recorded in the qualitative samples taken from some monitoring stations as early as May 17. On May 22, the abundance of *C. pengoi* ranged from 14 to 1200 ind. $m^{-3}$ (302 ind.$m^{-3}$, on average). The highest abundance was recorded in the Primorskaya Bight. Within a week, the species occurred at all stations, reaching maximum abundance (about 7000 ind. $m^{-3}$) in the Primorskaya Bight. Its average abundance was also the highest in late May (826 ind. $m^{-3}$), but it decreased during June. By late July, *C. pengoi* was already absent (Fig. 3 a).

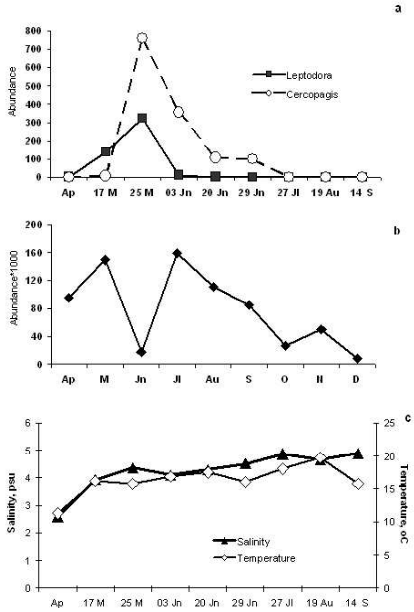


**Fig. 3.** Seasonal dynamics of the mean abundances of predatory cladocerans (ind. $m^{-3}$) (2000) (a) and zooplankton (1996-2000) (b) and water temperature (°C) and salinity (PSU) (2000) (c) in the Vistula Lagoon.

Single specimens of *L. kindtii* were found as early as April 26. Its abundance increased gradually, reaching maximal values in late May (503 ind.$m^{-3}$, on average). By the end of June, the population density had decreased to 1 ind. $m^{-3}$, and a month later the species was absent (Fig. 3 a).

Thus, both predatory cladocerans disappeared from the zooplankton by the end of July. At the end of June, total zooplankton density in the lagoon decreased sharply (Fig. 3 b). Changes in salinity were negligible, and the water temperature increased insignificantly (Fig. 3c). Thus, the development of the population is not considered to depend on these factors.

## Population structure

The population of *L. kindtii* consisted of juveniles and parthenogenetic females, and sexual generation was not noted.

Changes in the *C. pengoi* population structure in 2000 are presented in Fig. 4. Until June, the population consisted mainly of juveniles and parthenogenetic females. Sexual generation appeared as soon as May 25, but did not exceed 5% and was represented only by males. Then, in a week's time, the share of sexual generation in the population increased to 32% and was comprised of gamogenetic females (almost 70% of females had 2 resting eggs) and males. Then the share of juveniles and parthenogenetic females increased before the species disappeared from the lagoon in July.

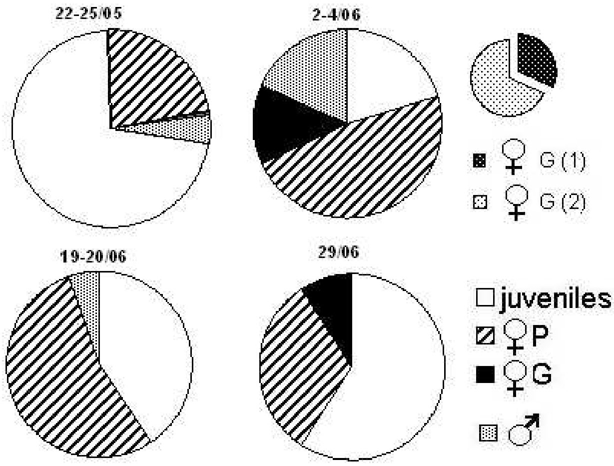


**Fig. 4.** Seasonal changes in the structure (percentage) of the *Cercopagis* population in the Vistula Lagoon in 2000.

According to the 1999-2000 data, the number of parthenogenetic eggs varied from 6 to 15 (10, on average) in 2000, which is fewer than that which the females carried in 1999 (Table 1).

**Table 1**

Number of parthenogenetic eggs per *C. pengoi* females in the Vistula Lagoon.

| Number of eggs | Years | |
|---|---|---|
| | 1999 | 2000 |
| Minimal | 7 | 6 |
| Average | 13 | 10 |
| Maximal | 22 | 15 |

Thus, asexual generation dominated the population of *C. pengoi* (89%, on average) during the whole vegetation season both in 1999 and 2000. The share of sexual generation was quite high (32%) in early June 2000. Two thirds of the females carried 2 resting eggs (Fig. 4).

The *C. pengoi* population in the lagoon was represented by all age-groups, and the mean specimen size was 1.26 mm, 1.84 mm, 1.93 mm, and 1.71 mm for juveniles, parthenogenetic females, gamogenetic females, and males, respectively.

## DISCUSSION

Salinity in the Vistula Lagoon ranges between 0.3 and 8.5 PSU and does not differ from values recorded in other regions where *C. pengoi* is distributed. Shallow, semi-enclosed lagoons, like the Vistula, warm faster than neighboring sea areas.

Since the native predator *L. kindtii* is not present each year in the lagoon, and, if it is, then not throughout the area and at low abundance, it is plausible that a relatively unsaturated niche exists for a new predator.

It is known that this species occurs when water temperature is 13-16°C in its native area. It is possible that its population in the lagoon developed from resting eggs produced in a previous year.

In the Vistula Lagoon, *Cercopagis* can occur in months when the temperature exceeds 15°C (in 2000 this happened as early as in May when the Baltic Sea surface water temperature was only 12.5°C according to data from the Laboratory of Coastal Systems, AB IORAS). Then its abundance increases and attains the maximum in about three weeks. After this maximum, males and gamogenetic females appear, and the population turns to sexual reproduction. After some time, their abundance decreases and the population disappears from the zooplankton. Such population development dynamics lead to the supposition that this species is monocyclic. Observations of *C. pengoi* in the Gulf of Finland (Krylov and Panov 1998, Telesh *et al*. 2000) and in the Gulf of Riga (Strake 2004, Ojaveer *et al*. 2004) revealed a very similar pattern of population development. Differences were shaped by the longer period during which the waters warmed to +15°C, which was due to the more northerly location of these gulfs.

In 2000, the character of the seasonal development of *C. pengoi* was not correlated with temperature or salinity dynamics in the Vistula Lagoon. Changes in salinity were slight, and the temperature increased gradually from May until August. At the same time, the seasonal dynamics of *C. pengoi* abundance reflected that of all the zooplankton; in late June and early July the density of zooplankton decreased sharply. Following this, an increase in total zooplankton abundance occurred, while the population of *C. pengoi* did not recover.

The Vistula Lagoon is one of the main herring spawning grounds in the southeastern Baltic Sea. Herring moves to the Baltic after spawning, while the development of the new generation continues in the lagoon. After metamorphosis, herring fry migrate to the sea. A segment of the population remains in the lagoon even during the summer months although mass downstream migration takes place at the beginning of June (Krasovskaya 1992). The maximal abundance of herring fry that had begun to feed exogenously was recorded in June, and, according to Naumenko (1992), this resulted in the considerable reduction of zooplankton density. It can be assumed that the decrease in *Cercopagis* abundance resulted from young herring feeding on it. It was shown, however, that *C. pengoi* was often found in stomachs of herring 8 to 17 cm in length, but not in fishes from smaller size classes (Ojaveer *et al*. 2004) that are present in the Vistula Lagoon in summer.

Thus, taking into consideration the decline of total zooplankton abundance (including rotifers and Copepoda and Cladocera juveniles, which *Cercopagis* are known to prey upon) in the June-July period (as a result of the predatory pressure of young herring), it seems that the most probable cause of the decrease in abundance that resulted in the complete disappearance of planktonic stages of *C. pengoi* is the shortage of food resources. The number of eggs produced by parthenogenetic females from the Vistula Lagoon population was similar to that noted in the Gulf of Finland (3 to 16 eggs, maximum 24 per female) (Telesh *et al*. 2000).

The Baltic population of *C. pengoi* commences sexual reproduction earlier than that from the Caspian Sea, which results in a considerable increase in the share of sexual generation as well as egg production. As soon as early June 2000, 13.5% of the *C. pengoi* population from the Vistula Lagoon consisted of gamogenetic females, and almost 70% of them had two resting eggs in the marsupium.

In the native area of this species, sexual reproduction begins in September or October. The early shift of the *C. pengoi* population to sexual reproduction was similar to that in the Gulf of Finland. In year following this species' introduction to the eastern Gulf of Finland, sexual generation occurred in August and almost 90% of the gamogenetic females had resting eggs (Krylov and Panov 1998, Telesh *et al*. 2000). It is probable that this mechanism of forming large numbers of resting eggs appears during the colonization of new areas as it favors genetically heterogeneous specimens that have an increased chance of survival in unfavorable conditions and eventually allows them to adapt to them.

It has been established that the Ponto-Caspian Cercopagidae originally derived from the genus *Bythotrephes*, a group with a more northern distribution that usually produce 2-4 resting eggs (Rivier 1969). It is possible that *C. pengoi* from the Baltic are able to produce larger numbers of resting eggs than those in the Caspian Sea. Females with three resting eggs noted in samples taken from the Gulf of Finland and the Vistula Lagoon confirm this supposition.

Specimens of *C. pengoi* from the Vistula Lagoon have a larger body size than those from the Caspian Sea, the Gulf of Finland or the Gulf of Riga (Grigorovich *et al*. 2000, Antsulevich and Välipakka 2000, Alimov and Bogutskaya ed. 2004). Two factors may contribute to this phenomenon:

- temperature conditions in the Vistula Lagoon are more favorable than those in the Gulf of Finland and the Gulf of Riga;
- the decrease in the abundance and biomass of spawning stocks of herring in the Vistula Lagoon (Krasovskaya 1992, 1999) have resulted in decreased fry abundance and, consequently, decreased predatory pressure on zooplankton, and possibly, as a further consequence, the increased sizes of plankton predators.

It can be concluded that the Vistula Lagoon population of *C. pengoi* was already self-reproducing in 2000. In the open sea and in the deep waters of the Gulf of Riga and the Gulf of Finland, this species has never appeared before June nor has it been noted to peak in May. Thus, the open Baltic Sea can serve as a source of new *Cercopagis* specimens only during summer.

The mass development of *L. kindtii* (together with that of the *C. pengoi* population) in the lagoon in the late 1990s indicates that there are enough food resources for both predators. Declining herring spawning stock abundance in the 1988-1996 period resulted in a decrease of fish pressure on zooplankton and permitted the intensive development of Cladoceran predator populations.

## CONCLUSIONS

1. A self-reproducing population of *C. pengoi* is established in the Vistula Lagoon.
2. The structure of the *C. pengoi* population has changed considerably in comparison with that in its original area. The population of *Cercopagis* consisted of juveniles, males, and parthenogenic and gamogenic females. Parthenogenic females had 6-15 eggs, while gamogenic had 1-2 resting eggs. The share of sexual generation in the *C. pengoi* population can reach 30%.

3. Neither simultaneous changes in the *L. kindtii* population structure nor sexual generation were noted.
4. The area of occurrence of *L. kindtii* has expanded since the *C. pengoi* invasion, but high densities occur only in the freshwater part of the lagoon, while *Cercopagis* occurs throughout.
5. The drastic decrease in the abundance of both predatory cladocerans in late June and early July can be explained by young herring feeding on zooplankton, which also constitutes a food resource for *C. pengoi* and *L. kindtii*.

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