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THE EFFECT OF SALINITY LEVELS ON THE STRUCTURE OF ZOOPLANKTON COMMUNITIES

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Abstract: The objective of this study was to determine the qualitative and quantitative structure of zooplankton communities in the Vistula Lagoon and to establish whether zooplankton abundance and biodiversity are affected by salinity levels. Samples for biological analyses were collected in the summer (June-September) of 2007-2011 at eleven sampling sites. Statistical analysis revealed a significant correlation between salinity levels and the number of species (r= -0.2020), abundance (r= 0.1967) and biomass (r= 0.3139) of zooplankton. No significant correlations were found between salinity and the biodiversity of zooplankton. The results of the study suggest that salinity affects the abundance and structure, but not the diversity of zooplankton communities in the Vistula Lagoon.

Key words: zooplankton abundance; biological diversity; brackish waters; Vistula Lagoon

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INTRODUCTION

Brackish water habitats are characterized by highly unstable environmental conditions, primarily salt concentrations (Cognetti and Maltagliati, 2000). They differ from marine and inland waters in terms of salinity levels, hydrological and ecological conditions, which is why they continue to arouse interest among researchers. The mixing of saline water with freshwater inflows leads to salinity and temperature changes that affect the biotic and abiotic components in the water body. The organisms living in brackish waters have to be able to tolerate rapid drops and fluctuations in salinity levels, which is why such water bodies are colonized by freshwater and seawater euryhaline species, accompanied by a few typical brackish water taxa (Paturej, 2005; 2006; Wooldridge and Deyzel, 2009). Variations in salt concentrations on both spatial and seasonal scales largely contribute to changes in the species composition and distribution of zooplankton communities (Silva et al., 2009). The biological and ecological specificity of brackish waters results from their hydrological distinctness. Brackish waters provide habitat for a lower number of species than marine and fresh waters. According to the species-minimum concept proposed by Remane (1934), the lowest number of taxa occur at critical salinity levels of 5-8 PSU, which is referred to as the "paradox of brackish waters". The highest decline is observed in the number of Rotifera and Oligochaeta species of freshwater origin. The overcoming of the critical salinity barrier was an important evolutionary event and a major step towards the colonization of freshwater habitats. Changes in salinity lead to increased mortality of both freshwater species adapted to brackish water environments and marine species adapted to freshwater environments. An adaptive response of zooplankton to adverse environmental conditions may involve disturbances in reproduction and development (Hart et al., 2003; Silva et al., 2009; Santangelo et al., 2014).

The aim of this study was to determine the qualitative and quantitative structure of zooplankton communities in the Vistula Lagoon and to verify the hypothesis that the number of species, abundance, biomass and biodiversity of zooplankton are affected by salinity levels.

MATERIALS AND METHODS

The study was conducted on the Vistula Lagoon situated in the southern coast of the Baltic Sea. The Vistula Lagoon is a large, but shallow water body. The Polish part of the lagoon has a total area of 328 km^2, an average depth of 2.6 m and a maximum depth of 4.4 m (Chubarenko and Margoński, 2008). The Vistula Lagoon is a brackish water body due to the mixing of saline water from the Baltic Sea with freshwater inflows from rivers that feed into the lagoon. Regarding dissolved salt concentrations, the Polish part of the Vistula Lagoon can be divided into two regions: a region close to the river mouth (Western Basin), dominated by fresh water (0.5-2 PSU, up to 4 PSU during storms) and the central region (Central Basin), dominated by saline water (2-4 PSU, up to 6 PSU during brackish water inflows) (Kruk et al., 2012; Witek et al., 2010).

Samples for biological analyses were collected once a month, in the summer season (June-September) of 2007-2011 at eleven sampling sites (Fig. 1), with a Ruttner sampler and a 10 dm^{-3} bucket at shallow sites in the coastal zone. The biological material (30 dm^{-3}) was concentrated using an Apstein plankton net (30 μm), and was fixed in Lugol's solution followed by a 4% formalin solution. A total of 108 samples were collected. Salt concentrations were measured with a WTW Multi 350i multi-meter.

Qualitative and quantitative determinations of zooplankton were made based on a microscopic analysis of the experimental material. For the purpose of a qualitative assessment, zooplankton were identified to the species level within three taxonomic groups: Rotifera, Cladocera and Copepoda, and the Copepoda were further subdivided into developmental stages of nauplius and copepodid. A quantitative analysis, including zooplankton abundance and biomass, was performed as recommended by Bottrell et al. (1976); Ejsmont-Karabin (1998); Hillbricht-Ilkowska and Patalas (1967) and Starmach (1955).

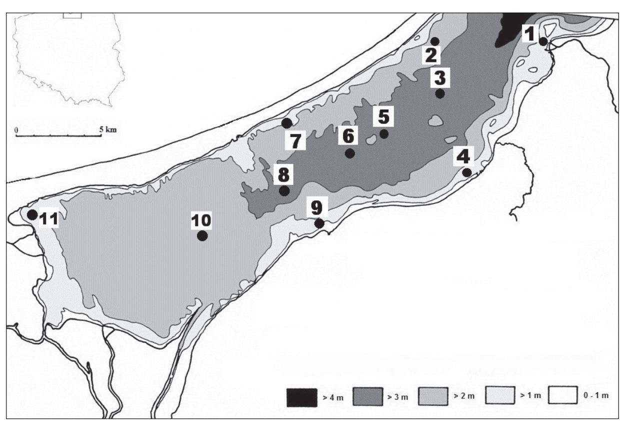

Fig. 1. Sampling sites in the Vistula Lagoon.

Table 1. List of recorded zooplankton species in the Vistula Lagoon over the experimental period.

	2007	2008	2009	2010	2011
Anuraeopsis fissa (Gosse, 1851)	+	+	+	+	+
Ascomorpha saltans Batrsch, 1870	+	+	+		+
Asplanchna priodonta Gosse, 1850	+	+	+	+	+
Brachionus angularis Gosse , 1851	+	+	+	+	+
Brachionus calyciflorus Pallas, 1766	+	+	+	+	+
Brachionus diversicornis Daday, 1883					+
Brachionus quadridentatus Hermann, 1783				+	+
Brachionus urceolaris Müller, 1773	+			+	+
Cephalodella catellina Müller, 1786				+	+
Cephalodella gibba Ehrenberg, 1832				+	+
Colurella colurus Ehrenberg, 1830	+	+	+	+	+
Colurella uncinata Müller, 1773				+	
Euchlanis dilatata Ehrenberg, 1832	+	+		+	+
Filinia brachiata Rousselet, 1901				+	
Filinia longiseta Ehrenberg, 1834	+	+	+	+	+
Hexarthra mira (Hudson 1871)	+				
Keratella cochlearis (Gosse,1851)	+	+	+	+	+
Keratella quadrata (Müller, 1786)	+	+	+	+	+
Lecane closterocerca (Schmarda, 1859)				+	+
Lecane flexilis (Gosse, 1886)				+	+
Lecane luna (Müller, 1776)				+	+
Lepadella ovalis (Müller, 1786)				+	+
Mytilina mucronata (Müller, 1773)					+
Polyarthra longiremis Carlin, 1943				+	+
Polyarthra platyptera Ehrenberg, 1838	+	+	+		
Polyarthra vulgaris Carlin, 1943		+	+	+	
Pompholyx sulcata Hudson, 1885	+	+	+	+	+
Proales sp.				+	+
Rotaria neptunia (Ehrenberg, 1832)				+	+
Rotaria rotatoria (Pallas, 1766)				+	+
Synchaeta sp.	+	+	+	+	+
Testudinella elliptica (Ehrenberg, 1834)				+	+
Testudinella patina (Hermann, 1783)				+	
Trichocerca cylindrica (Imhof, 1891)	+				
Trichocerca pusilla (Lauterborn, 1898)	+	+	+	+	+
Trichocerca similis (Wierzejski, 1893)	+	+	+		+
Trichotria pocillum (Müller, 1776)					+
Trichotria tetractis (Ehrenberg, 1830)					+
Alona rectangula G.O. Sars, 1862				+	+
Alonella nana (Barid, 1843)					+

Table 1 continued

	2007	2008	2009	2010	2011
Bosmina longirostris (Müller, 1785)			+	+	+
Cercopagis pengoi (Ostroumov, 1891)	+				
Ceriodaphnia quadrangula (Müller, 1785)		+		+	+
Chydorus sphaericus (Müller, 1776)	+			+	+
Diaphanosoma brachyurum (Liévin, 1848)	+	+	+	+	+
Eubosmina coregoni (Baird, 1857)				+	+
Leptodora kindtii (Focke, 1844)			+	+	
Sida crystallina (Müller, 1776)	+				
Acanthocyclops vernalis (Fischer, 1853)				+	
Acartia bifilosa (Giesbrecht, 1881)		+			+
Acartia longiremis (Dana, 1846)	+	+	+	+	+
Acartia tonsa (Dana, 1846)	+	+	+	+	+
Cyclops sp.	+	+	+	+	
Eurytemora affinis (Poppe, 1880)	+	+	+	+	+
Harpacticoida				+	+
Megacyclops viridis (Jurine, 1820)				+	
Mesocyclops leuckarti (Claus, 1857)				+	+
Metacyclops gracilis (Lilljeborg, 1853)				+	
Paracyclops affinis (G.O. Sars, 1863)					+
Temora longicornis (Müller, 1785)	+				
Thermocyclops oithonoides (G. O. Sars, 1863)				+	
kopepodit Calanoida				+	+
kopepodit Cyclopoida					+
nauplii Calanoida	+	+	+	+	+
nauplii Cyclopoida	+	+	+	+	+
nauplii Harpacticoida				+	+

The zooplankton structure was characterized using the following biocenotic indicators: species constancy (Tischler, 1949 cited by Trojan, 1980), species domination (Kasprzak and Niedbała, 1981), the Shannon diversity index (based on abundance and biomass), (Shannon, 1948) and Pielou's evenness index (Pielou, 1974).

The results obtained were processed statistically with the use of STATISTICA PL 10.0 software. The effect of salinity levels on the qualitative and quantitative structure of zooplankton was estimated using Pearson's correlation coefficient.

RESULTS

During the study, salinity in the Vistula Lagoon varied over a wide range, subject to sampling site and date. In 2007, salinity ranged from 2.4 to 9.3 PSU, in 2008 from 2.6 to 4.4 PSU, and in 2009 from 1.8 to 4.4 PSU. In the next two years, salinity did not exceed 4.0 PSU. Average salinity in 2010 and 2011 reached 2.1 PSU and 1.5 PSU, respectively.

The zooplankton of the Vistula Lagoon comprised three taxonomic groups: Rotifera, Cladocera and Copepoda (Table 1). The average number

Table 2. Eudominant and dominant zooplankton species* in the Vistula Lagoon over the experimental period.

	2007	2008	2009	2010	2011
Brachionus angularis	9.5			10.3	13.3
Filinia longiseta	5.3	10.2	20.7	10.2	18.8
Keratella cochlearis	53.8	67.9	65.0	30.6	37.7
Polyarthra longiremis				17.0	
Pompholyx sulcata				5.1	
Bosmina longirostris				6.6	

* Species dominance classes according to Kasprzak and Niedbała (1981): >10.0% eudominant species, 5.1-10.0% dominant species

of recorded species was 9 in 2007 and 2008, 10 in 2009 and 14 in 2010 and 2011. They were mostly freshwater organisms with a wide tolerance to salinity and a few brackish and marine taxa. In all years of the study, the qualitative structure of zooplankton was dominated by the rotifers *Filinia longiseta* and *Keratella cochlearis*, accompanied by *Brachionus angularis* in 2007, 2010 and 2011. Furthermore, in 2010 *Polyarthra longiremis*, *Pompholyx sulcata* and *Bosmina longirostris* formed a high proportion of the zooplankton community (Table 2). Over the experimental period, 17 constant species were recorded in the Vistula Lagoon. *Keratella cochlearis* and *Filinia longiseta* were absolutely constant species, whereas constant species were much more numerous (Table 3).

A quantitative analysis of the collected samples revealed that the average densities of zooplankton in the Vistula Lagoon ranged from 1235 to 5704 ind. dm^{-3} (Fig. 2). The Rotifera accounted for 78.4-94.2% of the total zooplankton abundance (Fig. 3).

Keratella cochlearis (9662-63007 ind. dm^{-3}), *Filinia longiseta* (18-17185 ind. dm^{-3}) and members of the genus *Brachionus* (675-4876 ind. dm^{-3}) reached the highest total abundance among rotifers in the studied years. Crustaceans had a 5.8-21.6% share of the total zooplankton abundance. Among cladocerans, *Diaphanosoma brachyurum* (104-1654 ind. dm^{-3}) and *Bosmina longirostris* (152-2084 ind. dm^{-3}) were characterized by high abundance values. Among copepods, high abundance values were reported for *Eurytemora affinis* (135-1498 ind. dm^{-3}) and the juvenile stages of crustaceans - nauplii (1960-4693 ind. dm^{-3}). The abundance of copepods was also indicated by the presence of *Acartia longiremis* (558-1468 ind. dm^{-3}) and *Acartia tonsa* (186-1102 ind. dm^{-3}).

Average zooplankton biomass ranged from 0.94 to 18.40 mg/dm^3 (Fig. 4), mostly due to the presence of crustaceans (Fig. 5) whose share of the total biomass reached 63.3-97.3%.

Among Cladocera, *Diaphanosoma brachyurum* was characterized by the highest total biomass (3.56-85.59 mg dm^{-3}) in the studied years. *Leptodora kindtii,* whose occurrence was seasonal, also contributed greatly to an increase in zooplankton biomass. The Copepoda, including *Eurytemora affinis* (2.75-68.86 mg dm^{-3}) and *Acartia longiremis* (20.15-36.11 mg dm^{-3}), also formed a high proportion of the total zooplankton biomass. Rotifera had a low percentage share of zooplankton biomass, except for *Keratella cochlearis* (0.89-18.83 mg dm^{-3}) and representatives of the genus *Brachionus* (0.36-4.00 mg dm^{-3}), which dominated also in terms of abundance.

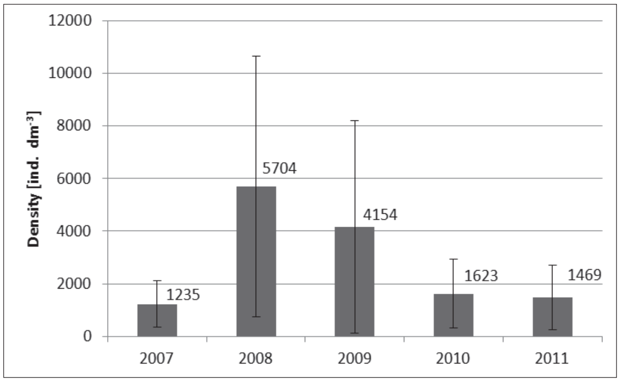

Fig. 2. Average densities [ind. dm^{-3}] of zooplankton in the Vistula Lagoon during the study period.

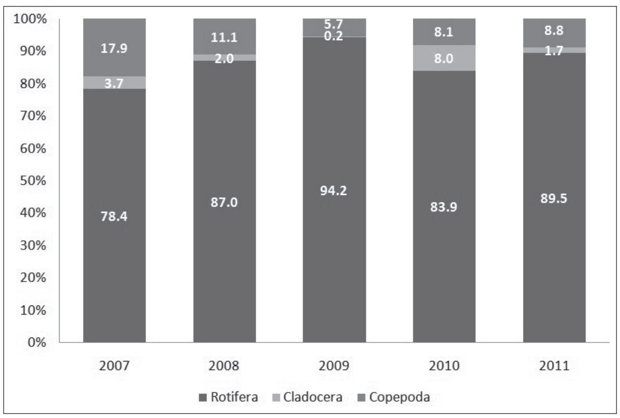

Fig. 3. Percentage share [%] of zooplankton groups in total zooplankton abundance

The biological diversity of zooplankton communities in the Vistula Lagoon was estimated based on Pielou's evenness index and the Shannon diversity index calculated using abundance and biomass values. Pielou's evenness index remained in the 0.24-0.72 range, indicating that the community was not even. The Shannon diversity index based on zooplankton abundance reached 0.6-2.1. The relatively low values of this index resulted from a clear dominance of one species. For instance, in August 2007, the Shannon diversity index was determined at 0.6, and *Keratella cochlearis* was the dominant species, with an 83.5% share of the total zooplankton abundance. A similar situation was encountered in June and July 2009, when the value of the index was also 0.6, and *Filinia longiseta* (83.2%) and *Keratella cochlearis* (83.5%), respectively, dominated in the zooplankton community.

The Shannon diversity index calculated based on zooplankton biomass remained in the 0.9-2.8 range. Similar to abundance, the minimal value of the index was noted when one taxon clearly dominated over the others (H' = 0.9 – *Eurytemora affinis* – 68.8%, H' = 1.0 – *Diaphanosoma brachyurum* – 64.6%)

There were significant correlations between salinity levels, the number of species, abundance and biomass of zooplankton. No significant correlations were found between salinity and the biodiversity of zooplankton (measured as the Shannon diversity index) based on abundance (Hl) and biomass (Hb), and Pielou's evenness index (e), (Table 4).

DISCUSSION

Lagoons are shallow bodies of water with both freshwater and saltwater inflows. During seawater intrusions, marine processes dominate over fluvial processes in entire estuaries or their parts. In the absence of saltwater inputs, the physicochemical properties of estuarine water are similar to those observed in extensive inland water bodies (Paturej, 2005; Paturej and Bogacka, 2001). Salinity may vary over a wide range (0.05-35 PSU) in lagoons, depending on the inflow of freshwater and seawater, wind direction and their individual characteristics (Paturej, 2006). Differences in salt concentrations affect the ecological processes in lagoons, including zooplankton abundance and diversity (Badsi et al., 2010; Dube et al., 2010; Gao

Table 3. Absolutely constant and constant species* in the Vistula Lagoon over the experimental period.

	2007	2008	2009	2010	2011
Acartia longiremis	85	85	80		
Acartia tonsa		60			
Eurytemora affinis	75	75			58
Asplanchna priodonta					54
Brachionus angularis			100	79	83
Brachionus calyciflorus			55		58
Brachionus urceolaris					54
Colurella colurus				63	
Euchlanis dilatata				54	67
Filinia longiseta		85	100	63	96
Keratella cochlearis	85	100	100	100	100
Lecane closterocerca					54
Polyarthra longiremis				67	
Pompholyx sulcata				83	71
Polyarthra vulgaris		60			
Polyarthra platyptera		70			
Trichocerca pusilla	70	75	60	67	100

*Frequency criterion according to Tishler (1949) as cited in Trojan (1980): 100-76% (absolutely constant species), 75-51% (constant species)

Table 4. Correlations between salinity and the values of zooplankton structure and biodiversity indicators.

	Number of species	Abundance [ind./dm^3]	Biomass [mg/dm^3]	Hl	Hb	E
R	**-0.2020**	**0.1967**	**0.3139**	0.0051	-0.0634	0.0871
P	**0.036**	**0.041**	**0.001**	0.958	0.515	0.370

et al., 2008; Paturej, 2009). Changes in salinity may directly and indirectly influence zooplankton abundance, leading to the extinction of some species and the appearance of others. Many organisms migrate to avoid high or low salinity. Salinity fluctuations may indirectly cause or contribute to food shortage, thus affecting zooplankton abundance (Perumal et al., 2009).

In the Vistula Lagoon, differences in salinity are caused by seawater intrusion or reduced freshwater inflow when the water level is low (Kruk et al., 2012). Therefore, primarily organisms with a wide tolerance to salinity fluctuations occur in animal plankton of the Vistula Lagoon. In the present study, we found mainly freshwater, euryhaline Rotifera, such as the genera *Brachionus*, *Keratella cochlearis* or *Filinia longiseta*. Among copepods mainly Calanoida – typical brackish water *Eurytemora affinis* and marine species of the genus *Acartia* (*A. tonsa* and *A. longiremis*), occur. Cladocerans appeared occasionally, on the freshwater sites, which is characteristic for this group, as they are typically freshwater organisms, and most spe-

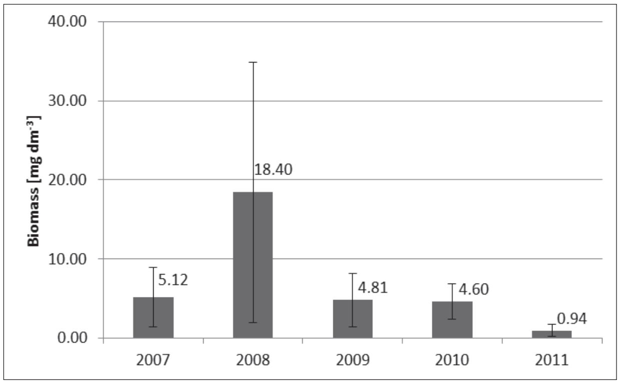

Fig. 4. Average zooplankton biomass [mg dm^{-3}] in the Vistula Lagoon during the study period.

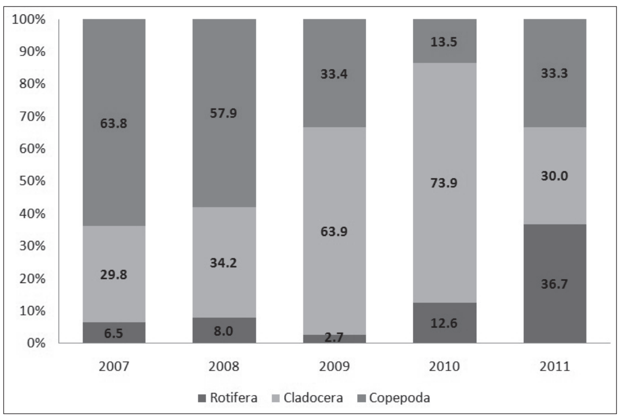

Fig. 5. Percentage share [%] of zooplankton groups in total zooplankton biomass

cies do not tolerate high salt concentrations (Boix et al., 2007; 2008; Brucet et al., 2009). Thus, even a slight increase in salinity reduces the abundance and richness of cladocerans. Their disappearance in saline waters promotes the development of rotifers, in particular euryhaline species of the genera *Brachionus* and *Colurella*, as representatives of both groups are mostly filtrators and compete for food (Anton-Pardo and Armengol, 2012). Thus, brackish waters are characterized by the domination of small organisms, such as rotifers and small-sized crustaceans (Brucet et al., 2009; 2010; Jeppesen et al., 1994).

Salinity affects not only the structure of zooplankton, but also its abundance. In the present study, a significant, positive correlation was observed between zooplankton density and biomass, and salinity in the Vistula Lagoon, which was probably related to the increased proportion of copepods in the structure of zooplankton, especially species such as *Eurytemora affinis*, *Acartia tonsa* and *Acartia longiremis*. The appearance of copepods, with an increase in salinity that resulted in an increase in abundance of planktonic fauna, has been observed also by Badsi et al. (2010); Gao et al. (2008) and Zakaria et al. (2007). The increase in salinity may also cause a decrease in the species richness. In the Vistula Lagoon, the number of zooplankton species was negatively correlated with salinity, which can be explained by the occurrence of the brackish water paradox phenomenon, attributable to the salinity of 5-8 PSU. Similar observations were made by Zorina-Sakharov et al. (2014) in the fore-delta shallow water habitats of Kyliya branch of the Danube River. The structure of zooplankton was dominated by freshwater species, but species richness decreased linearly with the increase of salinity. Nonetheless, Telesh et al. (2011) claim that planktonic organisms often do not show minimum species diversity within the marine-freshwater salinity gradient. Zooplankton biodiversity also depends on salinity, as evidenced by Echainz and Vignatti (2011) and Schallenberg et al. (2003), an an increase in salinity causes loss of biodiversity. This study, however, does not support this thesis, probably because salinity fluctuations were too small to cause changes in the diversity of zooplankton, or the study period was too short to capture changes in biodiversity.

It may be concluded that salinity is a key factor affecting the structure of zooplankton communities. In the Vistula Lagoon, the species composition and total abundance of zooplankton are determined by salinity. A small increase in salinity, observed in the examined water body, leads to a decrease in species richness as well as an increase in the abundance and biomass of zooplankton. According to literature data, a rise in salt concentrations causes changes in biodiversity measured with the use of biocenotic indicators. However, such changes were not noted in our study. Therefore, further research is needed to verify whether zooplankton biodiversity in the Vistula Lagoon is influenced by salinity.

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Conflict of interest disclosure: The above-mentioned manuscript has not been published before and is not under consideration for publication anywhere else. The publication of this article was approved by both authors, as well as by the responsible authorities.

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