A COMPARISON OF SALINITY CHANGES IN THE SZCZECIN LAGOON ALONG THE FAIRWAY SZCZECIN–ŚWINOUJŚCIE DURING 1956-57, 1973-76 AND 1991-94

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Abstract

Salinity of surface and near bottom water, determined by chlorinity equivalent, was studied in the Szczecin Lagoon along the fairway Szczecin–Świnoujście in April–November of 1991–1994. The results were compared with the data from earlier, analogous, studies from 1956–57 and 1973–76. A definite increase of water salinity in the Szczecin Lagoon was observed in the successive periods.

INTRODUCTION

Changes in the abundance of ichthyofauna in the Szczecin Lagoon, and in particular the decreasing number of fish species and specific changes in species quanta, observed in the recent half century [Garbacik–Wesołowska, 1994; Dunin–Kwinta, 1995] are mainly attributed to the intensive exploitation of fish resources in the lagoon — especially as regards „white fish stock" [Tobolicz, 1959; Garbacik–Wesołowska, 1994], increasing eutrophication of the basin and water contamination by pollutants, on one hand [Drzycimski, 1987; Kompowski and Pieńkowski, 1992; Wiktor and Garbacik–Wesołowska,

1992; Dunin–Kwinta, 1995], and hydrotechnical activity of man on the other. Pike can be regarded a victim of the latter activities, because it was cut off of its natural spawning grounds since the Lagoon banks were dysked [Garbacik–Wesołowska, 1994].

Hydrotechnical measures aimed at dredging and widening of the fairway between Szczecin and Świnoujście caused decline of the water level in the Szczecin Lagoon in relation to the Pomeranian Bay. This decline facilitates the penetration of saline water from the bay and results in an increase of salinity in the Lagoon, particularly under drought, when the average flow of the river Odra markedly decreases [Mielczarski, 1987a; 1987b]. The problem of increasing salinity in the Szczecin Lagoon was also discussed by Wiktor and Garbacik–Wesołowska [1993]. Water inflows and frequent back flows from the sea cause an increase of chemical composition astaticism, this in turn enhancing the effects of eutrophication in the Lagoon biotope and biocoenoses [Czachorowski, 1994].

Water quality of the Szczecin Lagoon and its salinity, in particular, was often subject of extensive studies [Majewski 1957, 1958, 1960, 1964, 1968, 1972, 1980; Mikulski 1960, 1970; Zaborowska–Młodzińska 1963; Młodzińska 1974, 1980; Mutko 1977, 1994; Jasińska 1987, 1991; Jasińska et al. 1986, 1989; Poleszczuk et al. 1992, 1995a, 1995b, 1995c, 1970]. The reviewed articles present results of studies carried out at various locations of the Odra river estuary and more so in different periods of the wide time span from 1952 to 1994. The data are often presented as the annual mean values from many measurement stations, so the analysis of salinity dynamics on the selected spot is not possible, nor the correlation of salinity to environmental parameters of importance can be traced.

This article presents an attempt to analyse changes of salinity in surface and near bottom water of the Szczecin Lagoon along the fairway from the Gate Way I to Gate Way IV from the years 1991–1994 and compare the results of analysis with the data from earlier studies (1956–1957) [Wypych, 1970] and with the data acquired from the State Environment Protection Agency (SEPA) in Szczecin from the years 1973–1976.

MATERIAL AND METHODS

Water samples for salinity measurements were collected from the subsurface layer (1 m below the surface) and from the near bottom layer (1 m above the bottom) at measurement stations: Gate Way I, Gate Way II, Gate Way III and Gate Way IV (Fig. 1.). Samples were taken from April to November 1991–1994.

Chlorinity was determined using the standard Knudsen procedure [Oxner,

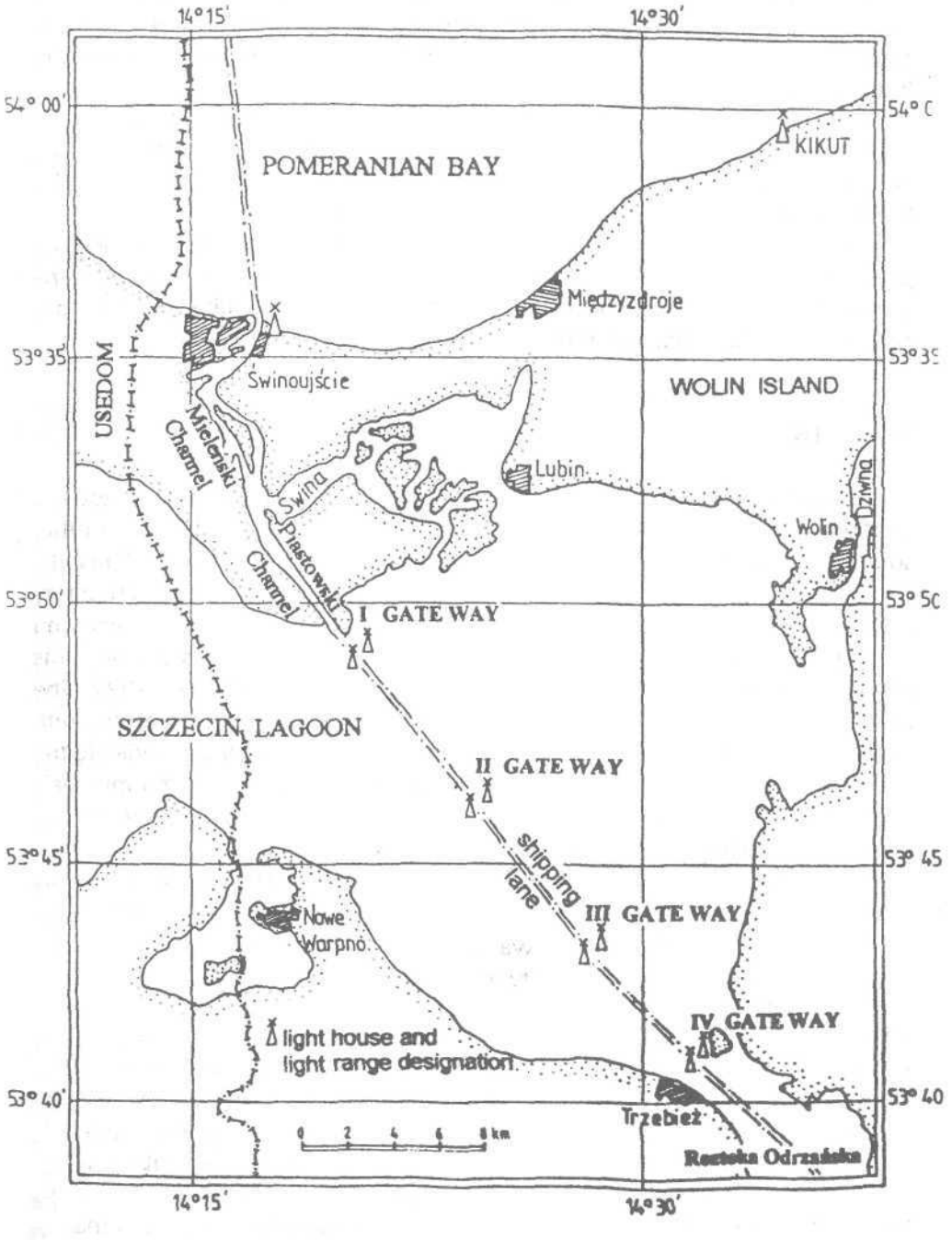

Fig. 1. The Szczecin Lagoon — location of sampling stations: Gate Way I, Gate Way II, Gate Way III and Gate Way IV

1952]. This procedure was introduced in water quality analyses of the Szczecin Lagoon by Wypych [1970], and although it is not appropriate [Wypych, 1970; Poleszczuk, in press] the measurements were continued by this method to ensure all data comparability.

The data on water salinity along the fairway in the Szczecin Lagoon in May-November 1956 and 1957 were acquired from Wypych [1970], and the data of chloride ion concentrations in April–November 1973–1976 from the Inspectorate of the State Environment Protection Agency in Szczecin.

The analyses of water in 1991–1994 formed a part of a complex scientific programme conducted by the Świnoujście Branch of the Sea Fisheries Institute, Gdynia. Some of these results have been already published [Poleszczuk et al. 1993, 1995, Poleszczuk and Sitek, 1995].

RESULTS

The results of chlorinity determination at measurement stations in the Szczecin Lagoon are presented in Table 1. The table contains also the data from other sources [Wypych, 1970; SEPA] and statistical characteristics of all results. Figs. 2 and 3 illustrate the selected items of the most unprecedented chlorinity changes along the Lagoon from the Gate Way I to the Gate Way IV recorded in the periods 1974–1976 and 1992–93. In Fig.4. Box-and-Whiskers diagrams are shown of chlorinity results from the years 1973–76 and 1991–1994. The median values represent 50% interval of an increasing series of results with equal (25%) numbers below and over the median. The „whiskers" indicate the minimal and maximal results. The field values, differing by 1.5 (the minimal) and 3-times (the maximal) the „box" width, are denoted by separate points: „o" and „x", respectively [Statistica, 1994].

The presented data indicate that in 1956–57 the highest salinity of surface water and the most frequent alterations were found at the station Gate Way I. In that period the near bottom water showed high mean values and considerable changeability of chlorinity at all measurement stations.

The mean salinity of surface water in 1973–1976 was higher than in 1956–57, except at the station Gate Way IV. Simultaneously, the variability of salinity, expressed as the amplitud [(max. Cl ‰) – (min. Cl ‰)], was smaller than in 1956–57. Near bottom water at all stations was less saline and indicated smaller amplitudes, while the coefficients of salinity variability (CV %) were rather high, increasing from the Gate Way I to the Gate Way IV.

In 1991–94 the mean salinity of surface and near bottom water of the Szczecin Lagoon was significantly higher at all measurement locations than in earlier studies. The amplitudes of chlorinity at Gate Way I and Gate Way II were lower, though comparable to those found in the 1950-ties and 70-ties.

Variability coefficients (CV %) of chlorinity at all measurement stations were mostly lower in 1990-ties than in the previous analyses.

Table 1

Statistical evaluation of surface and near bototm chlorinity [Cl ‰] of water in the Szczecin Lagoon

	GATE WAY I		GATE WAY II		GATE WAY III		GATE WAY IV	
	surface	near bottom	surface	near bottom	surface	near bottom	surface	near bottom
May-November 1956-1957 (data from Wypych 1970) n = 62 sample size								
Min. (Cl‰)	0,09	0,09	0,09	0,11	0,08	0,09	0,07	0,07
Average (Cl‰)	0,66	1,77	0,43	1,57	0,29	1,07	0,23	0,72
Median (Cl‰)	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
Max. (Cl‰)	3,83	4,23	1,34	3,96	0,85	3,67	0,40	3,73
SD	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
CV [%]	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
April-November 1973-1976 (data from SEPA*) n = 25 sample size								
Min. (Cl‰)	0,20	0,20	0,08	0,13	0,07	0,07	0,07	0,07
Average (Cl‰)	0,80	1,59	0,56	0,96	0,38	0,87	0,14	0,56
Median (Cl‰)	0,56	0,84	0,44	0,66	0,30	0,60	0,10	0,20
Max. (Cl‰)	2,76	4,01	1,64	3,40	1,06	2,98	0,39	2,73
SD	0,58	1,27	0,40	0,95	0,29	0,85	0,08	0,75
CV [%]	71,8	80,3	71,8	98,5	75,7	98,0	56,6	134,0
April-November 1991-1994 (this project data) n = 31 sample size								
Min. (Cl‰)	0,15	0,20	0,13	0,14	0,08	0,09	0,08	0,08
Average (Cl‰)	1,22	1,79	0,76	1,47	0,62	1,23	0,25	0,89
Median (Cl‰)	0,95	1,44	0,74	1,32	0,62	0,94	0,17	0,80
Max. (Cl‰)	3,40	3,54	1,62	3,16	1,48	3,60	1,10	2,98
SD	0,91	1,04	0,41	0,79	0,35	0,87	0,21	0,75
CV [%]	74,7	58,2	53,7	53,9	56,9	70,7	82,9	84,0

n.d. - no data

* - SEPA - State Environment Protection Agency Inspectorate in Szczecin

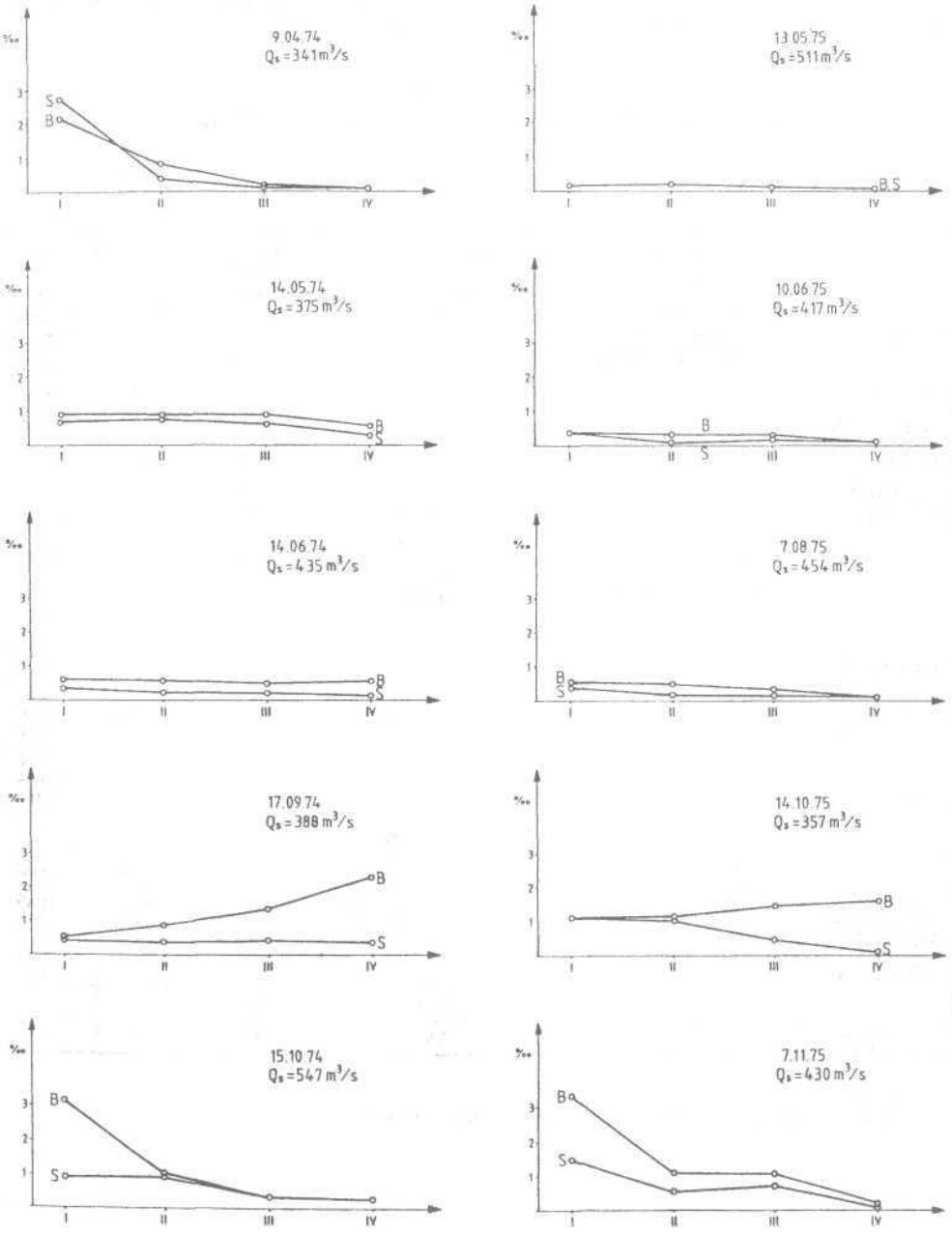

Fig. 2. Chlorinity changes in surface (S) and near bottom (B) water of the Szczecin Lagoon along the profile Gate Way I — Gate Way IV in 1974 and 1975

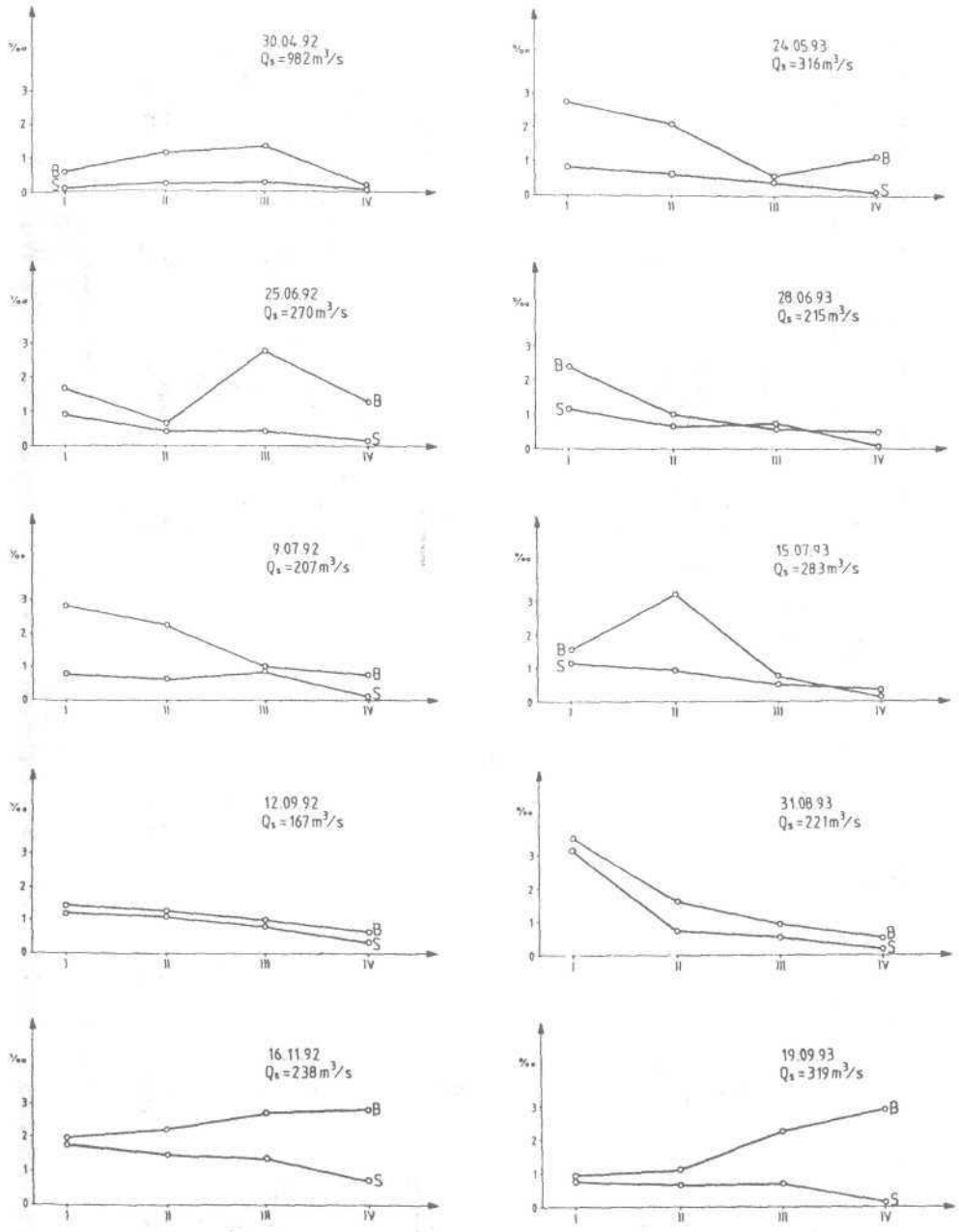

Fig. 3. Chlorinity changes in surface (S) and near bottom (B) water of the Szczecin Lagoon along the profile Gate Way I — Gate Way IV in 1992 and 1993

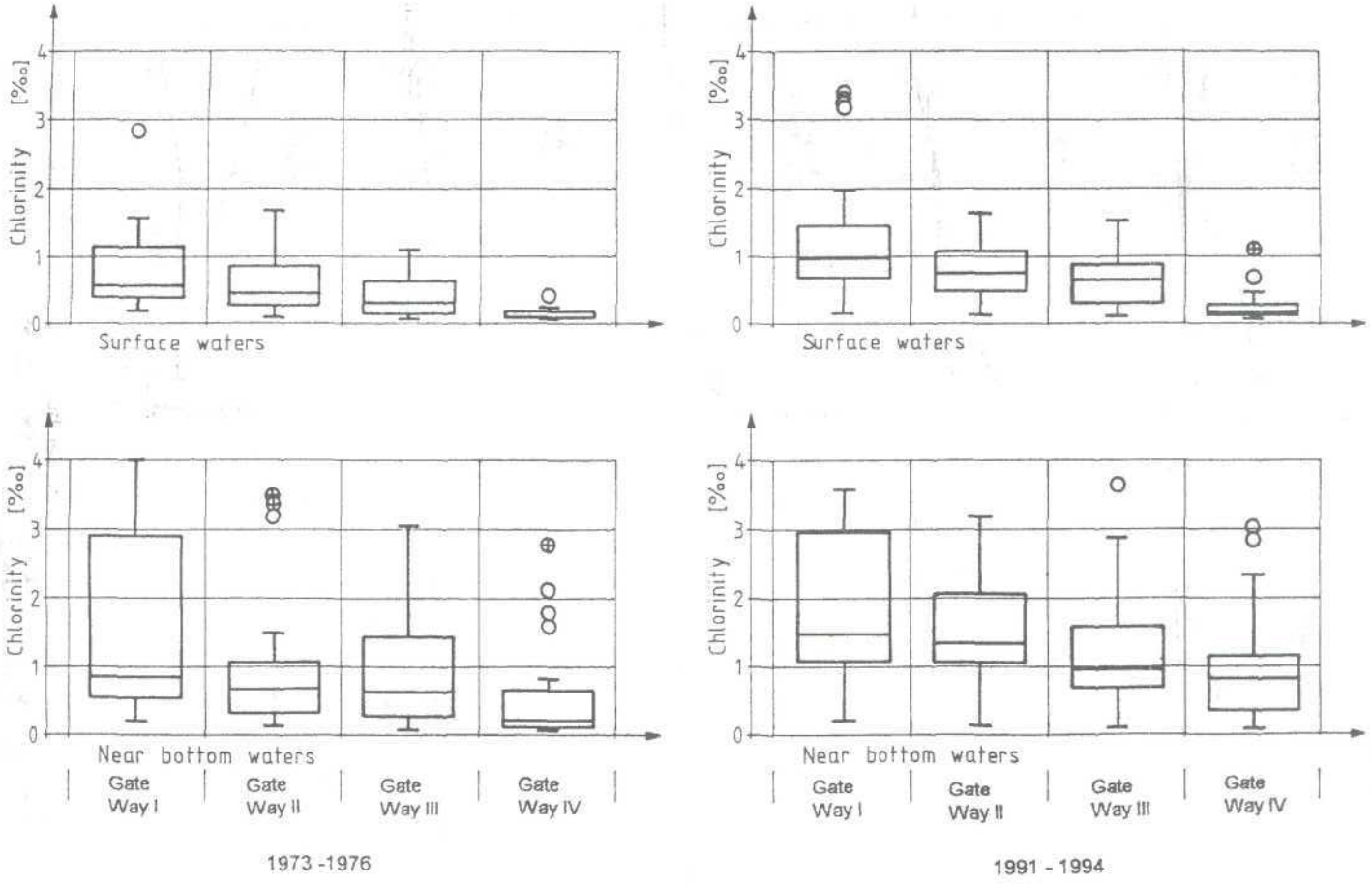

Fig. 4. Box-Whiskers plots of chlorinity of the Szczecin Lagoon water. Data for stations Gate Way I — Gate Way — IV

DISCUSSION

The observed changes of water salinity in the Szczecin Lagoon, expressed in the terms of chlorinity and analysed over the years 1956–57, 1973–76 and 1991-1994, are resultant of multiple factors; in particular the long- and short-term changes of the river Odra flow rate, oscillations of the sea level relatively to the predomianting climatic factors (frequency, direction and wind force, atmospheric pressure) [Majewski, 1980; Buchholz, 1989; 1990; 1991; Jasińska, 1991; Robakiewicz, 1993], on one hand, and on the other — they canbe related to hydrotechnical projects undertaken within the Odra estuary in the recent half-century [Mielczarski, 1987a, 1987b; Robakiewicz, 1993]. Specific changes of water salinity along the fairway Szczecin–Świnoujście, clearly marked in 1990-ties (Figs. 2 and 3), can be explained by the alterations of the fairway depth profile. The fairway forms a gully channel of 150–200 m width and the slightly increasing depth — from 9.8 m at the Gate Way I to 10.7 m at the Gate Way IV [Staszewicz, 1990]. The depth along the fairway changes continually (Fig. 5) depending on the topical dredging scheme and the river-inflow/sea-water-back-flow ratio. However, the general bottom profile remains unchanged and inclined.

The more saline water, inflowing under favourable conditions (high water level in the Pomeranian Bay — low water flow in the river Odra) from the sea, having forced the treshold of the Gate Way I, is „rolling" as if on an inclined plane into the Szczecin Lagoon and farther into the Roztoka Odrzańska basin, forming waves, recorded in the form of concentration waves [Jasińska et al. 1989]. Such concentration waves are depicted in Figs. 2 and 3.

To find a connection between the observed salinity changes and salinity magnitude and the impact of the riverine flow, the mean monthly flow of the river Odra, measured by the Institute of Meteorology and Water Management (IMWM) in Gozdowice, in the respective time intervals, was plotted in Fig. 6. The flow of the river Odra differed considerably in the considered time intervals, especially as regards the years 1991–94, when significant decline in the flow was observed from late spring till autumn.

Graphic comparison of surface and near bottom salinity at all measurement stations in 1973–76 and 1991–94 for the equal Q_s value is illustrated in Figs. 7 and 8. It is evident that more saline water at the Gate Way IV appeared in the 1990-ties. The same applies to the near bottom water, supporting thus the hypothesis that other factors influenced the salinity at that station not solely the Q_s.

The analysis of the Q_s impact on salinity changes at different measuremnt stations was carried out applying the procedure used in studies of the influence of hydrological conditions on the chemical composition of water [Gregory and Walling, 1973; Walling and Webb, 1986]. The values of deter-

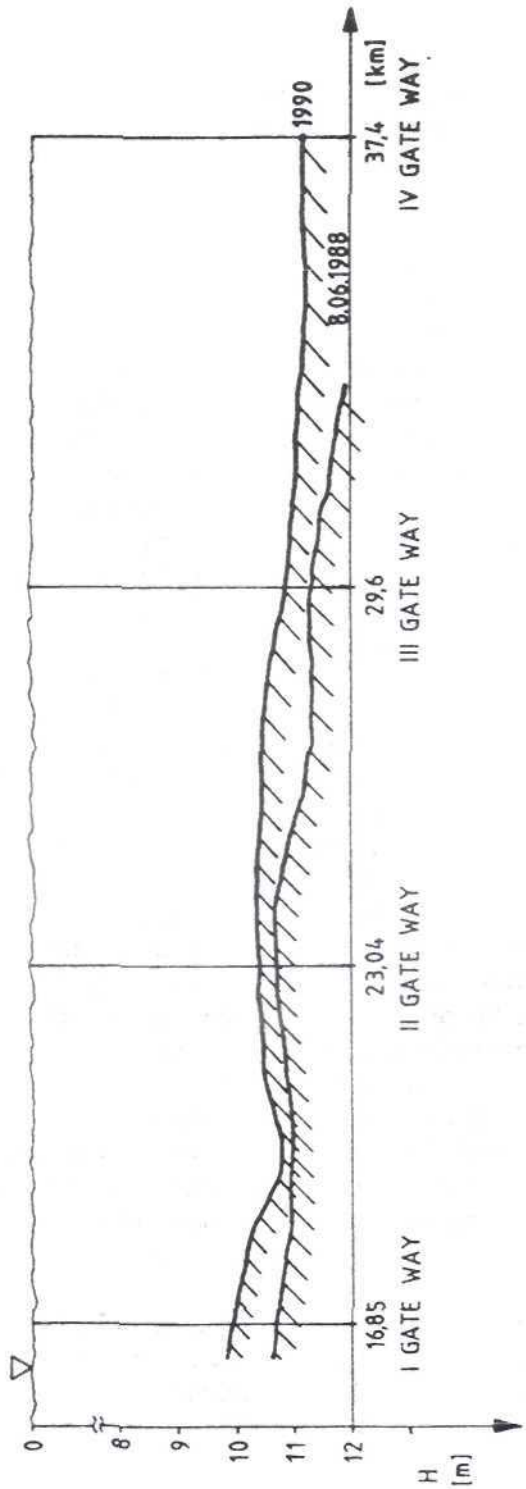

Fig. 5. Depth profile of the fairway channel Świnoujście-Szczecin from 16.85 km (Gate Way I) to 37.40 km (Gate Way IV) in 1988 — after *Jasińska et al. (1989) and in 1990 — after Staszewski (1990)*

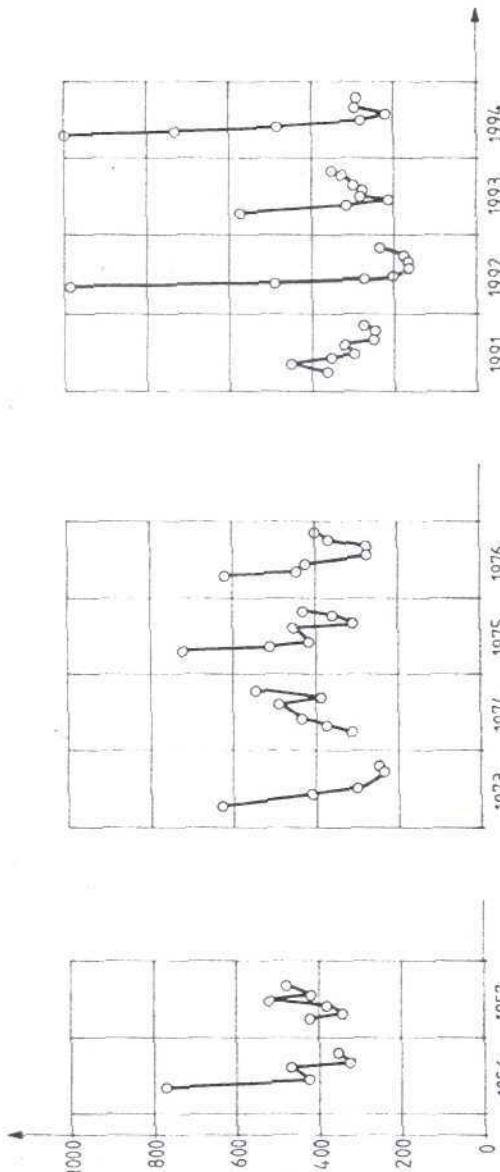

Fig. 6. Monthly mean values of the river Odra flow (Q_s) in May-November 1956 and 1957 (Roczniki Hydrograficzne 1956, 1957), April–November 1973–1976 (Roczniki Hydrologiczne 1973–1976) and 1991–1994 (data from IMWM — Branch Poznań)

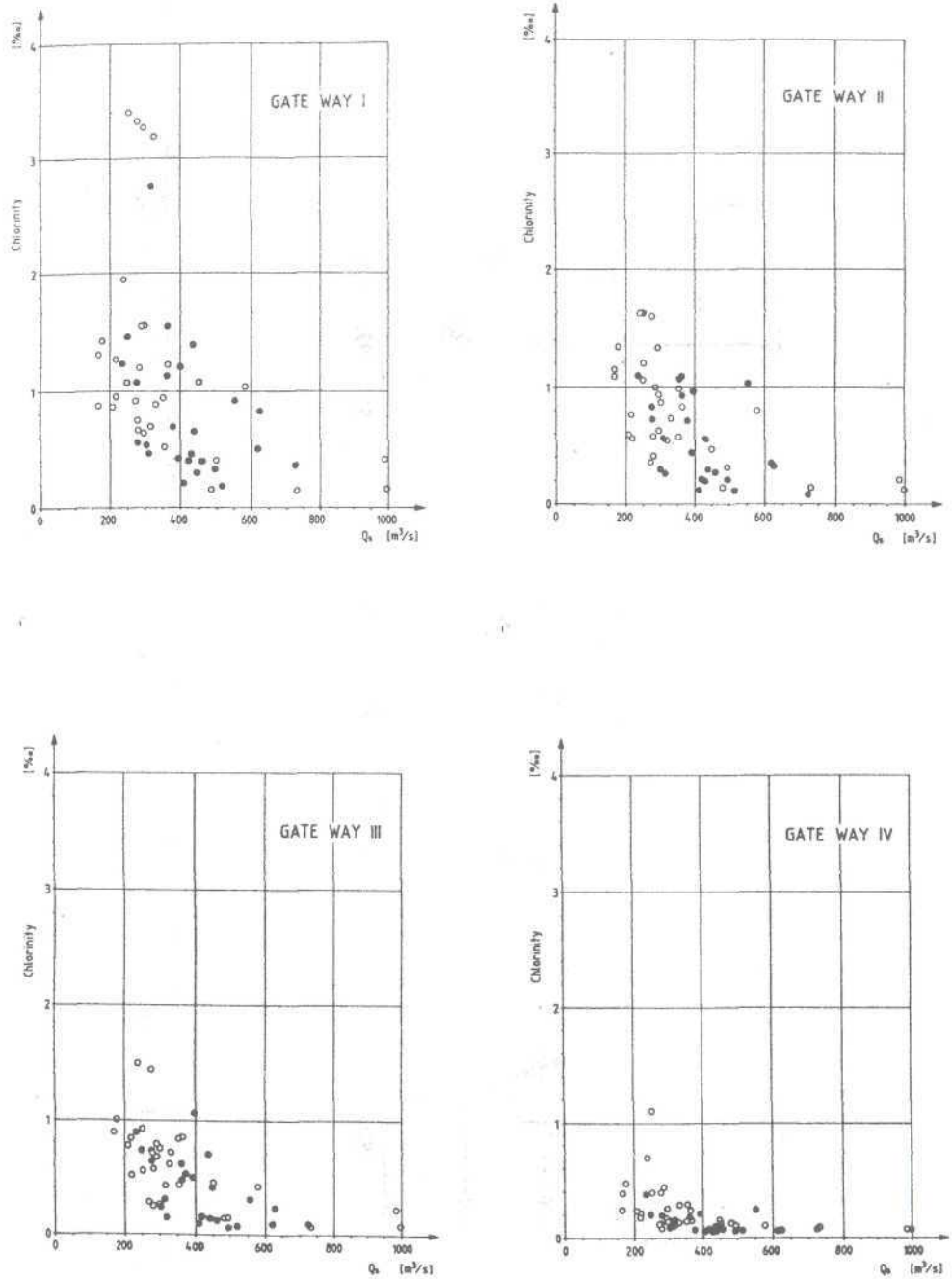

Fig. 7. A function of chlorinity of surface water in the Szczecin Lagoon at stations Gate Way I and Gate Way IV in 1973–1976 (black points) and in 1991–1994 (white points) versus the flow of the river Odra (Q_s)

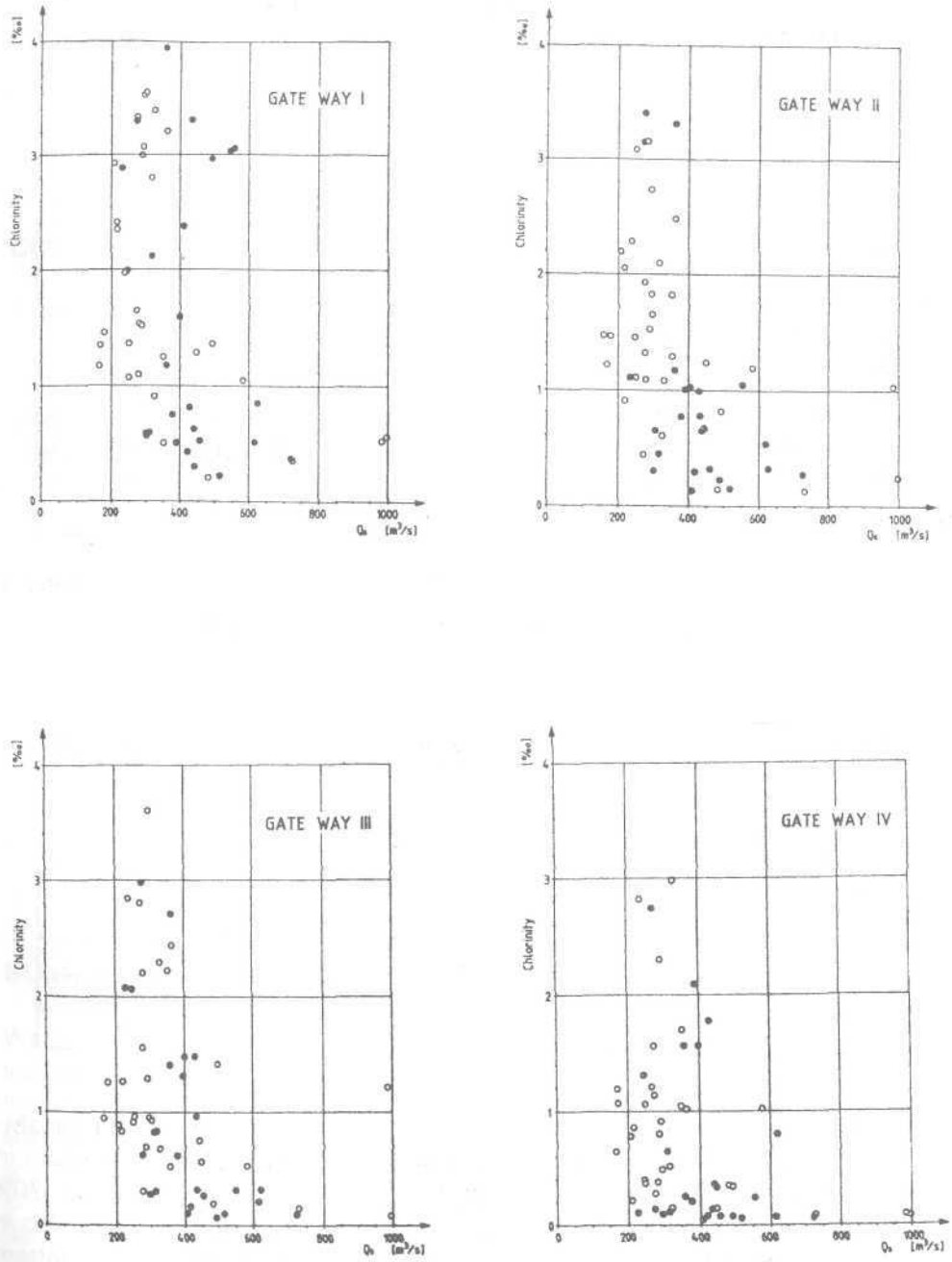

Fig. 8. A function of chlorinity of the near bottom water in the Szczecin Lagoon at stations Gate Way I and Gate Way IV in 1973–1976 (black points) and 1991–1994 (white points) versus the flow of the river Odra (Q_s)

mination coefficients R^2 (%) for various functions Cl ‰ = $f(Q_s)$ of the data from 1973–76 and 1991–94 are listed in Tables 2 and 3.

Table 2

Coeffficients of determination R^2 (%) of chlorinity in relation to the river flow (Cl ‰) = $f(Q_s)$. Data from the period 1973–1976

No	Stations		(Cl‰)=aQ_s+b	(Cl‰)=aQ_s^b	(Cl‰)=exp(a+bQ_s)
1	I GATE	surface	15,79	19,83	17,15
2	WAY	near bottom	14,39	19,38	17,96
3	II GATE	surface	27,41	33,91	32,40
4	WAY	near bottom	22,41	27,89	25,78
5	III GATE	surface	32,20	38,33	36,52
6	WAY	near bottom	31,44	37,96	37,09
7	IV GATE	surface	25,86	37,01	32,68
8	WAY	near bottom	4,45	4,80	6,06

Table 3

Coeffficients of determination R^2 (%) of chlorinity in relation to the river flow (Cl ‰) = $f(Q_s)$. Data from the period 1991–1994

No	Stations		(Cl‰)=aQ_s+b	(Cl‰)=aQ_s^b	(Cl‰)=exp(a+bQ_s)
1	I GATE	surface	16,28	37,54	40,62
2	WAY	near bottom	21,10	29,62	33,01
3	II GATE	surface	36,64	55,15	55,84
4	WAY	near bottom	21,51	29,38	30,75
5	III GATE	surface	35,72	54,54	52,84
6	WAY	near bottom	8,88	22,96	26,52
7	IV GATE	surface	16,96	43,74	39,17
8	WAY	near bottom	13,60	34,08	40,75

The linear, power and exponential functions explain the examined variability of surface and near bottom salinity due to Q_s changes at the Gate Way I in 1973–76 period in ca. 20%, in ca. 30% at the Gate Way II and in ca. 30% (surface water) and 40% (near bottom water) at the Gate Way III, and also in ca. 40% at the station Gate Way IV in respect to surface water. Near bottom salinity at the Gate Way IV was practically independent on the Q_s changes.

In the period 1991–1994 salinity changes in the surface water at the station Gate Way I could be explained by Q_s changes in 40%, near bototm

salinity changes — in 35%. At stations the Gate Way II and the Gate Way III — 55% and 30%, respectively; and at the station Gate Way IV — in 45 and 40%.

As indicated, Q_s changes are responsible for less than 50% of salinity variabilities in the Szczecin Lagoon water.

CONCLUSIONS

1. The comparison of chlorinity data obtained in May–November of 1956–57, and April–November 1973–76 and 1991–94 indicates an increase of the mean salinity of surface water in the Szczecin Lagoon, especially at the stations Gate Way I, Gate Way II and Gate Way III, this giving the evidence of increasingly easier penetration of saline sea water into the Lagoon in the successive measurement terms. Near bottom water showed more stable levels of the mean salinity.
2. The analysis of the chlorinity range pointed out to the most marked changes in surface and near bottom water at the station Gate Way I and in the near bottom water at the Gate Way IV.
3. Chlorinity data considered in the function of the Odra river flow (Q_s) in 1973–76 and 1991–94 indicated differences in salinity solely at the station Gate Way IV, with higher salinity in the later period.
4. Between 1991–94, when the Odra flow (Q_s) was clearly lower than in the previous period (1973–76), chlorinity changes were to a greater extent expressive by Q_s changes.
5. The changes in the river Odra flow answer only for 50% of water salinity changes in the Szczecin Lagoon between 1991–1994.

SUMMARY

Water salinity along the fairway Szczecin–Świnoujście was examined in measurement seasons April–November of 1991–1994. Sampling stations were located at the Gate Way I, Gate Way II, Gate Way III and Gate Way IV. The results of measurements were compared with the earlier data from 1956–57 and 1973–76. The comparison yielded an increasing tendency of water salinity in the Szczecin Lagoon. The chlorinity data were analyzed against the Odra river flow intensity (Q_s). It was revealed that at equal values of Q_s, in the 1990-ties saline water penetrates much easier from the Pomeranian Bay into the Lagoon, especially into the Roztoka Odrzańska basin. The observed increase of chemical composition astaticism of water in the Szczecin Lagoon is much stronger related to the changes of the river flow in dry years (low Q_s).

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