Changes in species composition of the genus *Gammarus* Fabr. in Puck Bay*

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Abstract

This paper describes the current species composition of the genus *Gammarus* in Puck Bay (western Gulf of Gdańsk, Poland). Samples were taken at 9 shallow (*ca* 0.4 m deep) and 4 deeper (*ca* 10 m) stations from April 1997 to March 1998. Six *Gammarus* species were recorded. *Gammarus salinus* was the most numerous, making up 34.95% of the total of identified amphipod specimens. This species was common throughout the bay but rarely predominant. *G. zaddachi* (34.75%) was dominant in the northern part of the bay from January to April and was found in almost 2/3 of samples. Less numerous were *G. oceanicus* (19.15%), common in the southern and eastern parts of Puck Bay, and *G. duebeni* (9.85%), prevalent in shallow and rocky locations. *G. inequicauda* and *G. locusta* made up only 1.13% and 0.12% of the total amphipod material respectively. The species composition of the genus varied considerably not only from one sampling locality to another but also from season to season. It is possible that two species (*G. locusta* and *G. inequicauda*) are currently withdrawing from Puck Bay.

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1. Introduction

Puck Bay is the westernmost and shallowest part of the Gulf of Gdańsk, which lies in the southern part of the Baltic Sea. It is separated from the deep part of the Gdańsk Basin by the Hel Peninsula to the northeast and by a sandy shoal known as Ryf Mew to the east (Fig. 1). The average depth of the bay is *ca* 2.5 m and the salinity varies from 3.84 to 8.00 PSU (Nowacki 1993).

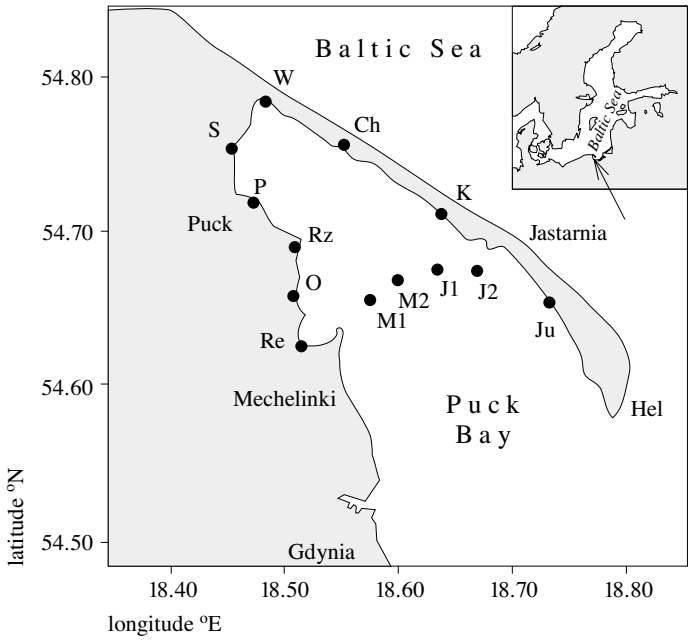


Fig. 1. Map of Puck Bay with sampling stations (the symbols of the stations refer to their names in Table 1)

The oxygen saturation of these waters is very unstable. Hypoxia and hyperoxia occur over a range of 80% oxygenation (Bolałek *et al.* 1993), which suggests that the oxygen balance is seriously disturbed. On the shore the situation is most unstable: during summer intense phytoplankton blooms occur in the pelagic layer and oxidation of the deposited organic matter occurs.

Over recent years significant changes have taken place in the composition of the phytobenthos. Fucus (*Fucus vesiculosus*) has disappeared completely, whereas the proportion of thallophytic alga of the *Ectocarpaceae* family has increased (Pliński & Florczyk 1993).

Many authors, including Jażdżewski (1973) and Osękowska (1990), have studied the population composition of *Gammarus* species in Puck Bay and

the Gulf of Gdańsk. In addition to these studies, which focused only on gammarids, more general research has been done on Malacostraca by Witek (1973) and on an even wider range of benthos by Legeżyńska & Wiktor (1981), Wenne & Wiktor (1982) and Turlińska (1993).

In the last few years, new species of *Amphipoda*, for example *Gammarus tigrinus* (Gruszka 1999), have been noted in the western Baltic. The expansion of this species into the Gulf of Gdańsk is to be expected. According to Żmudziński (1997) the biomass of the genus *Gammarus* in this area rose over 2.5 times from 239 tonnes in 1962 to 655 tonnes in 1985. In view of the changes taking place in the Baltic Sea, the gammarid population in Puck Bay should be investigated.

The aim of the present work is to describe the state of the population of *Gammarus* species and to evaluate the changes in the gammarid species composition in Puck Bay.

2. Methods

Animals were collected at nine shallow (depth *ca* 0.4 m) and four deeper (*ca* 10 m) stations from April 1997 to March 1998. The sampling stations were selected on the basis of their all-year-round accessibility. As the inner part of the bay is inaccessible from November to March, no sampling stations were set up there. In the shallow-water area, samples were collected with a metal frame 0.28 m^2 in area (Fig. 2), the animals being extracted from it with a small strainer fitted with a ϕ 1 mm sieve. In the deeper zone the samples were collected from on board the research vessel with a dredge equipped with a 50×25 cm frame and a ϕ 1 mm sieve. The actual area sampled was calculated with the aid of the Navstar system from the difference between the geographical positions of the research ship

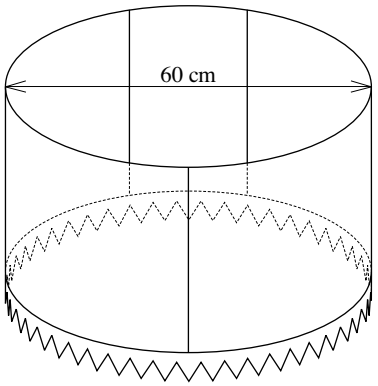


Fig. 2. Metal frame used for collecting amphipod samples from shallower stations

at the start and finish of dredging. The contents of the dredge were poured through a ϕ 6 mm sieve. The gammarids passed through the sieve and were retained on a much denser second screen of ϕ 0.5 mm. All the samples were frozen after collection, further investigation of the material taking place in the laboratory. The species were classified according to the diagnostic characters of Tsvetkova (1975) and, in part, those of Jażdżewski (1975) and Guryanova (1951). Specimens smaller than 5 mm were classified as *Gammarus* juveniles.

Broken specimens were classified as *Gammarus* spp. If only a portion of a body was found, only those with a head were counted.

The multivariate statistical analysis was done with PRIMER 4.0 software.

The mean monthly water temperatures and salinities were computed from a physical model of Gulf of Gdańsk water (Kowalewski 1997), with corrections being made to allow for the *in situ* measurements made during sampling (Table 1).

Table 1. Temperature, salinity and oxygen saturation of water during sampling

Name and symbol of station	Date	Temperature [°C]	Salinity [PSU]	Oxygen saturation [%]	Number of specimens
1	2	3	4	5	6
Rewa (Re)	15.04.97	15.9	5.9	93	46
	04.06.97	20.1	5.8	95	3
	17.07.97	14.6	5.9	97	1
	29.08.97	27.7	6.3	–	10
	16.10.97	8.0	5.5	89	0
	26.11.97	1.4	6.0	87	9
	15.12.97	0.4	6.8	87	6
	18.02.98	3.7	6.2	84	0
	10.03.98	3.7	7.1	–	2
Osłonino (O)	15.04.97	16.1	6.5	126	34
	04.06.97	20.1	5.7	168	45
	17.07.97	15.2	6.6	65	11
	29.08.97	21.9	4.1	–	0
	16.10.97	8.4	6.7	0	0
	26.11.97	2.3	6.8	89	1
	15.12.97	-0.1	4.3	86	2
	16.01.98	2.4	5.4	89	9
	18.02.98	3.4	7.0	87	12
	10.03.98	3.9	7.1	–	14

Table 1. (continued)

1	2	3	4	5	6
	15.04.97	16.2	6.7	98	58
	04.06.97	18.9	7.2	114	35
	17.07.97	15.3	6.7	84	14
	29.08.97	21.3	5.8	–	26
Rzucewo (Rz)	16.10.97	9.7	7.1	71	28
	26.11.97	2.6	7.1	78	54
	15.12.97	0.5	6.5	88	2
	16.01.98	2.8	6.6	88	9
	18.02.98	3.6	7.2	86	12
	10.03.98	4.5	7.0	–	23
	15.04.97	16.0	6.3	89	13
	04.06.97	14.7	7.0	95	9
	17.07.97	16.8	6.3	92	0
	29.08.97	22.8	7.1	–	4
Puck (P)	16.10.97	8.8	6.4	91	0
	26.11.97	1.0	6.4	95	14
	15.12.97	0.8	6.4	94	0
	16.01.98	4.3	6.8	107	0
	18.02.98	4.1	7.1	78	0
	10.03.98	5.0	6.9	–	0
	15.04.97	16.4	6.3	111	29
	04.06.97	19.2	6.1	106	10
	17.07.97	15.8	6.4	86	1
	29.08.97	21.9	6.6	–	6
Swarzewo (S)	16.10.97	9.0	6.8	79	7
	26.11.97	0.5	6.9	89	0
	16.01.98	2.8	6.6	88	5
	18.02.98	4.3	6.7	–	11
	10.03.98	3.9	6.7	–	0
	15.04.97	17.2	6.9	105	20
	04.06.97	19.4	6.8	108	17
	17.07.97	19.1	6.8	86	0
	29.08.97	22.3	7.2	–	23
Władysławowo (W)	16.10.97	7.8	5.8	71	0
	26.11.97	1.0	6.4	91	0
	15.12.97	-0.2	6.3	86	0
	16.01.98	2.7	6.3	93	1
	18.02.98	3.8	7.1	84	0
	10.03.98	4.3	6.5	–	3

Table 1. (continued)

1	2	3	4	5	6
	15.04.97	16.3	6.7	116	2
	04.06.97	17.5	7.4	94	2
	17.07.97	18.2	6.9	92	0
	29.08.97	22.6	6.8	–	10
Chałupy (Ch)	16.10.97	8.1	6.8	94	10
	26.11.97	-0.2	7.1	94	6
	15.12.97	0.2	6.9	91	43
	16.01.98	2.8	6.5	89	60
	18.02.98	3.8	7.1	–	44
	10.03.98	5.1	5.2	–	9
	15.04.97	16.1	6.9	96	3
	04.06.97	12.8	7.4	96	6
	17.07.97	19.1	6.9	94	0
	29.08.97	23.1	6.8	–	6
Kuźnica (K)	16.10.97	8.3	6.8	94	14
	26.11.97	0.9	6.9	93	6
	15.12.97	1.6	7.1	93	23
	16.01.98	3.3	7.2	88	21
	18.02.98	3.6	6.4	–	60
	10.03.98	4.1	7.1	–	34
	15.04.97	17.4	7.1	107	0
	04.06.97	10.6	7.4	95	66
	17.07.97	19.3	7.3	93	0
	29.08.97	24.2	5.8	–	98
Jurata (Ju)	16.10.97	8.8	6.8	96	63
	26.11.97	1.3	6.5	89	21
	15.12.97	-0.1	6.8	93	0
	16.01.98	3.3	6.8	89	11
	18.02.98	3.7	7.1	–	29
	10.03.98	3.8	7.2	–	95
	17.04.97	11.9	7.1	–	57
	05.06.97	11.4	7.3	–	30
	21.07.97	13.1	7.3	–	35
	05.09.97	12.8	7.4	–	9
Jastarnia 1 (J1)	29.10.97	9.4	7.2	–	23
	19.11.97	4.8	7.2	–	180
	04.12.97	2.6	7.3	–	200
	18.02.98	2.6	7.0	–	96
	23.03.98	3.7	7.3	–	84

Table 1. (continued)

1	2	3	4	5	6
	17.04.97	11.9	7.1	–	38
	05.06.97	11.4	7.3	–	115
	21.07.97	13.1	7.3	–	66
	05.09.97	12.8	7.4	–	348
Jastarnia 2 (J2)	29.10.97	9.4	7.2	–	2
	19.11.97	4.8	7.2	–	212
	04.12.97	2.6	7.3	–	104
	18.02.98	2.6	7.0	–	104
	23.03.98	3.7	7.3	–	37
	17.04.97	10.8	7.1	–	72
	05.06.97	10.9	6.9	–	336
	21.07.97	12.7	6.9	–	168
	05.09.07	12.6	7.3	–	140
Mechelinki (M1)	29.10.97	9.1	7.1	–	14
	19.11.97	4.4	6.9	–	33
	04.12.97	2.4	6.9	–	120
	18.02.98	2.6	7.2	–	40
	23.03.98	3.7	6.9	–	125
	17.04.97	10.8	7.1	–	124
	05.06.97	10.9	6.9	–	392
	21.07.97	12.7	6.9	–	665
	05.09.97	12.6	7.3	–	42
Mechelinki (M2)	29.10.97	9.1	7.1	–	240
	19.11.97	4.4	6.9	–	47
	04.12.97	2.4	6.9	–	108
	18.02.98	2.6	7.2	–	22
	23.03.98	3.7	6.9	–	103
				total	5912

Correlation coefficients were calculated for all abiotic factors and the species composition but were very low – from −0.45 for oxygen saturation to 0.23 for temperature.

3. Results and discussion

124 samples containing a total of 5912 specimens were collected. Six species of the genus *Gammarus* Fabr. were found (Table 2): *G. zaddachi* Sexton, 1912; *G. salinus* Spooner, 1947; *G. oceanicus* Segerstråle, 1947;

a

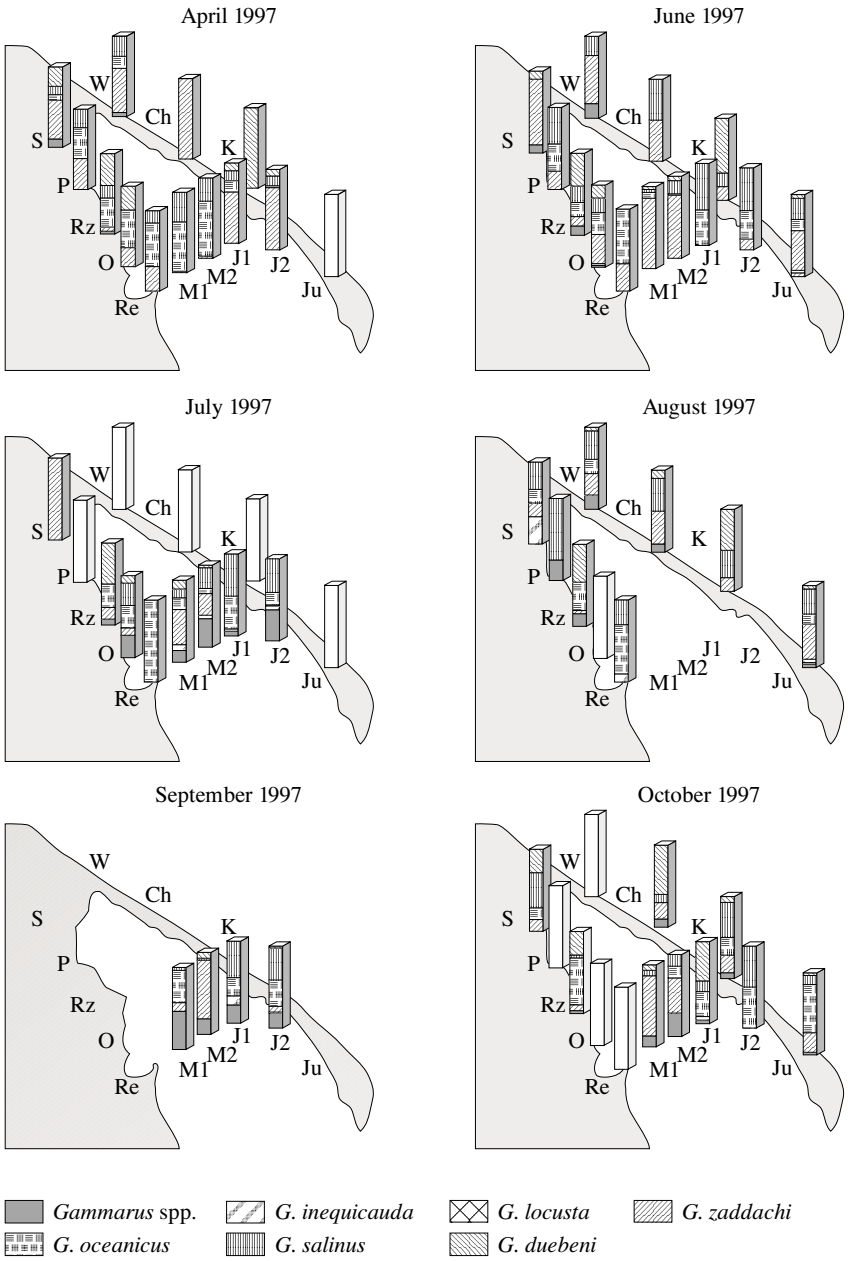
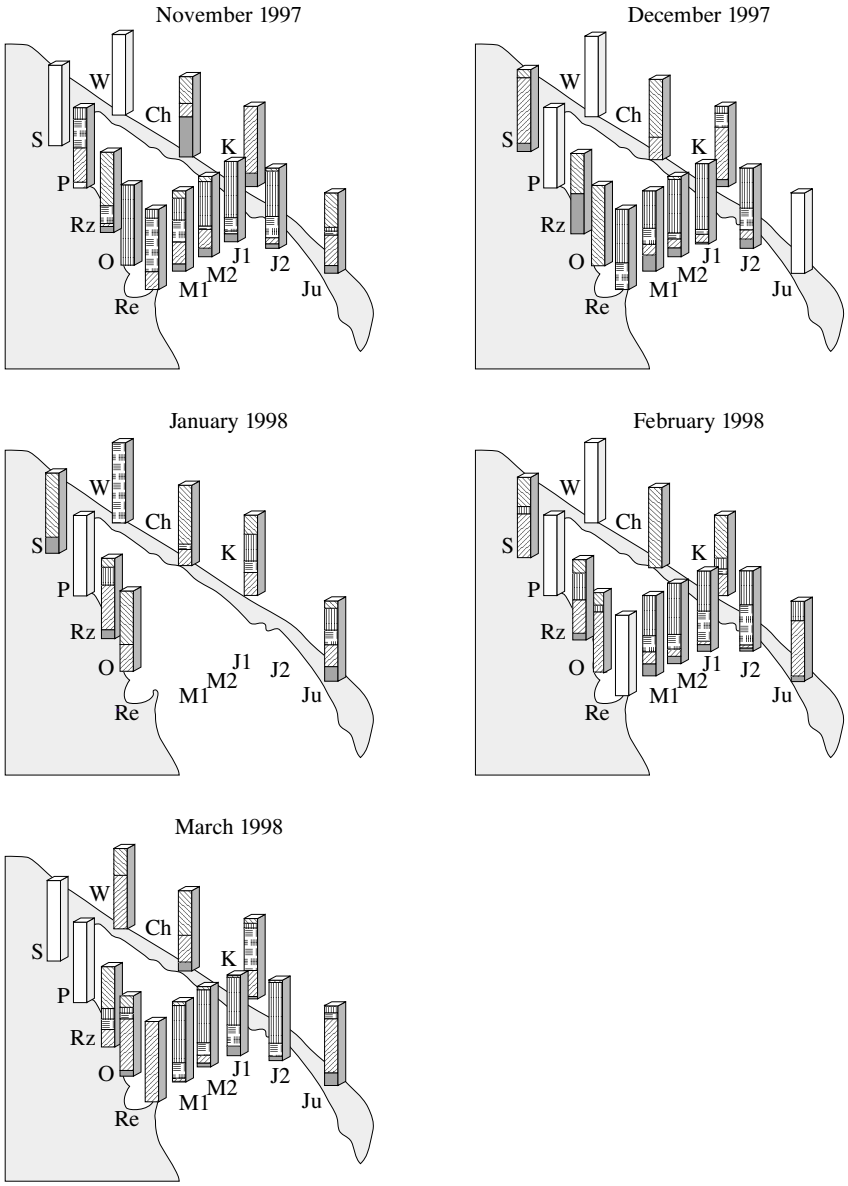


Fig. 3. Species composition of *Gammarus* in Puck Bay from April to October 1997 (a) and from November 1997 to March 1998 (b) (the symbols of the stations refer to their names in Table 1)

b



The white bar indicates that a sample was collected but that no gammarids were found.

Fig. 3. (continued)

G. duebeni Liljeborg, 1852; *G. locusta* (L., 1758) and *G. inequicauda* Stock, 1966. Fig. 3 shows the percentage of each of these species at every station. Table 2 sets out the frequency and species composition during sampling.

Table 2. Species percentage and frequency in Puck Bay from April 1997 to March 1998

Species	Number of specimens collected	Percentage [%]	Frequency [%]
Gammarus inequicauda	57	1.13	10.48
Gammarus locusta	11	0.12	2.42
Gammarus zaddachi	1754	34.75	66.13
Gammarus oceanicus	964	19.15	58.06
Gammarus salinus	1764	34.95	63.71
Gammarus duebeni	497	9.85	50.00

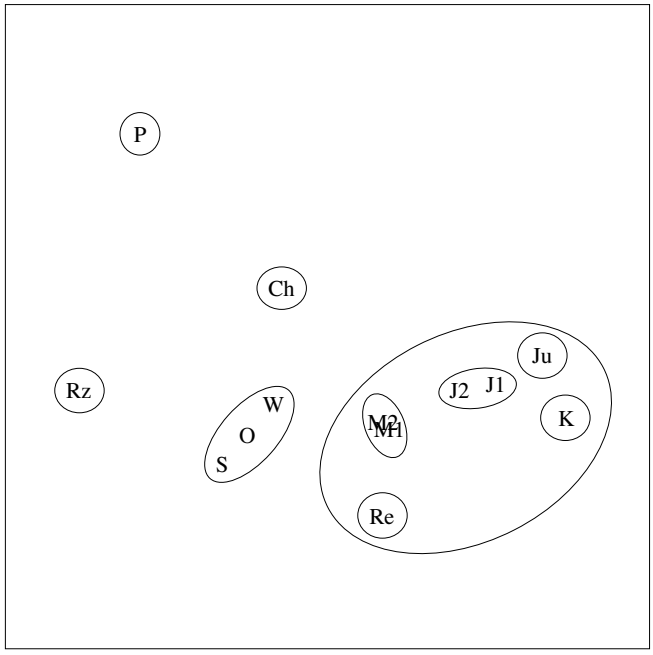


Fig. 4. Principal Component Analysis of temperature, salinity and oxygen at the sampling stations in Puck Bay

Principal Component Analysis (PCA) of abiotic factors – temperature, salinity and oxygen (abiotic data in Table 1) – (Fig. 4) shows groups of stations where similar conditions obtain. The greatest similarity was displayed by Mechelinki 1 and 2, and by Jastarnia 1 and 2; together with Jurata, Kuźnica and Rewa, these stations form a group of similar locations. Another group includes Swarzewo, Osłonino and Władysławowo. The conditions at Puck, Rzucewo and Chałupy are highly dissimilar, so these stations cannot be grouped together.

Gammarus zaddachi Sexton

This species was found at every station, though least often at Jastarnia 1 and Jastarnia 2, where its contribution to the gammarid population was $< 15\%$. The most common species in the Baltic, it is frequently the dominant invertebrate (Jażdżewski 1975). This gammarid is most abundant in the northern part of the bay, although it was not predominant in any region during the year. In shore samples, it was usually dominant from January to April, but at Mechelinki 1 and 2 it was prevalent from April to October. Kuźnica was an exception; here, this species became dominant in November. The situation at this station was peculiar because the proportion of *G. zaddachi* had begun to increase in August and reached 100% (counting only identified animals) in November. In subsequent months *G. zaddachi* was replaced successively by *G. salinus* and *G. duebeni*, the latter becoming the only species present in April. The opposite was the case for Chałupy (Fig. 3.): in April *G. zaddachi* was dominant with the proportion of *G. duebeni* rising from August to February.

Jażdżewski (1973) found *G. zaddachi* to be the prevailing species at the majority of his stations; only at one station, Mechelinki 1, was the percentage of this species low. The situation presented in the present paper is quite the opposite. What is more, Jażdżewski (1973) found 94% of *G. zaddachi* at Jastarnia 1, while currently at this station this species accounted for only 12% and then only in December and February.

In 1972 Puck Bay was investigated by Witek (1973), and some of his stations – Rewa, Osłonino, Puck and Swarzewo – were close to those sampled in this work. He did not record a high proportion of *G. zaddachi*, but then he did take his samples only from June to December. As mentioned previously, this species is most numerous from January to April, so *G. zaddachi* may have been underestimated, possibly because of the sampling time chosen.

The deep zone stations were special. Osękowska (1990) did not find *G. zaddachi* either at Mechelinki 1 and 2 or at Jastarnia 1 and 2. Similarly, Jażdżewski (1973) and Wenne & Wiktor (1982) found only 10% of *G. zaddachi* at Mechelinki 1 and 2. Sampling should be repeated in the

following year to determine whether this discrepancy is merely a one-year perturbation or a permanent change in the species composition at this location in Puck Bay.

Gammarus salinus Spooner

Though widespread throughout Puck Bay, this species is less numerous than *G. zaddachi*, only occasionally becoming dominant except at the deeper stations. At Jastarnia 1 and 2 *G. salinus* predominates for almost the whole year. At Mechelinki 1 and 2 this species is prevalent in the cold season from November to April, probably because it is linked with the banks of blue mussel (*Mytilus trossulus*) (Żmudziński 1967, Jażdżewski 1971, 1973).

The status of this species is much the same as that described by Jażdżewski (1973) from 1958–1965, Witek (1973) in 1972 and Legeżyńska & Wiktor (1981) in 1977.

In the most recent research, Osękowska (1990) found only two gammarid species – *G. salinus* and *G. oceanicus* – near Mechelinki and Jastarnia in 1989. It is interesting that the percentage of *G. oceanicus* at Mechelinki was highest towards the end of the year, in November, and that it rose from April onwards. This finding is in conflict with those of the present paper in that the largest proportion of this species was noted in March and had been rising since November. It is curious that Osękowska did not find any other species apart from those previously mentioned during her half-year sampling. Jażdżewski (1973) also found *G. inequicauda* and *G. locusta* at that site. During the present sampling in this area, *G. inequicauda* and *G. locusta* were found only from April to August.

G. salinus was associated with the deeper zones and in shallow waters other species were dominant. *G. salinus* was the only species found in November, probably because of the withdrawal of other species due to the oxygen deficit (Table 1) and the presence of hydrogen sulphide, the characteristic odour of which was noted during sampling.

Gammarus oceanicus Segerstråle

In the current investigations, this species was most abundant in the southern and eastern parts of Puck Bay, although it was found occasionally at every station, even at Władysławowo. It was most numerous at Jastarnia, Rewa and Rzucewo. At the last station, *G. oceanicus* was present from March to November.

Żmudziński (1967) described this species as dominant along almost the entire coastal zone, having found up to 100 000 specimens per square metre of bottom area. However, Jażdżewski (1973) found it to be the least

numerous and the least frequent species in the inner Puck Bay, and that it rarely crossed the Ryf Mew border in a westerly direction. As mentioned earlier, *G. oceanicus* was found even at Władysławowo during the present research. Witek (1973) recorded it in the cold season from October to April, except at Rewa where, as in the present paper, *G. oceanicus* was found nearly throughout the year.

Osękowska (1990) noticed a great number of *G. oceanicus* at Mechelinki and Jastarnia, but the periods of dominance of *G. oceanicus* and *G. salinus* described by Osękowska are quite the reverse of those presented in this work.

Gammarus duebeni Liljeborg

This species is typical of the rock pools so common along rocky shores (Jażdżewski 1973). It is known to be an extreme euryhaline species of great ecological potency but of low competitive potency (Kinne 1959, Steele & Steele 1969). Jażdżewski (1971) found nematodes in the brood pouches of many females and suggested that they may have reduced the fecundity of this species. Rygg (1972) stated that the lower percentage of this species is not due to its poorer competitive potency but to its strict biotope preference. He claimed that *G. duebeni* lives mainly close to the shore in a narrow belt, but only where places of concealment are numerous since it is a photophobic species. The present work confirms that hypothesis. As is shown in Fig. 3, *G. duebeni* is numerous at Rzucewo, where a large bottom area is covered with rocks and bricks and is very shallow (15–20 cm), and partly so at Osłonino, where there are rocks on the cliff. At Chałupy and Kuźnica specimens were collected from rocks, bricks and concrete which had fallen into the water from the artificial embankments. At Jurata, where the shore is similar to that at Chałupy, *G. duebeni* is only an admixture to the *G. zaddachi* – *G. salinus* structure. Jażdżewski (1975) confirmed Rygg's hypothesis in that he claimed that the percentage of *G. duebeni* increases with environmental eutrophication, although this work cannot confirm this. Rzucewo is highly polluted (Cyberski *et al.* 1993) by pig-farm sewage and the proportion of *G. duebeni* there is high. However, near the sewage treatment plant outfall in Swarzewo, where eutrophication is intense (Wołowicz *et al.* 1993), *G. duebeni* makes a large contribution to the species composition only in January, February and April. Chałupy, in contrast, is quite a clean place (Cyberski *et al.* 1993) compared with rest of the bay, and the population of *G. duebeni* is numerous, at least the cold season.

Gammarus locusta (Linnaeus)

In this work *G. locusta* was found only in a few samples. According to literature data (Steen 1951, Forsman 1956, Jażdżewski 1971, 1975), this species prefers the shallow sublittoral zone with a bare sandy bottom with loose skeins of algae. In Puck Bay this would be the 1-to-4-m-deep zone, which cannot be reached either from the shore or from a research vessel and was thus excluded from the present work. *G. locusta* was found only at Jastarnia, where a large amount of filiform algae was reported, and once in Jurata.

For the reasons mentioned above, we cannot be sure that this species is withdrawing from Puck Bay, and the eastern part of the bay needs to be examined more thoroughly to establish the present status of the *G. locusta* population.

Gammarus inequicauda Stock

The frequency of this species was very low in the present research, being found only at a few stations from July to October. According to Jażdżewski (1973), *G. inequicauda* is endemic to Puck Bay and very common there. He suggested (1975) that owing to the separation of the species from *G. locusta* in the 1960s (Stock 1966), it is possible that authors investigating Puck Bay previously could have classified *G. inequicauda* as *G. locusta*. Jażdżewski (1975) found *G. inequicauda* to be the most common species in the Fuceto-Furcellarietum community in the Rynna Pucka. Because this area was not sampled in the present work, it is possible that *G. inequicauda* was overlooked and that their actual numbers are greater than given here. However, because of the destruction of the previously mentioned plant community in Puck Bay, *G. inequicauda* may be withdrawing from this area.

A Bray-Curtis similarity dendrogram of species composition (Fig. 5) shows that Rewa, Puck and Władysławowo have a totally different species composition from the other sampling locations. Another group comprises the deeper stations – Mechelinki 1, Mechelinki 2, Jastarnia 1 and Jastarnia 2. The third group includes Chałupy, Swarzewo, Osłonino, Rzucewo, Kuźnica and Jurata. Together with the deeper stations, these constitute 'a super-group' of similar species composition.

Comparison of this dendrogram with PCA analysis of environmental conditions (Fig. 4) shows that species composition and abiotic factors are connected. The differences between the dendrogram and PCA analysis are probably the result of another important environmental factor. This could well be the structure of the sea bottom, be it rocky, sandy or muddy, which

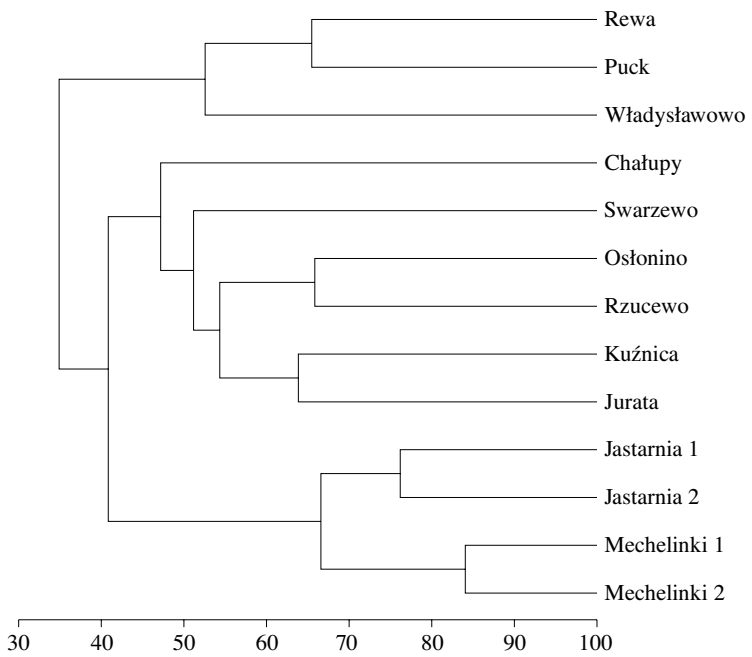


Fig. 5. Bray-Curtis similarity dendrogram of the *Gammarus* species composition at sampling locations in Puck Bay

cannot be included in this kind of analysis. PCA analysis and Bray-Curtis similarity suggest that the composition of the genus *Gammarus* is influenced not by single factor, but by a group of them, probably larger than that measured in this work.

4. Conclusions

The species composition of *Gammarus* Fabr. in Puck Bay appears to change not only with sampling station but also with season.

Both temperature and oxygen saturation have an influence on the species composition. Seasonal changes in species composition should be taken into consideration when planning experiments.

Over recent years it is possible that *G. locusta* and *G. inequicauda* have been withdrawing from Puck Bay while the number of *G. duebeni* has been increasing.

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