A comparative analysis of two allochthonous populations of the Chinese mitten crab (*Eriocheir sinensis* H. Milne-Edwards, 1853) from the Szczecin Lagoon (NW Poland) and San Francisco Bay (US west coast)

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Abstract

Selected biological and morphometric characters of two populations of the non-indigenous Chinese mitten crab, one from the Szczecin Lagoon (SL) and the other from San Francisco Bay (SFB), both sampled in autumn, were analysed. The SL crabs showed a significantly higher individual weight, length and carapace width. Males accounted for 55% (87 individuals) of the 179 SL crabs, and 62.9% (90 individuals) of the SFB crabs. Statistical analysis of metric characters, expressed as a percentage of carapace width (X_2), enabled four diagnostic characters to be identified: abdomen width (X_{11}), carapace height (X_3), left claw length (X_7) and carapace length (X_1). These jointly explain 71.75% of the differences between the SL and SFB crabs and are indicative of the distinctness of the populations.

The complete text of the paper is available at http://www.iopan.gda.pl/oceanologia/

1. Introduction

The fauna of many countries includes a number of alien species which, as a result of natural migrations or uncontrolled human activities, to name but two causes, have colonised areas new to them. One such species is the Chinese mitten crab (*Eriocheir sinensis*), a native of China and Korea, which is at present considered to be one of the most invasive species (Lowe et al. 2000), a result of both its high adaptive potential to various environmental conditions and its high fecundity (Rudnick et al. 2000). In Europe, the crab was recorded for the first time in the early 20th century in the River Aller in Germany (Panning 1939). Most probably, the crab had been brought there in the ballast water tanks of ships sailing between China and Europe (Cohen & Carlton 1997). European conditions turned out to be propitious for the Asian immigrant. It was subsequently reported from Denmark in 1927 (Peters 1938), from Poland in 1928 (Grabda 1973), from Holland and France in 1930 (Kamps 1937, Hoeslandt 1948), from Czechoslovakia in 1932 (Peters 1938), and from Portugal, the United Kingdom and Finland in later years (Ingle 1986, Cabral & Costa 1999). In the 1950s, the Chinese mitten crab invaded Hawaii and later on proceeded to North America, where it colonised the Great Lakes, the Mississippi delta and San Francisco Bay (Nepszy & Leach 1973, Cohen & Carlton 1995, Hieb & Veldhuizen 1998, Rudnick et al. 2000). The rapid dispersal of the crustacean has adversely affected both indigenous fauna (Dutton & Conroy 1998) and fisheries (Ingle 1986, Czerniejewski & Bełdowska 2003); in addition, by digging tunnel systems in the substrate, the crab affects the shores of estuaries. Unfortunately, knowledge of non-indigenous populations of the Chinese mitten crab – in many countries treated as a piece of media news – is scant and is based primarily on biological data concerning indigenous populations. The aim of this work was to determine and compare population parameters (e.g. sex ratio, size, condition) and morphometry between two populations of the Chinese mitten crab inhabiting two different areas of the globe (Fig. 1).

2. Material and methods

The study involved 179 Chinese mitten crab individuals harvested in the southern part of the Szczecin Lagoon (SL) and 143 individuals from San Francisco Bay (SFB) (Fig. 1). Both samples were collected in autumn (August–November). Upon delivery to the laboratory, the crabs were weighed (to 0.1 g) on Axis 2000B electronic scales and frozen (−20°C) in two-layered polythene bags to prevent sublimation of tissue water. After a batch of crabs had been thawed, they were sexed by examination of the

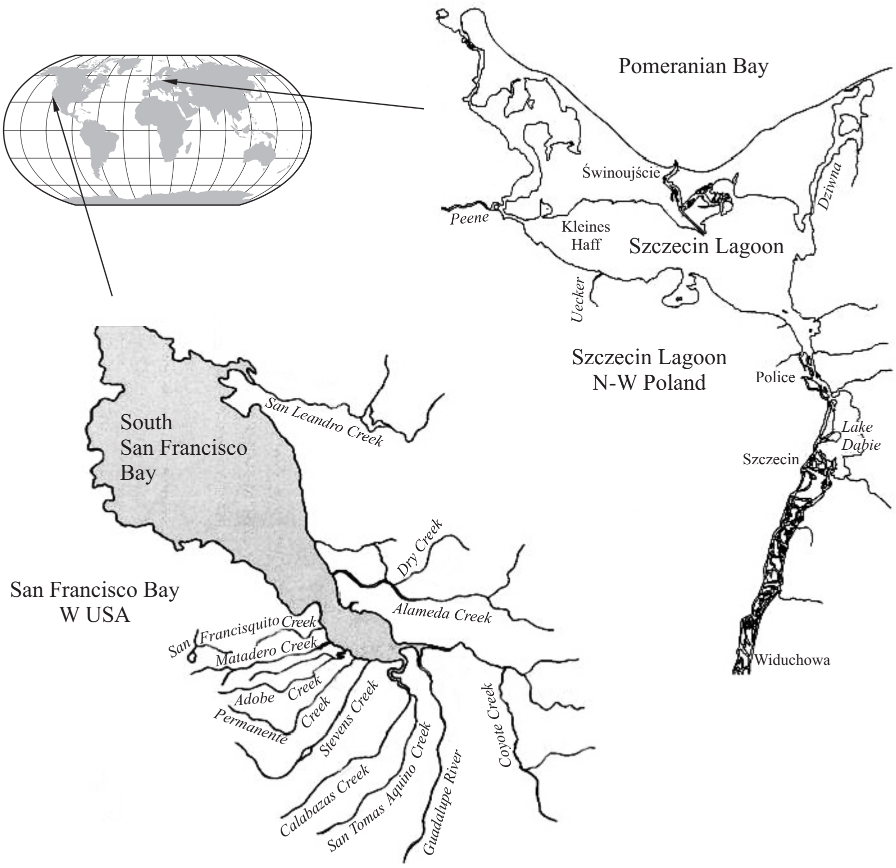

Fig. 1. Location of Chinese mitten crab collection sites

abdominal structures, as described by Schäferna (1935). Subsequently, the following 11 measurements were taken (to 0.01 mm) from each individual, in line with the measurement system presented by Czerniejewski et al. (2003): carapace length (X_1), width (X_2), and height (X_3); right claw length (X_4), width (X_5), and height (X_6); left claw length (X_7), width (X_8), and height (X_9); abdomen length (X_{10}) and width (X_{11}) (Fig. 2). All the measurements were taken with electronic callipers interfaced with a computer and were standardised by expressing them as a percentage of carapace width (X_2).

The values obtained were subjected to statistical treatment by calculating arithmetic means $\overline{x}$, standard deviations S, and coefficients of variation CV. The null hypothesis H_0 on the lack of significant differences between vectors of mean values of morphometric characters between crabs of different provenance was tested with the non-parametric Mann-Whitney U test (Sokal & Rohlf 1998) at $p = 0.05$. Discriminant analysis was used

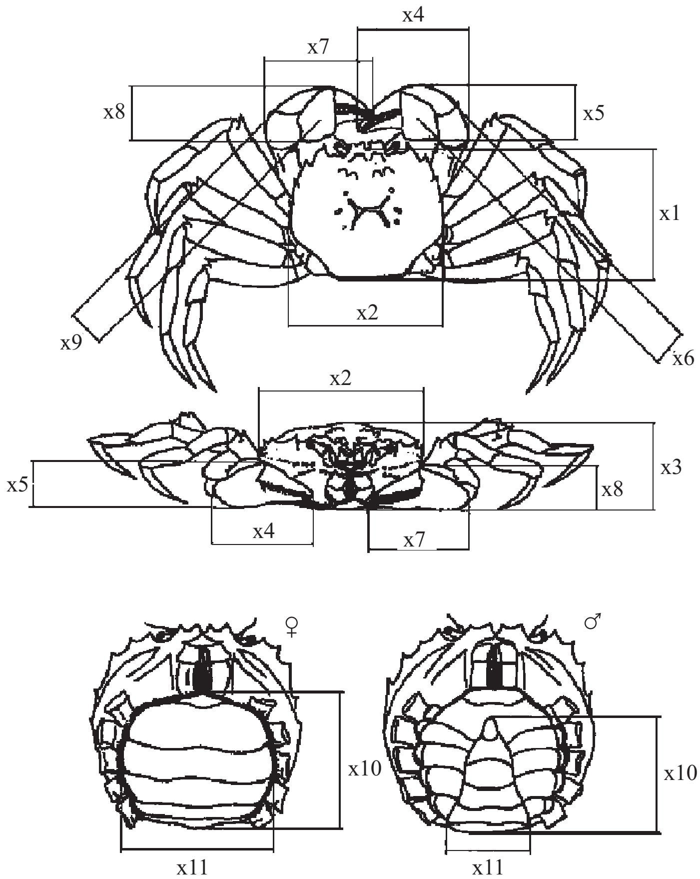

Fig. 2. A schematic diagram of the morphometric measurements (Czerniejewski et al. 2003)

to identify those metric characters (variables) that contributed most to the between-population differences. The null hypothesis H_0 was tested using the Wilks Λ, defined as

$$\Lambda = \frac{|W|}{|T|} = \frac{|W|}{|W + B|},$$

where $|W|$, $|B|$, $|T|$ denote determinants of within-group, between-groups, and total variation matrices, bearing in mind that

$$W = \sum_{i=1}^{k}\sum_{j=1}^{ni}(x_{ij} - \overline{x}_i)(x_{ij} - \overline{x}_i)',$$

$$B = \sum_{i=1}^{k} n_i (\overline{x_i - \overline{x}})(\overline{x_i - \overline{x}})',$$

$$T = \sum_{i=1}^{k}\sum_{j=1}^{ni} (x_{ij} - \overline{x})(x_{ij} - \overline{x})',$$

x_{ij} is a p-dimensional vector of the *j*th object in the *i*th population; $\overline{x}_i$ is a p-dimensional vector of means in the *i*th population; $\overline{x}$ is a vector of the overall mean.

An important application of Λ is its ability to measure the discriminant potential of variables, that is, their respective contributions to partitioning a set into sub-sets. This is therefore a way of eliminating variables with a relatively low discriminant potential. The lower the value of Λ, the higher the contribution of between-group variation to the total variability and hence the discriminant potential of the group of variables analysed.

Λ was approximated using Rao's (1951) method. The goodness of fit of assigning individual crabs to one or the other population was tested using the classification function, defined as

$$M_i = \overline{x}_i S^{-1} x + c, \qquad i = 1, 2, \ldots, k;$$

where $c = -\frac{1}{2}\, \overline{x}_i{}' S^{-1} \overline{x}_i + \ln q_i$; $\overline{x}_i{}'$ is a transpose of the p-dimensional vector of means in the *i*th population; S^{-1} is a common reverse covariance matrix for k populations; q_i is the a priori probability that object x belongs to the population with the highest M_i. The a priori probabilities are proportional to the group sizes. The computations were carried out with the Discriminant Analysis module of the Statistica software.

The Chinese mitten crab's condition coefficient was calculated with the formula

$$W = a\, L^b,$$

where
W – individual weight [g],
L – carapace width [mm],
a – regression equation intercept, and
b – regression coefficient, both calculated from the empirical data.

To compare the age distribution of males and females, the crabs were divided into carapace width and body weight classes.

3. Results

The SL crab sample showed a slightly skewed sex ratio, with 87 males (48.6%) and 92 females (51.4%). In contrast, the SFB sample contained almost twice as many males (62.9%, i.e. 90 individuals) than females (37.1%, i.e. 53 individuals).

The crabs harvested in the two areas showed a fairly wide range of individual weight (Table 1), the variability being particularly pronounced in the SFB sample, which contained an individual weighing a record-breaking 358.9 g. In spite of a clearly lower maximum weight, the SL crabs' mean individual weight was significantly higher ($p < 0.05$) than that of the SFB crabs. The difference is explained by the clearly different weight distribution displayed by the two samples (Fig. 3) and the markedly greater contribution of heavier individuals in the SL sample. For example, the SL sample was dominated (50.8% or 91 individuals) by crabs belonging to the 100.01–160 g class, the SFB sample showing dominance (32.9%; 47 individuals) of the 20.01–60 g class. Males in both samples were significantly ($p < 0.05$) heavier than females and were dominant in the individual weight classes above 170.1 g.

Table 1. Mean individual weight, carapace length and weight of the Chinese mitten crabs collected from the Szczecin Lagoon (SL) and San Francisco Bay (SFB)

Sex	Basin	n	Weight [g]		Carapace length [mm]		Carapace width [mm]	
			range	mean	range	mean	range	mean
together	SL	179	53.8–268.3	146.91*	47.36–76.16	62.25*	52.41–84.98	69.03*
	SFB	143	17.9–358.9	120.72*	34.21–79.61	55.82*	36.97–90.07	60.90*
male	SL	87	70.6–268.3	162.64	48.12–76.16	62.70	53.48–84.98	70.28
	SFB	90	22.3–358.9	156.84	35.53–79.61	60.56	38.06–90.07	66.64
female	SL	92	53.8–207.2	132.04*	47.36–73.30	61.83*	52.41–80.36	67.85*
	SFB	53	17.9–194.0	62.49*	34.21–73.62	47.76*	36.97–81.05	51.15*

*between-gender difference statistically significant ($p < 0.05$).

Table 1 also contains data on carapace length and width. Differences between the SL and SFB crabs in terms of those morphometric characters were significant in the sexes taken together as well as in males and females taken separately. The values in the total SFB sample and in SFB females were lower than in the SL sample, whereas, despite a similar range of carapace length and width, the mean length and width in SFB males were significantly higher than in SL males. It seems interesting that individual carapace width classes showed marked differences in the sex ratio between the two samples (Fig. 4). While an almost even ratio, with a slight dominance of males in the four extreme classes, was observed in the SL sample, the SFB one displayed a higher proportion of males than of females in nine classes (males were markedly more abundant in higher carapace

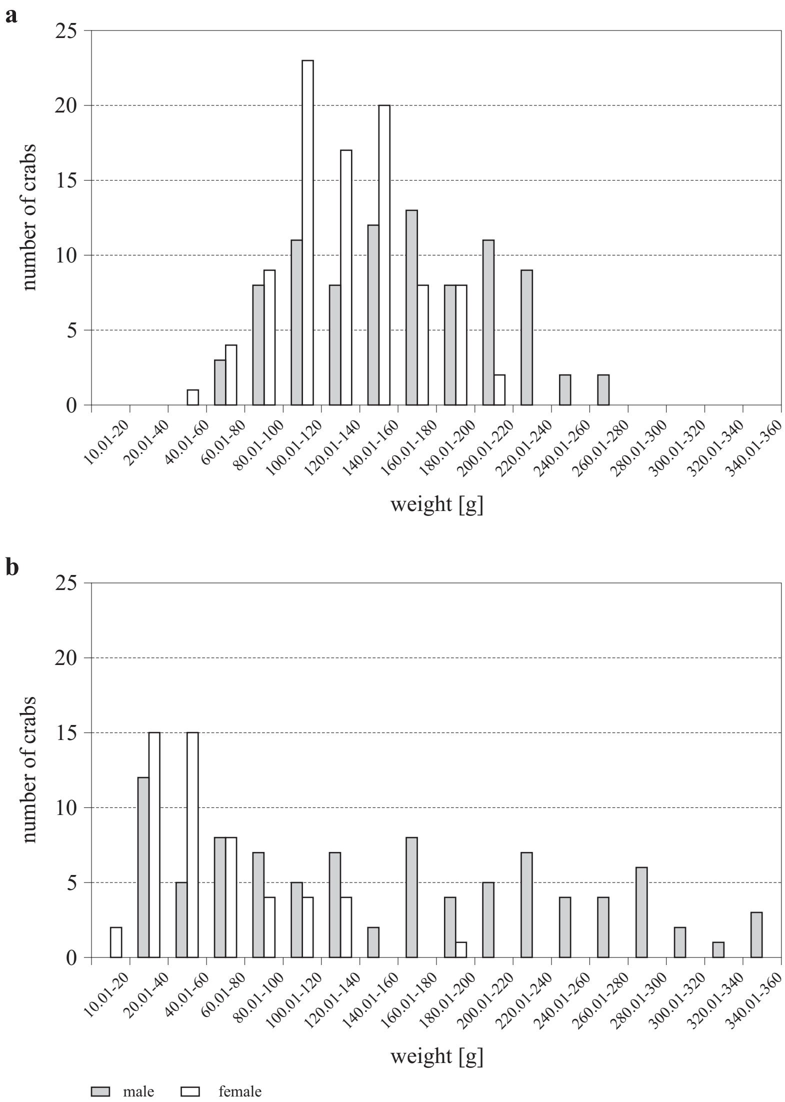

Fig. 3. Weight class distribution of the Chinese mitten crab in the Szczecin Lagoon (a) and San Francisco Bay (b)

width classes); females were dominant in only three classes (35.01–40; 40.01–45; and 45.0–50.0 mm).

Measurements of carapace width and individual weight of females and males enabled relationships between those parameters to be described (Fig. 5). Parameters k and n of the functions describing those relationships, indirectly reflecting the degree of nourishment of the crabs, showed only slight area-dependent differences, the sex-dependent ones being much

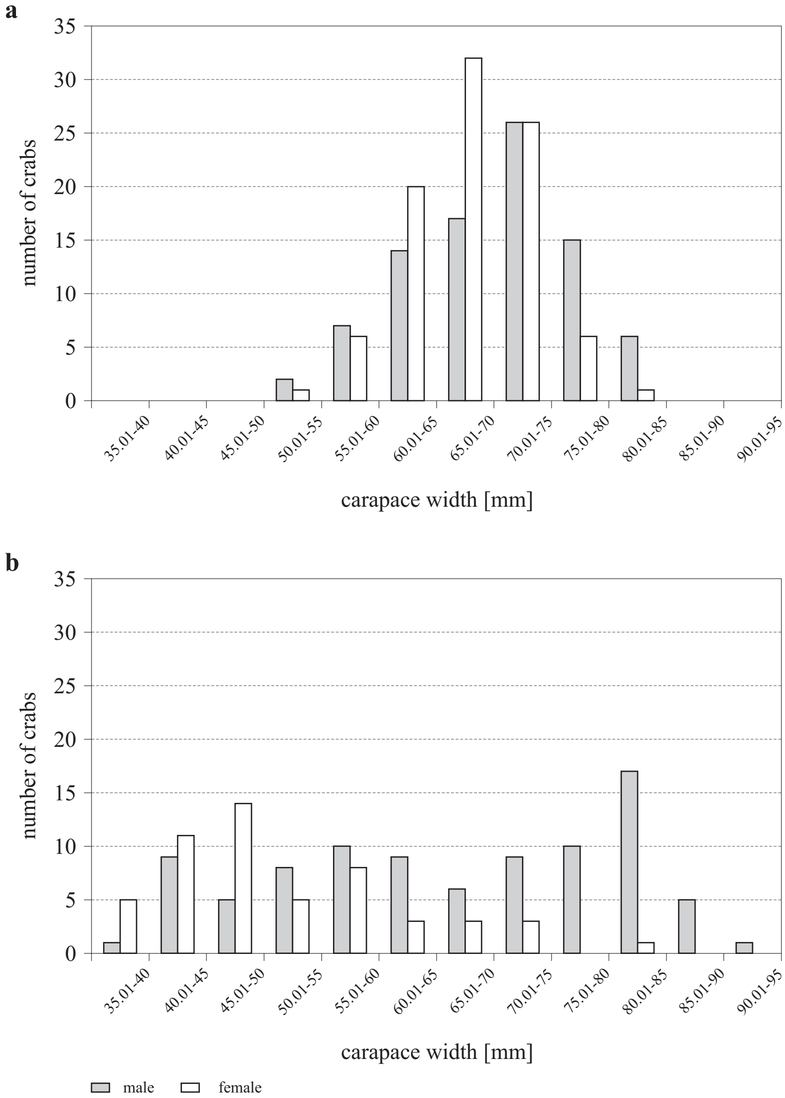

Fig. 4. Carapace width class distribution of the Chinese mitten crab in the Szczecin Lagoon (a) and San Francisco Bay (b)

more pronounced. In both populations, values of the function parameters demonstrated a slower weight growth rate in females than in males.

Tables 2 and 3 illustrate values of 10 metric characters as a percentage of carapace width, with their standard deviations S and coefficients of variation CV, presented separately for females and males. It is important that, prior to comparative analyses, a distinction be made between the sexes, because the Chinese mitten crab displays the sexual dimorphism typical of brachyurans.

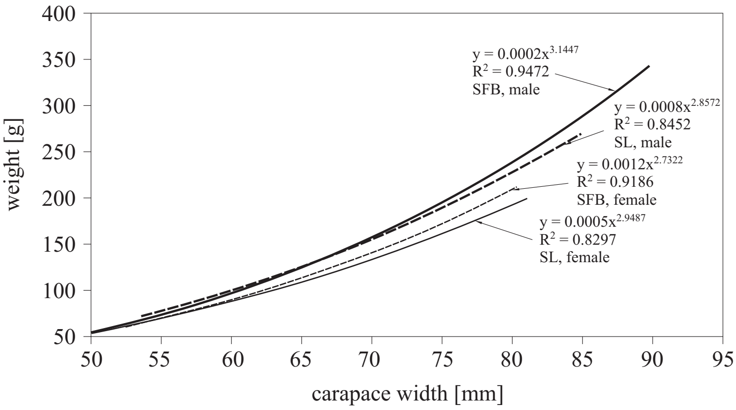

Fig. 5. Relationship between carapace width and individual weight of the Chinese mitten crab in the two populations under study

The dimorphism is seen, inter alia, in the male's larger claws and in the abdomen size. Variability was high ($CV > 10\%$) in the SL male's right claw height (X_6) and the female's left claw width (X_8) On the other hand, the SFB crabs showed that CV was $> 10\%$ in as many as six characters (Tables 2 and 3). The carapace length (X_1) was the most stable metric character ($CV < 3\%$) in both sexes in the two areas.

Table 2. Relative (% carapace length) metric characters of male and female Chinese mitten crabs collected in the Szczecin Lagoon (character symbols as in Fig. 2)

Symbol	Male (n = 87)			Female (n = 92)		
	$\bar{x}$	SD	V	$\bar{x}$	SD	V
X_1	89.24*	1.92	2.16	91.13*	2.05	2.25
X_3	47.40*	2.07	4.37	52.00*	2.02	3.88
X_4	71.73	5.22	7.28	55.88	2.61	4.67
X_5	36.14	3.36	9.31	28.19	1.87	6.65
X_6	23.76	2.44	1.27	16.43	1.00	6.06
X_7	72.13	3.56	4.93	56.01	2.70	4.82
X_8	36.99	2.98	8.05	28.28	2.92	10.33
X_9	23.75	2.21	9.30	16.41*	1.25	7.59
X_{10}	56.15*	1.57	2.79	69.56*	2.07	2.98
X_{11}	44.78*	1.47	3.28	77.72	3.32	4.27

SD – standard deviation, V – coefficient of variation, *between-gender difference statistically significant ($p < 0.05$).

Tables 2 and 3 summarise the results of the Mann-Whitney U test applied to test the null hypothesis of the lack of significant differences

Table 3. Relative (% carapace length) metric characters of male and female Chinese mitten crabs collected in the San Francisco Bay (character symbols as in Fig. 2)

Symbol	Male (n = 90)			Female (n = 53)		
	$\bar{x}$	SD	V	$\bar{x}$	SD	V
X_1	91.06	1.57	1.73	93.49*	3.23	3.45
X_3	49.04*	5.91	12.06	53.61*	3.46	6.45
X_4	72.47	7.90	10.90	54.95	3.88	7.06
X_5	37.13	7.06	19.01	27.77	2.66	9.56
X_6	24.20	3.34	13.80	16.37	1.45	8.85
X_7	73.11	7.08	9.68	55.56	2.57	4.62
X_8	37.33	4.61	12.36	27.67	2.22	8.01
X_9	24.18	3.94	16.28	15.82*	1.36	8.60
X_{10}	56.87*	1.79	3.14	66.83*	3.76	5.63
X_{11}	45.36*	1.49	3.29	76.65	4.45	5.81

SD – standard deviation, V – coefficient of variation, *between-gender difference statistically significant ($p < 0.05$).

in metric characters between crabs from the two areas. Four of the 10 linear dimensions measured (expressed as % carapace width) were found to distinguish (at $p < 0.05$) the two populations. In females, these characters were the carapace length (X_1) and height (X_3), and the abdomen length (X_{10}) and width (X_{11}); in males, in addition to the carapace length and height and the abdomen length, the left claw height proved to be a distinguishing character. The results of discriminant analysis, applied to identify the diagnostic metric characters, i.e. those characters that are most important in telling the SL and SFB crabs apart, are shown in Table 4. Values of Λ for each of the four statistically significant morphometric characters are higher than 0.76077, because the contribution of those variables in partitioning the data set cannot be lower than the individual contribution of each variable. The morphometric characters diagnostic for discrimination between the two populations are X_{11} (abdomen width), X_3 (carapace height) and X_7 (left claw length). In addition, the carapace length (X_1) is important despite its low discriminatory potential, because its partial Λ is sufficiently high and the tolerance coefficient T is high as well. The data in Table 4 show that for $i = 1.2$, $q_1 = \frac{87}{177} = 0.49$, $q_2 = \frac{90}{177} = 0.51$ and $p = 4$ the following classification functions were obtained for the SL (*M1*) and SFB crabs (*M2*):

$$M_1 = 27.71X_1 + 3.74X_7 + 0.25X_3 + 15.33X_{11} - 1721.44$$

$$M_2 = 28.28X_1 + 3.80X_7 + 0.30X_3 + 15.46X_{11} - 1785.16.$$

The fit of the results, as assessed from the classification matrix, was 71.75%.

Table 4. Results of the discriminant analysis for the Chinese mitten crabs from Szczecin Lagoon and San Francisco Bay

Wilk's Lambda: 0.76077 approx. F (4.172) = 13.521						
Symbol	Wilk's Lambda	Partial Wilk's Lambda	F removed −1.172	p level	Tolerance	1-Toler. (R^2)
X_1	0.931226	0.816960	38.53654	0	0.948340	0.051660
X_7	0.772181	0.985229	2.57871	0.110145	0.986944	0.013056
X_3	0.766998	0.991886	1.40703	0.237187	0.970446	0.029554
X_{11}	0.766648	0.992339	1.32782	0.250793	0.954001	0.045999

4. Discussion

Inland and coastal marine waters are inhabited by numerous animal species that are not members of indigenous faunas, but have immigrated or been introduced by man (Cohen & Carlton 1997). Alien immigrants in the Polish coastal zone include fish, such as the round goby (*Gobius melanostomus*) and the stone moroko (*Pseudorasbora parva*), and invertebrates such as the zebra mussel (*Dreissena polymorpha*) and the Chinese mitten crab (*Eriocheir sinensis*), abundant in the Szczecin Lagoon (Czerniejewski et al. 2003). The San Francisco Bay together with its delta is much more exposed to the immigration of new animal species; more than 230 alien species, such as the zebra mussel (*D. polymorpha*) and other bivalves, as well as crabs, including *Eriocheir sinensis*, have been recorded there (Cohen & Carlton 1995, 1997). *E. sinensis* is particularly noteworthy owing to the adverse effects its uncontrolled expansion exerts on the aquatic ecosystem (Halat 1996). Results of monitoring Chinese mitten crab populations in SFB and SL, carried out by Rudnick et al. (2000) and Czerniejewski et al. (2003), as well as the data presented in this paper point to a number of differences between the two populations in both biology and morphometry, the differences evidencing the distinct character of each population.

Compared to the SFB crabs, the SL individuals examined were statistically larger and heavier. The mean carapace widths, commonly regarded as a proxy for individual size, were 60.9 mm (range: 36.397 –90.07 mm) and 69.03 mm (range: 52.41–84.98 mm), respectively. The mean and range of the SL values are similar to the data reported by Normant et al. (2000) for the crabs harvested in Lake Dąbie (mean carapace width: 71.4 mm; range: 53–88 mm) and by Czerniejewski et al. (2003) for the crabs caught in 1999 from the Odra estuary (mean carapace width: 64.4 mm; range: 41.1–98.4). The range is slightly wider than that reported by Fladung (2000) for the population inhabiting the River Elbe in northern Germany (55–75 mm). Interestingly, individuals smaller than 50 mm formed only a small part (1.08%) of the batch of crabs harvested from the Odra estuary in 1999–2003; they were caught in 1999 in the Szczecin Lagoon. Individuals of such size accounted for as much as 31.5% (45 individuals) in the SFB population. In regard to the size ranges found, and in view of Hoestlandt's (1948) opinion that only those individuals larger than 50 mm in carapace width are sexually mature, it can be presumed that both Lake Dąbie and the Szczecin Lagoon supported individuals that were preparing for or were actually in the process of reproductive migration to the Baltic Sea and further to the actual spawning sites. In Europe, these are located – according to Panning (1939) – in the coastal part of the North Sea. It has to be added that the species is able to spawn only at a salinity of about 25 PSU (Vincent 1996), hence the SL females had no eggs beneath their abdomens. It seems that egg laying begins at further stages of the migration, in areas more saline than the Odra estuary. Harvesting mature individuals does not preclude the presence of abundant juveniles in Polish waters; these enter our freshwater areas in spring (Demel 1974). Most probably, they rarely leave their shelters, i.e. burrows located in the inshore zone, an area not visited by the professional fishermen who supplied the materials for this study.

The Chinese mitten crab sex ratio in samples harvested from natural water bodies is season-dependent. Studies carried out by Siegfried (1999) in autumn showed the pronounced dominance of males in September and the first decade of October; subsequently, the proportions of both sexes were approximately equal. A similar pattern was observed in the Polish populations of the crab, as reported by Normant et al. (2000) and Czerniejewski et al. (2003). It is difficult to offer an unequivocal explanation of the differences in sex ratio between the SL and SFB populations. The number of males in the latter, almost twice as high as that in the former, seems to result from 62.9% of the individuals examined being caught in August–September, while 99.6% of the SL crabs were harvested in October –November. However, as demonstrated by Kobayashi & Matsura (1994), the dominance of males in a population of related species (*Eriocheir japonicus*) was caused by their much higher locomotor activity, suggesting that the ability to move faster places the males at an advantage as it makes them more successful feeders, hence their higher growth rate and better condition. That this could be the case in the SL population is supported by a markedly better condition (as evidenced by the parameters of the equation describing the carapace width-body weight relationship) compared to the condition of females both in San Francisco Bay and in the Szczecin Lagoon.

In addition to the biological characters described above, area-dependent differences between the two populations studied are visible in the morphometric characters. As already mentioned, any comparative analysis should allow for the strong sexual dimorphism in this crab species, which is most pronounced in the abdomen and claw dimensions. Sexual dimorphism is fairly common among crabs of the family Grapsidae, to which the Chinese mitten crab belongs. The dimorphism is manifested inter alia as larger claws in males (Flores & Negreiros-Fransozo 1999). Comparison of the body morphology in the two populations revealed statistically significant differences and, hence, allowed certain diagnostic characters to be identified. These include the abdomen width (X_{11}), carapace height (X_3), left claw length (X_7), and carapace length (X_1), i.e. characters accounting for 71.75% of the differences between the SL and SFB Chinese mitten crab populations.

5. Conclusions

- Comparative analysis of two non-indigenous populations of the Chinese mitten crab, one inhabiting San Francisco Bay and the other occurring in the Szczecin Lagoon, revealed clear differences in morphometric and population parameters.
- The differences in biological characters involved a significantly lower individual weight, carapace length and carapace width in the San Francisco Bay crabs; the San Francisco Bay population showed a markedly higher proportion of males than females in comparison with the Szczecin Lagoon population (62.39 and 37.1% vs. 48.6 and 51.4%).
- Statistical analysis of 10 metric characters of the crabs showed significant differences between a number of them; the abdomen width (X_{11}), carapace height (X_3), left claw length (X_7) and carapace length (X_1) should be regarded as diagnostic features.
- The pronounced differences between the Szczecin Lagoon and San Francisco Bay Chinese mitten crab populations demonstrate the distinctness of each population of those non-indigenous crustaceans.

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