10. Ostracods of athalassic saline lakes

A review

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Introduction

In searching the literature for the present paper, it often proved difficult to determine authors' definitions of salinity and brackish water. This was especially applicable to articles published early this century which mentioned the presence of ostracods in salt waters and which used the following confusing variety of descriptive terms: 'brackish', 'high chlorinity', 'natron', 'mineralized water', or 'with high content of salts'. An additional difficulty was provided by the term 'coastal pond': it was usually not stated if the pond was connected to the adjacent sea or not, even if for a short time. Confusion also arose when the authors dealt with forms from the Pontocaspian region, that is the Caspian, Black and Aral Seas; rarely was it clearly stated if the ostracods had actually been collected from these inland seas or from adjacent lagoons (and if these were connected with an inland sea). Finally, when an ostracod was recorded from a large water-body, like the Caspian Sea, the exact locality was rarely provided. Such ostracod records could not be used, because water salinities in these inland seas vary in different areas; for example, they are often lower close to river deltas.

Before the publication of the Venice System of classification of brackish waters, the term *brackish* was commonly used loosely, often meaning diluted sea water or water with a salinity lower than that of the sea. In the present paper, which only deals with ostracods found in waters *not* in connection with sea water, the term *athalassic*, introduced by Bayly (1967), is used. Athalassic saline waters contrast with brackish waters (contiguous with sea water) by the former's lack of homogeneity in ionic proportions (Bayly 1969), a feature not always recognized by authors who have compared marine ostracods with those from inland saline waters. Chlorinity was often assumed to be a sufficient and adequate measure for salinity by such authors. Whilst chlorinity is indeed a reliable guide to sea water salinity, chloride is not always a predominant anion in athalassic saline waters, and its measurement can therefore be misleading in such waters. It is therefore impossible to use chlorinity as a measure of salinity, for strictly salinity is the total ionic concentration.

Electrical conductivity is another measurement which has been used to indicate salinity, but there are difficulties in the application of this determination to salinity values also.

German authors have used the term 'Saüerbingungvermögen' (SBV) as a measure of alkalinity to characterize various types of water. This usage, likewise, could not easily be used in the present study. At times, however, interesting results were noted when salinity and SBV measurements were compared. Thus, Löffler (1959) described the unusually high SBV value (500) of waters in which *Limnocythere inopinata* was found; this ostracod, however, was only recorded in waters of maximum salinity 10.6‰ (calculated from Löffler's 1959 data). Similarly, Hiller (1972) demonstrated the advantages of measuring both chlorinity and salinity in which ostracods occur: e.g. the highest known chlorinity tolerance for *Cypria ophthalmica* is 11.34‰ (Klie, 1925), whereas the highest tolerance to salinity is 5.8‰; on the other hand, *Sarscypridopsis newtoni* can often be found in waters of high salinity (15–20‰), but only in low chlorinity

Hydrobiologia 81, 131–144 (1981). 0018-8158/81/0813-0131/$ 02.80.

waters: 1.25–6.7‰ (Hiller 1972). This clearly illustrates the dangers of relating chlorinity to salinity.

To avoid any misunderstanding, all ion concentrations should be listed. Such a listing gives a universal way of comparing various waters and relating this to osmoregulation, often the most important factor controlling the tolerance of animals to water salinity (Beadle 1969). Chlorinity and alkalinity measurements should be provided as well, as they can sometimes explain the presence or absence of species. However, such measurements are not always reliable because of the possible combination of other factors – such as toxic substances and temperature, a very important environmental feature. It is now known (although no work has yet been published on ostracods) that salinity tolerance for species can also be affected by temperature (Dorgelo 1976; Neale 1964). As a result, the tolerance of a species at a certain time to a particular salinity could be quite different in different geographical regions. Sywula (1966) described the phenomenon where two *Candona* species, *C. fabaeformis* and *C. fragilis*, had annual cycles in saline water bodies in Poland different from those in freshwater bodies. The latter species, for example, which is a spring season species in fresh water, occurred as early as autumn in saline habitats. Not only do temperature or salinity, but probably both combined, determine the occurrence of this species; it is also very likely that field values of salinity tolerance do not represent optimal values for the species.

Gauthier (1928), when describing the presence of ostracods in different water-bodies in Algeria and Tunisia, made the following distinctions for ostracods and types of water: 'One species, typical of freshwater, *Cyprinotus incongruens*, can live in inland brackish ("saumâtres") waters up to a density of 1 007 [it is considered here to be approximately 7‰ salinity]. If the water density is higher, it is replaced by the euryhaline species *Cyprideis torosa* which can also live in freshwater, or the stenohaline species, typical of salt waters, *Eucypris ungulata*, or by forms typical of fresh waters which are represented by a variety *Cyprinotus barbarus* var. *inermis* in saline waters, or on the contrary, by a variety of a form typical of brackish water, and which lives in fresh water: *Cyprinotus salinus*' [translated from Gauthier (1928, 373–4)]. This statement is confusing because Gauthier apparently did not see the difference between species and forms which have different habits because they live in different environments.

Confusion has often existed, too, for species with morphologies which vary in different environments, as they were frequently regarded as separate species. The case is illustrated by the commonly known *Cyprideis torosa* (with nodose shell) and *C. littoralis* (smooth shell), both grouped under the former name (Kilenyi & Whittaker 1974)*.

Following Gauthier, in an attempt to classify groups based on salinity tolerance, a variety of terms has been used in the literature to define ostracods living in various types of saline waters. Thus, Sywula (1966), who attempted to distinguish halophilous and haloxene species, noted that 'halophilous species are those which have freshwater for their normal medium, but which, in their characteristic biotope with increased salinity of a given water mineralization type, form a thriving and common population, whereas the haloxenes in similar conditions are much less numerous and less common'. But the same author pointed out that prolonged periods of comparatively stable high salinity are the true inhibiting factors in the occurrence of freshwater species in increased salinity. This terminology is not used in the present paper as the differences defined by Sywula (1966) are known for few ostracods.

Hiller (1972) attempted to characterize ostracods according to their tolerance to salinity. He tried to define various groups on their occurrence in waters of different salinities. He used the terms true freshwater, oligo-, meso- and poly-halophilous species. Usskilat (1975) attempted a similar classification, but her study cannot be referred to here as she examined the salinity range of ostracods living in waters connected to the sea (the Schlei being a fjord of Kiel Bay, Germany). Hiller's arbitrary classification, which refers to marine brackish waters, should likewise not be used for those salinities which are thought to determine the presence or absence of athalassic saline ostracods as most are not marine in origin (see later discussion).

As previously stated, other factors, such as temperature, must also be taken into account.

* To avoid confusion, names of ostracods given in the present paper are those generally accepted in today's literature. For quite a few species mentioned in old papers, generic names had often to be changed.

Table 10.1 List of ostracods recorded in the literature from saline waters in Europe above 3‰ salinity. Numerical data as ‰ salinity.

	Calculated from Löffler 1957	Löffler 1961. Values in parentheses extrapolated from Cl values	Hiller 1972	Hartmann 1975	Usskilat 1975 L = literature record	Marazanof 1967	Highest value recorded
Candona albicans			1.4–4.5				4.5
angulata					3.2–5.9 L 0.4–14		14
candida			0.1–5.7	3?	0.5–5.3		5.7
compressa			0.5–5.8	5?			5.8
fabaeformis			0.5–5.8				5.8
levanderi			1.0–6.0	5.5			6.0
lobides			1.4–3.6				3.6
marchica			1.4–4				4
neglecta		5.5	1.5–15		0.5–5.9 L 0.5–15.3	15.7	15.7
parallela	0.5–5.1	5					5.1
pratensis	0.6–3.5				0.5–6.2		6.2
protzi			5.8				5.8
Candonocypris kingslei		5	5				5
Cypria ophthalmica		4	0.2–5.8 →?20		0.5–5.5		5.8
Cyclocypris laevis			0.1–6.4		0.5–5.1		6.4
ovum		0.5	0.1–6.4				6.4
Ilyocypris bradyi		1			0.5–4.4 L 4.5		4.5
gibba		(3.6)					?3.6
Notodromas monacha		1	1–3				3
Cypris bispinosa		3.6					3.6
pubera	0.6–4.2	4.2					4.2
Eucypris inflata		8?–110					110
virens	0.6–3.6	(4.4)	1.4–5.0				5.0
Herpetocypris reptans		(1)	0.5–6		0.5–5.1	1.9–15.7	15.7
Heterocypris barbara		(88)					?88
exigua						1.9–15.7	15.7
incongruens	0.5–7.28	7.2 (12.5)	20				20
salina	1.12–5.07	20 (25?)					20+
Cypricercus reticulatus			5				5
Cypridopsis vidua		1.7	1.0–8				8
Plesiocypridopsis inaequivalva		(16)					?16
newtoni		8	0.3–15.7			1.95–15.7	15.7
Sarscypridopsis aculeata		(5)				1.95	1.95+
Potamocypris unicaudata	0.6–3.86	3.7	3.7				3.86
smaragdina			14.5–28.5?				14.5+
steueri		1–12					12
Darwinula stevensoni		15			0.6–5.3 L 0.5–15		15
Limnocythere inopinata	−10.69	7.2, >25?	0.5–6.7 (26.5 durch Na_2CO_3, $NaHCO_3$)		0.5–5.9		10.69+
Metacypris caudata				3.5			3.5
Cythere triangulata		4					4
Leptocythere cribrosa		meso-polyhalin(?)					?
Cytheromorpha fuscata		1? 18?			0.7–5.3 L 1–29		29
Loxoconcha gauthieri		0.5–15					15
Cyprideis torosa		5, (23), (56?)			0.5–6.2 L 0.4–60		60

Moreover, if a species is found in water of a given salinity, its presence does not necessarily mean that it could live there indefinitely. Its presence could be accidental (specimens washed from a river into saline water), as suggested by Hiller (1972) for the occurrence of *Cypridopsis vidua* in an unusual salinity value of 43.0‰ (King & Kornicker 1970). The highest salinity value otherwise known for this cosmopolitan species is 9.7‰ (see Table 10.1). Similarly, *Diacypris whitei* has been recorded at a salinity of 180‰, in a salt lake near the Coorong Lagoon in South Australia, but at the time the lake was rapidly drying (and would have been dry in days) and, as a result, the salinity was unusually high. *D. whitei* was found inactive in certain parts of the lake (water depth 3 cm!), and sluggish in others. The salinity value of 180‰ should not therefore be considered as the highest it can tolerate; its usual range is 35–113‰. This sort of phenomenon cannot, however, always be detected.

Finally, there are difficulties in considering Pontocaspian records, for it is very likely that because of long acclimatization, tolerance of ostracods to saline waters is higher there than in other regions where freshwater is more common. The same may also apply in Australia, where saline waters abound, and where some ostracods are known to tolerate slightly higher salinities (e.g. *Eucypris virens*, see Tables 10.1 and 10.3).

Despite all the difficulties indicated above, and provided it is recognized that salinity rarely acts alone, it is useful and possible to review the occurrence of athalassic ostracods in relation to habitat salinity. To this end, an arbitrary value has been chosen to delimit fresh and saline waters. It is 3‰, a value that has been used by others (Bayly 1972; Williams 1964, 1978). A freshwater species will be considered in this paper as one found most commonly in waters near 1‰ or less in salinity but which can occasionally be found above 1‰. This is the case for animals which inhabit temporary pools where salinity can be above 1‰ when drying. Occasionally, these ostracods can be found in salinities up to 10‰ and more rarely up to 20‰, with very rare cases up to 30‰ (see Table 10.3: *Cyprinotus edwardi*). Species often found in salinities above 3‰, and even those usually found in waters above 10‰ (e.g. *Sarscypridopsis aculeata*), can either be called euryhaline or euryplastic [euryhaline: able to live in waters of wide ranging salinity; euryplastic: exhibiting great capacity for modification and adaptability to a wide range of environmental conditions]. Perhaps, in the present context, both terms ought to be considered as synonymous because, as mentioned, salinity alone is not the limiting factor to osmoregulation. To avoid confusion, however, the term euryhaline will be used so as to stress the fact that salinity is probably still the most important controlling factor. The term euryplastic is more appropriate for the previously used examples such as *Cypria ophthalmica* and *Plesiocypridopsis newtoni*. Finally, the term halobiont [living in saline water] will be used for ostracods which live in saline waters (3‰ salinity or above), and which never require truly freshwater during part of their life. Some ostracods, for example, have never been found living in low salinities at all: e.g. *Australocypris rectangularis* did not occur in a lake during the period of the year when salinity was below 50‰ (see Table 10.3).

Table 10.2 Ostracods from the Pontocaspian region. After various authors (see text).

	Number of species known	Species of marine/estuarine affinities	Species of freshwater affinity
Caspian Sea	32	26	6
Aral Sea	10 (total?)	4	6
Black Sea (coast?)	21	10	11
Kuban Delta adjacent to Azov Sea	15	5	10
Issyk-Kul	11	3	8

Records of ostracods in Athalassic saline waters of salinity above 3‰

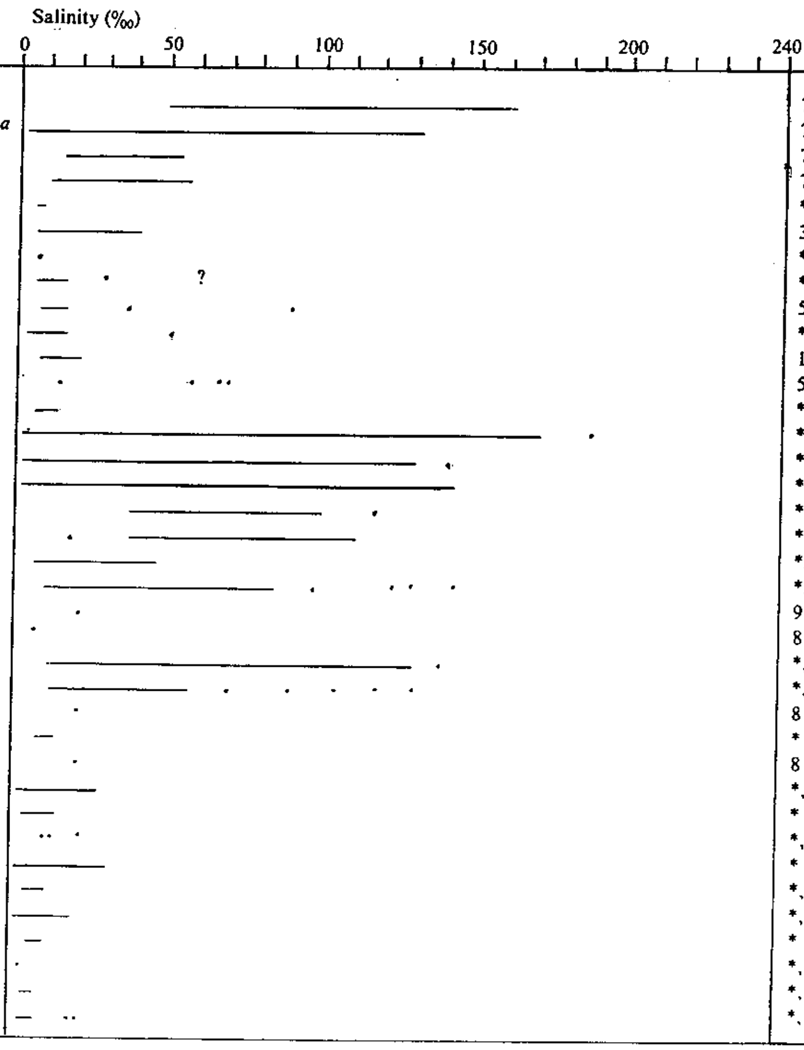
Europe

This region covers the countries north of the Mediterranean and between the Iberian Peninsula to the west and the Urals to the east. The Pontocaspian region will be dealt with separately. European ostracods from inland waters have been more thoroughly studied than those from any other part of the world; Löffler & Danielopol (1978), for example, have listed 409 ostracod species recorded from Europe (including, however, the Pontocaspian region).

Löffler (1959) provided the first list of ostracods to be accompanied by chemical determination of the waters in which they were found. It concerned the Seewinckel region in Australia. The list was subsequently updated in his review of the fauna of Iranian inland waters (Löffler 1961). Relevant parts of this list are given in Table 10.1. Estuarine faunas have been excluded. Hartmann's (1975) updating of Löffler's list is also added in Table 10.1.

Sywula (1966) in his thorough study of the fauna of inland saline areas of Poland provided new insights into the composition of ostracod fauna in

Table 10.3 List of ostracods and their salinity records from athalassic saline waters in Australia. From various sources.



Taxon	Source
Australocypris rectangularis	7, 9
insularis-hypersalina	7, 8, 9, 12
robusta	7, 8, 9, 12
n.sp.	7
Mytilocypris tasmanica	*
praenuncia	3, 7, 9
ambiguosa	*, 7
mytiloides	*, 8
minuta	5, 6, 8
splendida	*, 1, 3
henricae	1, 3, 11
tasmanica chapmani	5, 6
Trigonocypris globulosa	*
Platycypris baueri	*, 4, 5, 6, 7, 8
Diacypris compacta	*, 7, 8
dietzi	*, 7, 9
fodiens	*, 7, 8, 9
whitei	*, 7, 8, 9
n.sp. 1 (*spinosa*)	*, 7, 8
2 (*dictyote*)	*, 7, 9
3 (*phoxe*)	9
4 from W.A.	8
Reticypris herbsti-dedeckkeri	*, 7
n.sp. 1 (Coorong)	*, 7, 8
2 from W.A.	8
walbu	*
New genus from W.A.	8
Cyprinotus edwardi	*, 8, 9, 10
Limnocythere mowbrayensis	*
Cyprideis westraliensis-australiensis	*, 5, 6
Leptocythere sp.	*
'*Chlamydotheca*'	*, 8
Sarscypridopsis aculeata	*, 8
Ilyocypris sp.	*
australiensis	*, 10
Eucypris virens	*, 8, 9
Heterocypris sp. from W.A.	*, 8

* Original
1. Bayly & Williams (1966, 1967)
2. Bayly (1970)
3. De Deckker (1975)
4. Geddes (1976)
5. Williams and Buckney (1976)
6. McKenzie (1978b)
7. De Deckker and Geddes (1980)
8. Geddes *et al.* (1981)
9. Topping pers. comm.
10. Williams (1975)
11. McKenzie (1966)
12. Williams (1978)

athalassic saline waters. Although complete chemical analyses of waters were given by Sywula (1966), no additional information can be added to Löffler's list as no precise dates of collection for the ostracods were given.

Hiller (1972) provided more data for 43 species of ostracods collected in water-bodies near Hamburg. Unfortunately, he recorded chlorinity and not salinity, but he did tabulate salinity ranges previously recorded in the literature (mainly according to Klie (1925), Margalef (1953) and Löffler (1961)). In addition, information can be derived, although no precise salinity data were presented, from Heuss (1966) in his study of sewage waters from a potash factory running into the river Werra near Göttingen in Germany, from Järkevulg (1961) for some ostracods in the 'brackish' waters on the Estonian coast, and from Klekowski (1952) for ostracods in saline and sulfurous inland waters in Poland.

Neale's (1964) table of salinity range for ostracods from the British Isles, mainly collated from the literature, cannot be used because he did not state whether the data strictly related to inland waters.

Dumont & Gijsels (1971), in a study of ostracods from small water-bodies adjacent to the river Schelde in Belgium, presented a list of 9 ostracod species found in water of conductivities up to 5 400 μS at 20 °C. However, no value was higher than the maxima given by Löffler (1961) or Hiller (1972).

Usskilat (1975), in her important study of ostracods from the Schlei, listed salinity ranges for the ostracods examined. The highest salinity encountered was 6.2‰. Her data, additional to those of Hiller (1972), should be treated with care as her localities were typically estuarine. Nevertheless, these values should be considered as similar to those which probably could be reached by ostracods in athalassic inland waters. From Yugoslavia, Petkovski (1969) described an unusual ostracod (*Candona natronophila*) collected from a small water-body characterized by high natron content. The species has never been recorded outside that country even in the well-studied adjacent Seewinckel area (Löffler 1959, Löffler & Danielopol 1978).

Finally, Fryer (1978), who examined the crustacean fauna in lagoons from the Lower Aire Valley in Yorkshire, England, found both *Sarscypridopsis aculeata* and *Heterocypris salina* in Mickletown Flash, a marshy lagoon where water had a high ionic content and a conductivity of 5 313 μS at 25 °C.

For southern Europe, Marazanoff (1965) recorded ostracods from the Camargue region, but he was not explicit as to whether the 'brackish' waters from which the ostracods were collected were connected to the sea or not. The same author (Marazanoff 1967) recorded ostracods from the Marismas of the River Guadalquivir in southern Spain. Ostracods found in waters above 3‰ salinity are added to the list in Table 10.1. It is surprising that *Eucypris aragonica*, described by Brehm & Margalef (1948) from temporary saline waters in Aragon (north-eastern Spain), was not recorded in Andalusia by Marazanoff (1967). Margalef (1947, 1956), in his biological survey of temporary, highly mineralized waters of the Zammoran province in Spain and of the endorheic country in the Newcastilian Meseta, mentioned the presence of ostracod species, but did not provide adequate salinity data for localities. The same difficulty arises in considering his monograph dealing with the crustaceans from the Iberian Peninsula (Margalef 1953); useful ecological information on ostracods is provided, but salinity data for the salt tolerant species are lacking except for a little on chlorinity. All the salt tolerant species mentioned by Margalef (1953) are found in other parts of Europe and/or North Africa with the exception of *Eucypris aragonica* which is, so far as is known, endemic to Spain, and which, he noted, is found in high salt concentrations.

Pontocaspian region

This region is unique in the world because of its peculiar geological past, for it covers the remnant landlocked part of the Tethys Ocean on the eastern side of the Mediterranean. Ostracods recorded are mostly marine in affinity, as they have been 'trapped' in the various inland seas (Caspian, Aral, Black and Azov). For the latter two seas, still partly connected to the Mediterranean, it has been difficult to determine from the literature what authors considered to be a brackish water fauna. This applies, for example, to Klie (1937), who studied waters on the Bulgarian coast of the Black Sea. It was not clear whether the saline swamps he mentioned were directly connected to

: Black Sea or isolated from it. He recorded species of which 10 have a marine ancestry: :se ostracods, in fact, belong to genera charac- istic of shallow and/or estuarine marine envi- nments (*Cyprideis, Hemicythere, Eucytherura, ·xoconcha, Xestoleberis, Cytherois* and *Para- xostoma*). The other species described had a inity range similar to those given in Table 10.1, :ept for *Heterocypris maura* at 10‰, *Hetero- ›ris fretensis* at 3‰ and *Eucypris inflata* at 50‰. ter, Caraion (1962) provided a table of ostracods ›m the Ponto-Azov basin. In it she listed 21 :racods found in 'brackish waters', but did not :cify if these were connected to the Black and :ov Seas. Her list is very similar to Klie's (1937). e also provided a list of 7 species (*Potamocypris 'ueri, Darwinula stevensoni, Limnocythere ino- ıata, Cyprideis torosa, Cytheromorpha fuscata, ›xoconcha pontica, Cytherois cepa*) recorded ›m the Azov Sea. She gave no precise locality ta, and as a consequence, no salinity data can be :rapolated because salinity is known to vary in ferent parts of the Azov Sea (average salinity is .2‰, but in the northern region salinity is 40‰ d in the southern, 17.5‰ (Zenkevitch 1963)).

Hoffman's (1966) study of Caspian Sea ostracods ınot be used here, likewise, as it has been strongly ticized by Naydina (1968) on the grounds that ufficient attention was paid to the transported ·emblages of living and fossil ostracods. This int is important because the previous regime of · Caspian has changed drastically many times, at st during the Pleistocene. Naydina (1968), how- :r, listed 32 ostracod species from the Caspian ı given by other authors. Twenty six are marine ›rigin (16 species above being grouped under the ıus *Leptocythere* known elswhere to be typically uarine). The work of most value to the present dy (because it deals with definitely athalassic ʼironments) was that of Schornikov (1961) who estigated the ostracods of the Kuban River delta acent to the Azov Sea. He listed 15 species :rant to saline waters using chlorinity values ›vided by other authors. Five of them have rine ancestry. He included in that list an endemic m, *Limanocypris luridus*, with a range of 1–4‰ [*Limanocypris* is monospecific]. Subsequently, ıornikov (1964a) recorded one species of *Can- ıa* (*C. schweyeri*) from the Caspian Sea (and acent rivers), with 7 other species which have marine ancestors (6 belong to the genus *Leptocythere*). These were listed *inter alia* by Naydina (1968). In 1966, Schornikov also recorded an additional species (*Candona camelus*) from the Caspian. In an article on Azov-Black Sea ostracods, Schornikov (1964b) gave a salinity range of 25–33‰ for *Candona schweyeri*, and from freshwater, up to 70‰ salinity for *Cyprideis torosa*. He also indicated a very broad salinity range for *Eucypris inflata*, viz. 2.8–106‰. Finally, in 1974, Schornikov provided notes for 10 species in the Aral Sea, six of them of freshwater origin. The highest salinity recorded for *C. torosa* was 96‰. This must surely have been measured outside the Aral Sea proper.

In conclusion, it appears that the uniqueness of the Pontocaspian basin is reflected in its ostracod fauna; as in its other faunas, a high percentage of species with marine or estuarine ancestry is characteristic. This phenomenon appears to be unique so far as ostracod faunas from athalassic saline waters are concerned. As one proceeds eastwards from the Mediterranean, the number of marine species occurring in saline 'seas' diminishes (see Table 10.2 and section on Central Asia).

Central Asia – Eurasia region

This region covers parts of the U.S.S.R. and areas adjacent to the Persian Gulf. Löffler (1961), in his study of Iranian waters, added elements of the fauna of this region to his faunal list for Europe. The main ostracod he found to be tolerant to high salinities was *Eucypris inflata*; for this species, an upper value of 110‰ was given (Table 10.1). Hartmann (1964), in his monograph describing ostracods from Asia, recorded species similar to those recorded by Löffler, with an additional new species *Eucypris salina*, but he did not provide salinity data. However, he noted a new species from the Persian Gulf area, *Cypretta lindbergi*, as collected from 'brackish water'. He also described another species, *Cypretta foveata*, from north-western India as a salt tolerant form living in 'brackish water wells'. These two species belong to a genus which is otherwise typically freshwater elsewhere. This may indicate that in certain regions some species become more tolerant to saline waters, provided that time for acclimatization is adequate in areas which now have few freshwater bodies, for example, near the Persian Gulf. Yassini and Ghahreman's (1976) work on the ostracod fauna from the Pahlavi Lagoon near the Caspian Sea in North Iran cannot be considered here because they did not distinguish live and dead ostracod assemblages. They recorded 8 species of freshwater affinity, and 13 estuarine ones (*Leptocythere* and *Loxoconcha* species) and *Cyprideis.*

Sars (1903a, 1903b) listed and described 4 ostracod species from salt and bitter lakes and swamps in Central Asia in the Territories of Omsk, Akmolinsk and Atbassar: *Sarscypridopsis aculeata, Cypridopsis granulata, Eucypris inflata* and *Limnocythere incisa.* No salinity data were recorded, however.

Also in Central Asia, Lake Balkash has a salinity of about 3‰. There appear to be no records of ostracods from it. Lake Issyk-Kul, on the other hand, with a salinity close to 6‰ (Aleschinskaja & Bondarew 1969), possesses a very interesting ostracod fauna. It has been described by Daday (1909) and was later reviewed by Bronstein (1929). Two species are endemic, *Herpetocyprella mongolica* and *Candoda keiseri*) (*Eucypris mongolica,* described by Daday, is now thought to be a variety of *Eucypris inflata*). Of the 11 species recorded from that lake, 3 are of marine ancestry, including a species of *Cyprideis* (*C. pedaschenkoi*). *Limnocythere dubiosa* recorded there is also found in the Aral Sea (Schornikov 1974), whereas some others (*Sarscypridopsis aculeata, Cyclocypris laevis* and *Candona neglecta*) also occur in Europe.

Thus, in Central Asia, a few forms are endemic, and marine ancestral forms are rare (3 species). The fauna as presently known comprises 12 species recorded from athalassic saline waters. In Eurasia, some species are endemic, whereas others are also common to Europe and/or Central Asia. Few salinity data are available.

China and Siberia

No information on either region could be found.

North Africa

Moniez (1891) was the first to report the presence of ostracods in salt lakes in Algeria. No salinity data were presented. None of the species mentioned by him will be discussed here in detail as the fauna of that area has been subsequently and thoroughly examined by Gauthier (1928). *Cypris mareotica* mentioned by Moniez is probably synonymous to *Eucypris inflata,* whereas *Eucypris ungulata* (Moniez 1891) is an original species (Gauthier 1928).

Gauthier (1928) undertook a detailed study of the ostracod fauna of Algerian and Tunisian inland waters. He distinguished various types of waterbodies, and determined the ostracod fauna in each. His method of determining water quality was to measure its density (= d). This method is here approximated to salinity. His records for various species were as follows:

Cyprinotus incongruens d : 1 007 ≅ 7‰
Heterocypris barbarus var. *inermis* d : 1 005–1 050 ≅ 5–50‰
Heterocypris barbarus d : 1 030 ≅ 30‰
Eucypris inflata d : 1 005–1 030 ≅ 5 to 30‰
Cyprideis torosa d : 1 030 ≅ 30‰
Eucypris virens freshwater to 1 038 ≅ up to ? 38‰

[This value for *Eucypris virens* is high compared to others in other parts of the world.]

Gauthier (1928) added that in temporary chotts and sebkhas *Eucypris inflata* and *E. ungulata* were common, whereas in the permanent 'brackish' water swamps *Eucypris inflata, Heterocypris salina* and *Cyprideis torosa* were found. It was Gauthier who first attempted to recognize forms which have different habits in various habitats.

In 1943, Beadle mentioned the presence of ostracods in Algeria, but gave no identifications in his exhaustive list of inhabitants of athalassic saline waters. Recently, I have been able to examine some ostracod collections from the Saharan region given me by Prof. H. Dumont. It appears that *Eucypris inflata* is the most widespread inhabitant of saline waters there. Unfortunately, no detailed salinity data were available. *Cyprideis torosa* also occurs in these collections.

It is interesting to note that the fauna recorded from North Africa is very similar to that of Eurasia, Asia and southern Europe.

Central and South Africa

Even though the ostracod fauna of central and South African waters is fairly well-known as a result of work by Sars (1924a, 1924b), Lindroth

(1953), Rome (1963, and subsequent papers) and McKenzie (1971b, 1978a) little has been mentioned about ostracods in saline lakes, and no associated salinity data have been provided. Hutchinson *et al.* (1932), in their study of the hydrobiology of pans and other inland waters of South Africa, mentioned only the following ostracods: *Cypria capensis* and *Pseudocypris expansa* from neutral and alkaline waters, and *Plesiocypridopsis inaequivalva* and *Heterocypris congener* in alkaline localities. It was not until 1953 that Lindroth published a large study of the taxonomy and zoogeography of the ostracod fauna of inland waters of East Africa, with a few more salinity data. No ostracods were recorded from the highly alkaline lakes which are common there. The only interesting record was of *Cyprideis torosa* from Lake Rudolf (salinity 1.7–2.5‰, Beadle 1974). This species was not recorded in more saline waters by Lindroth (1953). Beadle (1974) in his review of African lakes gave no names for ostracods from saline waters.

The ostracod fauna of Aldabra Atoll, situated in the Indian Ocean to the north-west of Madagascar, was carefully studied by McKenzie (1971a). He paid particular attention to distribution according to habitat, and distinguished between ostracods occurring in athalassic salt waters, and in salt waters intermittently connected to the sea (due to tidal invasion). In athalassic waters, the following ostracods were recorded [the highest salinity value recorded is indicated after the species name]: *Heterocypris symmetricus* 12.7‰, *H. giesbrechti* 8.9‰, *Plesiocypridopsis aldabrae* ?4.4‰, *Zonocypris* cf. *madagascarensis* ?4.4‰, *Limnocythere notodonta* 7.8‰. All of these belong to genera typical of temporary pools and found in most parts of the world; the salinity values they usually tolerate can go as high as about 10‰.

To summarize, little is known about the distribution of the ostracod fauna of Central and South Africa with regard to salinity. The fauna, however, is distinct from that of North Africa.

Canada

The ostracod fauna of Canadian saline waters is well-known due to the extensive work of Delorme. It is surprising, however, that the often quoted works of Rawson & Moore (1944) and Moore (1952), which list cladocerans, copepods and anostracans from saline lakes in Saskatchewan, gave no names of ostracods. Yet Delorme (1967) listed 61 species known from Saskatchewan, with at least one, *Candona acutula*, present in slightly saline lakes. Neither Scudder (1969) nor Hammer *et al.* (1975) mentioned ostracods in their faunal lists for various Canadian saline lakes.

Delorme (1969a) listed some selected Canadian ostracods with approximate tolerance limits to cations, anions, pH, TDS, O_2 and CO_2. In addition, he has provided me with an unpublished report recording ostracods in Canadian inland waters where TDS is greater than 5‰ (Delorme 1979). These results, based on numerous records, are listed and compared with some of his earlier data in Table 10.4. I am informed (Delorme, personal communication) that the values for *Megalocypris macra* given in Delorme (1969a) are incorrect. The form species marked with an asterisk in Table 10.4 are those which Delorme (1979) stated to be actively associated with precipitating Glauber's salt ($Na_2SO_4 \cdot 10\,H_2O$) and Epsom salts ($MgSO_4 \cdot 7\,H_2$) in Canada. It is interesting to note that in Europe at least one species of *Candona* (*C. natronophila* Petkovski 1969) is found in natron waters and another, *Limnocythere inopinata*, can tolerate high alkalinities (SBV:500) (Löffler 1959, 1961) and Hiller (1972).

Table 10.4 Records of ostracods in Canadian inland waters with high TDS values (based on Delorme 1969a, 1969b). Data as TDS ‰.

Species	Delorme (1969a)		Delorme (1979)	
	Min.	Max.	Min.	Max.
Cyclocypris sharpei			0.018	5.2
Candona compressa			0.017	5.4
Cyclocypris ampla			0.016	6.5
Potamocypris unicaudata			0.058	7.2
Cyclocypris serena			0.019	8.8
* *Cypridopsis glaucus*			0.031	18.8
* *Candona rawsoni*	0.141	42.8	0.0331	18.8
* *Limnocythere sappaensis*			0.066	19.4
* *Limnocythere staplini*	0.149	19.9	0.122	205.5
Candona renoensis	0.097	6.1		
Ilyocypris gibba	0.099	3.1		
Megalocypris macra	0.368	6.5		
Megalocypris ingens	found in saline water bodies (Delorme 1969a)			

* See text.

No ostracod in Delorme's lists belongs to a marine genus. The record of *Limnocythere staplini* at a TDS value of 205.5‰ (Delorme 1979) is the highest value to have been reported so far for an ostracod.

United States

Recorded knowledge of ostracods found in athalassic saline waters in the United States is scant. Once more, ostracods have largely been ignored in faunal lists of crustaceans found in the saline lakes and playas common in parts of that country.

Ferguson (1967) described the new species *Pelocypris tuberculata* (Ferguson 1967) from the West Playa Lake, Roosevelt County, New Mexico, and another, *Cypriconcha gnathostoma* Ferguson 1967, from East Playa Lake. Sublette and Smith Sublette (1967) recorded the two species in both playas, but it appears that the water was fresh at the time of collecting. *C. gnathostoma* was only once recorded in a locality where the specific conductivity was 12 000 μS. No additional information can be extracted from that paper as the two species are not separated in the ecological discussion.

Heterocypris incongruens has been collected from the Death Valley region (sample given to me by Prof. H. Dumont) where the water was 'saline'.

Keyser (1977) in his study of the ecology of ostracods from a mangrove area in south-west Florida obtained some interesting salinity data. Most, however, refer to typically brackish ostracods and the data cannot therefore be used. However, nine species found at salinities of 3‰ or above belong to freshwater genera.

South America

No data are available despite the fact that there are many salt lakes on that continent, especially in the high Andes in Chile.

Australia

Most data are unpublished. The records presented here are derived from collections sent me for identification and accompanied by salinity data, and from my own collections from the southern part of Australia. Some also form part of faunal studies of various regions (Geddes *et al.* 1981; De Deckker & Geddes 1980; Williams 1978). All new records for Australian ostracods are found in Table 10.2.

Two groups of ostracods appear in that list:

(1) the following genera endemic to Australia: *Australocypris, Mytilocypris, Trigonocypris, Platycypris, Diacypris* (one species has been recorded in New Zealand), *Reticypris* and a new genus from Western Australia (see Geddes *et al.* 1981). All these genera belong to the superfamily Cypridacea which includes most freshwater ostracods, but none of the Australian genera mentioned seems to have freshwater ancestors. Apart from one species, *Trigonocypris timmsi* (only recorded once), all are presently halobionts. Such a phenomenon appears to be unique to Australia, and could be a direct result of the Pleistocene history (at least) in Australia where arid climates were common and where, as a result, salt lakes must have always been present and more abundant than freshwater ones.

(2) a group of either cosmopolitan euryhaline species or halobionts allied to freshwater genera. The cosmopolitan species *Sarscypridopsis aculeata, Ilyocypris australiensis, Eucypris virens* plus *Ilyocypris* sp., *Heterocypris* sp., *Limnocythere mowbrayensis* are euryhaline, whereas *Cyprinotus edwardi,* which belongs to a freshwater genus typical of temporary waters, is known at present to be a halobiont. (A new genus '*Chlamydotheca*' is also euryhaline and is recorded from Australian and New Zealand temporary waters which occasionally become saline.) *Cyprideis westraliensis*, of marine ancestry, was described by McKenzie (1978b). The salinity record for this species derived from Williams & Buckney (1976) relates to athalassic saline lakes, whereas Hartmann's records of this species under the synonym *C. australiensis* Hartmann 1978 is from estuaries in Western Australia. This ostracod and an undescribed species of *Leptocythere* are not recorded from ephemeral lakes in Australia; they are only found in athalassic permanent lakes or estuaries.

Thus, the Australian continent has a unique and endemic halobiont ostracod fauna which has no marine or known freshwater ancestry. Twenty-seven species are true halobionts; six genera have halobiont species only and these are endemic to Australia except for *Diacypris* which has one species in New Zealand. *Trigonocypris*, closely allied to *Australocypris, Mytilocypris* and the new

Western Australian genus, has one freshwater representative and one halobiont species. Only two species of 38 recorded from athalassic saline lakes are of known marine ancestry: *Cyprideis westraliensis* and *Leptocythere* sp.

New Zealand

Very few saline lakes exist in New Zealand and their ostracod fauna is consequently very poor. Bayly & Williams (1973) recorded one described species of *Diacypris* from a salt lake near Sutton in Otago (Jan. 1966 - 15‰ salinity). Chapman (in Chapman & Lewis 1976) mentioned that *Diacypris thomsoni* occurs in inland saline lakes in North Otago. It is likely that this is the species mentioned above by Bayly & Williams (1973).

Antarctica

No ostracods have been recorded from Antarctic saline lakes.

Epilogue

The term salinity ought to be defined by authors in their work dealing with athalassic saline waters to avoid future confusion. The terms 'brackish' and 'coastal pond' should be avoided when dealing with non-marine waters.

At present, ostracods cannot provide a biological classification of athalassic saline waters as there are no distinct physicochemical boundaries which precisely separate one group of ostracods from another. The arbitrary limit between freshwater and saline water (3‰ chosen here) crosses the range of salinity tolerance of many species. An attempt to plot such an arbitrary classification is even more difficult if one considers the additional effect of temperature on organisms.

A cosmopolitan group of ostracods, typically euryhaline and inhabiting temporary pools, is commonly found in athalassic saline waters which approach 3‰.

The Pontocaspian region is unique as it is characterized by inland 'seas' with an ostracod fauna consisting mainly of 'relict marine' forms with some freshwater species which became progressively adapted to changes of salinity during phases of isolation or connection between these 'seas' at least during the Pleistocene.

For other parts of the world, the athalassic saline lake ostracod fauna is generally of freshwater origin. Australia is an exception, as at least 5 endemic genera have no marine or known direct freshwater ancestors: this fauna is adapted to inhabit saline water only. Such a phenomenon is likely to result from a very long history of aridity in Australia. In Europe, 44 species are known from athalassic saline waters (5 are of marine ancestry); in Australia there are 37 (1 marine) species, North Africa 14 (1 marine) and Canada at least 13 (no marine). No ostracods of marine ancestry (i.e. which do not belong to genera including marine species today) are found in ephemeral saline lakes. This is because marine forms cannot withstand desiccation during the dry phase of ephemeral lakes. Only one ostracod of marine ancestry, *Cyprideis torosa*, is found in waters of salinities higher than that of sea water, whereas many non-marine species can tolerate high salinity values: the highest record is for *Limnocythere staplini* in Canada, viz. 205‰ TDS.

At present there is a need to describe and record the ostracod fauna from athalassic saline lakes in the following regions: Central and South Africa, China, Siberia, the United States, and Central and South America. This must be accompanied by salinity records.

There is also a need for osmoregulation studies, and studies of salinity tolerance and the effect of temperature on it.

Acknowledgements

I wish to thank Prof. W. D. Williams whose suggestion it was for me to prepare this review and for letting me use his reprint library. I am also grateful to Prof. G. Hartmann and Mr. H. H. Petersen for allowing me to use the ostracod card index and reprint collection held at the University of Hamburg. They also provided me with excellent xeroxing facilities. My thanks also go to Dr. L. D. Delorme for his correspondence and for providing me with a report on Canadian ostracods. Drs. J. Armengol and D. L. Danielopol sent me each a very valuable reprint. I also profited from discussions with Dr. K. G. McKenzie.

Finally my data on Australian ostracods could not have been completed without the ostracod collections sent to me by the following people: I. A. E. Bayly, M. C. Geddes, S. A. Halse, D. Hembree, D. Morton, B. V. Timms, M. Topping, W. D. Williams.

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