DISTRIBUTION AND ECOLOGY OF *GAMMARUS TIGRINUS* SEXTON, 1939 AND SOME OTHER AMPHIPOD CRUSTACEA NEAR BEAUFORT (NORTH CAROLINA, U.S.A.)

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SUMMARY

During summer 1977 the distribution and ecology of amphipod Crustacea in the coastal plain of north Carolina were studied. Ecological data were collected in particular on *Gammarus tigrinus*, a North American species, which has been introduced in western Europe. The present gammarid, able to endure high water temperatures and adapted to a wide variety of salinities, is found in the more upstream parts of the estuaries in North Carolina. More downstream, at higher salinities, it is replaced by *Gammarus palustris*, while at very low salinities or in fresh water *Gammarus fasciatus* is commonly met.

Moreover, some data are given on the distribution and ecology of several other amphipod species in the Beaufort region.

RÉSUMÉ

Pendant l'été 1977 la répartition écologique de Crustacés amphipodes a été étudiée dans la plaine littorale de Caroline du Nord. Des observations furent effectuées en particulier sur l'écologie de *Gammarus tigrinus*, espèce nord-américaine introduite en Europe. Ce Gammare, capable de résister à des températures élevées et adapté à des salinités très variables, est trouvé dans les parties plus en amont des estuaires de Caroline du Nord. Plus en aval, dans les eaux méso- et polyhalines, *Gammarus tigrinus* est remplacé par *Gammarus palustris*, tandis que dans les eaux douces et oligohalines *Gammarus fasciatus* est couramment rencontré.

En plus, cette étude a fourni des données sur la répartition et l'écologie de plusieurs autres espèces d'Amphipodes dans la région de Beaufort.

INTRODUCTION

During summer 1977 the distribution and ecology of amphipod crustaceans was investigated in the coastal plain of North Carolina. The present study was carried out during a stay at the Duke University Marine Laboratory at Beaufort. Amphipod samples were taken in estuaries and freshwater biotopes in the Beaufort region to collect data on the ecology of *Gammarus tigrinus* in particular. This species, originally inhabiting the eastern coast of North America, has at some time been introduced in western Europe and was first described from England by Sexton (1939). *Gammarus tigrinus* has rapidly invaded nearly all oligohaline waters in the Netherlands, competing successfully with the indigenous gammarid species. Its range extension, still proceeding, has been surveyed by members of the Institute of Taxonomic Zoology of the University of Amsterdam, resulting in a series of publications (Nijssen & Stock, 1966; Pinkster & Stock, 1967; Dennert et al., 1968; Gras, 1971; Smit, 1974; Pinkster, 1975; Dieleman & Pinkster, 1977).

STUDY AREA AND METHODS

The small town of Beaufort, situated on a tongue of mainland, is separated by water from the sandy offshore bank, known as Shackleford Bank. Access to the open ocean is gained by the Beaufort Inlet. The various waterways, which communicate directly or indirectly with Beaufort, are very complicated in shape and contain a large number of shoals, banks and islands.

While offering a variety of sandy and muddy substrates, no true natural rocks are found in the Beaufort region. Hard substrates are formed by jetties, sea walls, pilings, oyster shells and by miscellaneous man-made objects (bottles, beer cans, etc.). The coastal area of the mainland is characterized by extensive *Spartina* marshes. The mean tidal range is 0.75 m (about 0.9 m for spring tides).

The estuary of the Newport River [1]), a wide

[1]) Irrespective of the salinity or current, the water types in the area are locally called "rivers".

bay with polyhaline salinities, is connected by the Adam Creek Canal with the Neuse River. In summer, the freshwater supply of the latter is low to such an extent that marine influences are still measurable as far as New Bern, a town situated at almost 100 km from where the Neuse River discharges into the Pamlico Sound.

The vegetation of the river swamps of the coastal plain is characterized by the River-cypress (*Taxodium distichum*), growing in shallow water, often over a calcareous subsoil. This tree has a trunk gradually tapering near the base and root formations, which often provide the only hard substrate in the more upstream parts of the North Carolina estuaries.

Sampling of the amphipods was carried out with a dip net. As far as temperature readings have been made, a mercury thermometer was used (scale in 0.1°C). Salinities were measured with the aid of a refractometer. The pH was determined with a pH-meter "Leeds & Northrop".

The animals were fixed in 4% formaldehyde and preserved in 70% ethanol.

In appendix II the position of the sampling stations, visited during the present study, is given.

RESULTS

Fig. 1 shows the names of the amphipod species sampled at different localities in the estuary of the Neuse River, as well as the salinities measured at these stations. Near the bridge on highway 43, S.W. of Askin, gammarids still occurred, but more upstream, near Kinston, none have been found. The great majority of the Neuse River stations presented a sandy substrate. Only in those places where some hard substrate was available (mostly provided by the roots of the River-cypress) gammaridean Amphipoda were captured in the wave-washed zone of the river.

The temperature of the water varied from 18.5°C in May to 34°C in August, while the pH-range was 6.3-7.3.

Both stations sampled in the Trent River, a tributary of the Neuse River, yielded *Gammarus tigrinus* Sexton, 1939 (salinities 1 and 2$^0/_{00}$). Substrate, temperatures and pH in this stream resemble to a large degree those of the Neuse River estuary.

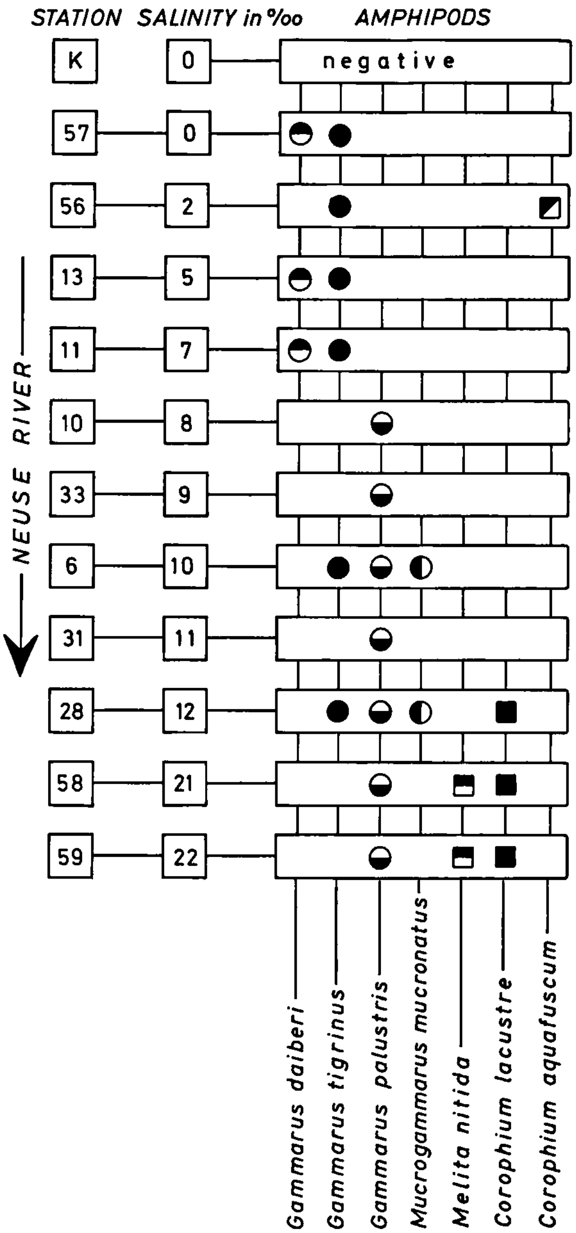

Fig. 1. Salinities and amphipods at the sampling stations in the Neuse River (station K = Kinston).

In another tributary, the South River (discharging in the Neuse River about 50 km downstream of New Bern), *Gammarus palustris* Bousfield, 1969, occurred at a salinity of 12$^0/_{00}$ and, together with *Mucrogammarus mucronatus* (Say, 1818), at a salinity of 18$^0/_{00}$. These amphipods were captured amongst submerged parts of the riverbank vegetation, on a bottom consisting of clay and mud.

Appendix I enumerates the amphipod species found during the present study, as well as the conditions at their sampling stations.

The following amphipods have been collected:

Family GAMMARIDAE (s.l.)

Gammarus tigrinus Sexton, 1939

Besides in the Neuse and Trent Rivers, *Gammarus tigrinus* was found in the White Oak River (fig. 2), discharging in the Bogue Sound near Swansboro, and in the Bay River (sta. 61), a tributary of the Pamlico Sound. During the present investigation this species was sampled at salinities varying from 0 to 12$^0/_{00}$ (only once it was found at 22$^0/_{00}$), always on sandy substrates, among roots of the River-cypress. In some localities *G. tigrinus* occurred together with other amphipods: In the Neuse River (figs. 1 & 2), near New Bern, together with *Gammarus daiberi* Bousfield, 1969 and *Corophium aquafuscum* Heard & Sikora,

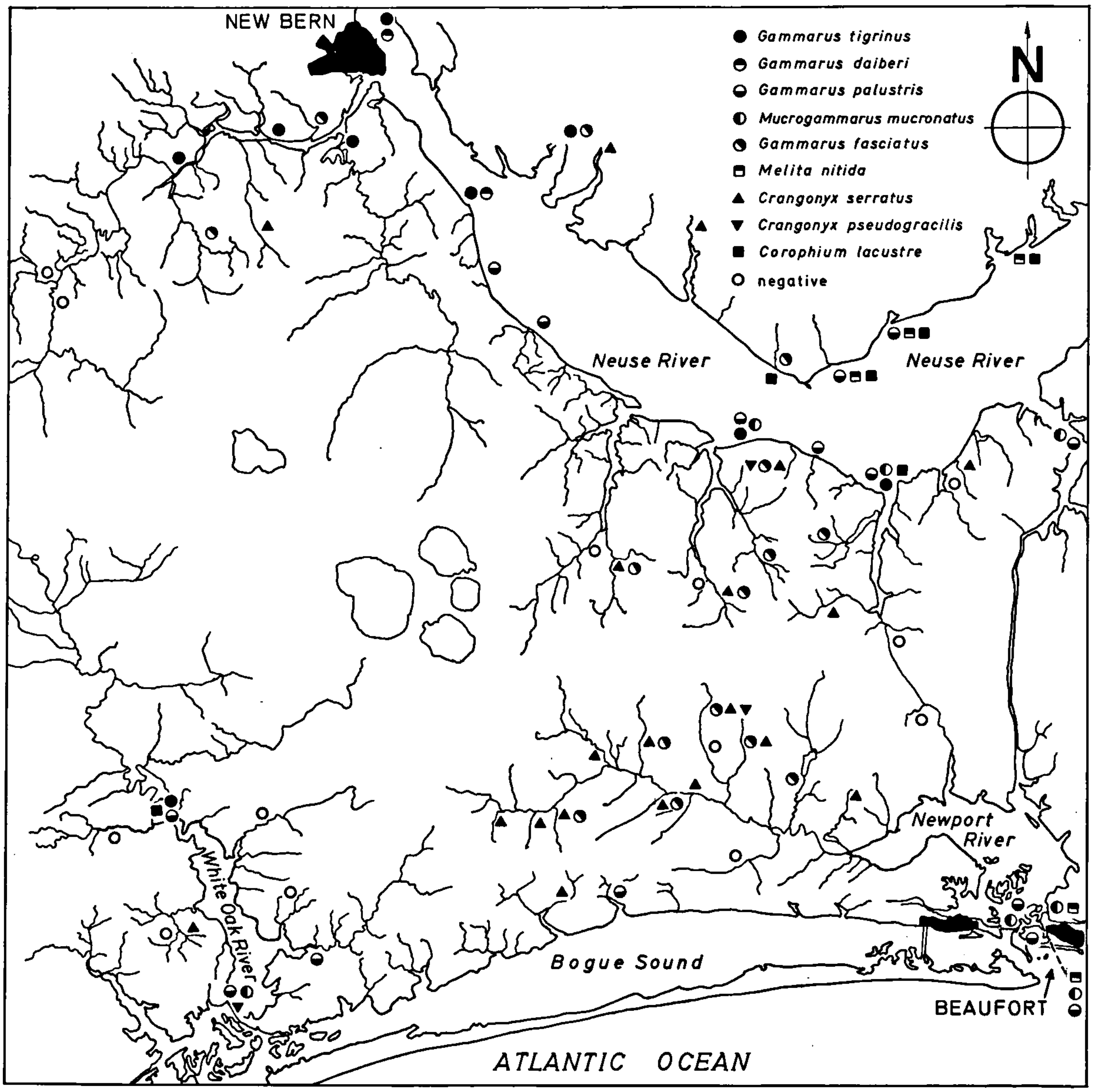

Fig. 2. Distribution of the amphipod species N.W. of Beaufort.

1972, at a salinity of $2^0/_{00}$; more downstream, at a salinity of $12^0/_{00}$, the sample contained also *Corophium lacustre* Vanhöffen, 1911, *Mucrogammarus mucronatus* (Say, 1818) and *Gammarus palustris* Bousfield, 1969; near Cherry Point (sta. 6), the latter two occurred together with *G. tigrinus* at a salinity of $10^0/_{00}$; in the White Oak River, at a salinity of $1^0/_{00}$, only single specimens of *G. palustris* and *C. lacustre* were sampled together with *G. tigrinus.*

Ovigerous females of *G. tigrinus* occurred in a sample taken in June (salinity $1^0/_{00}$, temp. 25.5°C).

Gammarus daiberi Bousfield, 1969

Gammarus daiberi, a species closely related to *Gammarus tigrinus*, occurred with the latter in the samples from the head of the Neuse River estuary, at salinities varying from 0 to $7^0/_{00}$.

Gammarus fasciatus Say, 1818

Gammarus fasciatus was collected mainly in moderately running streams and sometimes in slowly running or stagnant water. Water temperatures varied from 15.5 to 27°C, the pH from 5.6 to 7.5, and the salinity values in places where *G. fasciatus* occurred did not exceed $5^0/_{00}$. It lives in shallow freshwater streams or small marshy ponds (together with *Crangonyx serratus* (Embody, 1910)), varying in depth from 0.3 m to a few meters, among submerged parts of the marsh vegetation, on a sandy or muddy bottom.

In May and June ovigerous females of *G. fasciatus* have been observed.

Gammarus palustris Bousfield, 1969

Gammarus palustris [2]) is a very common species in the meso- and polyhaline waters around Beaufort. This gammarid, found at salinities of 8 to $36^0/_{00}$ (exceptionally at $1^0/_{00}$, vide supra), mostly occurred on a sandy substrate in the *Spartina* marshes or sometimes among marine algae (viz., *Fucus vesiculosus, Ulva, Chaetomorpha*). In some places, devoid of such a vegetation, *G. palustris* was collected amongst oyster shells or tree roots.

While collecting, the present species was easily recognized by its particular behaviour: the shrimps climbed out of the water (in the vial) and were able to "rise to their feet", like beachhoppers (Talitridae) use to do.

Ovigerous females and/or precopulae were found from May to August.

Mucrogammarus mucronatus (Say, 1818)

Mucrogammarus mucronatus occurred sometimes, together with *Gammarus palustris*, in the *Spartina* marshes, but never at salinities lower than $10^0/_{00}$. On muddy substrates, mixed with cobbles and shells, the present gammarid was found together with *Melita nitida* Smith, 1873 (viz., the Towncreek at Beaufort). In that case the vegetation consisted of *Ulva, Fucus vesiculosus* or *Chaetomorpha.* The salinities measured for *Mucrogammarus mucronatus* varied from 10 to $32^0/_{00}$.

Ovigerous females of the present species occurred in a sample collected in May.

Crangonyx serratus (Embody, 1910)

Crangonyx serratus seems to prefer stagnant water of small marshy ponds, although it sometimes occurs in running water, not rarely together with *Gammarus fasciatus.* The salinities at stations with *Cr. serratus* varied from 0 to $5^0/_{00}$. When alive, the present amphipod shows a characteristic milky white colour.

In May ovigerous females of *Cr. serratus* were observed.

Crangonyx pseudogracilis Bousfield, 1958

At two localities in freshwater biotopes, besides *Gammarus fasciatus* and *Crangonyx serratus, Crangonyx pseudogracilis* occurred among the marsh vegetation, on a bottom of sand and mud. Both samples, collected in May, contained ovigerous females.

Melita nitida Smith, 1873

Melita nitida was found mainly in the lower reaches of estuaries or in the tidal zone along the coast

[2]) Dr. E. L. Bousfield informed me (in litt., 9 May 1978) that my "*Gammarus palustris*" material consists of two distinct species: true *G. palustris*, occurring at the higher salinities, and a new species of gammarid, the description of which is soon to be published by him.

of the mainland of North Carolina. This amphipod was collected in muddy or sandy places, among marine algae (*Fucus vesiculosus*), in the *Spartina* marshes or under oyster shells. Downstream in the Neuse River estuary it occurred together with *Gammarus palustris* and *Corophium lacustre* (fig. 1).

In May ovigerous females of the present species were found at a salinity of 32‰.

Family COROPHIIDAE

Corophium lacustre Vanhöffen, 1911

Corophium lacustre was collected in the wave-washed zone of rivers, at salinities varying from 1 to 20‰, on sandy substrates or in burrows in dead tree stumps.

In August ovigerous females were found.

Corophium aquafuscum Heard & Sikora, 1972

Corophium aquafuscum occurred in the Neuse River (upstream of New Bern) in stagnant water at a salinity of 2‰, the substrate consisting of sand, debris and tree roots.

Besides the sampling stations in the coastal plain of North Carolina, some waters more inland, near Chapell Hill, were visited, which yielded no amphipods, apart from a few specimens of *Hyalella azteca* De Saussure, 1857 (family Hyalellidae), collected in a dammed creek, called Hogans Pond (Orange County).

DISCUSSION

Fox & Bynum (1975) mention *Gammarus tigrinus* to be very abundant in the oligohaline areas of the Neuse River. Boesch & Diaz (1974) and Bousfield (1973) found the present species in the oligo- and mesohaline waters of upper Chesapeake Bay and its tributary estuaries. The results obtained during the present study extend the distribution of *G. tigrinus* southward into the headwaters of Pamlico Sound and Bogue Sound in North Carolina.

G. tigrinus shows a wide salinity range as has been demonstrated also by the experiments of Dorgelo (1974, 1975). Not only was it found at widely different salinities in North Carolina, it appeared to be very tolerant to high water temperatures as well (34°C during August!). According to Hynes (1955), *G. tigrinus* seems adapted to a climate with warm summers and springs characterized by a rapid rise in temperature. Such marine climatic conditions prevail along the coastal plain of North Carolina: in the Neuse River estuary a rapid rise in temperature takes place in early spring, while the water temperature attains rather high values during summer (fig. 3).

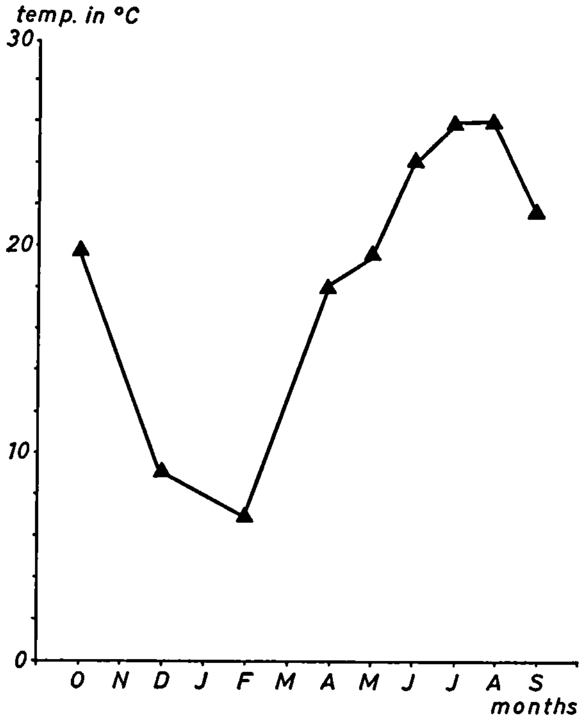

Fig. 3. Yearly temperature cycle in the Neuse River near New Bern (after data by Phibbs, 1969).

Steele & Steele (1975) mention *G. tigrinus* to be more successful in the southern parts of the United States (more generations per year at higher temperatures), than in the North. Salinity preference experiments by Dorgelo (1975) proved that *G. tigrinus* is distinctly selective towards salinity at lower temperatures, while at a temperature of 25°C the results are very variable. According to Pinkster (1975), the ability of the present gammarid to reproduce at high temperatures, while salinity is reduced, explains its success in competing the indigenous gammarids in the Netherlands. Although the mixohaline species

Gammarus zaddachi Sexton, 1912 and *G. duebeni duebeni* Liljeborg, 1852, can reproduce throughout the year provided that the salinity is high enough, they are unable to do so when the salinity drops to the level prevailing in most biotopes inhabited by *G. tigrinus*. Under suboptimal salinity conditions, *G. zaddachi* and *G. d. duebeni* are only able to reproduce at low temperatures.

In North Carolina the salinities established for *G. tigrinus* vary from 0 to 12$^0/_{00}$. The present species was found only in larger streams, often in stagnant or very slowly running waters. Never has it been found in smaller freshwater creeks, where *G. fasciatus* was commonly met. More downstream in estuaries *G. tigrinus* is replaced by *G. palustris*. A similar distribution pattern was established for *G. tigrinus* in the northern parts of the U.S.A. by Steele & Steele (1972), where the distribution of this gammarid seems to be limited by the presence of *G. fasciatus* upstream, and seawards by *G. lawrencianus* Bousfield, 1956, a very common species in the tidal zone from Newfoundland to Connecticut. In view of the situation described above, it is interesting to see that in the Netherlands *G. tigrinus* does neither invade running fresh waters, where *Gammarus pulex pulex* (Linnaeus, 1758) thrives, nor waters of higher salinities in which it is apparently unable to compete with *G. zaddachi* and *G. duebeni* (Pinkster et al., 1977).

— *Gammarus daiberi* and *Gammarus tigrinus* resemble to such an extent that the former was only recently recognized as a distinct species. Although both gammarids can easily be recognized in the Delaware and Chesapeake region, material from the southeastern states shows overlapping of characters to a large degree (Bousfield, 1969). Thanks to the kindness of Dr. E. L. Bousfield to check the present samples of *Gammarus tigrinus*, the presence of *Gammarus daiberi* could be detected in the samples from the most upstream parts of the Neuse River estuary. It occurred together with *G. tigrinus* at salinities varying from 0 to 10$^0/_{00}$. This is in agreement with the data of Ristich et al. (1977), who found *G. tigrinus* and *G. fasciatus* to be the most common amphipods in the freshwater zones of the Hudson River estuary, while in the oligo- and mesohaline reaches *G. tigrinus* occurred together with *G. daiberi*. In the Delaware and Chesapeake Bays the latter species is most abundant in the head of the estuaries at salinities ranging from 1 to 5$^0/_{00}$ (Bousfield, 1969). According to Feeley & Wass (1971) *G. daiberi* occupies the niche between *G. fasciatus* and the mesohaline *G. tigrinus*.

— *Gammarus fasciatus* was found to occur in the freshwater creeks discharging in the Neuse and Newport Rivers (fig. 2). According to Bousfield (1958) and Holsinger (1972) *G. fasciatus* lives in lakes as well as in large rivers, biotopes in which it was never observed in the Beaufort region.

— The occurrence of *Gammarus palustris* in the *Spartina* marshes of North Carolina was already recorded by Fox & Bynum (1975) and Cammen (1976). Also near its northern distribution limit, in New Hampshire, this gammarid was mentioned to occur in *Spartina* banks (Gable & Croker, 1977). The observations concerning its presence among marine algae confirm the data by Watling & Maurer (1972). The substrate preference experiments of Van Dolah (in press), who studied *G. palustris* from the salt marshes in the Chesapeake region, indicate a strong behavioural preference of this species for *Spartina* culms.

Bousfield (1973) records an optimal salinity range for *G. palustris* of 5-20$^0/_{00}$, but mentions that it is also able to survive, for shorter periods, in fresh water (at low temperatures) or in seawater (at high temperatures). During summer 1977, it was found at salinities varying from 0$^0/_{00}$ (temp. 20°C) to 36$^0/_{00}$ (temp. 30°C). Although *G. palustris* occurred at very low salinities, it was never observed in permanent fresh water.

The semi-terrestrial behaviour of *G. palustris*, as observed during the present study, is in agreement with the observations by Bousfield (1973), who mentions it to remain hidden in moisty places (under stones, debris and among *Spartina*), when the tide is out.

— In agreement with the data by Watling & Maurer (1972), *Mucrogammarus mucronatus* was found in the more sheltered places of the tidal zone.

On comparing *M. mucronatus* from the Beaufort region with specimens from Louisiana (in the collection of the Smithsonian Institution in Washington), the dorsal mucronations shown by the former animals are weakly developed, while those in the southern samples possess very pronounced dorsal elevations. Bousfield (1969) refers to *M. mucronatus*, originating from the coastal region of the southeastern states, as "micromucronate forms". Barnard & Gray (1968) also mention the variation in development of the pleonal teeth in the present species and state that it might reflect variations in physical factors or genetic isolation. A similar variability of the dorsal processes is recorded by Karaman & Pinkster (1977) for members of the *Gammarus roeseli*-group, which are, like *M. mucronatus*, characterized by the presence of dorsal mucronations on the metasome segments.

— Embody (1910), describing *Crangonyx serratus* for the first time, mentions it from a pond in Virginia. Bousfield (1958) indicates its occurrence in sloughs, ponds and ditches in Virginia, South Carolina and northern Florida. During the present investigation *Cr. serratus* was not only found in stagnant water, but has been observed in slowly and moderately running waters as well.

— In addition, *Crangonyx pseudogracilis* was found to occur in North Carolina. Holsinger (1972) supposed it to occur as far south as the Mississippi stream system, but remarks that *Cr. pseudogracilis* might be a complex of, very closely related, but different species.

— In agreement with the present results, Watling & Maurer (1972) found *Melita nitida* in polyhaline and marine localities, under oyster shells, a habitat mentioned also by Thomas (1976) for this species, in Louisiana.

— In the lower reaches of the Neuse River estuary, *Corophium lacustre* was commonly met. According to Bousfield (1973) this amphipod occurs from almost fresh water up to salinities as high as 25‰. Although mostly encountered in mesohaline waters, during the present study *C. lacustre* was found once at a salinity of 1‰, upstream in the White Oak River estuary (fig. 2).

— *Corophium aquafuscum*, found during the present study in the Neuse River, upstream of New Bern, at a salinity of 2‰, was recorded earlier from a nearby locality by Bynum & Fox (1977). They collected this amphipod under freshwater conditions, the vegetation consisting of River-cypress and *Spartina*.

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APPENDIX I

Amphipod species and environmental conditions at the sampling stations visited near Beaufort (the position of these stations is given in appendix II).

(A) *GAMMARUS TIGRINUS*

Station	Temp. (°C)	pH	Salinity (‰)	Substrate	Vegetation	Remarks
6	30		10	sand + wood	*Chaetomorpha*	among tree roots and in wood burrows
11	18.5	7.1	7	sand + shells + wood	—	in wave-washed zone; among tree roots
12	22	7.1	5	sand + detritus	riverbank vegetation	few gammarids
13	23	6.9	5	sand + wood	—	in wave-washed zone; among tree roots
28	24	7.1	12	sand + clay	*Spartina*	in wave-washed zone
34	25.5	6.8	1	mud + detritus	*Sagittaria*	slowly running brown water; ovigerous ♀♀
37	24	7.1	2	clay + detritus	riverbank vegetation	
46	26.5	6.5	1	sand + detritus	riverbank vegetation	
56	34	6.3	2	sand + detritus + wood	riverbank vegetation	stagnant water; among tree roots
57	29.5	7.2	0	sand + wood	—	slowly running water; precopulae
61	33	7.8	22	mud + detritus	riverbank vegetation	very few gammarids

Station	Temp. (°C)	pH	Salinity (‰)	Substrate	Vegetation	Remarks
(B) *GAMMARUS DAIBERI*						
11	18.5	7.1	7	sand + shells + wood	—	in wave-washed zone; among tree roots
13	23	6.9	5	sand + wood	—	in wave-washed zone; among tree roots
57	29.5	7.2	0	sand + wood	—	slowly running water
61	33	7.8	22	mud + detritus	riverbank vegetation	very few gammarids
(C) *GAMMARUS FASCIATUS*						
14	18.5	6.9	0	mud	riverbank vegetation	stagnant brown water; ovigerous ♀♀
20	15.5	7.5	0	sand + detritus + wood	—	moderately running water; ovigerous ♀♀
21		7.4	0	sand + mud	riverbank vegetation	moderately running water; ovigerous ♀♀
22	15	6.8	0	sand + mud	marsh vegetation	moderately running water; ovigerous ♀♀
23		7.1	0	sand + detritus	—	slowly running water
27	20	6.8	0	sand + mud	marsh vegetation	moderately running water; ovigerous ♀♀
29	21	7.0	0	mud	marsh vegetation	slowly running water
30	20.5	6.9	1	sand + mud	marsh vegetation	stagnant water; precopulae and ovigerous ♀♀
32	22.5	6.7	1	mud + detritus	marsh vegetation	slowly running water
36	20	6.5	1	sand + mud	riverbank vegetation	moderately running brown water
38	20	7.2	0.5	clay	marsh vegetation	moderately running water; many gammarids; precopulae and ovigerous ♀♀
39	18.5	6.9	5	sand + detritus	—	moderately running water; precopulae and ovigerous ♀♀
43	23	6.6	0.5	sand	marsh vegetation	moderately running brown water; precopulae
52b	25	6.6	0	sand + shells	—	moderately running water
55	27	5.6	0	mud	marsh vegetation	moderately running water
(D) *GAMMARUS PALUSTRIS*						
1				sand + mud + shells	*Fucus vesiculosus*	under shells, on rather dry substrate
2				sand + cobbles	*Ulva*	under cobbles
3	23		12	clay + detritus	riverbank vegetation	moderately running water
4	23		12	clay + detritus	riverbank vegetation	slowly running water; precopulae
5	23		12	clay + detritus	*Chaetomorpha*	slowly running water
6	30		10	sand + wood	*Chaetomorpha*	in wave-washed zone; among tree roots
10	20	7.3	8	sand	riverbank vegetation	in wave-washed zone; precopulae
17		7.5	32	mud + detritus	*Spartina*	slowly running water; precopulae
18	22	6.9	15	mud + detritus	*Spartina*	slowly running water; very few gammarids
25	24.5	6.9	15	sand + wood	—	in wave-washed zone; among tree roots; ovigerous ♀♀
28	24	7.1	12	sand + clay	*Spartina*	in wave-washed zone; precopulae and ovigerous ♀♀
31	26	6.8	11	sand + wood	—	in wave-washed zone; among tree roots and other wood
33	25.5	6.6	9	sand + wood	—	in wave-washed zone; among wood
44a		7.5	34	sand	*Spartina*	stagnant water; precopulae
44b	26.5	6.9	29	sand + shells	*Spartina*	—
46	26.5	6.5	1	sand + detritus	riverbank vegetation	very few gammarids; slowly running water
47	30	6.3	31	sand + clay + shells	*Spartina*	in wave-washed zone; precopulae
48	29	6.9	29	clay	*Spartina, Salicornia*	stagnant water
49	34	6.9	32	mud	*Spartina*	stagnant water
50	32.5	7.1	31	mud + sand + shells	*Ulva*	stagnant water
51	29.5	6.6	22	sand	*Spartina*	slowly running water
58	30	7.1	21	sand + wood	—	among tree roots
59	30		20	sand + detritus + wood	*Spartina*	—
62	35	7.3	24	sand + detritus + shells	—	stagnant water; precopulae

Station	Temp. (°C)	pH	Salinity (⁰/₀₀)	Substrate	Vegetation	Remarks
63	30	7.7	36	sand	*Spartina*	precopulae
64	29.5	7.8	18	sand	*Spartina*	precopulae and ovigerous ♀ ♀
(E) *MUCROGAMMARUS MUCRONATUS*						
1				sand + mud + shells	*Fucus vesiculosus*	under shells, on a rather dry substrate
2				sand + cobbles	*Ulva*	under cobbles
5	23		12	clay + detritus	*Chaetomorpha*	slowly running water
6	30		10	sand + wood	*Chaetomorpha*	in wave-washed zone, among tree roots; ovigerous ♀ ♀
7			32	sand + clay + shells	*Ulva*	under oyster shells
25	24.5	6.9	15	sand + wood	—	in wave-washed zone, among tree roots
28	24	7.1	12	sand + clay	*Spartina*	in wave-washed zone
44b	26.5	6.9	29	sand + shells	*Spartina*	—
47	30	6.3	31	sand + clay + shells	*Spartina*	in wave-washed zone
49	34	6.9	32	mud	*Spartina*	stagnant water
50	32.5	7.1	31	mud + sand + shells	*Ulva*	stagnant water
(F) *CRANGONYX SERRATUS*						
8	16	6.7	1	clay + detritus	—	stagnant brown water; ovigerous ♀ ♀
15		7.2	0	mud	marsh vegetation	—
19	15.5	7.1	0	mud + detritus	marsh vegetation	stagnant water; ovigerous ♀ ♀
20	15.5	7.5	0	sand + detritus + wood	—	moderately running water
22	15	6.8	0	sand + mud	marsh vegetation	moderately running water
24		6.8	0	mud + detritus	—	stagnant water
26	21	6.9	0	mud + detritus	marsh vegetation	stagnant, muddy water
29	21	7.0	0	mud	marsh vegetation	slowly running water
30	20.5	6.9	1	sand + mud	marsh vegetation	stagnant water
32	22.5	6.7	1	mud + detritus	marsh vegetation	slowly running water
35	21	6.9	1	clay + detritus	*Sagittaria*	slowly running water
39	18.5	6.9	5	sand + detritus	—	moderately running water
40	19.5	6.6	0.5	mud + detritus	riverbank vegetation	stagnant water
41	20	6.2	1	sand + mud + detritus	—	stagnant water
42	20	6.9	1	sand	riverbank vegetation	moderately running water
43	23	6.6	0.5	sand	marsh vegetation	moderately running water
45	21	6.9	1	mud	marsh vegetation	moderately running water
53	27	5.9	0.5	mud	marsh vegetation	stagnant water; few gammarids
54	27	5.6	1	mud	—	moderately running water
55	27	5.6	0	mud	marsh vegetation	moderately running water
(G) *CRANGONYX PSEUDOGRACILIS*						
22	15	6.8	0	sand + mud	marsh vegetation	moderately running water; ovigerous ♀ ♀
30	20.5	6.9	1	sand + mud	marsh vegetation	stagnant water
(H) *MELITA NITIDA*						
1				sand + mud + shells	*Fucus vesiculosus*	under shells, on a rather dry substrate
7			32	sand + clay + shells	*Ulva*	under oyster shells; ovigerous ♀ ♀
44b	26.5	6.9	29	sand + shells	*Spartina*	—
47	30	6.3	31	sand + clay + shells	*Spartina*	in wave-washed zone
50	32.5	7.1	31	sand + clay + shells	*Ulva*	stagnant water
58	30	7.1	21	sand + wood	—	in wave-washed zone
59	30		20	sand + cobbles + shells	*Spartina*	—
60	33	6.9	20	sand + mud + wood	—	in wave-washed zone
62	35	7.3	24	sand + detritus + shells	—	stagnant water; few gammarids
(I) *COROPHIUM LACUSTRE*						
28	24	7.1	12	sand + clay	*Spartina*	in wave-washed zone
46	26.5	6.5	1	sand + detritus	—	slowly running water
52a	31	6.4	11	sand + shells + wood	—	in wave-washed zone
58	30	7.1	21	sand + wood	—	in wave-washed zone
59	30		20	sand + cobbles + wood	*Spartina*	in wave-washed zone; ovigerous ♀ ♀
60	33	6.9	20	sand + mud + wood	—	in wave-washed zone; ovigerous ♀ ♀
(J) *COROPHIUM AQUAFUSCUM*						
56	34	6.3	2	sand + detritus + wood	riverbank vegetation	stagnant water

APPENDIX II

Position of the sampling stations as mentioned in fig. 1 and appendix I. The stations marked with an asterisk are not included in the map (fig. 2).

Station	Date (1977)	Position	County
1	3-V	Beaufort, beach E. of bridge near Pivers Island	Carteret
2	3-V	Newport River, left bank upstream of bridge on highway 70	Carteret
*3	4-V	South River, left bank near village South River	Carteret
*4	4-V	South River, right bank	Carteret
*5	4-V	South River, left bank, about 50 m downstream of jetty of D.U.M.L. boat	Carteret
6	5-V	Neuse River, right bank upstream of landing stage of Cherry Point ferry	Carteret
7	8-V	Beaufort, Towncreek, midway bridge and town	Carteret
8	10-V	tributary of Newport River, Newport, near bridge on highway 70	Carteret
9	10-V	Southwest Prong, N.W. of Havelock, highway 70	Craven
10	10-V	Neuse River, right bank near Fisher Landing, N.E. of Riverdale	Craven
11	10-V	Neuse River, right bank near Thurman, S.E. of New Bern	Craven
12	10-V	Trent River, left bank, S.W. of New Bern	Craven
13	10-V	Neuse River, left bank, upstream of bridge near New Bern	Craven
14	10-V	Cahooque Creek, E. of Havelock, near bridge on road to Cherry Point	Craven
15	10-V	Mortons Mill Pond, N.W. of Harlowe, near bridge on highway 101	Craven
16	10-V	Harlowe Creek, near Harlowe Church, N. of Morehead City	Carteret
17	13-V	Gale Creek, Bogue Sound, upstream of bridge on highway 24	Carteret
18	13-V	Pettiford Creek, N.E. of Swansboro, upstream of bridge on highway 58	Carteret
19	13-V	small stream discharging in Broad Creek (Knoll) near bridge on highway 1124	Carteret
20	15-V	Cedar Swamp, W. of Newport, near bridge on highway 1140 (Roberts Road)	Carteret
21	17-V	Little Deep Creek near Union Point, N.E. of Newport	Carteret
22	17-V	Deep Creek, N. of Newport, near bridge on loop road	Carteret
23	17-V	Black Creek near Mill Pond, E. of Newport, near bridge on highway 1154	Carteret
24	17-V	Little Creek Swamp, E. of Newport, near bridge on highway 1154	Carteret
25	20-V	Adams Creek, left bank, where road from Harlowe ends in Great Neck	Craven
26	20-V	Great Neck Creek, S.W. of Type	Craven
27	25-V	Mitchell Creek, near Piney Grove Church, bridge on highway 1711	Craven
28	25-V	Neuse River, right bank, near Temple, mouth of Clubfoot Creek	Craven
29	25-V	Hancock Creek, E. of Havelock, near bridge on highway 101 (New Bern Road)	Craven
30	31-V	small stream discharging in Neuse River, near Cherry Point	Craven
31	31-V	Neuse River, right bank, near Shade View Beach, downstream of Neuse River ferry	Craven
32	31-V	East Prong near Havelock, highway 101	Craven
33	3-VI	Neuse River, right bank, Flanner Beach, near camping ground of Croatan National Forest	Craven
34	3-VI	Brice Lees Brook, near Trent River, S.W. of New Bern	Craven
35	3-VI	Ready Brook, near bridge on highway 1004, S.W. of New Bern	Craven/Jones
36	3-VI	Island Creek, N.E. of Pollocksville, near bridge on highway 1004 (Island Creek Road)	Jones
37	3-VI	Trent River, near Mussy Cove, midway Pollocksville and New Bern	Craven/Jones
38	3-VI	small stream on left bank of Trent River, S.W. of New Bern	Craven
39	8-VI	Jason Brook, W. of Newport, near bridge on by-way (dirt road) of highway 1124	Carteret
40	8-VI	Peak Swamp, W. of Newport, near bridge on by-way (dirt road 128) of highway 1124	Carteret
41	8-VI	Mills Swamp, W. of Newport, near bridge on by-way (dirt road 128) of highway 1124	Carteret
42	8-VI	Northwest Prong near Holly Springs, N.W. of Newport, bridge on highway 1124	Carteret
43	8-VI	small stream near Masontown, N.W. of Newport	Carteret
44a	10-VI	beach midway Beaufort and Morehead City	Carteret
44b	15-VI	White Oak River, right bank, near Swansboro, bridge on highway 24	Onslow
45	15-VI	Holland Mill Creek, tributary, N.W. of Swansboro	Onslow
46	15-VI	White Oak River, near Stella	Onslow/Carteret
*47	20-VI	North River, N.E. of Beaufort, bridge on highway 70	Carteret
*48	20-VI	North River, near Otway, bridge on highway 70	Carteret
*49	20-VI	Core Sound, near Smyrna	Carteret
*50	20-VI	Core Sound, near bridge on highway 70, midway Williston and Davis	Carteret

Station	Date (1977)	Position	County
*51	20-VI	water in between Cedar Island and the mainland, connecting Long Bay and Core Sound	Carteret
52a	13-VII	Neuse River, left bank, near Arapahoe, Bennett Road, "Minnesott Manor"	Pamlico
52b	13-VII	small stream discharging in Neuse River near station 52a	Pamlico
53	13-VII	Beard Creek, discharging in Neuse River, across Cherry Point U.S. Naval Reservation	Pamlico
54	13-VII	Goose Creek, Reelsboro Fire district, S.E. of New Bern	Pamlico
55	13-VII	Upper Broad Creek, Tricommunity Fire district	Pamlico
*56	13-VII	Neuse River, right bank, upstream of New Bern, "Gap Landing"	Craven
*57	3-VIII	Neuse River, near Askin, N.W. of New Bern	Craven
58	9-VIII	Neuse River, left bank, midway Minnesott and Janeiro, downstream of Camp Don Lee	Pamlico
59	9-VIII	Neuse River, left bank, near Janeiro, bridge of tributary	Pamlico
60	9-VIII	Neuse River, left bank, near Oriental, Robert Scott bridge	Pamlico
*61	9-VIII	Bay River, near Stonewall, bridge on highway 55	Pamlico
*62	9-VIII	Bay River, left bank, near Vandemere, N.E. of Bayboro, highway 304	Pamlico
63	11-VIII	Newport River, upstream of bridge on highway 70, Morehead City	Carteret
64	22-VIII	South River, near village South River, downstream of jetty of D.U.M.L. boat	Carteret

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