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Benthic Foraminifera and Ostracoda from Virginia Continental Shelf

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Introduction

Benthic meiofaunas living on continental shelves comprise a significant proportion of the total biomass and species diversity in shallow marine environments and play important roles in the functioning of shallow marine ecosystem. Two important meiofaunal groups, benthic foraminifers (protists) and ostracodes (bivalved Crustacea), have been especially important in studies of benthic communities living along the U.S. Atlantic continental shelf. Buzas and Culver (1980) estimated that the number of benthic foraminifers in marine environments exceeds 10^6 per square meter and wet-weight biomass ranges from 0.02 to more than 10 g/m^2. Numerous other studies have documented the zoogeographic and bathymetric distribution of more than 800 species of benthic foraminifera (e.g., Culver and Buzas 1980; Buzas and Culver 1980) and several hundred species of marine ostracodes (Valentine 1971; Hazel 1970, 1975; Cronin 1983) along the U.S. Atlantic coast.

Most previous studies of Atlantic continental shelf foraminifers and ostracodes, however, were conducted at very large spatial and temporal scales. For example, the large USGS/Woods Hole Continental Margin Program which took thousands of Atlantic shelf and slope sediment samples during the 1960's (Emery 1966) provided extensive ostracode zoogeographic data spanning several marine zoogeographic provinces and climatic zones (e.g. Hazel 1970). Likewise, Culver and Buzas (1980) compiled foraminiferal species' distribution data from hundreds of published sources to produce distribution maps of the 150 most common species for the western North Atlantic Ocean. Prior studies of fossil benthic foraminifers and ostracodes of the Atlantic margin have also focused on long-term changes in microfaunal assemblages resulting from glacial-interglacial climatic cycles (Hazel 1968; Cronin 1988) and from community evolution over millions of years (Buzas and Culver 1984, 1989).

While these studies of living and fossil foraminifers and ostracodes provide excellent baseline information, they are insufficient to understand the small scale distribution of species within a limited region of the continental shelf, nor to understand short-term variability in meiobenthic populations. Such information is essential in the evaluation of potential impacts of short-term environmental disturbances from sand mining, pollution and nutrient influx or high-frequency climatic variability on continental shelf ecosystems.

Our main goal in the present study is to provide baseline information on the abundance and species diversity of foraminifers and ostracodes living in three potential sand mining areas off Virginia Beach. This study was carried out in collaboration with the Virginia Institute of Marine Science, College of William and Mary, in support of the Minerals Management Service program to understand environmental aspects of potential sand mining off the city of Virginia Beach, Virginia.

Study Area

The study region is located in the warm temperate marine climatic zone of the western North Atlantic Ocean between about 36.7 to 37.91 ° N and 75.85 to 75.92 ° W. (Figure 1). The oceanography of the region is dominated by the cool, southward flowing Virginia Coastal Current and the warmer, northward-flowing Gulf Stream/Florida Current. These currents converge near Cape Hatteras where strong isothermal convergence creates thermal barriers to the poleward and equatorward distribution of thermophilic (warm water) and cryophilic (cool water) species respectively. Off southeastern Virginia, the coldest bottom waters usually occur during February and range from about 5 to 10 °C, with generally cooler temperatures closer to shore. The warmest temperatures occur in August-September, reaching > 25 °C, decreasing offshore to 17-20 °C in the middle shelf region (Walford and Wicklund 1968).

On the geographic scale of faunal provinces, winter and/or summer bottom water temperatures are dominant factors influencing large-scale latitudinal distribution of ostracode and foraminiferal species on continental shelves (Hazel 1970). The Virginia shelf is located just north of the major zoogeographic boundary near the Cape Hatteras region. The benthic fauna off southeastern Virginia is composed mainly of temperate species common in regions north of Cape Hatteras. Many species living on the Virginia shelf are near the southernmost limit of their latitudinal distribution because either they cannot tolerate warmer water temperatures to the south or they require cooler winter temperatures for survival and/or reproduction (Hazel 1970).

As one moves from nearshore to offshore regions of the Atlantic margin (from the continental shelf to the slope), factors such as dissolved oxygen, light penetration, sediment texture and composition, and decreasing temperatures of the thermocline affect the distribution of species. For example, environmental gradients at the shelf/slope transition result in a major bathymetric turnover of benthic ostracode (Cronin 1983) and foraminiferal species (Culver and Buzas 1983) between 150-500 m water depth. All the samples in the present study came from the mid- to inner continental shelf and the studied fauna is not affected by the thermocline or by hypoxia.

Substrate is another important factor in the small-scale distribution of benthic foraminifers and ostracodes. Buzas et al. (1989), for example, conducted experiments with benthic foraminifers and showed a small amount of mud in a sandy benthic habitat can have important affects on benthic foraminiferal densities. Many ostracode species are also substrate-specific in nearshore and estuarine habitats (Cronin 1979). The shelf off southeastern Virginia is mainly composed of sands (Hollister 1973) and provides an ideal substrate for sand-dwelling taxa.

Methods

Surface sediment samples were collected on May 15 and June 5-6, 1996 (Spring samples) and October 21 and November 6, 1996 (Fall samples) from the VIMS R/V *Bay Eagle*. Collections were made from three regions which are referred to here as the northern, central and southern regions. There are no obvious barriers between or environmental differences among the three regions. All three are characterized by sandy substrates and generally similar temperature and salinity regimes. The regions were divided into a grid like pattern using longitude and latitude. Each square of the grids was considered a cell. These individual cells were assigned numbers 1-400. Of these, 39 were sampled for the Spring and 25 for the fall. Figure 2 shows the location of all the cells that were sampled. Figures 3-12 show sample stations for designated seasons; Appendices 1-3 give the latitude and longitude for each station. Additional information about the cruises can be found in the companion report by Diaz, Cutter et al. (in press).

Samples were obtained using a Smith/McIntyre grab sampler. Surface sediment from the uppermost 1-2 cm was scraped from a 10 cm^2 area within the grab sample and placed in plastic sample bags. The sediment samples were immediately stained shipboard with Rose Bengal to help distinguish between living and dead ostracodes and foraminifera (see Walton 1952).

Surface sediment samples were processed for foraminifera and ostracodes using standard procedures. The sediments were washed through a 63 μm sieve and dried at 50°C at VIMS laboratories. A total of 300 benthic foraminifers were picked from the residues when available. Samples yielding fewer than 300 specimens were picked of all the foraminifera present. All the samples in Appendices 1 and 2 contained stained representatives and we assume the populations represented at each site were living close to the time of collection. A total of 20 foraminiferal species were found.

Ostracodes were picked at the same time as foraminifers from the same quantity of sediment needed to obtain 300 foraminifers (time constraints did not allow us to pick the entire sample). Ostracodes occurred in most samples; they are typically less abundant than foraminifers in sandy substrates such as those of the Virginia shelf (the number of ostracodes specimens ranged from 0 to 36 per sample) compared to finer grained substrates of Atlantic estuaries and offshore continental slope regions.

A total of 31 ostracode species were found in the Virginia sandy shelf habitats. Many individual ostracodes (especially *P. edwardsi, P. bradyi, C. seminuda*, and *Bensonocythere*) were preserved as whole carapaces containing chitinous appendages and other "softparts". These specimens stained vivid pink and clearly were living at the time of collection. Other specimens, notably juvenile valves, stained faint pink in color and very likely represent the molt stages of living populations.

Foraminifera and ostracodes were examined under light and electron microscopes at the U.S. Geological Survey in Reston, Virginia. Specimens were identified to species level using USGS reference collections, following the taxonomy of Culver and Buzas (1980) and Loeblich and Tappan (1988) for foraminifers and Valentine (1971), Hazel (1975, 1983), and Cronin (1990) for ostracodes. The faunal slides containing foraminiferal and ostracodes are housed in the USGS microfaunal reference collections, Reston, Virginia 20191.

Results

The foraminiferal and ostracode species census data are given in Appendices 1-3 and are available electronically from the authors (tcronin@usgs.gov). Figures 2-11 plot the distribution of more common species of foraminifera and ostracodes; Plates 1-5 illustrate most of the identified species with scanning electron photomicrographs.

Ostracodes

A total of 31 species of ostracode were found in the study area. The ostracode assemblage is dominated by *Peratocytheridea bradyi, Hulingsina* sp., *Cushmanidea seminuda*, and *Protocytheretta edwardsi*. These species are typical inhabitants of sandy inner continental shelf environments of the temperate marine climatic zone of the Atlantic margin off the eastern United States.

The total species number and the composition of the ostracode assemblage is remarkably similar to that collected 30-35 years ago during the USGS-Woods Hole Oceanographic Institution (WHOI) Continental Margin Program (Emery 1966). A comparison between the assemblage found at station 43 of Valentine (1971) located near the current study area with our total 1996 assemblage indicates that Valentine found the same 31 species at this site in the 1960's sample found in the current study. These results leads to a fundamental conclusion from the current study that there has not been a long-term change in the overall ostracode assemblage at this site.

Although the overall ostracode faunal assemblage has not seen any net change over the past 30 years, we discovered important heretofore undiscovered seasonal and onshore-offshore variability in ostracode distributions revealed from the 1996 sampling program (Figures 6-11). Among the highlights:

- Several key ostracode species (*Loxoconcha williamsi*, *Hulingsina rugipustulosa*, *Cushmanidea seminuda*) have a more limited distribution in the Spring than in the Fall, suggesting there is a seasonal migration into new habitats during the Summer and early Fall months.
- The pattern of Summer/Fall range expansion may be related to the predominant southward direction to bottom drift of this region which may also be related to the prominent sand-swell crests in many regions of the mid-Atlantic shelf (Uchupi 1968; Hollister 1973).
- Several other species contract their range between the Spring and the Fall seasons. *Peratocytheridea bradyi* contracts its range from the northern and southern regions to only the southern region in the Fall. *Hulingsina americana* and *Protocytheretta edwardsi* are present in northern/central and northern/southern regions in the Spring, respectively, but they are almost totally absent from all samples taken in the Fall.

- The Virginia continental shelf contains several species encountered in sediments deposited over the past 1000 years in Chesapeake Bay. The shelf seems to serve as a source area for ostracodes species which periodically inhabit the more saline southern part and the deeper channel of Chesapeake Bay especially during periods when river discharge is reduced (Cronin unpublished data).

These results provide strong evidence that ostracode species have distinct population ecology linked to seasonal variability of the continental shelf. Major seasonal changes in ostracode populations have also been documented in estuarine ostracodes in the Patuxent River (Tressler and Smith 1948) and in Sippewisset Marsh, Cape Cod (Schweitzer and Lohman 1990) but until this time, were unknown for shelf species. We believe the southeastern Virginia 1996 data is the first to document such seasonality in Atlantic shelf marine ostracode distributions. Although additional analyses are merited to further document seasonal trends, we suspect that seasonal variability is related to bottom water currents. Southward flowing currents are considered especially important in affecting the distribution of *Loxoconcha williamsi, Hulingsina rugipustulosa, Cushmanidea seminuda.*

Benthic Foraminifera

A total of 20 species were identified from the surficial sediment samples. The dominant genus is *Elphidium,* a genus that includes several species common in nearshore environments of the North Atlantic Ocean. *Elphidium* is represented by three subspecies of *E. excavatum* (these are sometimes referred to separate species or distinct morphotypes of the same species): *Elphidium excavatum clavata, E. excavatum selseyensis,* and *E. excavatum excavata.* Figures 2 and 3 show the distributions of *E. excavatum selseyense,* the most abundant species found in our study, and *E. excavatum clavata* during Spring and Fall 1996.

Elphidium excavatum selseyensis is the dominant benthic foraminifer on the Virginia Beach continental shelf comprising up to 93% of the assemblage. The Spring distribution of *E. selseyensis* shows it comprises greater than 80% of the assemblage in northern and central areas, and 70% to 80% of the assemblage in the southern region. The distribution of *E. selseyensis* in the fall is reduced with a greater than 80% occurrence in the northern and central areas, and 60% to 80% in the southern area and the southern part of the central area.

Elphidium excavatum clavata is the dominant benthic foraminifer in the northern and southern areas. It makes up a much smaller percentage (< 8%) of the assemblage in the central area. This species expands to significant proportions in the fall where it composes greater than 8% (sometimes exceeding 16%) in much of the central and southern regions.

The occurrence off southeastern Virginia of these forms of the genus *Elphidium* is consistent with benthic foraminifer distributions reported from the mid-Atlantic continental shelf of North America. Murray (1991) and Culver and Buzas (1980), for example, mapped the *Elphidium* predominance from Cape Cod to Cape Hatteras and off the North American Atlantic coast, respectively. Schnitker (1971) also found an abundance of *Elphidium clavatum* north of Cape Hatteras on the inner shelf.

Other species occurring on the Virginia shelf, in order of abundance, include *Quinqueloculina seminula, Ammonia parkinsoniana, Buccella frigida, Hanzawaia atlanticus, Hanzawaia concentrica* and *Eggerella advena.* Figures 4 and 5 show the distribution of *A. parkinsoniana* and *Q. seminulum* during Spring and Fall, 1996; plates 4 and 5 illustrate most of these species.

Although the relative abundances of *Ammonia parkinsoniana* in the Virginia Beach shelf samples are low, 5% or less, the distribution of this species seems to reflect distinct environmental conditions in the central study area. *A. parkinsoniana* is common throughout the world in estuarine environments due to its tolerance of highly fluctuating salinities ranging from brackish (oligohaline, 0.5-5 ppt) to hypersaline (>40 ppt). It lives on the surface of fine-grained sediments down to a depth of 10 cm into the substrate and has a complex life history involving bacterial and algal endosymbionts (Goldstein and Moodley 1993). Chandler et al. (1996) found that *Ammonia* would only reproduce in culture under specific conditions that included the addition of silty-clay obtained from the Gulf of Mexico and a regular diet of phytoplankton.

The Spring distribution of *A. parkinsoniana* shows its greatest abundance in the southern part of the central area with only sparse occurrences in northern and southern regions. The fall distribution of *A. parkinsoniana* shows a slight expansion into the northern and western sections of the central area 2 but it is still rare to absent in northern and southern regions. It is unlikely that salinity variations restricted *A. parkinsoniana* from inhabiting northern and southern regions. Rather, we suspect that its limited range has more to do with resource limitations such as the availability of food, nutrients and/or finer grained sediments which may be available in the central region.

Quinqueloculina seminula is the dominant miliolid foraminifer that occurs in our surficial samples. It is present in percentages ranging from 5-10% to 20-25% in the central and southern regions in the Spring. However, its distribution changes in Fall when it expands into the northern region but disappears in parts of the central region. In the Fall its abundance is greatly reduced to < 2 %.

Conclusions

The modern benthic foraminiferal and ostracode faunas from three areas on the Virginia Beach continental shelf allow several important new conclusions about the meiobenthic fauna of sandy substrate environments of the continental shelf off Virginia Beach, Virginia.

- The 1996 faunal assemblages are extremely similar in species composition to those obtained in previous sampling program of the North American Atlantic continental shelf conducted during the 1960's. There has been no major long-term changes in the faunas from these regions.
- Seasonal benthic foraminiferal and ostracode distribution data show that significant changes in the relative abundance of the dominant species characterize the Spring and Fall assemblages. Several ostracode species expand their range southward from Spring to Fall suggesting bottom drift currents may play a role in seasonal dispersal of populations. Other ostracode species are common in the Spring but are almost totally absent in the Fall reflecting a complex, still poorly known population ecology.
- Foraminiferal species richness and geographic distributions are slightly greater in the fall with the expansion of the species *E. clavata*, *A. parkinsoniana*, and *Q. seminula*, and reduction in spatial distribution of *E. selseyensis*.
- *Ammonia parkinsoniana* has a distinct range limited to the central study region, possibly due to food and/or substrate limitations.
- The Virginia shelf is an important source habitat for species migrating into Chesapeake Bay. Two examples are the ostracode species, *Loxoconcha williamsi* and *Protocytheretta edwardsi*, which occur commonly on the Virginia shelf and have also been discovered in sediments in Chesapeake deposited prior to large-scale land clearing of the early 19th century.

Overall, our preliminary results indicate that a complex meiobenthic community inhabits the southeastern Virginia shelf. It is very likely that the entire community is potentially sensitive to environmental disruption to surficial sediments. However, due to the variable ecological requirements of each foraminiferal and ostracode species, the impact of habitat disturbance will vary widely among the 50 or so species recovered.

Furthermore, whereas the Virginia shelf is itself important habitat for meiobenthic species, this region must also be considered an important source area region for species able to migrate into coastal estuaries and bays like Chesapeake Bay. Consequently, species' population dynamics in the shelf region must be examined in the context of seasonal monitoring of conspecific populations living in adjacent areas.

Additional benthic sampling of the Virginia shelf through a second seasonal cycle, new sampling of the Virginia shelf/Chesapeake Bay mouth transition, supplemented by physical and chemical oceanographic data, would provide an ideal platform from which to fully understand shallow marine foraminiferal and ostracode species ecology and determine the least disruptive way to mine sand from shelf regions.

Acknowledgments

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Figure Captions

Figure 1. Map showing general location of Virginia shelf study area.

Figure 2. Map showing the individual cells sampled within the three regions

Figure 3. Distribution map showing the proportions of *Elphidium excavatum selseyense* in total foraminiferal population on continental shelf off Virginia Beach during Spring (upper map) and Fall (lower map) 1996. Small dots indicate station locations.

Figure 4. Distribution map showing the proportions of *Elphidium excavatum clavata* in total foraminiferal population on continental shelf off Virginia Beach during Spring (upper map) and Fall (lower map) 1996. Small dots indicate station locations.

Figure 5. Distribution map showing the proportions of *Ammonia parkinsoniana* in total foraminiferal population on continental shelf off Virginia Beach during Spring (upper map) and Fall (lower map) 1996. Small dots indicate station locations.

Figure 6. Distribution map showing the proportions of *Quinqueloculina seminulum* in total foraminiferal population on continental shelf off Virginia Beach during Spring (upper map) and Fall (lower map) 1996. Small dots indicate station locations.

Figure 7. Distribution map showing the number of *Peratocytheridea bradyi* specimens on continental shelf off Virginia Beach during Spring (upper map) and Fall (lower map) 1996. Small dots indicate station locations.

Figure 8. Distribution map showing the number of *Cushmanidea seminuda* specimens on continental shelf off Virginia Beach during Spring (upper map) and Fall (lower map) 1996. Small dots indicate station locations.

Figure 9. Distribution map showing the number of *Hulingsina rugipustulosa* specimens on continental shelf off Virginia Beach during Spring (upper map) and Fall (lower map) 1996. Small dots indicate station locations.

Figure 10. Distribution map showing the number of *Loxoconcha williamsi* specimens on continental shelf off Virginia Beach during Spring (upper map) and Fall (lower map) 1996. Small dots indicate station locations.

Figure 11. Distribution map showing the number of *Protocytheretta edwardsi* specimens on continental shelf off Virginia Beach during Spring 1996. Small dots indicate station locations.

Figure 12. Distribution map showing the number of *Hulingsina americana* specimens on continental shelf off Virginia Beach during Spring 1996. Small dots indicate station locations.

Scanning Electron Microscope Plates of Virginia Shelf Ostracodes and Foraminifera

Plate 1

Figure 1: *Bensonocythere sapeloensis* Hall 1965. x 134, Sta. 64, Cell 308, female, left valve.

Figure 2: *Bensonocythere sapeloensis* Hall 1965. x 133, Sta. 62, Cell 316, female, right valve, internal view.

Figure 3: *Bensonocythere sapeloensis* Hall 1965. x 141, Sta. 1, Cell 209, male, left valve.

Figure 4: *Puriana rugipunctata* (Ulrich and Bassler 1904) , x 143, Sta. 55, Cell 264, female, right valve.

Figure 5: *Muellerina ohmerti* Hazel 1983, x 178, Sta. 52, Cell 52, female, left valve.

Figure 6: *Protocytheretta edwardsi* (Cushman 1906)., x 83,4, Sta. 64, Cell 64, female, right valve.

Figure 7: *Cytherettid*, x 71,3, Sta. 62, Cell 316, female, left valve, internal view.

Figure 8: *Protocytheretta edwardsi* (Cushman 1906, x 91,7, Sta. 204, Cell 204, female, left valve, internal view.

Plate 2

Figure 1: *Hulingsina americana* (Cushman 1906). x 88,1 , Sta. 64, Cell 308, female?, left valve.

Figure 2: *Cushmanidea seminuda* (Cushman 1906). x 94,2 , Sta. R2, Cell 185, female, right valve.

Figure 3: *Sahnia sp.*, x 141, Sta. 24, Cell 234, male, left valve.

Figure 4: *Hulingsina rugipustulosa* (Edwards 1944) x 147, Sta. 46, Cell 46, female, right valve.

Figure 5: *Peratocytheridea bradyi* (Stephenson 1938). x 139, Sta. 52, Cell 213, female, left valve, internal view.

Figure 6: *Peratocytheridea bradyi* (Stephenson 1938). x 124, Sta. 209, Cell 209, female, left valve.

Figure 7: *Peratocytheridea bradyi* (Stephenson 1938). x 134, Sta. 51, Cell 204, female, left valve, Note hole in middle where predator bored through carapace.

Figure 8: *Eucythere declivis* (Norman 1865). x 151, Sta. R11, Cell 49, female?, left valve, soft parts.

Plate 3

Figure 1: *Tetracytherura* sp. A of Valentine 1971, x 166, Sta. R11, Cell 49, male, left valve.

Figure 2: *Tetracytherura* sp. A of Valentine 1971, x 166, Sta. 64, Cell 308, left valve, internal view.

Figure 3: *Cytherura* sp., x 167, Sta. 64, Cell 64, female, left valve.

Figure 4: *Cytherura* sp. x 307, Sta. 53, Cell 365, left valve.

Figure 5: *Proteoconcha tuberculata* (Puri 1960). x 104, Sta. 54, Cell 263, male, right valve.

Figure 6: *Proteoconcha tuberculata* (Puri 1960). x 121, Sta. 53, Cell 246, female?, left valve, internal view.

Figure 7: *Loxoconcha williamsi* (= aff *granulata* Sars 1865). x 151, Sta. R10, Cell 66, female, left valve.

Figure 8: *Cytherura wardensis* Howe and Brown 1935. x 176, Sta. 229, Cell 229, female, left valve.

Figure 9: *Microcythere* sp., x 280, Sta. 53, Cell 365, lateral view.

Figure 10: *Microcythere* sp. x 307, Sta. 53, Cell 365, dorsal view.

Plate 4

Figure 1: *Elphidium clavata*, x 191, Sta. 52, Cell 213.

Figure 2: *E. selseyensis*, x 164, Sta. 57, Cell 372.

Figure 3: *Quinqueloculina seminulum*, x 122, Sta. 54, Cell 332.

Figure 4: *E. clavata*, x 176, Sta. 57, Cell 372.

Figure 5: *E. selseyensis*, x 178, Sta. R11, Cell 49, aperture L.

Figure 6: *Hanzawaia concentrica*, x 147, Sta. R9, Cell 104.

Figure 7: *Ammonia parkinsoniana*, x 176, Sta. R2, Cell 185, spiral side.

Plate 5

Figure 1: *Buccella frigida*, x 217, Sta. 57, Cell 372, umbilical view.

Figure 2: *Ammonia parkinsoniana*, x 181, Sta. R14, Cell 24, umbilical view.

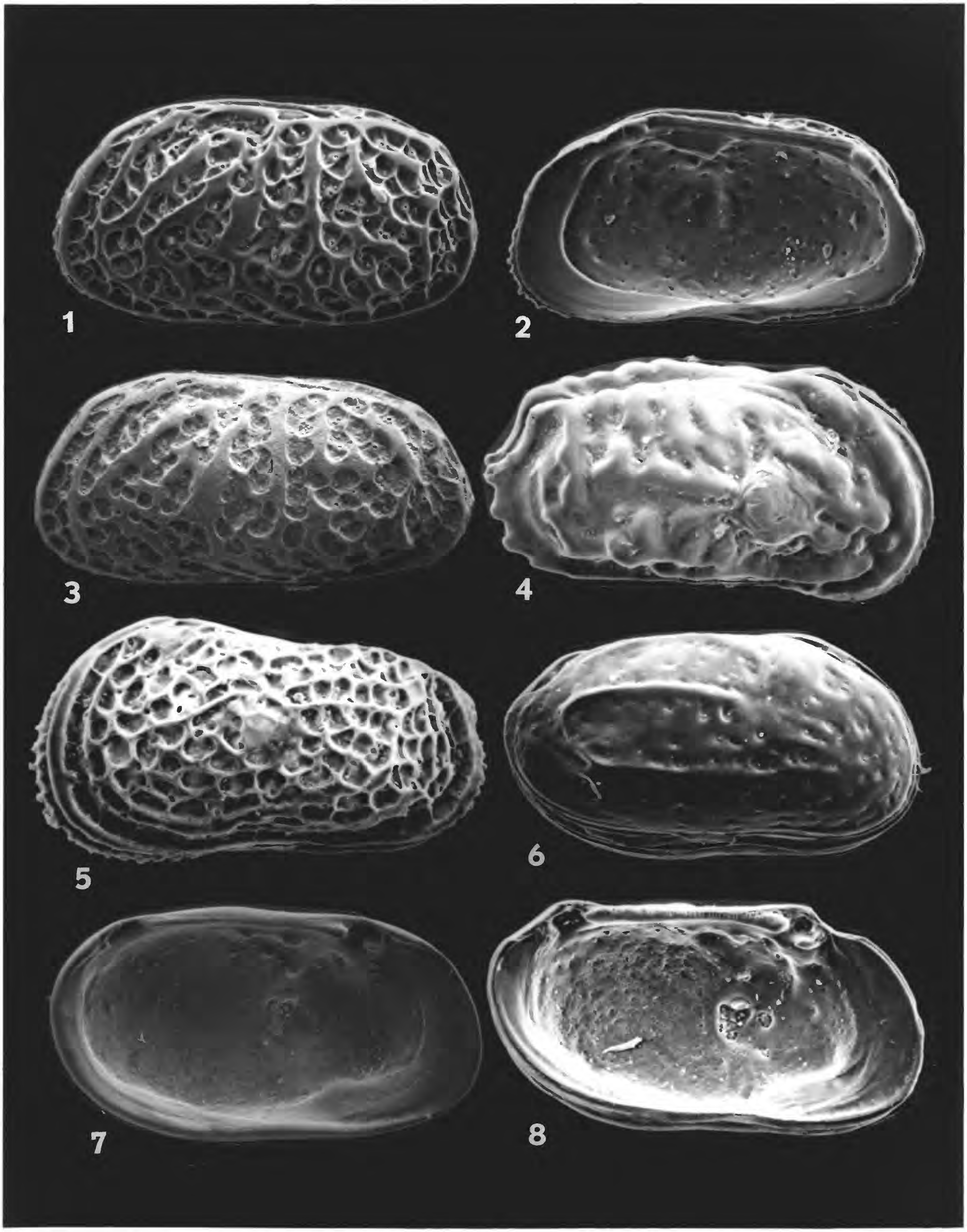
Figure 3: *Planulina mera*, x 141, Sta. 52, Cell 213.

Figure 4: *Hanzawaia atlanticus*, x 122, Sat. R4, Cell 183.

Figure 5: *Guttulina lactea*, x 176, Sta. 59, Cell 360.

Figure 6: *Buccella frigida*, x 217, Sta. R2, Cell 185.

Figure 7: *Hanzawaia concentrica*, x 151, Sta. 51, Cell 204, flat side view.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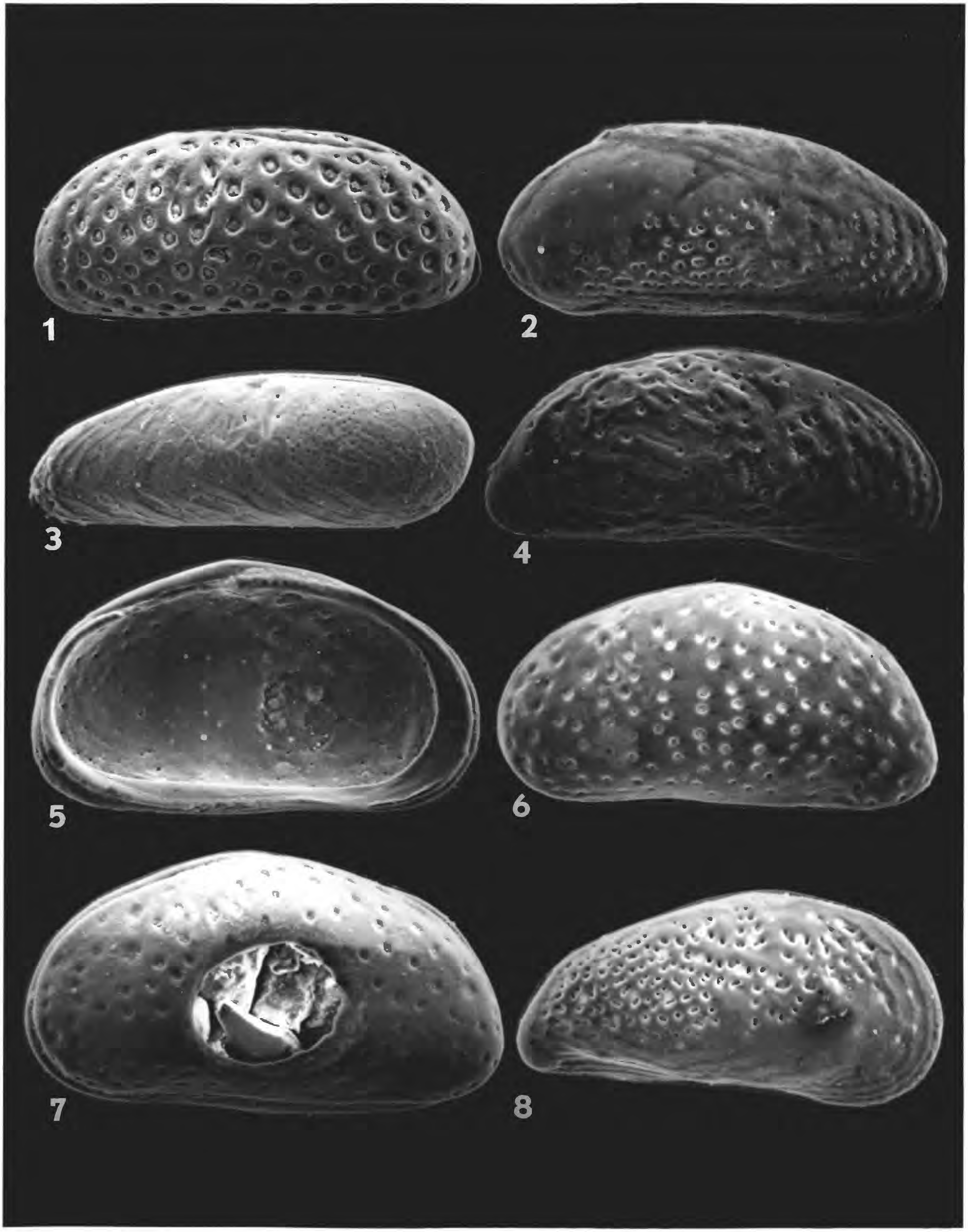
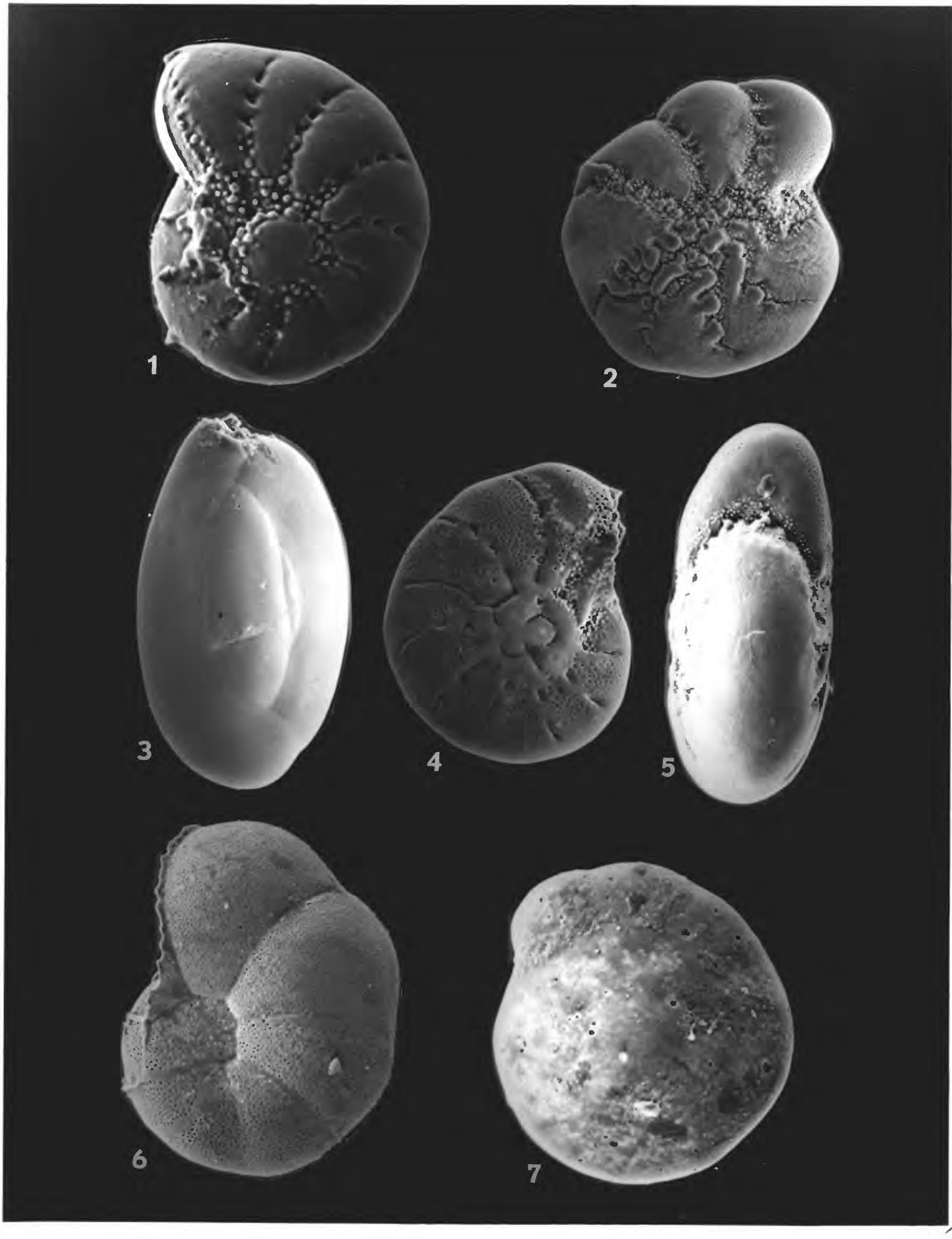
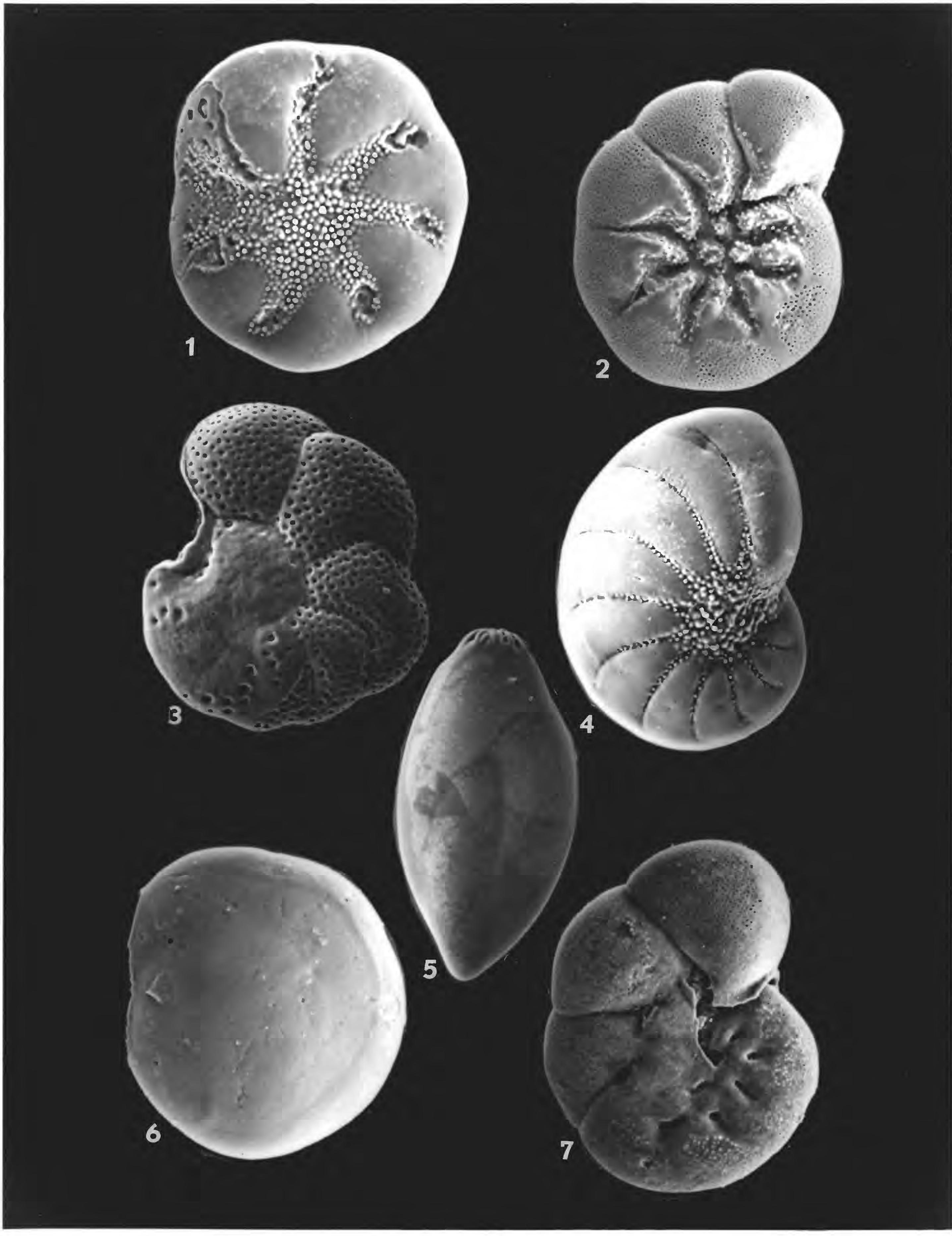
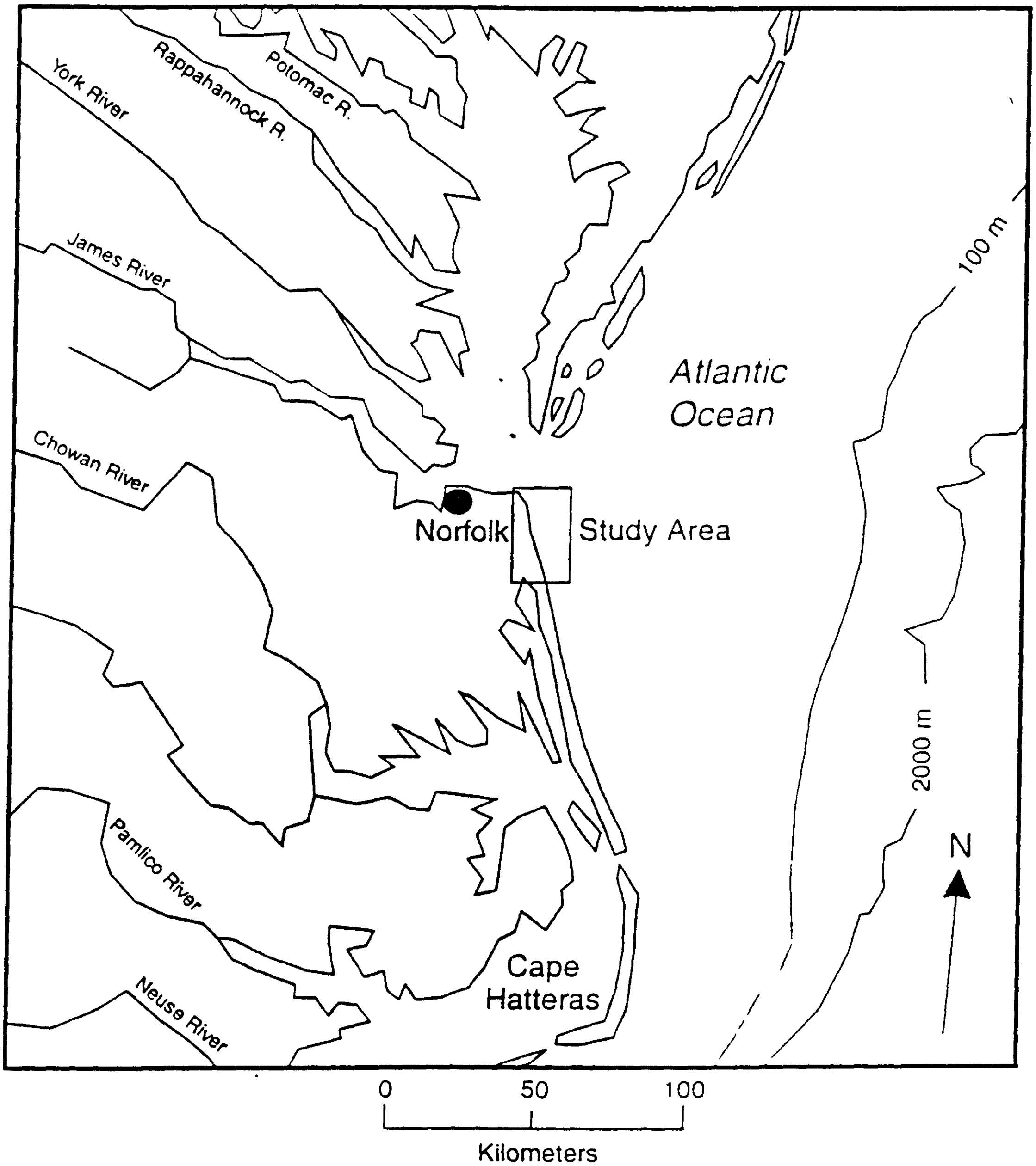

1
2
3
4
5
6
7
8


1
2
3
4
5
6
7
8
9
10


1
2
3
4
5
6
7


1
2
3
4
5
6
7


Potomac R.
Rappahannock R.
York River
James River
Chowan River
Atlantic Ocean
100 m
Norfolk
Study Area
2000 m
N
Pamlico River
Cape Hatteras
Neuse River
0
50
100
Kilometers

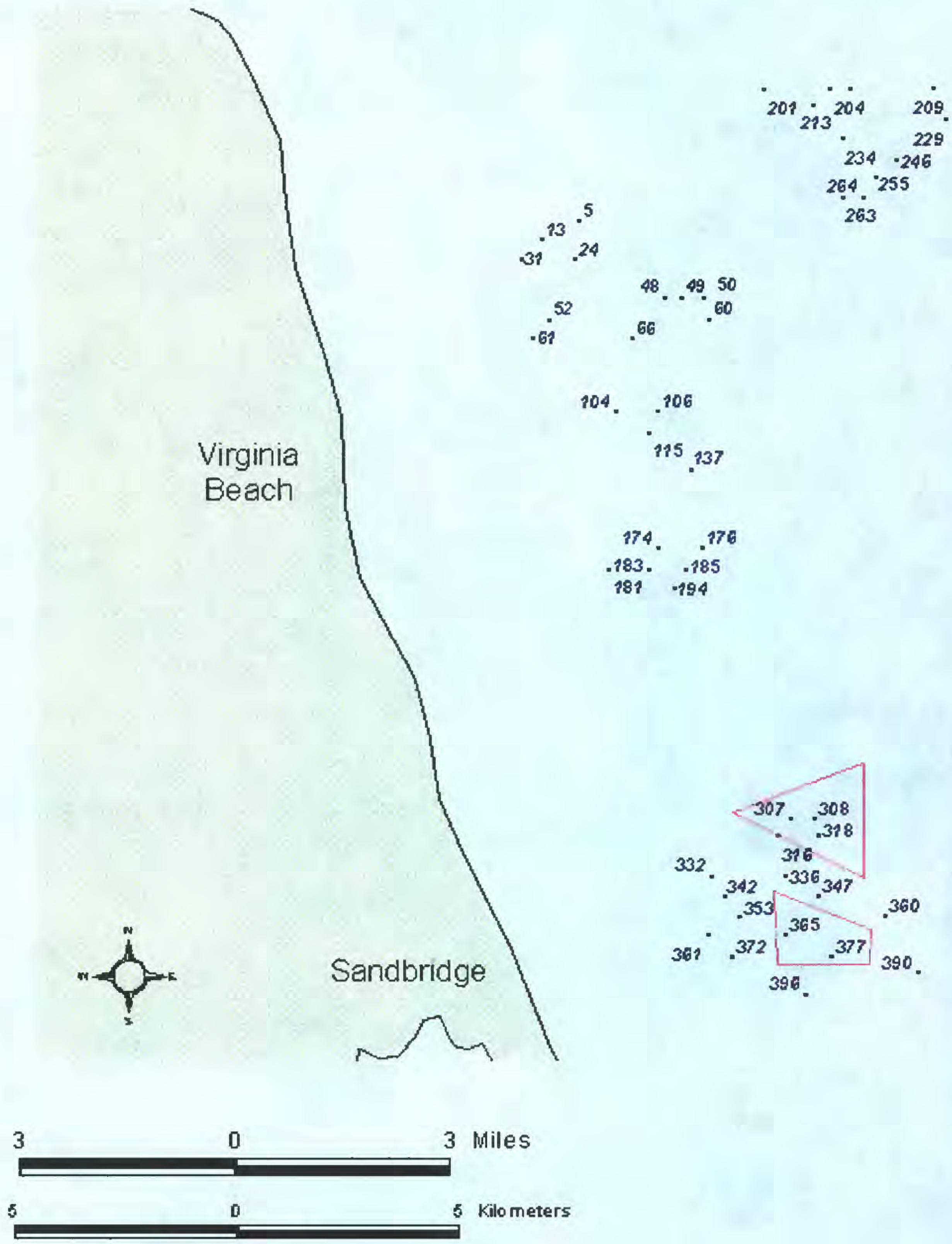
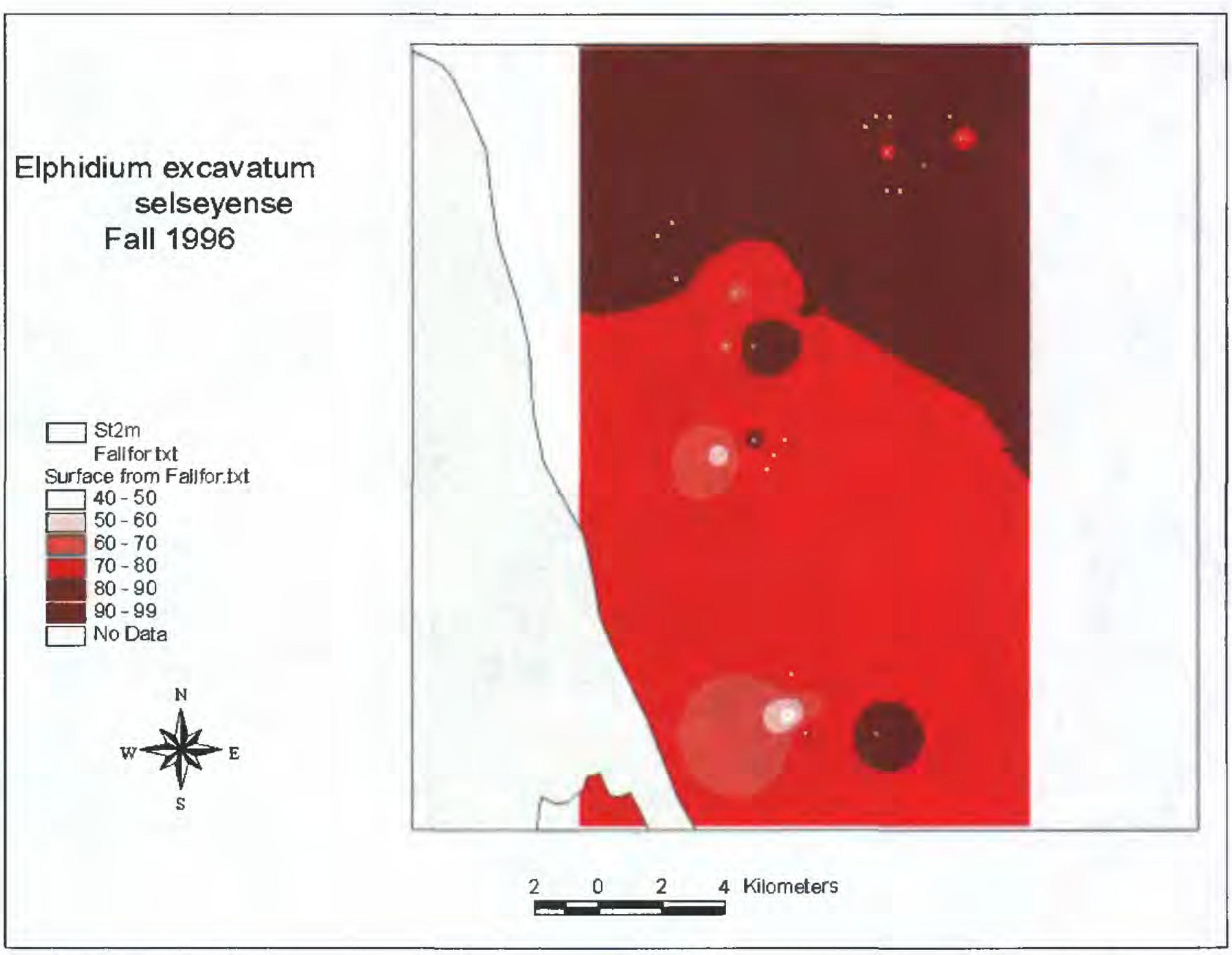
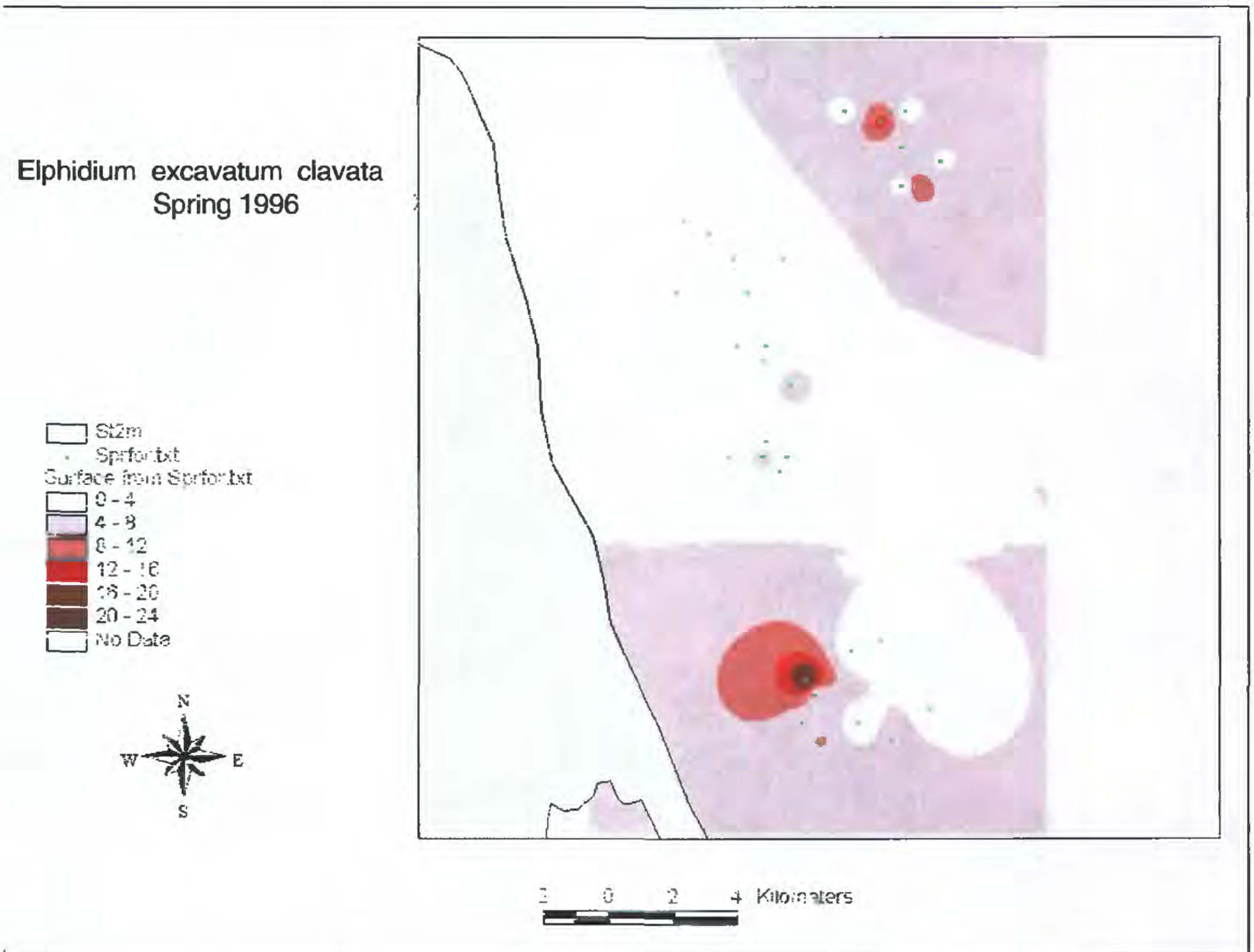


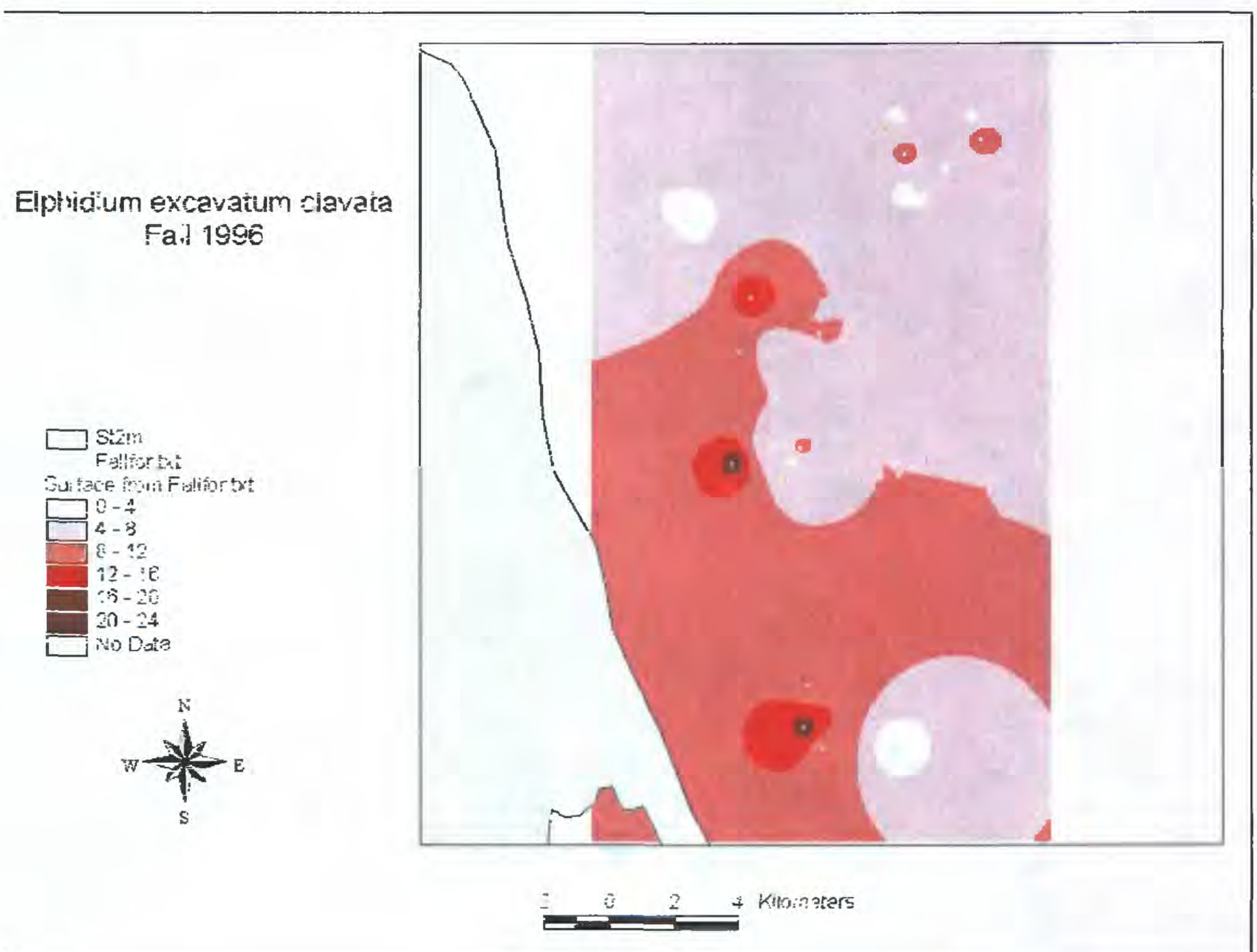
Figure . 1996 Smith-MacIntyre grab sample locations, and proposed borrow areas (delineated by red lines).


Elphidium excavatum
selseyense
Spring 1996
St2m
Fallfor.txt
Surface from Sprfor.txt
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 99
No Data
N
W
E
S
2 0 2 4 Kilometers

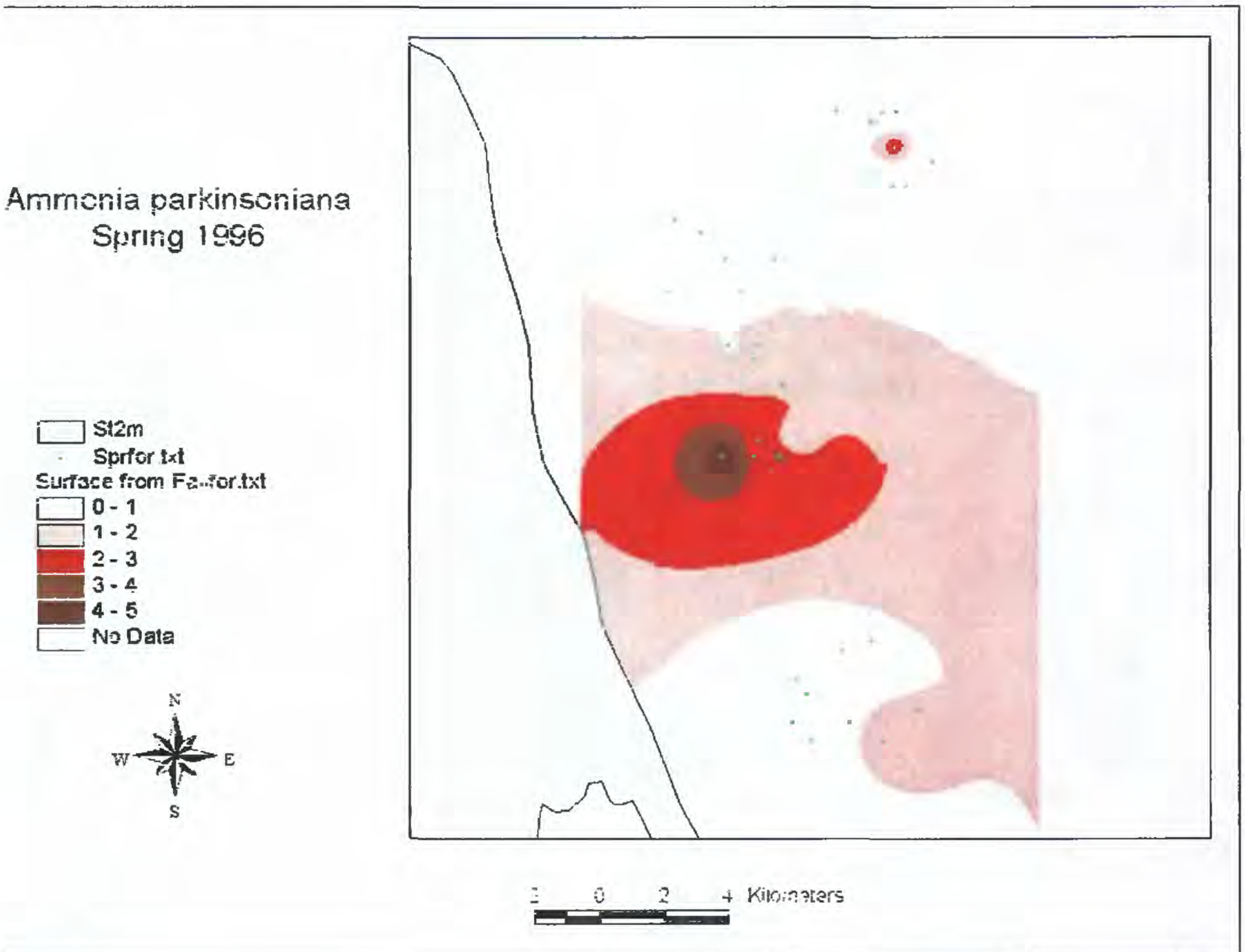

Elphidium excavatum
selseyense
Fall 1996
St2m
Fallfor.txt
Surface from Fallfor.txt
40 - 50
50 - 60
60 - 70
70 - 80
80 - 90
90 - 99
No Data
N
W
E
S
2 0 2 4 Kilometers

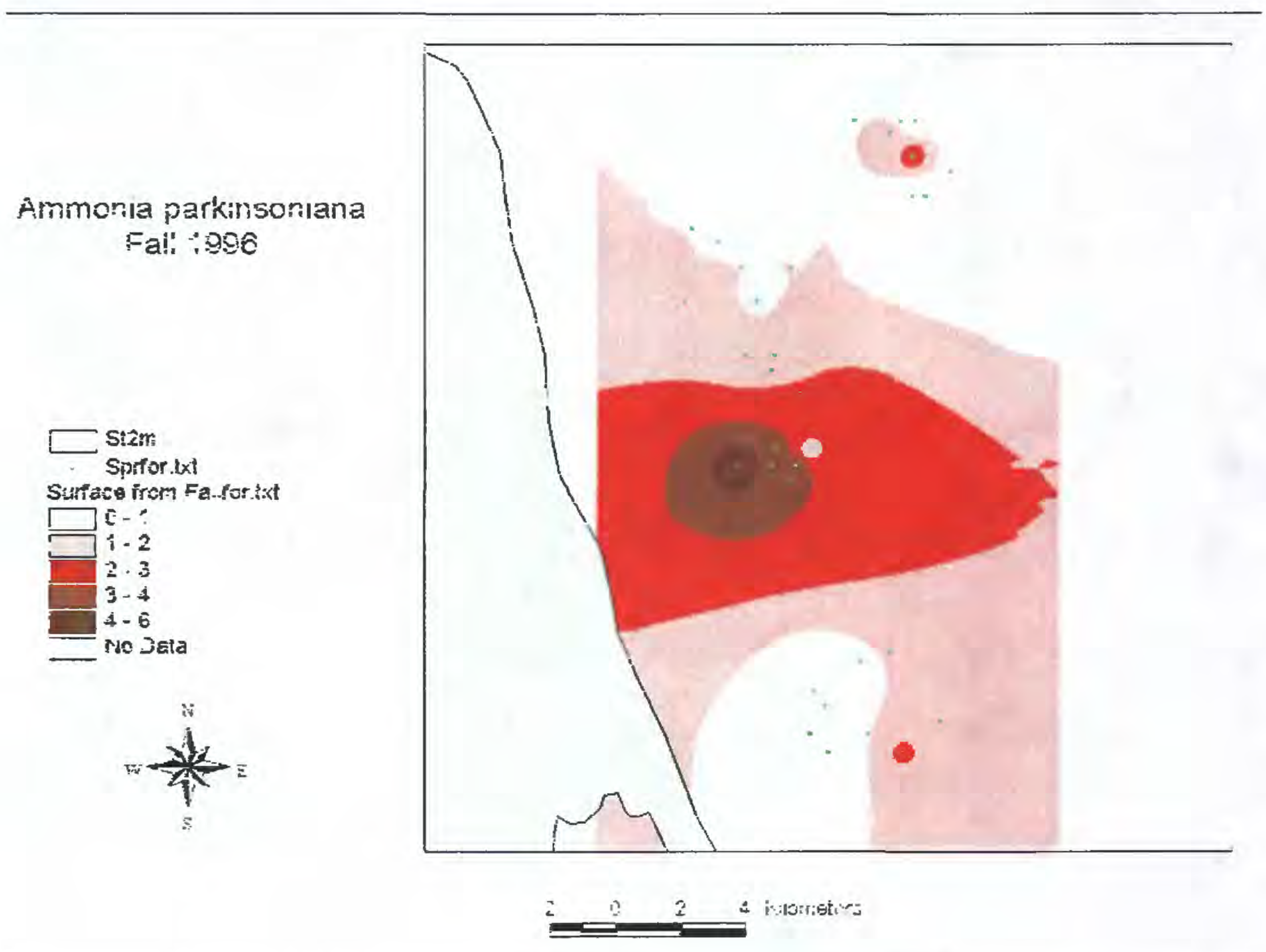


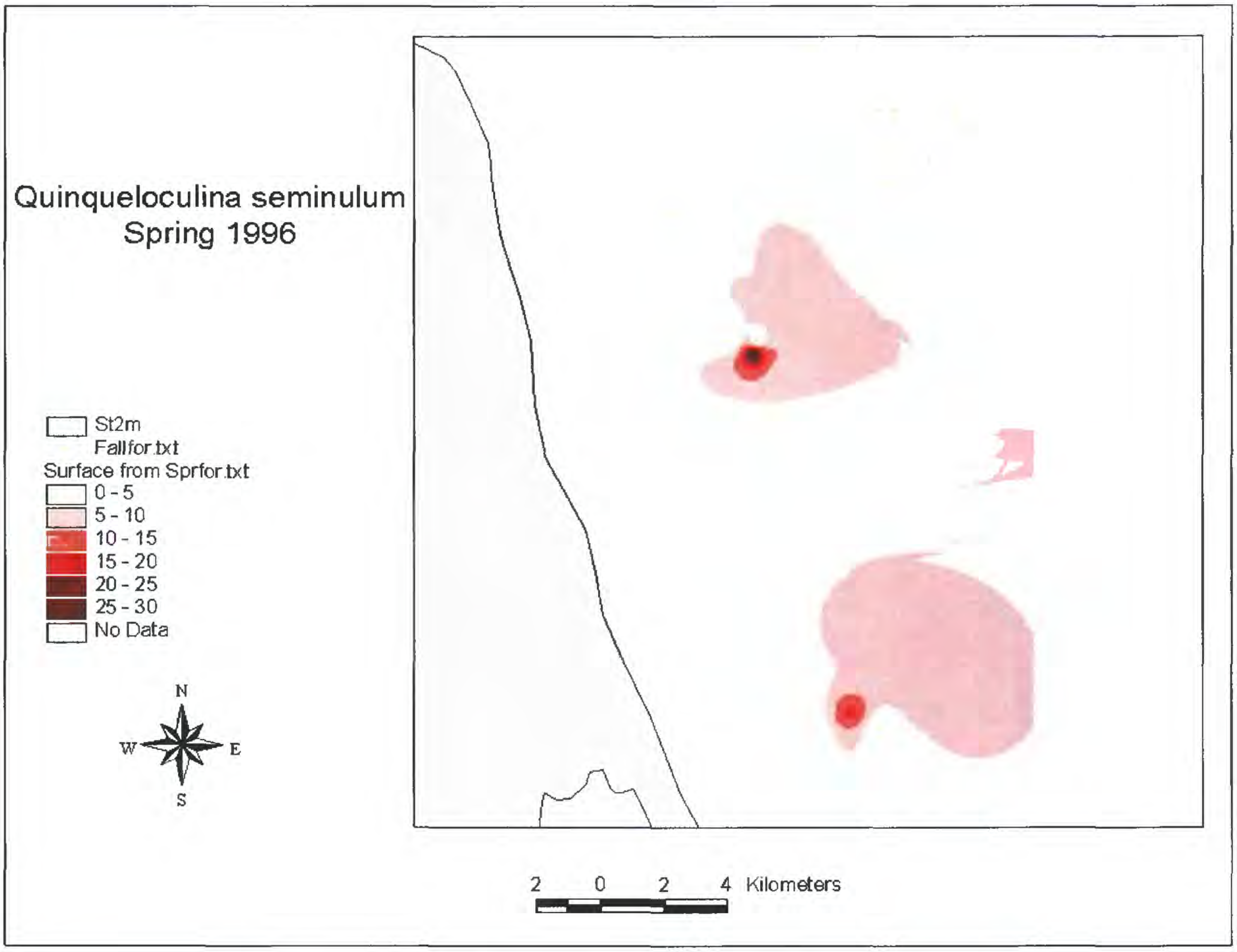
Elphidium excavatum clavata
Spring 1996

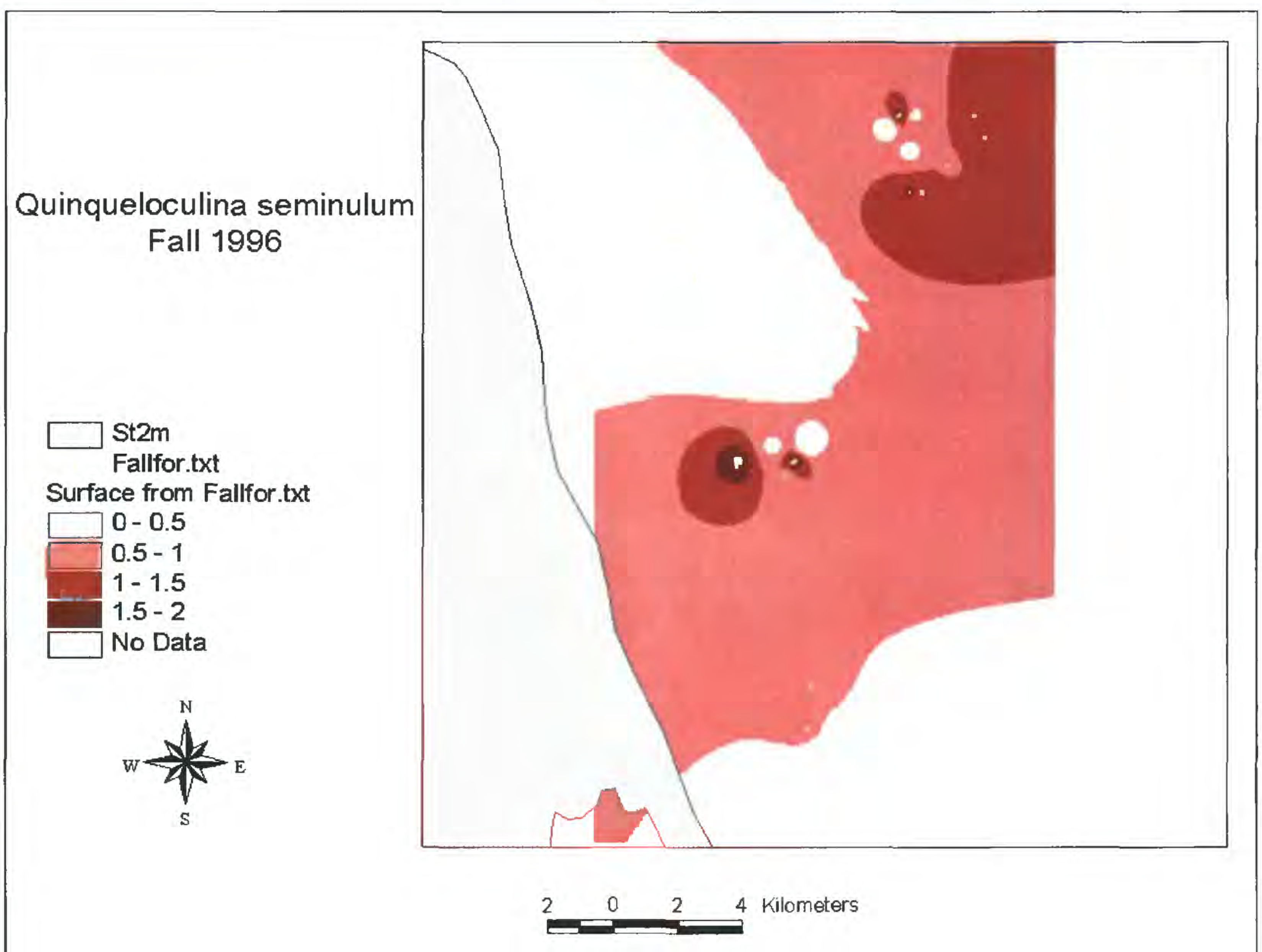


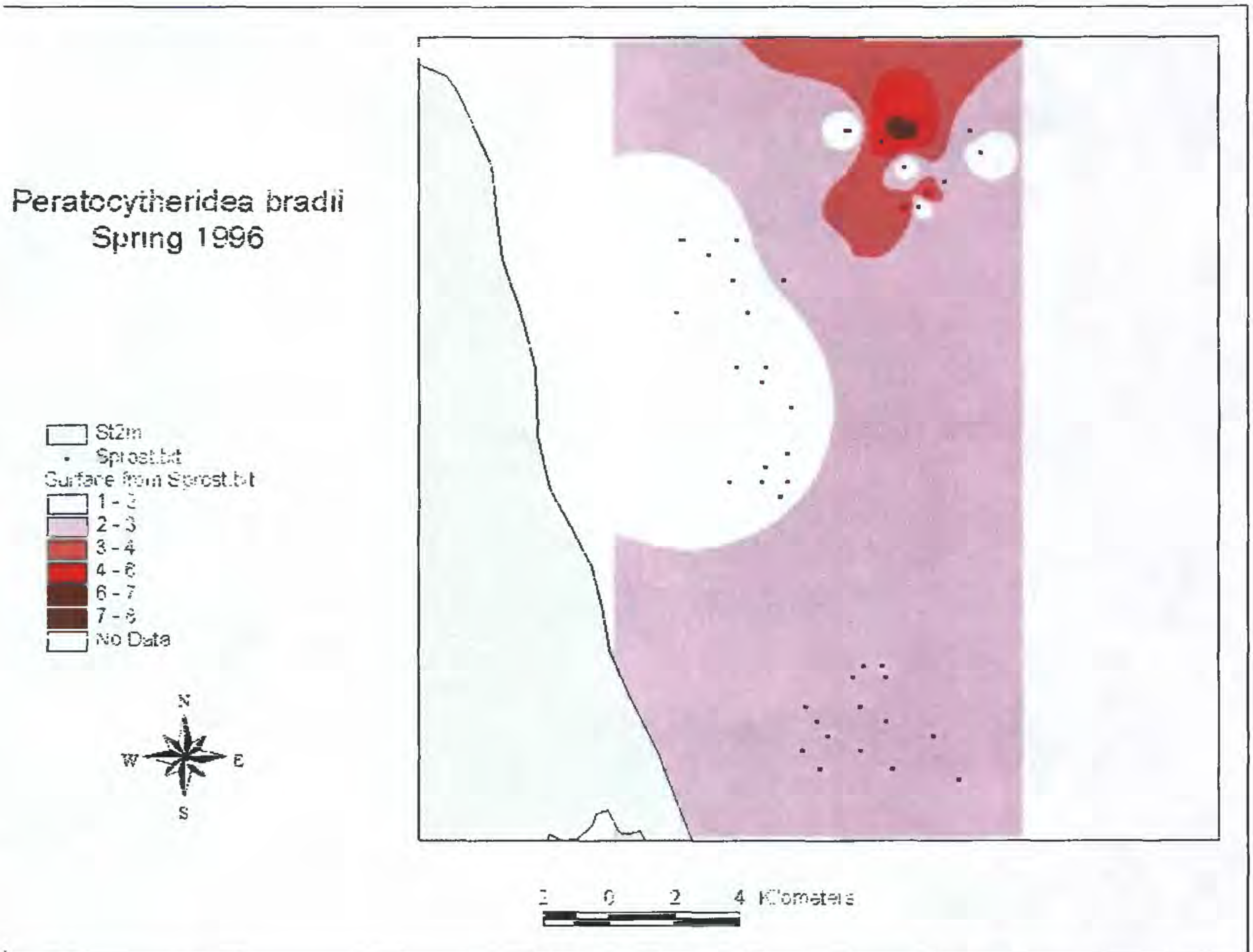
Elphidium excavatum clavata
Fall 1996

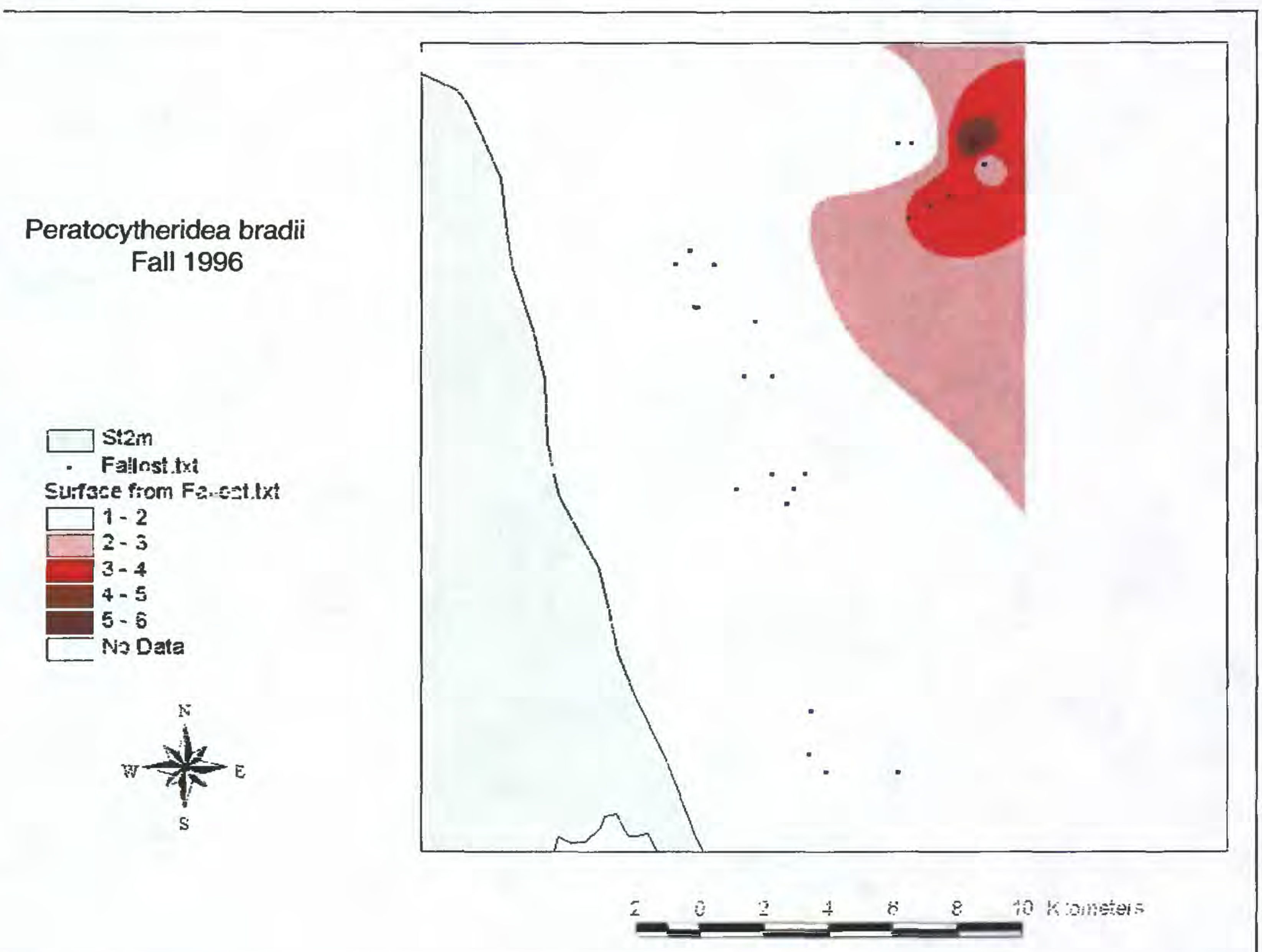

Ammonia parkinsoniana
Spring 1996
St2m
Sprfor.txt
Surface from Fa-for.txt
0 - 1
1 - 2
2 - 3
3 - 4
4 - 5
No Data
N
W
E
S
2 0 2 4 Kilometers

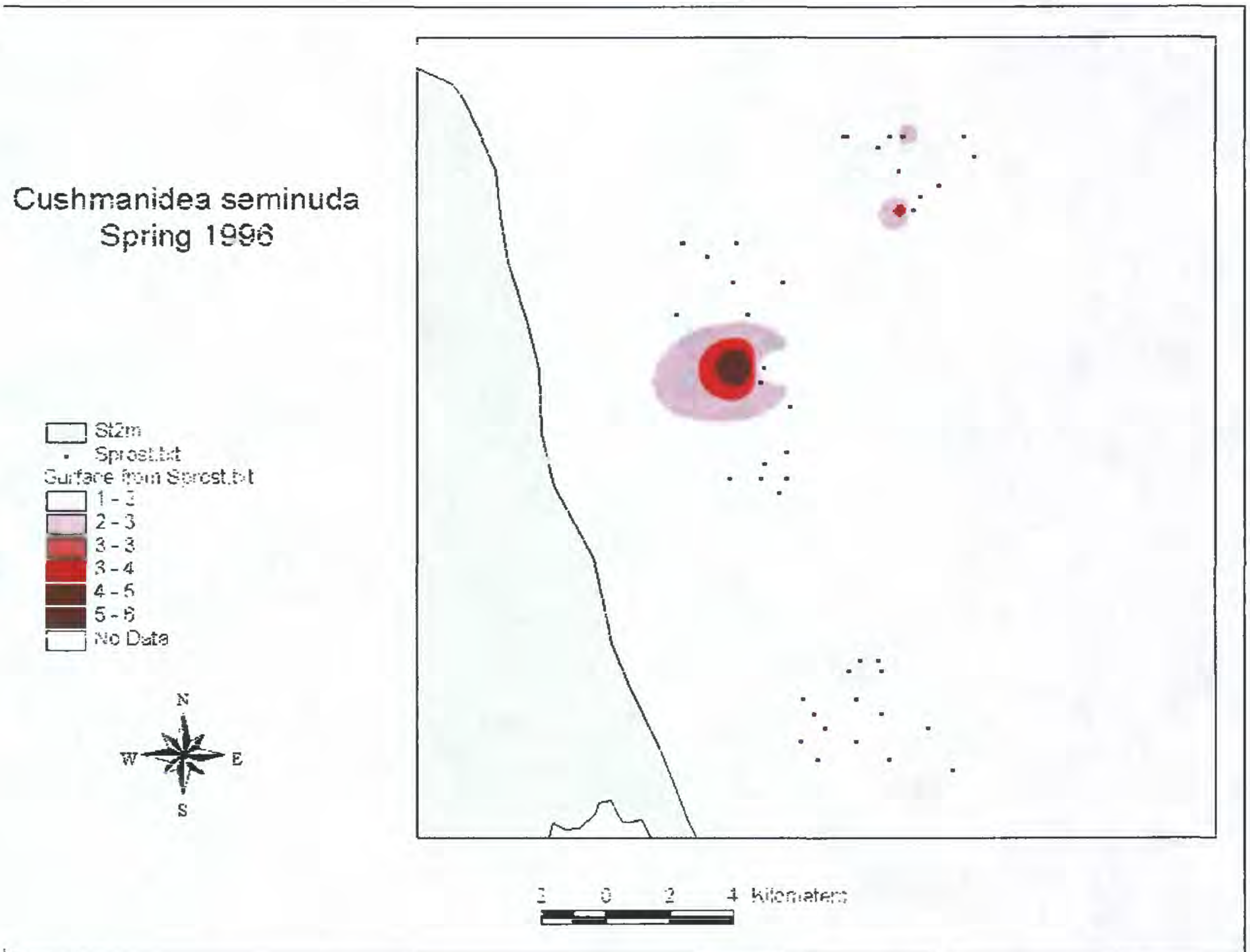

Ammonia parkinsoniana
Fall 1996
St2m
Sprfor.txt
Surface from Fa-for.txt
0 - 1
1 - 2
2 - 3
3 - 4
4 - 6
No Data
N
W
E
S
2 0 2 4 Kilometers


Quinqueloculina seminulum
Spring 1996
St2m
Fallfor.txt
Surface from Sprfor.txt
0 - 5
5 - 10
10 - 15
15 - 20
20 - 25
25 - 30
No Data
N
W
E
S
2
0
2
4
Kilometers

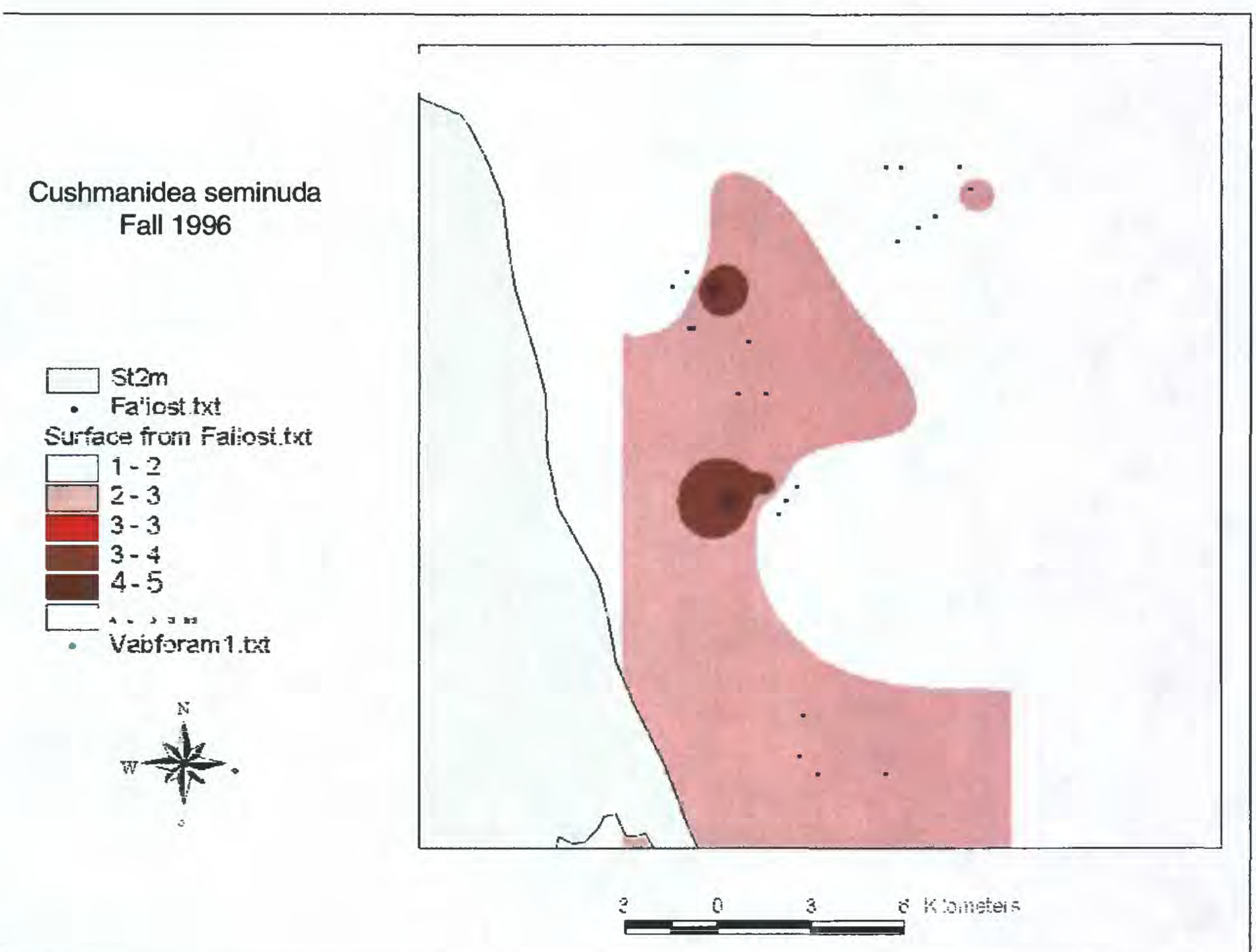

Quinqueloculina seminulum
Fall 1996
St2m
Fallfor.txt
Surface from Fallfor.txt
0 - 0.5
0.5 - 1
1 - 1.5
1.5 - 2
No Data
N
W
E
S
2
0
2
4
Kilometers


Peratocytheridea bradii
Spring 1996
St2m
2 - 3
3 - 4
6 - 7
No Data
N
W
E
S
2
4
Kilometers

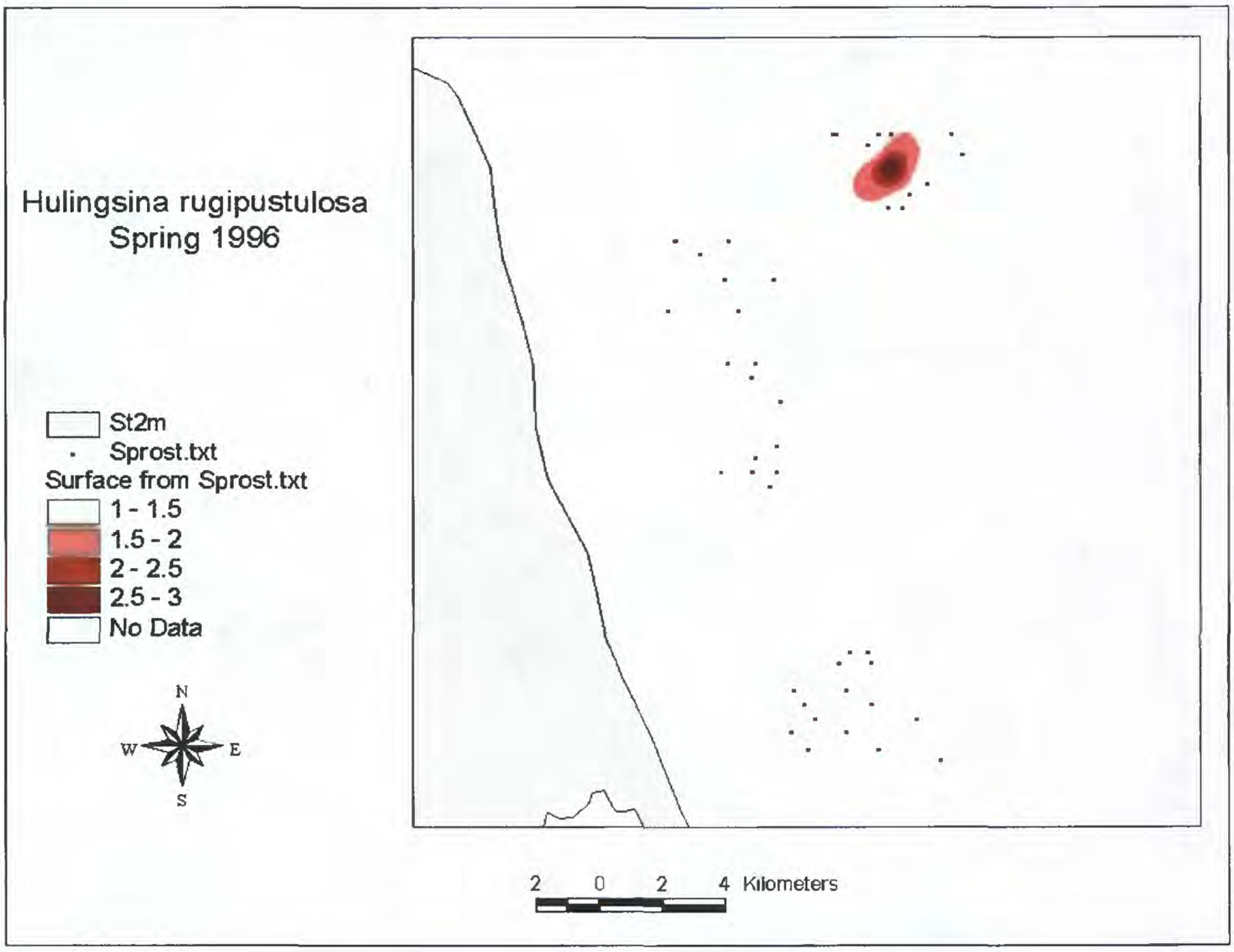

Peratocytheridea bradii
Fall 1996
St2m
Fallost.txt
1 - 2
2 - 3
3 - 4
4 - 5
5 - 6
No Data
N
W
E
S
2
0
2
4
6
8
10

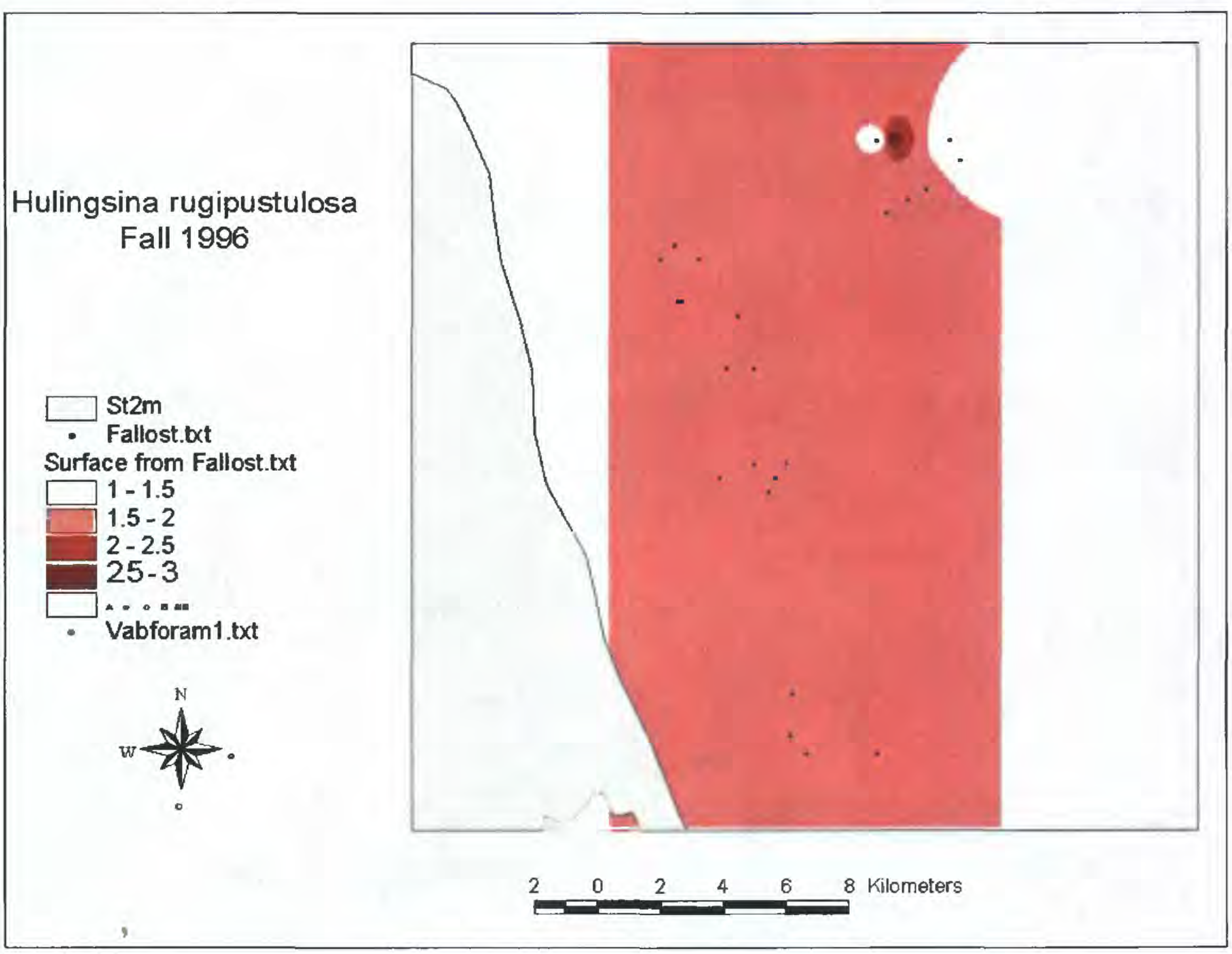


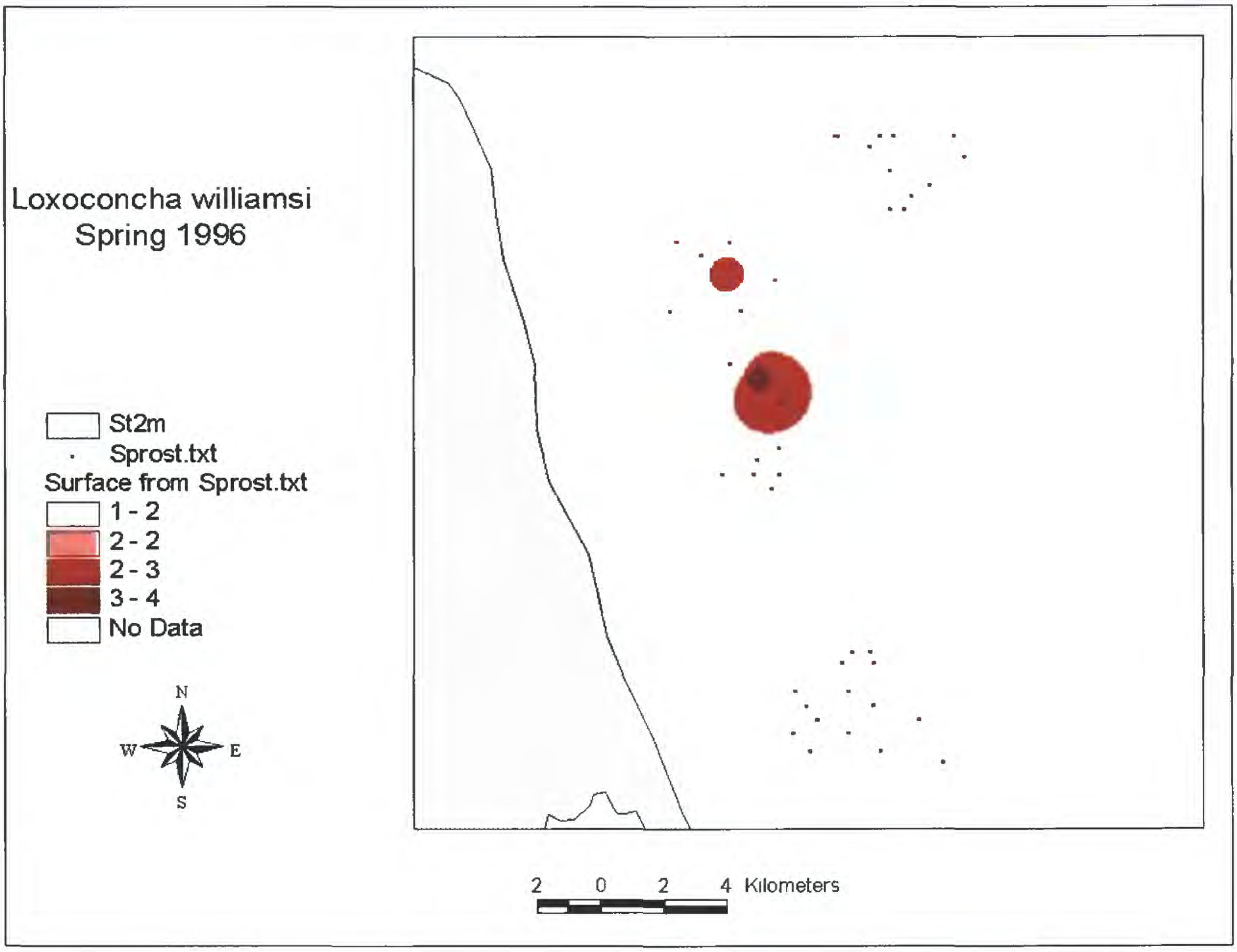
Cushmanidea seminuda
Spring 1996
St2m
Sprost.txt
Surface from Sprost.txt
2 - 3
3 - 3
3 - 4
4 - 5
No Data
N
W
E
S
0
2
4



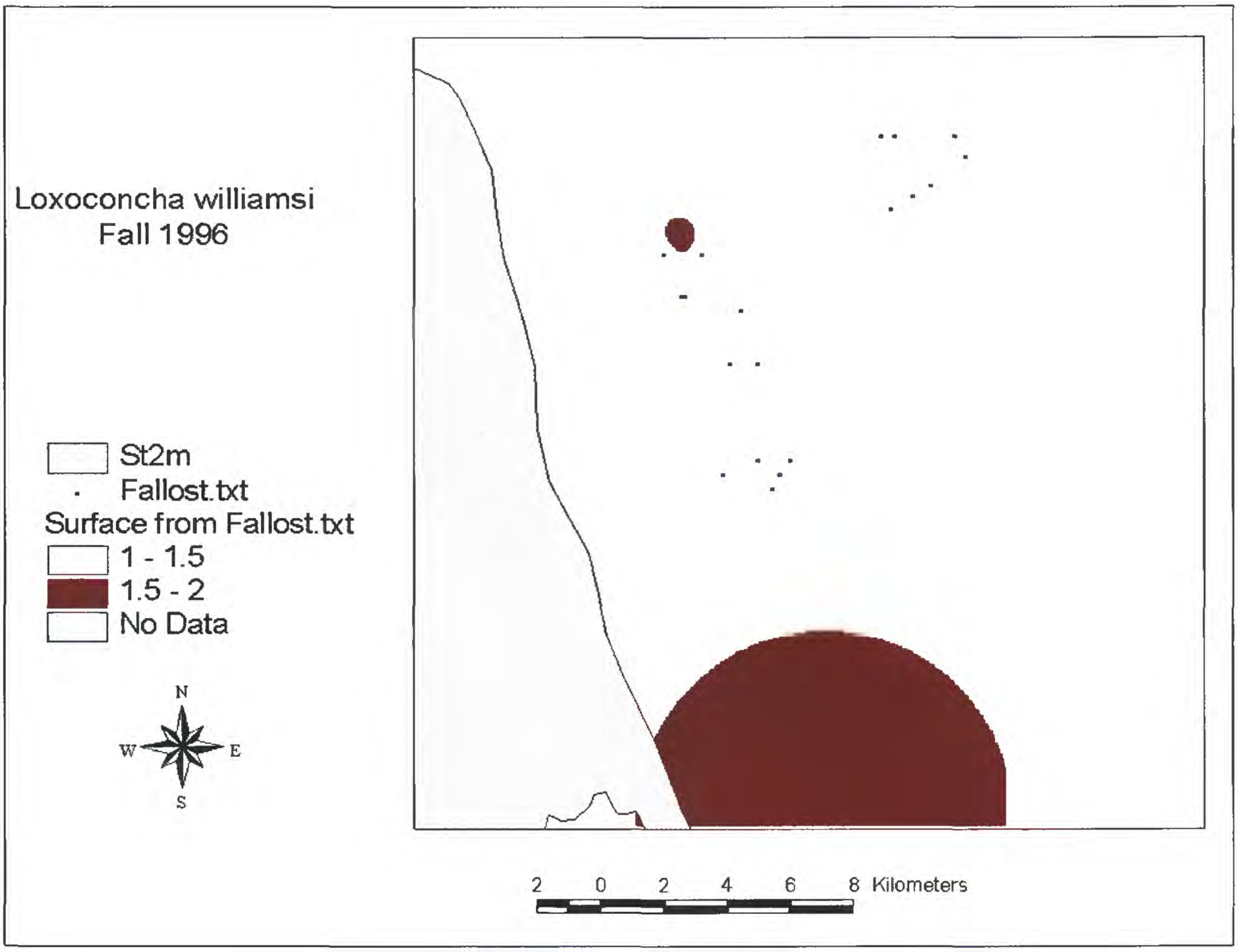
Cushmanidea seminuda
Fall 1996
St2m
Fallost.txt
Surface from Fallost.txt
1 - 2
2 - 3
3 - 3
3 - 4
4 - 5
Vabforam1.txt
N
W
0
3
6
Kilometers


Hulingsina rugipustulosa
Spring 1996
St2m
Sprost.txt
Surface from Sprost.txt
1 - 1.5
1.5 - 2
2 - 2.5
2.5 - 3
No Data
N
W
E
S
2 0 2 4 Kilometers

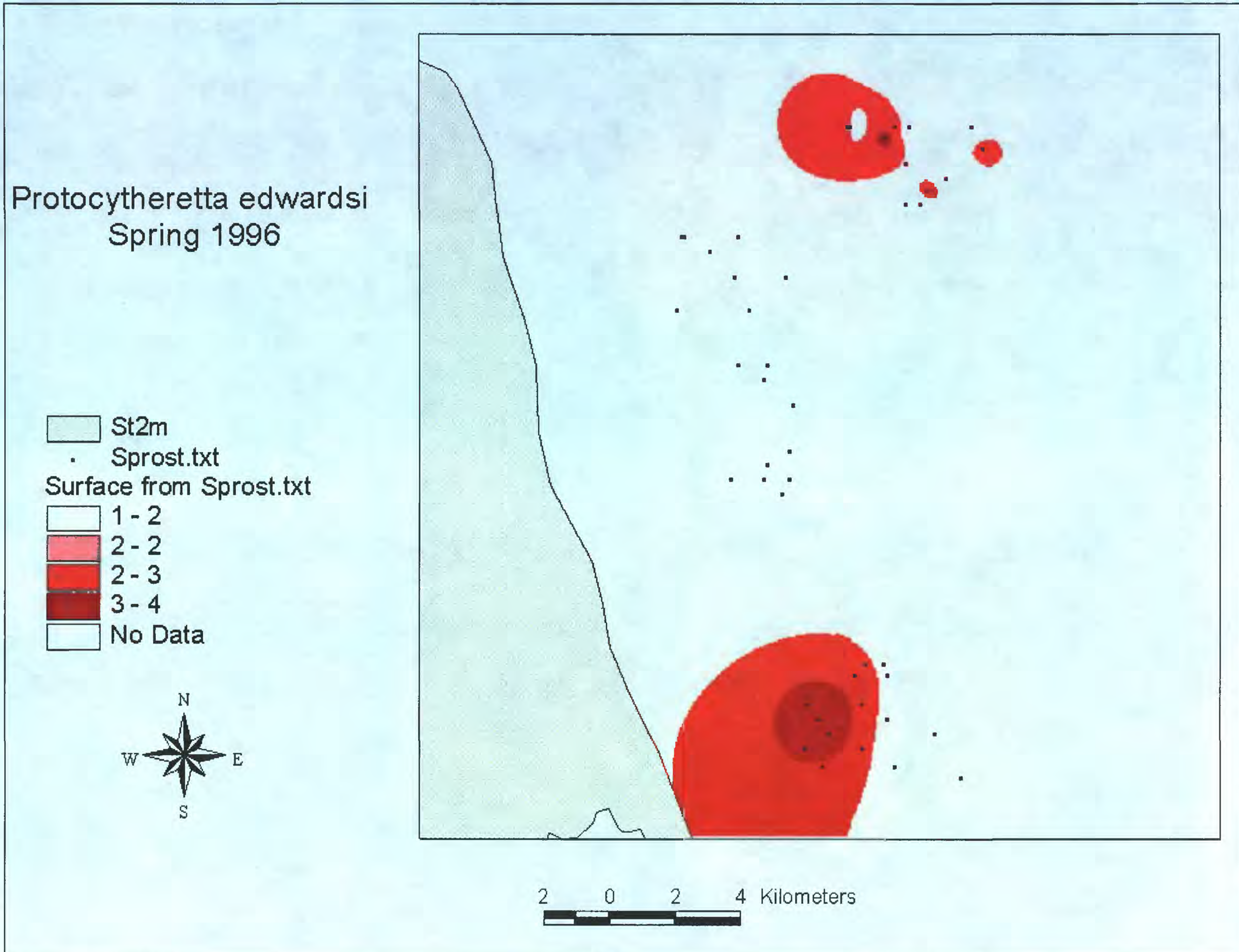

Hulingsina rugipustulosa
Fall 1996
St2m
Fallost.txt
Surface from Fallost.txt
1 - 1.5
1.5 - 2
2 - 2.5
25 - 3
Vabforam1.txt
N
W
2 0 2 4 6 8 Kilometers

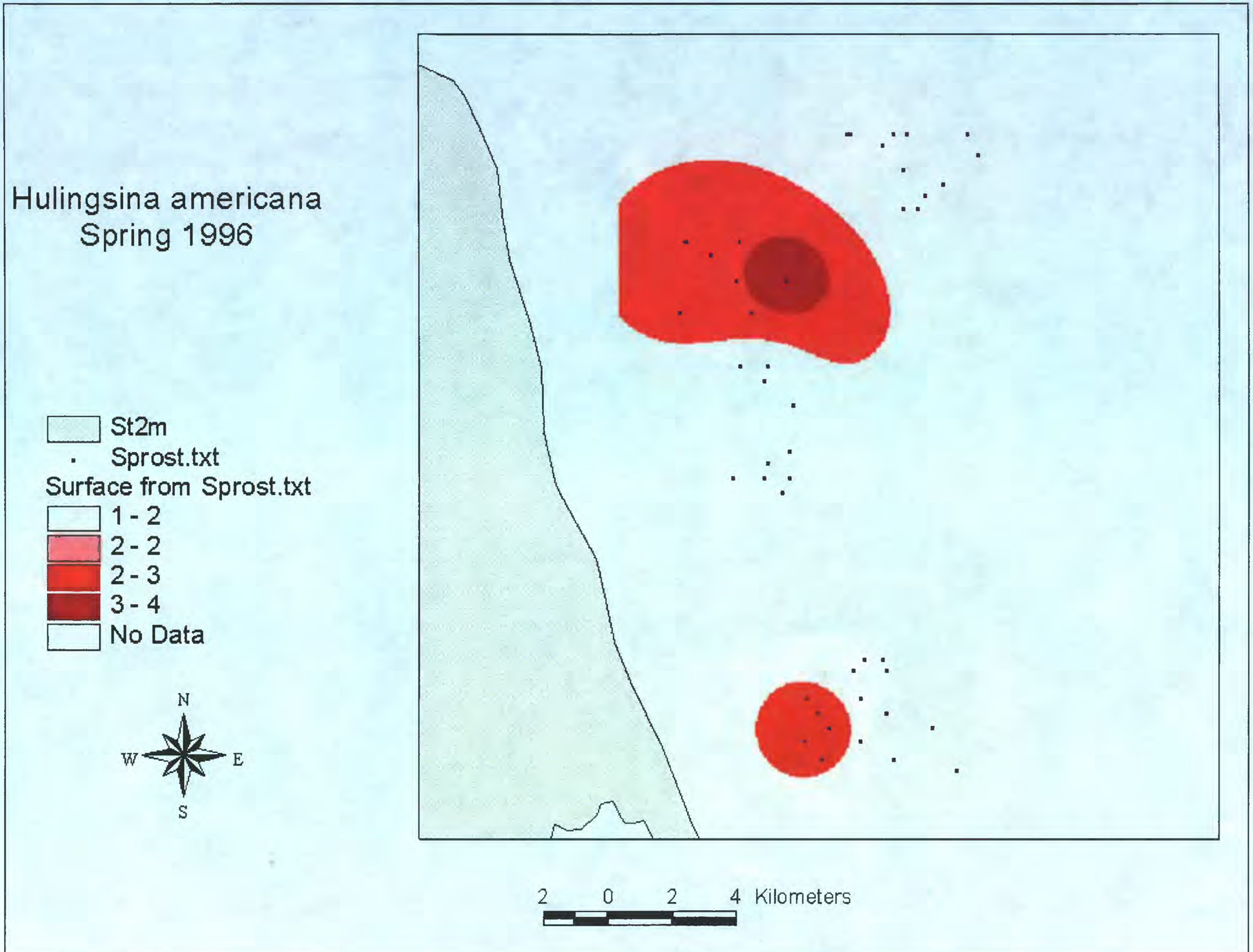


Loxoconcha williamsi
Spring 1996
St2m
Sprost.txt
Surface from Sprost.txt
1 - 2
2 - 2
2 - 3
3 - 4
No Data
N
W
E
S
2 0 2 4 Kilometers



Loxoconcha williamsi
Fall 1996
St2m
Fallost.txt
Surface from Fallost.txt
1 - 1.5
1.5 - 2
No Data
N
W
E
S
2 0 2 4 6 8 Kilometers


Protocytheretta edwardsi
Spring 1996
St2m
Sprost.txt
Surface from Sprost.txt
1 - 2
2 - 2
2 - 3
3 - 4
No Data
N
W
E
S
2 0 2 4 Kilometers


Hulingsina americana
Spring 1996
St2m
Sprost.txt
Surface from Sprost.txt
1 - 2
2 - 2
2 - 3
3 - 4
No Data
N
W
E
S
2 0 2 4 Kilometers

Date	Cell	Longitude	Latitude	*Elphidum excavatum clavata*	*Elphidum excavatum selseyensis*	*Elphidum excavatum excavata*	*Ammonia parkinsoniana*	*Bucella cf hamai*	*Hanzawaia concentrica*	*Quinqueloculina seminula*	*Florilus atlanticus*	*Cibicides bradyi*	*Guttulina lactea*	*Bulimina*	*Quinqueloculina jugosa*	*Bucella frigida*	*Planulina mera*	*Discorbis mira*	*Eggrelia advena*	*Trochamnina sp.*	Total
6/5/96	174	75.907	36.816	6	206	3	6	2	1	10											234
6/5/96	185	75.901	36.812		188	4	6	2	2	5	2										209
6/5/96	194	75.903	36.808	10	221	9	4	6	2	2	2		2	1							259
6/5/96	183	75.908	36.812	15	234	13	3	4	1		4	1									275
6/5/96	181	75.917	36.812	6	249		3					1	1								260
6/6/96	137	75.9	36.832	1	14			1		1			1								18
6/6/96	115	75.908	36.839	3	140	15	8	2	1	80	2		22		5						278
6/6/96	106	75.907	36.843		209	24				2											235
6/6/96	104	75.915	36.843	4	183	28	2	1	1						1						220
6/6/96	66	75.912	36.858	5	101	13	1			8											128
6/6/96	49	75.902	36.867		227	8		1		22	1		2		3						264
6/6/96	50	75.916	36.867	4	222	32		4	2	2			1								267
6/6/96	61	75.932	36.858	4	228	40				1			1			1					275
6/6/96	24	75.923	36.874	2	223	51	6			3											285
6/6/96	13	75.93	36.878	3	225	44	4			1											277
5/15/96	229	75.869	36.887	6	267	5				3											281
5/15/96	205	75.868	36.908	4	255	15		1		6	1										282
5/15/96	201	75.885	36.908	8	247	20		1		4											280
5/15/96	234	75.869	36.898	12	243	6			1	2	2						2				268
5/15/96	263	75.869	36.887	8	253	16	2	1	2	2	2				1						287
5/15/96	204	75.872	36.908	22	234	16	1		1	3	1						1	1			280
5/15/96	213	75.875	36.905	43	223	20			6	5	1					1	1				300
5/15/96	246	75.858	36.894	10	251	12	1	1	3	8	1						3				290
5/15/96	264	75.865	36.887	38	240	17			5	5	4					3	2				314
5/15/96	264	75.865	36.887	30	207	20	1	1	1	9	2				1		1				273
6/5/96	377	75.872	36.733	23	232	28				1						5			1		290
6/5/96	365	75.881	36.738		16					4			1		1	1					23
6/5/96	342	75.893	36.746	13	241	10	6		2	12	3		2			8					297
6/5/96	332	75.896	36.75	69	192	26															287
6/5/96	372	75.892	36.733	24	253	10	1									3					291
6/5/96	361	75.897	36.738	17	250	6	1		3	2						5					284
6/5/96	360	75.861	36.742	1	77	2			1	9	2		7				1		15	1	116
6/5/96	316	75.883	36.758	1	99	1	3			9	2		10		4				2	1	132
6/5/96	308	75.875	36.761	1	81	1	1	2	1	9	2		3		3						104

Appendix 2: Species Census data of Foraminifera on the Virginia Continental Shelf, Fall 1996

Date	Cell	Longitude	Latitude	*Elphidum excavatum clavata*	*Elphidum excavatum selseyensis*	*Elphidum excavatum excavata*	*Ammonia parkinsoniana*	*Bucelia cf hamai*	*Hanzawaia concentrica*	*Quinqueloculina seminula*	*Florilus atlanticus*	*Cibicides bradyi*	*Guttulina lactea*	*Bulimina*	*Quinqueloculina jugosa*	*Bucella frigida*	*Planulina mera*	*Eggrella advena*	*Trochamnina sp.*	*Eponides sp.*	*Rosalina floridana*	*Textularia sp.*	*E. disciodale*	Total
10/21/96	13	75.93	36.878	5	272	8	1	1			4					1		1						293
10/21/96	234	75.869	36.898	31	225	14	9			1	3					1		3						287
10/21/96	46	75.913	36.867	13	275	5	2			3						1								299
10/21/96	264	75.865	36.887	22	238	12	2		5	4	6						1							290
10/21/96	64	75.917	36.857	5	273	3	1		2	3	1				1	1	4							294
10/21/96	209	75.851	36.908	11	237			2	3	4	6						6							269
10/21/96	229	75.848	36.902	32	229	23	1		2	4	1	1					1							294
10/21/96	263	75.869	36.887	11	259	5	1	2	3	5	5			1	1		2							295
10/22/96	31	75.934	36.874	17	248	10	4	4		1	2								1					287
10/22/96	213	75.875	36.905	25	239	18	5				2													289
10/22/96	60	75.929	36.862	20	219	23	3	2									3		1					271
10/22/96	66	75.912	36.858	41	182	29	2	5													3	1		263
10/22/96	104	75.915	36.843	33	189	43	4		1		1					2								273
10/22/96	106	75.907	36.843	16	265	3	5	2					2											293
10/22/96	204	75.872	36.908	10	261	6			5	6	2						2			1				293
10/22/96	205	75.868	36.908	13	247	13		1	3	1	1					1	1							281
11/6/96	377	75.872	36.733	1	40		1	2			2		1											47
11/6/96	332	75.896	36.75	28	210	14		1	4	2	2					4								265
11/6/96	372	75.892	36.733	24	199	9			1		1		1	1		9								245
11/6/96	361	75.897	36.738	46	120	77	1		1	2	1					6		1						255
11/6/96	181	75.917	36.812	54	167	38	15	3	6	6	1	1	1											292
11/6/96	194	75.903	36.808	25	231	9	9	4	3	2	5		1			3								292
11/6/96	185	75.901	36.812	11	217	27	11		7	6		1	3		1	2							3	289
11/6/96	174	75.907	36.816	15	223	13	9	2	2	1	1		1			2								269
11/6/96	176	75.898	36.816	26	225	12	4	2	5		1	1				5								281

Date	cell	Latitude	Longitude	Actino. captionis	Benson. sp. A	Benson. sapeloensis	Benson.whitei	Bensonocythere	Campylocythere laeva	Cytherura howei	Cytheromorpha warneri	Cytherura sp.	Cytherura sp.	Cytheridea	Cushmanidea seminuda	Eucythere declivis	Hemicytherura	Hulngs.americana	Hulings.rugipustulosa	Hulingsina sp.	Loxo. sperata	Loxo. sp. A	Microcythere	Microcytherura sp. A	Microcytherura sp. B	Muellerina ohmerti	Paradox. delicata	Peratocytheridea bradyi	Proteo.gigantica	Prot.edwardsi	Puriana rugipunctata	Sahnis	Indeterminate	Other	Total
May-96	229	36.902	75.848												1			1										1		3					6
May-96	205	36.908	75.868												3					1								7		1					12
May-96	201	36.908	75.885												1				1											4					6
May-96	234	36.898	75.869																3									1	2			2			8
May-96	229	36.902	75.848												1				1	1								6		1					10
May-96	204	36.908	75.872												2													8	2	3					15
May-96	213	36.905	75.875																1									5	1	4					11
May-96	246	36.894	75.858																1									3	2	1					7
May-96	263	36.887	75.869												4										1			5	2	2					14
May-96	264	36.887	75.865												1				1									1		2	1	2			8
Jun-96	390	36.73	75.854																																0
Jun-96	377	36.733	75.872																																0
Jun-96	365	36.738	75.881									2								1			28		1										32
Jun-96	353	36.742	75.89																																0
Jun-96	342	36.746	75.893		2		1								1			3		1		1		2		1				4					16
Jun-96	332	36.75	75.896	1											1							1							1						4
Jun-96	372	36.733	75.892																																0
Jun-96	361	36.738	75.897					1							2							1					1								5
Jun-96	360	36.742	75.861		2		1			1			1			2							2	6	3					1			2		21
Jun-96	347	36.746	75.874																																0
Jun-96	336	36.75	75.881																																0
Jun-96	316	36.758	75.883		3								6					2		1			6	5	1									1	25
Jun-96	318	36.758	75.874																																0
Jun-96	308	36.761	75.875		1	1							2		1	1		1		1			4	2	2										16
Jun-96	307	36.761	75.88																																0
Jun-96	174	36.816	75.907												2				1							1									4
Jun-96	185	36.812	75.901												2					1															3
Jun-96	194	36.808	75.903																	3										1					4
Jun-96	183	36.812	75.908																																0
Jun-96	181	36.812	75.917												1															1					2
Jun-96	137	36.832	75.9																																0
Jun-96	115	36.839	75.908		5											2		2				4	1	12	10										36
Jun-96	106	36.843	75.907												2																				2

Appendix 3: Species Census data of Ostracoda on the Virginia Continental Shelf, Spring and Fall 1996

Jun-96	104	36.843	75.915												6												1	1							8
Jun-96	66	36.858	75.912																				1		1										2
Jun-96	49	36.867	75.902												2	1		4	1			2		2	1				1						14
Jun-96	50	36.867	75.916						1						1							3													5
Jun-96	61	36.858	75.932		1																	1													2
Jun-96	24	36.874	75.923																1																1
Jun-96	13	36.878	75.93			1									1					1															3
Jun-97		36.878	75.93												1					1						1							1	1	5
Jun-96		36.8195	75.901												2															2					4
Jun-97	169	36.878	75.9304												1				1									1	1		1				5
Jun-97	13	36.878	75.915																															1	1
Jun-97	104	36.843	75.915																	1		1													2
Jun-97		36.908	75.884									2												1						1					4
Jun-97	201	36.908	75.885																	1								1							2
Jun-97	205	36.908	75.868		1										1			1		1								5		3				1	13
Jun-97	209	36.908	75.851		1										1					4								3		1					10
Jun-97	234	36.898	75.869											1	1					1					1			2						1	7
Jun-97	246	36.894	75.858									1		1	1				1	1	1							6	1	4				1	18
Jun-97	255	36.891	75.863											2	2													5		3	1			1	14
Oct-96	13	36.878	75.93												1							2													3
Oct-96	24	36.874	75.923												5							1													6
Oct-96	31	36.874	75.934			1									2							1													4
Oct-96	46	36.867	75.913								1								2			1						4		1					9
Oct-96	52	36.862	75.928																							1		1							2
Oct-96	55	36.863	75.917				1								2				2									4							9
Oct-96	60	36.862	75.929																			1													1
Oct-96	64	36.857	75.917									1	1		2												1	2	1	2					10
Oct-96	66	36.858	75.912													1						1													2
Oct-96	104	36.843	75.915																			1		1						1					3
Oct-96	106	36.843	75.907												3					1		1													5
Oct-96	204	36.908	75.872												2				1									1		1					5
Oct-96	205	36.908	75.868																3									1							4
Oct-96	209	36.908	75.851									1			1				1									6							9
Oct-96	229	36.902	75.848									1			3				1									3						1	9
Oct-96	263	36.887	75.869										1					1											2						4
Nov-96	377	36.733	75.872						1																					1					2
Nov-96	332	36.75	75.896			1														3													2		6
Nov-96	372	36.733	75.892			1																2													3
Nov-96	361	36.738	75.897			1										1				2						1									5
Nov-96	181	36.812	75.917												5												1								6
Nov-96	194	36.808	75.903			1									1					2								1					1	1	7
Nov-96	185	36.812	75.901												1											1									2
Nov-96	174	36.816	75.907												4										1	1									6
Nov-96	176	36.816	75.898											1																					1

Cronin, Ishman, Wagner, Cutter