MARYLAND

TASK 23

ZANNICHELLIA PALUSTRIS: A MODERN AND PALEOECOLOGICAL INDICATOR OF HUMAN DISTURBANCE IN CHESAPEAKE BAY

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Abstract

Title: _Zannichellia_ _palustris_: A Modern and Paleoecological Indicator of Human Disturbance in Chesapeake Bay

An examination of _Zannichellia_ _palustris_ from disturbed and undisturbed habitats in Chesapeake Bay reveals differences in size and seed production of two populations, referred to as tall and short forms. The tall form of _Zannichellia_ produces a mean of 13 fruits per plant and the short form 4 fruits per plant, while surface sediments yield 150 _Zannichellia_ seeds per 100 cc where the tall form grows, and 13 seeds per 100 cc where the short form occurs. Seeds of the two forms are indistinguishable morphologically.

Robin Cove, a relatively undisturbed embayment, is the habitat of five species of submerged aquatic vegetation (SAV) including the tall and short forms of _Zannichellia_. The tall form grows in predominantly clay sediment beyond the intertidal zone, and is the dominant SAV where it occurs during May and June. The short form inhabits the sandier substrates in shallower water and intertidal zones. It is subdominant to _Elodea_ _nuttallii_. In addition to _Zannichellia_, surface sediments in Robin Cove

contained seeds of 16 species of plants, 71% occurring within a 30 meter radius of the transect.

The short form of _Zannichellia_ is the only SAV growing in Brewer Creek, a tributary heavily used for recreation, where it is found in a range of water depths and occurs predominantly in sand. Surface sediments of Brewer Creek contained 6 species of shoreline flora adjacent to the transects.

Distributions of _Zannichellia_ populations indicate that the different forms may be used to monitor human disturbance around an estuary. Diversity of seeds in the sediment along with abundance of _Zannichellia_ seeds can also be used as historical indicators of water quality and disturbance in the past.

LISTS OF FIGURES

Figure	Name	Page
1	Map of Chesapeake Bay	8
2a	Location of Robin Cove	10
3a	Location of Brewer Creek	12
2b	Transects in Robin Cove	14
3b	Transects in Brewer Creek	15
4a	Cross-sections of Transects 1 & 2 in Robin Cove	17
4b	Cross-sections of Transects 3 & 4 in Robin Cove	18
5	Cross-sections of Transects in Brewer Creek	19
6	Morphology of Fruits of *Zannichellia*	20
7	Core SR3a from Brewer Creek	39
8	Distribution of Z.p. from Cores	44
9	Core CHR6c from Langford Creek	46
10	Core SR1a from Severn River	47

LIST OF TABLES

Table	Name	Page
1a	Percent Cover, SAV in Robin Cove	23
1b	Percent Cover, SAV in Brewer Creek	24
2	Mean Water Depth	26
3	Number of Seeds in Sediment	27
4	Percent Cover & Percent Seed Number	29
5	Fruit Length & Rostrum/Fruit Ratio	32
6	Stem Length & Number of Fruits	33
7	Height of _Zannichellia_ Plants	34
8	Sediment Descriptions	35

TABLE OF CONTENTS

Page

ABSTRACT ii

ACKNOWLEDGEMENTS iv

LIST OF FIGURES v

LIST OF TABLES vi

TABLE OF CONTENTS vii

INTRODUCTION.. 1

GROWTH FORMS & ECOLOGY OF ZANNICHELLIA.............. 4

AREA OF STUDY....................................... 6

Robin Cove.. 9

Brewer Creek.. 11

METHODS... 13

Field Sampling...................................... 13

Laboratory Analysis................................. 16

Statistical Analysis................................ 22

RESULTS... 22

DISCUSSION.. 36

CONCLUSION.. 48

LITERATURE CITED.................................... 50

VITA.. 57

INTRODUCTION

Declines in populations of submerged aquatic vegetation (SAV) in Chesapeake Bay, particularly in the 1960's and 1970's, have been attributed to changes in water quality, primarily increased eutrophication and turbidity from anthropogenic activity (Orth and Moore 1983; 1984; Stevenson and Confer 1978). The decline in areal coverage and number of species affected has been unprecedented. However, studies of SAV in lakes have shown that eutrophication and turbidity are not always followed by a decline in SAV abundance. Rather this kind of disturbance tends to promote the growth of environmentally tolerant, eutrophic species with a widespread distribution, at the expense of local, endemic species, while a concomitant decline in species diversity occurs (Ehrenfeld 1983; Jupp and Spence 1977; Morgan and Phillip 1986; Stuckey 1971; 1978).

One such SAV which is widespread geographically and appears to have a tolerance to eutrophication and human disturbance is Zannichellia palustris. It is nearly cosmopolitan in distribution, occurring over a wide temperature and salinity gradient. Populations have increased or remained constant in eutrophic waters of western Europe (Van Vierssen 1982b), Scotland (Jupp and Spence 1977), and in lakes in the central United States

(Lind and Cottam 1969; Stuckey 1971). In Chesapeake Bay, Zannichellia is not present in some eutrophic tributaries and since the 1960's has been increasing in other nutrient-rich areas, leading some investigators to believe that Z. palustris is an ephemeral, pioneer species (Stevenson and Confer 1978).

The fossil record of Zannichellia palustris seeds however, shows that the species has been a persistent occupant of Chesapeake Bay for over 2000 years, with some fluctuations in populations related to climatic events and human activities (Brush, Hilgartner and Thorton in prep). Changes in fossil seed numbers indicate a general expansion during European colonization in the mid-1700's, when increased siltation and nutrients from runoff of agricultural land occurred throughout much of Chesapeake Bay (Brush 1984a; 1984b; 1986; 1989; Brush and Davis 1984). Following this period and until about 1970, seed influxes decreased with intensification of agriculture and expansion of urban development. Since the 1970's, the range of Zannichellia palustris has expanded in the lower tributaries of the western shore and in Chester River (Fig. 1), while declining in the upper stretches of many tributaries.

While an appreciable amount of information concerning the autecology of Zannichellia is available (see Stevenson and Confer 1978; Van Vierssen 1982a; 1982b; 1982c), knowledge of its precise ecological requirements in North America is lacking. Both growth forms have been described from Europe, but the ecology in Europe differs from what has been observed in Chesapeake Bay (Hilgartner pers. obs.). For example, Z. palustris in Europe is generally confined to freshwater, a stratification period of 2 months at 4°C is required for the seeds to germinate in early spring, and the tall form is considered a perennial while the short form is considered an annual (Van Vierssen 1982a). In Chesapeake Bay, Z. palustris is most common in brackish water with a salinity tolerance of up to 20 ppt., germination appears to occur in late summer when no stratification period is required, and the tall form is evidently annual, dying back by early June (Stevenson and Confer 1978; Hilgartner, pers. obs.). The relationship of disturbance, sediment, wave action, water depth, and water quality as well as seed production and fossilization, with growth patterns of Zannichellia palustris needs to be more clearly defined.

The purpose of this study was to explore the possibility of using population characteristics of Z. palustris as an indicator of water quality in Chesapeake Bay. Zannichellia vegetation and associated SAV were compared in two sites that differed in the degree of anthropogenic disturbance. The relationship of plant cover, seed production and seed abundance in surface sediments of Zannichellia was compared to plant cover and seed abundance of associated species. The broad spatial distribution of Zannichellia, its abundant seed record in sediments, and response to changes in water quality suggest that a few simple measurements of plant growth and/or seeds in surface sediments might serve as a water quality monitoring tool. Additionally, seed numbers along with associated flora, could be used to refine analyses of environmental changes in the paleoecological record.

GROWTH FORMS AND ECOLOGY OF *ZANNICHELLIA PALUSTRIS*

Zannichellia palustris is cosmopolitan in distribution, occurring throughout Eurasia and the Sahara, North America from Alaska to Guatemala in the northern hemisphere, and in South Africa, India, Madagascar, and New Zealand in the southern hemisphere, being absent only from Australia and the tropics (Haynes and Holm-Nielson 1987; Ridley 1930). This wide distribution of *Zannichellia* has presented problems concerning its taxonomy and ecology (Van Vierssen 1982a). In western Europe, where there are four taxa of *Zannichellia*, *Z.*

palustris occurs in two growth forms (Van Vierssen 1982a,1982b). The short, creeping form, Z.p. repens, is an annual that occurs in northern latitudes in a wide range of water depths from near water edge to depths greater than 1 meter. These plants are tolerant of disturbances by current and wave action. The tall form, Z.p. palustris, grows more than one meter in length in water depths of 1.85 m, and behaves as a perennial. Both forms are found primarily in fresh water, being intolerant of salinities > 3.5 ppt. Seeds must undergo a stratification period of two months at 4°C before germination the following spring.

By contrast, in North America, Zannichellia consists of a single annual species Z. palustris, which reproduces solely by seeds (Haynes 1988; Haynes and Holm-Nielsen 1987). Like its counterpart in Europe, there are two growth forms in Chesapeake Bay, a prostrate form and an upright form (Hurley 1990). Stevenson and Confer (1978) noted that the species is never found where wave action is significant.

Zannichellia generally grows in shallow, quiet water 0.5 to 1.5 m deep and occurs in a wide salinity range from freshwater lakes high in sulfate ions in Minnesota to mesohaline waters of estuaries in salinities up to 20 ppt (Lind and Cottam 1969; Moyle 1945; Stevenson and Confer

1978; Hurley 1990). Seed germination can occur during the year of deposition. Two fruiting and growth periods, one in late spring and one in late summer have been reported (Stevenson and Confer 1978), but *Z. palustris* has been observed in fruit each month from May to October in Chesapeake Bay (Hilgartner, personal observation).

It is possible that the short and tall forms in Chesapeake Bay are homologous to the two subspecies *Z.p.repens* and *Z.p.palustris* found in Europe. However, it has been suggested that these two forms could also represent two species (Haynes, pers comm). Also possible is that these forms represent ecotypes or climatic races (Clausen et al 1941) or environmentally induced growth forms called ecophenes by Mooring et al (1971), similar to those which occur in the two growth forms of *Spartina alterniflora*.

AREA OF STUDY

To assess the effects of human activity on *Zannichellia palustris*, populations were examined in a disturbed and undisturbed tributary. In this study, disturbance includes heavy recreational use and proximity to residential development. Recreational factors that directly affect submerged vegetation include motorboats, which tear and uproot plants and produce exhaust gases and engine oil which have detrimental effects on plants. Dredging, retaining walls, boat docks and foot traffic all affect shallow-water habitats (Stuckey 1971; 1978). The residential community also stresses organisms by affecting water quality through septic systems and runoff. The Chester River on the eastern shore and Severn River on the western shore of Chesapeake Bay were chosen for the study (Fig. 1). Human activity along the Chester River is primarily rural. Large tracts of privately owned land are used for agriculture, game management and private use. There are numerous isolated coves and tributaries. On the other hand, heavily residential development including the city of Annapolis characterize the environs of the Severn River.

Brewer Creek, a small tributary of the Severn River, supporting heavy boat traffic and dense residential use, is the study site for the disturbed tributary. Robin Cove, near the confluence of the Corsica and Chester Rivers, surrounded by marshland and loblolly pine is the study site for the relatively undisturbed environment. _Z. palustris_ grows in both tributaries.

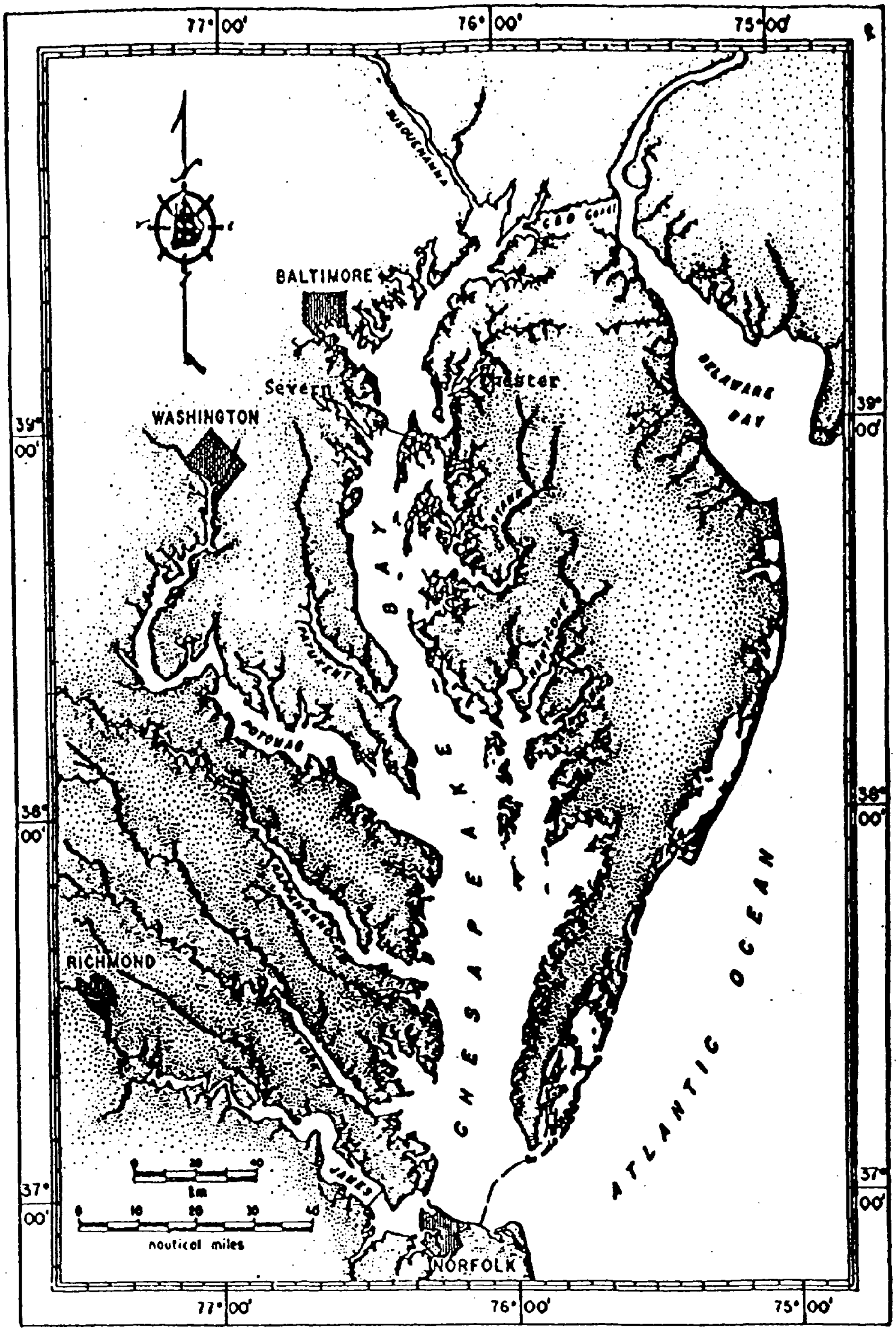


Figure 1. Map of Chesapeake Bay, showing location of Chester and Severn Rivers

Robin Cove ($39^{\circ}04'$N and $76^{\circ}09'$W) (Fig.2a)

This protected tidal tributary runs through Corsica Neck, a peninsula at the confluence of the Corsica and Chester Rivers. It is underlain predominantly by Quaternary lowland deposits of gravel, sand, silt and clay (Cleaves et al 1968), and surrounded by tidal marsh on the north, east and south sides, and forest dominated by Pinus taeda (loblolly pine) and Liquidambar styraciflua (sweetgum) on the southeast side. The cove has been privately owned at least since 1928 (Peter Sheaffer, personal communication). Maps from 1860, 1915, and 1951 show virtually no change in the configuration of Robin Cove or in the surrounding land use during the past 130 years. On the Besley Map of 1915, the pine forest is clearly shown where it exists today. On the north and east sides of the cove is a private game management farm abutting the surrounding marsh. The closest residence is about 0.5 km distant. A wooden structure built in the 1950's, prevents boats from entering the mouth of the cove, but does not disrupt the natural ebb and flow of tides.

The sediment where SAV grows is predominantly soft clay mixed with some sand, into which a person can sink to 25 cm in some places. Dominant emergent vegetation growing in, or just beyond the intertidal zone includes Spartina alterniflora, S. patens, S. cyansuroides, Iva frutescens,

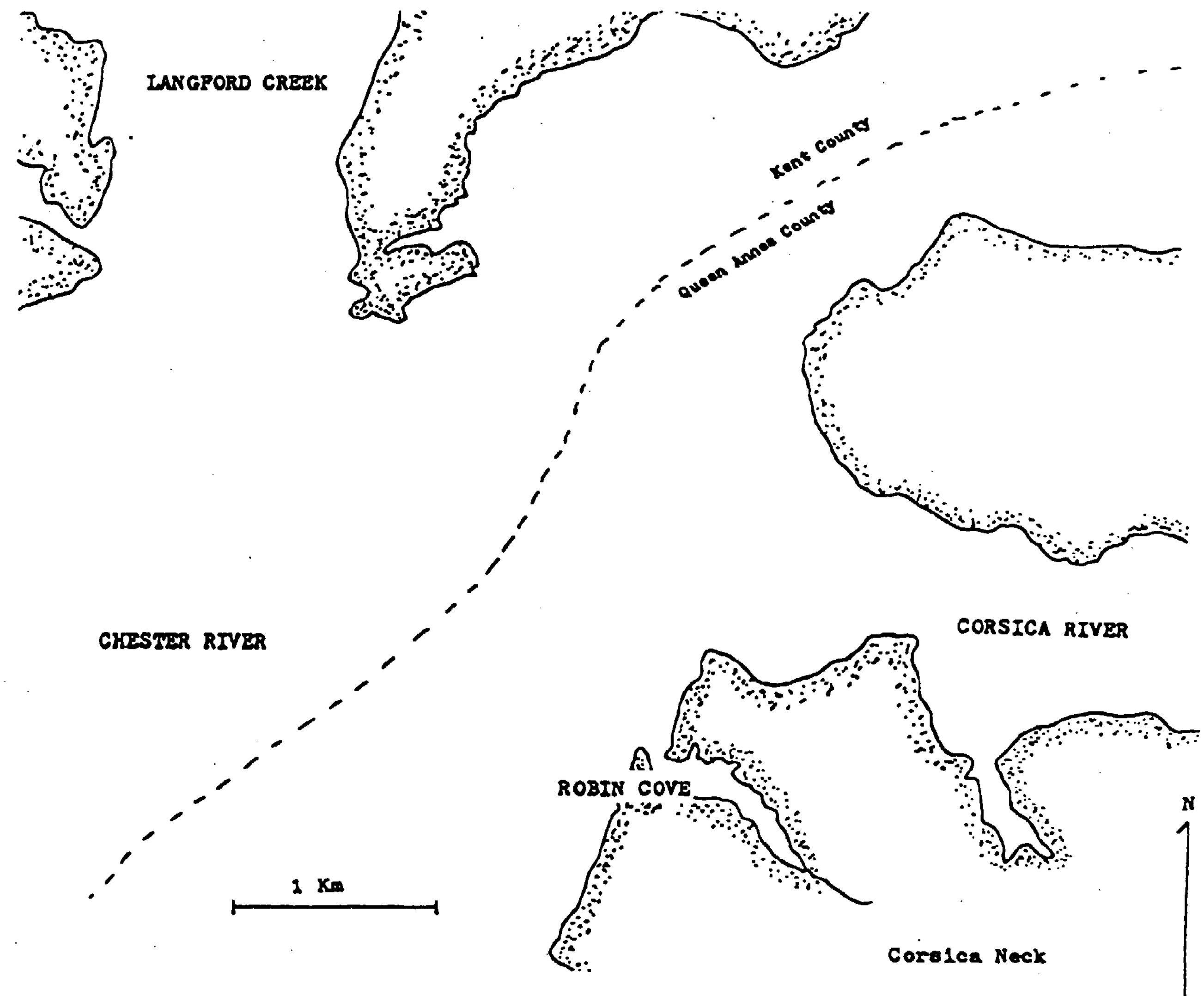


Figure 2a. Map showing location of Robin Cove

Acnida cannibina and Aster tenuifolius. Five species of submerged angiosperms were observed growing along the northeast shore: Zannichellia palustris (both short and tall forms), Elodea cf. nuttallii, Potamogeton perfoliatus, Myriophyllum spicatum and Ruppia maritima. The above suite of species is typically found in an average annual salinity range of 9-14 ppt (Phillip and Brown 1965).

Elodea nuttallii was distinquished from E. canadensis on the basis of leaf size and salinity .tolerance. E. nutallii is found in salinities of 14 ppt; E. canadensis cannot tolerate salinities > 3.6 ppt (Cook and Urmi-Konig 1985; Phillip and Brown 1965).

Brewer Creek (39°02′N and 76°32′W) (Fig.3a):

Brewer Creek, a tidal tributary of the Severn River, is surrounded by steep slopes of upper Cretaceous fine to coarse grained sand (Cleaves et al 1968; Vokes and Edwards 1974). Sherwood Forest, a community of summer homes established in 1920's is surrounded by mature Quercus spp. (oaks) and Liriodendron tulipifera (tulip tree). Boat traffic is heavy and is accomodated by boat marinas. There is frequent foot traffic on the firm, fine

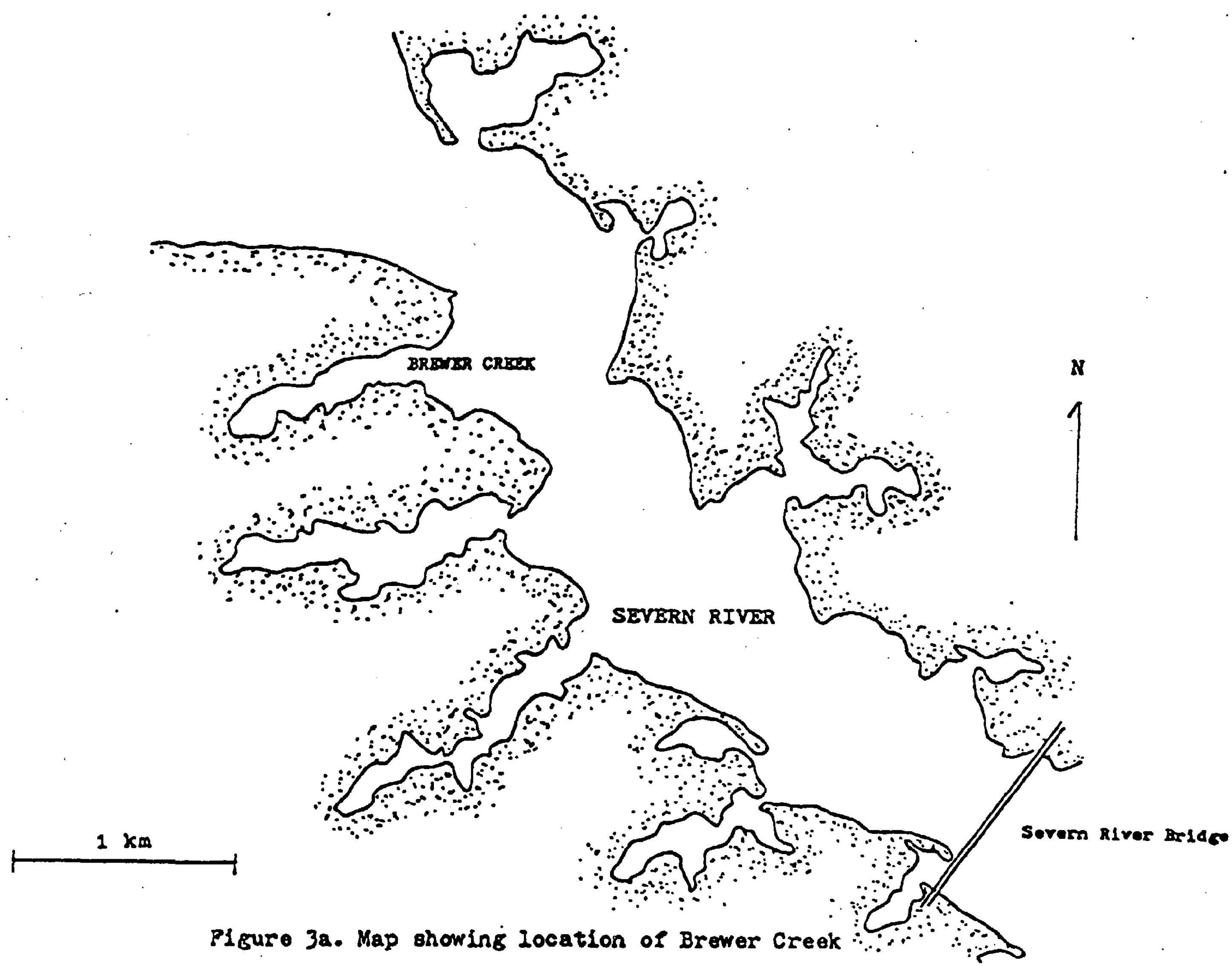


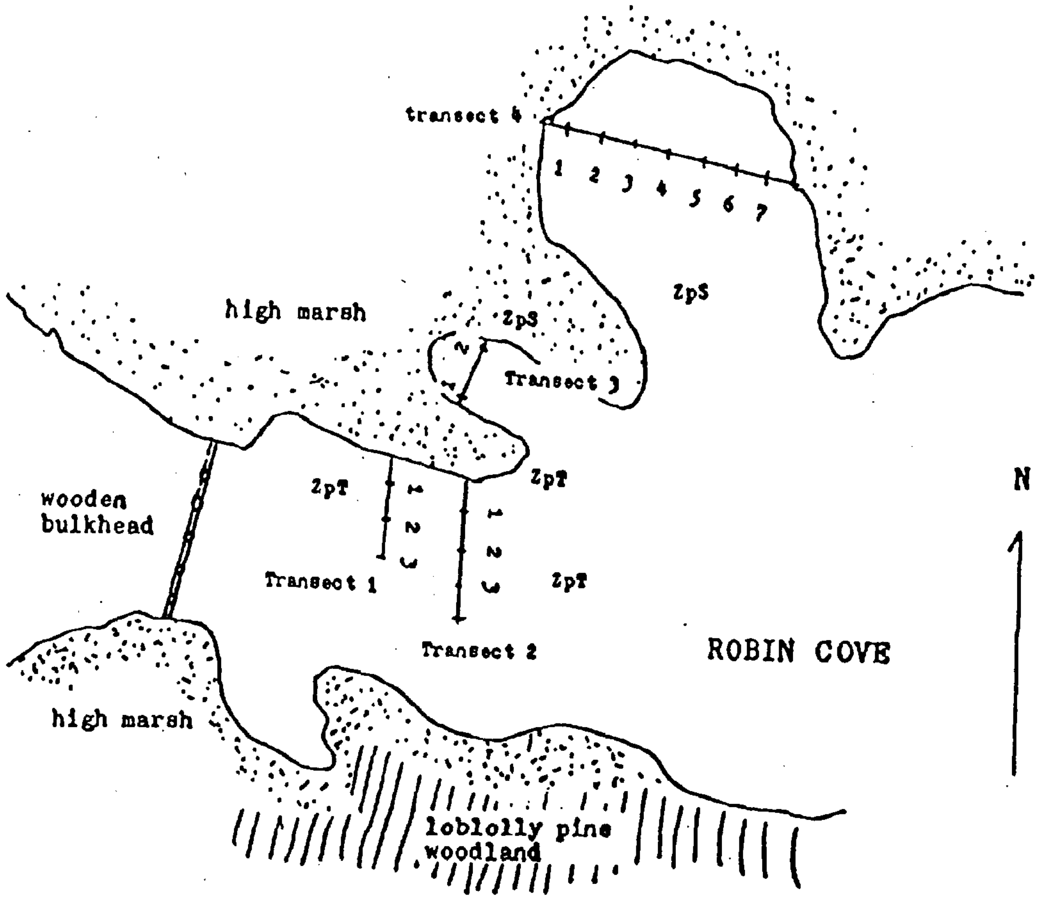
Figure 3a. Map showing location of Brewer Creek

intertidal sand. Scirpus americanus and an unidentified grass are the dominant emergent plants growing in the intertidal zone. The short form of Z. palustris was the only SAV observed at the site during the summers of 1987 and 1990.

METHODS

Field Sampling

Vegetation: Percent cover for all SAV was determined from 1 m quadrats spaced at 5 m intervals along transects ranging in length from 10 to 40 m. In Robin Cove, 16 quadrats were sampled along 4 transects. The transects were made by walking one meter away from the transect line in order to minimize disturbance of plants within the quadrat. Two transects were run through beds of tall Zannichellia palustris adjacent to a sand bar, and 2 transects were run through beds of short Z. palustris in shallower water (Fig. 2b). In Brewer Creek, nine quadrats were sampled along three transects positioned perpendicular to the shoreline and 1 transect parallel to shore (transect 4) (Fig.3b). Data collected from quadrats in transect 4 included only plant cover and buried seeds. Each 1 m2 quadrat was divided into one

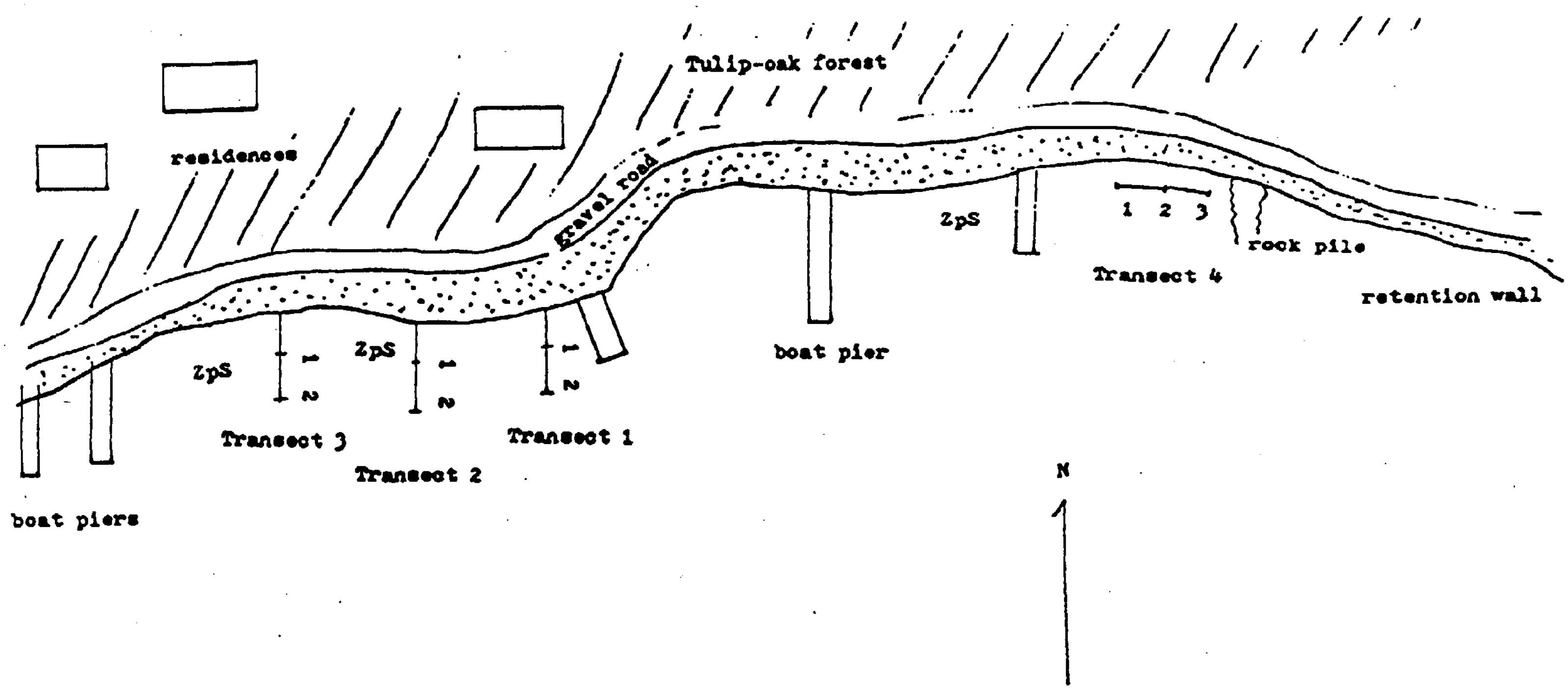


ZpS: __Zannichellia__ __palustris__ (short form)

ZpT: __Zannichellia__ __palustris__ (Tall form)

—+— : Quadrat

Figure 2b. Location of transects in Robin Cove



ZpS: *Zannichellia palustris* (short form)

⊢ : Quadrat

Figure 3b. Locations of transects in Brewer Creek hundred 10 cm X 10 cm units. The number of units in which a species occurred in each quadrat provided the measure of percent cover for that particular species. Total percentage in each quadrat could exceed 100%. Height of plants within quadrats and along transects was also measured. Depth of water at high tide was measured. Samples of both forms of <u>Zannichellia</u> were collected. Other species growing at the site but not included in the transects were recorded. Transect cross-sections are shown in Figs. 4 and 5.

Sediment: Surface sediment samples were collected from randomly chosen points within each quadrat for seed analysis. A short tube with a piston was inserted into the sediment, which when extruded, provided a sample 2 cm long. The sediment sample was placed in a ziploc bag, labeled, and stored at 4°C in the laboratory.

Laboratory Analysis

Seeds (fruits) on plants: The fruiting structure of *Zannichellia* has been referred to as an endocarp, achene, and nutlet (Fernald 1970; Gleason 1952; Haynes and Holm-Nielsen 1987; Montgomery 1977; Pierce and Tiffney 1986; Ridley 1930). The general term 'fruit' is used here (Fig. 6). Morphometrics conforming with Van Vierssen (1982a) include number of fruits, fruit length, fruit rostrum

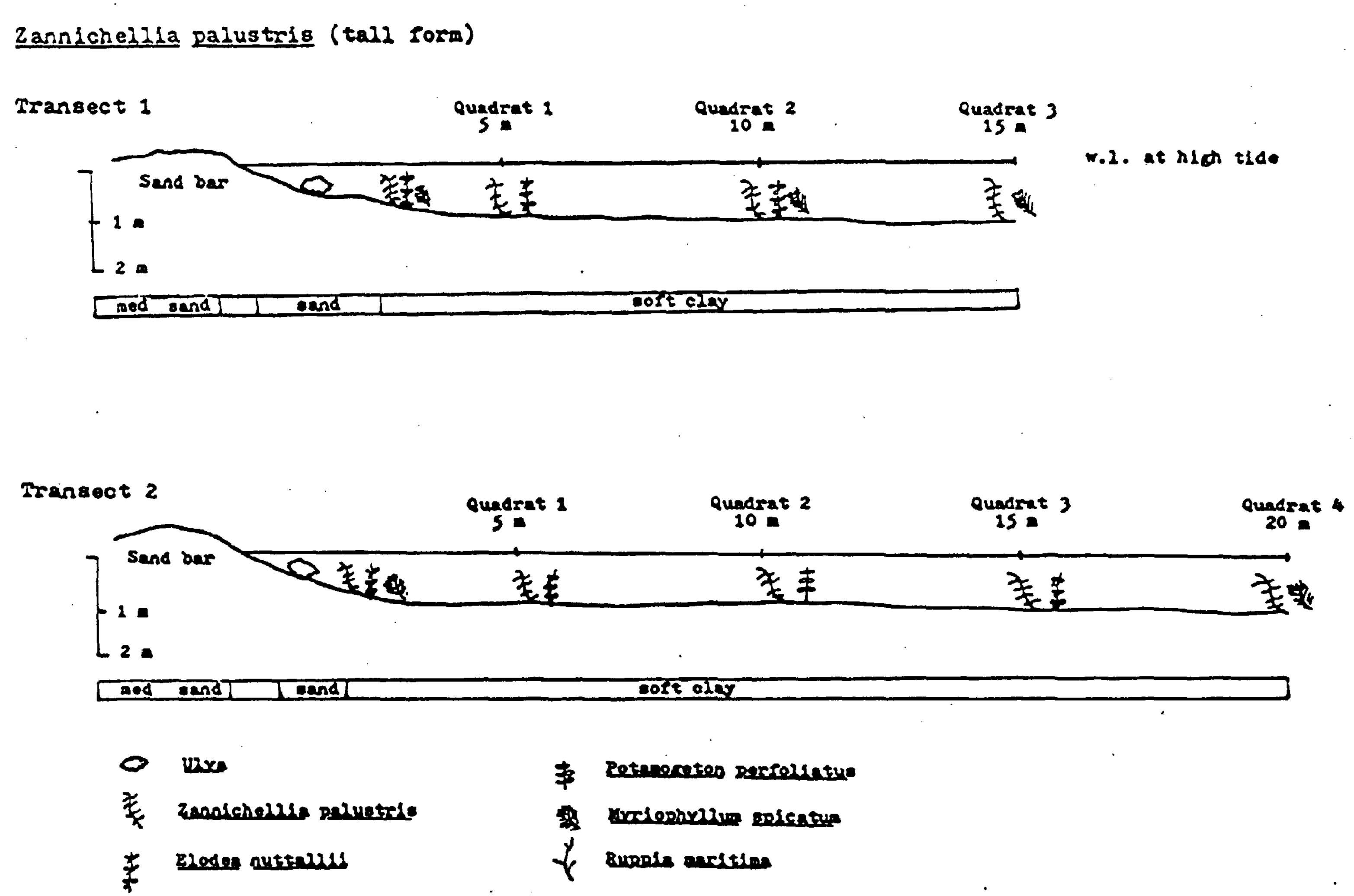


Figure 4 a. Cross-sections of Transects 1 and 2 in Robin Cove

Zannichellia palustris (short form)

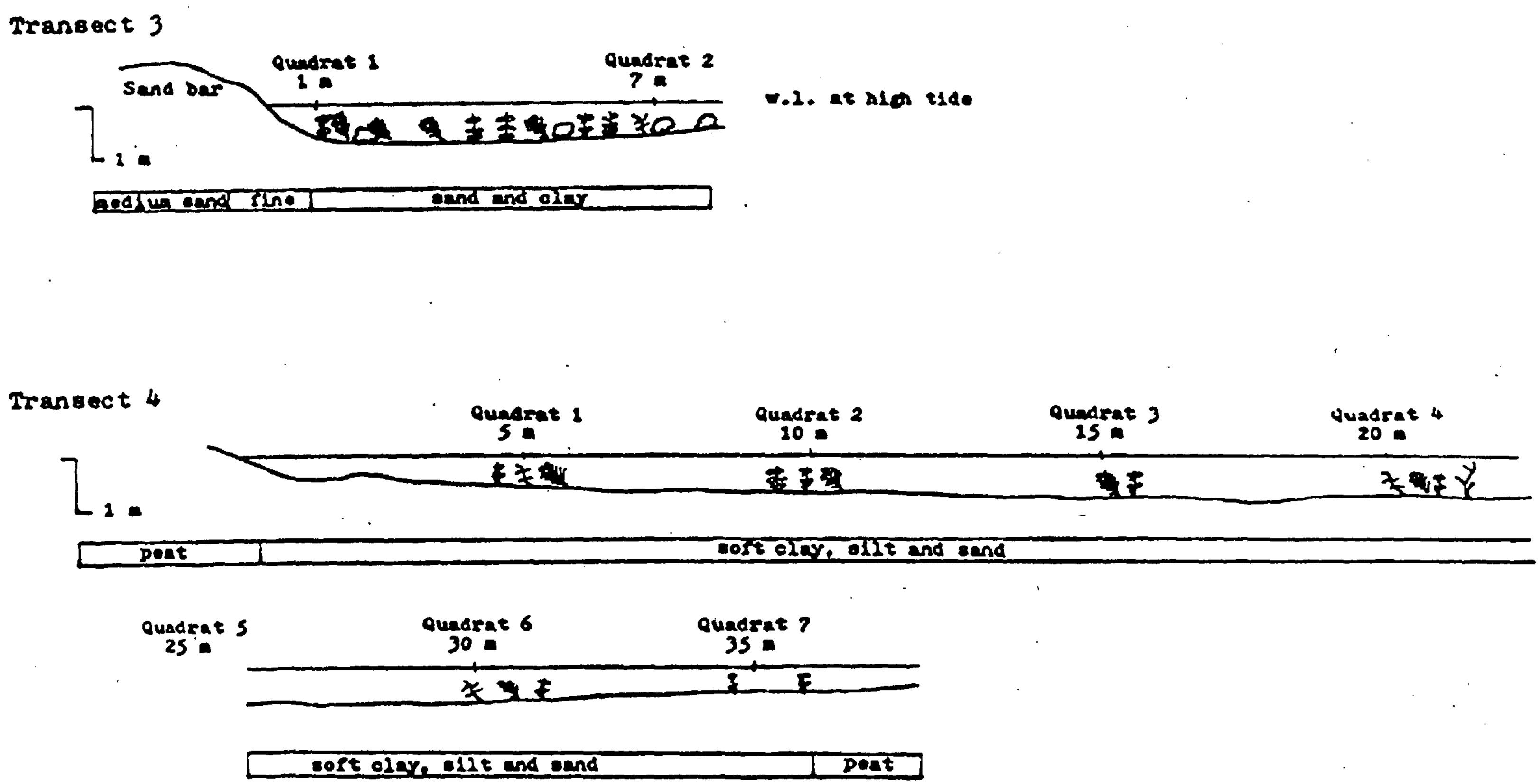


Figure 4 b. Cross-sections of Transects 3 and 4 in Robin Cove

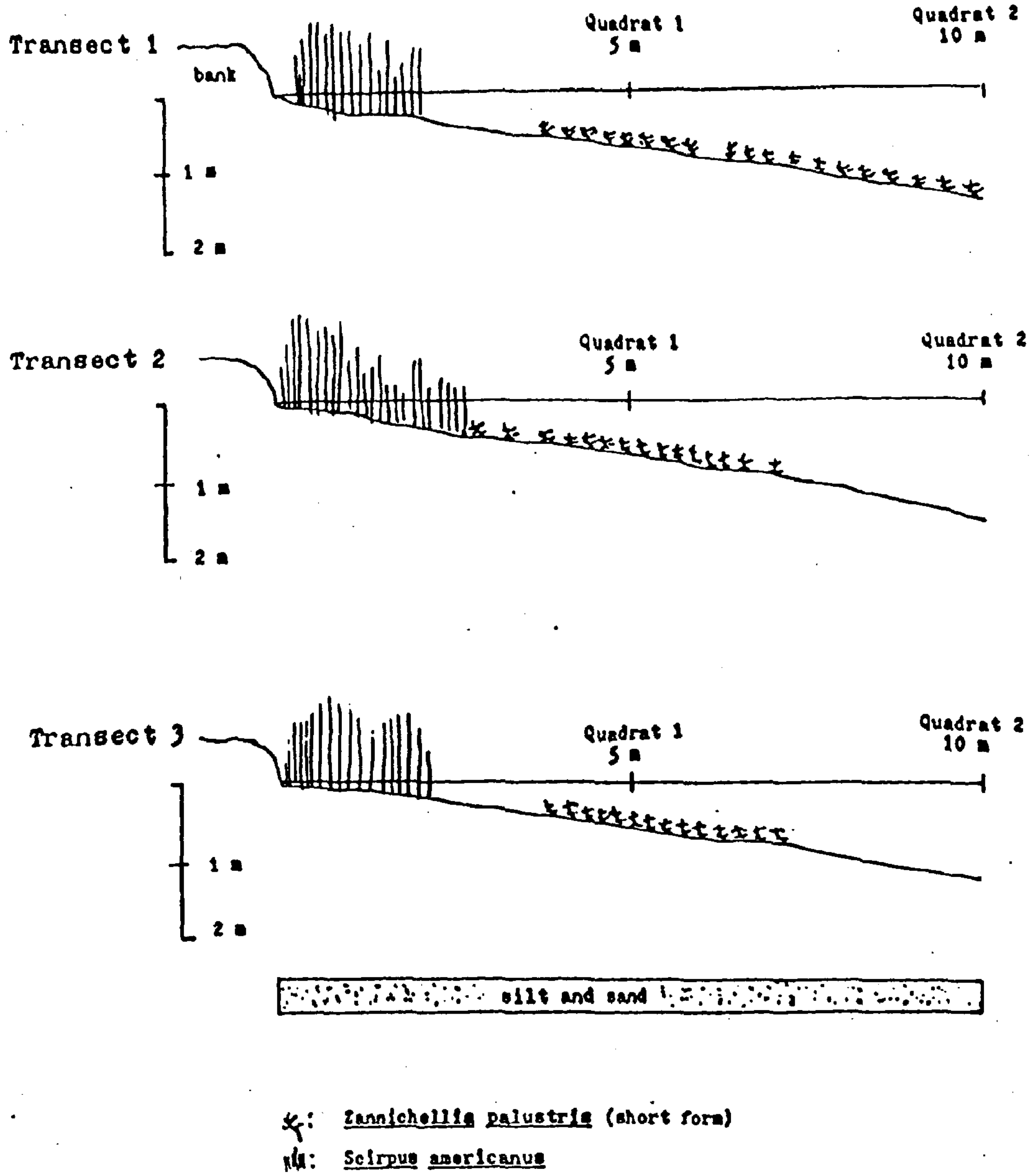


Figure 5. Cross-sections of transects in Brewer Creek

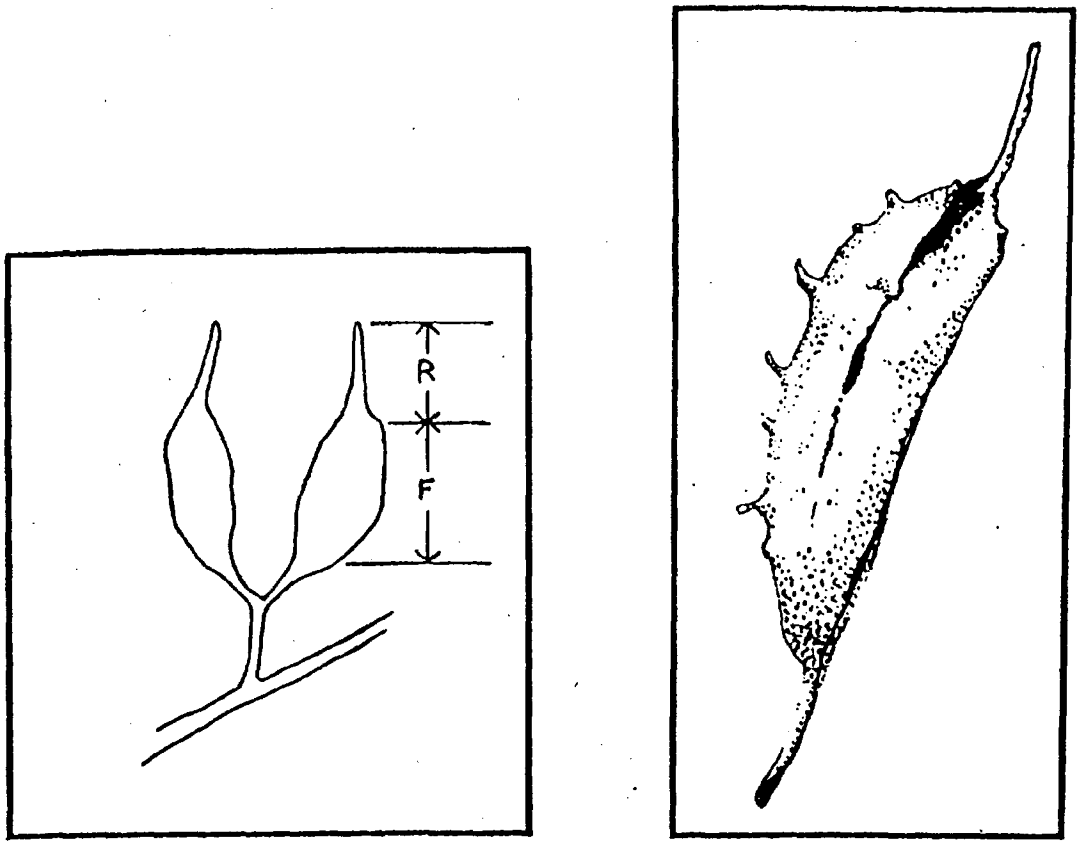


Figure 6. Morphology of fruits of <u>Zannichellia palustris</u>. Fruits on left show location of rostrum and fruit length measurements. Fossil seed on right shows the typical appearance of seeds found in sediment, with teeth along the convex margin.

length, and the ratio of rostrum to fruit length. Number of fruits per cm of internode is multiplied by the mean height of plants in the quadrats to arrive at an estimate of the mean number of fruits per plant. Morphological features, such as teeth along the convex margin of the fruit, were also noted, in an attempt to distinquish the seeds of the two growth forms.

Seeds in Sediment: The term 'seed' includes any angiosperm fruiting body retrieved from surface sediments, often referred to in paleoecological literature as macrofossils. A subsample of each sediment sample was placed in a measured volume of 10% HNO_3. The volume of the subsample was measured by the amount of displaced liquid. The sediment was allowed to remain in the acid for 2 hours, whereupon it was wet-sieved through two nested sieves. Seeds were isolated and examined under 10X and 40X magnification. Identification was accomplished using the seed reference collection at the Johns Hopkins University and seed identification keys (Gleason 1952, Martin and Barkley 1973, Montgomery 1977).

Sediment: Sediment samples from selected transects were examined under 15X magnification to estimate the percent sand in the substrate. Randomly chosen sand grains from each sample were measured with a dial caliper to arrive at a mean grain size for sand.

Statistical Analysis

A Pearson-r test was used to examine the correlation between seed numbers in the sediment and percent cover of *Zannichellia* in each quadrat. A t-test was used to test the difference in means between rostrum-fruit ratios of the short and tall forms of *Zannichellia*, the null hypothesis being that the rostrum:fruit ratios are the same for both forms. A t-test was also used to test the difference between mean number of seeds of *Zannichellia* in all sediment samples in Robin Cove and Brewer Creek, the null hypothesis being that there is no difference between seed numbers in either area.

RESULTS

SAV Composition and Cover (Tables 1a and 1b):

Five species of SAV were identified in Robin Cove where greatest diversity occurred along transect 4. Percent relative cover was highest for *Zannichellia palustris* in transects 1 and 2, and *Elodea nuttallii* in transects 3 and 4. *Potamogeton perfoliatus*, *Myriophyllum spicatum* and *Ruppia maritima* were each represented by < 10% relative cover. *Zannichellia palustris* was the only SAV observed in Brewer Creek.

Table 1a. Percent cover and percent relative cover of SAV in Robin Cove and Brewer Creek.
Zp= *Zannichellia palustris* (ZpS = short form, ZpT = tall form); Rm = *Ruppia maritima*; Ms = *Myriophyllum spicatum*; En = *Elodea nuttallii*; Pp = *Potamogeton perfoliatus*.

Robin Cove (Percent cover)

	Tall form beds							Short form beds								
Transects	Tr 1			Tr 2				Tr 3		Tr 4						
Quadrats	1	2	3	1	2	3	4	1	2	1	2	3	4	5	6	7
Zp	24	68	20	60	34	20	43	0	52	25	0	0	20	10	40	0
Rm	0	0	0	0	0	0	0	0	0	0	0	0	17	15	0	0
Ms	1	8	13	2	0	0	2	3	2	3	1	12	8	2	6	0
En	100	1	0	58	16	12	0	12	0	19	26	40	8	14	50	100
Pp	0	0	0	0	15	0	0	0	20	0	24	0	0	20	0	0

Robin Cove (Percent relative cover of SAV)

Zp	19	88	61	50	52	62	96	0	70	53	0	0	38	16	42	0
Rm	0	0	0	0	0	0	0	0	0	0	0	0	32	24	0	0
Ms	1	10	39	2	0	0	4	20	3	6	2	23	15	3	6	0
En	80	1	0	48	25	37	0	80	0	40	63	77	15	23	52	100
Pp	0	0	0	0	23	0	0	0	27	0	58	0	0	33	0	0

Robin Cove (Mean percent cover for each transect)

Transects	1	2	3	4	Mean
ZpT	37	29	0	0	38
ZpS	0	0	26	14	20
Rm	0	0	0	5	1
Ms	7	1	2	5	4
En	34	21	6	37	24
Pp	0	4	10	6	5

(Mean percent relative cover - transects)

Transects	1	2	3	4	Mean
ZpT	56	65	0	0	60
ZpS	0	0	35	21	28
Rm	0	0	0	8	2
Ms	17	15	11	8	9
En	27	28	40	39	33
Pp	0	6	13	13	8

The short form of *Z. palustris* (ZpS) occurred in transects 3 and 4 in Robin Cove, and in all transects in Brewer Creek. The tall form of *Z. palustris* (ZpT) occurred in transects 1 and 2 in Robin Cove and was not observed in Brewer Creek. At Robin Cove, ZpT was dominant in transects 1 and 2 until ~ 15 June; *E. nuttallii* was dominant and ZpS was second dominant in transects 3 and 4. After ~ 15 June when ZpT died back, *Elodea* became dominant in transects 1 and 2. Although ZpS populations changed somewhat in transects 3 and 4 throughout the summer, *Elodea* remained dominant.

Water Depth and the Occurrence of Zannichellia (Table 2):

In Robin Cove, ZpT grows in depths ranging from 0.70 and 1.20 meters, but grows most abundantly about 1 meter (between 0.96 and 1.10 m). ZpS grows in shallower water ranging from 0.35 to 0.60 m, occurring most abundantly at 0.4 m. In Brewer Creek, where only ZpS was observed, it was found in water ranging from 0.3 to 1.4 m and was most abundant between 0.65 to 0.70 m.

Seed Numbers in Surface Sediments (Table 3):

Six species of SAV and eleven species of emergent plants are represented by seeds buried in surface sediments at

Table 2. Mean depth at high tide for all transects perpendicular to shore, and depth at which *Zannichellia* has the highest percent cover along each transect. Tidal range is 0.50 m.

	Robin Cove				Brewer Creek		
Transects	1	2	3	4	1	2	3
Length of transect (m)	15	20	8	38	10	10	10
Mean depth along transect (m)	0.94	0.94	0.48	0.46	0.78	0.78	0.72
Standard deviation (±)	0.23	0.24	0.07	0.12	0.39	0.45	0.39
Range of depth where Zp occurs (m)	0.71-1.19	0.94-1.14	0.35-0.46	0.42-0.59	0.33-1.40	0.32-0.94	0.29-0.87
Depth of highest % cover - ZpT (m)	1.10	0.96					
Depth of highest % cover - ZpS (m)			0.43	0.44	0.71	0.68	0.65
Highest % cover (%)	68	60	52	40	79	82	25

Table 3. Number of seeds 100 cm^2 of emergent and submerged vegetation in sediments along transects. Quadrats are at 5 meter intervals, except in transect 3, where the 2 quadrats are 7 meters apart. Zannichellia palustris (Z.p.), Ruppia maritima (R.m.), Potamogeton perfoliatus (P. perf.), Potamogeton pectinatus (P. pect.), Potamogeton sp. (P. sp.), Najas guadalupensis (N.g.), Scirpus olneyi (S.o.), Scirpus sp. (S. sp.), Iva frutescens (I.f.), Phragmites sp. (Phrag. sp.), Gramineae (Gram.), Polygonum punctatum (Polyg. pun.), Cyperaceae (Cyperac.), Carex sp., Eleocharis parvula (E.p.), Rubus, Pinus sp., Liriodendron tulipifera (L.t.), Carex lurida (C.l.), Eupatorium sp. (Eup. sp.), Prunus sp. (Prun. sp.), Scirpus americana (S.a.)

Robin Creek

	Tr 1		Tr 2				Tr 3		Tr 4						
quads	2	3	1	2	3	4	1	2	1	2	3	4	5	6	7
Z.p.	173	115	127	144	71	223	13	64	67	105	400	197	85	83	68
R.m.	50	20	12	83	35	64	9	59	48	24	91	25	6	12	20
P.perf.	9	10	15	6	12	5	4	14	14		9	17	13	4	
P.pect.											13	12			
P.sp.		5	4		5										
N.g.	5	5	19	17	29	73		5	14	19	74	4	9	4	4
S.o.										5	35	17	18	29	156
S.sp.			4							9			24		
I.f.		5					4		5	9					
Phrag.sp.							9	5	5	5					
Gram.		5						9		9	9				4
Polyg.pun.								5	5		4			4	
Cyperac.								9			9			4	20
Carex sp.										5					
E.p.										9	13	4			4
Rubus											9				
Pinus sp.											4				
Unknown			12		6		5	9		5	26	4			

Brewer Creek

	Tr 1		Tr 2		Tr 3			Tr 4		
quadrats	1	2	1	2	1	2	3	1	2	3
Z.p.	24	17	25	11	10	6	6	11	21	5
L.t.	8		11		5	17				
C.l.		4								
Eup.sp.					5					
Gram.					5					
Prun.sp.						6				
S.a.										10

Robin Cove. Greatest diversity occured along transect 4, where 16 species of seeds were recovered. Seeds of Zannichellia represented the highest percentage of buried seeds in all 4 transects. Seeds of Ruppia were the next most common. Seeds of emergent species represented 13% of all seeds recovered, but represented 23% of the seeds in transect 4. The most abundant emergent species represented by seeds was Scirpus olneyi.

The only SAV species represented by seeds in Brewer Creek is Zannichellia. This is consistent with the plant cover for Brewer Creek. In addition, six other species represented by a few seeds included sedges, grasses, and tulip tree from the neighboring shoreline vegetation.

Relationship of Plant Cover to Seed Number (Table 4):

A greater number of species were represented by seeds than by plants at both locations. In Robin Cove, 5 species of plants were recorded in the vegetation and 17 species by seeds in the sediment. The five species represented in the vegetation quadrats were SAV, while 6 of the 17 species from seeds belonged to SAV. The remaining eleven species were represented by seeds of nearby marsh emergents not represented in the quadrats. Highest number of both plants and seeds were found along

Table 4. Comparison of mean percent relative cover and mean percent of relative seed number in Robin Cove. C = cover; S = seeds; (s) = submerged plant; (e) = emergent plant.

	Tr 1		Tr 2		Tr 3		Tr 4		Mean Total	
	C	S	C	S	C	S	C	S	C	S
Zannichellia (s)	56	72	65	59	35	34	21	53	44	55
Ruppia (s)	0	17	0	20	0	30	8	12	2	20
Myriophyllum (s)	17	0	1	0	11	0	8	0	9	0
Elodea (s)	27	0	27	0	40	0	39	0	33	0
Potamoget. perf. (s)	0	5	6	4	13	8	13	3	8	5
Potamoget. pect. (s)	0	0	0	0	0	0	0	1	0	.2
Potamoget. sp. (s)	0	1	0	0	0	2	0	0	-	-
Najas guad. (s)	0	2	0	14	0	2	0	7	0	6
Scirp. olneyi (e)	0	0	0	0	0	0	0	14	0	3.
Iva frutes. (e)	0	1	0	0	0	2	0	1	0	1
Phragmites (e)	0	0	0	0	0	6	0	0	0	1.
Others (e)	0	1	0	2	0	16	0	8	0	7

Fruit Morphology and Production of *Zannichellia*:

Measurements of rostrum length and fruit length of both forms of *Zannichellia* (Fig.6) were made in an attempt to separate the two forms by seed morphology (Table 5). The mean ratio of rostrum length to fruit length in ZpT is 0.64 and in ZpS is 0.59. A t-test shows no significant difference between the two means ($t(81) = 0.325$, $p > .05$). Both forms produced fruits that were dentate or entire along the convex margin.

Number of fruits per cm of internode was 0.2 for ZpT and 0.4 for ZpS (Table 6). When fruits per cm of internode are multiplied by mean height of the plants, ZpT produces a mean of 13.2 fruits per plant, and ZpS 4.2 seeds per plant (Table 7).

Sediment Description (Table 8):

The preliminary analysis of sediment indicates that ZpT grows primarily in mud with 5 - 15% sand. In Robin Cove, ZpS grows in a sand-mud mixture, with sand comprising ca. 75% of the sediment. In Brewer Creek, ZpS grew in sediment that was 100% very fine to coarse-grained sand.

Table 5. Comparison of fruit length, rostrum length and the ratio of rostrum to fruit length in *Zannichellia palustris*.

	Mean fruit length (mm)	Mean rostrum length (mm)	Rostrum: Fruit ratio
ZpT (n=40)	2.99	1.90	0.64
ZpS (n=43)	2.85	1.69	0.59

Table 6. Comparison of stem length to numbers of fruits in *Zannichellia palustris*.

	Total length of all internodes (cm)	Total number of fruits	Number of fruits per internode length (no. fruits/cm)	Mean height of plants in quadrats (cm)	Mean number of fruits per plant
ZpT	250.6	49	0.2	66.0	13.2
ZpS	99.6	43	0.4	10.4	4.2

Table 7. Maximum height of *Zannichellia* plants along transects in cms. Plants in transect 4 were measured every 5 meters; at all other transects, plants were measured at 1 meter intervals.

Robin Cove

	tall form		short form	
meters	transect 1	transect 2	transect 3	transect 4
0	0	0	0	
1	0	0	0	
2	0	0	0	
3	45	60	0	
4	87	60	0	
5	56	55	0	10
6	100	50	0	
7	70	0	10	
8	70	65	0	
9	66	58		
10	75	60		0
11	70	0		
12	78	45		
13	85	60		
14	120	0		
15	20	40		0
16		60		
17		70		
18		66		
19		58		
20		58		10

Brewer Creek

meters	transect 1	transect 2	transect 3
1	0	0	0
2	0	0	0
3	0	25	0
4	13	9	8
5	9	16	10
6	8	8	24
7	8	8	9
8	6	0	0
9	6	0	0
10	6	0	0

Table 8. Sediment descriptions. Sediment type, estimated % sand, and sand grain size, where *Zannichellia* is rooted. All measurements made at 15X magnification.

	Tributary, transect & quadrat	Sediment type & general descrip.	Estimated percent sand	Sand grain size (mm)
ZpT	Robin Cove Tr 1, 15 m	mud; material too fine to discern indiv. grains	5	not measured
	Tr 1, 10 m	mud; with some sand	15	range = 0.1-0.8 mean = 0.43
ZpS	Robin Cove Tr 3, 7 m	sand-mud mixture	75	range = 0.25-0.70 mean = 0.44
	Tr 4, 5 m	sand-mud mixture	75	range = 0.20-0.60 mean = 0.37
	Tr 4, 30 m	sand-mud mixture	75	range = 0.10-1.10 mean = 0.53
	Brewer Creek Tr 3, 5 m	fine to med sand	100	range = 0.05-0.6 mean = 0.22

DISCUSSION

Differences in seeds and plant cover of the short and tall forms of Zannichellia palustris suggest that this plant may be an indicator of disturbance. In the relatively undisturbed tributary, plant cover includes both ZpT and ZpS. ZpT coexists with 3 other species of SAV and is dominant, and ZpS coexists with 4 other species and is the second dominant. In the disturbed tributary, ZpS is the sole SAV. Seeds recovered from surface sediments were significantly fewer in the disturbed locale.

The relationship of Zannichellia to water depth is equivocal. Where both forms occur, ZpT occurs in deep water and ZpS in shallow water and the intertidal zone, but where ZpS occurs alone, it is found in depths ranging from the intertidal zone to 1.4 m. ZpS is not restricted to shallow water, and ZpT is absent from the deep water of Brewer Creek, the disturbed area. Water depth is important because it affects the amount of light required for germination and growth, as well as affecting the amount of exposure of the plants to evaporation and increased salinity that can occur in shallow water. In unpolluted waters 2% of the surface light, the minimum light requirement for submerged aquatic plants, occurs at depths of 1.3 to 1.6 meters (Southwick and Pine 1975). In polluted waters light becomes a limiting factor in depths of 0.6 to 1.0 meters. Light does not appear to be a factor affecting the two growth forms of Zannichellia in the depths studied in Robin Cove and Brewer Creek. ZpS occurs in the well-lit shallow zone in Robin Cove as well as depths of 1.4 meters in Brewer Creek. Shallow water areas, including the intertidal zone, can experience evaporation, increased salinity and increased chance of dessication. These factors influence the growth forms of Ruppia in New Hampshire tidal marshes (Richardson 1980). There, plants growing in shallow pannes have a creeping, spreading habit, while those growing in deeper water have an ascending habit.

Sediment may be an important factor on the distribution of Zannichellia. In both areas ZpS was found growing in sediment that was 75% to 100% sand. ZpT was found in mud containing < 15 % sand. These observations, though preliminary, are in agreement with Van Vierssen (1982a), who observed an increase in stem length with increased clay percentage for both forms of Zannichellia palustris in Europe. The restriction of ZpS to Brewer Creek may be due to the high percentage of sand and near absence of clay in the substrate. A sediment core collected at the south shore of Brewer Creek also supports this conclusion (Brush et al in prep). Sediment deposited prior to 1940 consisted of silt and clay, and after 1940 was predominantly silt and sand. Seeds of Zannichellia are common in sediment deposited between 1800 and 1930, when there is a decline, followed by disappearance in 1940 (Fig. 7). Seeds of Zannichellia reappear around 1955 and continue in smaller numbers to the present. The core shows a switch from mud to sand about the time the community of Sherwood was established. Increased runoff from construction could have resulted in high influxes of sand, the predominant sediment type of the surrounding hillsides, and could have led to a recent establishment of ZpS. However, since the seeds of these two forms cannot be distinguished morphologically, this possibility remains conjectual.

The two growth forms of Zannichellia cannot be distinquished on the basis of fruit morphology. Both ZpS and ZpT produce fruits which are dentate and entire or slightly crenate along the convex margin. Nor are there differences in fruit and rostrum length or in the ratio of rostrum to fruit length. Van Vierssen (1982a) reported that the rostrum-fruit ratio is the most distinctive morphological feature in separating several species of Zannichellia in Europe. The mean ratio of 0.62 in this study conforms to Zannichellia pedunculata in Europe, where rostrum-fruit ratios >0.5, and not to Z. palustris, where ratios are <0.5. The mean rostrum length of 1.69 mm for ZpS samples in this study are identical to the mean

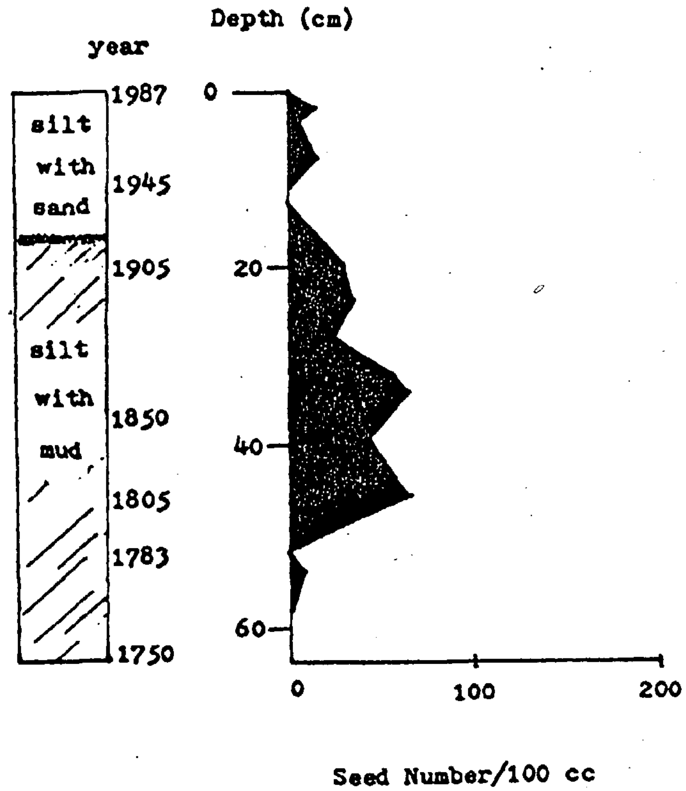


Figure 7. Core SR3a from Brewer Creek showing changing abundance of *Zannichellia palustris* from ca. 1750 to 1987. (from Brush, Hilgartner and Thorton, in prep)

rostrum length of Z. pedunculata in Europe. The taxonomic importance of this requires further study, but fruit dimensions and morphology alone indicate that the two growth forms are variations of the same species, and may be more closely related to Z. pedunculata than to Z. palustris.

There are some important differences in fruit production and preservation in sediments between the two forms. ZpT produces three times more fruits than ZpS. This greater production is reflected by a greater abundance of Zannichellia seeds in sediments where ZpT grows. However, it cannot be inferred that an abundance of seeds in sediment represents ZpT. High seed numbers in sediments where ZpS occurs in Robin Cove could have been dispersed from nearby ZpT beds.

Duration of growth differs for the two growth forms, with ZpT growing only during the spring, and ZpS growing well into July and returning in fall.

The high diversity of both SAV plant cover and seeds in the undisturbed tributary contrasted sharply with the low diversity in the disturbed environment. Zannichellia was the only SAV species present at the disturbed site. Discrepancies did occur between plant cover and seeds in sediment, with some dominant plants not being represented by seeds such as Elodea and Myriophyllum. In other cases, seeds were present in the sediment where there were no plants, e.g. Najas and Potamogeton pectinatus. Both of these genera have been overlooked in vegetation surveys, yet are represented by seeds in surface sediments of lakes (Birks 1973; Birks and Birks 1980).

Despite these discrepancies between plant cover and the seed record, the local vegetation was fairly well represented by the seed record in terms of numbers of species. Seventy-one percent of the taxa recovered as seeds were common components of the vegetation within a 30 meter radius of the sampling sites. Annuals were more abundant among the seed taxa than perennials, which contrasts with the fact that perennials are among the most important components of submerged and emergent vegetation in wetlands (Van der Valk 1981). The selective predominance of seeds of annuals buried in surface sediments has been reported in paleoecological and seed bank studies elsewhere (Birks 1973; Birks and Birks 1980; Leck 1989; Parker and Leck 1985).

In this study, low diversity is indicative of disturbance. Stuckey (1971) observed a decline in diversity in Put-In-Bay Harbor, Lake Erie, during 70 years of human activity. Morgan and Phillip (1986) found a similar pattern in the New Jersey Pine Barrens.

Ehrenfeld (1983) found that species diversity increased in some disturbed wetlands of New Jersey even while eutrophic species were favored, suggesting that patterns of plant diversity reflect a particular habitat and will vary between sites. In this study as well as others, species favored by human disturbance including both eutrophication and mechanical disturbance, are species with broad ecological tolerances that respond positively to increased nutrient inputs. Besides Zannichellia, one such species is Scirpus americanus, a dominate shoreline emergent with a broad tolerance range found in a series of sites along the Patuxent River and elsewhere (Anderson et al 1965). This species is the dominant shoreline emergent in Brewer Creek.

Understanding the relationship between plant cover and seed production is important in interpreting the paleoecological record (Birks 1973; Birks and Birks 1980; Watts 1978). Davis (1985) found Zannichellia vegetation overrepresented by seeds in Leeds Creek, a tributary of Chesapeake Bay, but admitted that his values for plant cover may have been low, since data were collected after the peak growing period. In the undisturbed site for this study Zannichellia represented 44% of 5 species in the plant cover and 55% of 17 species in the seeds in surface sediments. In the disturbed site, Zannichellia represented 100% of the SAV plant cover and 72% of 7 species in the seeds recovered from sediment samples. This indicates that Zannichellia is more closely represented in the seed record than has been thought.

Seeds preserved in surface sediments closely approximate plant cover in an embayment or cove, even when there is virtually no correlation between individual quadrats and a sediment sample taken from the quadrat. Macrofossils within a sediment core therefore represent the vegetation of the embayment, at least within a 30 meter radius of the coring site, for different time intervals (different depths). Periods of high and low disturbance can therefore be interpreted on the basis of the number of fossil seeds at particular depths within the core.

Paleoecology provides a long-term perspective for modern ecological problems (Brush 1986; Foster et al 1990). In an extensive stratigraphic analysis of SAV in the upper Chesapeake Bay, Brush et al (in preparation) have found Zannichellia seeds common throughout many sediment cores, but found that they varied in abundance through time. Assuming that seed abundance reflects plant cover, correlations between the abundance of fossil Zannichellia seeds and particular periods of land use were used to infer the response of Zannichellia populations to different kinds and intensity of disturbance (Fig. 8). The most significant increase in seed numbers occurred

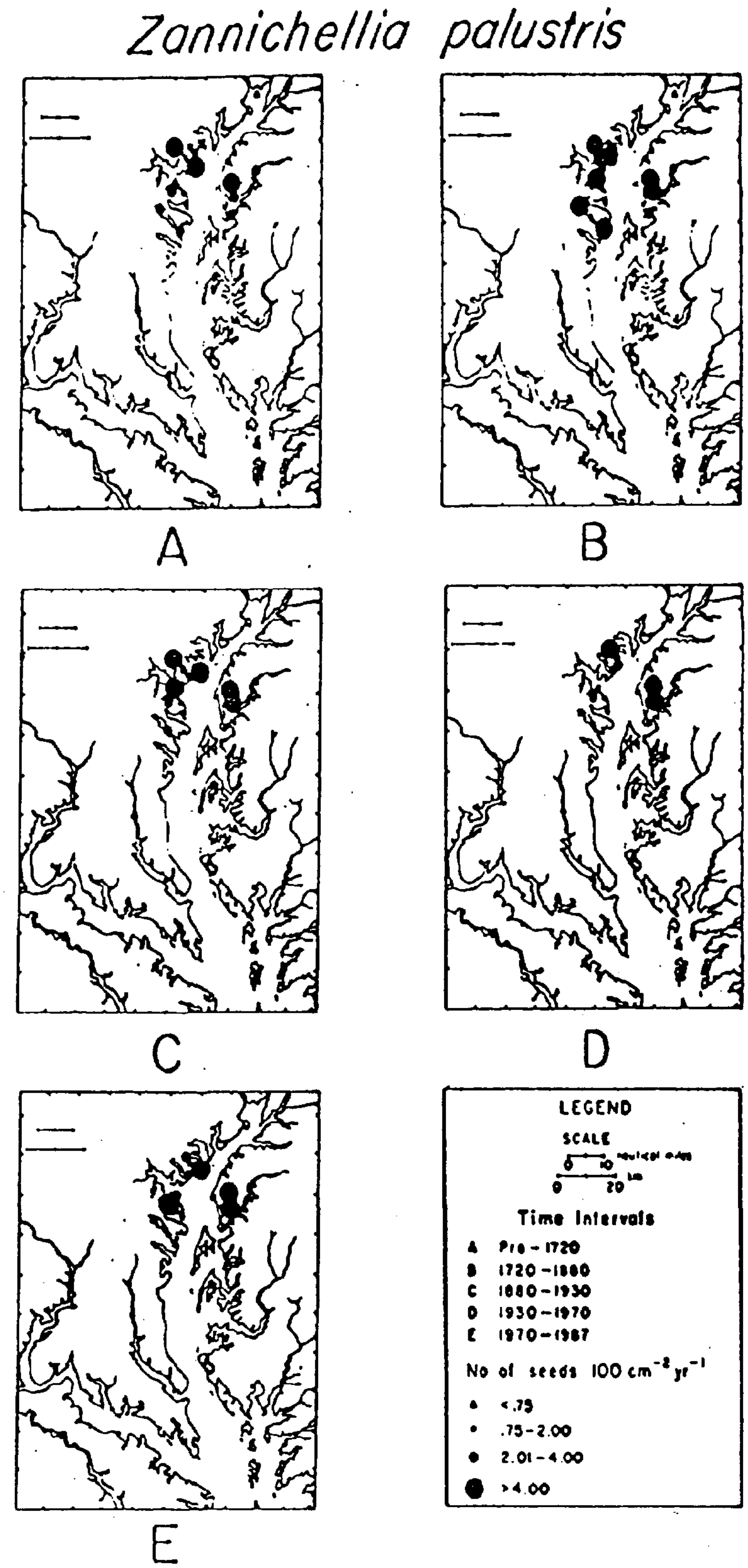


Figure 8. The distribution of Zannichellia palustris from core analyses, showing changing abundance through time (from Brush, Hilgartner & Thornton, in prep.).

during the period from 1650 -1780, when agriculture and land clearance expanded. Initial land clearance by early colonists was followed later by a clustering of small farms into tobacco plantations during this period. Sedimentation rates increased along with an increase in nutrients and fertilizers. It appears that the initial response of Zannichellia to increased nutrients was an increase in plant cover. However, with further intensification of land clearance and increase in the human population from the mid-1800's into the 20th century, Zannichellia steadily declined. The precipitous decline of the 1960's and 1970's is revealed by the seed record. Plant cover expanded again in the 1980's perhaps in response to reduced sedimentation rates in some tributaries in recent years. There appears to have been a positive response of Zannichellia to moderate land use and disturbance, and a negative response to intense agriculture and urban land use. Cores from the Chester River and Severn River illustrate this pattern (Figs.9 and 10). The paleoecological pattern allows inferences to be made about the cause and effect of disturbance. The hypothesis that Zannichellia is a newcomer to Chesapeake Bay (Stevenson and Confer 1978) is erroneous. Historical perspectives therefore, provide a background in which to analyze plant populations including SAV.

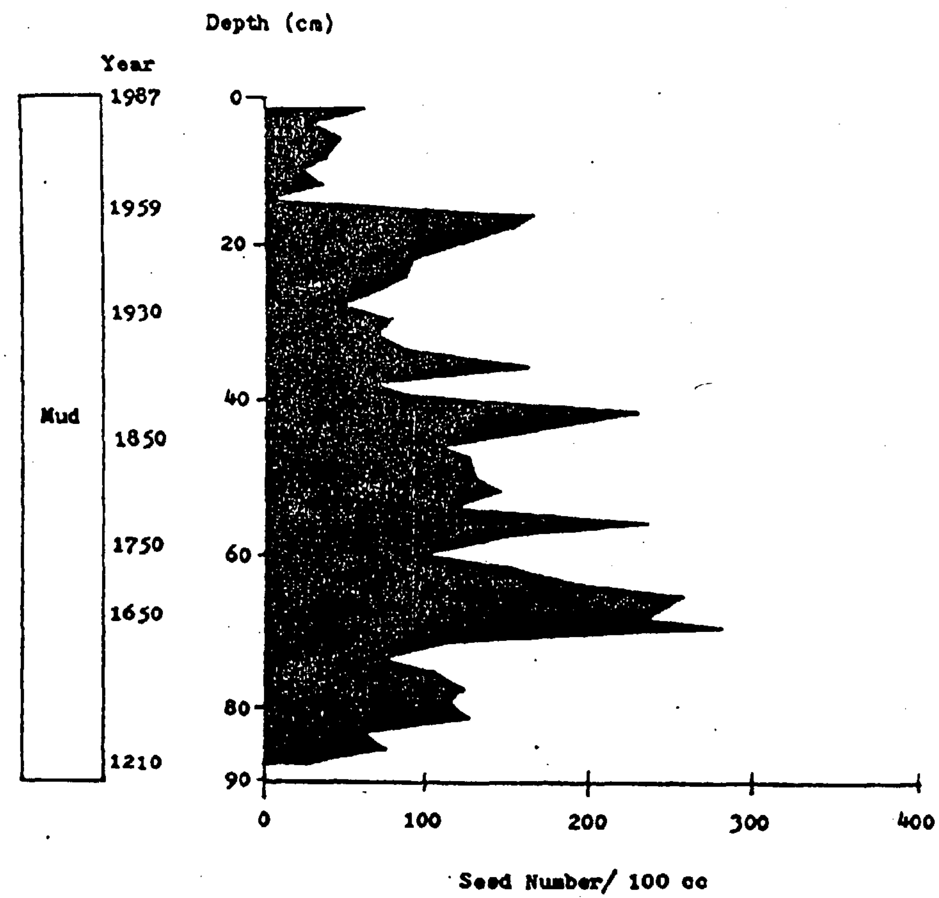


Figure 9. Core CHR6c from the mouth of Langford Creek near its confluence with the Chester River, showing the changing abundance of Zannichellia palustris from ca. 1210 to 1987 AD. (from Brush, Hilgartner and Thorton, in prep).

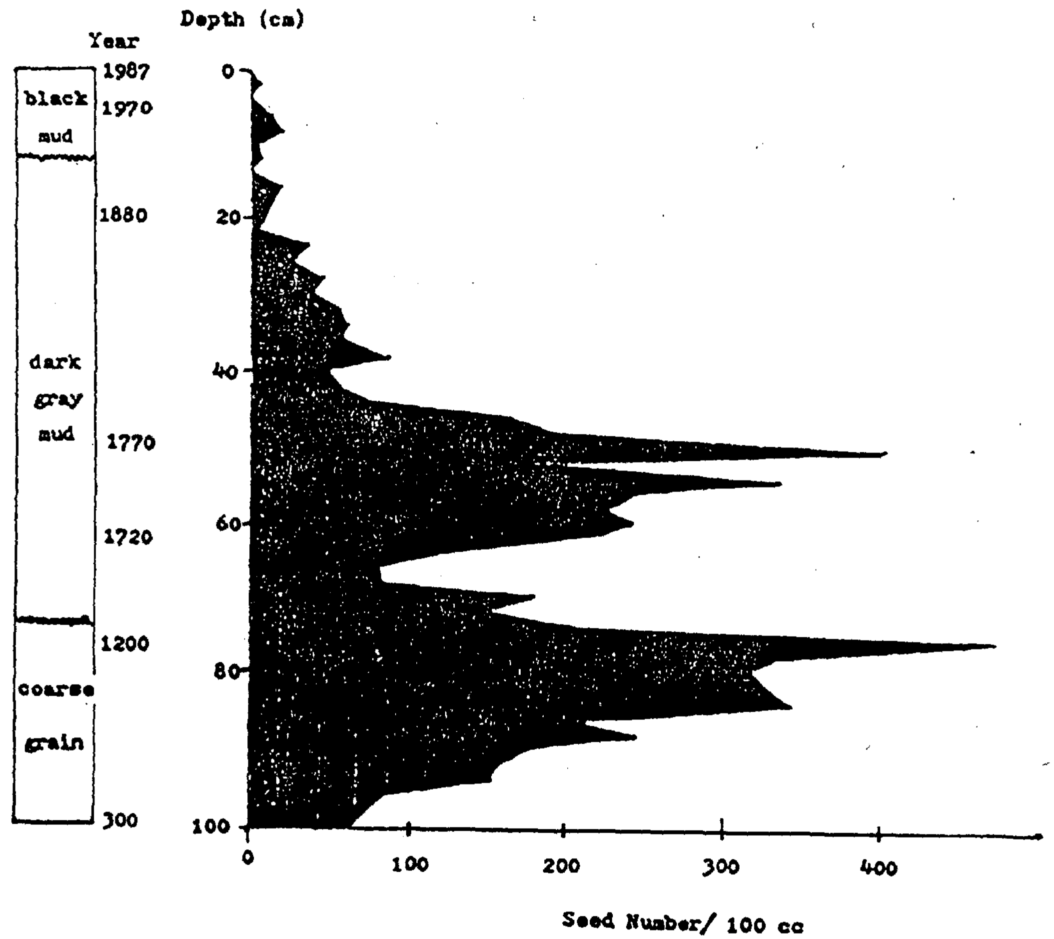


Figure 10. Core SR1a from the upper Severn River, showing the changing populations of <u>Zannichellia palustris</u> from ca. 300 to 1987 AD (from Brush, Hilgartner and Thorton, in prep).

CONCLUSION

Differences in the distributions of two growth forms of Zannichellia palustris in a disturbed and undisturbed estuary indicate that this species is a potential indicator of environmental disturbance. Both the short and tall growth forms occur in the undisturbed estuary, but only the short form was found in the disturbed site. Along with this distribution, it was noted that the short form was found growing on substrates of predominantly sand, whereas the tall form grows on substrates that are predominantly mud. The species was also separated by water depth in the undisturbed area, with the tall form growing in deeper water, but in the disturbed area, the short form grew in a wide range of water depths.

Neither form is identifiable by seed morphology, but the tall form produces about 3x the number of seeds as the short form. Lack of any identifying morphological traits prevents the identification of these forms in the fossil record. However, a comparison of seed abundance in sediment cores with the history of land use indicates that the response of Zannichellia to moderate land use is positive, while the response to intense land use is negative. Also, an abundance of seeds of Zannichellia in conjunction with a high diversity of other species in the sediment can be used to indicate relatively undisturbed conditions.

Both modern and paleoecological distributions of Zannichellia palustris indicate strongly that the species is an indicator of disturbance. This conjecture is now being tested by mapping the distributions of the two forms over a wide range of environmental conditions, including both substrate and disturbance history.

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