SEDIMENTARY ENVIRONMENT ADJACENT TO TIVOLI BAYS

A Final Report of the Tibor T. Polgar Fellowship Program

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ABSTRACT

Multibeam bathymetric surveying was done in the Hudson River in water depth greater than 3 meters as part of a larger university consortium project during two cruises in November and December of 1998 and May of 1999. The images obtained from surveying served as a basis for choosing sediment sampling sites, studying physical processes in the main stream of the river, determining sediment transport and deposition and the possible link between the main stream of the river and Tivoli North and South Bay.

Surface grab samples were taken in the main stream of the river from Kingston to Saugerties off the R/V Walford in December of 1998 and off the R.V. Lionel Walford in May of 1999. Surface grabs were also taken off smaller boats in July and November of 1999 in the shallows adjacent to Tivoli North and South Bays; at the mouth of Esopus Creek; in the shallows north and south of the creek's delta and within Tivoli South Bay.

The sediment samples taken in the main stream of the river are predominately fine sands changing to finer grains silts and clays as you move south. A small portion of the samples were predominately gravel, but this gravel fraction was mostly zebra mussels, in masses, whole or broken. The samples taken in the shallows are predominately silts and clays and contain abundant roots, grass and water chestnut seeds. Within Tivoli South Bay, the sediment samples are predominately silt and clay, with a gravel fraction in the grabs taken near the openings of the railroad embankment and near the mouth of the Saw Kill. These samples also contained abundant roots, grass and water chestnut seeds.

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INTRODUCTION

Understanding the link between the physical processes at work in the river, the sediment transport and final deposition of sediments along the shoreline and into the marshes is an important part of any attempt to protect the ecosystems of the river. The benthic environment of the river adjacent to Tivoli North and South bays, the ecosystems of the bays and the fate of the bays themselves depend on sediment quantity, grain size, bottom type (hard or soft bottom) and morphology. These in turn depend on physical processes in the river north and south of this area, sediment quantity supplied to the bays from the river's tributaries and the pathways of sediment into the bays. However, data and analysis of bottom sediment facies in the Hudson River Estuary is sparse owing to the large effort required for collection of samples.

A greater understanding of sediment transport, deposition and substrate type are important in assisting in the study of submerged rooted vegetation, the transport and fate of contaminants down river and/or into the fringing wetlands and the possible habitats of invasive species such as zebra mussels. Contaminants tend to preferentially distributed in fine grain sediments by adsorption onto the silt and clay fraction, while sand-sized fractions are less contaminated.

Sediment data collected in this study was used to investigate the exchange between the deeper channel and the fringing shallows in an attempt to determine the physical processes transporting and depositing fine-grained sediment into North and South Tivoli Bays.

The study site ranged from just south of Saugerties (42° 00'N, ~76° 56'W) to just north of Barrytown (42° 00.5'N, ~76° 56'W)(Figure 1). This area of the river is marked by a complicated system of transport patterns creating numerous shallows, shoals and channels (Figure 1). In this system, marshes and wetlands are sediment sinks and areas of high accumulation. Fine-grained sediments are supplied to the marshes through overland runoff, tidal exchange, downstream transport and as sediment load transported through the river's various tributaries. The existence of marshes depends on an adequate supply of sediment to keep pace with sea level rise. Assuming a 3mm/yr rise in sea level in the Hudson River (Ellsworth, 1982), sediment deposition in Tivoli North and South Bay must be at least 3 mm/yr. Studies have shown that there is a large variation in the rate of sediment deposition. Sediment deposition in Tivoli South Bay has been measured to vary from 0.8 cm/year by Robideau (1997) and between 0.59-2.92 cm/year by Benoit, et.al.(1999). Robideau measured the deposition rate in Tivoli North Bay to be approximately 0.6 cm/year and in Tivoli South Bay to be approximately 0.8 cm/year. At these rates, both Tivoli North and South Bays are silting in rapidly. North Bay has a very small area of standing water; depths within South Bay were measured to be from 15.9 to less than 3 feet. At low tide, most of Tivoli South Bay exposed mudflats.

While tributary input is variable, depending on many factors, in 1992 and 1993 the tributaries north of the study area, from the Lock and Dam at Troy to (and including) Esopus Creek, supplied 48,374 metric tons and 59,518 metric tons respectively. In 1992 and 1993, Esopus itself contributed 1,145 metric tons and 1,406 metric tons respectively. In the same two years the tributaries south of the study area, from Rondout Creek to

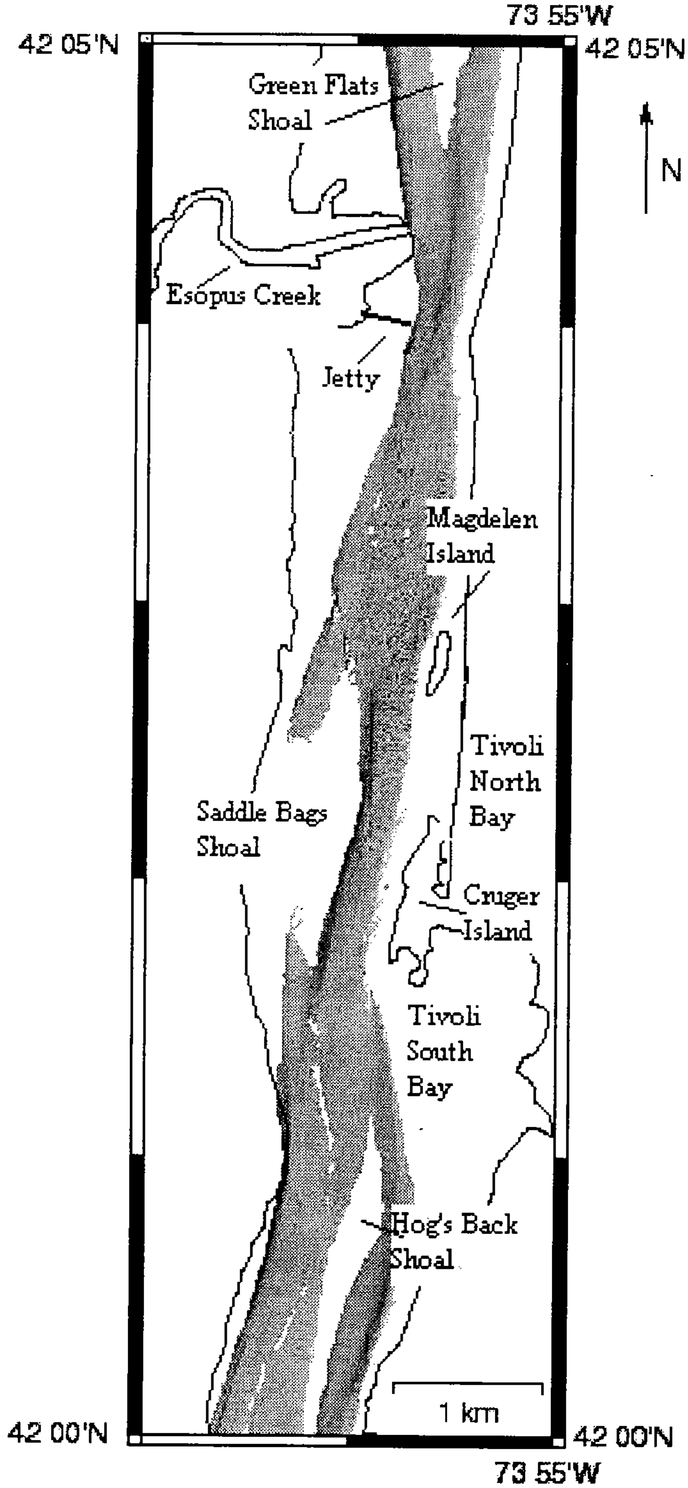

Figure 1: Study area

Haverstraw Bay supplied 75,258 metric tons of sediment to the river, approximately 7,525.8 metric tons of this being coarse-grained (Lodge, 1997).

Assuming that approximately 10 % of this sediment from the river's northern tributaries is coarse-grained supplied as bedload, in this two year period approximately 97,102.8 metric tons of fine-grained sediment was supplied to the Hudson from these upriver sources, with 2,295.9 metric tons supplied from Esopus Creek. Ellsworth (1986) calculated the total annual mass rate of fine-grained sediment accumulation into the fringing tidal wetlands of the lower Hudson River to be about 12,000 metric tons. This figure includes input from shoreline erosion, other fluvial sources, anthropogenic wastes, biological production, input from the sea and atmospheric sources. He found that 96-97% of the silt/clay input can be accounted for by three sources: tributaries, the sea, and in situ biological production, with only 1% of the fines coming from shoreline erosion.

Much of the sediment once delivered to the Hudson through Esopus Creek is now trapped in Ashoken Reservoir, which was completed in 1916, thereby reducing the present sediment load delivered to the river. The creek itself has a large delta, which may be eroding due to the reduced sediment supply over the last 84 years. The high sediment load before completion of Ashoken Reservoir, combined with the construction of the railroad embankment on the eastern shore have contributed to the filling in of Tivoli North Bay.

The shape of the Hudson River channel can have an effect on sediment transport and sedimentation rates. It has been found that fine-grained sediment concentrations increase by as much as 50 mg/L as water moves from deeper water over vegetated shallows (Findlay, et.al.,1999). This high concentration of sediment actually increases resuspension in shallow water, overtaking the ability of submerged rooted vegetation (SRV) to act as a baffle trapping sediment. There is abundant SRV in the shallow areas around Esopus Creek and along the west bank near Tivoli North and South Bays. The channel at this location forms a steep ledge just offshore of Tivoli North and South Bays.

Bedforms are also useful tools for deciphering flow conditions. Even when the mechanics of current flow and conditions are absent, the features themselves provide a basis with which to compare active sedimentary environments (Flood and Bokuniewicz, 1986). Shear stress along the river bottom, rate of fluid transport and turbulence associated with bottom morphology affect transport and deposition of sediments. Composition of sediment has an affect on benthic organisms that choose sites based on grain size. Zebra mussels (Dreissena polymorpha), for example inhabit rocky areas and/or hard bottom. They have caused large declines in standing phytoplankton stocks thereby slightly increasing light penetration (Caraco et.al.,1997). The rate of fluid transport near the bed can affect the dispersion of larvae.

The Esopus delta deflects the downriver current to the east and towards Tivoli North Bay. Rapid, erosive flows are therefore expected along the east bank, but because the bank is armored by the railroad the finer grained sediments are trapped and deposited in North Bay. The fines are also trapped at that location by Magdelan Island just to the west and Cruger Island immediately to the south. There is a noticeable shelf just west of North Bay, which is probably scoured by the deflection of the current. Saddle Bag shoal lies along the west bank of the river opposite North Bay. The jetty just south of Esopus acts as a sediment trap for upriver and downriver flow on the western bank of the river. At South Bay, the northward flow is defected around Hog's Back Shoal towards Cruger

Island. There is a deep, natural channel along the eastern shore just to the west of Tivoli North and South Bays. Due to rapid fluid transport through this channel it is expected that coarse grain sediments should be found there, with the fines deposited along the edges and/or carried downstream.

ACOUSTIC MAPPING

This study takes advantage of a larger university consortium study joint between The Marine Sciences Research Center of SUNY Stony Brook (MSRC) and Lamont Doherty Earth Observatory of Columbia University (LDEO). The goal of this project was to characterize the Hudson River bottom using a wide range of acoustic mapping and ground penetrating radar techniques, and sediment sampling. Four sections of the river were surveyed one of which, Area 3 - from Kingston to Saugerties encompasses this study area from Esopus Creek in the north to Rondout Creek in the south (Figure 2). The multibeam provided information important in the analysis of physical processes affecting the transport and deposition of sediments in the area of Tivoli North and South Bays The multibeam images show:

Bathymetry (Figure 3):

Bathymetry is a measure of river depth, equivalent to topography. Bathymetry data provides basic information on the dimensions of riverbed features, including rock outcrops and sediment bedforms. Bathymetry also reveals variations in channel structure that control sediment transport.

The bathymetric contours in the main stream show areas of the main stream of the river with depths greater than three meters. All depth measurements taken with the EM3000 are mean low water and corrected for tides. A contour interval of one meter

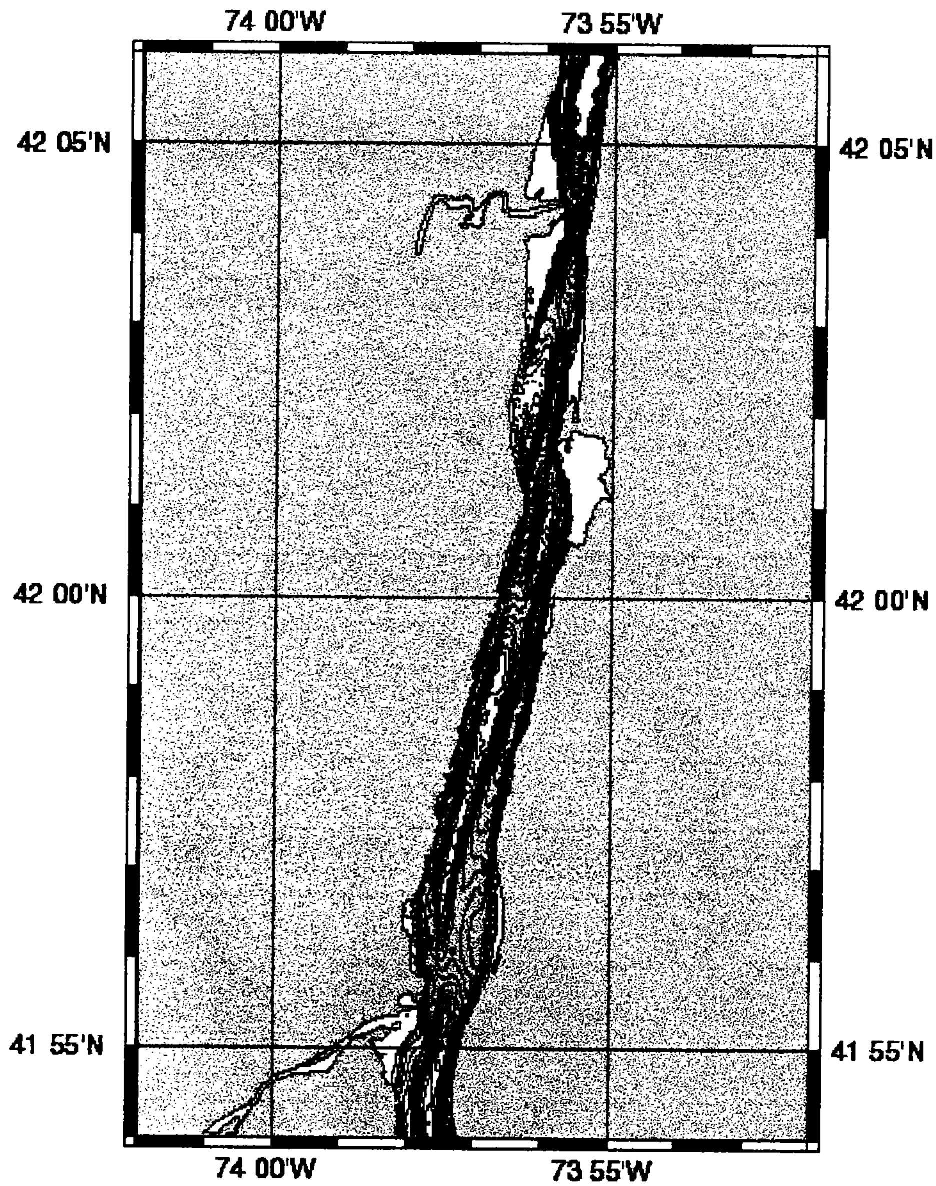

Figure 2: Area 3. Kingston, N.Y. and Rondout Creek mark the southern boundary (41° 55'N). Saugerties, N.Y. and Esopus Creek mark the northern boundary (42° 05'N)

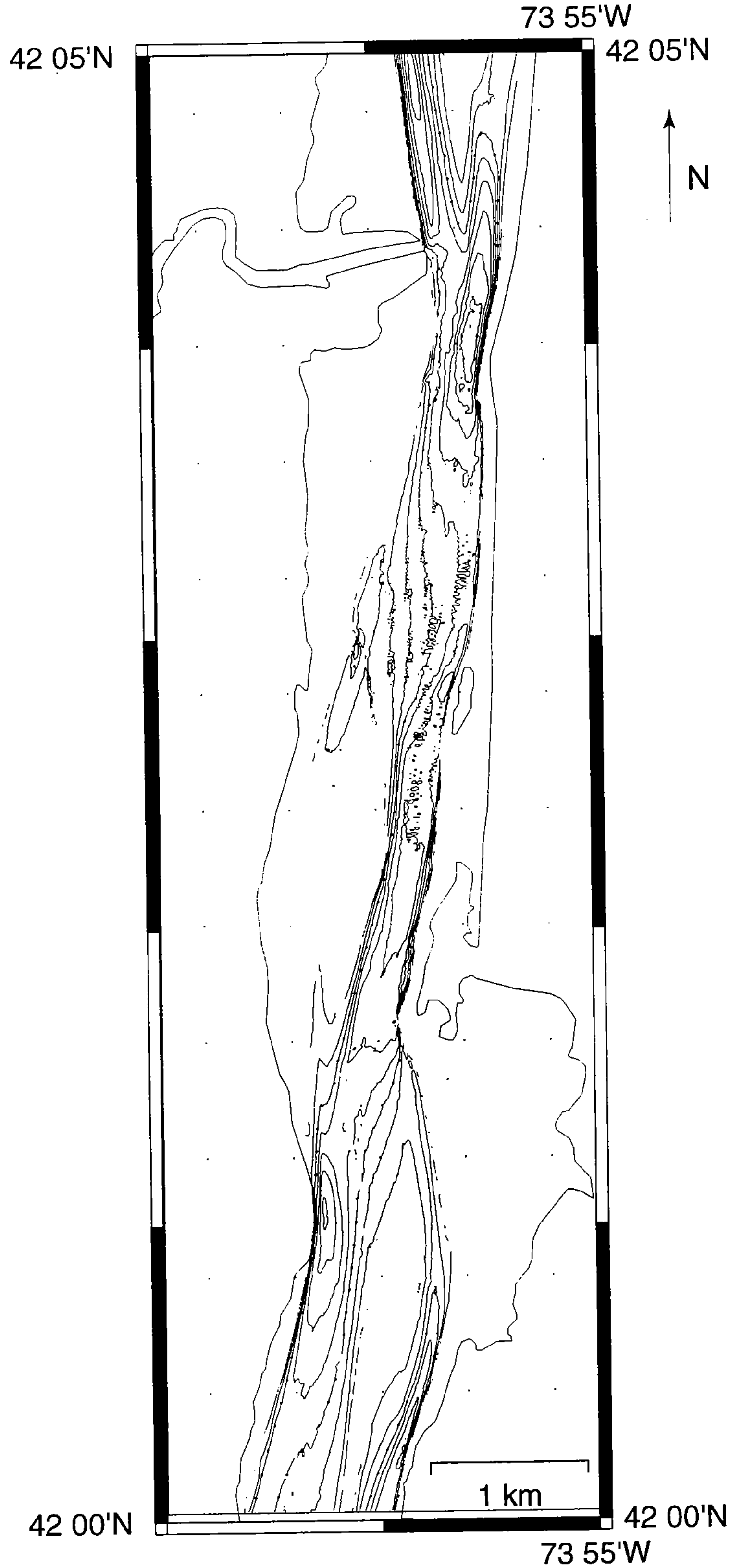

Figure 3: Bathymetry (contours): One meter contours

was used. Depth measurements taken with the hand held depth meter were taken over a tidal cycle and not corrected for tides.

Backscatter (or reflectivity)(Figure 4):

Backscatter was collected by the EM300 Multibeam Echosounder as a typical side-scan sonar image. Backscatter data is a measure of the amplitude of the acoustic signal bouncing off the riverbed, which reflects the composition of the riverbed. Backscatter distinguishes between sediment types based on differing acoustic properties, for example: coarse versus fine grain sediments; hard versus soft bottoms; homogenous versus bioturbated regions. In MSRC's multibeam sonar image coarse grain sediments or hard bottoms appear light gray; fine grain sediments or soft bottoms appear very dark gray or black.

Sun-illuminated Bathymetry (Figure 5): shows bottom topography in detail. The image is computer-generated view of what the bottom would look like if all the water were drained from the river and the sun was casting a shadow across the topography.

METHODS

Choosing Sampling Sites:

The general strategy of grab sample collection was to acquire transects across the river in key regions. The location of these transects and the position of individual grab sites were chosen to sample major reflectivity terrain and major morphological terrain. Other factors included local geology, location of tributaries, wetlands and anthropogenic structures.

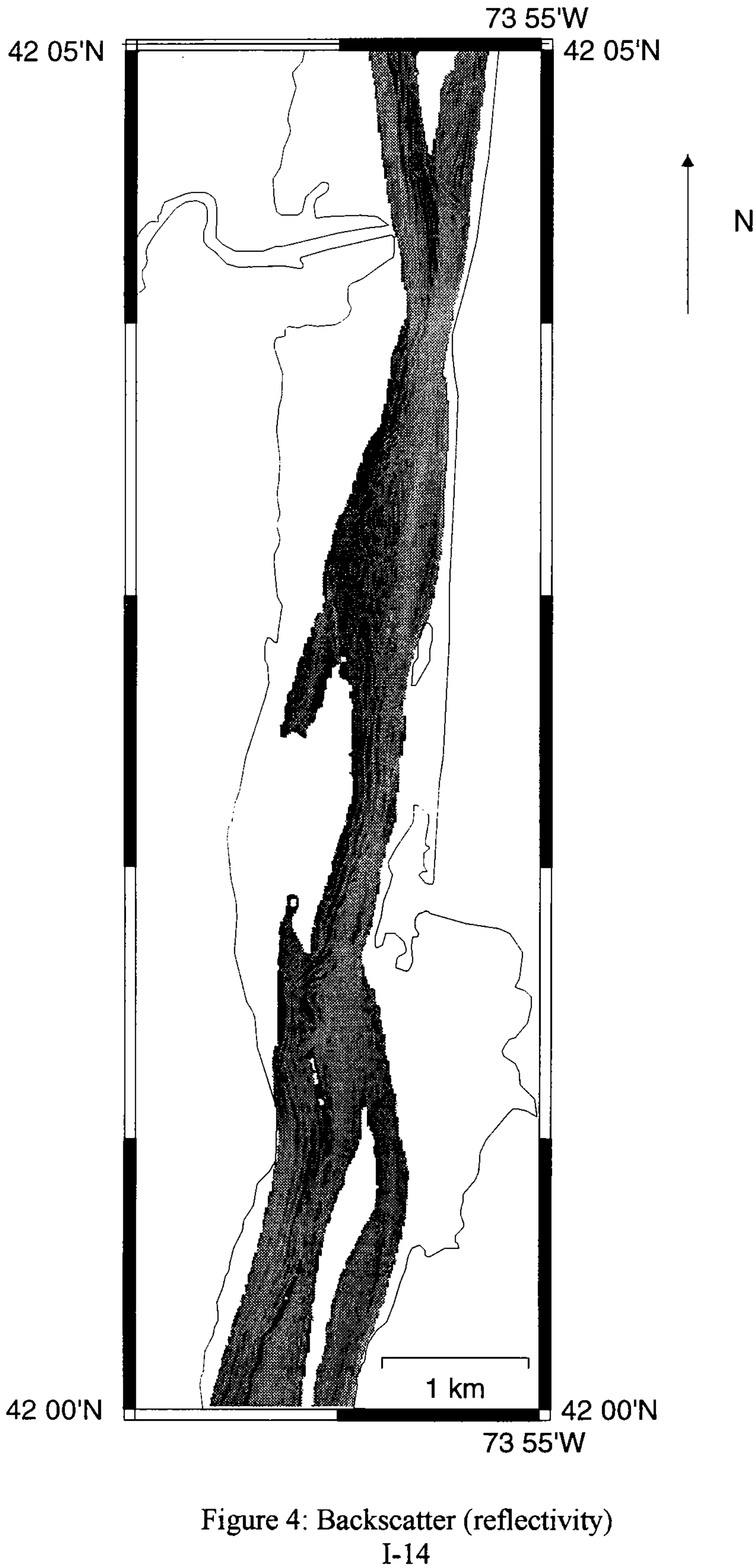

Figure 4: Backscatter (reflectivity)

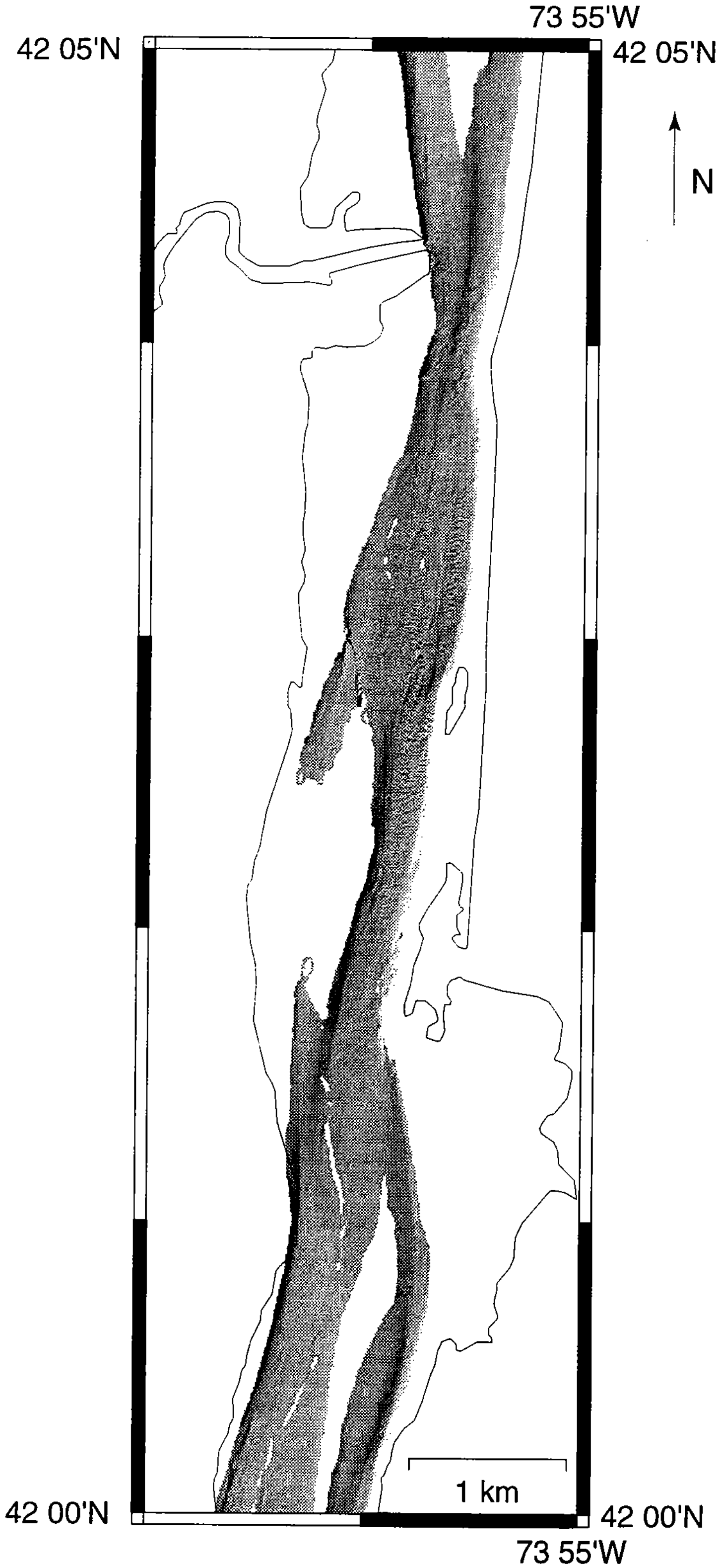

Figure 5: Sun-illuminated bathymetry. Sun is in the northwest.

Sites in the main stream of the river (Figure 6) were chosen based on change in reflectivity, on the change in depth between the main stream of the river and the fringing shallows and on bottom morphology. Using MSRC's side scan sonar imagery (Figure 4) which shows possible fine grain sediments and/or soft bottom as black or very dark gray; coarse grain sediments and/or hard bottom as pale gray, transition areas were sampled. Using sun-illuminated bathymetry, which shows bottom morphology in detail (Figure 5), erosional and depositional features were targeted.

Within Tivoli South Bay transects were laid out from the railroad embankment on the west to the eastern shore of the bay (Figure 7). From north to south within the bay, the transects were placed at the openings of the low railroad bridges and between openings in an attempt to study the physical processes affecting the exchange of sediments between the main stem of the river and Tivoli South Bay. Also targeted were the areas north and south of the Kingston-Rhinecliff Bridge and the area of the jetty just south of the delta of Esopus Creek. Sites in the shallows were also chosen based location of shoals and their relation to Esopus Creek, Tivoli North and South Bays.

Collection of Samples:

Samples were collected during four cruises. In the winter of 1998 samples were collected in the main stream of the river using a Shipeck grab from the R/V Onrust (Cruise 1, Tables 1a,b). These samples are labeled ON. In the spring of 1999 additional grab samples were collected in the main stream using a Smyth-McIntyre grab from the R/V Lionel Walford (Cruise 2, Tables 2a-d). These samples are labeled LW. In shallow

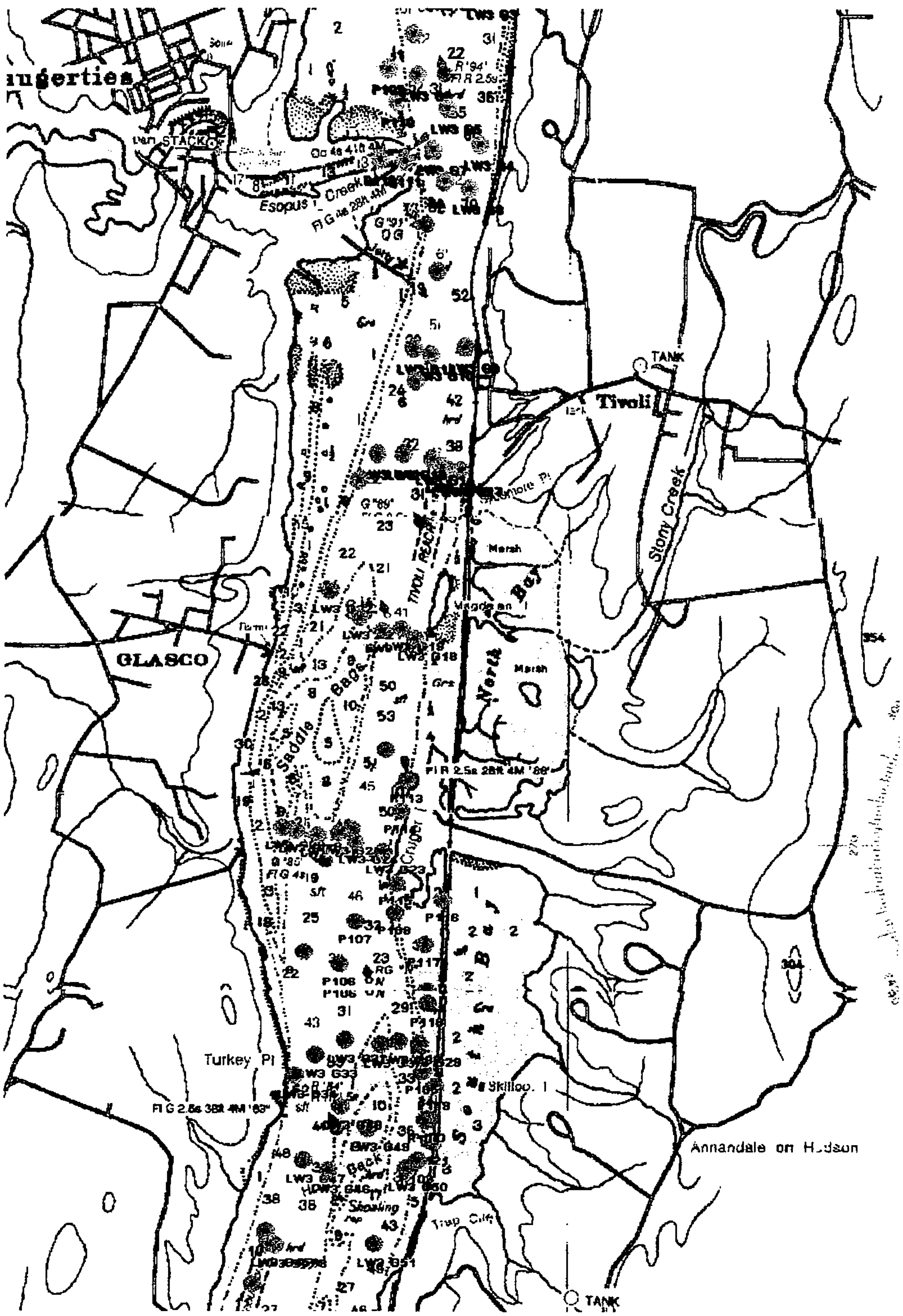

Figure 6:Sampling sites, main stream of the Hudson River

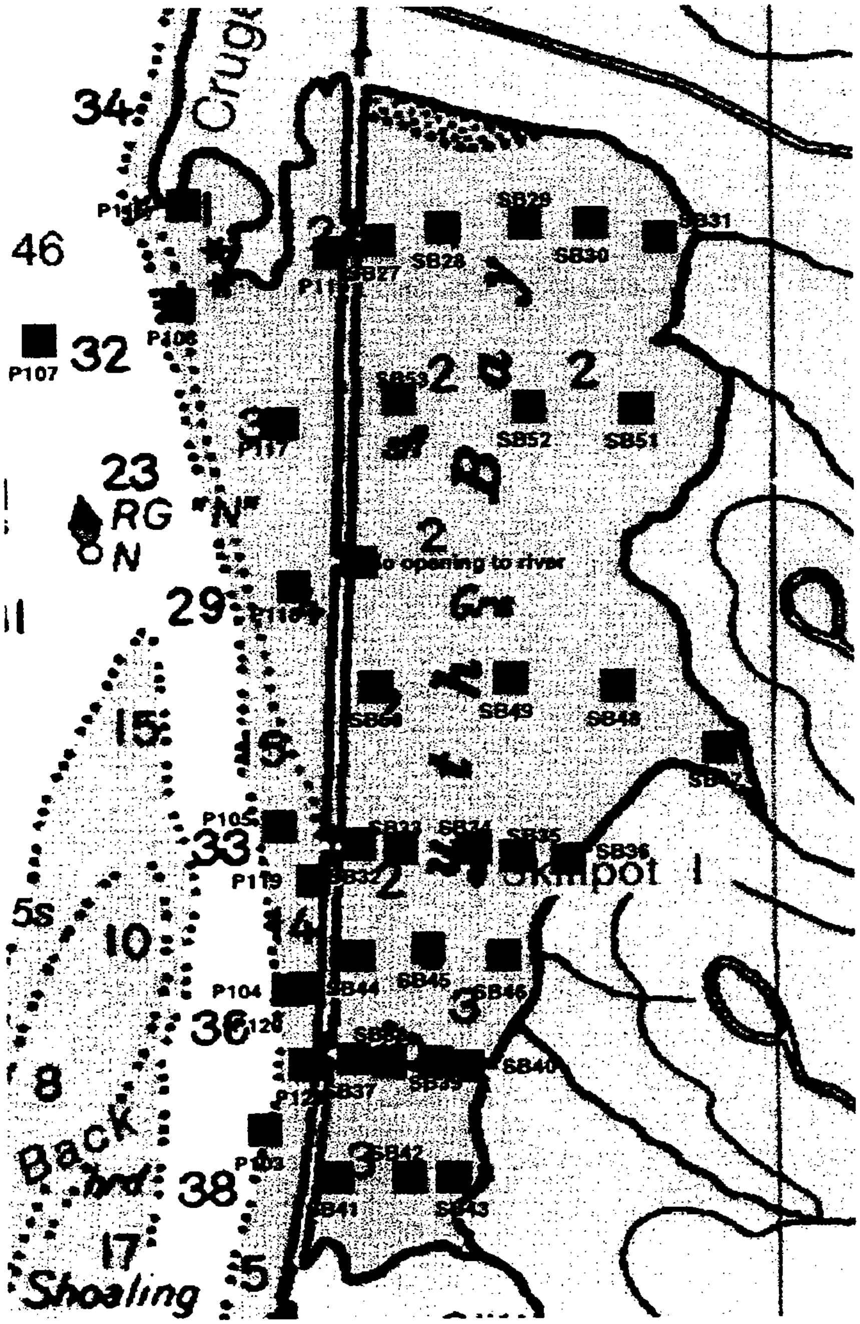

Figure 7: Sampling sites within Tivoli South Bay.

Cruise 1

Table 1a **Samples Taken off the R/V Onrust**

2-Dec-98

Sample ID	Latitude	Longitude	Depth (ft)	% Gravel	% Sand	% Silt & C	% Clay*	% Water
ON3-G1	42.045	-73.929	57.7	0.03	99.64	0.33		24.10
ON3-G2	42.082	-73.929	77.2	0.07	99.57	0.36		24.43
ON3-G3	42.071	-73.927	57.3	0.00	99.07	0.93		25.18
ON3-G4	42.065	-73.927	66.6	2.94	95.89	1.17		29.23
ON3-G5	42.059	-73.929	51.5	0.06	99.51	0.43		26.91
ON3-G6	42.054	-73.933	30.3	0.03	99.30	0.66		26.75
ON3-G7	42.036	-73.931	73.6	0.68	97.76	1.56		23.47
ON3-G8	42.031	-73.934	62.8	0.00	99.42	0.58		22.15
ON3-G9	42.023	-73.937	43.4	0.00	55.42	40.02	4.48	39.37
ON3-G10	42.007	-73.940	50.2	14.72	83.31	1.96		31.92
ON3-G11	42.004	-73.941	48.4	0.58	99.29	0.14		23.25

*Samples with 20% or greater silt/clay content were analyzed for separate silt and clay content

Cruise 2

Table 1b **Samples Taken off the R/V Onrust**

0=absent
1=rare
2=some
3=abundant

Sample ID	Zebra Mussel Shells	Other Shells	Leaves	Wood	Slag	Coal
ON3-G1	0	0	1	1	0	0
ON3-G2	0	0	0	1	0	0
ON3-G3	0	0	0	0	0	0
ON3-G4	0	0	3	3	0	0
ON3-G5	0	0	1	0	0	0
ON3-G6	1	0	0	3	0	0
ON3-G7	0	0	0	1	0	0
ON3-G8	0	0	0	1	0	0
ON3-G9	0	0	0	0	0	0
ON3-G10	3	1	0	3	0	0
ON3-G11	0	0	0	0	1	0

Table 2a

Cruise 2
Samples Taken off the R/V Walford
30-31-May, 99

Date	Sample ID	Latitude	Longitude	Depth (ft)	% Gravel	% Sand	% Silt & Clay	% Clay*	% Water
30-May-99	LW3-G1	42.084	-73.930	56.2	0.20	98.76	1.03		23.41
	LW3-G2	42.081	-73.927	8.6	0.08	97.23	2.70		25.18
	LW3-G3	42.081	-73.924	24.4	2.48	96.58	0.94		30.56
	LW3-G4	42.072	-73.924	50.5	0.59	98.12	1.29		27.22
	LW3-G5	42.074	-73.926	27.0	0.02	98.98	1.00		21.88
	LW3-G6	42.076	-73.929	60.1	5.73	94.00	0.27		27.04
	LW3-G7	42.072	-73.928	42.0	60.14	39.65	0.21		26.81
	LW3-G8	42.070	-73.925	63.2	11.04	82.96	6.00		21.61
	LW3-G9	42.061	-73.925	na	92.47	6.68	0.85		67.21
	LW3-G10	42.061	-73.928	49.7	10.37	89.33	0.30		19.76
	LW3-G11	42.061	-73.929	35.1	0.03	99.81	0.16		21.57
	LW3-G12	42.055	-73.932	20.9	0.08	99.31	0.61		22.57
	LW3-G13	42.055	-73.930	31.4	6.52	92.48	0.99		24.34
	LW3-G14	42.055	-73.928	38.9	35.09	64.31	0.60		24.61
	LW3-G15	42.054	-73.927	39.4	3.96	95.85	0.20		14.69
	LW3-G16	42.054	-73.926	43.5	3.64	80.84	15.52		34.09
	LW3-G17	42.054	-73.925	38.4	45.59	45.17	9.25		32.96
	LW3-G18	42.043	-73.929	53.1	5.92	93.85	0.23		23.61
	LW3-G19	42.044	-73.930	50.5	0.00	99.71	0.29		22.70
	LW3-G20	42.044	-73.931	35.2	0.02	99.70	0.27		19.64
	LW3-G21	42.045	-73.933	15.6	0.49	94.69	4.83		23.38
	LW3-G22	42.046	-73.935	23.9	14.63	84.54	0.83		24.37

*Samples with 20% or greater silt/clay content were analyzed for separate silt and clay content