THE UNIVERSITY OF NEW SOUTH WALES

water research laboratory

Manly Vale N.S.W. Australia

BROOKLYN ESTUARY PROCESS STUDY - APPENDICES (VOLUME II OF II)

by

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Appendix A

RMA Hydrodynamic and Water Quality Modelling

APPENDIX A – RMA HYDRODYNAMIC AND WATER QUALITY MODELLING

A1.1 Hydrodynamic Modelling

A.1.1.1 Introduction

RMA-2 is a two-dimensional finite element hydrodynamic model for depth averaged flow (King, 1998). The shallow water forms of the Navier-Stokes equations are solved in two dimensions to obtain velocities and water surface elevations at each node on the finite element mesh. The model can either be operated in steady-state or dynamic modes.

A two-dimensional finite element model was developed for the Brooklyn Estuary study area to gain an understanding into the current hydrodynamics of the area and also in order to model how the hydrodynamics of the system would be altered in the event that the railway causeway from Brooklyn to Long Island was removed. Two flow regimes were examined. These were base flows and the peak flows that would be expected for a 20% AEP flood.

A.1.1.2 Previous Hydrodynamic Modelling

Hydrodynamic modelling that has previously been carried out on the Hawkesbury River includes a calibrated hydrodynamic RMA2 model (Hawkesbury Model) that was designed to examine flood behaviour on the Lower Hawkesbury River from Sackville to Broken Bay (AWACS, 1997). For the Brooklyn Estuary Processes Study hydrodynamic modelling, boundary conditions were extracted from the flood model. Therefore the hydrographic and tidal inputs of the flood model used for the Lower Hawkesbury River Flood Study were altered to simulate the flow conditions required for this study.

A.1.1.2.1 Hawkesbury Model Input Data

<u>Hydrograph Data</u>

The hydrographs used in the flood study were manipulated so that baseflows and the 20% AEP peak flows were entered at the hydrograph input points (the major creeks that discharge to the Hawkesbury River). These flow rates were determined from the hydrographs used in the Lower Hawkesbury River Flood Study.

<u>Tidal Data</u>

Tide data was input on the downstream boundary of the Lower Hawkesbury River Flood Study model. This data was generated using the program WXTide32, for Little Patonga. The data generated by WXTide32 was in ISLW and was converted to the Australian Height Datum. A full tidal cycle (spring-neap-spring) was used as an input to the model, which took approximately eighteen days. The two days prior to the tidal cycle were also used to ‘warm up’ the model.

Bathymetry

The bathymetry used in the flood model was taken from hydrographic surveys conducted from 1978 and 1984 (see AWACS, 1997).

A.1.1.1.3 Brooklyn Model Input Data

Boundary Conditions

As mentioned previously, the flow rates and water levels for the upstream and downstream boundaries of the Brooklyn model respectively, were extracted from the results file of the Hawkesbury Model. The boundaries of the Brooklyn model were beyond that of the Brooklyn Estuary study area boundaries. In order to negate boundary impacts and obtain a true representation of the hydrodynamics within the study area .

Hydrographs

Two significant creeks (Mooney-Mooney Creek and Mullet Creek) discharge into the Hawkesbury River in the Brooklyn Estuary study area. Baseflows and peak flood flows used as inputs into the model for Mooney Mooney Creek were obtained from the discharge hydrographs used in the Lower Hawkesbury River Flood Study and were estimated for Mullet Creek. No other diffuse source inputs were considered.

Bathymetry

The 1978 and 1984 data used in the Hawkesbury Model was used to define the bathymetry in the Brooklyn model. However, further definition of the bathymetry of Sandbrook Inlet was needed for the Brooklyn Estuary Processes Study modelling and therefore hydrographic surveys of the inlet from 1975 were incorporated into the bathymetry of the area.

Frictions and Eddy Constants

Friction losses in the model are determined from Manning's Equation, and therefore mannings n was an input parameter. The value for mannings n was generally constant across the study area, however Mannings n values were varied at sections of the model that corresponded to real world changes in channel roughness (ie, oyster leases and mangroves). The mannings n value used for the river bed for most of the study area was 0.023, for oyster leases and mangroves a value of 0.150 was used and for areas where seagrasses were present a mannings n value of 0.033 was used.

Turbulence parameters used in the model are input as eddy coefficients. In this case, scale factors of the element size were entered to determine the eddy coefficients. When this option is used, the relative size of each element is taken into consideration in the determination of turbulence.Values of 0.5 were used as scale factors to determine the eddy coefficients in both the x and y direction.

A.1.1.2 Description of Brooklyn Model

A.1.1.2.1 Hydraulic Model Schematisation

The model developed to simulate the hydrodynamics of the Brooklyn Estuary study area was a two-dimensional finite element numerical model (RMA2) (King, 1998). RMA2 computes a finite element solution of the Reynolds form of the Navier-Stokes equations for turbulent flows.

The two-dimensional model is configured such that:

- Velocities are depth averaged;
- Friction losses in the model are based on Mannings 'n';
- The model network is constructed by quadrilaterals and triangles;
- Within each element velocity and stage characteristics are calculated by a quadrilateral approximation; and
- Eddy viscosity coefficients are used to define turbulence characteristics.

Two different layouts of the finite element mesh were designed for the study area, one with and one without the railway causeway. The element meshes generated to model the hydrodynamics can be seen in Figure 4.4. As can be seen in these figures the meshes were refined in the region of Sandbrook Inlet to delineate the boundaries of oyster leases, marinas and mangroves. This was done as water movement in Sandbrook Inlet was of particular interest to the study. The impact of oyster leases, marinas and different types of benthic flora on the hydrodynamics in the area were incorporated by changing the friction losses in these areas.

RMA-2 Model Calibration

The Brooklyn finite element model was calibrated using ADCP data measured by MHL on the 16th October 2001 at four cross sections within the study area. ADCP bottom tracking profiling current meters were used to measure velocities at these sites. Although multiple cross sections were measured, the peak ebb and flood discharges were used to calibrate the model.

Depth average velocity data was extracted from the RMA model results file at the where the ADCP data was measured and at the same time period. The depth averaged ADCP readings and the data extracted from the RMA results file were plotted in ArcInfo GIS for comparison.

Model parameters used to calibrate the model were the Manning's bed roughness and the eddy viscosity. These parameters were set at values based upon experience with similar types of models. The Manning's roughness was increased for areas where mangroves, seagrasses, oyster leases and marinas were present and was 0.023 for the remainder of the model.

A.1.2 Water Quality Modelling

The water quality of the Brooklyn Estuary study area was modelled in terms of determining the length of time required to flush a conservative pollutant from the system. Flushing times were predicted under low flows and peak flood flows from the 20% AEP flood event and for the causeway/non-causeway option.

To simulate the water quality the water quality model RMA11 (King, 1998) was used. RMA-11 is a finite element water quality model is able to use the hydrodynamic results generated by RMA2. Therefore, in this case, as the results used from the hydrodynamic modelling were depth averaged a two-dimensional approximation of water quality was calculated.

To simulate the flushing of a conservative pollutant from the system, the model was configured so that the initial concentration of the pollutant was 100mg/L over the entire study area. The water quality at the boundaries of the model was then decreased from 100mg/L to 0mg/L over a short period of time.

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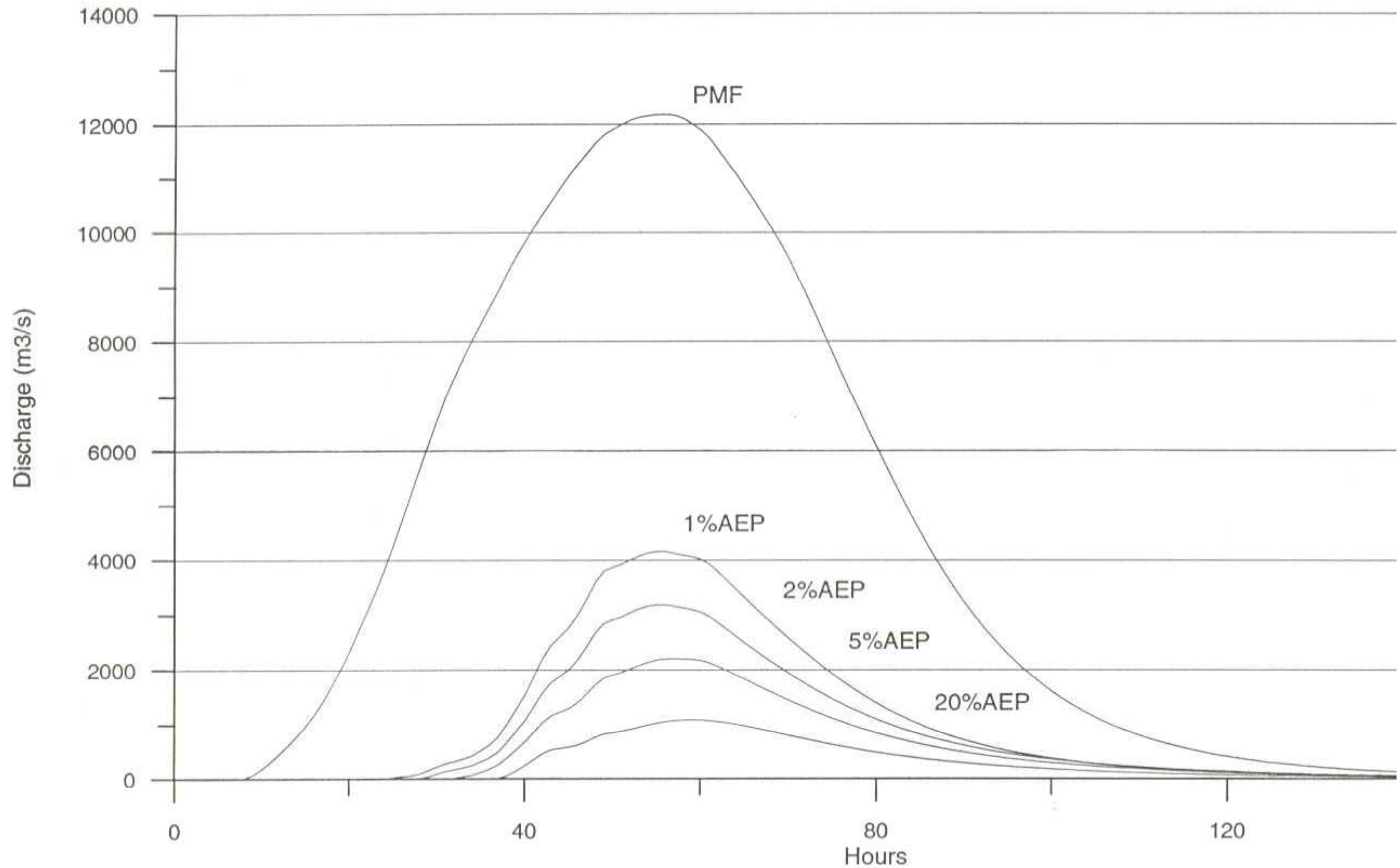
Report No. 2002/20

COLO RIVER DESIGN FLOOD HYDROGRAPHS



(Source: AWACS, 1997)

Figure
A1

fig1.doc

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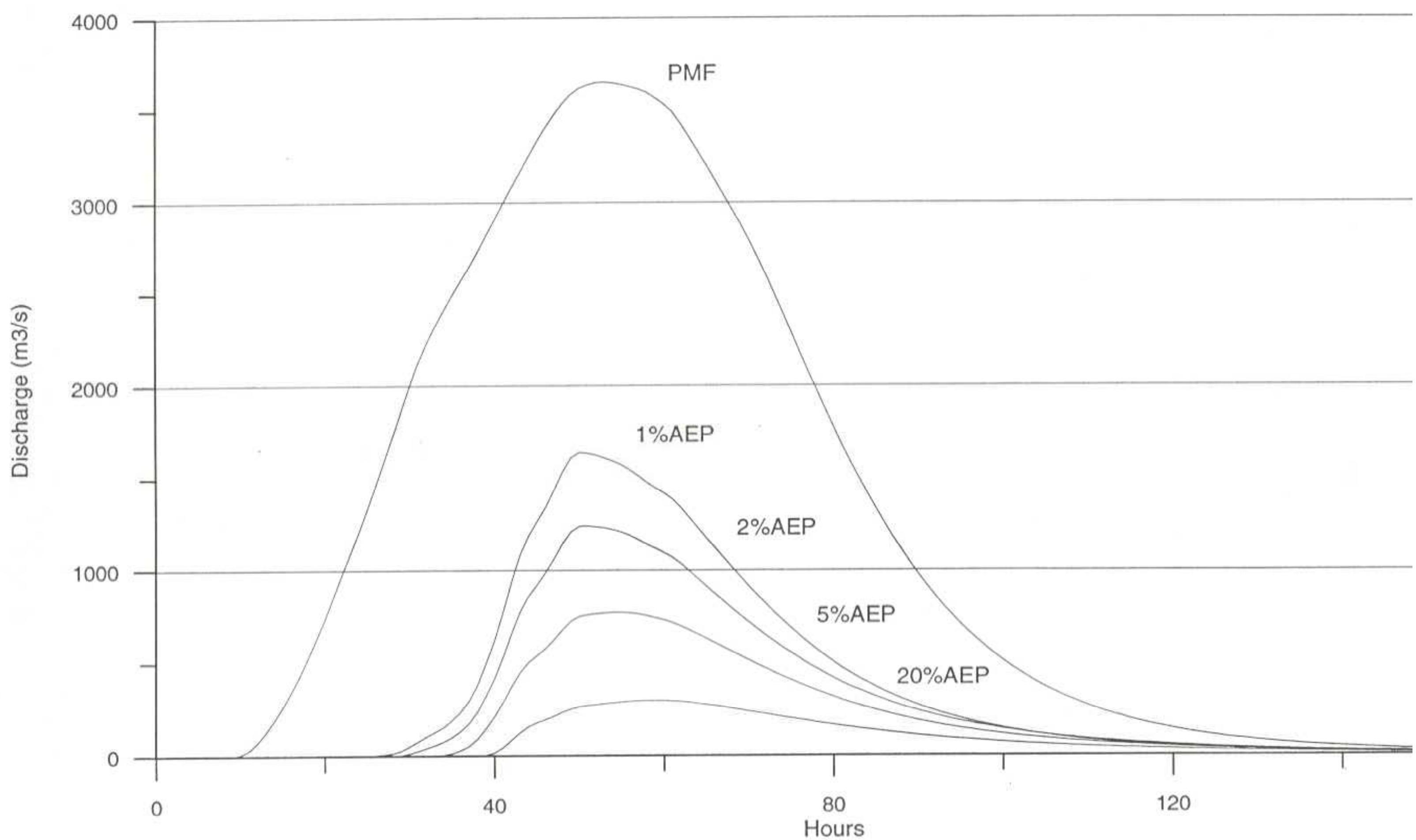
MACDONALD RIVER DESIGN FLOOD HYDROGRAPHS



(Source: AWACS, 1997)

Figure
A2

fig2.doc

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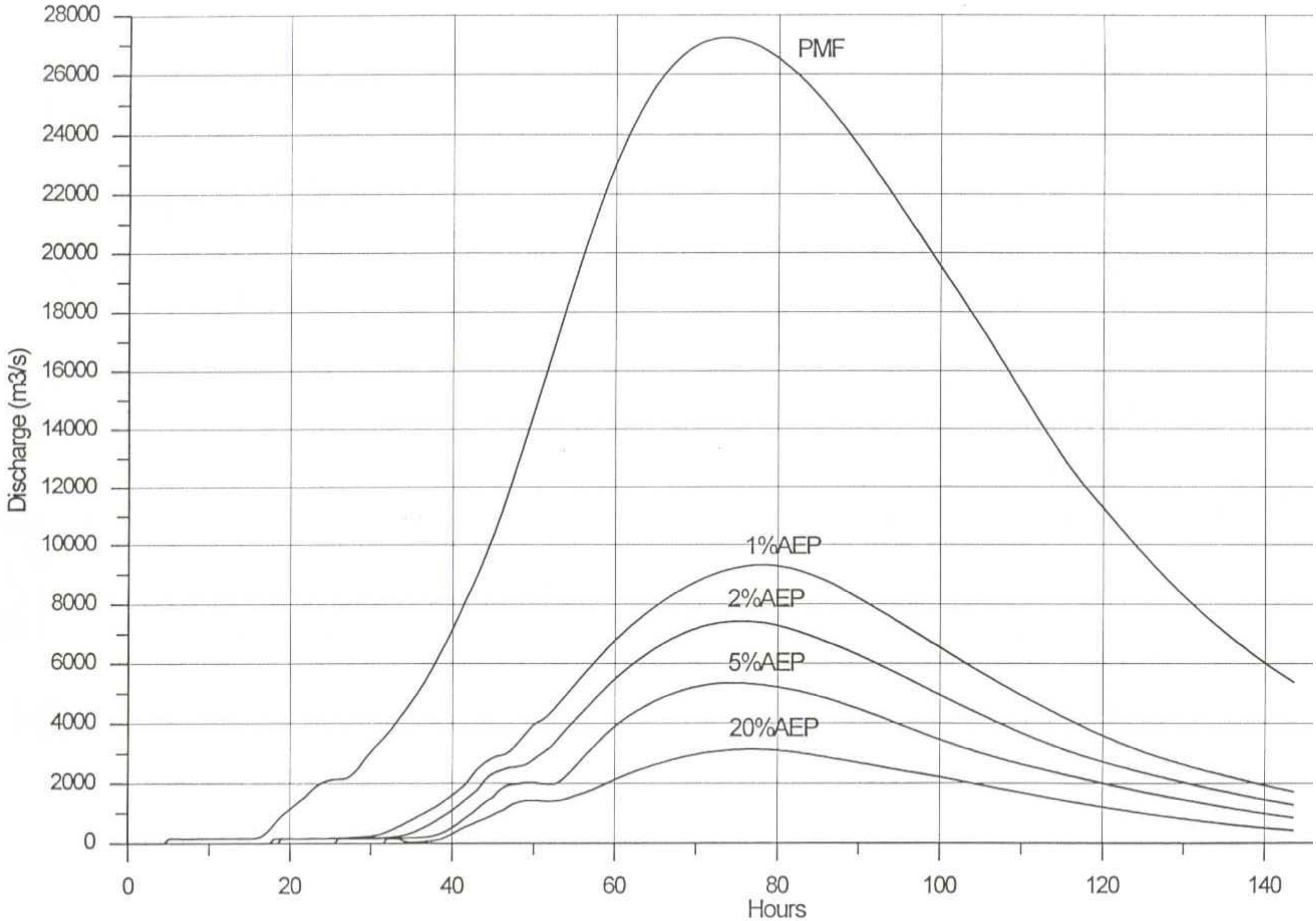
SACKVILLE DESIGN FLOOD HYDROGRAPHS

Figure
A3

fig3.doc



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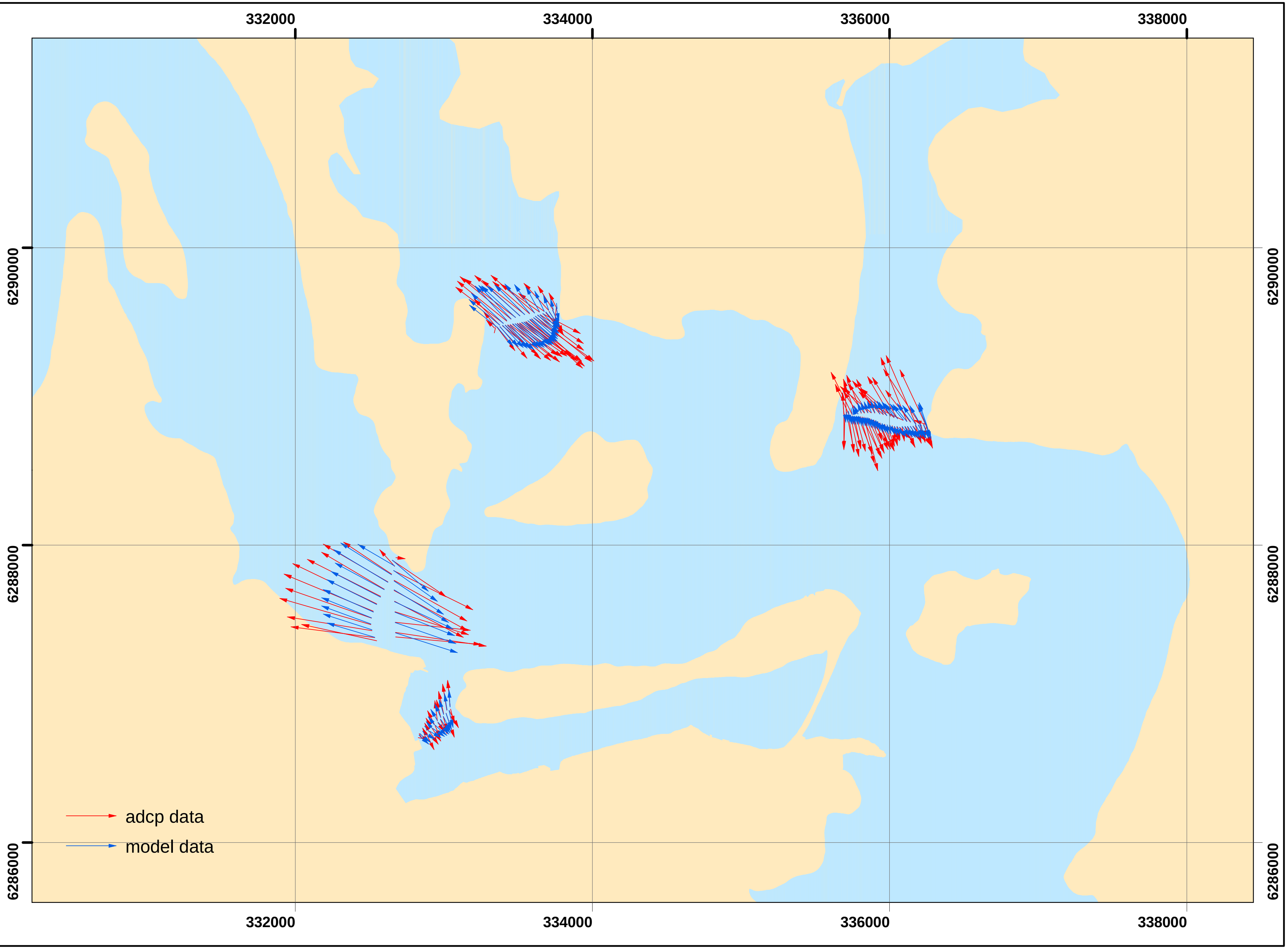

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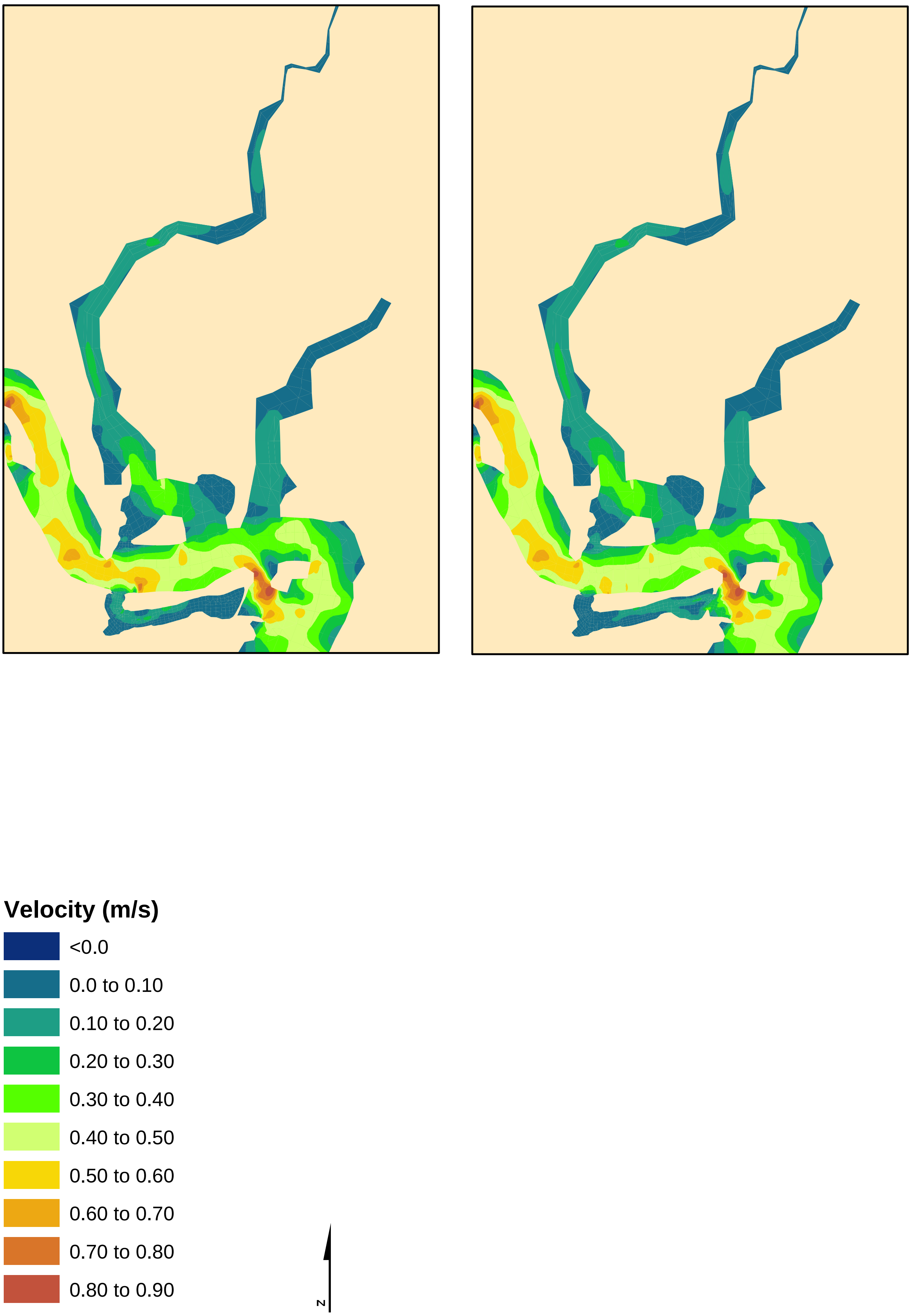
MODEL CALIBRATION
FOR TYPICAL PEAK FLOOD AND EBB TIDES

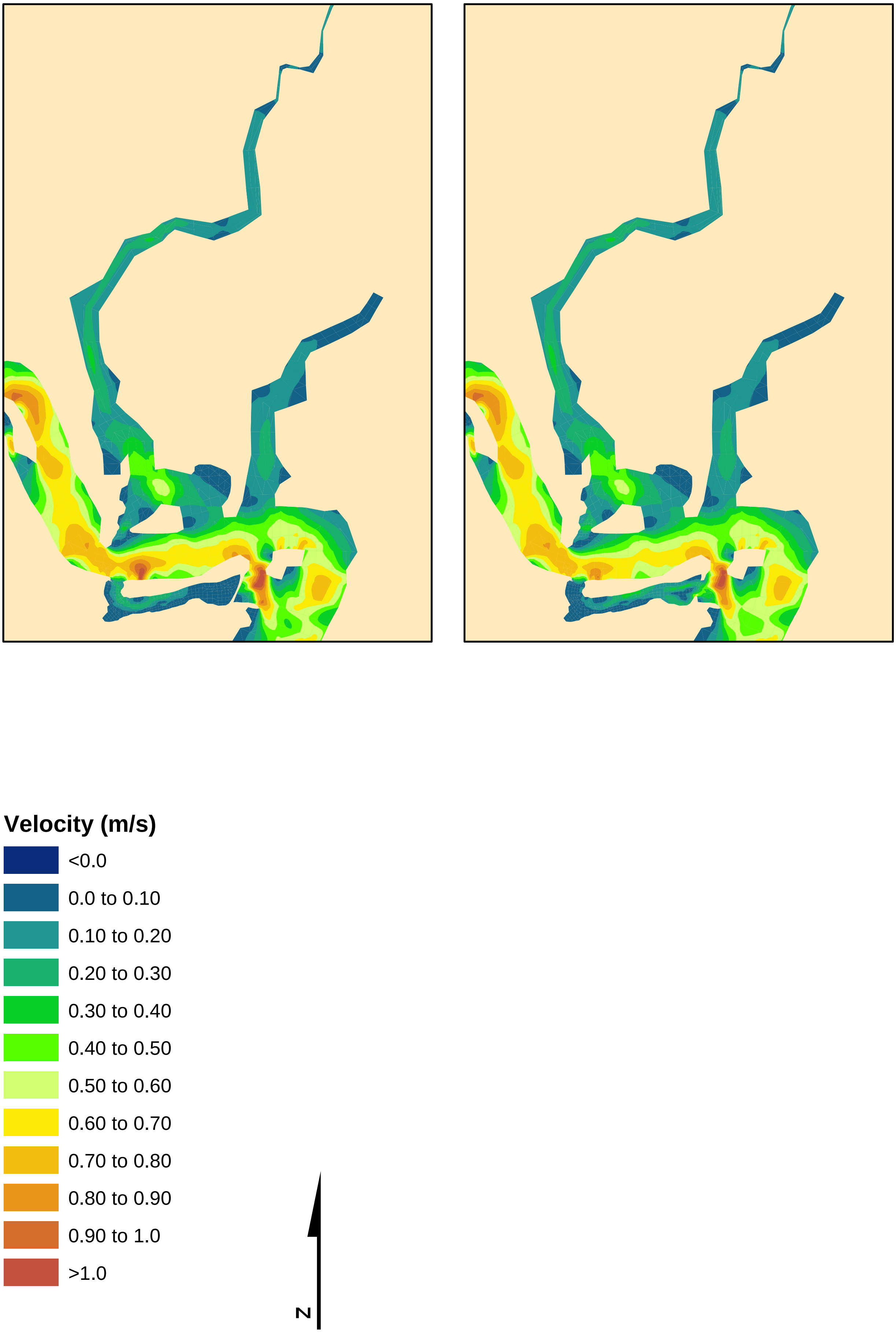
Figure A4

fig4.mxd



WRL Report No. 2002/20	TYPICAL FLOOD TIDE PEAK VELOCITIES WITH BASE FLOWS WITH AND WITHOUT CAUSEWAY	Figure A5

fig5.mxd



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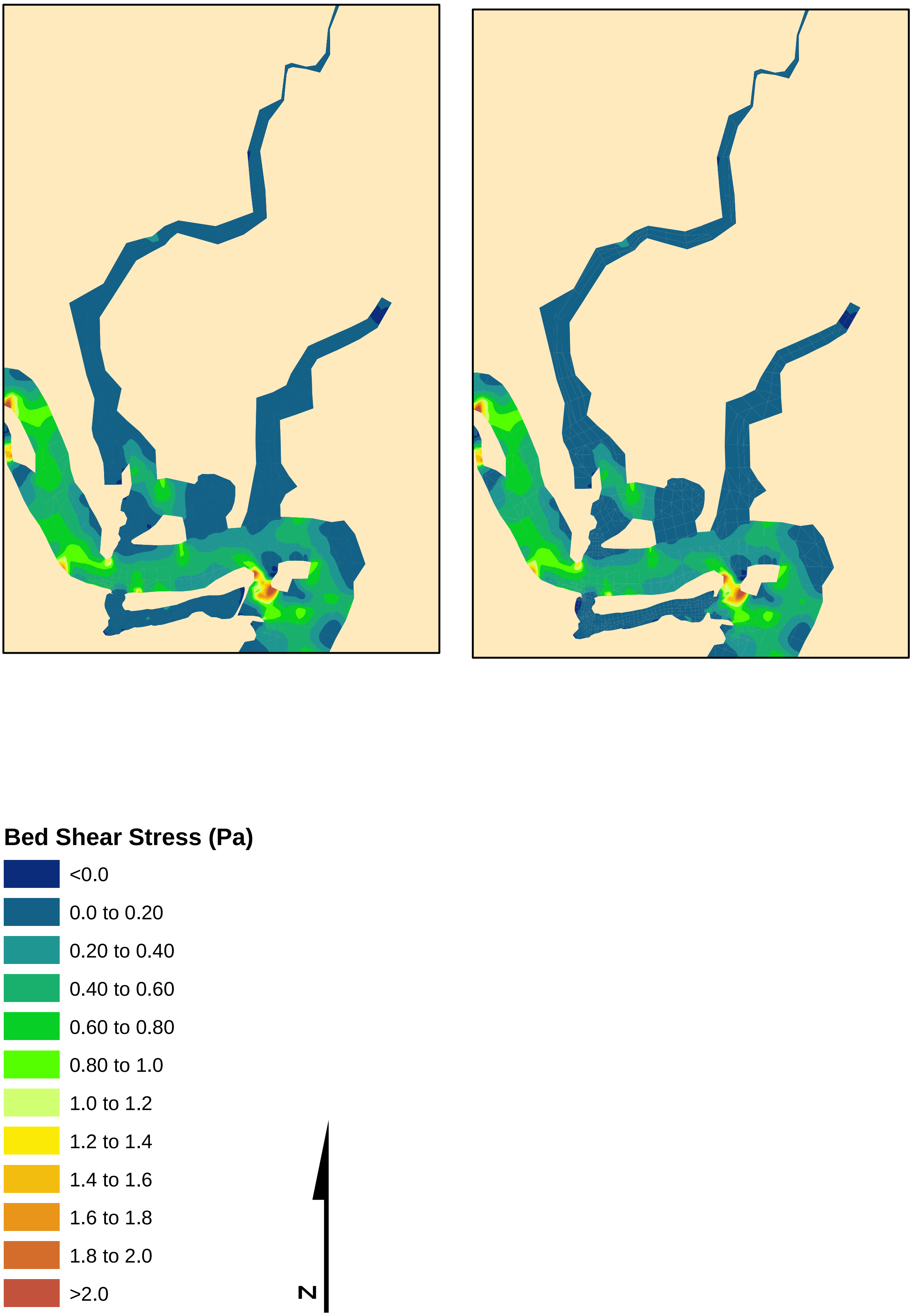
TYPICAL EBB TIDE PEAK VELOCITIES WITH BASE FLOWS WITH AND WITHOUT CAUSEWAY

Figure A6

fig6.mxd



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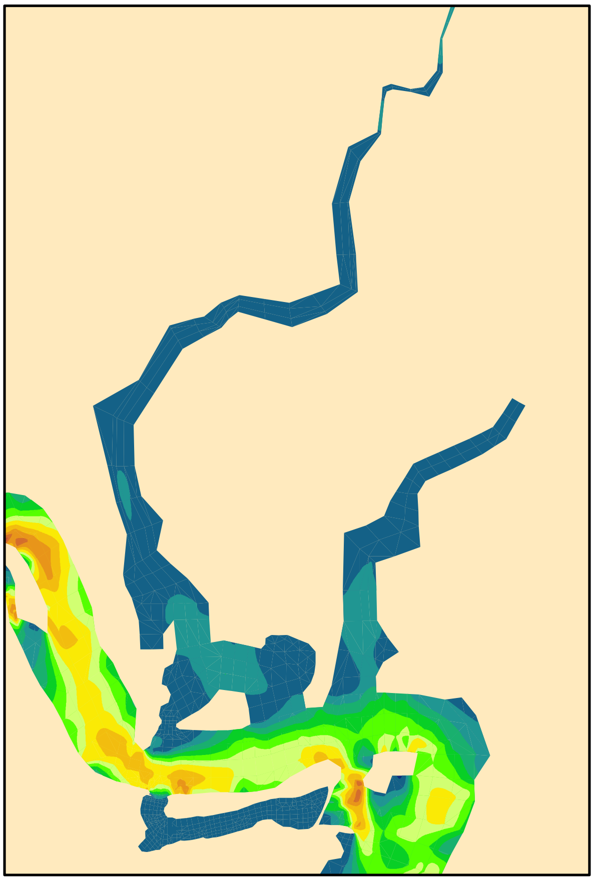
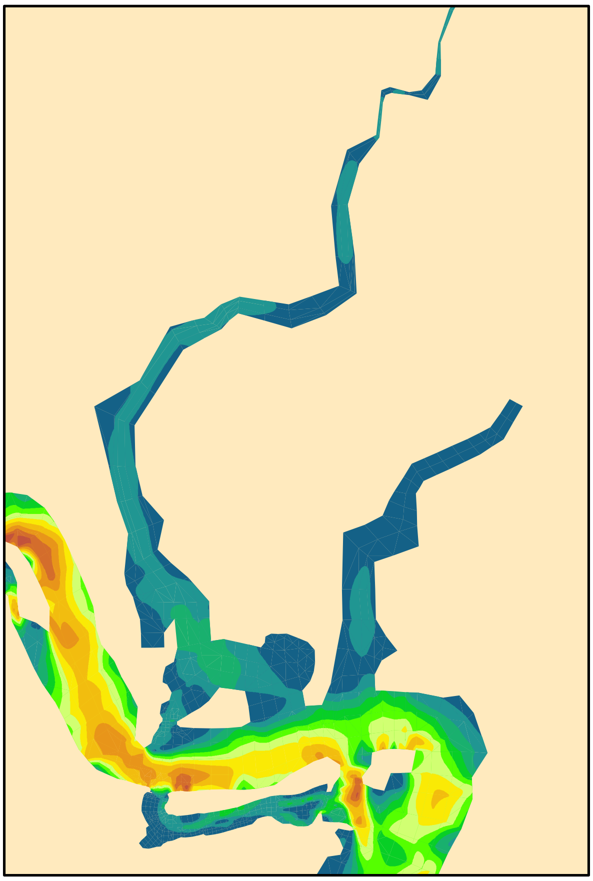
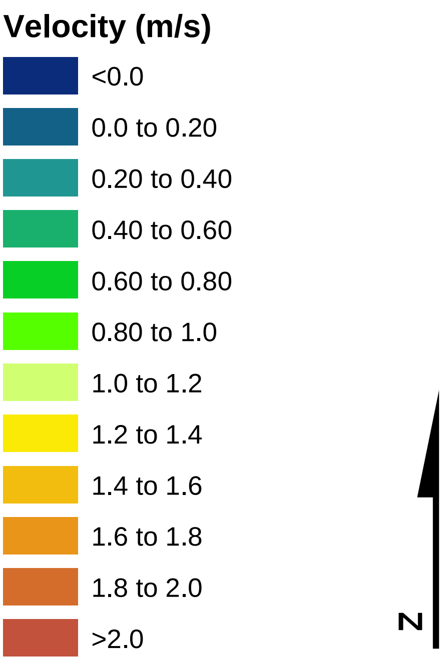
TYPICAL FLOOD TIDE PEAK VELOCITIES WITH FLOOD FLOWS WITH AND WITHOUT CAUSEWAY

Figure A7

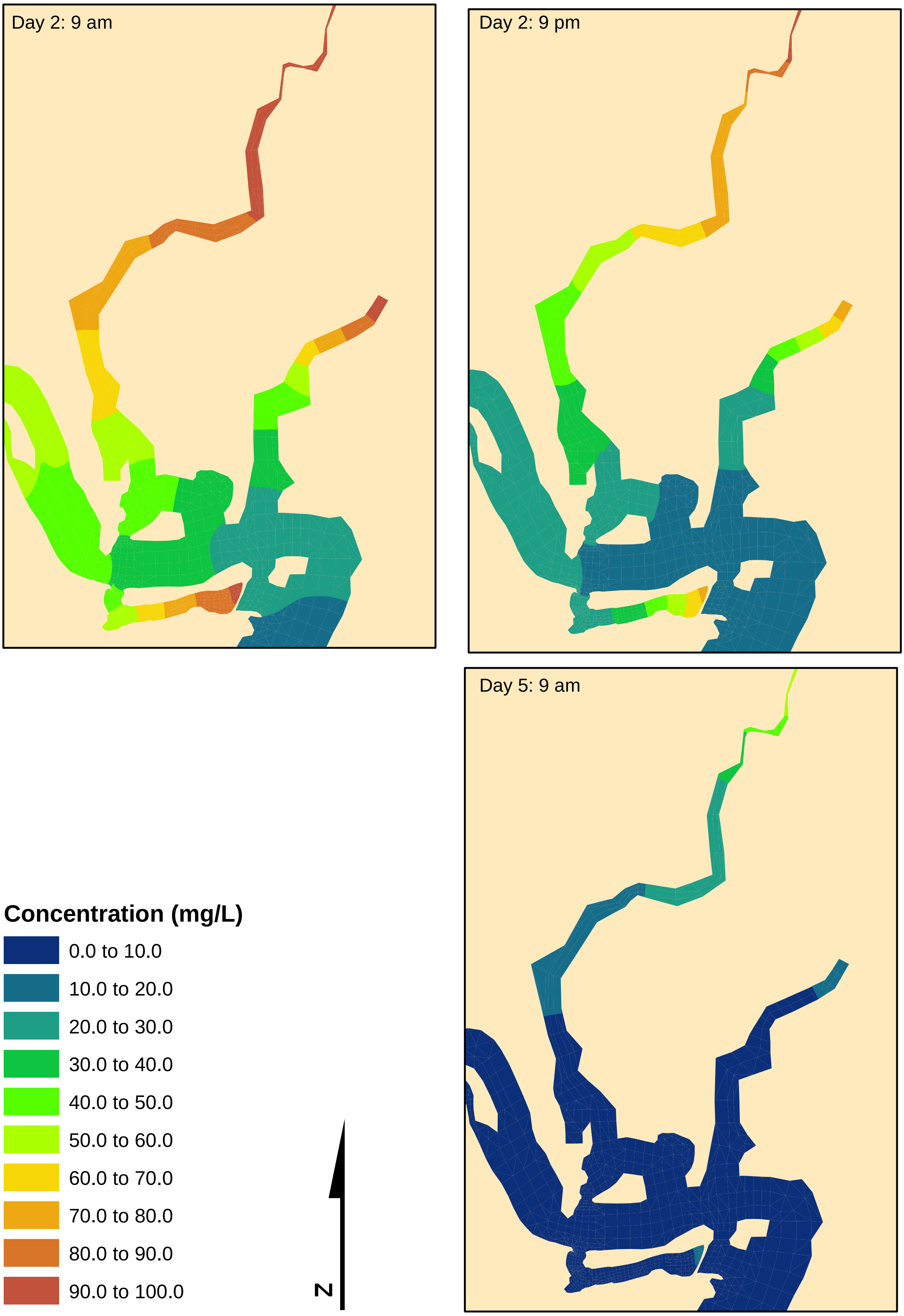
fig7.mxd







WRL Report No. 2002/20	TYPICAL EBB TIDE PEAK VELOCITES WITH FLOOD FLOWS WITH AND WITHOUT CAUSEWAY	Figure A8
		fig8.mxd



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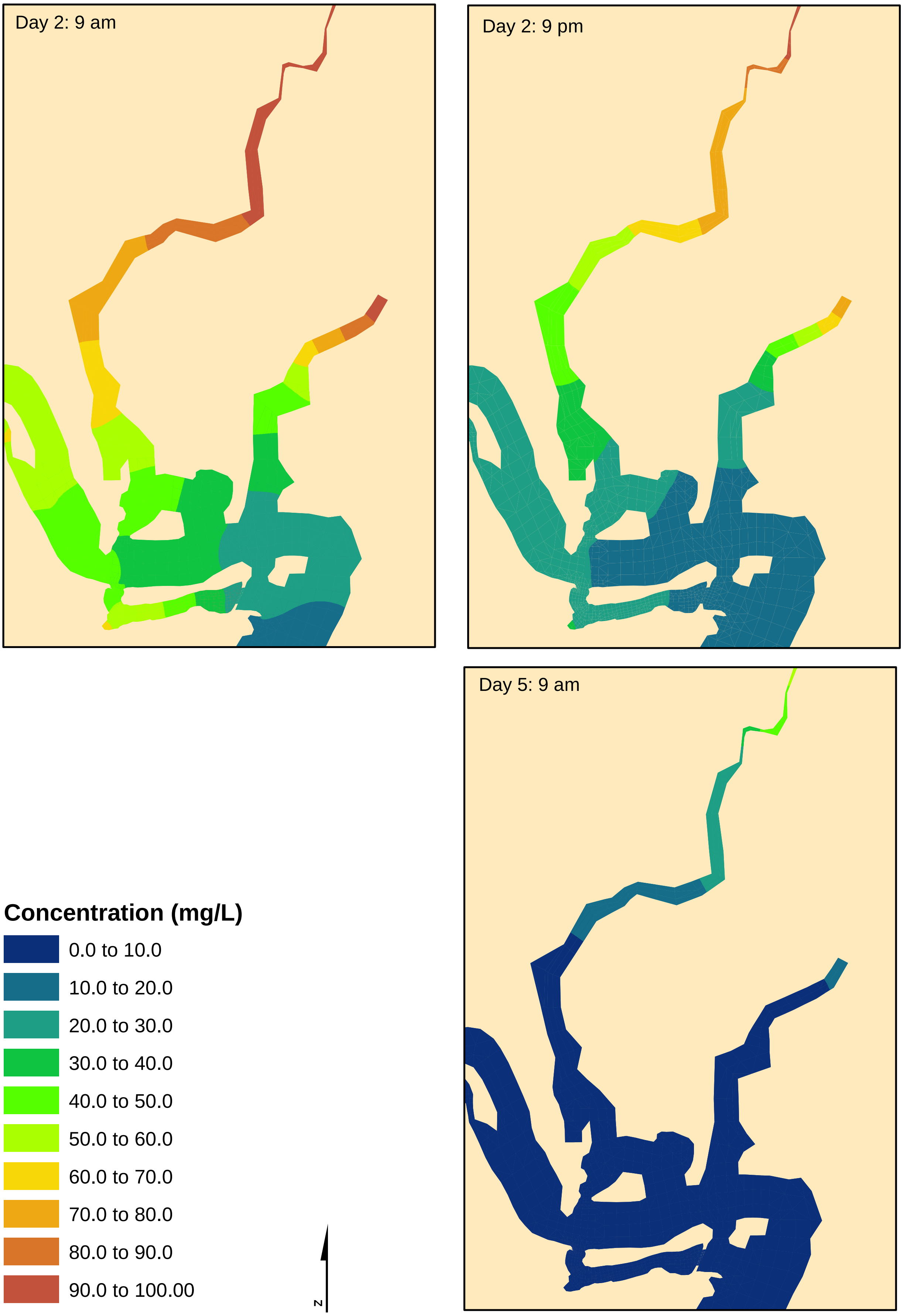
WATER QUALITY MODELLING RESULTS WITH BASE FLOWS WITH CAUSEWAY

Figure A9

fig9.mxd



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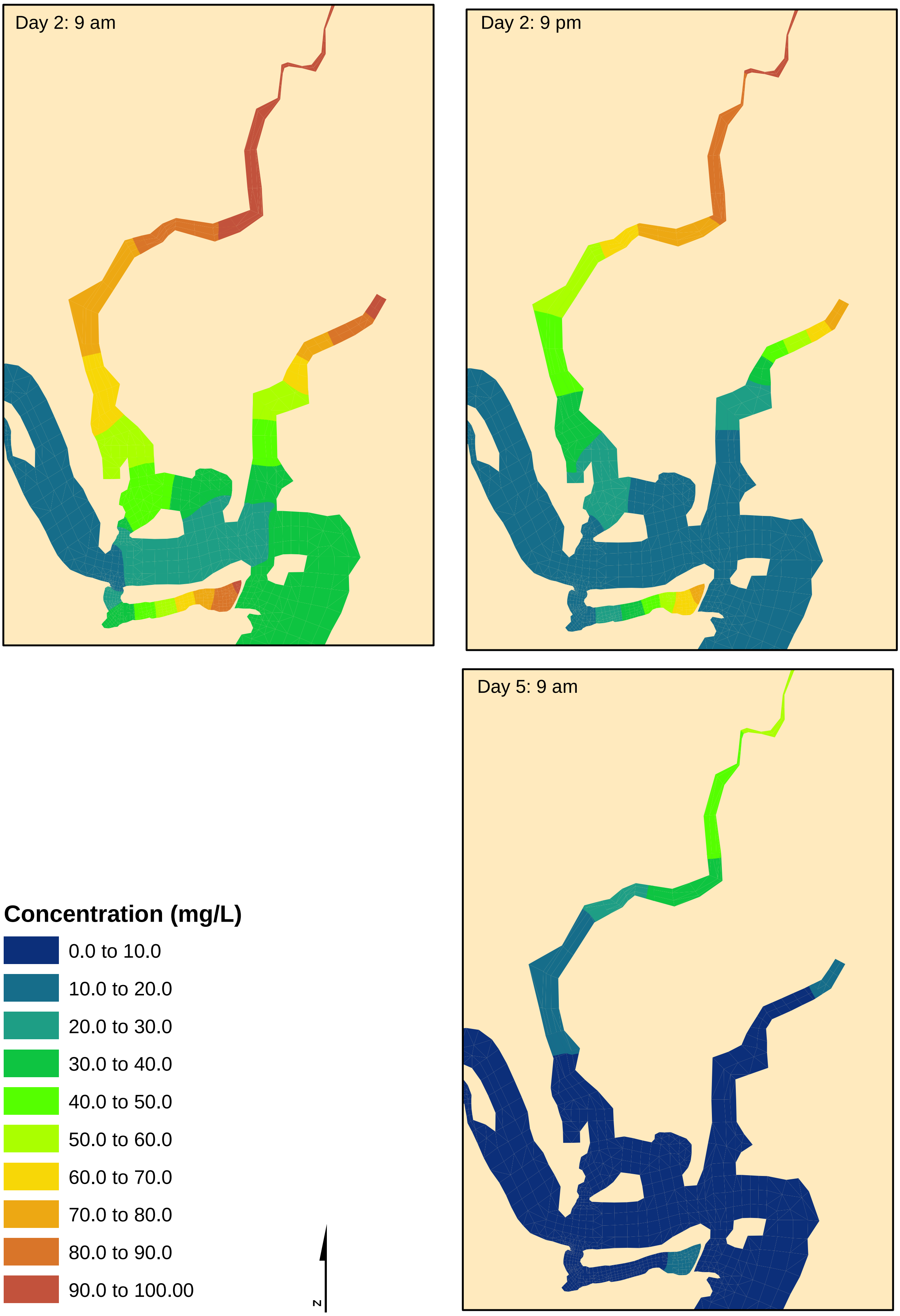
WATER QUALITY MODELLING RESULTS WITH BASE FLOWS WITHOUT CAUSEWAY

Figure A10

fig10.mxd



WRL Report No. 2002/20	WATER QUALITY MODELLING RESULTS WITH FLOOD FLOWS WITH CAUSEWAY	Figure A11
		fig11.mxd

Appendix B

Water Quality Analysis

Appendix B: Water Quality

B.1 Summary of Water Quality Data Provided

Table B.1 Water Quality Data Provided by the NSW Environment Protection Authority (EPA) and Hornsby Shire Council (HSC)

	Site	Source	Start Date m/d/y	End Date m/d/y	Frequency
Chl-*a*	Berowra	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	7/5/96	fortnightly
	Bar Point	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	7/2/96	fortnightly
	Mullet	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			1/24/94	7/5/96	fortnightly
	Mooney Mooney	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			2/8/94	7/5/96	fortnightly
	Sandbrook Inlet	HSC	10/10/94	6/8/01	monthly
Turbidity	Berowra	EPA	3-4/92, 1-2/93		monthly
			10/93, 11/93-1/94, 8/94-7/96		fortnightly
	Bar Point	EPA	3-4/92, 1-2/93		monthly
			9/7/93	7/2/96	fortnightly
	Mullet	EPA	3-4/92, 1/93		
			1/24/94	7/5/96	fortnightly
	Mooney Mooney	EPA	3-4/92, 1/93		
			3/23/94	7/5/96	fortnightly
	Sandbrook Inlet	HSC	10/10/94	6/8/01	monthly
	Spectacle Island	HSC	1/9/97	6/8/01	monthly
	Mooney Mooney	HSC	1/9/97	6/8/01	monthly
	Mullet	HSC	6/5/97	6/8/01	monthly
Suspended Solids	Berowra	EPA	9/7/93	7/5/96	fortnightly
	Bar Point	EPA	9/7/93	7/2/96	fortnightly
	Mullet	EPA	1/24/94	2/5/96	fortnightly
	Mooney Mooney	EPA	2/8/94	7/5/96	fortnightly
	Sandbrook Inlet	HSC	10/10/94	6/8/01	monthly
Secchi depth	Berowra	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			10/6/93	7/5/96	fortnightly starting 8/4/95
	Bar Point	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	7/2/96	fortnightly with gap 3/3/95-8/4/95
	Mullet	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			1/24/94	7/5/96	fortnightly
	Mooney Mooney	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			2/22/94	7/5/96	fortnightly

	Site	Source	Start Date m/d/y	End Date m/d/y	Frequency
NH_3	Berowra	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	7/5/96	fortnightly
	Bar Point	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	7/2/96	fortnightly
	Mullet	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			1/24/94	7/5/96	fortnightly
	Mooney Mooney	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			2/8/94	7/5/96	fortnightly
	Sandbrook Inlet	HSC	10/10/94	6/8/01	monthly
NO_x	Berowra	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	7/5/96	fortnightly
	Bar Point	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	7/2/96	fortnightly
	Mullet	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			1/24/94	7/5/96	fortnightly
	Mooney Mooney	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			2/8/94	7/5/96	fortnightly
	Sandbrook Inlet	HSC	10/10/94	6/8/01	monthly
TKN	Berowra	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	7/5/96	fortnightly
	Bar Point	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	7/2/96	fortnightly
	Mullet	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			1/24/94	7/5/96	fortnightly
	Mooney Mooney	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			2/8/94	7/5/96	fortnightly
	Sandbrook Inlet	HSC	10/10/94	6/8/01	monthly
Soluble P	Berowra	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
	Bar Point	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
	Mullet	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
	Mooney Mooney	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
TP	Berowra	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	7/5/96	fortnightly
	Bar Point	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	7/2/96	fortnightly
	Mullet	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			1/24/94	7/5/96	fortnightly
	Mooney Mooney	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			2/8/94	7/5/96	fortnightly
	Sandbrook Inlet	HSC	10/10/94	6/8/01	monthly

	Site	Source	Start Date m/d/y	End Date m/d/y	Frequency
Salinity (top)	Berowra	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	7/5/96	fortnightly
	Bar Point	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	7/2/96	fortnightly
	Mullet	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			1/24/94	7/5/96	fortnightly
	Mooney Mooney	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			2/8/94	7/5/96	fortnightly
	Sandbrook Inlet	HSC	10/10/94	6/8/01	monthly
	Spectacle Island	HSC	1/9/97	6/8/01	monthly starting 6/5/97
	Mooney Mooney	HSC	1/9/97	6/8/01	monthly starting 6/5/97
	Mullet	HSC	6/5/97	6/8/01	monthly
Salinity (bottom)	Berowra	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	7/5/96	fortnightly
	Bar Point	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	7/2/96	fortnightly
	Mullet	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			1/24/94	7/5/96	fortnightly
	Mooney Mooney	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			2/8/94	7/5/96	fortnightly
DO ppm (top)	Berowra	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	7/5/96	fortnightly
	Bar Point	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	7/2/96	fortnightly
	Mullet	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			1/24/94	7/5/96	fortnightly
	Mooney Mooney	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			2/8/94	7/5/96	fortnightly
	Sandbrook Inlet	HSC	10/10/94	6/8/01	monthly
	Spectacle Island	HSC	1/9/97	6/8/01	monthly starting 6/5/97
	Mooney Mooney	HSC	1/9/97	6/8/01	monthly starting 6/5/97
	Mullet	HSC	6/5/97	6/8/01	monthly
DO ppm (bottom)	Berowra	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	7/5/96	fortnightly
	Bar Point	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	7/2/96	fortnightly
	Mullet	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			1/24/94	7/5/96	fortnightly
	Mooney Mooney	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			2/8/94	7/5/96	fortnightly

	Site	Source	Start Date m/d/y	End Date m/d/y	Frequency
DO % sat	Sandbrook Inlet	HSC	6/4/96	6/8/01	monthly
	Spectacle Island	HSC	1/9/97	6/8/01	monthly starting 6/5/97
	Mooney Mooney	HSC	1/9/97	6/8/01	monthly starting 6/5/97
	Mullet	HSC	6/5/97	6/8/01	monthly
pH	Berowra	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	7/5/96	fortnightly
	Bar Point	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	7/2/96	fortnightly
	Mullet	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			1/24/94	7/5/96	fortnightly
	Mooney Mooney	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			2/8/94	7/5/96	fortnightly
	Sandbrook Inlet	HSC	10/10/94	6/8/01	monthly
	Spectacle Island	HSC	1/9/97	6/8/01	monthly starting 6/5/97
	Mooney Mooney	HSC	1/9/97	6/8/01	monthly starting 6/5/97
	Mullet	HSC	6/5/97	6/8/01	monthly
Faecal coliforms	Berowra	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	3/23/94	fortnightly
	Bar Point	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	3/23/94	fortnightly
	Mullet	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			1/24/94	3/23/94	fortnightly
	Mooney Mooney	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			2/8/94	3/23/94	fortnightly
	Sandbrook Inlet	HSC	10/10/94	6/8/01	monthly
	Spectacle Island	HSC	1/9/97	6/8/01	monthly starting 6/5/97
	Mooney Mooney	HSC	1/9/97	6/8/01	monthly starting 6/5/97
	Mullet	HSC	6/5/97	6/8/01	monthly
Enterococci	Berowra	EPA	11/6/91	6/3/93	monthly
	Bar Point	EPA	11/6/91	6/3/93	monthly
	Mullet	EPA	11/6/91	6/3/93	monthly
	Mooney Mooney	EPA	11/6/91	6/3/93	monthly
Faecal Streptococci	Berowra	EPA	1/14/93	6/3/93	monthly
			9/7/93	3/23/94	fortnightly
	Bar Point	EPA	1/14/93	6/3/93	monthly
			9/7/93	3/23/94	fortnightly
	Mullet	EPA	1/14/93	6/3/93	monthly
			1/24/94	3/23/94	fortnightly
	Mooney Mooney	EPA	1/14/93	6/3/93	monthly
			2/8/94	3/23/94	fortnightly

	Site	Source	Start Date m/d/y	End Date m/d/y	Frequency
Temperature	Berowra	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	7/5/96	fortnightly
	Bar Point	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			9/7/93	7/2/96	fortnightly
	Mullet	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			1/24/94	7/5/96	fortnightly
	Mooney Mooney	EPA	6/6/90	6/3/93	monthly - with gap 6-12/92
			2/8/94	7/5/96	fortnightly
	Sandbrook Inlet	HSC	10/10/94	6/8/01	monthly
	Spectacle Island	HSC	1/9/97	6/8/01	monthly starting 6/5/97
	Mooney Mooney	HSC	1/9/97	6/8/01	monthly starting 6/5/97
	Mullet	HSC	6/5/97	6/8/01	monthly

B.2 Reliability of HSC and EPA Water Quality Data

The Hornsby Shire Council (HSC) and EPA data were collected according to standard methods. In-situ measurements made by HSC used a YEOKAL 611 Water Quality Analyser and laboratory analysis was performed by NATA-accredited Australian Water Technologies – Ensight using the techniques listed in Table A.2 (HSC 2000).

Table B.2 Analytical Techniques Used by AWT-Ensight for HSC Data

Analyte	Method	Detection Limit
Faecal coliforms	APHA(5) 9222-D	2 CFU/100mL
Suspended solids	APHA(5) 2540 D & E	1 mg/L
Total nitrogen	APHA(5) 4500-NO3 H	0.05 mg/L
Oxidised nitrogen (NOx)	APHA(5) 4500-NO3 H	0.0001 mg/L
Ammoniacal nitrogen	APHA(5) NH3 G	0.01 mg/L
Total phosphorus	APHA(5) 4500-P F	0.002 mg/L
Chlorophyll-*a*	APHA(5) 10200-H 1 & 2	0.1 µg/L

Source: HSC (2000)

EPA field measurements were taken using a variety of meters as listed in Table B.3. Water samples were analysed by three different laboratories over the data collection period; GM Laboratories from June 1990 to January 1991 and June 1991 to December 1991, Judell Platt Thomas and Associates from February 1991 to May 1991, and the EPA water chemistry laboratory from January 1992. The analytical methods used by each laboratory are listed in Table B.4. Where provided, the detection limits and precision levels give an indication of the reliability of the data particularly when measured at low concentrations.

Table B.3 Instrumentation Used for Field Measurements by the EPA

Water quality variable	Meter
Dissolved oxygen & temperature	Yeo-Kal Model 603
Conductivity	Hach Model 44600 YSI SCT 33M *or* Yeo-Kal Conductivity Dipper
Salinity	Yeo-Kal Model 605 *or* Yeo-Kal Salinity/Temperature Bridge

Table B.4 Analytical Techniques Used by Laboratories for EPA Data

Analyte	Method	Detection Limit	Precision %
GM Laboratories			
TKN	APHA	0.01 mg/L	5
Ammonia Nitrogen	CSIRO #55	0.01 mg/L	5
Oxidised Nitrogen	CSIRO #51	0.005 mg/L	5
Orthophosphate	Grasshoff (1976)	0.01 mg/L	3
Total Phosphorus	Grasshoff (1976)	0.02 mg/L	5
Suspended Solids	APHA 2540D	1 mg/L	5
Faecal Coliforms	EML	1 CFU/100mL	
Turbidity	APHA 2130B	0.1 NTU	2
Chlorophyll-*a*	Parsons et al. (1984)	0.5 µg/L	5
Judell, Platt, Thomas and Associates			
TKN	APHA 4500-Norg+NH3 CuSO4 as catalyst	0.02	
Ammonia Nitrogen	Major et al. (1972)	0.001	
Oxidised Nitrogen	Major et al. (1972)	0.001 mg/L	
Orthophosphate	APHA 4500-P E	0.001 mg/L	
Total Phosphorus	APHA 4500-P E	0.001 mg/L	
Suspended Solids	APHA 2540D	1 mg/L	
Faecal Coliforms	APHA 909C	1 CFU/100mL	
Turbidity	APHA 2310B	0.05 NTU	
Chlorophyll-*a*	APHA 1002G1	0.1 µg/L	
EPA/SPCC Water Chemistry Laboratory			
TKN	APHA 4500-NO_3 F	0.3 mg/L	10
Ammonia Nitrogen	APHA 4500-NH_3 H/Jirka	0.009 mg/L	10
Oxidised Nitrogen	APHA 4500-NO_3 E	0.01 mg/L	10
Orthophosphate	APHA 4500-P F	0.005 mg/L	10
Total Phosphorus	APHA 4500-P F/Jirka	0.012 mg/L	10
Suspended Solids	APHA 2450 D		
Faecal Coliforms		1 organism/100mL	
Faecal Streptococci		1 organism/100mL	
Turbidity	APHA 2130 B	0.3 NTU	10
Chlorophyll-*a*	APHA 10200 H 2 & 3	2 µg/L	10

Source: EPA (1994)

B.3 Water Quality Data Analysis

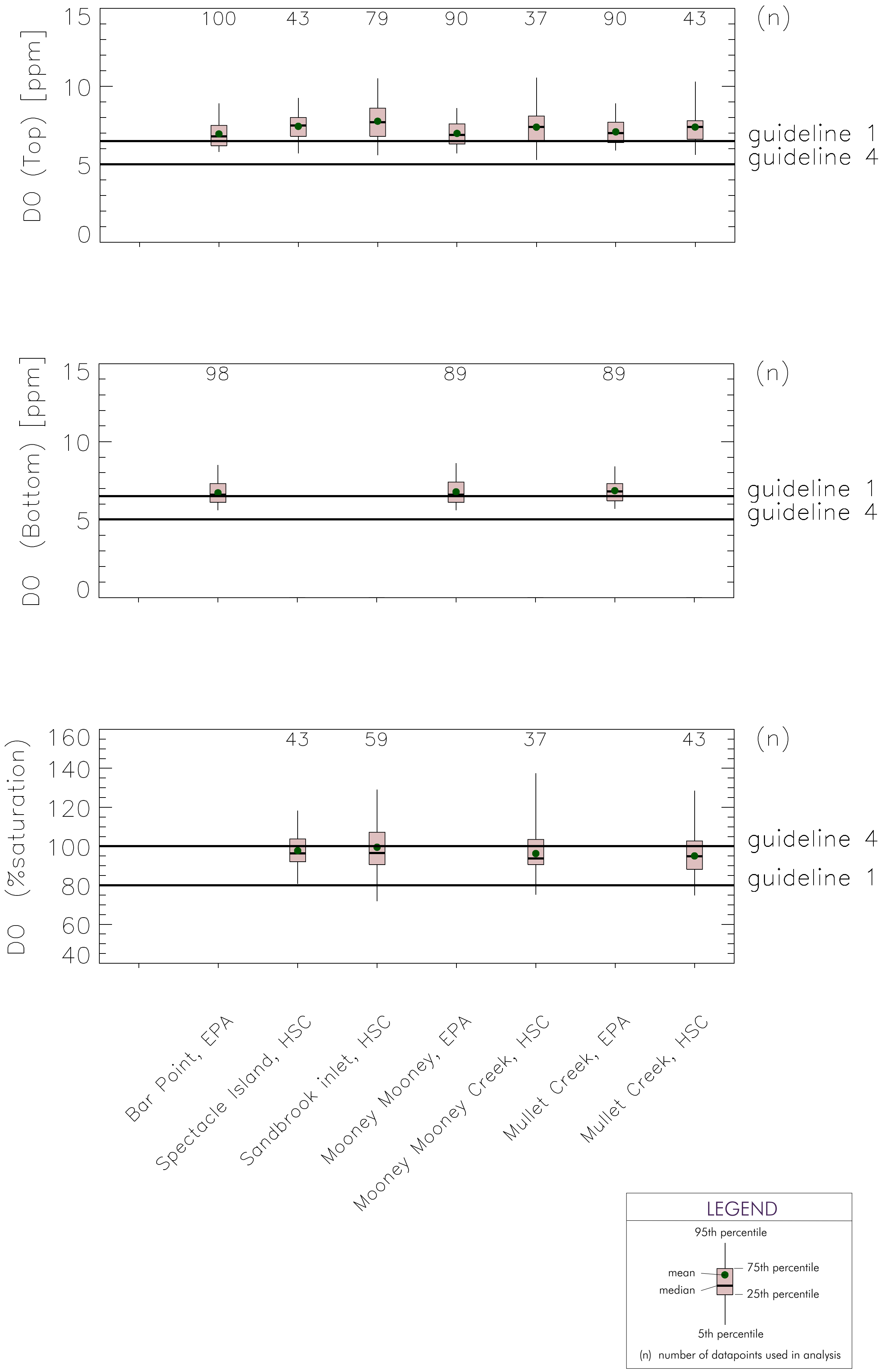
B.3.1 Spatial Trends

Available HSC and EPA data were analysed to investigate spatial trends amongst the sampling sites and to compare the data with current ANZECC (2000) and HRC (1998) guidelines. Box and whisker plots displaying the mean, median, 5^{th}, 25^{th}, 75^{th} and 95^{th} percentiles were produced for all data at each site and are presented below. The relevant guideline values have been added to these plots to allow visual comparison. The codes used in the plots for each of the guidelines are:

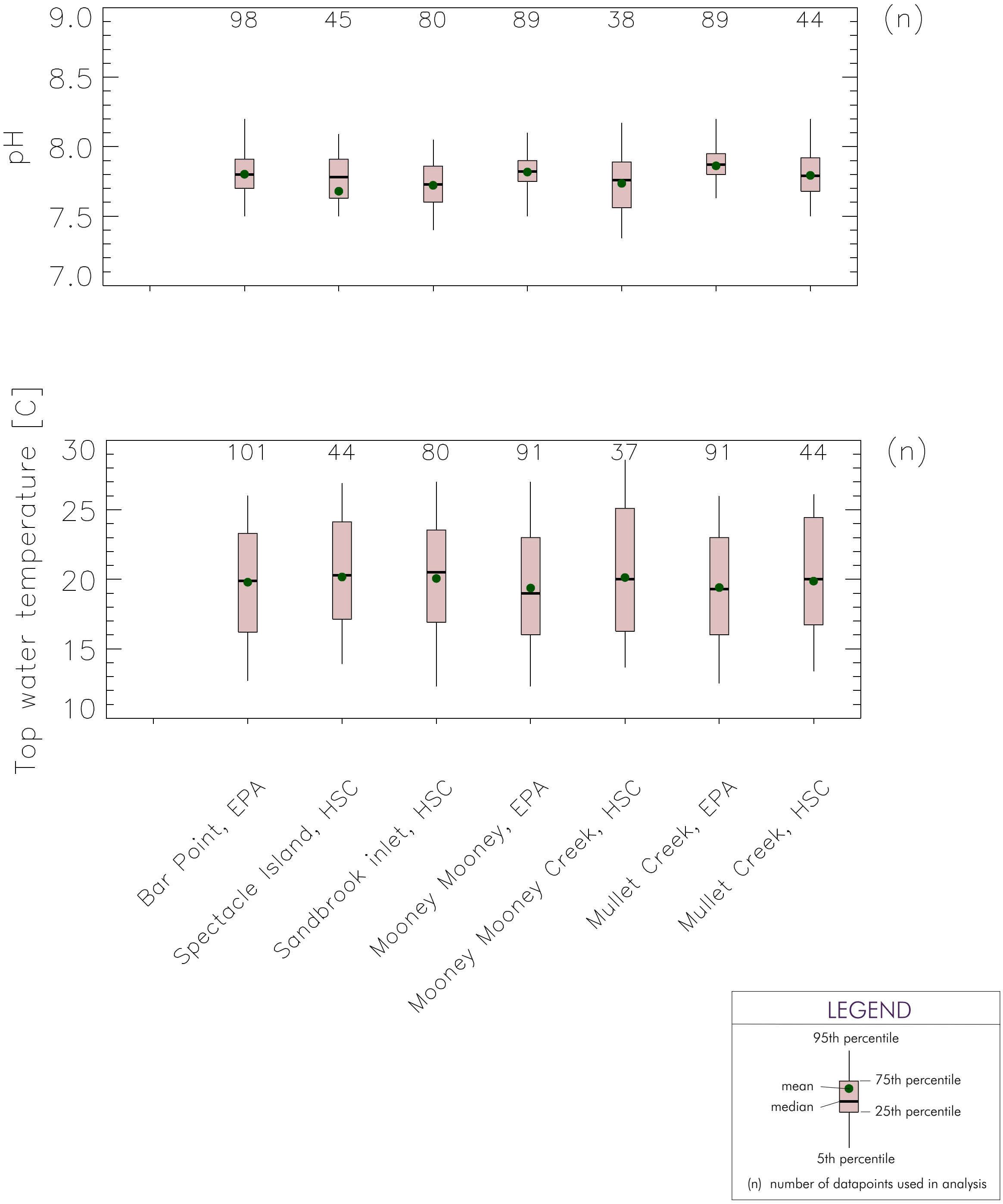
- Guideline 1: ANZECC recreational guideline (primary contact)
- Guideline 2: ANZECC recreational guideline (secondary contact)
- Guideline 3: ANZECC aquatic ecosystem trigger value
- Guideline 4: ANZECC aquaculture protection guideline
- Guideline 5: HRC recommendation (for the Hawkesbury-Nepean River system)

B.3.2 Temporal Trends

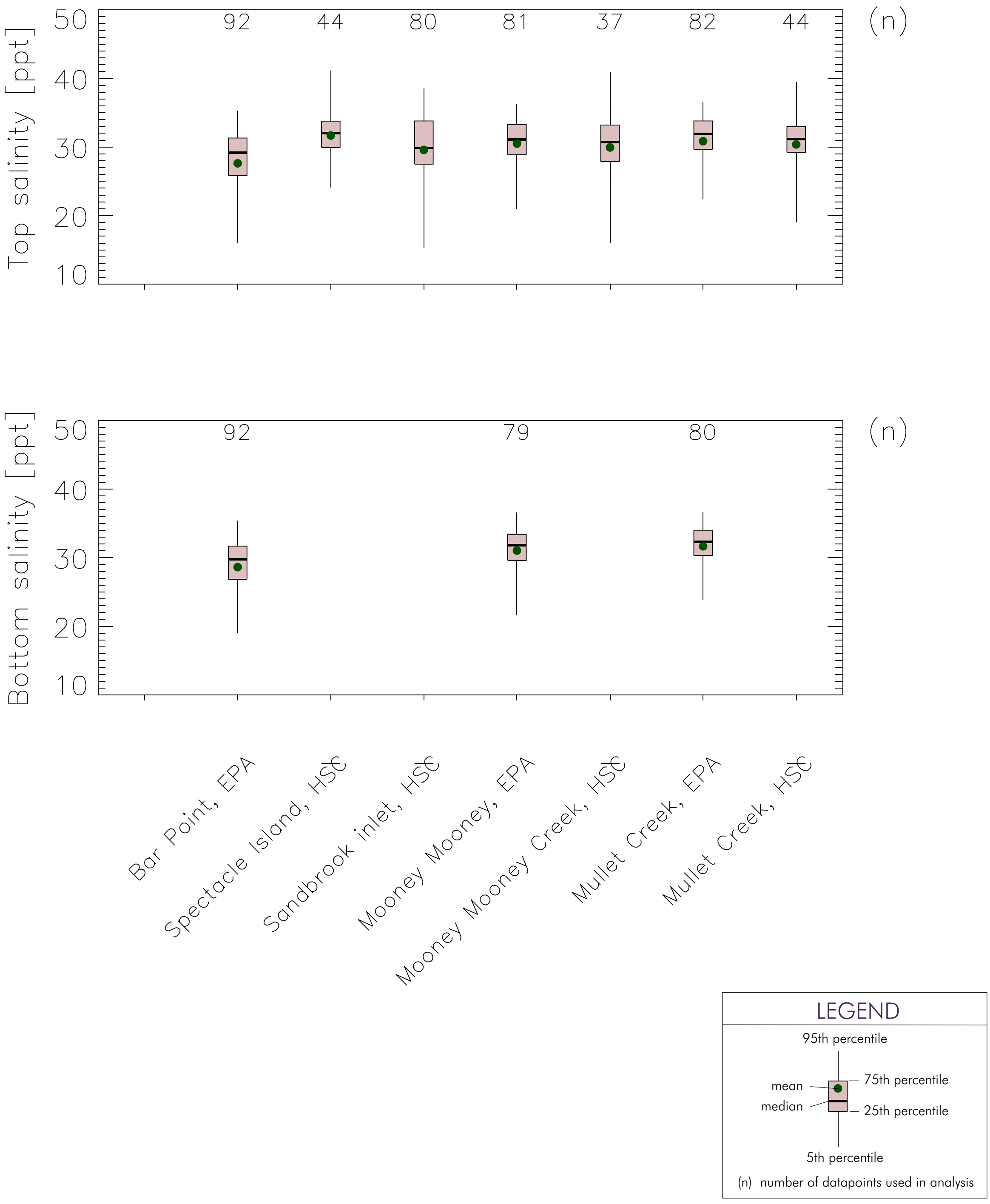
Analysis of temporal trends was restricted to water quality variables with at least a four year data span. Time series plots were assessed using linear gradient analysis to examine the direction and degree of change over time. These plots are presented below. There were no statistically reliable trends found for any of the water quality variables measured.



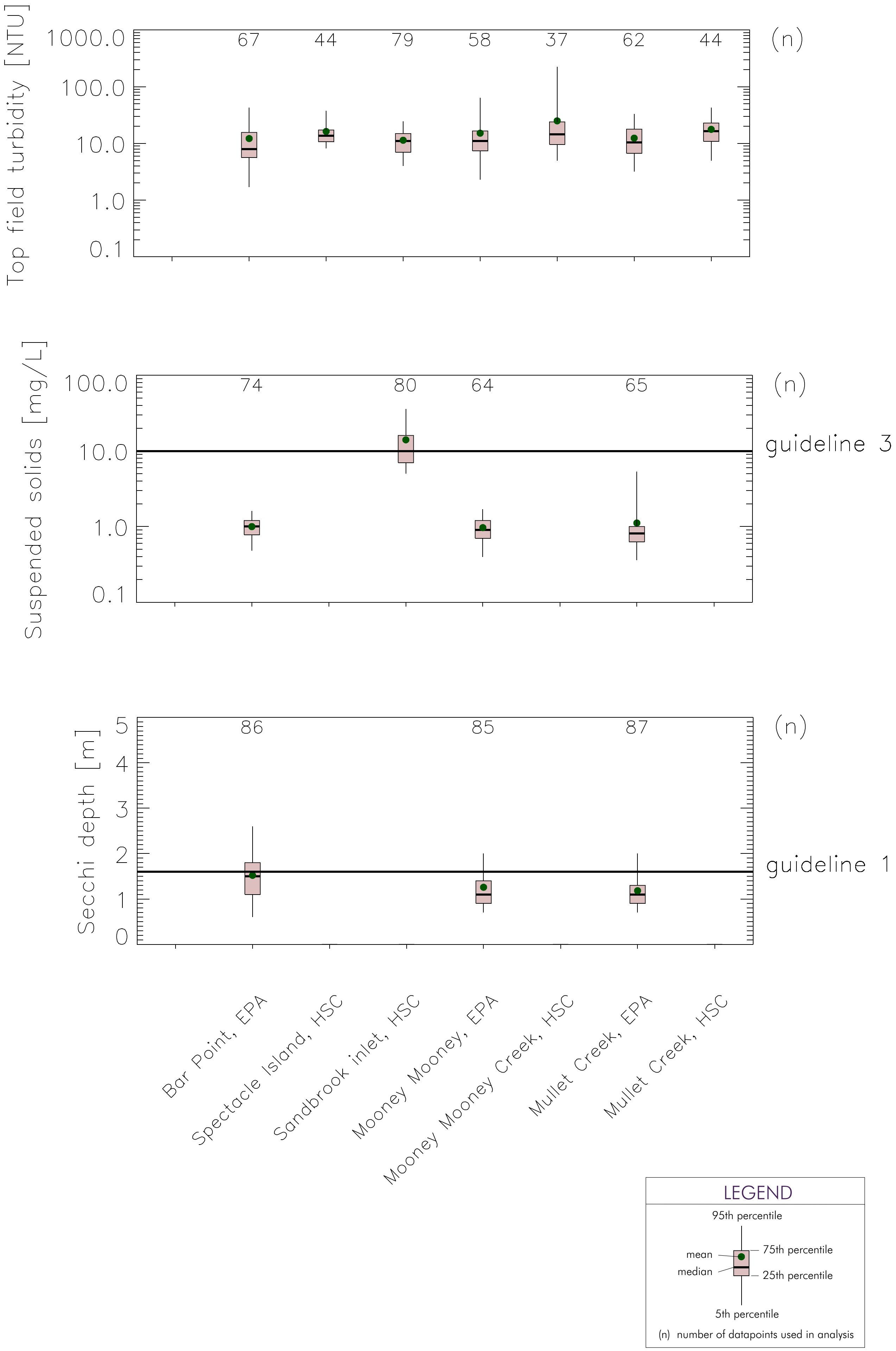
DO (Top) [ppm]
15
10
5
0
100
43
79
90
37
90
43
(n)
guideline 1
guideline 4
DO (Bottom) [ppm]
15
10
5
0
98
89
89
(n)
guideline 1
guideline 4
DO (%saturation)
160
140
120
100
80
60
40
43
59
37
43
(n)
guideline 4
guideline 1
Bar Point, EPA
Spectacle Island, HSC
Sandbrook inlet, HSC
Mooney Mooney, EPA
Mooney Mooney Creek, HSC
Mullet Creek, EPA
Mullet Creek, HSC
LEGEND
95th percentile
mean
median
75th percentile
25th percentile
5th percentile
(n) number of datapoints used in analysis



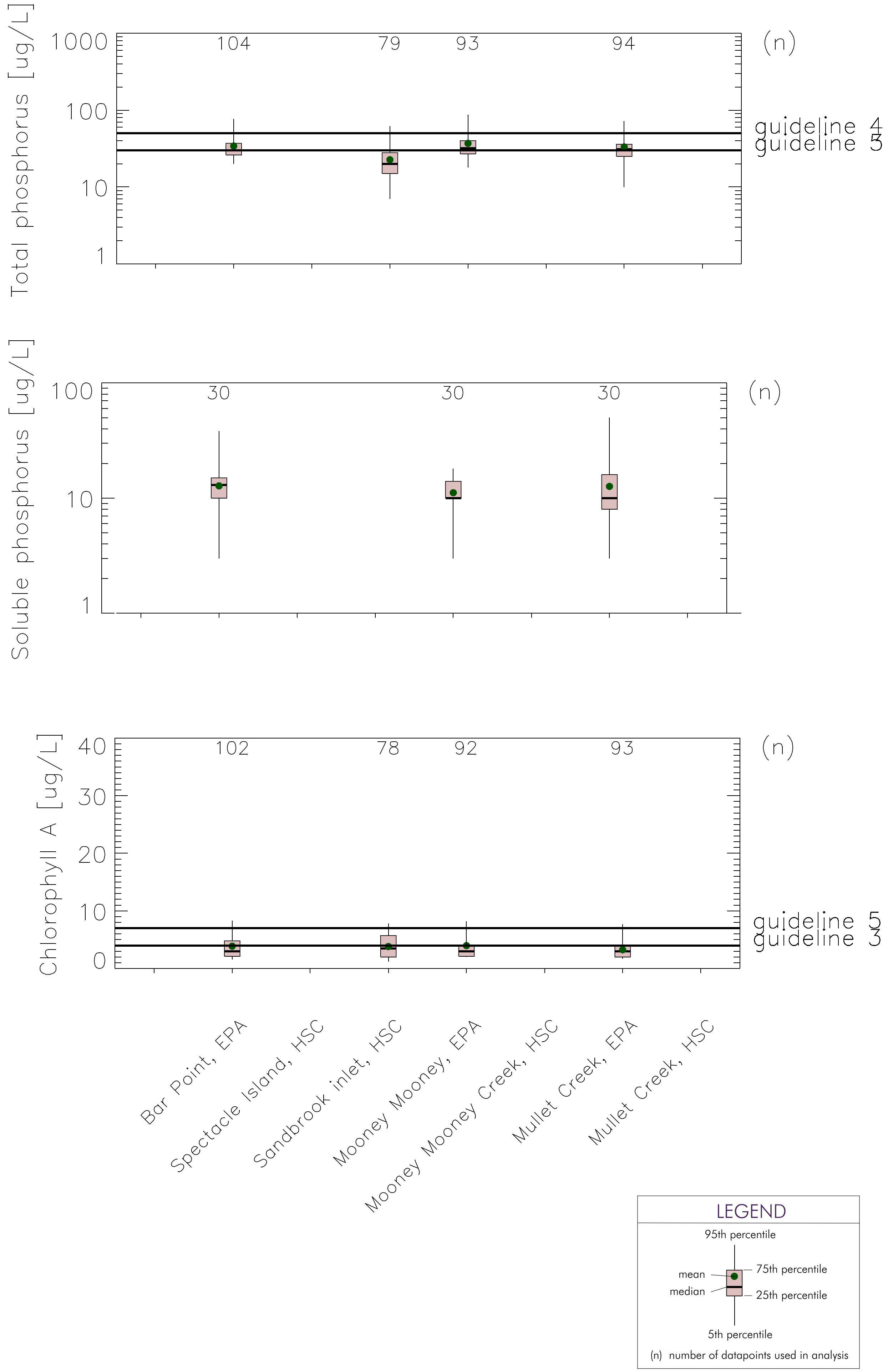
9.0
8.5
8.0
7.5
7.0
pH
98 45 80 89 38 89 44
(n)
30
25
20
15
10
Top water temperature [C]
101 44 80 91 37 91 44
(n)
Bar Point, EPA
Spectacle Island, HSC
Sandbrook inlet, HSC
Mooney Mooney, EPA
Mooney Mooney Creek, HSC
Mullet Creek, EPA
Mullet Creek, HSC
LEGEND
95th percentile
mean
median
75th percentile
25th percentile
5th percentile
(n) number of datapoints used in analysis

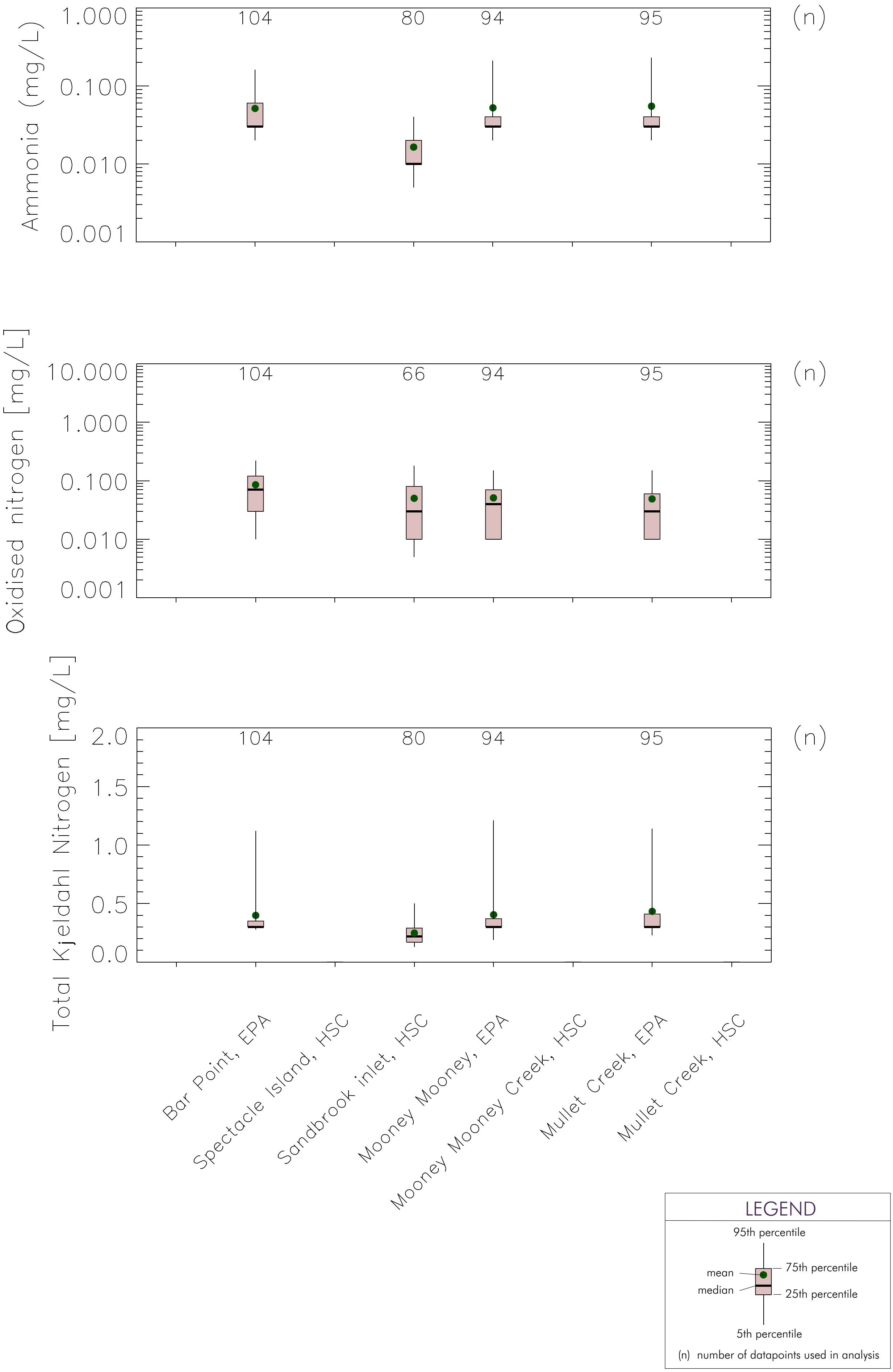


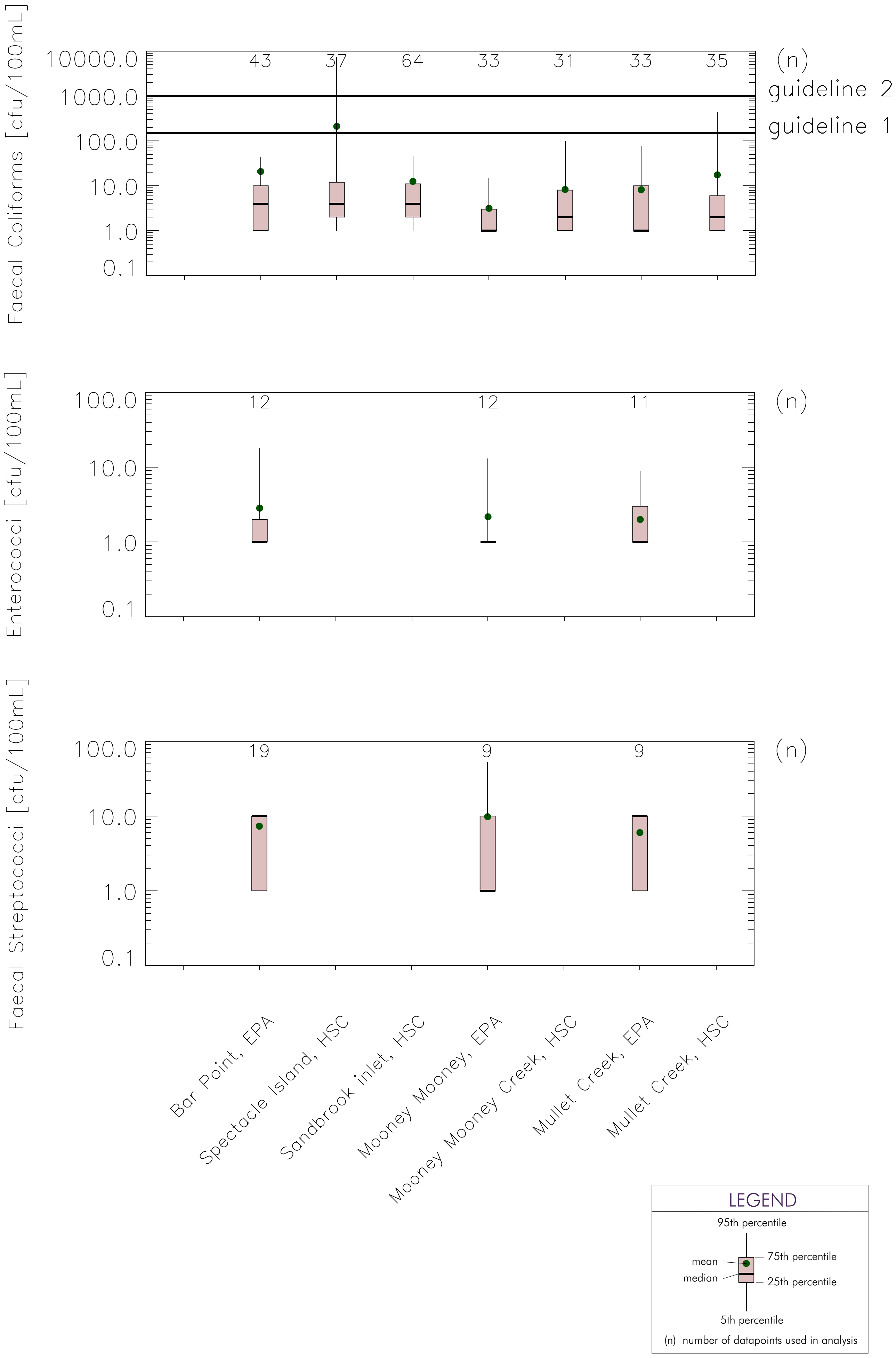
Top salinity [ppt]
50
40
30
20
10
92
44
80
81
37
82
44
(n)
Bottom salinity [ppt]
50
40
30
20
10
92
79
80
(n)
Bar Point, EPA
Spectacle Island, HSC
Sandbrook inlet, HSC
Mooney Mooney, EPA
Mooney Mooney Creek, HSC
Mullet Creek, EPA
Mullet Creek, HSC
LEGEND
95th percentile
mean
median
75th percentile
25th percentile
5th percentile
(n) number of datapoints used in analysis



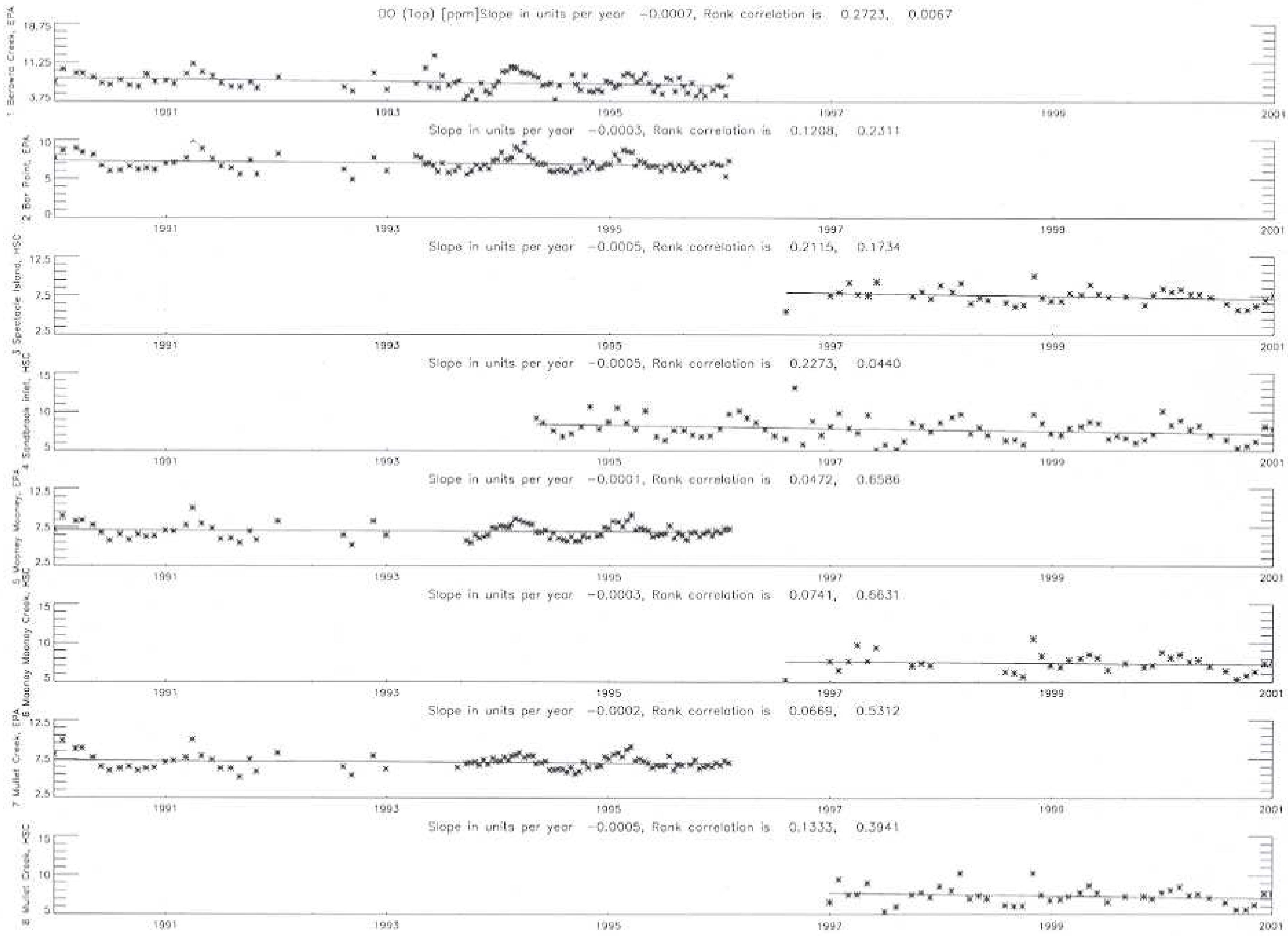
Top field turbidity [NTU]
1000.0
100.0
10.0
1.0
0.1
67
44
79
58
37
62
44
(n)
Suspended solids [mg/L]
100.0
10.0
1.0
0.1
74
80
64
65
(n)
guideline 3
Secchi depth [m]
5
4
3
2
1
0
86
85
87
(n)
guideline 1
Bar Point, EPA
Spectacle Island, HSC
Sandbrook inlet, HSC
Mooney Mooney, EPA
Mooney Mooney Creek, HSC
Mullet Creek, EPA
Mullet Creek, HSC
LEGEND
95th percentile
mean
median
75th percentile
25th percentile
5th percentile
(n) number of datapoints used in analysis


Total phosphorus [ug/L]
1000
100
10
1
104
79
93
94
(n)
guideline 4
guideline 3
Soluble phosphorus [ug/L]
100
10
1
30
30
30
(n)
Chlorophyll A [ug/L]
40
30
20
10
0
102
78
92
93
(n)
guideline 5
guideline 3
Bar Point, EPA
Spectacle Island, HSC
Sandbrook inlet, HSC
Mooney Mooney, EPA
Mooney Mooney Creek, HSC
Mullet Creek, EPA
Mullet Creek, HSC
LEGEND
95th percentile
mean
median
75th percentile
25th percentile
5th percentile
(n) number of datapoints used in analysis

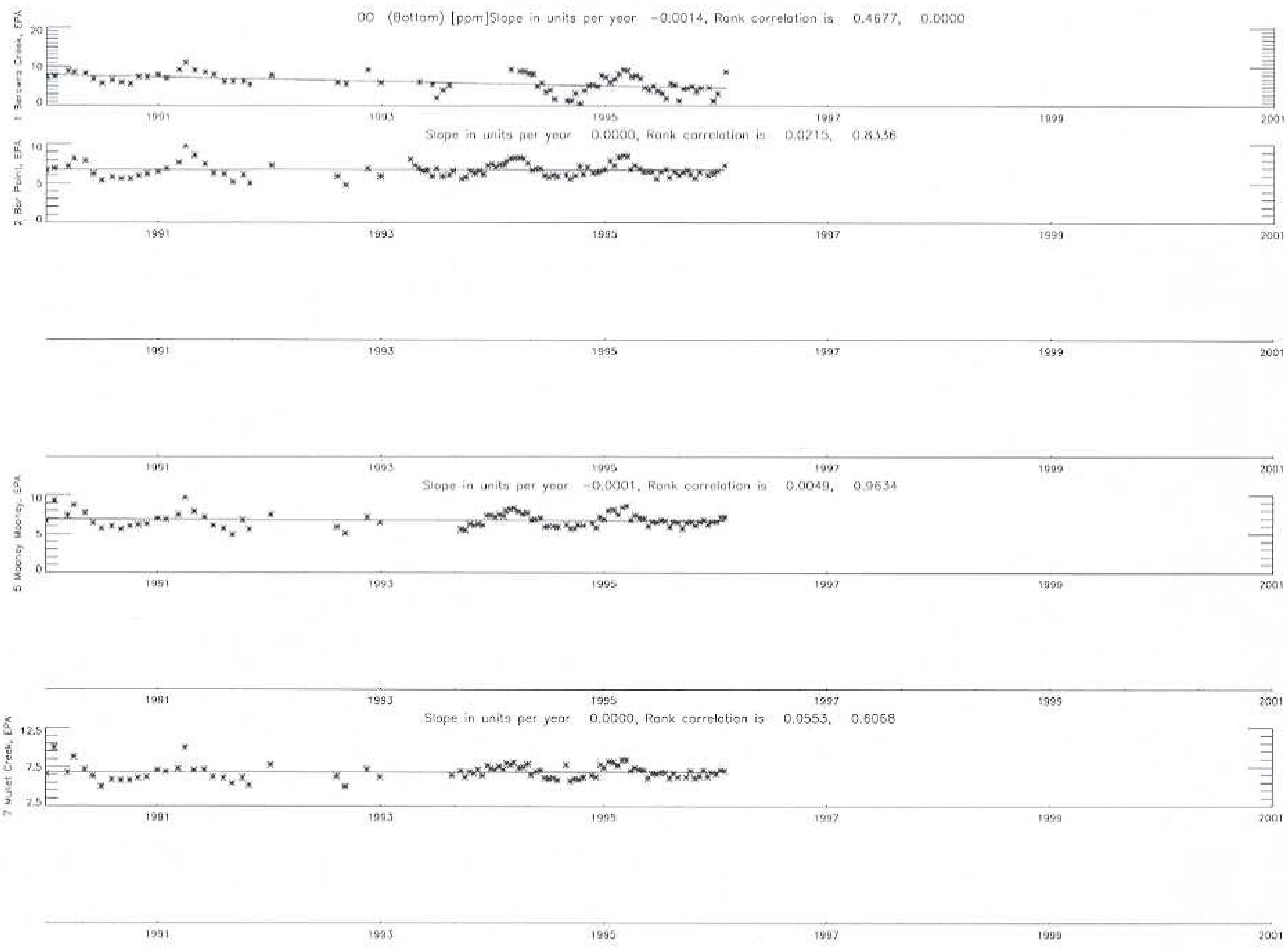

Ammonia (mg/L)
1.000
0.100
0.010
0.001
104
80
94
95
(n)
Oxidised nitrogen [mg/L]
10.000
1.000
0.100
0.010
0.001
104
66
94
95
(n)
Total Kjeldahl Nitrogen [mg/L]
2.0
1.5
1.0
0.5
0.0
104
80
94
95
(n)
Bar Point, EPA
Spectacle Island, HSC
Sandbrook inlet, HSC
Mooney Mooney, EPA
Mooney Mooney Creek, HSC
Mullet Creek, EPA
Mullet Creek, HSC
LEGEND
95th percentile
mean
median
75th percentile
25th percentile
5th percentile
(n) number of datapoints used in analysis



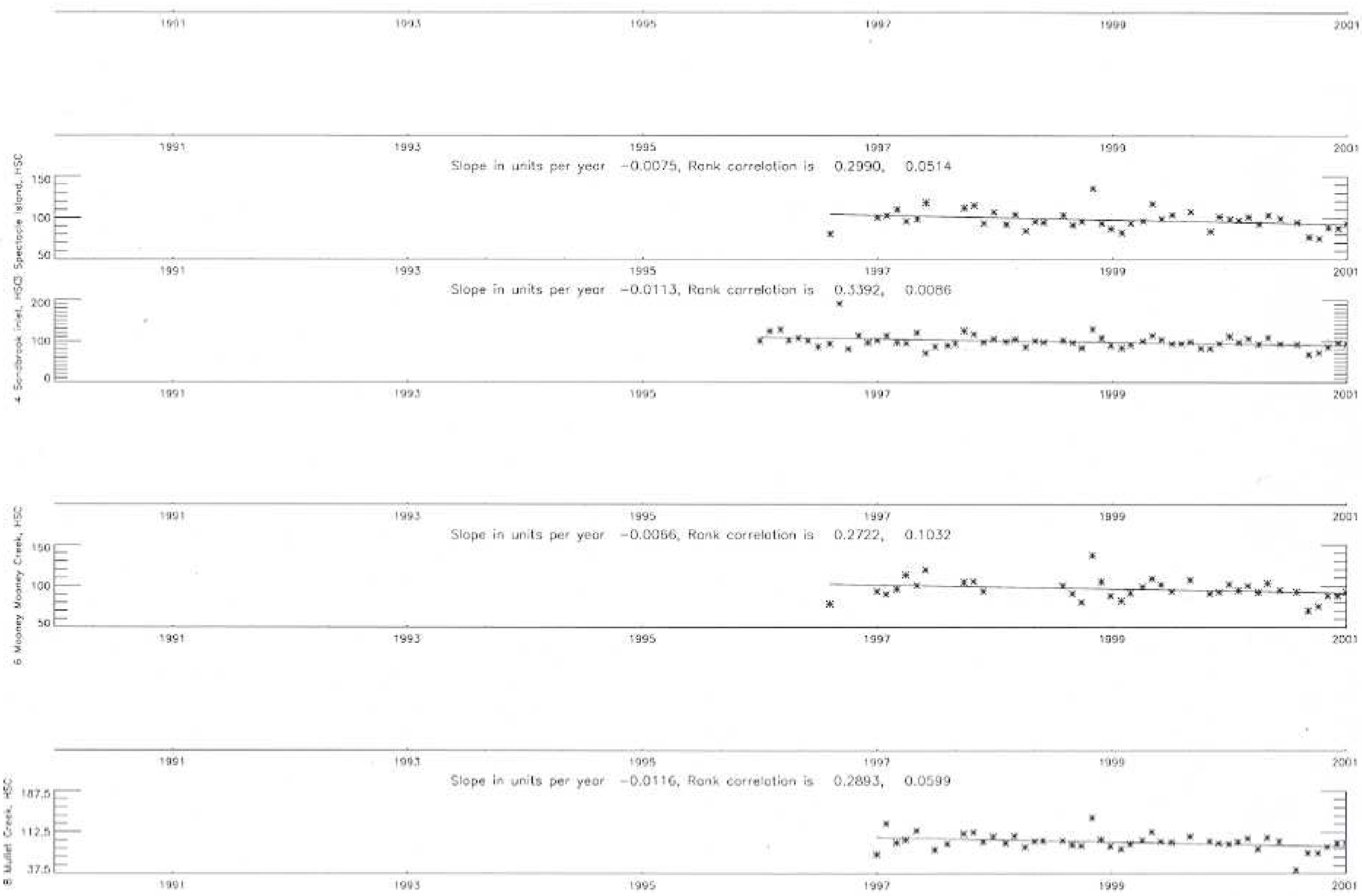
Faecal Coliforms [cfu/100mL]
10000.0
1000.0
100.0
10.0
1.0
0.1
43
37
64
33
31
33
35
(n)
guideline 2
guideline 1
Enterococci [cfu/100mL]
100.0
10.0
1.0
0.1
12
12
11
(n)
Faecal Streptococci [cfu/100mL]
100.0
10.0
1.0
0.1
19
9
9
(n)
Bar Point, EPA
Spectacle Island, HSC
Sandbrook inlet, HSC
Mooney Mooney, EPA
Mooney Mooney Creek, HSC
Mullet Creek, EPA
Mullet Creek, HSC
LEGEND
95th percentile
mean
median
75th percentile
25th percentile
5th percentile
(n) number of datapoints used in analysis

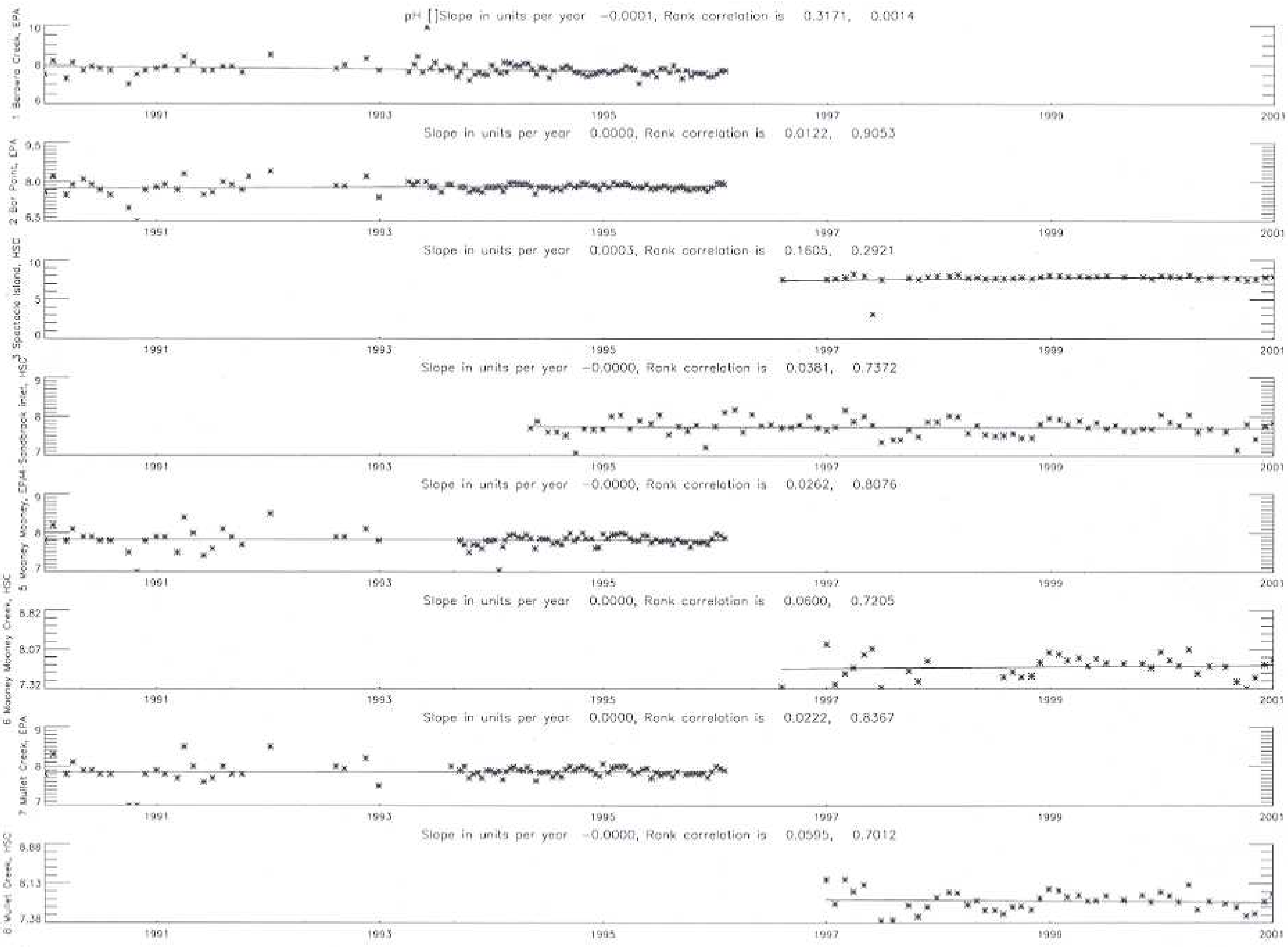


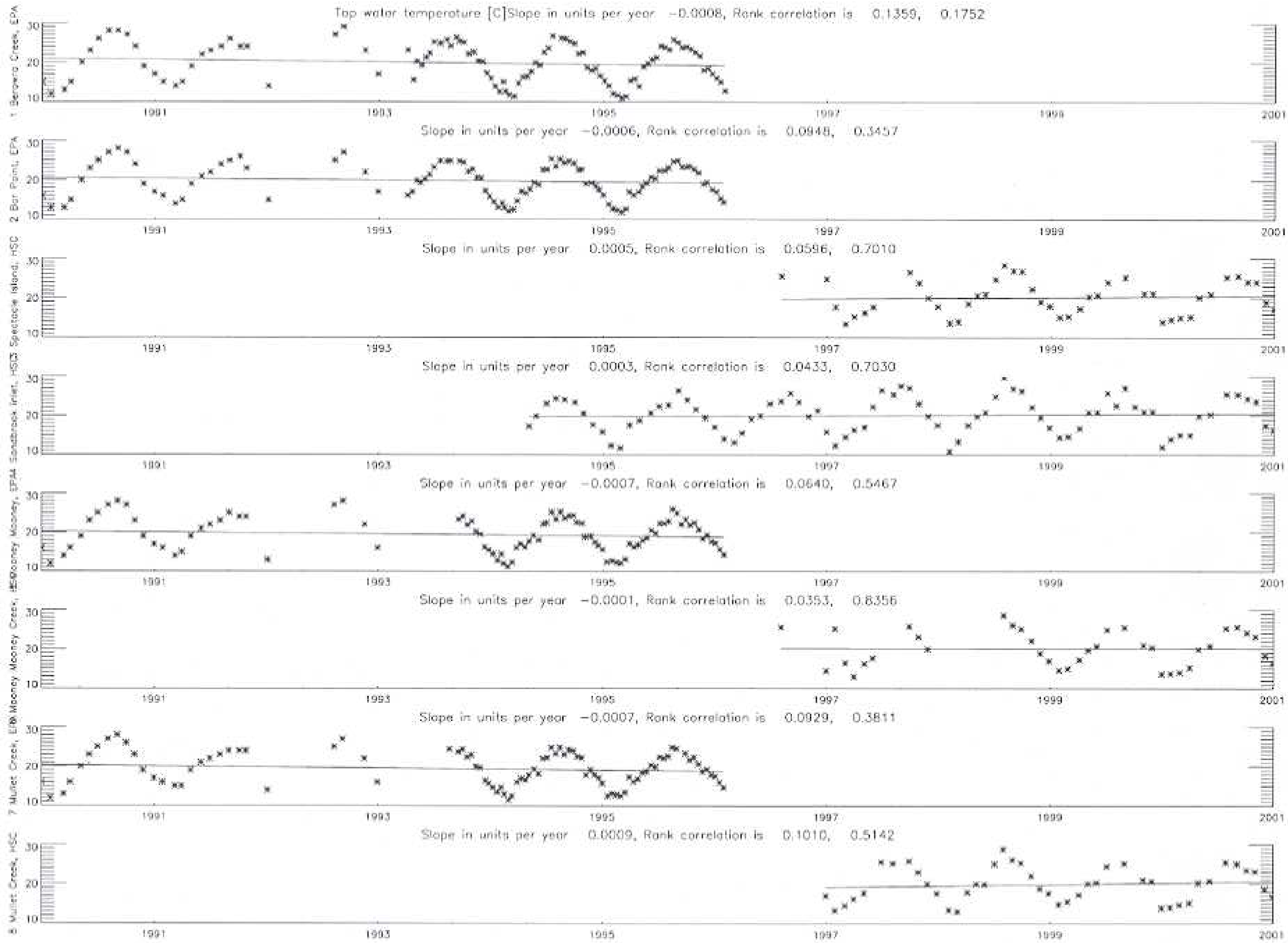
DO (Top) [ppm]Slope in units per year -0.0007, Rank correlation is 0.2723, 0.0067
1 Berowra Creek, EPA
18.75
11.25
3.75
1991
1993
1995
1997
1999
2001
Slope in units per year -0.0003, Rank correlation is 0.1208, 0.2311
2 Bar Point, EPA
10
5
0
Slope in units per year -0.0005, Rank correlation is 0.2115, 0.1734
3 Spectacle Island, HSC
12.5
7.5
2.5
Slope in units per year -0.0005, Rank correlation is 0.2273, 0.0440
4 Sandbrook Inlet, HSC
15
10
5
Slope in units per year -0.0001, Rank correlation is 0.0472, 0.6586
5 Mooney Mooney, EPA
Slope in units per year -0.0003, Rank correlation is 0.0741, 0.6631
6 Mooney Mooney Creek, HSC
Slope in units per year -0.0002, Rank correlation is 0.0669, 0.5312
7 Mullet Creek, EPA
Slope in units per year -0.0005, Rank correlation is 0.1333, 0.3941
8 Mullet Creek, HSC


DO (Bottom) [ppm]Slope in units per year -0.0014, Rank correlation is 0.4677, 0.0000
1 Barwens Creek, EPA
Slope in units per year 0.0000, Rank correlation is 0.0215, 0.8336
2 Bar Point, EPA
Slope in units per year -0.0001, Rank correlation is 0.0049, 0.9634
5 Mooney Mooney, EPA
Slope in units per year 0.0000, Rank correlation is 0.0553, 0.6068
7 Mullet Creek, EPA
1991
1993
1995
1997
1999
2001

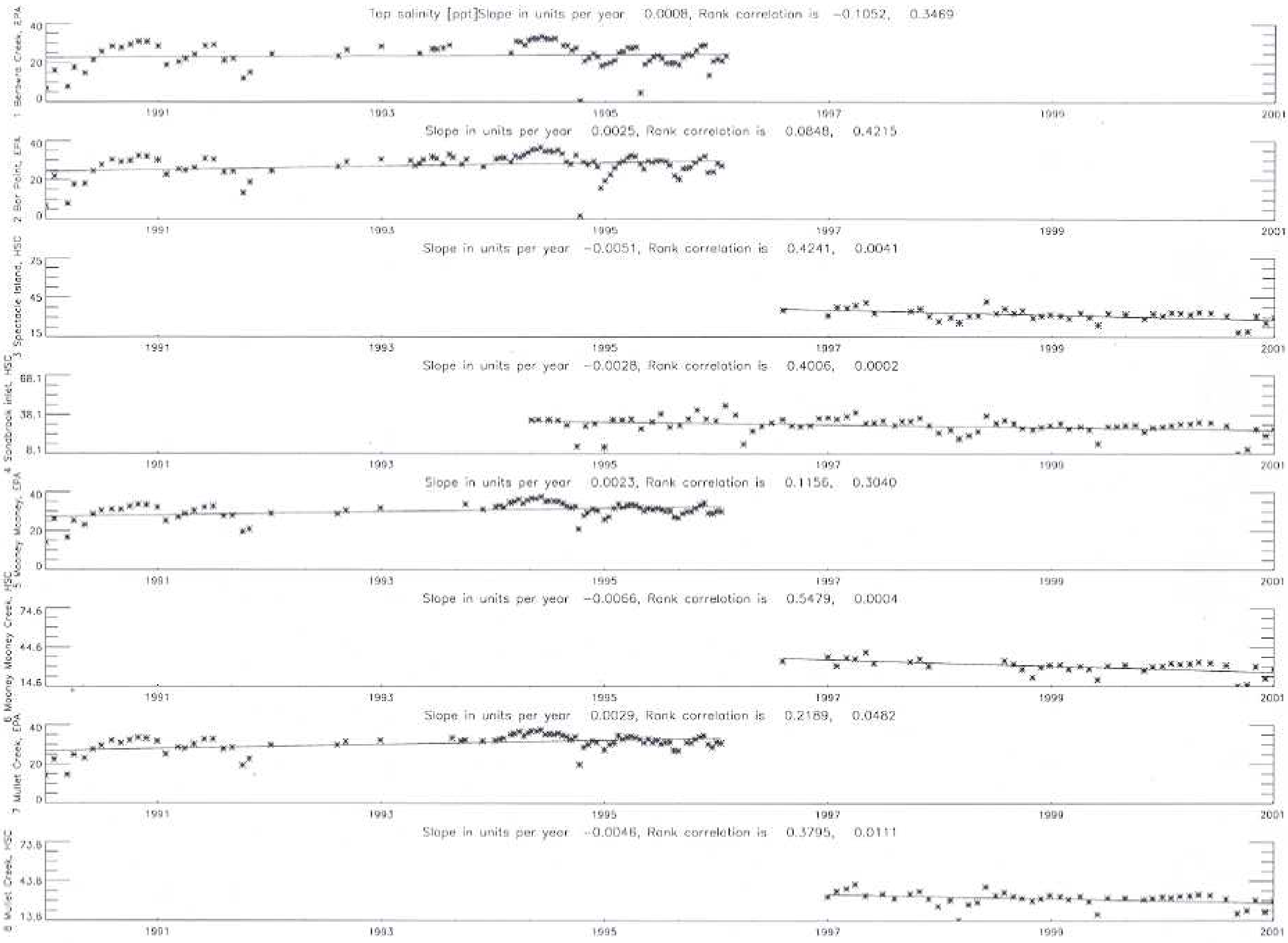
DO [%saturation]



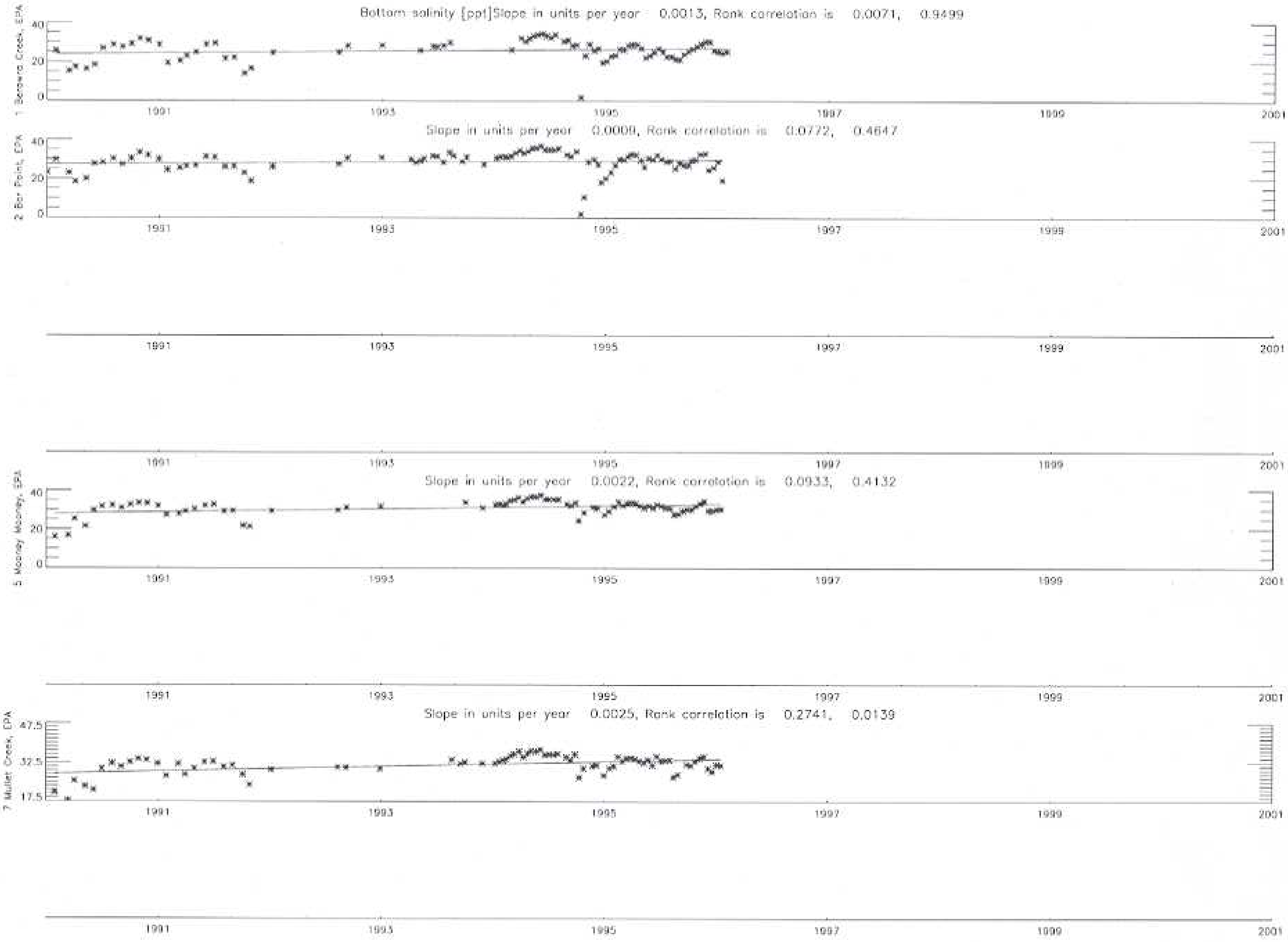

pH [ ]Slope in units per year -0.0001, Rank correlation is 0.3171, 0.0014
1 Barbara Creek, EPA
Slope in units per year 0.0000, Rank correlation is 0.0122, 0.9053
2 Bar Point, EPA
Slope in units per year 0.0003, Rank correlation is 0.1605, 0.2921
3 Spectacle Island, HSC
Slope in units per year -0.0000, Rank correlation is 0.0381, 0.7372
4 Sandbrook Inlet, HSC
Slope in units per year -0.0000, Rank correlation is 0.0262, 0.8076
5 Mooney Mooney, EPA
Slope in units per year 0.0000, Rank correlation is 0.0600, 0.7205
6 Mooney Mooney Creek, HSC
Slope in units per year 0.0000, Rank correlation is 0.0222, 0.8367
7 Mullet Creek, EPA
Slope in units per year -0.0000, Rank correlation is 0.0595, 0.7012
8 Mullet Creek, HSC
1991
1993
1995
1997
1999
2001



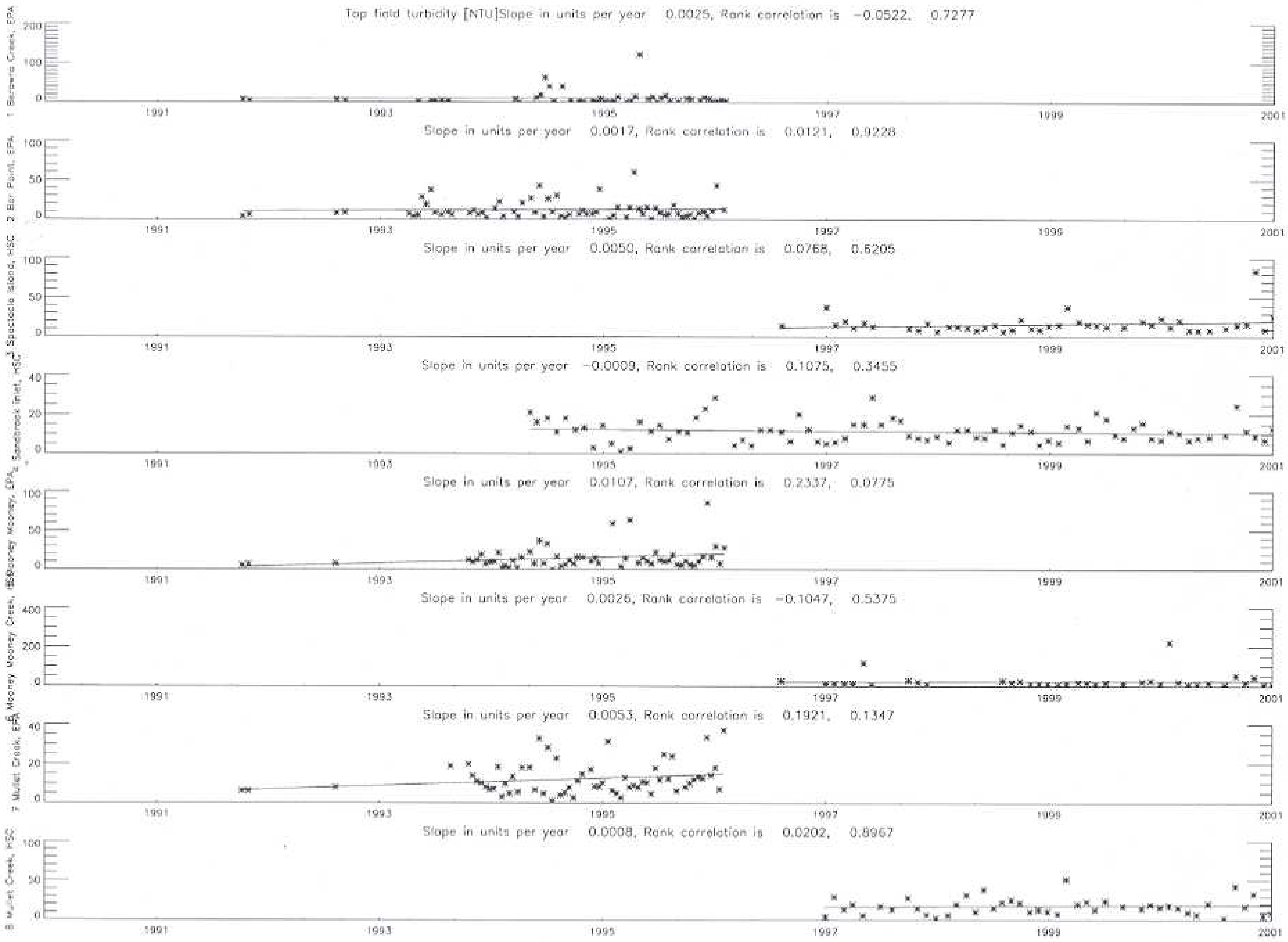
Top water temperature [C]Slope in units per year -0.0008, Rank correlation is 0.1359, 0.1752
1 Berowra Creek, EPA
Slope in units per year -0.0006, Rank correlation is 0.0948, 0.3457
2 Bar Point, EPA
Slope in units per year 0.0005, Rank correlation is 0.0596, 0.7010
3 Spectacle Island, HSC
Slope in units per year 0.0003, Rank correlation is 0.0433, 0.7030
Sandbrook Inlet, HSC
Slope in units per year -0.0007, Rank correlation is 0.0640, 0.5467
Mooney Mooney, EPA
Slope in units per year -0.0001, Rank correlation is 0.0353, 0.8356
Mooney Mooney Creek, HSC
Slope in units per year -0.0007, Rank correlation is 0.0929, 0.3811
7 Mullet Creek, EPA
Slope in units per year 0.0009, Rank correlation is 0.1010, 0.5142
8 Mullet Creek, HSC
1991
1993
1995
1997
1999
2001



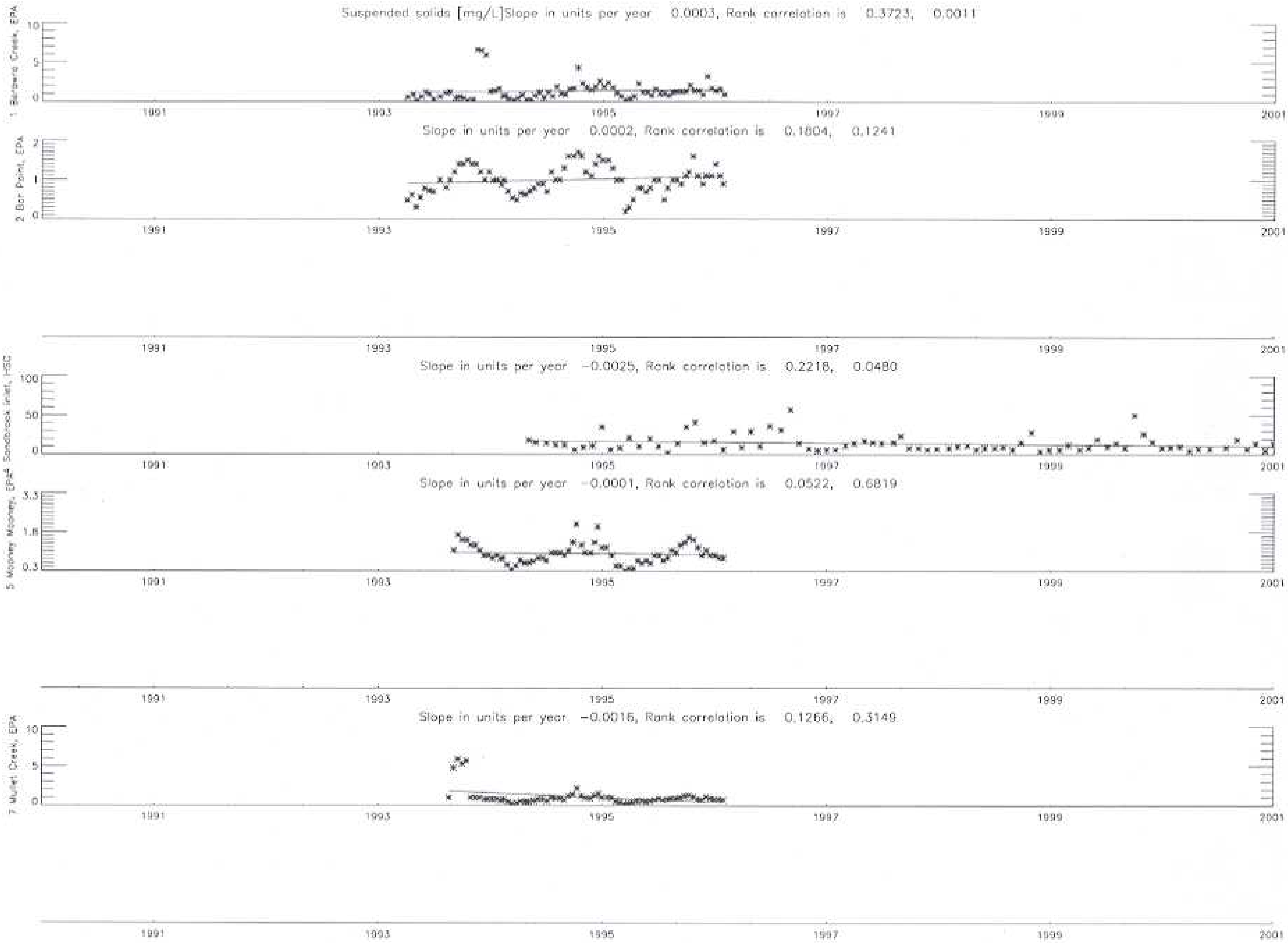
Top salinity [ppt]Slope in units per year 0.0008, Rank correlation is -0.1052, 0.3469
1 Barwon Creek, EPA
Slope in units per year 0.0025, Rank correlation is 0.0848, 0.4215
2 Bar Point, EPA
Slope in units per year -0.0051, Rank correlation is 0.4241, 0.0041
3 Spectacle Island, HSC
Slope in units per year -0.0028, Rank correlation is 0.4006, 0.0002
4 Sandbrook Inlet, HSC
Slope in units per year 0.0023, Rank correlation is 0.1156, 0.3040
5 Mooney Mooney, EPA
Slope in units per year -0.0066, Rank correlation is 0.5479, 0.0004
6 Mooney Mooney Creek, HSC
Slope in units per year 0.0029, Rank correlation is 0.2189, 0.0482
7 Mullet Creek, EPA
Slope in units per year -0.0046, Rank correlation is 0.3795, 0.0111
8 Mullet Creek, HSC
1991
1993
1995
1997
1999
2001



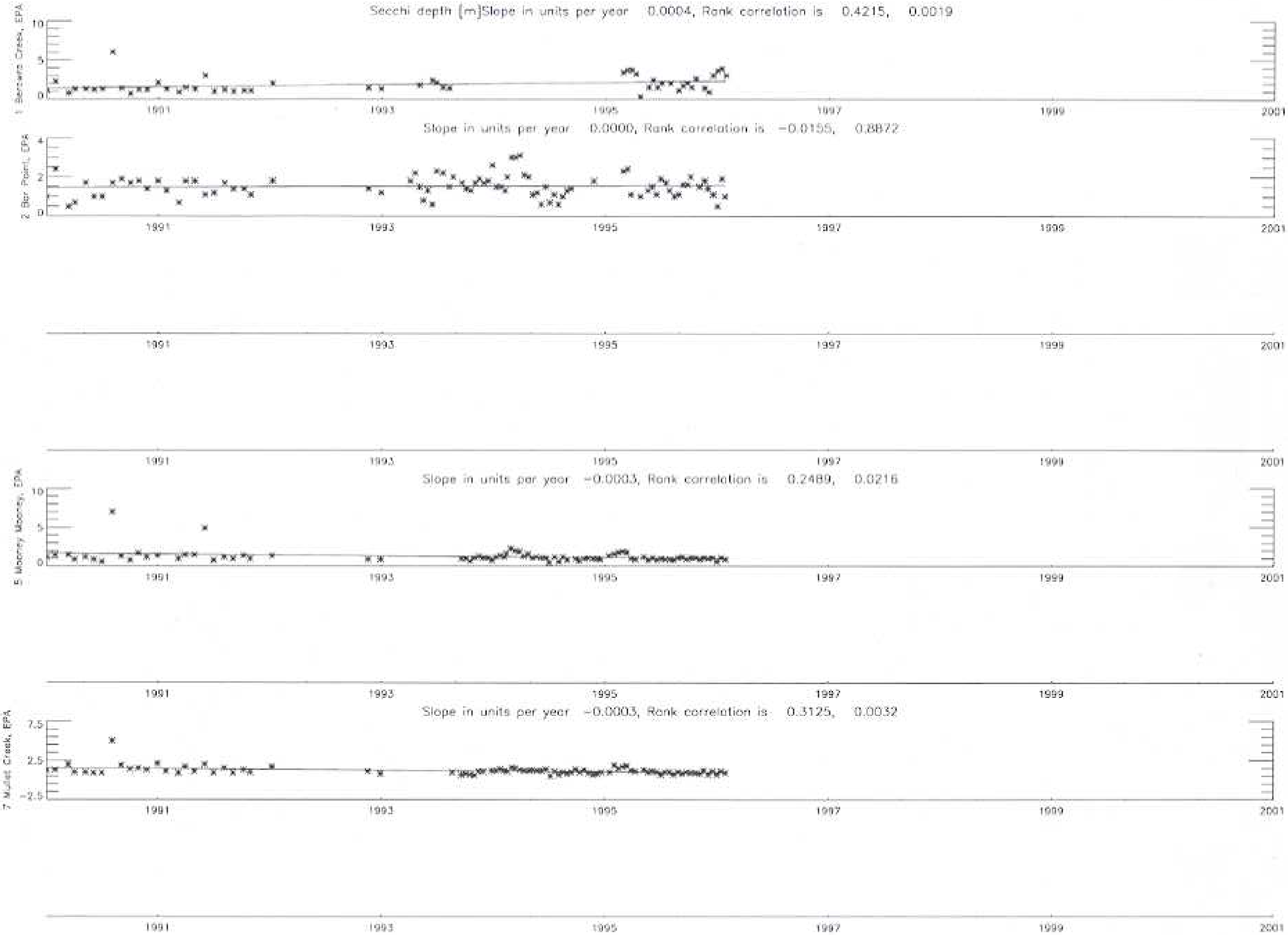
Bottom salinity [ppt]Slope in units per year 0.0013, Rank correlation is 0.0071, 0.9499
1 Berowra Creek, EPA
40
20
0
1991
1993
1995
1997
1999
2001
Slope in units per year 0.0009, Rank correlation is 0.0772, 0.4647
2 Bar Point, EPA
Slope in units per year 0.0022, Rank correlation is 0.0933, 0.4132
5 Mooney Mooney, EPA
Slope in units per year 0.0025, Rank correlation is 0.2741, 0.0139
7 Mullet Creek, EPA
47.5
32.5
17.5



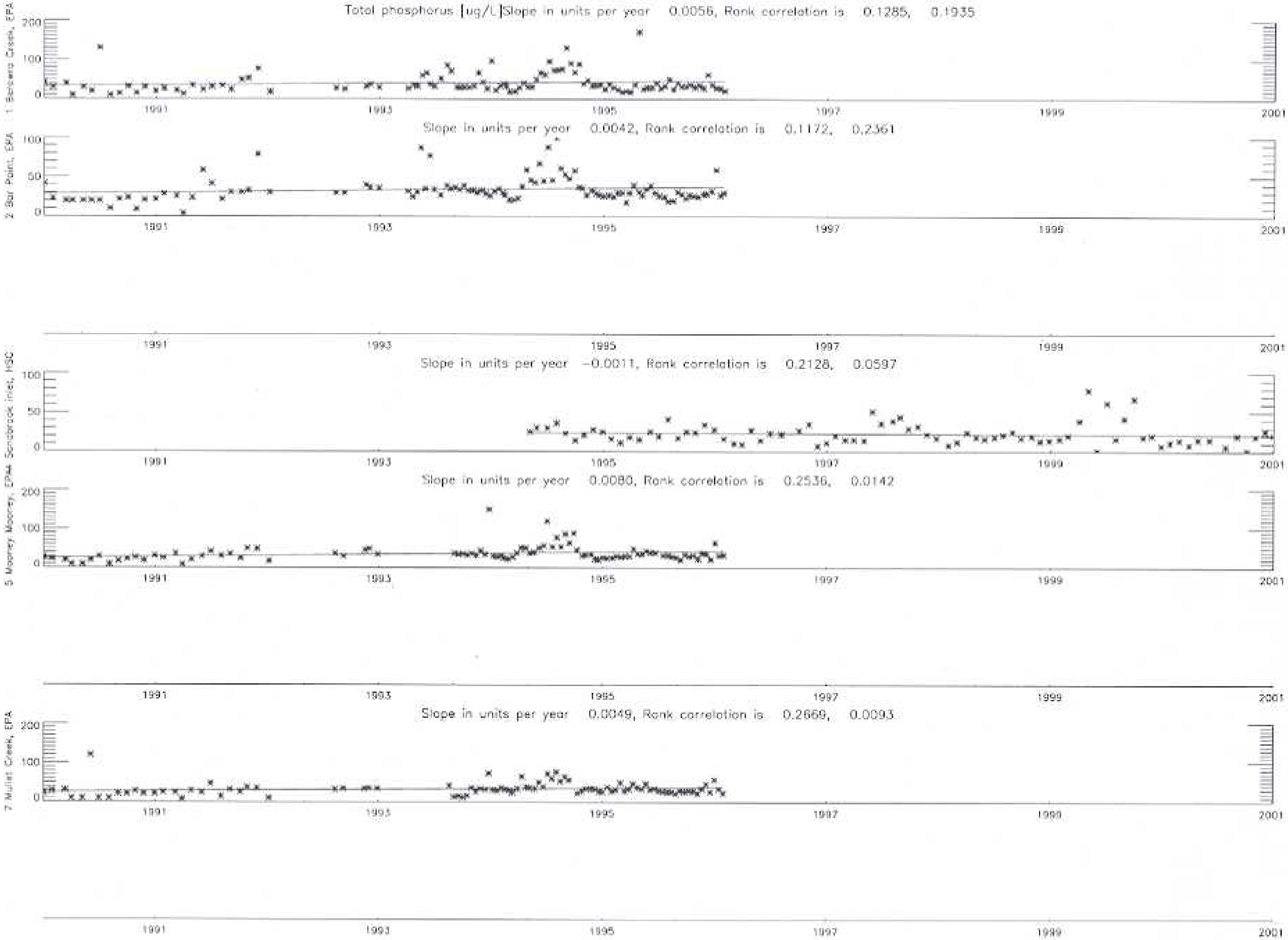
Top field turbidity [NTU]Slope in units per year 0.0025, Rank correlation is -0.0522, 0.7277
1 Barbara Creek, EPA
Slope in units per year 0.0017, Rank correlation is 0.0121, 0.9228
2 Bar Point, EPA
Slope in units per year 0.0050, Rank correlation is 0.0768, 0.6205
3 Spectacle Island, HSC
Slope in units per year -0.0009, Rank correlation is 0.1075, 0.3455
4 Sandbrook Inlet, HSC
Slope in units per year 0.0107, Rank correlation is 0.2337, 0.0775
5 Mooney Mooney, EPA
Slope in units per year 0.0026, Rank correlation is -0.1047, 0.5375
6 Mooney Mooney Creek, HSC
Slope in units per year 0.0053, Rank correlation is 0.1921, 0.1347
7 Mullet Creek, EPA
Slope in units per year 0.0008, Rank correlation is 0.0202, 0.8967
8 Mullet Creek, HSC
1991
1993
1995
1997
1999
2001

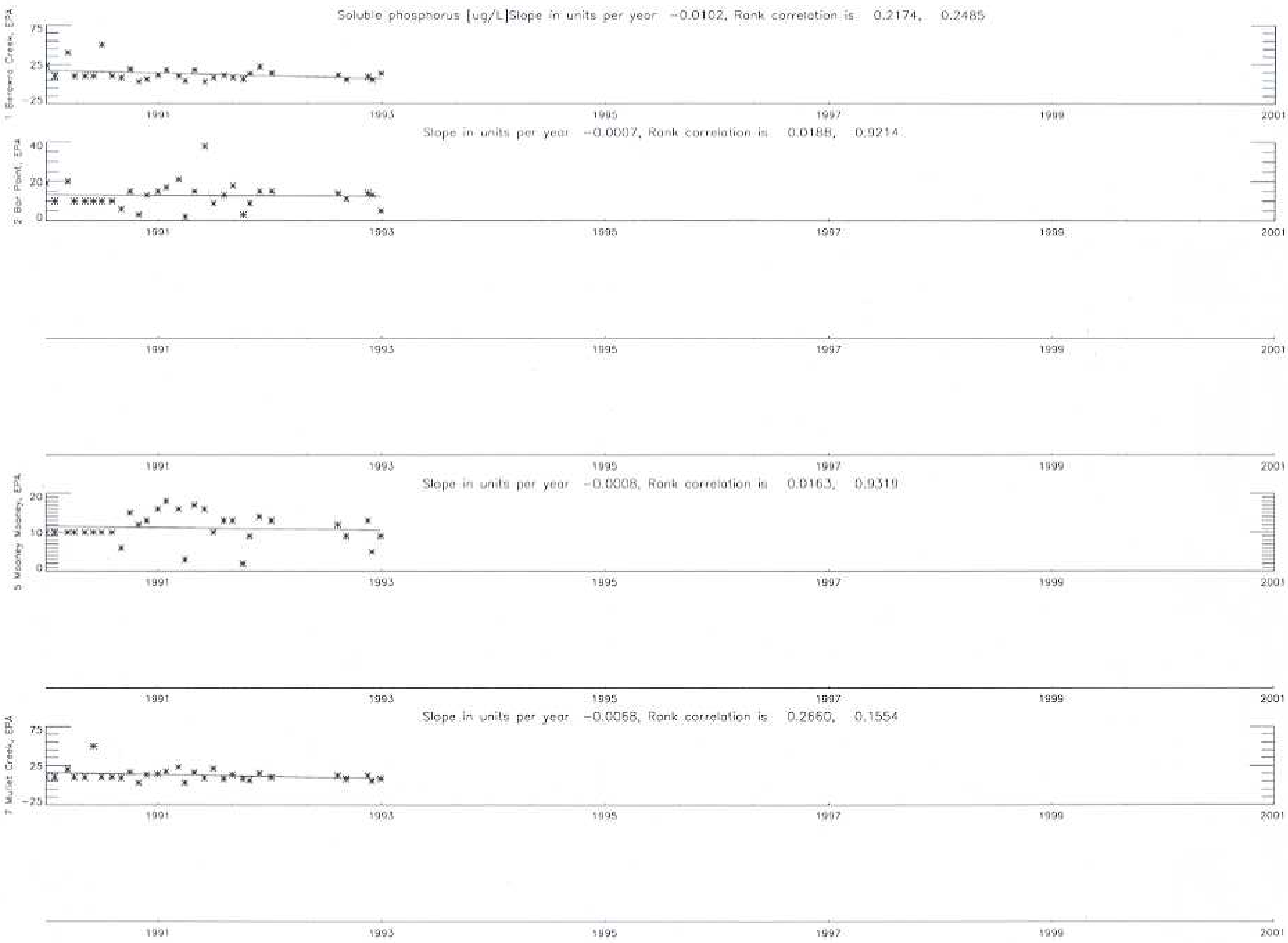


Suspended solids [mg/L]Slope in units per year 0.0003, Rank correlation is 0.3723, 0.0011
1 Barbara Creek, EPA
Slope in units per year 0.0002, Rank correlation is 0.1804, 0.1241
2 Bar Point, EPA
Slope in units per year -0.0025, Rank correlation is 0.2218, 0.0480
4 Sandbrook Inlet, HSC
Slope in units per year -0.0001, Rank correlation is 0.0522, 0.6819
5 Mooney Mooney, EPA
Slope in units per year -0.0016, Rank correlation is 0.1266, 0.3149
7 Mullet Creek, EPA
1991
1993
1995
1997
1999
2001

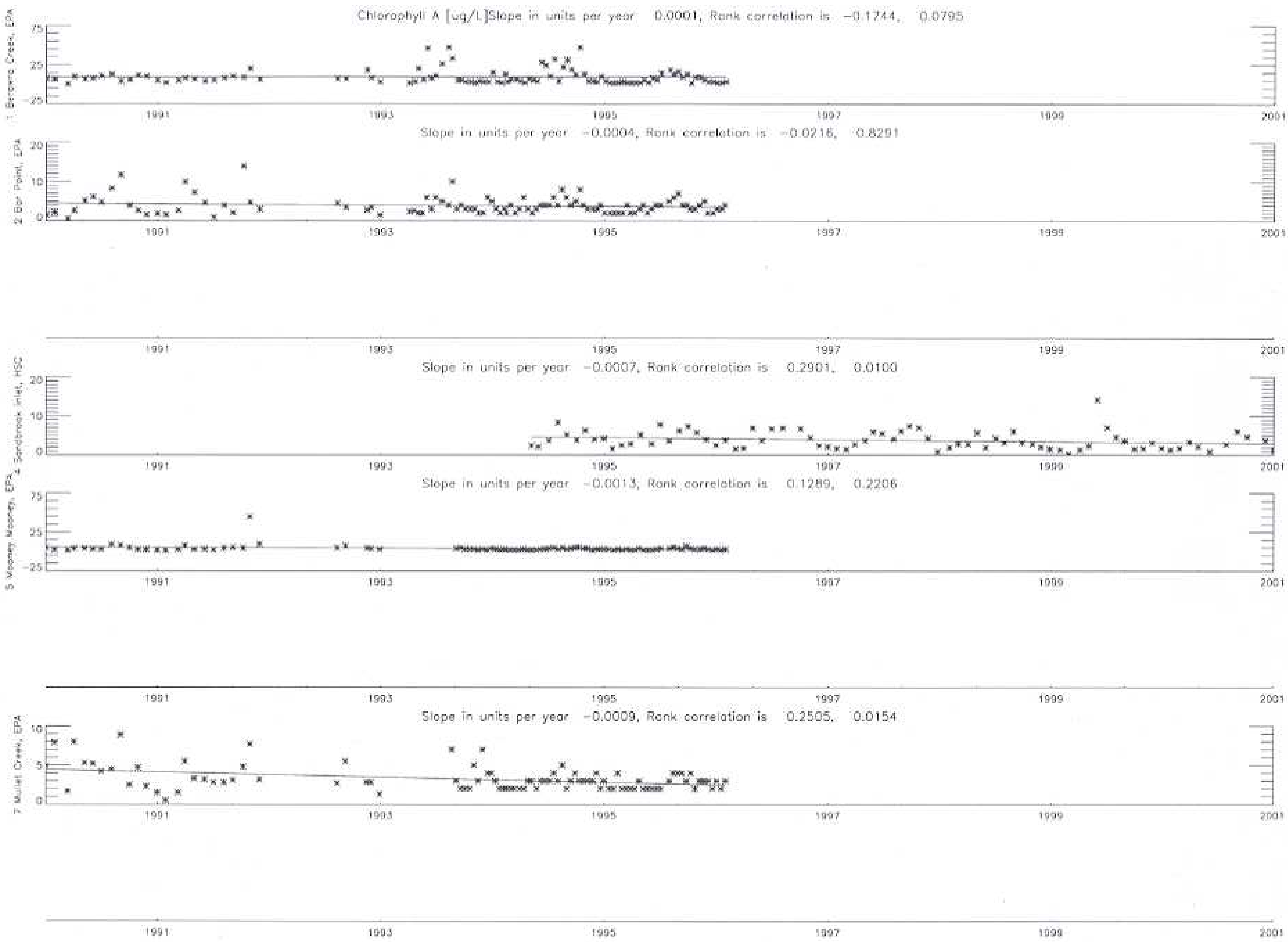


Secchi depth [m]Slope in units per year 0.0004, Rank correlation is 0.4215, 0.0019
1 Bercero Creek, EPA
Slope in units per year 0.0000, Rank correlation is -0.0155, 0.8872
2 Bar Point, EPA
Slope in units per year -0.0003, Rank correlation is 0.2489, 0.0216
5 Mooney Mooney, EPA
Slope in units per year -0.0003, Rank correlation is 0.3125, 0.0032
7 Mullet Creek, EPA
1991
1993
1995
1997
1999
2001

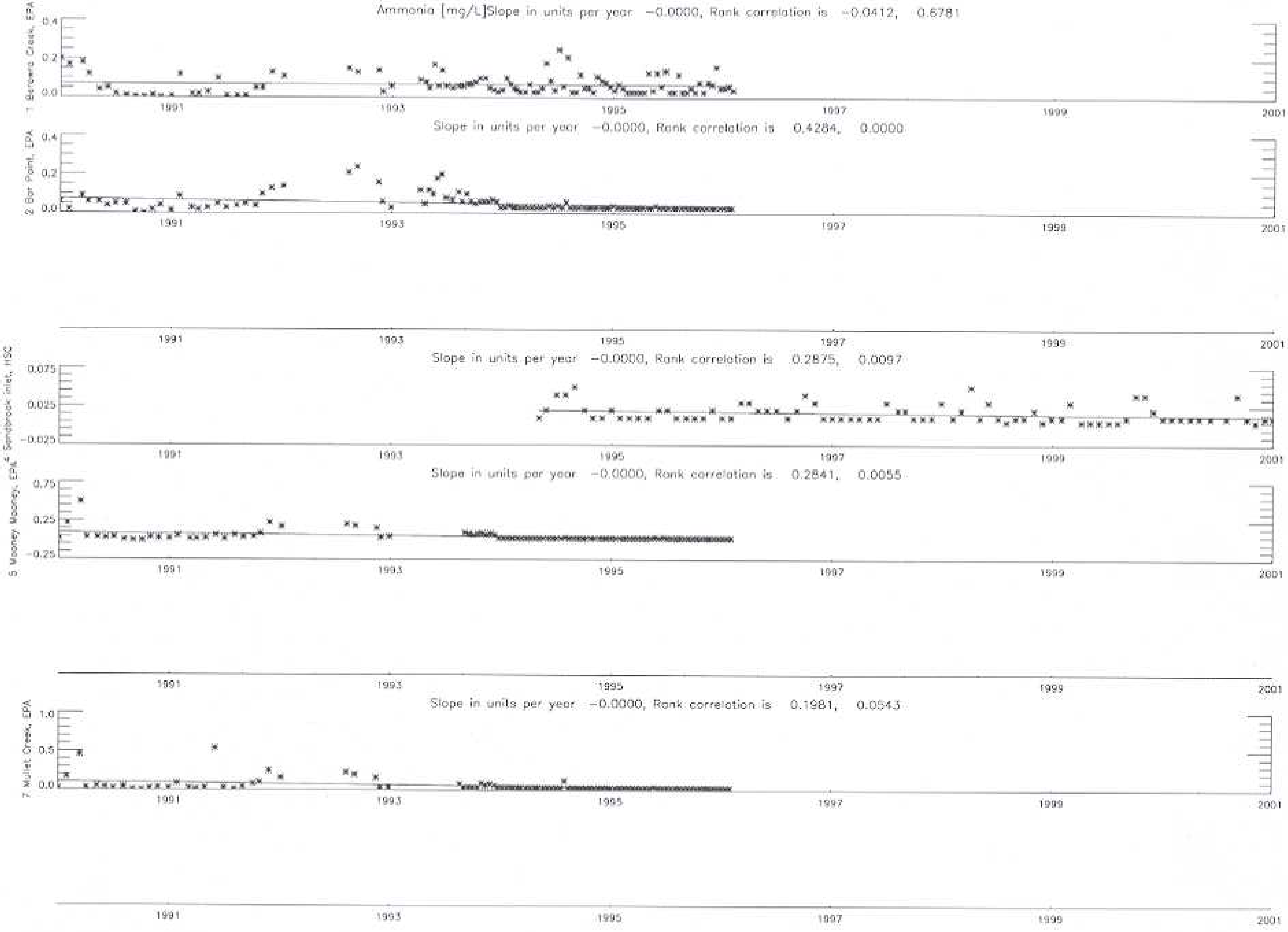

Total phosphorus [ug/L]Slope in units per year 0.0056, Rank correlation is 0.1285, 0.1935
1 Barcoo Creek, EPA
Slope in units per year 0.0042, Rank correlation is 0.1172, 0.2361
2 Bar Point, EPA
Slope in units per year -0.0011, Rank correlation is 0.2128, 0.0597
Sandbrook inlet, HSC
Slope in units per year 0.0080, Rank correlation is 0.2536, 0.0142
5 Mooney Mooney, EPA4
Slope in units per year 0.0049, Rank correlation is 0.2669, 0.0093
7 Mullet Creek, EPA
1991
1993
1995
1997
1999
2001



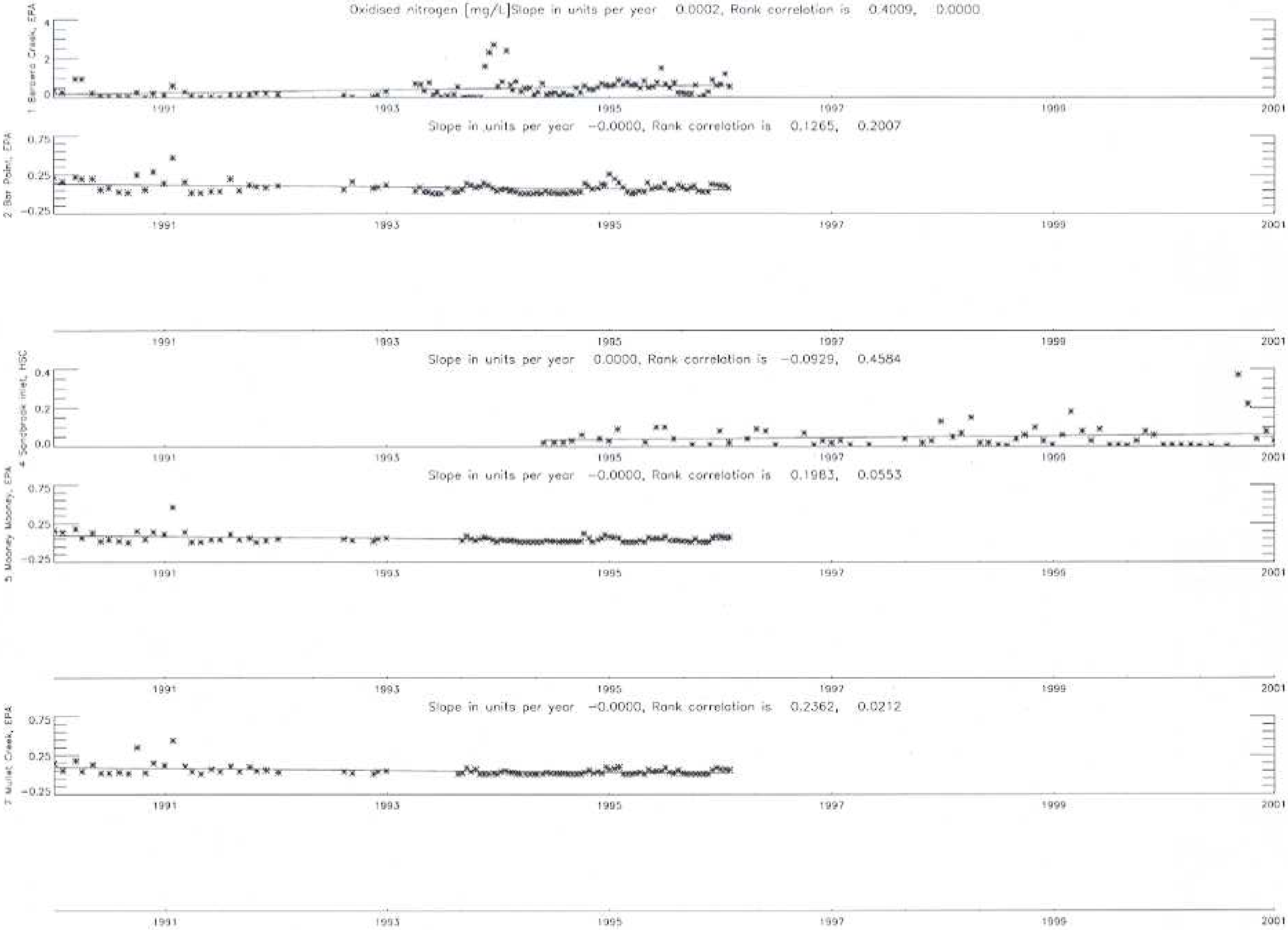
Soluble phosphorus [ug/L]Slope in units per year -0.0102, Rank correlation is 0.2174, 0.2485
1 Barlows Creek, EPA
75
25
-25
Slope in units per year -0.0007, Rank correlation is 0.0188, 0.9214
2 Bar Point, EPA
40
20
0
Slope in units per year -0.0008, Rank correlation is 0.0163, 0.9319
5 Mooney Mooney, EPA
20
10
0
Slope in units per year -0.0058, Rank correlation is 0.2660, 0.1554
7 Mullet Creek, EPA
75
25
-25
1991
1993
1995
1997
1999
2001

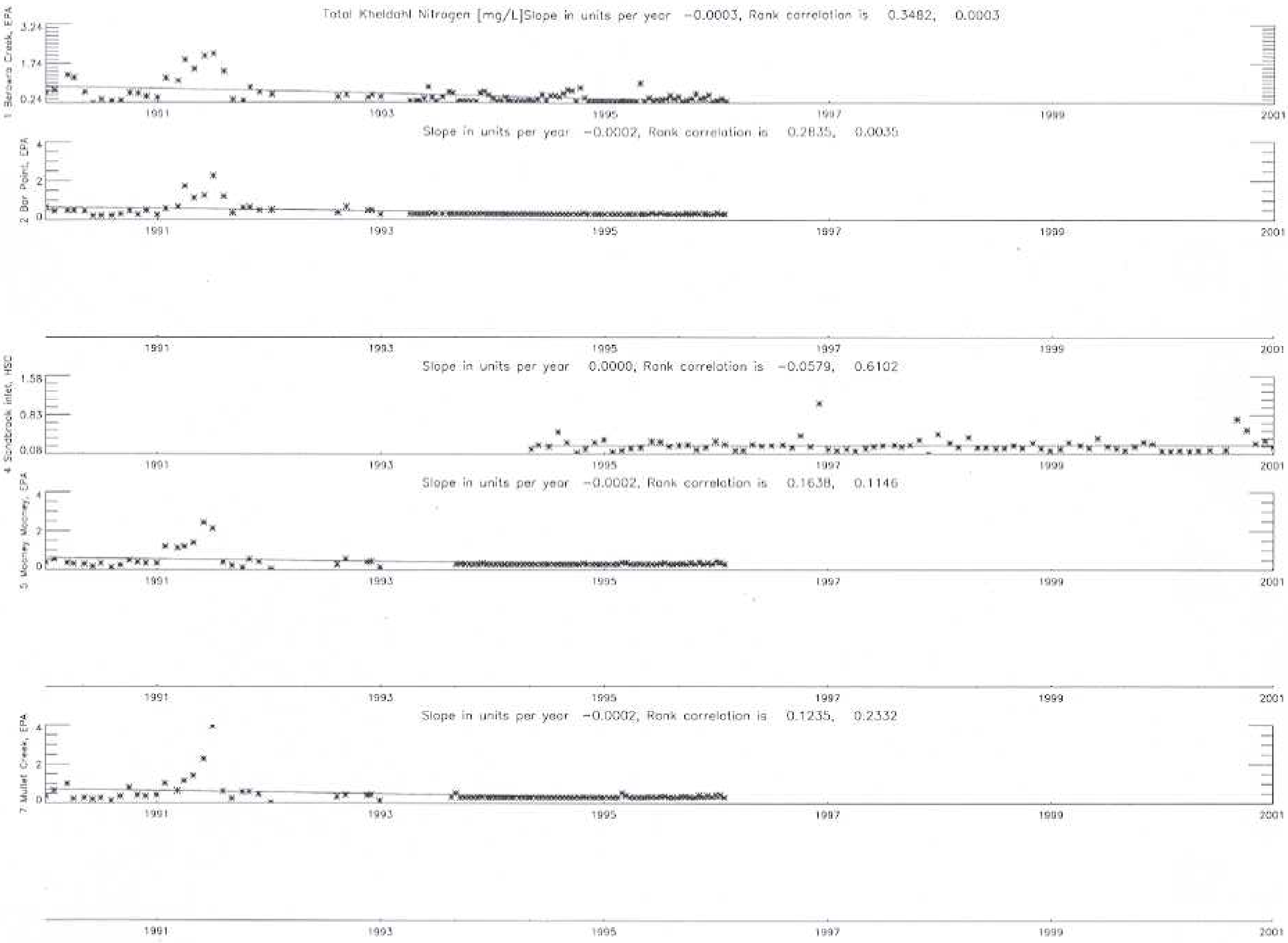


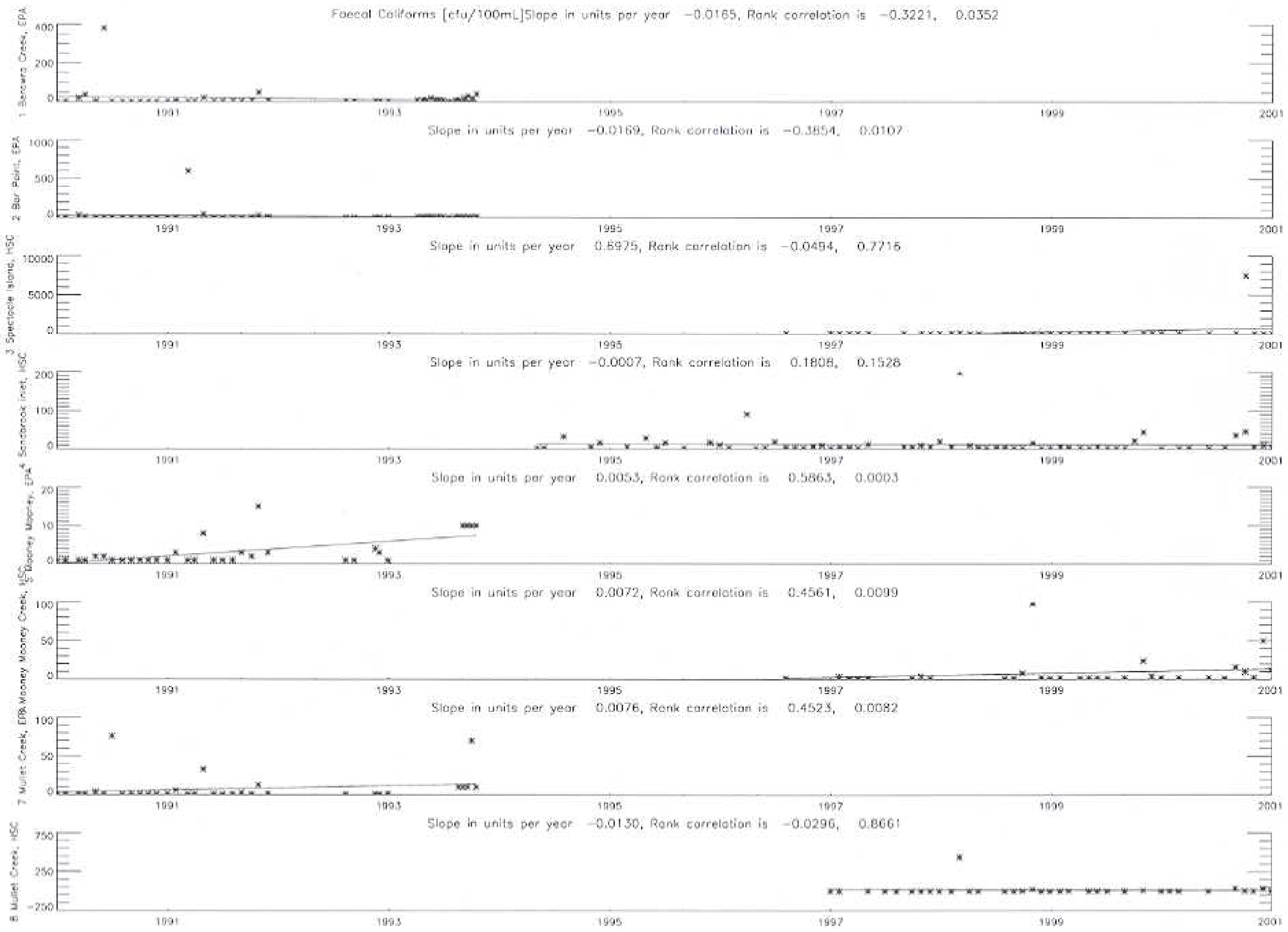
Chlorophyll A [ug/L]Slope in units per year 0.0001, Rank correlation is -0.1744, 0.0795
1 Barcena Creek, EPA
Slope in units per year -0.0004, Rank correlation is -0.0216, 0.8291
2 Bar Point, EPA
Slope in units per year -0.0007, Rank correlation is 0.2901, 0.0100
4 Sandbrook Inlet, HSC
Slope in units per year -0.0013, Rank correlation is 0.1289, 0.2206
5 Mooney Mooney, EPA
Slope in units per year -0.0009, Rank correlation is 0.2505, 0.0154
7 Mullet Creek, EPA
1991
1993
1995
1997
1999
2001



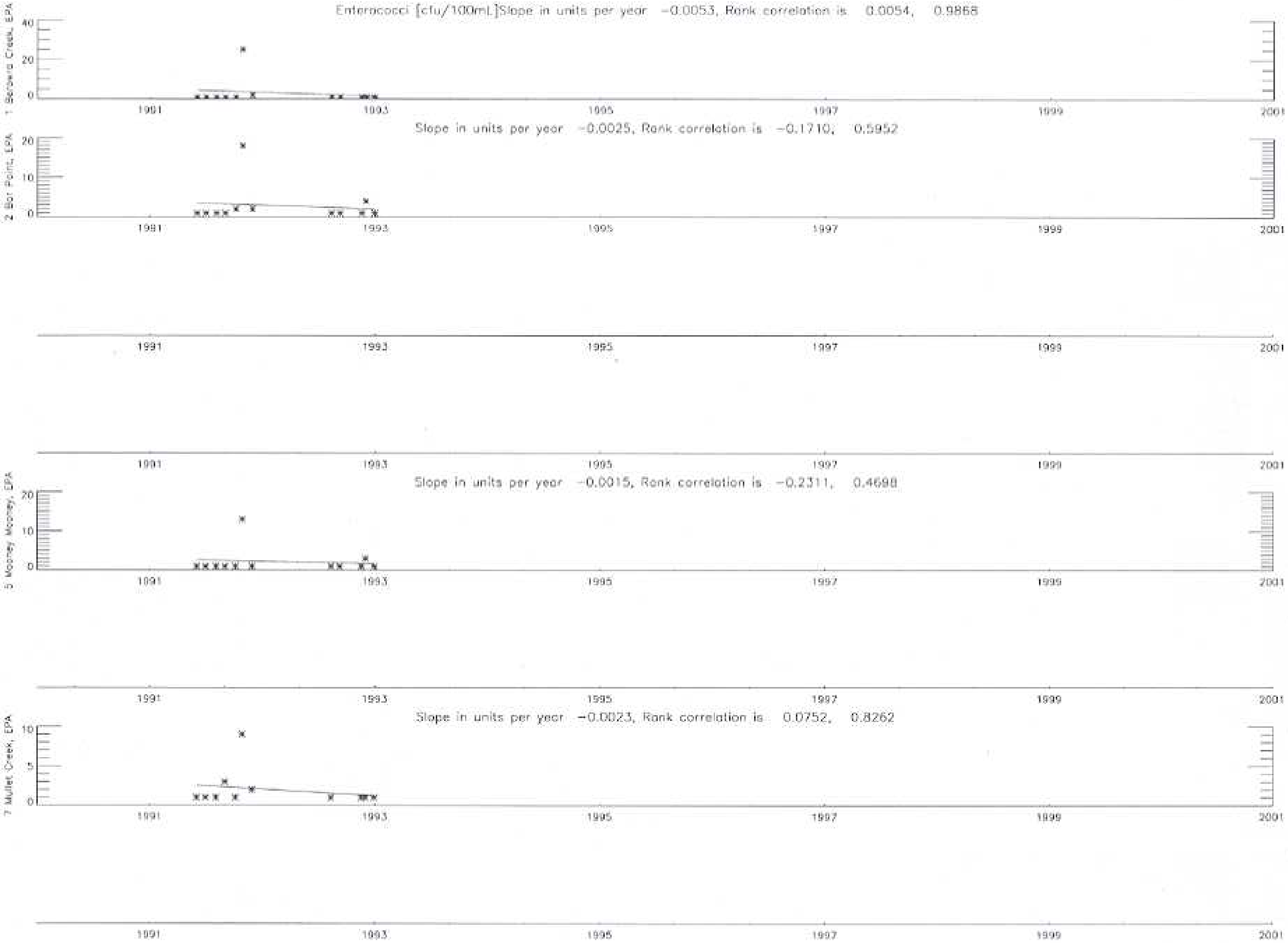
Ammonia [mg/L]Slope in units per year -0.0000, Rank correlation is -0.0412, 0.6781
1 Bensons Creek, EPA
Slope in units per year -0.0000, Rank correlation is 0.4284, 0.0000
2 Bar Point, EPA
Slope in units per year -0.0000, Rank correlation is 0.2875, 0.0097
4 Sandbrook inlet, HSC
Slope in units per year -0.0000, Rank correlation is 0.2841, 0.0055
5 Mooney Mooney, EPA
Slope in units per year -0.0000, Rank correlation is 0.1981, 0.0543
7 Mullet Creek, EPA
1991
1993
1995
1997
1999
2001


Oxidised nitrogen [mg/L]Slope in units per year 0.0002, Rank correlation is 0.4009, 0.0000
1 Barbara Creek, EPA
Slope in units per year -0.0000, Rank correlation is 0.1265, 0.2007
2 Bar Point, EPA
Slope in units per year 0.0000, Rank correlation is -0.0929, 0.4584
4 Sandbrook inlet, HSC
Slope in units per year -0.0000, Rank correlation is 0.1983, 0.0553
5 Mooney Mooney, EPA
Slope in units per year -0.0000, Rank correlation is 0.2362, 0.0212
7 Mullet Creek, EPA
1991
1993
1995
1997
1999
2001

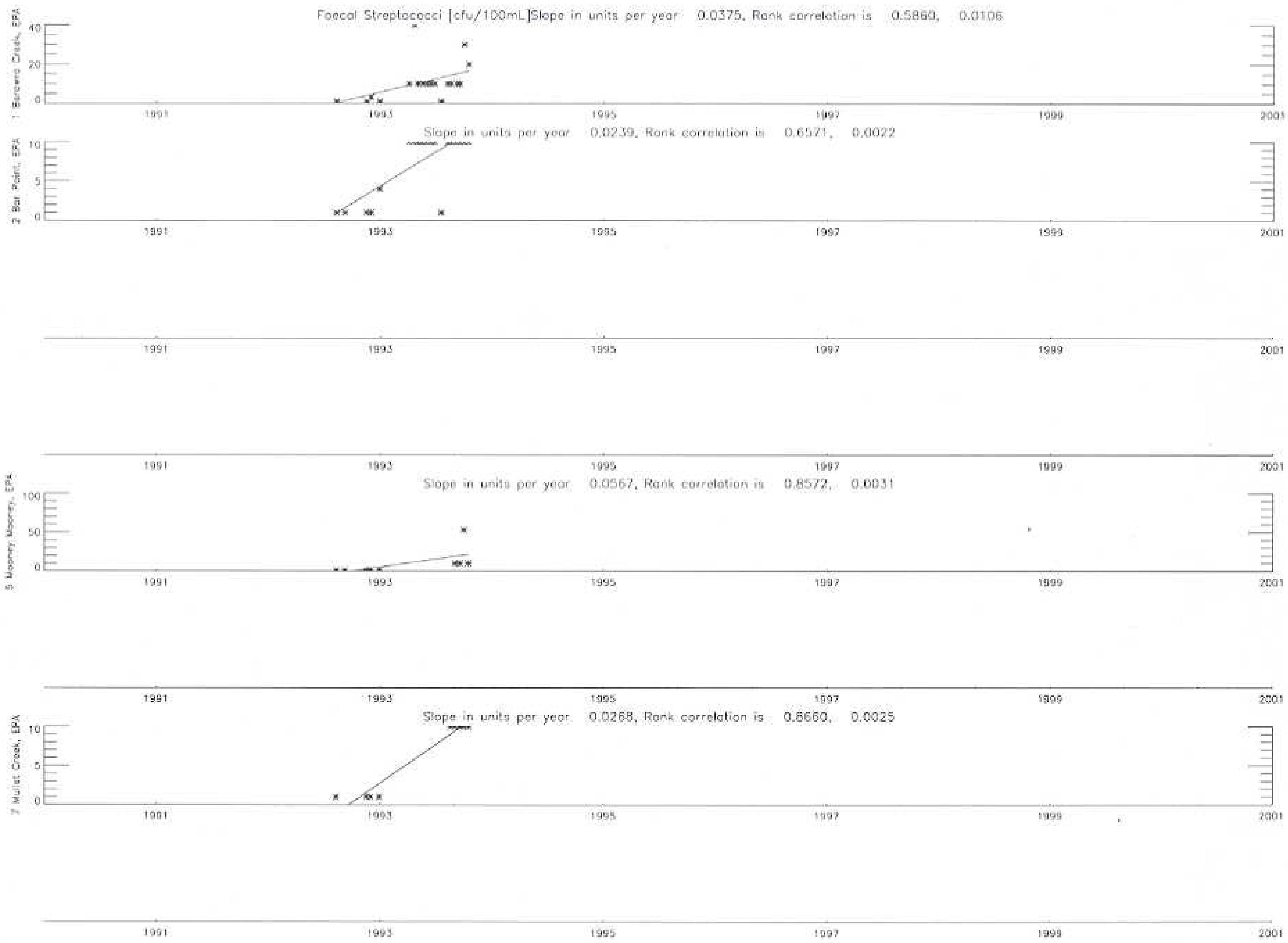

Total Kheldahl Nitrogen [mg/L]Slope in units per year -0.0003, Rank correlation is 0.3482, 0.0003
1 Barbara Creek, EPA
Slope in units per year -0.0002, Rank correlation is 0.2835, 0.0035
2 Bar Point, EPA
Slope in units per year 0.0000, Rank correlation is -0.0579, 0.6102
4 Sandbrook inlet, HSC
Slope in units per year -0.0002, Rank correlation is 0.1638, 0.1146
5 Mooney Mooney, EPA
Slope in units per year -0.0002, Rank correlation is 0.1235, 0.2332
7 Mullet Creek, EPA
1991
1993
1995
1997
1999
2001



Faecal Coliforms [cfu/100mL]Slope in units per year -0.0165, Rank correlation is -0.3221, 0.0352
1 Bensons Creek, EPA
Slope in units per year -0.0169, Rank correlation is -0.3854, 0.0107
2 Bar Point, EPA
Slope in units per year 0.6975, Rank correlation is -0.0494, 0.7716
3 Spectacle Island, HSC
Slope in units per year -0.0007, Rank correlation is 0.1808, 0.1528
4 Sandbrook Inlet, HSC
Slope in units per year 0.0053, Rank correlation is 0.5863, 0.0003
5 Mooney Mooney, EPA
Slope in units per year 0.0072, Rank correlation is 0.4561, 0.0099
6 Mooney Mooney Creek, HSC
Slope in units per year 0.0076, Rank correlation is 0.4523, 0.0082
7 Mullet Creek, EPA
Slope in units per year -0.0130, Rank correlation is -0.0296, 0.8661
8 Mullet Creek, HSC
1991
1993
1995
1997
1999
2001



Enterococci [cfu/100mL]Slope in units per year -0.0053, Rank correlation is 0.0054, 0.9868
1 Barbwire Creek, EPA
Slope in units per year -0.0025, Rank correlation is -0.1710, 0.5952
2 Bar Point, EPA
Slope in units per year -0.0015, Rank correlation is -0.2311, 0.4698
5 Mooney Mooney, EPA
Slope in units per year -0.0023, Rank correlation is 0.0752, 0.8262
7 Mullet Creek, EPA
1991
1993
1995
1997
1999
2001



Faecal Streptococci [cfu/100mL]Slope in units per year 0.0375, Rank correlation is 0.5860, 0.0106
1 Barwera Creek, EPA
40
20
0
Slope in units per year 0.0239, Rank correlation is 0.6571, 0.0022
2 Bar Point, EPA
10
5
0
Slope in units per year 0.0567, Rank correlation is 0.8572, 0.0031
5 Mooney Mooney, EPA
100
50
0
Slope in units per year 0.0268, Rank correlation is 0.8660, 0.0025
7 Mullet Creek, EPA
10
5
0
1991
1993
1995
1997
1999
2001

Appendix C

Sedimentological Analysis

Brooklyn Estuary Process Study

Sediment Core Sampling

Report prepared by Coastal & Marine Geosciences
for UNSW Water Research laboratory & Hornsby Shire Council

June 2002

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1. Background

Hornsby Shire Council has commissioned the University of New South Wales Water Research Laboratory to supervise an estuary process study of the Brooklyn area in the lower Hawkesbury River. The study involves a review of the existing information and the collection of additional field data, as required, to assist in delivering the process study outcomes (see UNSWWRL Study Proposal, 2001).

The study area includes a 7km long reach of the Hawkesbury River between the Sydney-Newcastle Freeway road bridge downstream to Croppy Point, northern tributaries Mooney Mooney and Mullet Creeks as well as Sandbrook Inlet (Figure 1). Previous investigations have suggested elevated levels of contaminants, primarily metals and synthetic organic compounds, occur in the vicinity of Sandbrook Inlet and sections of the Hawkesbury River channel (see Appendix A). These data were seen as having limited value in identifying contemporary and background levels of sediment contaminants due to variations in sampling and analytical methodologies. As a consequence, a reconnaissance program of sediment coring was proposed.

Selection of core sites was preceded by a surface sediment sampling program conducted in February 2002 (see Appendix B). Nine potential core sites were identified, of which seven were sampled in April 2002 (Figure 1). Core sites were selected to assess sediment contamination levels in three main areas of the estuary: the Hawkesbury River channel, Sandbrook Inlet and tributaries Mooney Mooney and Mullet Creeks.

This report summarises the results of the sediment coring program and provides an interpretation of the chemical analyses of estuarine sediments in the study area.

2. Methods

The sediment coring was conducted by representatives of Hornsby Council and Coastal & Marine Geosciences on 5 April, 2002. Core samples were collected with a gravity corer deployed from a 10m motorised punt equipped with a davit and power-assisted capstan (Figure 2). Samples of the estuary bed were recovered to a maximum depth of 1.3m. The corer utilised 80mm (OD), 74mm (ID) polycarbonate tubing and was operated in water depths of 1 to 7m. Coring in shallow water (<1m) was completed by simply pushing the core barrel into the substrate. Core locations reported here approximate the locations of surface sediment samples shown in Figure 1 marked “Core SIte”.

A minimum of 4 cores was collected at each site, three samples of the top 5cm of the estuary bed and one sample at the maximum depth of core penetration. Core samples were logged and processed immediately on recovery. Processing involved subsampling, placing samples in glass jars and storing the samples on ice. A total of twenty seven samples were collected and delivered the same day to the Australian Water Technology (AWT) analytical laboratories at Ryde by Hornsby Council staff.

A summary of the core samples and their analyses is presented in Tables 1, 2 and 3. These results were provided by AWT to Hornsby Council and subsequently forwarded to Coastal & Marine Geosciences for interpretation. All analytical results are for total sample.

The range of chemical analyses undertaken was determined in consultation with Hornsby Shire Council representatives and included determinations of %Gravel:Sand:Mud, Total Organic Content, nutrients (TKN, TP, TN) selected metals and polycyclic aromatic hydrocarbons. The analyses allow a reliable estimation of sediment contamination with due consideration of the effects of grainsize and total organic carbon.

Contaminants bind differently to different sediments and knowledge of sediment grainsize and organic carbon content is critical in interpretations of contaminant transport, load and availability. Fine sediment (muds) can be transported long distances in suspension plus contaminants tend to bind more effectively to fine grained particles than to coarser grained sediments such as sand. High organic carbon contents also promote stronger binding of contaminants, reducing their availability. Analytical results were compared to the ANZECC 2000 Recommended Sediment Quality Guidelines (Table 3.5.1; ANZECC 2000).

3. Results

3.1 Core Locations

Samples were collected in the Hawkesbury River channel (Sites 5, 6, 7 - Depositional Environment: fluvial channel/estuarine mud basin), Sandbrook Inlet (Sites 8, 9 - Depositional Environment: estuarine mud basin) and tributaries Mooney Mooney and Mullet Creeks (Sites 1 and 2 respectively - Depositional Environment: estuarine mud basin) (Figure 1). The sites are considered representative of areas of fine sediment deposition in the lower Hawkesbury River estuary and, as such, can be expected to identify regional and local sources of anthropogenic-related sediment contamination. Samples from Mooney Mooney and Mullet Creeks are remote from the main Hawkesbury River channel and were selected to assess possible sediment contamination associated with their respective catchments.

3.2 Physical Sediment Properties

A comparison of the basic physicochemical parameters of the core samples is shown in Figure 3. Core samples are grouped by site along the x-axis; triplicate surface samples are indicated by values Site ID.1, Site ID.2 and Site ID.3, single samples at depth by Site ID.4. Samples were collected at depth at all sites except C7 as limited core penetration at this site (<0.1m) precluded further sampling.

Figure 3 shows a range of sediment textures were encountered with 18 of the 27 samples containing more than 50% mud (%<0.063mm). Coarse grained sediments, typically muddy sands (<50% mud), tend to occur in areas experiencing stronger tidal currents (eg Hawkesbury River Site 7, Sandbrook Inlet Site 8 and Mooney Mooney Creek Site 1). Finer grained sediments (>50% Mud) characterise lower energy parts of the estuary (eg. Mullet Creek Site 3, Hawkesbury River Sites 5 and 6, Sandbrook Inlet Site 9). A similar observation on the distribution of fine and coarse grained surface sediments in the lower Hawkesbury River estuary has previously been made by Birch et al. (1998; 1999).

There is considerable variability in sediment texture with depth; uniform (Sites 3 and 6), fining down (Site 1), fining up (Site 5, 8 and 9) and mixed (Site 7) sediment sequences are present. Of interest is a surficial layer of fine grained mud blanketing coarser sediments (muddy sand) in the Hawkesbury River channel near Spectacle Island and Sandbrook Inlet which suggest long term trapping of fine grained sediments in these areas.

While grainsize variability clearly complicates assessments of intra- and inter-core comparisons, surface sediments (top 5cm of estuary bed) with sufficiently high proportions of mud (>50%) and similar %TOC (<4.3%) were recovered from Sandbrook Inlet, Hawkesbury River, Mullet and Mooney Mooney Creeks to assess sediment contamination within the study area. Overall, percentages of mud and TOC in surface samples ranged 31.3-99.7% and 1.36 to 4.12% respectively; percentages in the samples collected at depth ranged 14.6-99.7% and 0.51-4.86% respectively. ANZECC guidelines are normalised for 1% organic carbon, the relatively high proportion of organic carbon in the study area sediments will influence (reduce) the availability of contaminants.

3.3 Nutrients

There are no ANZECC guidelines for nutrients in sediments although water quality guidelines can be used when assessing algal bloom risk. Relationships between elevated nutrient levels, particularly phosphorous, are shown in Table 1. With due consideration of variations in sediment texture, TP and TN values are similar across most sites. Phosphorous levels tend to be highest in the Mullet Creek (max. 842 mg/kg) and Sandbrook Inlet (Site 9 - max. 821 mg/kg) (Table 1). While phosphorous levels in the sediment exceed recommended water quality guidelines (0.1 mg/kg), it is unlikely these sediment nutrient levels are the same as nutrient levels in the sediment pore water. Despite this, the values are sufficiently elevated in comparison to other sites to be of concern in terms of the possibility of early triggering of algal blooms in the future.

3.4 Metals/Metalloids/Organometallics

Analyses of total arsenic, cadmium, chromium, copper, lead, nickel, selenium, tin and zinc are summarised in Table 2 and plotted in Figure 4. Exceedances of the “low probability of biological effects” (ISQG-Low) trigger value guidelines were noted for arsenic in surface sediments at Site 7 (Hawkesbury River - Dangar Island sample C7.3) and nickel in subsurface sediments at Site 3 (Mullet Creek sample C3.4). The remainder of sites returned analyses below the minimum trigger values. Exceedance of trigger values do not necessarily indicate a problem level but rather scope for further testing to determine safety issues or causes. The relatively high organic carbon content of the samples may also act to mitigate effects of the contaminants by lowering their bioavailability.

A slight elevation of the levels of copper, lead and zinc occurs in surface sediments in the eastern portion of Sandbrook Inlet (Site 9), near the railway causeway, which may indicate long term trapping of contaminants in this area. A similar pattern of elevated metal contaminant levels, some above ISQG-Low, have been reported previously for the eastern portion of Sandbrook Inlet (JBA Urban Planning Consultants, 1998).

Comparison of samples collected in the study area show elevated levels of tin (0.34-0.39 mg/kg) in surface sediments at Sites 1 (Mooney Mooney Ck), 7 (Hawkesbury River near Dangar Island) and 8 (Sandbrook Inlet) as well as in subsurface sediments (0.24-0.42mg/kg) at Sites 3 (Mullet Ck.), 5 (Hawkesbury River near Spectacle Is) and 6 (Hawkesbury River). Elevated levels of tin in surface sediments in Mooney Mooney Ck, Sandbrook Inlet and the Hawkesbury River near Dangar Island may indicate a recent source, possibly related to marinas.

3.5 Organics

Analyses focused on a range of 18 polycyclic aromatic hydrocarbon compounds (PAHs) (Table 3). PAHs are produced in the incomplete combustion of organic matter (natural and anthropogenic sources) and are a widespread contaminant in the environment with some PAHs known or suspected carcinogens. They are a good indicator of anthropogenic-related sources of contamination. Common input points for PAHs to an estuary would include deposition of airborne particles, surface runoff from roads and land surfaces and direct inputs from industrial and sewage effluents and fossil fuel products.

All individual PAH compounds were found to be below ISQG-Low guidelines. Total PAH's ranged from detection limit in sandy sediments (<10 ug/kg) up to a maximum of 2530 ug/kg in the muddy sediment at Site 9 (Sandbrook Inlet). Figure 5 is a plot of Total PAH, Heavy Molecular Weight PAH and Light Molecular Weight PAH for all samples. Heavy Molecular Weight PAHs tend to take longer to breakdown and their presence can indicate long term contaminant accumulation. The plot shows elevation of the PAH levels in Mooney Mooney Creek, with the highest levels encountered in Sandbrook Inlet (Sites 8 & 9). ISGQ-Low levels for high and low molecular weight PAHs (552ug/kg and 1700ug/kg respectively) and Total PAH (4000ug/kg) were not exceeded.

While ANZECC guidelines for PAHs were not exceeded, a clear difference can be observed between Site 9 (eastern portion of Sandbrook Inlet) and all other sites indicating that future issues of sediment contamination in this area will need to be addressed (Figure 4). Elevated values in Mooney Mooney Creek also warrant further investigation.

4. Summary

Physical and chemical analyses of sediment cores collected for the Brooklyn estuary process study reported here give an appreciation of the sediment contamination trends in the study area which are interpretable in terms of current estuarine processes and likely patterns of sediment dispersal and accumulation. Low energy sections of the estuary away from the influence of strong tidal currents are blanketed with fine grained muds, indicating areas of sediment accumulation and, in some areas, build up of metallic and organic contaminants.

Selected chemical analyses of sediments at a majority of sites were found to be within the ANZECC 2000 guidelines for nutrients, metals and PAHs with the following observations and qualifications:

- Core sample grainsize differences make interpretations of background values difficult and further sampling to a greater depth below the estuary bed would be required to reliably establish natural levels of sediment contaminants. Of all analytes tested, PAH values seem to show the most consistent decrease with depth. Metal values are far more variable

- Levels of phosphorous are elevated with respect to other areas sampled in this study in Mullet Creek and Sandbrook Inlet. The levels of total phosphorous (>821mg/kg) in these areas may lead to an early triggering of algal blooms in the future.

- Exceedance of ISQG Low metal guidelines were noted for arsenic in surface sediments near Dangar Island and nickel in subsurface sediments Mullet Creek. Most metals selected have not exceeded guidelines indicating no environmental concern at this time. An exceedance of a trigger level does not necessarily indicate a problem but rather support for further testing (eg. an assessment of metal bioavailability using acid volatile sulphides/ simultaneously extracted metals).

- While within ANZECC guidelines, elevated levels of contaminants (metals and PAHs) in Mooney Mooney Creek and Sandbrook Inlet are a concern and point to the long term accumulation of fine grained sediments and their contaminant load. Bioavailability testing using toxicity tests may be warranted to assist management options.

Consistency in the results of this study and previous work indicates long term accumulation of sediments and their contaminant load in Sandbrook Inlet is a management issue. Tidal flows within the inlet appear to be too low to remove fine grained sediments, leading to a build up of contaminants from local sources. In view of this, important considerations for estuary management must be enhanced tidal flushing to minimise the build up of fine sediments and their contaminant load in the inlet and the identification and reduction of local sources of contaminants. Sampling elsewhere in the study area suggests contamination issue are not as pronounced as those within Sandbrook Inlet due to a combination of greater tidal flushing and/or remote location away from anthropogenic pollution sources.

5. References

ANZECC, 2000, Australian and New Zealand Guidelines for Fresh and Marine Water Quality - The Guidelines, Australian and New Zealand Environment and Conservation Council, October 2000

Birch, G., Shotter, N., Steetsel, P., 1998, The environmental status of Hawkesbury River sediments. Australian Geographical Studies, 36(1), pp. 37-57

Birch, G. F., Eyre, B.D. and Taylor, S.E., 1999, The use of sediments to assess environmental impact on a large coastal catchment - the Hawkesbury River system. AGSO Journal of Geology and Geophysics, 17(5/6), pp.175-191.

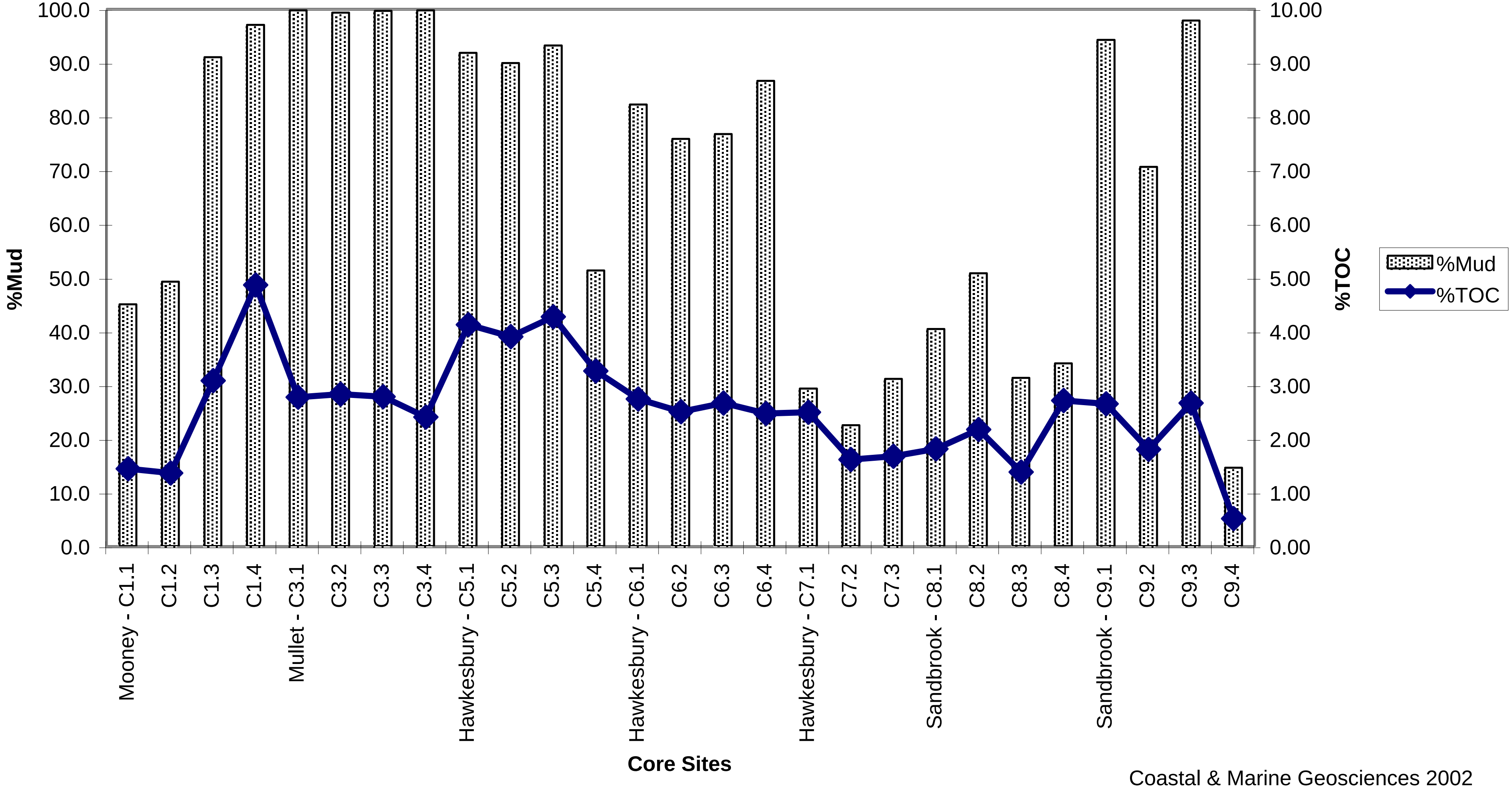
JBA Urban Planning Consultants, 1998, Development application to Hornsby Shire Council - Brooklyn resort tourist facility. Statement of Environmental Effects, Volume B. Prepared for Concensus Development, July 1998.

Figures and Tables


Figure 1. BROOKLYN ESTUARY STUDY - CORE LOCATIONS (Circled)
(April 2002)
Inferred boundary between fluvial sands and estuarine mud basin deposits
Fluvial Delta
Mud Basin
Fluvial Delta
Mud Basin
Site 1
Site 2
Site 3
Site 4
Site 5
Site 6
Site 7
Site 8
Site 9
Core Location
Brooklyn Estuary Study
(Surface Sediment Samples - 20/02/02)
Gravel (1)
Gravel (Muddy) (2)
Gravel (Sandy) (1)
Mud (17)
Mud (Gravelly) (3)
Mud (Sandy) (7)
Sand (4)
Sand (Gravel & Mud) (2)
Sand (Gravelly) (2)
Sand (Muddy) (2)
Mt White
PACIFIC HIGHWAY
NEWCASTLE
Native Dog B
Two Dollar B
Walbank Pt
Foleys B
Lemon Tree Pt
Oyster Leases
Creek
Mooney
Green Point B
Morrow Pt
Fox B
Mooney
Muller
BRISBANE
WATER
NATIONAL
Cheero Pt
Sunshine B
Snake I
Milson I
Big B
Mooney Mooney
Cogra B
Mullet Pt
HAWKESBURY RIVER RAILWAY BRIDGE
Spectacle I
Peat I (Hosptl)
Olga B
HAWKESBURY ROAD BRIDGES
BRIDGE CLEARANCES
Kangaroo Pt
Long Island
Sanbrook Inlet
Dangar I
Brooklyn
Flat Rock Pt
Patonga Creek

Figure 2. Gravity corer used in sampling program. Polycarbonate core barrel contains 1.3m long intact sample of estuarine bed.

Figure 3. Brooklyn Estuary Process Study
%Mud and %TOC Total Sample - All Cores



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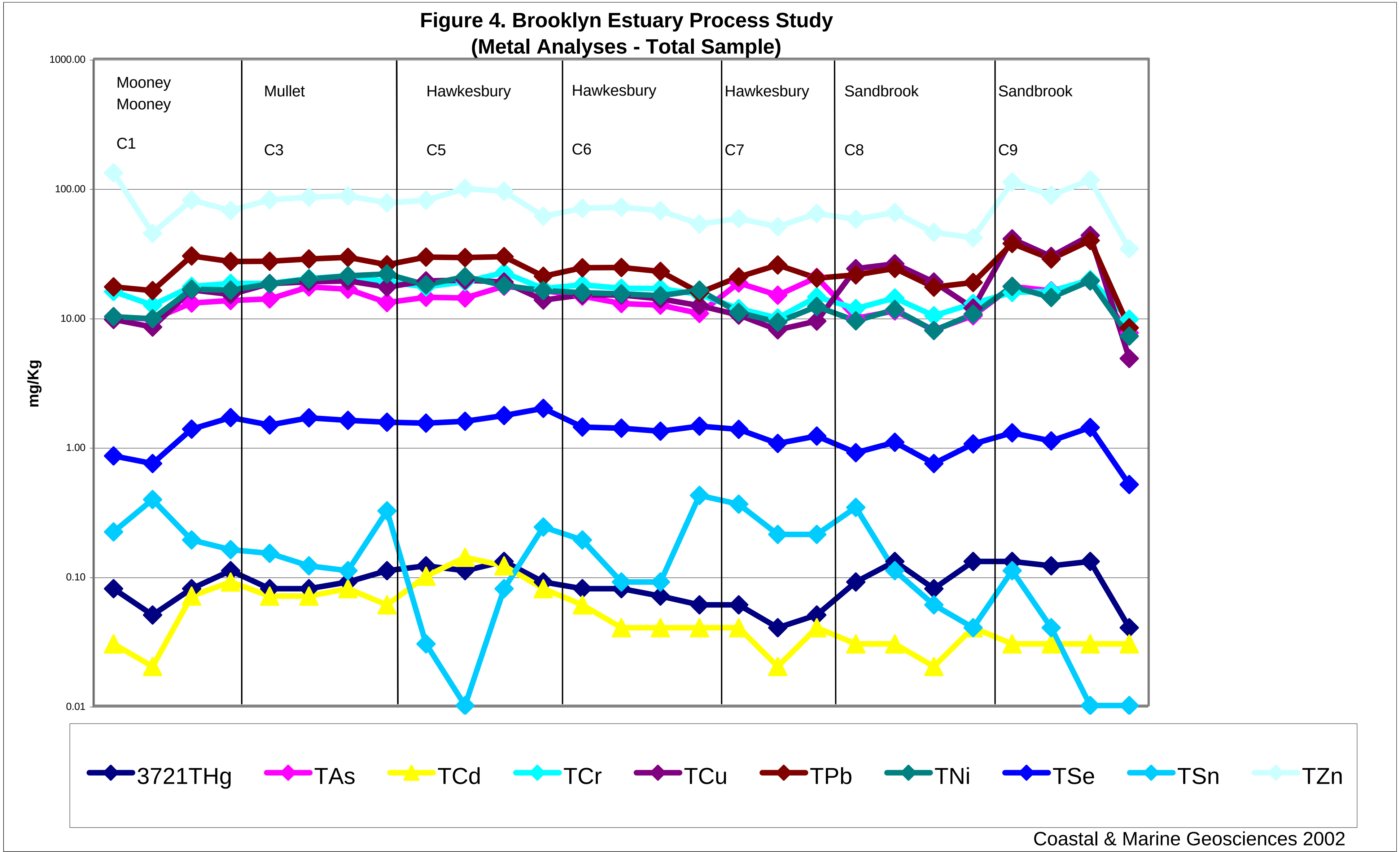

Figure 4. Brooklyn Estuary Process Study
(Metal Analyses - Total Sample)
mg/Kg
1000.00
100.00
10.00
1.00
0.10
0.01
Mooney Mooney
C1
Mullet
C3
Hawkesbury
C5
Hawkesbury
C6
Hawkesbury
C7
Sandbrook
C8
Sandbrook
C9
3721THg
TAs
TCd
TCr
TCu
TPb
TNi
TSe
TSn
TZn
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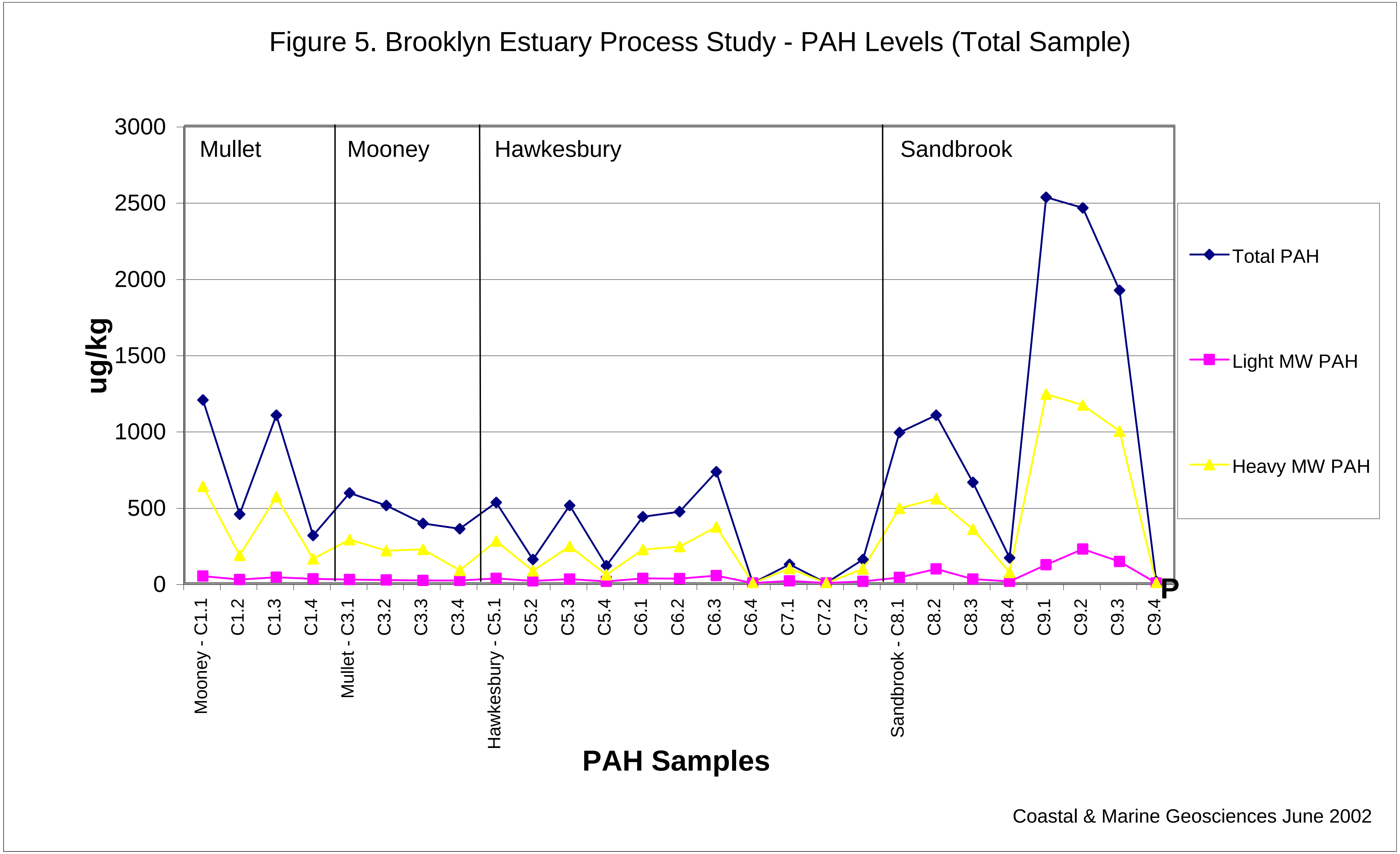
Figure 5. Brooklyn Estuary Process Study - PAH Levels (Total Sample)
ug/kg
3000
2500
2000
1500
1000
500
0
Mullet
Mooney
Hawkesbury
Sandbrook
Total PAH
Light MW PAH
Heavy MW PAH
Mooney - C1.1
C1.2
C1.3
C1.4
Mullet - C3.1
C3.2
C3.3
C3.4
Hawkesbury - C5.1
C5.2
C5.3
C5.4
C6.1
C6.2
C6.3
C6.4
C7.1
C7.2
C7.3
Sandbrook - C8.1
C8.2
C8.3
C8.4
C9.1
C9.2
C9.3
C9.4
P
PAH Samples
Coastal & Marine Geosciences June 2002

TABLE 1: Brooklyn Estuary Process Study Core Samples - Grainsize, Total Organic Carbon and Nutrient Values (Total Sample)

Sample ID	Client Sample ID	Date Sampled	Site	Water Depth m Approximate	Depth Interval (m)	Environment	<0.063mm %	>0.063mm %	>2.0mm %	moisture % wt/wt	TOC %	TKN mg/kg	TN %	3363TP mg/kg
202023250	Mooney - C1.1	5/04/2002	1 - Mooney Mooney Ck	5	0.0 - 0.05	Mud Basin	45.0	55.0	0.00	41.9	1.44	726	0.10	402
202023251	C1.2	5/04/2002	1 - Mooney Mooney Ck	5	0.0 - 0.05	Mud Basin	49.2	50.8	0.00	41.9	1.36	664	0.11	443
202023252	C1.3	5/04/2002	1 - Mooney Mooney Ck	5	0.0 - 0.05	Mud Basin	91.0	8.97	0.00	61.2	3.08	1660	0.20	685
202023253	C1.4	5/04/2002	1 - Mooney Mooney Ck	5	1.05 -1.10	Mud Basin	97.0	3.04	0.00	56.9	4.86	2210	0.25	475
202023254	Mullet - C3.1	5/04/2002	3 - Mullet Ck	7	0.0 - 0.05	Mud Basin	99.7	0.28	0.00	74.2	2.77	2010	0.21	752
202023255	C3.2	5/04/2002	3 - Mullet Ck	7	0.0 - 0.05	Mud Basin	99.3	0.68	0.00	72.6	2.83	1580	0.21	**831**
202023256	C3.3	5/04/2002	3 - Mullet Ck	7	0.0 - 0.05	Mud Basin	99.6	0.42	0.00	71.4	2.78	1360	0.21	**842**
202023257	C3.4	5/04/2002	3 - Mullet Ck	7	1.25 - 1.30	Mud Basin	99.7	0.27	0.00	64.7	2.40	1270	0.17	696
202023258	Hawkesbury - C5.1	5/04/2002	5 - Hawkesbury R (Spectacle Is)	1	0.0 - 0.05	Fluvial Channel	91.8	8.16	0.00	56.9	4.12	2110	0.24	495
202023259	C5.2	5/04/2002	5 - Hawkesbury R (Spectacle Is)	1	0.0 - 0.05	Fluvial Channel	89.9	9.01	1.12	42.6	3.90	1480	0.20	541
202023260	C5.3	5/04/2002	5 - Hawkesbury R (Spectacle Is)	1	0.0 - 0.05	Fluvial Channel	93.2	6.76	0.00	59.1	4.27	1690	0.24	572
202023261	C5.4	5/04/2002	5 - Hawkesbury R (Spectacle Is)	1	0.75 - 0.80	Fluvial Channel	51.3	18.0	30.7	40.1	3.26	1450	0.19	504
202023262	Hawkesbury - C6.1	5/04/2002	6 - Hawkesbury R	6	0.0 - 0.05	Fluvial Channel	82.2	17.8	0.00	53.7	2.74	1670	0.17	618
202023263	C6.2	5/04/2002	6 - Hawkesbury R	6	0.0 - 0.05	Fluvial Channel	75.8	24.2	0.00	50.5	2.50	875	0.16	537
202023264	C6.3	5/04/2002	6 - Hawkesbury R	6	0.0 - 0.05	Fluvial Channel	76.7	23.3	0.00	52.4	2.66	906	0.16	526
202023265	C6.4	5/04/2002	6 - Hawkesbury R	6	1.05 - 1.11	Fluvial Channel	86.6	13.4	0.00	40.4	2.47	1010	0.15	439
202023266	Hawkesbury - C7.1	5/04/2002	7 - Hawkesbury R (Dangar Is)	1	0.0 - 0.05	Mud Basin	29.3	47.9	22.8	34.5	2.49	911	0.11	502
202023267	C7.2	5/04/2002	7 - Hawkesbury R (Dangar Is)	1	0.0 - 0.05	Mud Basin	22.5	53.1	24.4	33.7	1.61	782	0.09	405
202023268	C7.3	5/04/2002	7 - Hawkesbury R (Dangar Is)	1	0.0 - 0.05	Mud Basin	31.1	68.9	0.00	38.9	1.67	922	0.10	546
202023269	Sandbrook - C8.1	5/04/2002	8 - Sandbrook Inlet	1	0.0 - 0.05	Mud Basin	40.4	59.6	0.00	42.6	1.81	710	0.12	403
202023270	C8.2	5/04/2002	8 - Sandbrook Inlet	1	0.0 - 0.05	Mud Basin	50.8	49.2	0.00	40.1	2.17	884	0.14	414
202023271	C8.3	5/04/2002	8 - Sandbrook Inlet	1	0.0 - 0.05	Mud Basin	31.3	68.7	0.00	35.3	1.38	800	0.10	341
202023272	C8.4	5/04/2002	8 - Sandbrook Inlet	1	0.85 - 0.95	Mud Basin	34.0	63.6	2.42	32.8	2.71	994	0.10	291
202023273	Sandbrook - C9.1	5/04/2002	9 - Sandbrook Inlet	1	0.0 - 0.05	Mud Basin	94.2	5.76	0.00	62.6	2.65	1600	0.20	**803**
202023274	C9.2	5/04/2002	9 - Sandbrook Inlet	1	0.0 - 0.05	Mud Basin	70.6	29.4	0.00	58.4	1.80	1100	0.14	550
202023275	C9.3	5/04/2002	9 - Sandbrook Inlet	1	0.0 - 0.05	Mud Basin	97.8	2.24	0.00	65.2	2.66	1500	0.20	**821**
202023276	C9.4	5/04/2002	9 - Sandbrook Inlet	1	0.85 - 0.90	Mud Basin	14.6	85.4	0.00	22.2	0.51	392	0.04	212

TABLE 2: Brooklyn Estuary Process Study Core Samples

Sample ID	Client Sample ID	Site	Depth Interval (m)	<0.063mm %	moisture % wt/wt	TOC %	3721THg mg/kg	TAs mg/kg	TCd mg/kg	TCr mg/kg	TCu mg/kg	TPb mg/kg	TNi mg/kg	TSe mg/kg	TSn mg/kg	TZn mg/kg
202023250	Mooney - C1.1	1 - Mooney Mooney Ck	0.0 - 0.05	45.0	41.9	1.44	0.08	10.1	0.03	15.8	9.62	17.2	10.1	0.85	0.22	131
202023251	C1.2	1 - Mooney Mooney Ck	0.0 - 0.05	49.2	41.9	1.36	0.05	9.65	0.02	12.4	8.42	16.1	9.76	0.74	0.39	44.5
202023252	C1.3	1 - Mooney Mooney Ck	0.0 - 0.05	91.0	61.2	3.08	0.08	12.9	0.07	17.3	16.3	29.8	16.5	1.37	0.19	80.6
202023253	C1.4	1 - Mooney Mooney Ck	1.05 -1.10	97.0	56.9	4.86	0.11	13.5	0.09	18.3	15.0	27.0	16.2	1.68	0.16	66.9
202023254	Mullet - C3.1	3 - Mullet Ck	0.0 - 0.05	99.7	74.2	2.77	0.08	13.9	0.07	18.3	18.2	27.1	18.1	1.47	0.15	80.8
202023255	C3.2	3 - Mullet Ck	0.0 - 0.05	99.3	72.6	2.83	0.08	17.2	0.07	19.9	18.8	28.2	19.8	1.67	0.12	85.0
202023256	C3.3	3 - Mullet Ck	0.0 - 0.05	99.6	71.4	2.78	0.09	16.5	0.08	20.9	19.1	29.1	20.9	1.60	0.11	86.7
202023257	C3.4	3 - Mullet Ck	1.25 - 1.30	99.7	64.7	2.40	0.11	13.0	0.06	18.8	17.1	25.5	21.6	1.55	0.32	76.7
202023258	Hawkesbury - C5.1	5 - Hawkesbury R (Spectacle Is)	0.0 - 0.05	91.8	56.9	4.12	0.12	14.3	0.10	17.2	19.1	29.2	17.8	1.52	0.03	80.1
202023259	C5.2	5 - Hawkesbury R (Spectacle Is)	0.0 - 0.05	89.9	42.6	3.90	0.11	14.1	0.14	18.8	19.4	29.0	20.6	1.57	0.01	99.0
202023260	C5.3	5 - Hawkesbury R (Spectacle Is)	0.0 - 0.05	93.2	59.1	4.27	0.13	17.4	0.12	22.2	18.7	29.4	17.6	1.74	0.08	94.0
202023261	C5.4	5 - Hawkesbury R (Spectacle Is)	0.75 - 0.80	51.3	40.1	3.26	0.09	16.1	0.08	16.7	13.6	20.8	16.1	1.98	0.24	60.5
202023262	Hawkesbury - C6.1	6 - Hawkesbury R	0.0 - 0.05	82.2	53.7	2.74	0.08	14.6	0.06	17.8	14.9	24.2	15.5	1.42	0.19	69.4
202023263	C6.2	6 - Hawkesbury R	0.0 - 0.05	75.8	50.5	2.50	0.08	12.8	0.04	16.8	14.9	24.3	15.2	1.39	0.09	70.8
202023264	C6.3	6 - Hawkesbury R	0.0 - 0.05	76.7	52.4	2.66	0.07	12.4	0.04	16.7	13.9	22.6	14.7	1.32	0.09	66.8
202023265	C6.4	6 - Hawkesbury R	1.05 - 1.11	86.6	40.4	2.47	0.06	10.7	0.04	15.0	12.3	15.5	16.2	1.44	0.42	52.6
202023266	Hawkesbury - C7.1	7 - Hawkesbury R (Dangar Is)	0.0 - 0.05	29.3	34.5	2.49	0.06	18.4	0.04	11.7	10.4	20.5	10.9	1.36	0.36	57.9
202023267	C7.2	7 - Hawkesbury R (Dangar Is)	0.0 - 0.05	22.5	33.7	1.61	0.04	14.8	0.02	9.86	7.99	25.4	9.16	1.06	0.21	50.2
202023268	C7.3	7 - Hawkesbury R (Dangar Is)	0.0 - 0.05	31.1	38.9	1.67	0.05	20.3	0.04	14.4	9.34	20.1	12.1	1.21	0.21	63.6
202023269	Sandbrook - C8.1	8 - Sandbrook Inlet	0.0 - 0.05	40.4	42.6	1.81	0.09	9.81	0.03	11.7	23.8	21.3	9.40	0.90	0.34	57.3
202023270	C8.2	8 - Sandbrook Inlet	0.0 - 0.05	50.8	40.1	2.17	0.13	11.2	0.03	14.1	25.9	23.9	11.5	1.08	0.11	64.5
202023271	C8.3	8 - Sandbrook Inlet	0.0 - 0.05	31.3	35.3	1.38	0.08	7.97	0.02	10.3	18.7	17.1	7.90	0.74	0.06	45.3
202023272	C8.4	8 - Sandbrook Inlet	0.85 - 0.95	34.0	32.8	2.71	0.13	10.3	0.04	12.8	11.8	18.6	10.6	1.05	0.04	41.3
202023273	Sandbrook - C9.1	9 - Sandbrook Inlet	0.0 - 0.05	94.2	62.6	2.65	0.13	17.3	0.03	15.6	40.4	37.2	17.3	1.28	0.11	111
202023274	C9.2	9 - Sandbrook Inlet	0.0 - 0.05	70.6	58.4	1.80	0.12	16.0	0.03	15.9	29.6	28.2	14.2	1.11	0.04	87.9
202023275	C9.3	9 - Sandbrook Inlet	0.0 - 0.05	97.8	65.2	2.66	0.13	19.1	0.03	19.5	42.9	39.2	19.1	1.41	0.01	115
202023276	C9.4	9 - Sandbrook Inlet	0.85 - 0.90	14.6	22.2	0.51	0.04	7.60	0.03	9.65	4.80	8.31	7.16	0.51	0.01	33.8

TABLE 3: Brooklyn Estuary Process Study Core Samples - PAH (Total Sample)

Sample ID	Client Sample ID	Site	Depth Interval (m)	<0.063mm %	moisture % wt/wt	TOC %	PAH ug/kg	AcNapthy ug/kg	Acenten ug/kg	Anthrac ug/kg	B(A)Ant ug/kg	B(A)Pyr ug/kg	B(B)Flu ug/kg	B(E)Pyr ug/kg	B(GHI)P ug/kg	B(K)Flu ug/kg	Chrysen ug/kg	D(AH)an ug/kg	Fluoran ug/kg	Fluoren ug/kg	I-123CD ug/kg	Naphtha ug/kg	Perylene ug/kg	Phenant ug/kg	Pyrene ug/kg
202023250	Mooney - C1.1	1 - Mooney Mooney Ck	0.0 - 0.05	45.0	41.9	1.44	1200	<10	<10	<10	85	110	109	75	117	90	107	<10	159	<10	101	<10	33	45	173
202023251	C1.2	1 - Mooney Mooney Ck	0.0 - 0.05	49.2	41.9	1.36	451	<10	<10	<10	<10	52	56	37	56	43	52	<10	<10	<10	55	<10	<10	22	78
202023252	C1.3	1 - Mooney Mooney Ck	0.0 - 0.05	91.0	61.2	3.08	1100	<10	<10	<10	79	96	100	69	104	83	96	<10	137	<10	102	<10	44	38	157
202023253	C1.4	1 - Mooney Mooney Ck	1.05 -1.10	97.0	56.9	4.86	312	<10	<10	<10	19	<10	23	18	33	21	24	<10	57	<10	30	<10	<10	28	59
202023254	Mullet - C3.1	3 - Mullet Ck	0.0 - 0.05	99.7	74.2	2.77	590	<10	<10	<10	<10	59	59	45	67	49	56	<10	80	<10	63	<10	<10	23	89
202023255	C3.2	3 - Mullet Ck	0.0 - 0.05	99.3	72.6	2.83	509	<10	<10	<10	<10	<10	55	40	60	50	52	<10	71	<10	57	<10	15	20	89
202023256	C3.3	3 - Mullet Ck	0.0 - 0.05	99.6	71.4	2.78	391	<10	<10	<10	31	39	43	28	<10	33	38	<10	53	<10	39	<10	11	16	60
202023257	C3.4	3 - Mullet Ck	1.25 - 1.30	99.7	64.7	2.40	356	<10	<10	<10	<10	<10	19	16	<10	16	18	<10	27	<10	17	<10	88	16	39
202023258	Hawkesbury - C5.1	5 - Hawkesbury R (Spectacle Is)	0.0 - 0.05	91.8	56.9	4.12	529	<10	<10	<10	42	<10	42	32	48	42	48	<10	83	<10	41	<10	19	30	102
202023259	C5.2	5 - Hawkesbury R (Spectacle Is)	0.0 - 0.05	89.9	42.6	3.90	155	<10	<10	<10	<10	<10	16	13	<10	17	18	<10	27	<10	16	<10	<10	13	35
202023260	C5.3	5 - Hawkesbury R (Spectacle Is)	0.0 - 0.05	93.2	59.1	4.27	509	<10	<10	<10	<10	33	46	44	49	43	43	<10	79	<10	42	<10	19	25	86
202023261	C5.4	5 - Hawkesbury R (Spectacle Is)	0.75 - 0.80	51.3	40.1	3.26	113	<10	<10	<10	<10	<10	12	10	<10	13	13	<10	18	<10	12	<10	<10	11	24
202023262	Hawkesbury - C6.1	6 - Hawkesbury R	0.0 - 0.05	82.2	53.7	2.74	435	<10	<10	<10	37	<10	39	26	37	33	40	<10	69	<10	34	<10	16	30	74
202023263	C6.2	6 - Hawkesbury R	0.0 - 0.05	75.8	50.5	2.50	467	<10	<10	<10	40	<10	39	30	40	34	43	<10	75	<10	39	<10	17	29	81
202023264	C6.3	6 - Hawkesbury R	0.0 - 0.05	76.7	52.4	2.66	730	<10	<10	<10	60	<10	62	45	60	58	69	<10	116	<10	59	<10	29	49	123
202023265	C6.4	6 - Hawkesbury R	1.05 - 1.11	86.6	40.4	2.47	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
202023266	Hawkesbury - C7.1	7 - Hawkesbury R (Dangar Is)	0.0 - 0.05	29.3	34.5	2.49	122	<10	<10	<10	13	<10	<10	<10	<10	<10	17	<10	33	<10	13	<10	<10	14	32
202023267	C7.2	7 - Hawkesbury R (Dangar Is)	0.0 - 0.05	22.5	33.7	1.61	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10
202023268	C7.3	7 - Hawkesbury R (Dangar Is)	0.0 - 0.05	31.1	38.9	1.67	154	<10	<10	<10	18	<10	20	14	<10	<10	24	<10	24	<10	16	<10	<10	11	27
202023269	Sandbrook - C8.1	8 - Sandbrook Inlet	0.0 - 0.05	40.4	42.6	1.81	987	<10	<10	<10	<10	100	103	69	93	81	97	15	129	<10	87	<10	26	37	150
202023270	C8.2	8 - Sandbrook Inlet	0.0 - 0.05	50.8	40.1	2.17	1100	<10	<10	12	<10	105	101	69	94	83	93	<10	173	<10	86	<10	26	80	182
202023271	C8.3	8 - Sandbrook Inlet	0.0 - 0.05	31.3	35.3	1.38	660	<10	<10	<10	<10	113	62	42	58	51	59	<10	87	<10	53	<10	17	25	93
202023272	C8.4	8 - Sandbrook Inlet	0.85 - 0.95	34.0	32.8	2.71	165	<10	<10	<10	<10	<10	17	13	22	15	15	<10	24	<10	18	<10	<10	11	30
202023273	Sandbrook - C9.1	9 - Sandbrook Inlet	0.0 - 0.05	94.2	62.6	2.65	2530	20	<10	16	<10	247	258	189	234	211	229	43	350	<10	217	<10	64	84	369
202023274	C9.2	9 - Sandbrook Inlet	0.0 - 0.05	70.6	58.4	1.80	2460	19	<10	20	<10	225	231	167	209	203	220	40	338	<10	204	<10	54	183	344
202023275	C9.3	9 - Sandbrook Inlet	0.0 - 0.05	97.8	65.2	2.66	1920	15	<10	17	<10	174	183	115	153	146	176	27	318	<10	147	<10	40	109	301
202023276	C9.4	9 - Sandbrook Inlet	0.85 - 0.90	14.6	22.2	0.51	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10	<10

Appendix D

Baseline Survey of the Benthic Invertebrate Assemblages Associated with Fringing Mangroves in the Brooklyn Region of the Hawkesbury River

APPENDIX D- BASELINE SURVEY OF THE BENTHIC INVERTEBRATE ASSEMBLAGES ASSOCIATED WITH FRINGING MANGROVES IN THE BROOKLYN REGION OF THE HAWKESBURY RIVER

CONTENTS

EXECUTIVE SUMMARY

Baseline data on the benthic invertebrate assemblages associated with the low-shore area of fringing mangrove forests in the Brooklyn region of the Hawkesbury River were collected as part of the Brooklyn Estuary Processes Study. Samples collected from two locations in the poorly flushed Sandbrook Inlet were compared with those from two reference locations, Mooney Mooney Point and Mullet Creek, adjacent to the main channel of the river. To ensure that variability among locations was not obscured by smaller-scale variability within locations, two sites were sampled at each location. Previous studies around Sydney have shown that mangrove forests in poorly flushed areas support fewer invertebrates than do well-flushed locations. It was therefore predicted that assemblages in the inlet would differ from those near the main channel. Univariate and multivariate statistical procedures were used to test this hypothesis.

Significant differences in the invertebrate assemblages were evident both among and within locations. The assemblage at the eastern end of Sandbrook Inlet differed from that at the western end and both of these differed from those at the reference locations. There was, however, no evidence to suggest that the assemblages in the Inlet were depauperate relative to the reference locations. The univariate analyses showed that nereid worms were more abundant at the two locations in Sandbrook Inlet than at the reference locations, but sabellid worms and oligochaetes were only more abundant at the eastern end of the Inlet.

Because assemblages of benthic invertebrates are known to exhibit considerable short- and long-term temporal variability, these results can not be regarded as definitive, or as representative. Also, the spatial differences observed cannot be attributed to any particular cause, because a number of different natural and anthropogenic factors determine the abundance of benthic invertebrates. To gain a better understanding of these invertebrate assemblages and the factors that control them, a sampling programme must be designed with adequate small- and large-scale temporal and spatial replication. Appropriate experiments are also needed to understand any of the processes causing and maintaining differences between Sandbrook Inlet and elsewhere.

INTRODUCTION

Many invertebrate animals, particularly crustaceans, molluscs and polychaete worms, live on or in the sandy and muddy sediments of estuaries. These are called benthic invertebrates and they have considerable effects on the structure of the sediment. Many of them disturb and loosen the sediment whilst burrowing. Others are responsible either for binding sediment particles together or for re-working the sediments (Kennish, 1990; Little, 2000). The activities of these animals also affect the chemistry of sediments, particularly the concentration of oxygen, organic content and recycling of nutrients. Benthic invertebrates also play an important role in estuarine food-webs, because they are a major source of food for various other animals, including commercially important crustaceans and fish.

A number of physico-chemical and biological factors are known to influence the distribution and abundance of invertebrates in estuarine sediments. The major physical factors are salinity, type and size composition of particles in sediments, depth of water, wave-action, currents and turbidity of the overlying water. The responses of animals to these physical variables are modified by biological factors such as food-supply, competition for food and space, behaviour and the presence of predators (Kennish, 1990). The distribution and abundance of benthic invertebrates is also influenced by natural disturbances such as periodic flooding and cyclones and by human-mediated disturbances, such as coastal developments, disposal of dredged material and other solid wastes, discharge of wastewaters, manipulation of the hydrological cycle, tidal modification, recreation, fisheries, aquaculture and the introduction of alien species (GESAMP, 1990). Changes in the composition of soft-bottom macrofaunal assemblages (groups of animals larger than 0.5 mm in size found living together in muddy, sandy or silty habitats) are, in fact, often used to detect the impact of human activities on marine environments. This is because these benthic assemblages are relatively easy to sample quantitatively, their constituents can be identified fairly easily, their responses to disturbances are better known than for some other biological groupings and, because many of them are sedentary, they can be used to study the localized effects of disturbances (Warwick, 1993).

Populations of benthic invertebrates in estuaries often exhibit large temporal and spatial variations in abundance (see Kennish, 1990 for review). The only reports, to date, of temporal and spatial patterns in the macrobenthic communities of the Hawkesbury River estuary are restricted to sublittoral assemblages (Jones et al., 1986; Jones, 1987). Several studies, however, have been done on the life-history and biology of individual species in this estuary system (Jones et al., 1988), their responses to toxic substances (Hyne and Everitt, 1998; MacFarlane et al., 2000) and the effects of natural and anthropogenic disturbances on assemblages (Jones et al., 1986; Jones, 1990; Underwood and Anderson, 1997).

OBJECTIVE OF THIS STUDY

The sampling outlined below was designed to obtain baseline data on the benthic invertebrate assemblages associated with mangrove forests in the Brooklyn region of the Hawkesbury River. Because fringing mangroves were more common in the general study area than extensive mangrove forests, the former were sampled. Samples collected from two locations in Sandbrook Inlet, an area that is poorly flushed due to the blockage of the eastern end of the inlet by the railway causeway, were compared with those from two reference locations adjacent to the main channel of the Hawkesbury river. As previous studies around Sydney have indicated that mangrove forests which are not regularly flushed by water support less invertebrates than do well-flushed locations (Chapman and Underwood, 1996a, 1996b), it was hypothesized that assemblages in the inlet would differ from those at the reference locations.

One-off baseline studies of this type have very serious limitations. They can only provide a brief indication of the current status of the assemblage. To understand ecological processes and the impact of various anthropogenic disturbances, a comprehensive description of the temporal and spatial patterns of variability in assemblages and manipulative experiments are needed (Green, 1979; Underwood, 1992, 1994).

MATERIALS AND METHODS

The methods used in this study are based on techniques used successfully in projects examining invertebrate assemblages in mangrove forests in the Sydney region (Chapman and Underwood, 1996a, 1996b; Chapman et al., 1997; Kelaher et al., 1998).

Study sites

Four locations in the Brooklyn region of the Hawkesbury River were sampled: Location 1 was near the Hawkesbury River railway station at the eastern end of Sandbrook Inlet. Location 2 was towards the western end of Long Island facing into the Inlet. Location 3 was opposite Spectacle Island just to the north of Mooney Mooney Point. Location 4 was in the second embayment inside Mullet Creek (Fig. 1). Locations 3 and 4 are Reference Locations; these are needed to test the hypothesis that patterns in assemblages in Sandbrook Inlet would differ from those occurring typically in the main part of the river. At each location, five replicate 0.1 m^2 quadrats were collected from the low-shore area of two sites, situated approximately 30 metres apart. This resulted in a total of 40 sample units (i.e. 4 areas X 2 sites X 5 replicate quadrats). This sampling design enabled any differences in assemblages to be identified at a range of spatial scales: among quadrats metres apart, between sites tens of metres apart and among locations hundreds to thousands of metres apart. Sampling at these different spatial scales is needed to ensure that variability among locations is not obscured by smaller-scale variability within locations (Morrisey et al., 1992a). This is essential because previous studies have shown that the benthic assemblages associated with mangrove forests in Port Jackson are very variable and differ significantly from place to place (Chapman and Underwood, 1996a).

The numbers of mangrove saplings, pneumatophores and large, conspicuous epifauna (e.g. mussels, oysters and gastropod snails) in each quadrat were recorded and the percentage cover of leaf-litter, algae and oysters measured under a grid of 100 points. The leaf-litter and sediment in each quadrat were then collected to a depth of 1 - 2 cm and returned to the laboratory. These variables were measured because previous studies have shown that the biological structure of the habitat (e.g. presence of more/fewer pneumatophores, more/less leaf litter, more/less epiphytic algae) influences the density and diversity of crabs and molluscs (Kelaher et al., 1998; Skilleter and Warren, 2000).

Laboratory work (sorting and identification of invertebrates)

Samples were preserved in 7% formalin. The material collected from each quadrat was subsequently divided into a coarse (> 1 mm) and fine (> 500 µm but < than 1 mm) component by sieving through a 1 mm mesh sieve and then through a 500 µm mesh sieve. The coarse component was sorted using a magnifying lamp and the fine component was sorted under a dissecting microscope. The invertebrates found in each component were removed, identified and counted. Relatively little is known about the taxonomy of some groups of animals, particularly nematode and nemertean worms. Many species have not been described so the taxonomic level to which the invertebrates were identified varied among taxa. Animals in samples from Brooklyn were identified as in other successful projects in mangroves around Sydney. The levels of identification for the more common taxa were: molluscs and crabs to species, amphipods and isopods to species or morphospecies, polychaetes to family, oligochaetes to class, nemerteans and nematodes to phylum and other less common taxa to appropriate levels. Several researchers have shown that it is not necessary to identify animals to species to detect differences in assemblages among locations (Warwick, 1988; Olsgard et al., 1997; Chapman, 1998).

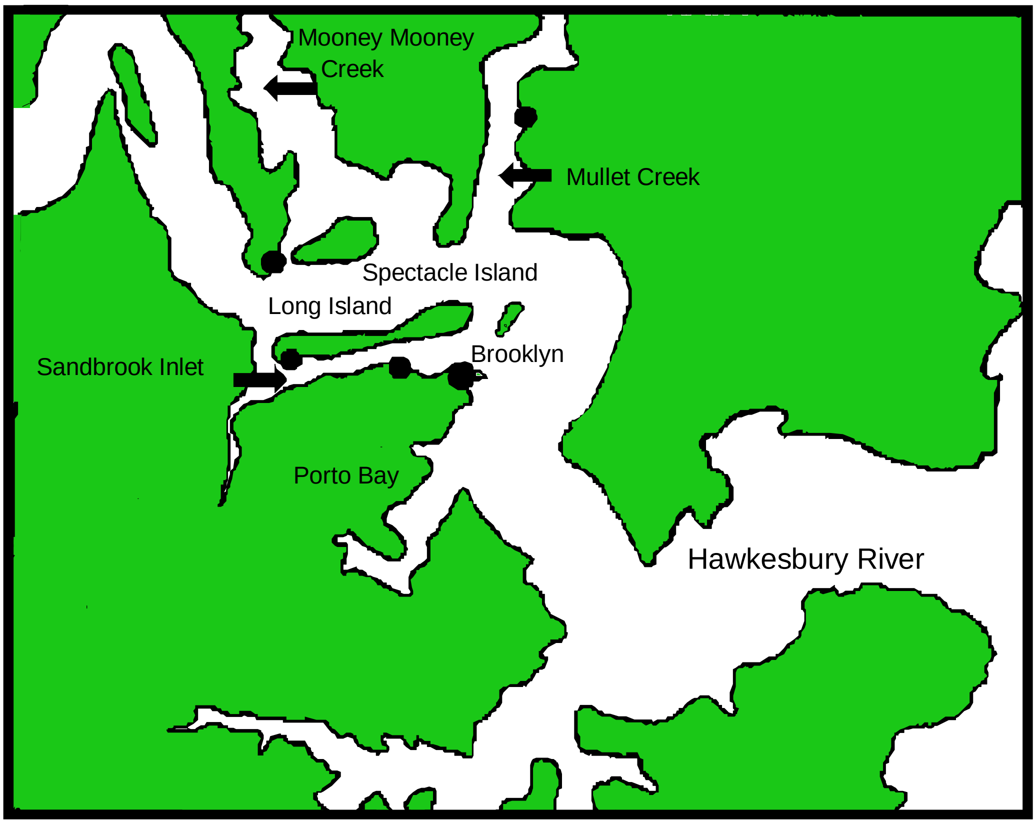

Figure 1. Map showing the locations sampled in the Brooklyn region of the Hawkesbury River.

Statistical analyses

The data consist of numbers of individuals in each taxonomic group in each of the 40 quadrats. These were analysed by univariate and multivariate statistical procedures. Univariate analyses tested specific hypotheses about differences in the total number of various types of animals and the abundances of specific taxonomic groups among and within locations. Multivariate analyses tested hypotheses about the overall structure of the assemblage of benthic invertebrates.

Univariate methods

Nested analyses of variance were used to compare the total number of different types of invertebrate taxa in addition to the abundances of selected individual taxa among quadrats, between sites and among locations (Underwood, 1997). We used an asymmetrical design to compare each of the locations in Sandbrook Inlet with the two reference locations. Similar analyses were done on the numbers of mangrove saplings and pneumatophores and on the percentage covers of leaf-litter, algae and oysters. Where necessary, data were transformed before analysis to remove heterogeneity of variances.

Multivariate comparisons

The difference in taxonomic composition and relative abundances of the taxa in each pair of samples was estimated by calculating their respective Bray-Curtis dissimilarity coefficients. Variability between samples and differences among locations were examined using a non-parametric nested analysis, NPMANOVA (Anderson, 2001). Dissimilarity among samples was presented graphically, using non-metric multidimensional scaling (nMDS). This makes a map of the samples so that samples with similar assemblages are closer together on the map than ones with more different mixtures of species (Clarke, 1993). SIMPER was used to identify taxa which characterized each location and to identify those that contributed to the dissimilarities among assemblages in different places (Clarke, 1993).

RESULTS

The various different kinds of animals (taxa) found in the samples collected from the four localities at Brooklyn are listed in Table 1. A total of 51 taxa representing 5 phyla were found in the samples. The most abundant groups of animals found at Brooklyn were oligochaetes, nephythidae, nereidae, sabellidae, insect larvae and amphipod 3 (see groups highlighted by asterisks in Table 1). These six groups accounted for 84 % of the total number of animals collected.

Table 1. Taxa found in samples of sediment collected from the four localities in the Brooklyn region of the Hawkesbury River (* indicates the most abundant groups).

Phylum	Class	Order	Family	Species
Nematoda				
Nemertea				
Annelida	Oligochaeta *			
	Polychaeta		Arabellidae	
			Capitellidae	
			Magelonidae	
			Nephtyidae *	
			Nereididae *	
			Opheliidae	
			Orbiniidae	
			Oweniidae	
			Sabellidae *	
			Spionidae	
Mollusca	Bivalvia *			*Arthritica helmsi*
				Saccostrea commercialis
				Soletellina donacioides
				Xenostrobus securis
				Spisula (Notospisula) trigonella
				Unidentifiable bivalve
				Bivalve 27
	Gastropoda			*Ascorhis victoriae*
				Bembicium auratum
				Bembicium nanum
				Tatea huonensis
				Gastropod 26
				Patelloida mimulus
				Salinator fragilis
Arthropoda	Collembola			
	Insecta			Unidentified adults
				Unidentified larvae *
(Crustacea)	Copepoda			
	Malacostraca	Tanaidacea		
		Isopoda		Isopod 5
				Isopod 8
				Isopod 10
				Isopod 14
				Isopod 13
		Amphipoda		Amphipod 7
				Amphipod 3 *
				Amphipod 4
				Amphipod 21
				Amphipod 18
				Amphipod 42
				Amphipod 1
				Unidentified amphipod
		Decapoda		*Heloecius cordiformis*
				Paragrapsus laevis
				Sesarma erythrodactyla
				Macrophthalmus sp
				Brachyuran megalopa
				Juvenile Crab

Multivariate analyses

The symbols representing the assemblages from one of the sites at the western end of Sandbrook Inlet form a distinct, but loosely clustered group at the top of the nMDS plot (Figure 2). The cluster of symbols in the bottom half of the left-hand side of the nMDS represent the assemblages from the two sites at the eastern end of Sandbrook Inlet. The dense grouping of symbols on the right-hand side of the nMDS represents the assemblages sampled at the sites in the two reference locations and the other site at the western end of Sandbrook Inlet. This pattern suggests that three distinct benthic assemblages exist at Brooklyn.

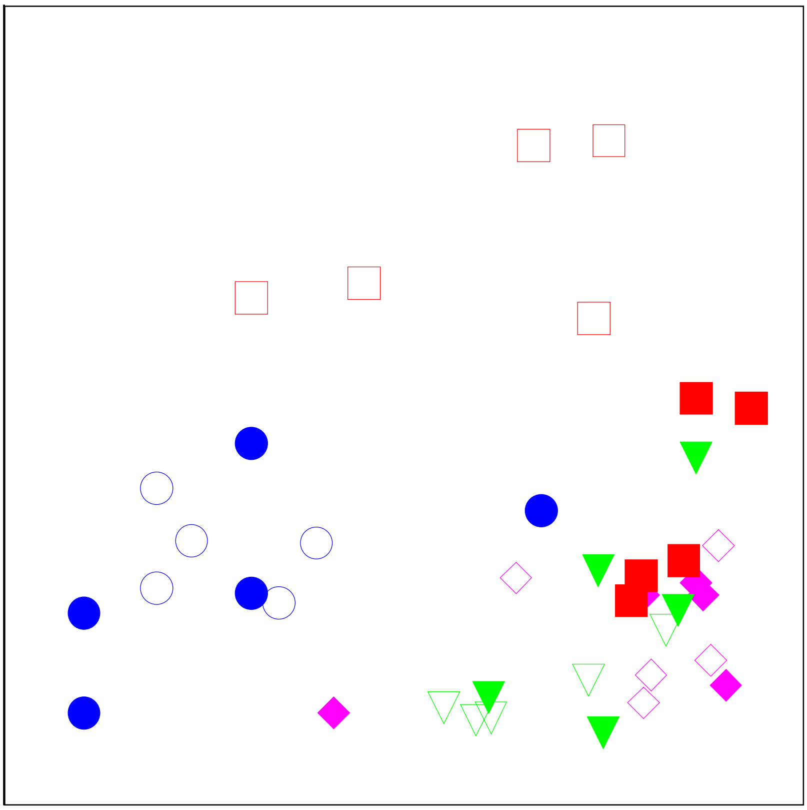

Figure 2. nMDS plot representing spatial differences in the benthic invertebrate assemblages at four localities around Brooklyn (●, sites at the eastern end of Sandbrook Inlet; ■, sites at the western end of Sandbrook Inlet; ▼, the reference sites at Mooney-Mooney Creek, ◆, the reference sites at Mullet Creek; filled symbols represent quadrats at site 1 and empty symbols quadrats at site 2; stress value = 0.13).

There were significant differences in the structure of assemblages among locations and between sites within locations (NPMANOVA; Table 2). Pair-wise *a posteriori* comparisons indicated that the structure of the assemblages at the eastern end of Sandbrook Inlet was significantly different from that at the three other locations and that the assemblages at the two sites sampled at the western end of Sandbrook Inlet differed.

Table 2. NPMANOVA of Bray-Curtis dissimilarities for the benthic macrofaunal assemblages at Brooklyn (d.f., degrees of freedom; SS, sum of squares; MS, mean squares; F, F-ratio; P, probability level, T, T-statistic).

Source of variation	d.f.	SS	MS	F	P
Location	3	38634.57	12878.19	4.36	<0.001***
Sites(location)	4	11817.52	2954.38	2.07	0.001**
Residual	32	45581.91	1424.43		
Total	39	96034.00			

Comparison	T	P
East vs West Sandbrook	1.93	0.002 **
East Sandbrook vs Mooney-Mooney	3.66	<0.001 ***
East Sandbrook vs Mullet Creek	5.25	<.0001 ***
West Sandbrook vs Mooney-Mooney	1.31	0.15
West Sandbrook vs Mullet Creek	1.34	0.13
Mooney-Mooney vs Mullet Creek	1.64	0.09
Between sites at East Sandbrook	0.74	0.80
Between sites at West Sandbrook	2.09	0.009 **
Between sites at Mooney-Mooney	1.367	0.13
Between sites at Mullet Creek	0.751	0.77

Each location was characterized by a different group of animals and more types of animals contributed to the average similarity in the assemblage at the locations in Sandbrook Inlet than at the reference locations (Table 3). Nereids, oligochaetes, crab-holes, sabellids and amphipod 3 were the major taxa characterizing the assemblage (i.e. those contributing >5% to the average measure of similarity) at the eastern end of Sandbrook Inlet. Crab-holes, nephtyids, owenids and the gastropod *Bembicium auratum* characterized the assemblage at the western end of the Inlet. The assemblage at Mooney Mooney was characterized by crab-holes, nephtyids and insect larvae and that at Mullet Creek by crab-holes.

Table 3. Major taxa that characterized the assemblages in each location. Only taxa contributing >1 % to the average similarity measure are shown.

Taxon	Eastern end of Sandbrook Inlet	Western end of Sandbrook Inlet	Mooney Mooney Creek	Mullet Creek
Oligochaeta *	25.4			
Capitellidae		1.2		
Magelonidae		1.0		
Nephtyidae *		9.3	26.7	2.6
Nereididae *	30.4	1.6		
Oweniidae		8.0		
Sabellidae *	12.6	2.7		
Spionidae		1.0		
Saccostrea commercialis				2.5
Bembicium auratum		7.1		1.6
Insect larvae	6.4	1.9	4.8	
Tanaidacea	1.1		2.5	
Amphipod 7		1.0		
Amphipod 3 *	9.3			
Crab holes	13.6	61.7	60.8	90.1

Average measures of dissimilarity showed that the variability in assemblages was generally smaller in a location than between locations except at the western end of Sandbrook Inlet (Table 4). Assemblages at site 1 at the eastern end of Sandbrook Inlet and at site 2 at the western end of Sandbrook Inlet were more variable than at the other sites (Table 5). There was also more variability in the assemblages from site to site at the western end of Sandbrook Inlet than between sites at the other locations.

Table 4. Average measures of the dissimilarity in benthic assemblages within and between locations sampled at Brooklyn.

Comparison	% Dissimilarity
Within East Sandbrook	51
Within West Sandbrook	70
Within Mooney-Mooney	47
Within Mullet Creek	45
East Sandbrook vs West Sandbrook	83
East Sandbrook vs Mooney-Mooney	78
East Sandbrook vs Mullet Creek	79
West Sandbrook vs Mooney-Mooney	69
West Sandbrook vs Mullet Creek	68
Mooney-Mooney vs Mullet Creek	51

Table 5. Average measures of dissimilarity in benthic assemblages among replicate quadrats within and between the sites in each location.

Location	Site	% Dissimilarity within each site	% Dissimilarity between sites
East Sandbrook	1	62	50
	2	42	
West Sandbrook	1	49	79
	2	69	
Mooney Mooney	1	50	48
	2	40	
Mullet Creek	1	49	44
	2	42	

There was, an average, 80% dissimilarity between the assemblages at east Sandbrook Inlet and those at the three other locations (SIMPER analysis). The major contributors to this dissimilarity were, in order of importance: oligochaetes, nereids, sabellids, crab-holes and amphipod 3. Oligochaetes and nereids were forty times more abundant and sabellids and amphipod 3 four times more abundant, on average, at east Sandbrook Inlet (Table 6). The major contributors to the dissimilarity in the assemblages at sites in the western end of Sandbrook Inlet were, in order of importance: crab-holes, oweniids, sabellids, nephthyids and the oyster *Saccostrea commercialis* (Table 7). Crab-holes, nephtyids and oysters were all more abundant at the first site.

Table 6. SIMPER analyses comparing the structure of the assemblages at the eastern end of Sandbrook Inlet with those in the three other locations at Brooklyn.

Taxa	Average density at east Sandbrook Inlet	Average density at the other locations	Average dissimilarity	Cumulative % contribution to total dissimilarity
Oligochaetes	62.8	1.3	17.2	21.6
Nereidae	44.0	0.7	15.7	41.2
Sabellidae	51.5	11.2	13.4	57.9
Crab holes	16.2	35.2	9.4	69.7
Amphipod 3	15.2	3.7	5.7	76.9
Nephtyidae	0.0	14.1	4.9	82.9
Insect larvae	11.1	4.3	4.0	87.9

Table 7. Results of similarity percentages (SIMPER) analysis comparing the structure of the assemblages at the two sites at the western end of Sandbrook Inlet.

Taxa	Average density at site 1	Average density at site 2	Average dissimilarity	Cumulative % contribution to total dissimilarity
Crab holes	28.2	6.4	20.0	25.2
Oweniidae	0.4	12.4	11.6	39.8
Sabellidae	0.0	11.8	10.0	52.4
Nephtyidae	6.0	3.9	5.6	59.5
Saccostrea commercialis	5.0	1.0	4.1	64.7
Bembicium auratum	1.2	3.4	3.6	69.2
Nereidae	1.2	2.2	2.7	72.6
Oligochaeta	0.2	2.1	2.3	75.5

Univariate analyses

The total number of animals and the numbers of nereid, sabellid and oligochaete worms at the eastern end of Sandbrook Inlet were significantly more abundant than at the two reference sites averaged together (Table 8 and Fig. 3) The numbers of pneumatophores and nereid worms at the western end of Sandbrook Inlet were significantly more abundant than at the two reference sites (Table 8 and Fig. 3). Crab-holes were less abundant. There was also a marked difference in the number of crab-holes at the two sites sampled at the western end of Sandbrook Inlet.

Table 8. Probabilities of differences in asymmetrical analyses of variance of numbers of various types of animals in: (a) sites at the eastern and (b) the western end of Sandbrook Inlet versus the average at the two Reference locations ((I vs C), impacted vs controls; (c1 vs c2, control 1 vs control 2).

(a)	Source of variation					
Variable	**Location**	**Lo(I vs C)**	**Lo(c1 vs c2)**	**Site(location)**	**Si(I)**	**Si(c1 vs c2)**
Volume of mud	ns	ns	ns	ns	*	ns
Pneumatophores	*	*	*	ns	ns	ns
No. of crab-holes	**	***	*	ns	ns	ns
Amphipod 3	ns	ns	ns	*	ns	*
Insect larvae	*	*	*	ns	ns	ns
Nephtys	ns	ns	ns	*	ns	*
Nereids	***	***	ns	ns	ns	ns
Oligochaetes	**	***	ns	ns	ns	ns
Sabellids	*	*	ns	ns	ns	ns
Total # of species	ns	ns	ns	ns	ns	ns
Total # of animals	ns	*	ns	ns	ns	ns

(b)	Source of variation					
Variable	**Location**	**Lo(I vs C)**	**Lo(c1 vs c2)**	**Site(location)**	**Si(I vs C)**	**Si(c1 vs c2)**
Volume of mud	ns	ns	ns	ns	ns	ns
Pneumatophores	0.06	*	ns	nz	ns	ns
No. of crab-holes	nz	*	nz	ns	*	ns
Amphipod 3	nz	nz	nz	*	ns	**
Insect larvae	*	*	*	ns	ns	ns
Nephtys	nz	nz	nz	*	ns	*
Nereids	ns	*	ns	ns	ns	ns
Oligochaetes	ns	ns	ns	ns	ns	ns
Sabellids	ns	ns	ns	ns	ns	ns
Total # of species	ns	ns	ns	ns	ns	ns
Total # of animals	ns	ns	ns	ns	ns	ns

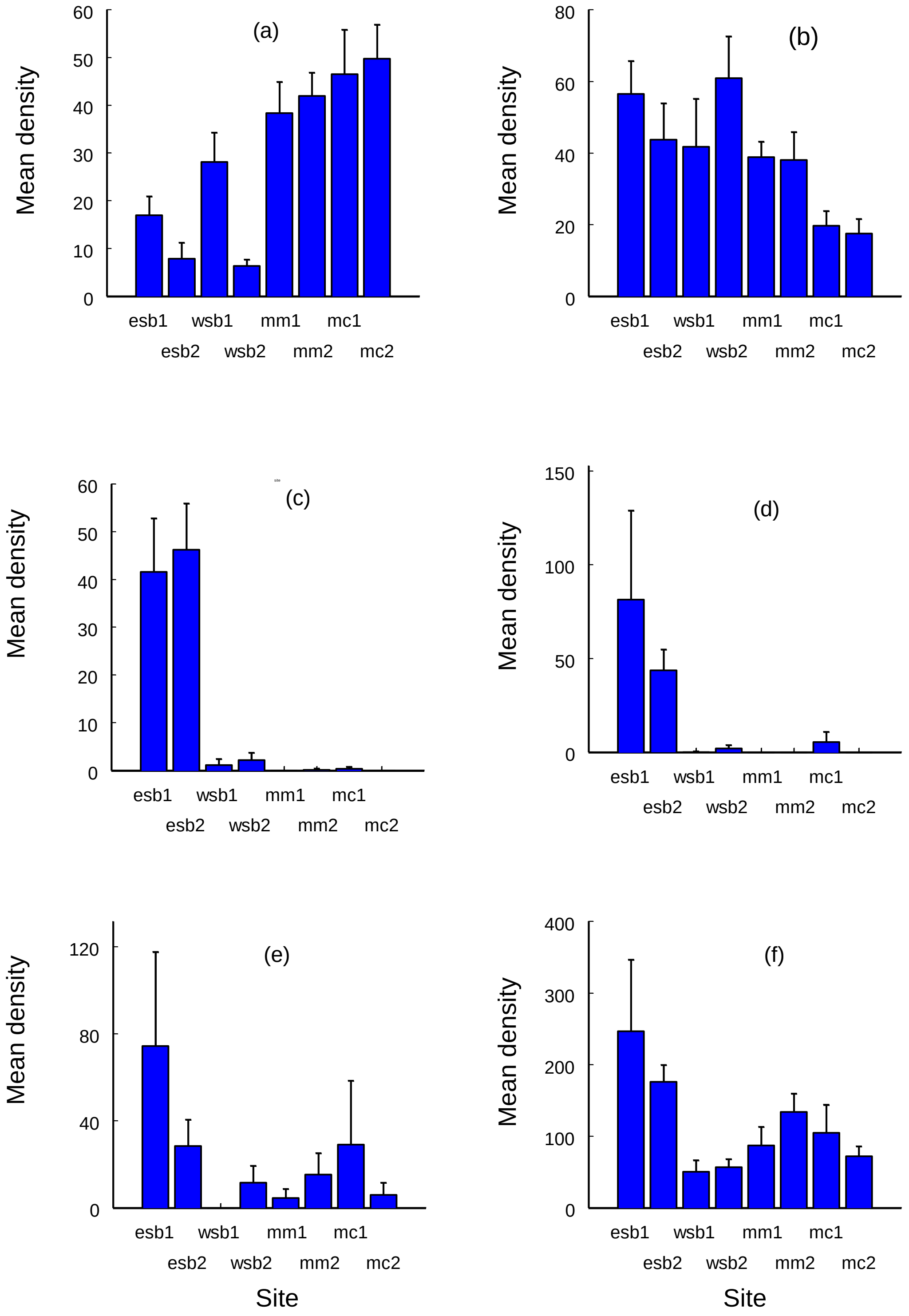

Figure 3: Mean (±SE) numbers of (a) crab holes, (b) pneumatophores, (c) nereids, (d) oligochaetes, (e) sabellids and (f) total animals found at each site in each location (esb, eastern end of Sandbrook Inlet; wsb, western end of Sandbrook Inlet; mm, Mooney Mooney Creek; mc, Mullet Creek; 1 and 2, sites 1 and 2, respectively).

DISCUSSION

Assemblages of benthic invertebrates in fringing mangroves in the Brooklyn region of the Hawkesbury River were very variable and differed significantly at both spatial scales examined. There were apparently three distinct benthic assemblages. The assemblage at the eastern end of Sandbrook Inlet differed from that at one of the sites at the western end of the Inlet and both of these differed from those at the two reference locations. The abundances of some of the dominant taxa were different, making these assemblages different. Some of the dominant taxa were significantly more abundant at the locations in Sandbrook Inlet than at the two reference locations. Only one group of animals, nereid worms, showed a similar trend, being more abundant at both locations in the Inlet. Sabellids and oligochaetes were more abundant at the eastern end of the Inlet, whereas pneumatophores were more abundant at the western end of the Inlet than at the reference sites.

Previous studies on benthic assemblages in soft-sediment habitats have shown that spatial patterns are not consistent over either short- or long-term temporal scales (Warwick and Uncles, 1980; Livingston 1987; Morrisey et al., 1992b). Temporal patterns also vary with spatial scale (Morrisey et al. 1992a), so the present results should not be regarded as definitive. Significant seasonal and annual differences in the number of species, number of individuals and identity of dominant species have, in fact, been reported in the subtidal macrobenthos found in the lower, mid and upper reaches of the Hawkesbury estuary (Jones 1987). Jones (1987) also noted that differences varied among sites and that seasonal differences were not the same from year to year. Sampling which incorporates small- and large-scale temporal and spatial replication is needed to gain a better understanding of the variability in assemblages (Underwood 1994).

The differences in benthic macrofauna observed here cannot be attributed to any particular cause because a number of different natural and anthropogenic factors are known to influence the abundance and distribution of benthic fauna. To understand the processes responsible for the observed patterns, it is necessary to predict how these factors, both singly and in combination, influence the structure of assemblages or abundances of taxa and to then design appropriate manipulative experiments to test these hypotheses (Underwood and Chapman 1985). Few manipulative studies have been done in mangrove habitats generally and none in the present study area. It is therefore only possible to speculate about factors that might affect benthic assemblages at Brooklyn. One possibility is that some of the differences in fauna among locations are due to differences in biogenic structure of the mangrove habitat. Our knowledge of the effects of biogenic features, such as oyster shells, crab-holes pneumatophores and their associated epiphytic algae, on benthic organisms is, at present, restricted to crabs and molluscs (Warren and Underwood 1987; Underwood and Barrett 1990; Skilleter and Warren 2000). Previous studies around Sydney have suggested that poorly flushed wetlands support fewer species than well-flushed areas (Berents 1993; The Ecology Lab 1994; Chapman and Underwood 1996). Here, the supposedly less flushed locations in Sandbrook Inlet supported similar numbers of taxa to the reference locations.

If Hornsby Shire Council goes ahead with its plan to increase the flushing of water though the causeway, they must implement a well-replicated before and after sampling programme to establish whether their managerial decision have the claimed beneficial effects on benthic assemblages in Sandbrook Inlet.

CONCLUSIONS

The assemblages of benthic invertebrates in the fringing mangroves in the Brooklyn region of the Hawkesbury River differed significantly both among and within locations. Although the assemblages in Sandbrook Inlet differed from those at the two reference locations, there was no evidence to suggest that they were depauperate, as is the case in other poorly-flushed mangrove forests in the Sydney region. Further studies are needed to gain a better understanding of the temporal and spatial variability of these assemblages and the factors that control them.

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APPENDIX 1 – RESULTS OF ASYMMETRICAL ANALYSES OF VARIANCE

A1.1. Volume of mud (untransformed data; Cochran's C = 0.29 and 0.40 respectively)

(esb, eastern end of Sandbrook Inlet; Ref1 and Ref 2, reference locations 1 and 2, wbs, western end of Sandbrook Inlet; df, degrees of freedom; MS, mean squares, F, F-ratio; P, probability level)

		esb vs Ref 1 & Ref 2			wsb vs Ref 1 & Ref 2		
Source of variation	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**
Location	2	0.77	0.25	0.79	1.33	5.29	0.10
Location(I vs C)	1	0.24	0.08	0.80	1.36	5.41	0.10
Location(c1 vs c2)	1	1.30	0.43	0.56	1.30	5.18	0.11
Site(Location)	3	3.05	2.15	0.12	0.25	0.18	0.91
Site(I)	1	8.59	6.06	0.02	0.21	0.15	0.70
Site(c1 vs c2)	2	0.27	0.19	0.83	0.27	0.20	0.82
Residual	24	1.42			1.39		
Total	29						

A1.2. Pneumatophores (untransformed data; Cochran's C = 0.54 and 0.42 respectively)

		esb vs Ref 1 & Ref 2			wsb vs Ref 1 & Ref 2		
Source of variation	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**
Location	2	2538.03	17.99	0.02	2715.23	8.71	0.06
Location(I vs C)	1	3096.02	21.94	0.02	3450.42	11.07	0.04
Location(c1 vs c2)	1	1980.05	14.03	0.03	1980.05	6.35	0.09
Site(Location)	3	141.10	0.57	0.64	311.77	0.89	0.46
Site(I)	1	409.60	1.66	0.21	921.60	2.62	0.12
Site(c1 vs c2)	2	6.85	0.03	0.97	6.85	0.02	0.98
Residual	24	246.62			352.07		
Total	29						

A1.3. Crab holes (untransformed data; Cochran's C = 0.43 and 0.36 respectively)

		esb vs Ref 1 & Ref 2			wsb vs Ref 1 & Ref 2		
Source of variation	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**
Location(I vs C)	1	5226.67	243.48	0.00	4824.07	11.61	0.04
Location(c1 vs c2)	1	320.00	14.91	0.03	320.00	0.77	0.44
Site(Location)	3	21.47	0.11	0.95	415.37	2.09	0.13
Site(I)	1	6.40	0.03	0.86	1188.10	5.97	0.02
Site(c1 vs c2)	2	29.00	0.15	0.86	29.00	0.15	0.87
Residual	24	188.93			198.97		
Total	29						

A1.4. Amphipod 3 (ln(x+1) data; Cochran's C = 0.34 and 0.46 respectively)

		esb vs Ref 1 & Ref 2			wsb vs Ref 1 & Ref 2		
Source of variation	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**
Location	2	8.34	2.50	0.23	4.36	1.39	0.37
Location(I vs C)	1	14.94	4.48	0.12	6.98	2.22	0.23
Location(c1 vs c2)	1	1.75	0.52	0.52	1.75	0.56	0.51
Site(Location)	3	3.33	3.54	0.03	3.15	4.48	0.01
Site(I)	1	0.55	0.59	0.45	0.00	0.00	1.00
Site(c1 vs c2)	2	4.72	5.01	0.02	4.72	6.73	0.00
Residual	24	0.94			0.70		
Total	29						

A1.5. Insect larvae (ln(x+1) data; Cochran's C = 0.34 and 0.46 respectively)

		esb vs Ref 1 & Ref 2			wsb vs Ref 1 & Ref 2		
Source of variation	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**
Location	2	6.39	12.25	0.04	4.55	13.93	0.03
Location(I vs C)	1	6.81	13.06	0.04	3.14	9.61	0.05
Location(c1 vs c2)	1	5.96	11.43	0.04	5.96	18.24	0.02
Site(Location)	3	0.52	0.46	0.71	0.33	0.32	0.81
Site(I)	1	0.97	0.86	0.36	0.39	0.38	0.54
Site(c1 vs c2)	2	0.30	0.26	0.77	0.30	0.29	0.75
Residual	24	1.13			1.02		
Total	29						

A1.6. Nephthyids (untransformed data; Cochran's C = 0.39 and 0.37 respectively)

		esb vs Ref 1 & Ref 2			wsb vs Ref 1 & Ref 2		
Source of variation	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**
Location	2	2485.39	4.39	0.13	1952.65	3.42	0.17
Location(I vs C)	1	2319.65	4.09	0.14	1254.16	2.20	0.23
Location(c1 vs c2)	1	2651.14	4.68	0.12	2651.14	4.65	0.12
Site(Location)	3	566.61	3.59	0.03	570.37	3.36	0.04
Site(I)	1	0.00	0.00	1.00	11.29	0.07	0.80
Site(c1 vs c2)	2	849.92	5.39	0.01	849.92	5.00	0.02
Residual	24	157.81			169.86		
Total	29						

A1.7. Nereids (untransformed data; Cochran's C = 0.57 and 0.80 respectively)

		esb vs Ref 1 & Ref 2			wsb vs Ref 1 & Ref 2		
Source of variation	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**
Location	2	6400.67	350.47	0.00	8.03	8.03	0.06
Location(I vs C)	1	12801.28	700.94	0.00	16.02	16.02	0.03
Location(c1 vs c2)	1	0.05	0.00	0.96	0.05	0.05	0.84
Site(Location)	3	18.26	0.10	0.96	1.00	0.31	0.82
Site(I)	1	54.29	0.30	0.59	2.50	0.77	0.39
Site(c1 vs c2)	2	0.25	0.00	1.00	0.25	0.08	0.93
Residual	24	181.47			3.23		
Total	29						

A1.8. Oligochaetes (ln(x+1) data; Cochran's C = 0.46 and 0.67 respectively)

		esb vs Ref 1 & Ref 2			wsb vs Ref 1 & Ref 2		
Source of variation	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**
Location	2	40.7915	109.58	0.0016	0.4464	0.76	0.5393
Location(I vs C)	1	81.0254	217.6932	0.000675	0.3352	0.573678	0.503861
Location(c1 vs c2)	1	0.5576	1.498119	0.308319	0.5576	0.954304	0.400671
Site(Location)	3	0.3722	0.46	0.7127	0.5843	1.05	0.3892
Site(I)	1	0.0016	0.001978	0.964896	0.6379	1.144626	0.295319
Site(c1 vs c2)	2	0.5576	0.689246	0.511617	0.5576	1.000538	0.382507
Residual	24	0.809			0.5573		
Total	29						

A1.9. Sabellids (ln(x+1) data; Cochran's C = 0.28 and 0.41 respectively)

		esb vs Ref 1 & Ref 2			wsb vs Ref 1 & Ref 2		
Source of variation	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**
Location	2	12.36	15.79	0.03	0.59	0.18	0.84
Location(I vs C)	1	24.07	30.77	0.01	0.54	0.17	0.71
Location(c1 vs c2)	1	0.64	0.82	0.43	0.64	0.20	0.69
Site(Location)	3	0.78	0.26	0.85	3.21	1.34	0.28
Site(I)	1	0.02	0.01	0.93	7.31	3.05	0.09
Site(c1 vs c2)	2	1.16	0.39	0.68	1.16	0.49	0.62
Residual	24	2.98			2.39		
Total	29						

Total number of taxa (untransformed data; Cochran's C = 0.47 and 0.40 respectively)

		esb vs Ref 1 & Ref 2			wsb vs Ref 1 & Ref 2		
Source of variation	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**
Location	2	39.43	3.73	0.15	34.53	4.18	0.14
Location(I vs C)	1	45.07	4.26	0.13	35.27	4.27	0.13
Location(c1 vs c2)	1	33.80	3.20	0.17	33.80	4.09	0.14
Site(Location)	3	10.57	1.56	0.22	8.27	0.75	0.53
Site(I)	1	16.90	2.50	0.13	10.00	0.90	0.35
Site(c1 vs c2)	2	7.40	1.09	0.35	7.40	0.67	0.52
Residual	24	6.77			11.07		
Total	29						

Total number of animals (ln(x+1) data; Cochran's C = 0.39 and 0.35 respectively)

		esb vs Ref 1 & Ref 2			wsb vs Ref 1 & Ref 2		
Source of variation	**df**	**MS**	**F**	**P**	**MS**	**F**	**P**
Location	2	1.77	6.21	0.09	1.31	3.98	0.14
Location(I vs C)	1	3.28	11.54	0.04	2.38	7.19	0.07
Location(c1 vs c2)	1	0.25	0.89	0.42	0.25	0.77	0.45
Site(Location)	3	0.28	0.70	0.56	0.33	0.86	0.47
Site(I)	1	0.00	0.00	0.97	0.14	0.36	0.55
Site(c1 vs c2)	2	0.43	1.04	0.37	0.43	1.12	0.34
Residual	24	0.41			0.38		
Total	29						

Appendix E

Specialist Report on Aquatic Ecology

Report to:

Water Research Laboratory

Brooklyn Estuary Processes Study

Specialist Report on Aquatic Ecology

FINAL

October 2003

Report prepared by:

The Ecology Lab Pty Ltd

The Ecology Lab Pty Ltd Marine and Freshwater Studies

Brooklyn Estuary Processes Study
Specialist Report on Aquatic Ecology

October 2003

Report Prepared for:

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Table of Contents

SUMMARY

Hornsby Shire Council commissioned a team of environmental scientists to undertake the Brooklyn Estuary Process Study. The team was lead by the Water Research Laboratory in conjunction with Manly Hydraulics Laboratory, The Ecology Lab Pty Ltd, Coastal and Marine Geosciences and the Centre for Research on Ecological Impacts of Coastal Cities (EICC). The Ecology Lab and the EICC undertook the study of aquatic ecological processes.

Issues outlined by The Brooklyn Estuary Management Committee requiring special management consideration included: threats to the aquaculture and fishing industries, impacts of the rail causeway on tidal flushing in Sandbrook Inlet and maintaining the ecological quality of the waterway.

This report presents the findings from The Ecology Lab study of aquatic ecological components and processes in the Brooklyn area. Existing information on riparian and aquatic flora, fauna, and fisheries relevant to the study were summarised and assessed. The studies included a qualitative habitat assessment of the Brooklyn area, a quantitative intertidal survey of macrofauna and flora, quantitative sampling of fish and macroinvertebrates and a study of bioaccumulation in oysters.

Habitat assessment of mangrove, seagrass, saltmarsh and riparian vegetation was compiled using observations made in the field. Assemblages of intertidal invertebrates and algae were sampled at two heights along either side of the causeway. Small demersal fish and invertebrates were sampled at several locations in the estuary on two occasions. Concentrations of heavy metals and polycyclic aromatic hydrocarbons (PAHs) were measured in oysters collected from several locations on two occasions.

Zostera capricorni was the dominant seagrass species in the Brooklyn area, although *Halophila* sp. was also present. Comparisons of various maps indicate that seagrass beds in Mullet Creek and Brooklyn Harbour have increased while beds in Sandbrook Inlet and on the south side of Dangar Island have remained unchanged. Mangrove forests were dominated by *Avicennia marina* and have either increased or remained unchanged since the construction of the freeway. It was not possible to quantify any changes in saltmarsh vegetation.

The Hawkesbury River fishery is the 4^{th} largest estuarine fishery in NSW and has remained stable for many years. The lower Hawkesbury River is the second largest oyster producing area in NSW and more than half of the farmers operate in the Brooklyn area. Oyster production peaked most recently in 1997/1998 and has remained stable in recent years. Since 1989 there has been a State ban on the use of TBT for antifouling vessels smaller than 25 m in length. TBT can concentrate in molluscs up to 250,000 times higher than surrounding sediments or seawater. Affected molluscs such as oysters have deformed shells, slow growth rates and poor reproduction. Since the ban was introduced, it can be expected that concentrations of TBT in Sandbrook Inlet and Brooklyn Harbour have reduced significantly.

Numbers and types of intertidal invertebrates observed either side of the causeway differed significantly. All the species observed are typical of intertidal estuarine shores. A number of factors including reduced tidal flushing in Sandbrook Inlet compared with Brooklyn Harbour could explain observed differences.

The assemblage of demersal fish and mobile invertebrates sampled in Sandbrook Inlet were similar to those sampled in other parts of Brooklyn estuary. Therefore, reduced tidal

flushing in Sandbrook Inlet does not affect the type of demersal fish species and their abundances.

The study of bioaccumulation in wild oysters found significantly greater concentrations of arsenic, copper and zinc in Brooklyn Harbour and selenium and copper in Sandbrook Inlet compared to Mooney Mooney Creek and Mullet Creek, while PAHs were not detected in the study area. Potential sources of heavy metals in the study area could include boat maintenance activities, point source pollution and road and rail runoff. Copper and arsenic concentrations in oysters from Sandbrook Inlet and Brooklyn Harbour exceeded maximum ANZFA food standards.

It is likely that environmental threats to aquaculture have decreased since TBT was banned. While no significant environmental threats to the estuary fishery were detected in this study, it is likely that fishing and possibly assemblages of economically important fishes would have been previously affected by changes to habitat, boating activities and fishing pressure. The reduced tidal flushing in Sandbrook Inlet could increase the residence time of pollutants within the inlet. The proximity of Sandbrook Inlet and Brooklyn Harbour to the Brooklyn urban area and associated roads and railways could explain the higher concentrations of heavy metals detected in oysters. The area of wetland vegetation has remained constant or shown some increase in different parts of the study area, suggesting that the habitats are being maintained.

1.0 INTRODUCTION

1.1 Study Background and Aims

A team of environmental scientists was commissioned by Hornsby Shire Council to undertake the Brooklyn Estuary Process Study. The team was lead by Water Research Laboratory (WRL) in conjunction with Manly Hydraulics Laboratory, The Ecology Lab Pty Ltd, The Centre for Research on Ecological Impacts of Coastal Cities (EICC), and Coastal and Marine Geosciences. The EICC studied macroinvertebrates within mangrove habitats; The Ecology Lab focussed on habitat mapping, fish and oyster bioaccumulation issues.

The Hawkesbury–Nepean River system, which is located in the west and north of Sydney drains a large catchment of approximately 22,000 km^2. The study area, as defined in the study brief, extends from downstream of the freeway-bridge to an imaginary line from Parsley Bay to Croppy Point, Hawkesbury River. It encompasses the waterbody and its interacting catchment areas including Sandbrook Inlet, Mullet Creek and Mooney Mooney Creek.

The Brooklyn Estuary Management Committee has identified several issues relating to aquatic ecological processes that may pose a threat to the environmental, social and economic values and community expectations for the estuary. The key issues were:

- Aquaculture and fishing - industry impacts and threats (eg. acid sulfate runoff, biotoxins),
- Impacts of the rail causeway on tidal flushing in Sandbrook Inlet,
- Maintaining the ecological quality of the waterway including benthic diversity and aquatic habitat protection (e.g. seagrasses, mangroves, saltmarsh, and associated biota),
- Protection of high conservation areas such as hanging swamps, pristine creeks, fish spawning sites and habitats,
- Protection of fish habitats and fisheries resources.

To address these issues, The Ecology Lab undertook field, laboratory and desktop studies in collaboration with the Centre for Studies of Ecological Impacts of Cities at the University of Sydney.

The scope of works undertaken by The Ecology Lab included:

1. Summarise and assess existing information on riparian and aquatic flora and fauna and fisheries relevant to the study. This was done using topographic maps and recent aerial photographs supplied by the client, recent maps of aquatic habitats (e.g. West *et al.*, 1985) and more recent data on macrophytes collected by NSW Fisheries. Information was sourced from our own extensive library, Hornsby Council's resources, relevant government departments and agencies (e.g. NSW EPA, DLWC, NPWS and The Australian Museum), published and unpublished reports and relevant research done at Universities and research centers. This summarised information served as a basis for refining field investigations.
2. Undertake field studies:
   - *Qualitative habitat assessment of the Brooklyn area*. Data collected on aquatic habitats including flora (seagrass, saltmarsh and mangrove) and fauna (fish and mobile

invertebrates) were mapped using GIS and combined with existing information to assess the extent of changes to habitats.

- *Quantitative intertidal survey of macrofauna and flora.* An intertidal survey of the biota either side of the rail causeway was commissioned as part of the Brooklyn Rail Upgrade EIS and was included in this report as additional information.
- *Quantitative survey of benthic macrofauna associated with fringing mangroves.* The Centre for Research on Ecological Impacts of Coastal Cities (EICC) undertook a baseline survey of the benthic invertebrate assemblages using samples collected with hand-held cores in the Brooklyn region of the Hawkesbury River.
- *Quantitative sampling of fish and macroinvertebrates.* Basic information on the patterns of distribution and abundance of fish and invertebrates, especially those of economic significance that utilise intertidal mudflats are not available. The diversity and abundance of fish and mobile invertebrate were examined by sampling using beam trawls. Fish populations and assemblages were analysed to assess their temporal and spatial variation within the estuary. The aim of this component of the study, therefore, was to collect information on fish and invertebrates associated with inundated intertidal mudflats adjacent to mangroves at various locations throughout the Brooklyn study area.
- *Study of heavy metals bioaccumulation in oysters.* The uptake of contaminants by sessile animals was examined through studying the bioaccumulation of heavy metals and Polycyclic Aromatic Hydrocarbons (PAH) in oysters. Resulted were analysed to assess spatial variation within the estuary.

3. Assessment of ecosystem health: compile and summarise the main processes known or predicted to be driving the ecological functions of the Brooklyn area.

This report presents the findings from the three stages of the specialist investigation of aquatic ecological components and processes in Brooklyn area. It describes the principle factors influencing the spatial and temporal variability of aquatic vegetation communities and aquatic fauna communities. Key issues as outlined by The Brooklyn Estuary Management Committee requiring special management consideration were identified and assessed.

1.2 Sources of Information

1.2.1 Riparian and Aquatic Flora

A number of studies have used aerial photographs, field surveys and GPS mapping to provide information on the distribution and abundance of the riparian and aquatic flora of Brooklyn area. These studies have been summarised in Table 1.

1.2.2 Aquatic Fauna

Information on the estuarine fauna of Brooklyn area is extensive but restricted to mangrove habitats, subtidal benthic invertebrates and fish fauna of Sandbrook Inlet. Relevant studies have been summarised in Table 2.

1.2.3 Recreational Fishing

Personal communications with Mr Paul Scheutrumpf of NSW Fisheries, Brooklyn and Mr Gary Henry of NSW Fisheries Cronulla. Publications are also available on fishing within the Hawkesbury River (e.g. Ross 1995, Powell & Powell 2000) were compiled and assessed.

1.2.4 Commercial Fishing

Information on commercial fishing was compiled from recent NSW Fisheries statistics and data provided by Ms Marnie Tanner of NSW Fisheries and discussions with Mr Paul Scheutrumpf NSW Fisheries).

1.2.5 Oyster Farming

A summary of Sydney rock oyster (*Saccostrea commercialis*) farming in Australia is provided in a general review by Nell (1993). His review includes information on the history, geographic distribution, farming techniques, processing and marketing, production trends, diseases, environmental hazards and government regulations associated with oyster farming.

Information on the production of oysters from Brooklyn area was derived from NSW Fisheries reports including: Pease and Grinberg (1995) which includes fisheries data from 1940 to 1992; Scribner and Kathuria (1996) which includes fisheries data for the 1992/93 financial year; and NSW Fisheries oyster production data for the years 1994/5, 1995/96 and 1996/97. Information was also provided by discussions with various local oyster farmers, and Mr Paul Scheutrumpf of NSW Fisheries, Brooklyn.

1.2.6 Pollution and Bioaccumulation

Levels of pollution and bioaccumulation have been sampled in Sandbrook Inlet during several studies, including: sampling of water and sediments in January 1998 in relation to a proposed development at Kangaroo Point, Brooklyn (The Ecology Lab 1998a); heavy metal concentration in sediments of the Hawkesbury River from Windsor to Pittwater in February 1994 (Birch *et al*. 1998); and heavy metal, TBT and DDT accumulation in oysters from the Hawkesbury River and Brisbane Water (Hardiman & Pearson 1995). The Brooklyn EPS assessed sediment contamination levels in the Hawkesbury River channel, Sandbrook Inlet and Mooney Mooney Creek and Mullet Creek tributaries. Recently, both gradient and reference area approaches were used to sample wild oysters from three major estuaries including the Hawkesbury River, their soft tissues analysed for heavy metals, phenols and polycyclic aromatic hydrocarbons (PAHs) (Lincoln Smith & Cooper, in prep.).

1.3 Review of Information

1.3.1 Seagrasses and Algae

Recent research has emphasised the importance of seagrasses to the ecology of shallow estuarine environments (reviewed by Larkum *et al*. 1989). Briefly, seagrasses stabilise sediments (Fonesca *et al.* 1982), provide an important habitat for juvenile fishes and mobile invertebrates, many of which are of commercial or recreational importance (Bell and Pollard

1989) and are significant components in the cycling of nutrients within estuaries (Kenworthy *et al*. 1982).

Eelgrass (*Zostera capricorni*) is the only species of seagrass that has been recorded in Brooklyn area, though West *et al*. (1985) included paddle weed (*Halophila* spp.) only in the key to the map for the study area. Strapweed (*Posidonia australis*) has been recorded recently by Williams & Watford (1999), scattered in beds of the adjacent Cowan Creek catchment. Eelgrass occurs in most estuaries from Tweed River in northern NSW to Womboyn River in the south extending both north and south of the state borders. Strapweed is a southern temperate species in Australia, confined to embayments south of Wallis Lake on the mid north coast of NSW and extending around southern Australia to Shark Bay in the west. In NSW it is generally restricted to sandy and muddy habitats of estuaries and protected embayments and particularly favours hyposaline (marine) conditions, being absent from intermittently open lagoons (McNeil 1997). Paddle weed occurs in a wide range of habitats throughout temperate and tropical Australia (Larkum *et al*. 1989). Species of paddle weed appear to be very seasonal in growth, can grow in very shallow to deep waters, and often occur in small patches and/or at low densities (Larkum *et al*. 1989).

West *et al*. (1985) recorded seagrass beds at the head of Mullet Creek (Figure 1). These were also recorded by Williams & West (2001) (Figure 2), who found additional beds to the east of Kangaroo Point and south of Dangar Island not recorded by West *et al.* (1985). Seagrass beds also occur to the east of the railway causeway between Brooklyn and Long Island (Nexus 2000; SMEC 2000) (Figure 3). These discrepancies in the distribution of seagrass communities recorded in the estuary may have occurred for several reasons. First, seagrass communities may have developed within the estuary during the 16 years of the four studies. Alternatively, aerial photographs through time may have differed in factors such as the time of day, tidal conditions, season, scale, size of the seagrass bed and turbidity of the water.

Using field techniques, The Ecology Lab (1997) estimated the area of seagrass in Sandbrook Inlet to be 0.64 ha consisting of a single bed which was 90 m in diameter, and partially exposed during low tide. This was similar to an estimate of 0.7 ha by Williams & Watford (1999) (Figure 4) using aerial photography.

A seagrasses bed occurs east of the causeway (Figure 3), although the bed does not appear in Williams & Watford (1999), (Figure 4). Analysis of an aerial photograph (Nexus 2000) determined the extent of this bed as 1.7 ha. The bed was mapped in detail by The Ecology Lab (2002) and consisted of *Zostera capricorni* and covers 2.37 ha. The density of shoots of *Zostera* was moderate near the middle of the bed but became sparse closer to the margins. Shoots ranged in length from approximately 10 to 30 cm. Overall, the seagrass appeared "healthy" with a low epiphyte load (i.e filamentous algae and sessile fauna attached to the blades of the shoots). The bed essentially follows the –1.0 m AHD contour and much of the bed occurs within the boundary of oyster lease 123-209 and 123-211 (Figure 23) (The Ecology Lab 2002).

Physical characteristics of the seagrasses have also been recorded for the bed in Sandbrook Inlet (The Ecology Lab 1997). The average shoot length was 21.5 cm, and each plant had an average of 4.3 shoots. Similar findings were reported for other studies in the Sydney region (The Ecology Lab 1994). Seagrass health, as shown by chlorophyll *a* fluorescence, was better in the adjacent Berowra Creek affected by sewage effluent, than the unaffected Cowan Creek to the other side of Brooklyn area (Silberschneider 1997). A possible explanation could be that the effluent provided additional nutrients for seagrass growth.

Six taxa of algae occurring within the intertidal zone have been recorded at three sites at Brooklyn (The Ecology Lab 1988; The Ecology Lab 1997). *Enteromorpha intestinalis* was reported from Kangaroo Point, the mouth of Seymours Creek, and the southwest tip of Long Island. Blue-green algae (no species given), *Bostrychia* sp. and *Caloglossa* sp. were reported from the former two sites, *Catanella* sp. occurred at the former and latter site, and *Cystophora* sp. was reported from the latter site only. They were also reported as being arboreal (i.e. on mangroves) or attached to a hard or mud substratum. The green alga, *E. intestinalis*, has unbranched, hollow, tubular, green fronds, is often found at the edges of fresh water soaks, and can be abundant in polluted areas with high nutrient levels (Edgar 1997). Hutchings *et al*. (1977) also recorded the tufted red alga *Catanella* sp. attached to the pneumatophores of grey mangrove (*Avicennia marina)*. Different epiphytic algal species were also recorded by Silberschneider (1997) in the adjacent Berowra and Cowan Creeks.

1.3.2 Mangroves

Mangroves grow along the shores of many NSW estuaries, with the general exception of those that are intermittently opened and closed (West *et al*. 1985). They often occur seaward of saltmarshes and are subject to regular tidal inundation. They can form dense intertidal forests where sediment builds up to from a thick layer capable of supporting the roots of many large trees. Another common growth form of mangroves is called "fringing mangroves" in which trees grow in narrow bands along the edges of tidal creeks, often one or two trees deep, as seen in the upper sections of Berowra Creek (The Ecology Lab, 1997). The flora of mangroves is limited to the trees themselves and a variety of algae, which provide habitat for fish, crabs, birds and other animals.

Mangroves are thought to contribute significantly to estuarine productivity as well as trap sediment and pollutants (Burchmore *et al.* 1993), acting as sinks for contaminants (Tam & Wong 1995). They also stabilise shorelines from erosion. The plants and animals of mangrove forests are considered to be fundamental to the production and cycling of nutrients within estuaries.

Both grey mangroves (*Avicennia marina*) and river mangroves (*Aegiceras corniculatum*) occur in Brooklyn area (Hutchings *et al*. 1977; The Ecology Lab 1988; 1997; Saintilan 1997; Williams & West 2001) (Plate 2). The grey mangrove is the most common of all mangroves in NSW, occurring in most permanently open estuaries around mainland Australia (Edgar 1997). River mangroves are much less common, and occur further upstream in NSW estuaries from the Queensland border south to Merimbula. Shoot biomass of these species is reported to decline, and root/shoot ratios increase, with increasing substratum salinity in the Hawkesbury River (Saintilan 1997). In addition, a biomass of 40 $kg.m^{-2}$ for grey mangroves in the Hawkesbury River is the highest recorded for temperate mangrove communities (Saintilan 1997).

A survey of the Hawkesbury River by West *et al*. (1985) (Figure 1) estimated mangroves covered almost 11 km^2. The amount of each type of vegetation along major waterways such as the Brooklyn area, however, was not presented. Comparisons with maps produced by Williams & Watford (1999) for Sandbrook Inlet, Spectacle Island and Mooney Mooney Point (Figure 4), and those produced by Williams & West (2001) (Figure 2) for the remainder of the Brooklyn area, allows insight into apparent changes in mangrove distribution.

Sandbrook Inlet has remained relatively unchanged in mangrove distribution for about the last 15 years (compare Figures 1 and 4) (West *et al*. 1985; Williams & Watford 1999), however fairly large mangrove communities have appeared on the west of Spectacle Island and around Mooney Mooney Point. The map produced by Williams & West (2001) (Figure 2) shows that the mangrove stands around Mooney Mooney Point are comprised solely of grey mangroves, but those mapped by West *et al*. (1985) (Figure 1) on Spectacle Island are not apparent, perhaps because of the difference in scales between the two maps. Distributions of mangroves in Mullet and Mooney Mooney Creeks have also remained relatively unchanged (compare Figures 1 and 2) (West *et al*. 1985; Williams & West 2001). A more recent map (Figure 2), however, shows that the mangrove stands at the mouths of those creeks are comprised of grey mangroves, and those upstream have both mangrove species.

Grey and river mangroves occur together in Sandbrook Inlet, with stands varying from between 360 m in width at the mouth of Seymours Creek (Hutchings *et al*. 1977) to individual trees fringing Long Island and other shores within the inlet (The Ecology Lab 1988). Decline in mangrove distribution within the inlet prior to 1985 probably occurred as a result of land reclamation and the construction of the Sydney-Newcastle Freeway, perhaps because siltation led to the 'suffocation' of pneumatophores (Hutchings *et al*. 1977). After completion of the freeway in 1978, mangroves recovered rapidly, and cover is presently at greater levels than recorded previously (The Ecology Lab 1997). The large stand at the mouth of Seymours Creek forms a buffer zone between the creek and the inlet, trapping sediments washed down the creek. It is listed by the National Herbarium as being of 'high conservation value' (Dove *et al*. 1986).

1.3.3 Saltmarsh

Saltmarshes are estuarine habitats that occur high on the shore between the average high water of spring and neap tides. They consist generally of soft sediments occupied by grasses, succulents, herbaceous and rush plants. Saltmarshes are usually waterlogged and frequently flooded during tidal inundation. In NSW, saltmarshes may form zones; the lowest zone is generally occupied by samphire (*Sarcocornia quinqueflora*) which sometimes grades into the edge of the mangrove forest in areas where both habitats coincide and the upper zone is often colonised by sedges and rushes. Further landward, the saltmarsh grades into adjacent terrestrial vegetation such as she-oaks (*Casuarina glauca*) and paperbarks (*Melaleuca* sp.) (Adam 1981).

The ecology of Australian saltmarshes has been little studied and knowledge of the factors influencing the distribution and abundance of the plants and animals is sketchy (McGuinness 1988). Saltmarshes are thought to have important physical and biological functions in estuarine systems. Physically, they are thought to trap sediments and pollutants from the water column and biologically, they contribute to estuarine productivity through the export of organic material (Middleton 1985).

Samphire, (*Sarcocornia quinqueflora)*, sea rush (*Juncus kraussii*), and sand couch (*Sporobolus virginicus*) have been reported from among mangroves near the road causeway at Sandbrook Inlet (Hutchings *et al*. 1977), however, no quantitative data were recorded. SMEC (2000) reported three additional species, native reed (*Phragmites australis*), swamp oak (*Casuarina glauca*), and broad-leafed paper-bark (*Maleleuca quinquenervia*), at the landward margins of mangrove stands in Sandbrook Inlet.

West *et al*. (1985) (Figure 1) recorded 1.126 km^2 of saltmarsh within the Hawkesbury River, but again the amount along major waterways such as Brooklyn area was not specified. In addition, the map presented for this study area did not show any saltmarsh habitats. However, saltmarsh communities in the Brooklyn area have been mapped recently, specifically at Brooklyn, Long Island and Spectacle Island (Williams & Watford 1999) and the head of Mooney Mooney Creek (Williams & West 2001), always adjacent to and shoreward of mangrove stands (Figures 4 and 2 respectively). A recent review of 28 surveys in southeast Australian estuaries concluded that the widespread decline in saltmarsh communities is often associated with invasion by grey mangroves (Saintilan 2000), and the fate of these habitats is uncertain.

1.3.4 Riparian Vegetation

Smith & Smith (1990) identified six riparian vegetation communities from Brooklyn and Dangar Island, and the only other information available for riparian vegetation in the study area also comes from Brooklyn. Appendix 1 lists all plants observed within approximately 5km of Brooklyn (NSW NPWS Wildlife Atlas). The vegetation is influenced primarily by aspect and drainage and has a high floristic diversity that is associated with Hawkesbury Sandstone settings (The Ecology Lab 1998b). The most extensive communities are tall open forest, open forest and woodland formations (adjacent to residential areas of Brooklyn and on ridgetop areas of Dangar Island) and are as follows (Smith & Smith 1990):

- Community A: open forest with a dominance of Sydney peppermint (*Eucalyptus piperita*) and smooth-barked apple (*Angophora costata*), predominantly found in gullies and sheltered slopes.
- Community D: woodland with a dominance of grey gum (*Eucalyptus punctata*), red bloodwood (*E. gummifera*), scribbly gum (E. *haemastoma*) and smooth-barked apple restricted to exposed slopes.
- Community P: tall open forest with a dominance of blackbutt (*Eucalyptus pilularis*) and rough-barked apple (*Angophora floribunda*), restricted to alluvial flats on the western end of Dangar Island.
- Community Q: open forest with a dominance of rough-barked apple and forest oak (*Allocasuarina torulosa*), on the steep lower slopes fringing the estuary.
- Community S: woodland with a dominance of smooth-barked apple, red bloodwood and bastard mahoghony (*Eucalyptus umbra*), on easterly steep slopes with exposure to salt breezes.
- Community T: woodland dominated by yellow bloodwood (*Eucalyptus eximia*), on steep, exposed, north-facing slopes.

Nexus (2000) reported that the bushland areas of McKell Park at Brooklyn are analogous to Community S of Smith & Smith (1990) and also noted some introduced species, including African lovegrass, couch, kikuyu and dandelion. Similar findings were reported by SMEC (2000). The Ecology Lab (1988) also noted that 22% of the 97 species recorded from the western foreshores of Brooklyn were introduced, however the majority of the area was covered by native vegetation. A full list of species and their abundance scores was presented.

1.3.5 Plankton

Plankton is composed of plants (phytoplankton) and animals (zooplankton) that range in size from tiny microbes (< 0.05 mm) to jellyfish (over 1 m wide) that inhabit the water column. Phytoplankton thrive on nutrients in the surrounding water and produce organic material by photosynthesis; thereby contributing to primary productivity in the estuary, whereas zooplankton are consumers. As a whole, plankton provides an important source of food to animals living in mud, sand and rocky reefs. Plankton is the source of food for suspension feeders (e.g. oysters) feeding on live and dead particles in the water column and detritus feeders, which feed on the 'rain' of particulate material falling from the water column to the bottom. The larvae of animals that live in estuarine environments may spend their early life as plankton in coastal waters outside the estuary before they are swept or swim back into the estuaries.

Unfortunately, the only relevant study in the area, a thesis entitled 'The Ecology of Estuarine Zooplankton in the Hawkesbury River (Bugler 1979) was unavailable for this review.

1.3.6 Intertidal and Subtidal Benthic Invertebrates

Benthic invertebrates are common in saltmarshes, mangroves, seagrass beds, intertidal and subtidal mudflats and sandflats and on rocky substratum. They exhibit a wide range of sizes which are commonly used to categorise them as macrofauna (> 1mm diameter), meiofauna (< 1mm but > 0.062 mm) and microfauna (< 0.062 mm). They are an important component of estuarine fauna, being eaten by each other and a variety of predators (e.g. birds and fish) and they play an important role in pathways of detrital and nutrient recycling. They are also good indicators of environmental disturbance such as pollution. Benthic invertebrates can also be categorised according to where they live; 'infauna' live within the sediment and 'epifauna' live on the surface of sediment or plants such as seagrasses, mangroves etc.

Benthic macrofauna typically comprise invertebrate animals such as marine worms (polychaetes), shells (bivalves and gastropods) and crustaceans which live on or in the seafloor (often termed the 'substratum').

Hutchings *et al*. (1977) recorded 27 species of benthic invertebrates along transects through mangrove and saltmarsh habitats at Brooklyn. The largest groups were brachyuran crustaceans (crabs) and gastropod molluscs, but also recorded were species of bivalve molluscs, shrimps, isopod and amphipod crustaceans, and polychaete worms. The animals along the transect at the entrance of Seymour's Creek were much more specious than those along a foreshore transect due south of the inlet, which was reported to have a highly anaerobic substratum. However, transects at each site were not replicated.

The Ecology Lab (1988) surveyed intertidal benthos along twelve randomly placed transects in mangrove stands at Brooklyn, and the subtidal benthos by collecting replicate benthic cores from twelve stations within Sandbrook Inlet. No intertidal polychaetes were sampled in this study, however arboreal and hard substratum barnacles were recorded. A more limited study carried out almost a decade later in the same area recorded only fourteen species (The Ecology Lab 1997).

A count of 475 individuals from 26 invertebrate species was recorded from the 48 subtidal benthic cores collected by the Ecology Lab (1988). Numbers of crustaceans collected from the man-made marina sites were significantly greater than from the natural sites. The dominant species at all sites were the polychaetes *Nephtys australiensis* (Nephtyidae), *Notomastus torquatus* (Capitellidae) and *Terebellides stroemi* (Trichobranchidae), and the bivalve *Notospisula trigonella*. These species also dominated many of the samples from other parts of the Hawkesbury River in a study by Jones *et al*. (1986), however, the benthos of Sandbrook Inlet was relatively depauperate by comparison. This reduction in species may be due to repeated dredging of the maintenance channel over the last 20 years. Seaward transects of the Hawkesbury River were usually more speciose than those further upstream, though not always significantly so, and there was no clear pattern with sediment grade (Jones *et al*. 1986; Jones 1988). In addition, a temporal study of the benthos of the Hawkesbury produced unrepeatable, seasonal and annual differences in numbers of species and individuals at all sites (Jones 1987). This suggested that factors such as space, time, salinity and sediment interact with other variables to produce unpredictable results.

Subtidal benthos was also sampled pre- and post-maintenance dredging and after spoil disposal at Brooklyn (Jones 1986). Densities of animals decreased as a result of dredging, and species differed in their rates of recolonisation. Dominant species survived spoil disposal (e.g. the trichobranchid polychaete *Terebellides stroemi*). Polychaetes collected from this study and other studies such as the Hawkesbury River Survey and Cowan Waters Survey by the Australian Museum over several years were studied for taxonomic purposes (Hutchings & Murray 1984). A taxonomic key was provided, and 28 new species and 4 new genera were described.

More recently, intertidal and subtidal benthic organisms were sampled in Brooklyn Harbour to assess the effects of maintenance dredging and partial foreshore reclamation (The Ecology Lab 2002). Fewer benthic taxa from subtidal soft sediment were found in Brooklyn Harbour compared to two reference locations (Parsley Bay and Dangar Island). This suggested that the subtidal infaunal assemblages in the harbour were depauperate relative to nearby areas. This finding was consistent with Jones (1986) who found fewer species and abundances of benthic invertebrates in Brooklyn Harbour compared to a control location in the Hawkesbury River.

Life history parameters and the population biology of the dominant bivalve *Notospisula trigonella* have been determined in the Hawkesbury River (Jones *et al*. 1988). Spatial and temporal differences in their abundance were correlated with salinity, and water depth and sediment grade had little effect.

Other abundant benthic invertebrates from the estuary have also been used in bio-indication experiments. The tidal amphipod, *Corophium* sp. (Hyne & Everett 1998) and the semaphore crab *Heloecius cordiformis* (MacFarlane *et al*. 2000) were examined as suitable indicators of sediment toxicity. Field and lab experiments on the Sydney rock oyster (*Saccostrea commercialis*) conducted in the lower Hawkesbury, showed that Sandbrook Inlet had the highest rates of oyster mortality and shell deformation when compared with other sites (Scammel 1987). The higher mortality rate in Sandbrook Inlet was likely due to the high concentration of the contaminant TBT (tributyl tin) in the inlet. Sandbrook Inlet was found to have the longest residence time for contaminants in the study area (refer to section 3.4.5 of the EPS). TBT can concentrate in molluscs up to 250,000 times higher than surrounding sediments or seawater. Affected molluscs like oysters have deformed shells, slow growth rates and poor reproduction. Since 1989 there has been an Australian ban on the use of TBT for antifouling vessels smaller than 25 m in length. TBT takes up to ten years to degrade to safe levels (ANZECC undated). It can be expected that environmental impacts from TBT have reduced in recent years.

1.3.7 Fish and Mobile Invertebrates

Mobile invertebrates and fish are discussed together here because the techniques used to sample them are usually the same. Mobile invertebrates include those animals that are found either associated with a habitat, such as seagrass, or in the water column, and include animals such as crabs, prawns and squid. Estuarine fish are known to utilise a variety of habitats such as seagrass beds and algal beds as nursery grounds during juvenile stages.

Studies of marine vegetated habitats such as seagrasses and mangroves have received considerable attention in the scientific literature (e.g. West *et al*., 1985; Bell and Pollard, 1989; Larkum *et al*., 1989; Skilleter, 1996). By comparison, very little information exists on intertidal mudflats common in Australian estuaries despite the fact that they are thought to provide important foraging habitats for some species of fish (when inundated) and wading birds (when exposed). An exception to this, however was a review of the ecology of intertidal mudflats by Inglis (1995). Whilst this review provides a comprehensive description of the benthic infauna and some of the factors affecting the distribution and abundance of animals that occur on intertidal mudflats, the utilisation of these habitats when inundated at high tide by fish or mobile invertebrates, e.g. crustaceans, was not considered. West *et al*. (1985) provides a good example of how intertidal mudflats are often overlooked in scientific surveys. They mapped estuarine habitats including seagrasses, saltmarshes and mangroves occurring throughout 133 estuaries along the NSW coastline but provided no information on any areas of intertidal mudflats.

Intertidal mudflats are thought to provide important foraging habitats for fish (when inundated) and wading birds (Inglis, 1995) yet very little information exists on the ecology of unvegetated intertidal mudflats in Australia. Whilst this review provided good information on the benthic infauna of mudflats, the utilisation of these habitats when inundated at high tide by fish or mobile invertebrates, (e.g. crabs and prawns), was not considered.

Replicate beam trawl, beach seine and gill net collections were made by The Ecology Lab (1988) within Sandbrook Inlet at several sites and, in contrast to the infauna (see previous section), the epifauna was diverse and abundant. A count of 87,351 individuals from 21 invertebrate species, and 553 individuals from 14 fish species were collected from the beam trawls. The mysid shrimp, *Rhopalophthalumus brisbanensis* comprised 58-99% of the abundance. The next most dominant species was again the bivalve, *Notospisula trigonella*, and other abundant species included the king prawn (*Penaeus plebejus*), the sergestid shrimp, *Acetes sibogae australis*, and the bivalve, *Theora fragilis*. Importantly, three prawn species found as juveniles at most stations, are of commercial value. The fish fauna was dominated by species of gobies. Beach seines collected 27 fish and 5 crustacean species, and gobies were again the most abundant group, however, 16 of the fish and 3 crustacean species were of commercial or recreational value. Gill netting caught very few fish (8 individuals) all of which were common in collections by other methods.

Overall, 31 species of fish were collected in Sandbrook Inlet during the study referred to above, whereas 36 and 29 (45 overall) species of fish were collected in beach seines from the adjacent Berowra and Cowan Creeks, respectively (Booth & Schultz 1997). In both studies, mullet, bream, whiting, tailor, flounder and leatherjackets were some of the most abundant species of fish of economic importance.

In the entire Hawkesbury-Nepean River 164 fish species have been recorded (Gehrke & Harris 1996) varying from 90 species near Broken Bay, to less than 15 species in upstream freshwaters. The composition of by-catch (fish caught incidentally to a targeted species) from prawn trawling in three areas of the Hawkesbury recorded 75 species of fish, 13 species of crustaceans and 5 species of molluscs, also showing trends with respect to salinity (Gray *et al*. 1990). Forty-two species were recorded as commercially valuable.

Juveniles of the commercially important mulloway, *Argyrosomus japonicus*, were examined for their distribution and growth characteristics in the Hawkesbury River (Gray & McDonall 1993). They were most abundant during autumn to winter in the mid sections of the estuary. Gut content analyses determined the diets of commercially valuable leatherjackets in Berowra and Cowan Creeks (Silberschneider 1997). Encrusting bryozoans were the most abundant source of food for the six-spined leather jackets, *Meuschenia freycineti,* whilst the major food items in diets of fan-belly leatherjackets, *Monacanthus chinensis,* were small crustaceans. Only one size class was examined for each species, which limits the generalityof conclusions.

1.3.8 Birds

Appendix 2 lists all the birds observed within 5 km of the Brooklyn area (NSW NPWS Wildlife Atlas). In addition, Hutchings *et al*. (1977) reported the grey teal (*Ardea giberifrons*), the common egret (*Egretta alba*), and the yellow-billed spoonbill (*Platalea flavipes*) from casual observations at Brooklyn made over eight years. The Ecology Lab (1988) also recorded a pied currowong (*Strepera graculina*) and an australian magpie (*Gymnorhina tibicen*) from Brooklyn. Some of the most common sea birds and river birds are shown in Powell & Powell (2000) along with notes about some of their more interesting characteristics.

A total of 207 species of birds have been recorded for the estuary, including five species listed as endangered under the *TSC* Act: the bush stone-curlew (*Burhinus grallarius*); little tern (*Sterna albifrons*); regent honeyeater (*Xanthomyza phrygia*); Gould's petrel (*Pterodroma leucoptera*); and swift parrot (*Latahamus discolor*). Fifteen species were listed as vulnerable under the Act including: osprey (*Pandion haliaetus*); black bittern (*Ixobrychus flavicollis*); sooty oystercatcher (*Haematopus fuliginosus*); pied oystercatcher (*H. longirostris*); glossy black-cockatoo (*Calyptorhynchus lathami*); rose-crowned fruit-dove (*Ptilinopus regina*); superb fruit-dove (*P. superbus*); sooty tern (*Sterna fuscata*); black-breasted buzzard (*Hamirostra melanosternon*); turquoise parrot (*Neophema pulchella*); terek sandpiper (*Xenus cinereus*); barking owl (*Ninox connivens*); powerful owl (*N. strenua*); masked owl (*Tyto novaehollandiae*); and sooty owl *(T. tenebricosa*).

In addition, three species listed as threatened and covered by the migratory provisions of the *EPBC* Act (1999) (Appendix 3) are likely to occur within the vicinity of Brooklyn area. They are the southern-giant petrel (*Macronectes giganteus*), the northern-giant petrel (*M. halli*) and the shy albatross (*Thalassarche cauta*).

1.3.9 Other Fauna

Appendix 2 also lists other fauna observed within 5 km of Brooklyn area. As with most information on birds in the estuary, this information was based on records held in NPWS databases. A total of 108 other species have been recorded around the estuary, including three species listed as endangered and five listed as vulnerable under the *TSC* Act. The endangered species include: southern brown bandicoot (*Isoodon obesulus*); giant barred frog (*Mixophyes iteratus*); and the green and golden bell frog (*Litoria aurea*). The vulnerable species include: southern right whale (*Eubalaena australis*); humpback whale (*Megaptera novaeangliae*); heath monitor (*Varanus rosenbergi*); red-crowned toadlet (*Pseudophryne australias*); and the giant burrowing frog (*Heleioporus australiacus*). As the scope of works done by The Ecology Lab was on aquatic habitats and biota, no observations of terrestial fauna were made during this study.

1.4 Relevant Legislation

In NSW, the *Threatened Species Conservation* (*TSC*) Act, 1995 is aimed at protecting animals and plants considered vulnerable and endangered from human activities. The legislation provides for the listing of threatened species, populations and ecological communities and has replaced the endangered fauna list known as Schedule 12 of the *National Parks and Wildlife* Act, 1974. 'Threatened' species are now listed in Schedules 1 and 2, endangered and vulnerable species respectively. New Commonwealth legislation, the *Environment Protection and Biodiversity Conservation* (*EPBC*) Act, 1999 also lists threatened species. Threatened species identified in each of these pieces of legislation within approximately 5 km of Brooklyn area are highlighted in Appendices 1,2 and 3.

Eight endangered and twenty vulnerable fauna species, and two endangered and nine vulnerable plant species identified under the *TSC* Act (1995) have been recorded within 5 km of Brooklyn area. A search of the *EPBC* Act (1999) database found nine endangered and twenty-nine vulnerable species of flora and fauna. The search also detected a number of animals protected under other sections of the *EPBC* Act (1999) including: 3 marine birds; 5 marine species; 6 terrestrial species and 2 wetland bird species covered by the migratory provisions of the Act; and 11 birds; 21 fish and 3 reptiles covered by the marine provisions of the Act (Appendix 3).

The *Fisheries Management* (*FM*) Act, 1994 protects fish species listed as endangered or vulnerable. Three vulnerable species of fish that potentially use the estuary during part of their lifecycle are the grey nurse shark (*Carcharias taurus*), the great white shark (*Carcharadon carcharias*) and the black rock cod (*Epinephelus daemilii*). The *Fisheries Management* Act, 1994 also provides protection for estuarine habitats including seagrass and mangroves, both of which occur in Brooklyn area.

1.5 Fisheries

There are few contentious issues with respect to commercial and recreational fishing within Brooklyn. However, there is reported to be occasional low level conflict between commercial fishers using mesh nets and recreational fishers at the road bridges (P. Scheutrumpf, NSW Fisheries, pers. comm.) NSW Fisheries have received complaints from residents along Wobby Beach due to the noise of commercial fishing boats. The theft of commercial mud traps and hoop nets also have been reported.

1.5.1 Recreational Fishing

Recreation fishing occurs throughout the study area but tends to be concentrated around the main channel of the Hawkesbury (P. Schuetrumpf, pers. comm. 2001). Figure 5 identifies some of the regular fishing spots for most species caught within the study area. Many of the preferred target species are caught year around although some fishers will have their own secret seasons and locations for individual species. For example a good time for jewfish is believed to be a full tide on a full moon just after sunset (P. Scheutrumpf, pers. comm. 2001). The major species targeted include, yellow fin bream, flathead, hairtail, leatherjackets, luderick, mulloway or jewfish, tailor, whiting, juvenile snapper and occasionally Australian bass (Ross 1995). Jewfish are a common target of recreational anglers, and the Hawkesbury is famous for this species as they are large and abundant (Ross 1995).

Weekends are the busiest times for recreational fishers with over 300 boats fishing within the estuary, particularly in summer and on Public Holidays (P. Scheutrumpf, pers. comm. 2001).

Boats can be chartered from a number of outlets in Sandbrook Inlet. Many people also fish from their own boats and from the shore. Boat launching areas are available in Sandbrook Inlet, and Parsley Bay and many fishers use the ramp to the west of the bridge at Mooney Mooney Point (Ross 1995).

The compliance rates for recreational fishers appear to be high with only 5-10% of people being caught with undersize fish. Furthermore, over 80% of recreational fishers in Brooklyn have current recreational fishing licences. Recreational fishers are not allowed to trawl for prawns anywhere in NSW. They can, however, use a hand-hauled pawn net or push/scissor nets in some areas, but the nets must be registered with NSW Fisheries. Crab trapping is also permitted (P. Scheutrumpf, pers. comm. 2001).

Best estimates from NSW Fisheries for recreational fishing in the Hawkesbury River indicate that there are approximately 150,000 recreational fishing outings in the Hawkesbury River each year. Of these, 18% occur from the shore and 82% are boat based. The initial results also suggest that the catch retained by fishers in the Hawkesbury Estuary is approximately 580,000 fish per annum, with about twice that number returned to the water. Ten of the most commonly caught species are whiting, flathead, bream, leatherjacket, flounder or sole, yellowtail, tailor, catfish, jewfish and trevally. The most commonly caught crustaceans are blue swimmer crabs and the most commonly collected molluscs are cockles.

1.5.2 Commercial Fishing

In 2001 estuarine fisheries in NSW were worth $19.6 million producing over 5,000 tonnes of fish (Tanner & Liggins 2000; 2001). The Hawkesbury River fishery is the 4th largest in NSW after the Clarence River, Wallis Lakes, and Port Stephens/Myall Lakes, supplying, over 268 t of fish in 1998/1999 (Tanner & Liggins 2001).

Commercial fishers who operate in the Hawkesbury area provide NSW Fisheries with information about their catches, but this information is not specific to Brooklyn. Any attempt to get more specific information about catches solely within Brooklyn would require specific surveys. For the purposes of stock management, however, specific information on commercial exploitation in Brooklyn will probably not prove useful because there is almost certainly considerable movement of many fish species between Brooklyn and nearby waterways. That is, because fish are highly mobile, it will only be sensible to manage or to try to understand the fishery on a large spatial scale, such as the entire Hawkesbury region, or perhaps even larger scales for certain species.

Over the past 15 years, 66% of the total commercial catch for the Hawkesbury River has been finfish, followed by crustaceans (27%) and molluscs (6%). Over the past 15 years, the most commonly caught finfish species were sea mullet (40% of the total finfish catch, by weight) followed by bream (9%) mulloway (6%) luderick, trevally, whitebait and silverbiddy (each 4%). The mollusc catch is dominated by squid (97%) and crustaceans are dominated by prawns (76%) followed by blue swimmer crabs (7%) and mud crabs (4%) (Tanner and Liggins 2001)

The number of commercial fishers in the Hawkesbury, the number of days fished and the commercial catch (kg) are presented for the past 15 years in Figures 6 and 7. The effort by method is also presented for the past 15 years in appendix 4. The number of fishers in the Hawkesbury decreased from over 100 during the early 1990s to 80 in 1999-2000.

There is no hauling within Brooklyn, and prawn trawling is not permitted between Croppy Point and the railway bridge due to high abundances of juvenile jewfish and heavy boat traffic (P. Scheutrumpf, NSW Fisheries, pers. comm). Furthermore, prawn trawling is not permitted on weekends and public holidays in the estuary, however, many fishers have moved from prawn to squid trawling to take advantage of the development of a new squid net. Splash netting, which involves setting a gill net for a short period of time, is permitted in the estuary within periods specified by fishing regulations.

1.5.3 Oyster Farming

1.5.3.1 Description of Oyster Farming Practices

Of the 28 oyster farmers in the Hawkesbury, 15 operate within the Brooklyn area. Most of these leases are located within Mooney Mooney and Mullet Creeks (Plate 1) but there are leases in other areas of the estuary (Figure 8). The Lower Hawkesbury River is the second largest oyster producing area in NSW and cultivation methods have changed considerably since the early days when sandstone rocks so easily found in the area were used to catch spat. Later, Mangrove sticks were used to collect spat (juveniles), then fibro slats or tarred hardwood stakes. In the last ten years there has been a concerted move to using cemented 1' x 1' sticks for catching the spat, and the oysters are grown to a medium size on these then removed and placed on trays to complete the growing cycle (www.oysterfarmers.asn.com).

Oyster spat is collected in the main estuary (e.g. Brooklyn Harbour) and the sticks are then broken up and moved up the creeks. From there, they are sent to depot (e.g. Sandbrook Inlet). Oysters on racks are predominantly found outside Brooklyn within Marramarra Creek and Coba Bay. The location of oyster leases is shown in Figure 8.

Natural spatfalls of oysters are not frequent enough to sustain the industry within the Brooklyn area. Oysters at various stages of growth are therefore purchased from growers in other estuaries. This is a common practice for oyster farming in NSW and strict controls and inspections are carried out by NSW Fisheries to ensure the practice does not lead to widespread contamination of estuaries with diseases and introduced Pacific oysters (*Crassostrea gigas*). NSW Fisheries Officers regularly inspect the leases and issue notices if farmers fail to remove Pacific oysters. They also work with growers to ensure leases and adjacent foreshores are kept free of Pacific oysters.

As part of a Quality Assurance Program (QAP), farmers are required to purge their oysters for 36 hours prior to delivery to market for sale for human consumption. Water for purging is drawn from the inlet adjacent to the sheds that the farmers use. Any potential threat to the purity of the water could potentially cause problems for the farmers. As another part of the QAP, farmers are required to conduct water and meat sampling each week to ensure compliance with food safety standards.

Oysters can concentrate metals and other contaminants many times the levels in the ambient water and thus, poor water quality can be a problem for oyster farmers (Nell, 1993). Levels of metals (except arsenic), phenols, and PAHs were not significantly elevated in wild oysters collected from the Hawkesbury when compared with another reference area at Port Stephens, and the study area adjacent to the steelworks on the Hunter River (Lincoln Smith & Cooper in prep.). Interestingly, levels of arsenic in both reference areas were about twice that of the study location. Mackay *et al*. (1975) also found elevated levels of arsenic at sites within Wagonga inlet, being three times the recommended limit. The source of the arsenic was unclear, but it was suggested that timbers treated with arsenate preservative compounds have been used in oyster cultivation. The possibility of contamination from that source was suggested as an area warranting further investigation (Mackay *et al.* 1975).

The practices of oyster farming in NSW are at present the subject of a major review and a draft Management Plan is being prepared by ACIL Economics after consultation with industry representatives, NSW Fisheries and the EPA to cover the management of the oyster industry.

1.5.3.2 Oyster Production Data

The NSW oyster industry is characterised by a large number of small producers (Nell, 1993). In NSW, oysters are grown in 41 estuaries with a total lease area of about 4 700 ha. Figure 9 demonstrates the variability in production of oysters in NSW since 1940 that can be explained by the following factors. During the 1950's and 1960's, the NSW Sydney rock oyster industry exhibited consistent growth as production methods improved and the total lease area increased. Oyster production then peaked in the 1970's largely due to the practice of transporting oysters between estuaries to take advantage of differences in the timing of prime growing or fattening conditions. Since then, production has stabilised to around 80 to 90 thousand bags per year (Nell, 1993).

The production of oysters from the Hawkesbury has also been somewhat variable since 1940 (Figure 9). Oyster production in the Hawkesbury generally declined until it reached an all time low in the mid-1950’s. Since then, it has followed the same general trend as the total NSW oyster production, peaking in the 1970’s, and most recently in the year 1997/98.

1.5.3.3 Pollution & Bioaccumulation

Water and sediment sampling by The Ecology Lab (1998a) indicated that turbidity, levels of nutrients and levels of chlorophyll-*a* were relatively high within Sandbrook Inlet with greatest levels often occurring in the southeast corner near the railway causeway. Levels of nutrients were also elevated outside Sandbrook Inlet, at the entrance to Mooney Mooney Creek. Cadmium, copper and lead concentrations in water samples exceeded ANZECC (1992) guidelines for the protection of marine waters at some sites within the inlet. Concentrations of arsenic, mercury and TBT exceeded low values of ANZECC (1997) interim guidelines for sediment quality and no contaminants exceeded high values, indicating low to moderate pollution in Sandbrook Inlet sediments.

Birch *et al*. (1998) used concentrations of copper, lead and zinc from sediments as indicators of anthropogenic effects and found that the most polluted areas of the Hawkesbury were the headwaters of Berowra Creek, Cowan Creek and southeast Pittwater. By comparison, sediments in Sandbrook Inlet were generally moderately polluted.

Hardiman and Pearson (1995) found that there were significantly greater concentrations of contaminants, particularly cadmium, copper, zinc, DDT and TBT in oysters collected from Sandbrook Inlet, but variation among sites within the inlet was large. In addition, the only metal above the food standard was copper. Lincoln Smith & Cooper (in prep.) found that most heavy metals, phenol and PAH concentrations in wild oysters sampled from reference locations in the Hawkesbury River and Port Stephens were generally not different from oysters sampled near a steelworks in the Hunter River. The trace metal arsenic, however, was present in oysters from both references in concentrations twice that of oysters collected adjacent to the steelworks.

2.0 STUDY METHODS

2.1 Qualitative Habitat Assessment

A qualitative habitat assessment was compiled based on observations made in the field between 18 and 20 September 2001. Ecologists visited various parts of the estuary by boat, allowing easy access to the shoreline when necessary. The perimeter of the study area was inspected, and for ease of observation and reference, it was divided into four sections; Mullet Creek, Mooney Mooney Creek, Sandbrook Inlet and the main channel of the Hawkesbury River. Within each section the topography and characteristics of the surrounding land, foreshore and subtidal habitats was summarised. Within each of these habitats, the type and extent of aquatic and fringing flora and fauna was noted. General observations on the presence of birds, fish and other fauna and on the types and magnitude of foreshore development were also recorded.

The results of the habitat assessment were described in detail and based on field observations. Many seagrass beds were shallow and could be observed from the boat, while deeper beds such as the one south of Dangar Island required diving. Recent mapping of estuarine habitat by NSW Fisheries (Williams and Watford 1999, Williams and West 2001) was compared to field observations. Any changes noted since those maps were prepared, were discussed.

2.2 Intertidal Invertebrate Communities

Intertidal flora and fauna were sampled at low tides between 30/01/02 and 01/02/02 as part of a separate study for an EIS prepared on the Central Coast Rail upgrade (Halliburton KBR, in prep.). The aim of this survey was to identify if significant differences occurred in intertidal biota between both sides of the causeway. Three sites sampled each on the eastern and western sides of the railway causeway at Brooklyn, between the Hawkesbury River railway station and Long Island (Figure 10). Those sites sampled on the eastern side of the causeway are referred to as "outer" or Brooklyn Harbour side, and those on the Sandbrook Inlet side were referred to as "inner" or Sandbrook Inlet side of the causeway (Figure 10).

2.2.1 Field Methods

At each location, a hand-held Global Positioning System (GPS) was used to record the location of sampling sites and to estimate the distance between each site (Appendix 5). Qualitative descriptions included: weather conditions; rock type and topography; and any other obvious identifying features. The dominant fauna and flora were quantified for each of the zones and photographs were taken to record notable features of the intertidal assemblages.

On each side of the causeway sites were selected 50 to 100 m apart. At each site sampling was done at two heights on the shore denoted as:

- The highshore littorinid zone, and;
- The lowshore oyster zone.

In each zone, samples were taken in 10 quadrats (50 x 50 cm) placed randomly on the substratum. Percentage covers of primary algae (attached directly to the substratum) was estimated using 100, evenly-spaced points per quadrat. Numbers of live and dead oysters were counted within each quadrat. The abundance of sessile and slow-moving-mobile animals (e.g. barnacles and gastropods) was recorded within each quadrat. The presence of highly mobile animals such as crabs and isopods were also noted for each quadrat, but not counted.

2.2.2 Statistical Methods

Data from the intertidal survey were analysed using univariate analyses. Figure 11 illustrates the statistical design for these data. A 3-factor mixed model was used with the terms being Height on shore (fixed and orthogonal); Locations (fixed and orthogonal) and Sites (random and nested within Locations). For two taxa found only in the lower intertidal zone (*Chamaesipho tasmanica* and *Patelloida mimula*) and one found only in the upper zone (*Noddilitorina unifasciata*) a 2-factor design was used with the factors Location and Sites (nested within Locations). Cohran's C Test was used to test for heterogeneity of variances, and data were transformed accordingly or the results were interpreted conservatively. Significant factors were further examined using Student Newman Keuls (SNK) tests (Appendix 6). Multivariate analyses were not used because the number of taxa present was generally small.

2.3 Quantitative Sampling of Demersal Fish and Invertebrates

2.3.1 Field and Laboratory Methods

Small demersal fish and invertebrates were sampled in muddy subtidal habitats on two occasions using a beam trawl. The first time (17-19/09/01) of sampling was commissioned specifically for the Brooklyn EPS. Halliburton KBR commissioned the second time of sampling (29-31/01/02) for the Central Coast Rail Upgrade EIS (The Ecology Lab 2002). Identical sites and methodologies were used for both studies permitting a combined analysis of the data.

Small fish and invertebrates were sampled using a beam trawl, which comprises a conical shaped net (1.5 m x 0.6 m x 2.0 m) with a mesh size of 1 mm attached to a metal sled. The beam trawl was towed by a small boat over a distance of 50 m at the average boat speed of about 1.5 – 2 knots. Shots were less than 5 minutes. All sampling was done within 1 hour of the high tide.

Five replicate trawls were collected at 2 sites within each of 5 locations on the first sampling occasion and 6 locations on the second occasion. Two locations were within Sandbrook Inlet, two within Mooney Mooney Creek and one within Mullet Creek. In all cases, trawls were within 50 m of fringing mangrove forests. The sixth location was selected to provide additional information for the Central Coast Rail Upgrade (Halliburton KBR in press) however it was not included in the EPS. Trawls were generally inshore of oyster leases, (except at one site near the entrance to Sandbrook Inlet and another near the mouth of Mooney Mooney Creek (Figure 10).

All material collected in the beam trawl was placed in plastic bags and preserved in approximately 10% formalin in seawater. Samples were sorted in the lab and animals were identified to the lowest practical taxon.

2.3.2 Statistical Methods

The data collected were analysed using 2 main statistical procedures, multivariate and univariate analyses. The experimental design (Figure 12) analysed data from both sampling times for locations 1 to 5. Variation in the assemblage of species among sites, locations, and times were assessed using the multivariate Bray-Curtis similarity measures and presented graphically using multi-dimensional scaling MDS plots (Appendix 6). Spatial and temporal variations in assemblages were examined using analysis of similarities (ANOSIM). The replicates were averaged for each site prior to conducting the ANOSIM. If variation in assemblages was detected, the species that contributed most to the dissimilarity among places or times was identified using Similarity of Percentages (SIMPER) analyses.

Species richness, total abundance and individual taxa that accounted for more than 2% of the total abundance of all individuals recorded were analysed using ANOVA. Here a 3 factor mixed model was used, with the terms being times (random and orthogonal); Locations (random and orthogonal) and Sites (random and nested within locations).

2.4 Bioaccumulation in Oysters

2.4.1 Field and Laboratory Methods

Wild oysters (e.i. not from oyster leases) were sampled twice (12/11/01 and 05/02/02) to measure bioaccumulation of metals and polycyclic aromatic hydrocarbons (PAHs). At each time, 4 locations were sampled. Two of the locations (Sandbrook Inlet, Plate 3 and Brooklyn Harbour, Plate 4) were in areas of extensive boating activities and urban development (Figure 4). The other two locations (Mullet Creek and Mooney Creek) were more remote from human disturbance. Within each location, sampling was done at two sites. The sites were < 100 m apart and were used to provide a measure of small scale variation in levels of contaminants.

Four replicate samples of oysters were collected at low tide for each site. Each replicate consisted of a composite sample of oysters to provide sufficient oyster tissue for analysis. The composites consisted of clumps of oysters (between 2 and 8 oysters) occurring on intertidal rocks or other suitable surfaces. The spatial scale of oysters within composites was < 0.5 m, while that between composites was 5 – 10 m. Wild oysters were removed from rocks using a small chisel and were stored on ice on the day of collection and frozen pending dissection. Oysters were opened using stainless steel equipment. At least 30 g of oyster flesh was obtained per replicate and dispatched to the Australian Government Analytical Laboratories (AGAL) for analyses.

The metals analysed included copper, lead, zinc, cadmium, chromium, nickel, arsenic, mercury and selenium. Polycyclic aromatic hydrocarbons were analysed for all Sandbrook Inlet samples only at each time. Each composite sample of oysters was homogenised in a blender equipped with a titanium blade. For heavy metals, a small portion of each sample (1 g) was digested with 3 ml of re-distilled nitric acid over a steam-bath for 1.5 hours and then made up to appropriate volume with Milli-Q water. Trace metals were determined using both ICP-MS and ICP-AES. Indium was used as the internal standard. For PAHs, the homogenised sample was freeze-dried and a portion (2 g) extracted with dichloromethane solvent using soxhlet extraction. The extract was filtered through dichloromethane solvent using soxhlet extraction. The extract was filtered through sodium sulphate and cleaned using silica gel. The preparation was analysed using GCMS in SIM (selected ion monitoring) mode. Quantitation of the analytes was done using primary characteristic ions as specified in the USEPA 8270 method. The volumetric internal standard compound and the surrogate internal compounds used were those specific in the method. The analytical techniques used by the laboratory were based on USEPA 3540 (for sample preparation) and USEPA 8270 (for detection).

2.4.2 Statistical Analysis of Data

Data were reported as mg/kg on a wet weight basis. Concentrations of metals reported below the detection limit for the chemical analysis were treated as zero (Scanes and Roach 1999). For each metal, a 3-way symmetrical ANOVA was used to compare metal concentration between times, locations and sites (Figure 13). The experimental design had the factor 'times' as random and orthogonal; the factor 'location' was fixed and orthogonal; and the factor 'sites' was random and nested. Homogeneity of variances was tested using Cochran's C Test (Appendix 6). The analysis provided for the following other comparisons, including between sites within locations, between locations at each time, between times, between locations and between time at each location. Multiple comparisons were done on the means of significant terms using Student Newman Kuels (SNK) tests. Only significant results were represented graphically.

3.0 RESULTS

3.1 General Habitat Assessment

The following sections provide a general description of the subtidal, intertidal and fringing terrestrial habitats of the study area assessed during the site inspection by The Ecology Lab between 18 and 20 September 2001. These results are not definitive; rather they are indicative of the most dominant assemblages occurring during the site visit. They describe the major sections of the estuary moving upstream from Croppy Point along the northern banks, Mullet and Mooney Mooney Creeks, Dangar Island, Spectacle Island, Sandbrook Inlet, then back along the southern banks to Parsley Bay. The locations of the sections referred to below are shown in Figure 20. For the location of oyster leases, refer to Figure 8 and 20.

3.1.1 Main Channel of the Hawkesbury River

This section included the foreshore upstream from a line between Croppy Point and Parsley Bay, to Peats Ferry Bridge, excluding Mooney Mooney and Mullet Creeks and Sandbrook Inlet. Narrow foreshores of sandstone rubble backed by steep sloping hillsides dominated the shoreline, with sandstone boulders and rocky outcrops common in intertidal and subtidal areas. Typical hillside vegetation consisted mainly of eucalypts and she-oaks (*Casuarina glauca*), interspersed with wattle (*Acacia* spp.) and grass trees (*Xanthorrhoea* spp.). Intertidal rocks were heavily to moderately encrusted with oysters (*Saccostrea commercialis*) and mussels (Family Mytilidae). Periwinkles (*Bembicium* spp.) were common higher in the intertidal zone and the limpets *Siphonaria denticulata* and *Patelloida mimula* were often scattered amongst oysters. Sargassum (*Sargassum* spp.) and kelp (*Ecklonia radiata*) were common in subtidal areas. The green alga *Codium fragile* was occasionally found growing in low intertidal areas, as were small patches of *Caulerpa filiformis*.

The foreshore between Brooklyn Wharf and Parsley Bay is well developed with a marina and public boat ramp, respectively. The intertidal rock rubble and concrete seawall in this area had an almost continuous band of oysters. These were interspersed with periwinkles and barnacles, and high on intertidal rocks were occasional patches of green filamentous algae. An orange sponge occurred extensively on low intertidal rocks in Parsley Bay, and again sargassum and kelp dominated the subtidal environment.

Some of the common birds seen within the main estuary included: great cormorants (*Phalacrocorax carbo*); little pied cormorants (*P. melanoleucos*); maned ducks with ducklings (*Chenonetta jubata*); mallards (*Anas platyrhynchos*); Australian pelicans (*Pelecanus conspicillatus*); silver gulls (*Larus novaehollandiae*); pied oystercatchers (*Haematopus longirostris*); Australian ravens (*Corvus coronoides*); Australian magpies (*Gymnorhina tibicen*); and pied currawongs (*Strepera graculina*).

Occasional grey mangroves (*Avicennia marina*) were growing out of rocky foreshore areas, individual plants separated by as much as several hundred metres. However, there were no mangrove forests mapped in the main channel section of study area as these were not different from those mapped by NSW Fisheries (Figure 1 – 4).

There were two main patches of seagrasses in the main estuary. One occurred immediately to the south of Dangar Island; the other was found to the east of the railway causeway, within Brooklyn Harbour. The area of seagrass in Brooklyn Harbour mapped by Nexus

(2000) was 1.7 ha, and by the Ecology Lab (2002), 2.37 ha. This indicates that the bed has increased in size, although the techniques used to map the bed in 2000 are unknown .

Oyster leases occurred in three main areas: north of Little Wobby Beach, east of the railway causeway at Brooklyn, and outside the breakwater in Parsley Bay. One of the leases in the first area appeared to be derelict, whilst the remaining leases were operational and had six to ten oyster sticks to a stack, indicating that they were being used for catching oyster spat. Foreshore development was mainly concentrated along Little Wobby Beach, and from between Brooklyn Wharf and Parsley Bay. Little Wobby Beach had private hillside residencies with sandstone seawalls and wooden jetties, some private boat harbours, slipways with boatsheds, scattered moorings and one public wharf. Brooklyn Wharf was an extensive marina development. A rocky wall bounded two sides of Brooklyn Harbour. There were some wooden jetties, several dozen moorings, and a public baths enclosure. The remaining foreshore in the main estuary was largely undeveloped.

3.1.1.1 Dangar Island

Hillside and foreshore topography, and animal and plant assemblages of Dangar Island were similar to the main estuary, except that the northeast point of the island and Coolongolook Point to the south had large intertidal mudflat areas. The entire foreshore had private hillside residences with jetties and moorings. Two beaches on Dangar Island easily accessible to the public are Bradley's Beach and North Beach located west of the wharf. Oyster leases occurred over a small area of the northern shore.

A large seagrass bed (*Zostera capricorni*) covered much of the mudflat at Coolongolook Point. Shoots of most plants were short, and individual plants were sparse along the western, northern and eastern fringes, with occasional dying/dead patches higher on the mudflat. The southern tip of the mudflat had dense eelgrass with long shoots, extending further south in small patches into deeper areas. Eelgrass beds extend east towards Bradleys' Beach, however exact extend not known because of poor visibility at time of inspection.

3.1.2 Mullet Creek

Mullet Creek extends north and east from Alison and Cogra Points on the Hawkesbury River. Narrow sandstone rubble foreshores backed by steep sloping hillsides dominated the fringing terrestrial topography on the eastern shores of the creek. Western foreshores along the entire length of the creek were wider, and there were artificial rock rubble seawalls along which the main northern railway line ran. A thin strip of weedy riparian vegetation occurred between the waters edge and the railway line. Typical hillside vegetation on both banks consisted mainly of eucalypts and she-oaks, interspersed with wattle and grass trees, and occasional banksias. Intertidal rocks, both artificial and natural, were encrusted with oysters above low water levels and scattered mussels occurred below. Periwinkles were common higher in the intertidal zone, whilst sargassum was often attached to subtidal rocks. Grapsid crabs (*Sesarma erythrodactyla*) were occasionally seen crawling over the rocky foreshore on the natural, eastern banks.

Birds observed in Mullet creek included the common estuarine forms listed in the previous section, as well as: white-bellied sea-eagles (*Haliaetus leucogaster*); wrens (Family Maluridae); glossy black cockatoos (*Calyptorhynchus lathami*). Fishes commonly seen included: mullet (Family Mugilidae); yellowfin bream (*Acanthopagrus australis)* toadfish (Family Tetraodontidae); garfish (Family Hemiramphidae); and sting rays (Family Dasyatididae). Jellyfishes (*Aurelia* sp.) were also spotted occasionally.

Tucked into the backs of most bays along the eastern foreshore were small stands of mangroves ranging from thirty square metres at the head of Mullet Creek to approximately eighty square metres at bays near the mouth. Mangrove stands at the head of Mullet Creek comprised both grey mangroves and river mangroves, whilst those at the mouth comprised only grey mangroves. Where both species occurred, small river mangroves no more than 2 m tall were backed by large grey mangroves up to 10 m tall. Stands of grey mangroves alone consisted of scattered juvenile plants fronting mature trees.

An extensive bed of patchy seagrass occurred over the sand shoal at the head of Mullet Creek. Eelgrass dominated this bed, and some paddleweed (*Halophila* sp.) also occurred. In shallow areas, eelgrass was sparse with short shoots, whilst deeper areas had a more consistent cover of plants with longer shoots and high epiphyte loads. Eelgrass also occurred within the adjacent two bays to the south and east of the head of Mullet creek, as narrow bands of scattered plants along the subtidal edge of mudflats.

Oyster leases extended south from Wondabyne Station along both sides of the creek (Plate 1). Oyster stacks appeared to have between one and six sticks of oysters indicating both depot leases and catch leases respectively. The largest areas of oyster leases occurred around the mouth of Mullet Creek where there was no foreshore development. No more than a dozen private residencies occurred along the entire length of Mullet Creek. These were concentrated mainly around the area of Wondabyne Station where there was a wharf, a grassy park with stone statues, and some dumped rubbish. Associated with the private foreshore properties were occasional sandstone seawalls, jetties and moorings.

3.1.3 Mooney Mooney Creek and Spectacle Island

Mooney Mooney Creek extends upstream from Cogra Point and Peats Ferry Bridge on the Hawkesbury River, and included Spectacle Island. As in other areas, narrow sandstone rubble foreshores backed by steep sloping hillsides dominated the shoreline. Sandstone boulders and rocky outcrops were common in intertidal and subtidal areas between embayments, whilst within bays extensive intertidal mudflats were more common. Typical hillside vegetation did not differ from that described for the main estuary (Plate 2), and nor did typical rocky intertidal assemblages.

Birds seen in Mooney Mooney Creek again included the common estuarine forms, as well as: eastern whipbirds (*Psophodes olivaceus*); bellbirds (Family Pachycephalidae); wedge-tailed eagles (*Aquila audax*); and hawks (Family Accipitridae). White-faced herons (*Ardea novaehollandiae*) were seen in moderate numbers, feeding over each of the mudflats within the creek, particularly on the extensive mudflats to the west of Spectacle Island. These mudflats also had huge numbers of ocypodid crabs (*Heloecius cordiformis*).

Mangrove stands backed each of the bays within Mooney Mooney Creek, behind intertidal mudflats. At the head of the creek where it meets Piles Creek, mangroves flanked both shores. Bays to the north of Fox Bay had mixed mangrove stands comprising both grey and river mangroves, whilst mangroves in Fox Bay and other bays to the south comprised solely grey mangroves. Again, river mangroves were much smaller than grey mangroves, and usually occurred in front of and sometimes interspersed with them. Mangrove stands ranged from about thirty square metres in small bays to several hundred square metres at the head of the creek and on the western fringe of Spectacle Island. Individual grey mangroves did not exceed 10 m in height, and river mangroves did not exceed 3 m. Some mangrove stands on the western banks at the head of the creek had erosion stepped foreshores, whilst some eastern bays to the south had extensive sedimentation, evidenced by the burial of some derelict oyster leases

Adjacent to a mangrove stand opposite Native Dog Bay, a fringe of scattered eelgrass plants with long shoots extended approximately one hundred metres. This was the only seagrass bed mapped within Mooney Mooney Creek.

Oyster leases extended to the mouth of Mooney Mooney Creek south of Two Dollar Bay, and immediately to the south of Spectacle Island. Again, there were stacks of one to six oyster sticks, indicating depot and catch leases respectively. In conjunction with this foreshore development was also scattered along this length of the creek, with the exception of the township of Mooney Mooney, which was heavily built-up. The entire headland at Mooney Mooney was covered with private hillside residences having sandstone seawalls and wooden jetties, slipways with boatsheds, scattered moorings and one public wharf.

3.1.4 Sandbrook Inlet

Sandbrook Inlet (Plate 3) extends south and east from Kangaroo Point at Peats Ferry Bridge to between the Brooklyn shore and Long Island. It is closed at the lower end by the railway causeway.

The inlet was shallow with extensive mudflats at low tide and occasional oyster-covered rocks. There were extensive areas of fringing grey mangroves along the Brooklyn and Long Island shores. Individual trees were up to 8 m. Mangrove stands occurred at the mouth of Seymours Creek and midway along the Brooklyn shore. The foreshore behind varied from gently sloping hills to steep sandstone cliffs with eucalypt forests. Hillside eucalypts were interspersed casuarina, acacia and other typical native vegetation described for the main estuary. There were scattered small sandy beaches on Long Island between large areas of intertidal sandstone boulders and fringing grey mangroves.

Oyster leases occurred midway along the Brooklyn shore, at the lower end of the inlet, and on the southwest edge of Long Island. Stacks of single oyster sticks indicated that they were depot leases. The entire foreshore along the Brooklyn shore had private hillside residences with numerous wooden jetties and moorings, marinas and other businesses. Brooklyn Park was located along this foreshore with its river flat swamp forest boardwalk. The eastern end of Long Island was developed with railway infrastructure and electricity substation. The remaining foreshore in Sandbrook Inlet was largely undeveloped. Long Island is a nature reserve and as such was entirely undeveloped. There were up to 300 boats moored in the inlet.

3.2 Intertidal Invertebrate Communities

3.1.1 General Observations

GPS coordinates for intertidal sampling sites are given in Appendix 5.

The intertidal organisms observed on the rocky substratum of the rail causeway (Plate 3, Plate 4) were typical of those from estuarine habitats (Appendix 7). They were dominated by littorinid snails (*Bembicium auratum)*, Sydney rock oysters (*Crassostrea commercialis)*, honeycomb barnacles (*Chamaesipho tasmanica)* and small patellid limpets (*Patelloida mimula* and *Patelloida insignis)*.

The intertidal organisms on the lower shores of Brooklyn Harbour and inner Sandbrook Inlet differed slightly. On the Sandbrook Inlet side, muddy substrata and interspersed oyster-covered rocks occurred in the low tide zone. In contrast, on the Brooklyn Harbour side, there was no mud at the low tide zone. On the Sandbrook Inlet side, the oyster shell morphologies were high and rounded in their cross-section, while those on the Brooklyn side were more flattened against the rocks. This difference may be due to the smaller size of the rocks and the greater prevalence of mud on the Sandbrook Inlet side, or to differences in tidal flushing, wind and wave exposure.

Overall, more individuals and species were present on the outer side of the causeway (Appendix 7). Nine species (3 snails, 1 whelk, 2 limpets, 1 isopod and 2 algae) occupied the Brooklyn Harbour side, whereas only four species (1 bivalve, 1 gastropod and 2 crabs) were observed on the Sandbrook Inlet side.

3.1.2 Univariate Analyses

The diversity of organisms on the low shore of the Brooklyn Harbour (e.i. outer) side was significantly greater than that in the low shore on the Sandbrook Inlet side (Table 4, Figure 14). Patterns of abundance of organisms varied according to height on the shore and locations (within sites), but on the Brooklyn side of the causeway significantly more organisms were found in the low zone compared to the high intertidal zone (Table 3, Figure 14). Significantly more live and dead oysters were counted in the low intertidal zone on the Brooklyn Harbour side of the causeway than in the comparable habitat on the Sandbrook side (Table 3, Figure 14). The two species of littorinid snail (*Bembicium nanaum* and *B. auratum*) were more abundant on the lower than upper shore and were more numerous on the Sandbrook Inlet side. The mussel, *Mytilus edulis,* was found only on the Sandbrook Inlet side and was more abundant high on the shore (Figure 15). More of the limpet, *Patelloida mimula,* were found on the Brooklyn Harbour side, as they are known to be associated with live and dead oyster shells (Edgar, 1997) (Table 4, Figure 15).

Some differences in abundance were apparent at different sites along the causeway. On the Sandbrook Inlet side, more honeycomb barnacles (*Chamaesipho tasmanica*) were present at the site closest to the railway bridge (Figure 15, Table 4). On the Brooklyn Harbour side, more purple periwinkles (*Noddilitorina unifasciata*) were counted at site three (closest to the Brooklyn marina) than at the two sites closer to the railway bridge (Table 4, Figure 15). These results suggest that relatively large difference in patterns of diversity and abundance occur in intertidal flora and fauna on either side of the causeway.

3.2 Fish and Macroinvertebrates

3.2.1 General Observations

GPS coordinates for beam trawling are given in Appendix 8. In total, the beam trawl samples contained at least 46 species, including six species of commercial value (Appendix 9). These six species were yellowfin bream (*Acanthopagrus australis*), leatherjacket (*Acanthaluteres sp*.), sandy sprat (*Hyperlophus vittatus*), eastern king prawn (*Penaeus plebejus*), school prawn (*Metapenaeus macleayi*) and greasyback prawn (*Metapenaeus bennettae*). These commercial species accounted for 2.2% of the 11,859 individuals counted in total. The three numerically dominant species were pelagic shrimp (*Acetes sibogae australis*), glass goby (*Gobiopterus semivestita*) and Opossum shrimp (*Rhopalopthalmus brisbanensis*). Together, these three species accounted for more than 81% of the total number of individuals sampled. None of the species collected in the beam trawl samples is listed as protected under the Threatened Species Conservation Act, 1995.

3.2.2 Multivariate Analyses

The community structures of the fauna assemblages caught in the Beam Trawls significantly differed over the two sampling times (p = 0.012, Global R = 0.65) and between locations (p = 0.008, Global R = 0.415). It was not possible to identify which specific locations significantly differed at the alpha value of 0.05, as the numbers of permutations in the pairwise tests were inadequate. However, judging from the R-values created in the pairwise tests, there were clear contrasts between the community structures in lower Mooney Mooney Creek and inner South Sandbrook Inlet (pairwise R = 0.875) and in lower Mooney Mooney Creek and upper Mooney Mooney Creek (pairwise R = 1). For all other pairwise comparisons of the locations, the R-value was only 0.5 or less, meaning their assemblages were not clearly different. The taxa that best segregated the times and differing locations are listed in Table 5 (SIMPER results).

The differences between the Times and Sites are represented pictorially in the MDS ordination of Figure 16. Some samples are missing from this ordination because they did not contain any individuals (e.g. three of the five samples from Site 4 at outer Sandbrook Inlet, Time 1). In addition, one sample (from Site 7, lower Mooney Mooney Creek, Time 1) was deliberately removed from the ordination. This was done because this sample was so different from the others that it was obscuring the patterns amongst them. When this sample was included in the ordination, it sat at one side of the plot, whilst all the other samples sat on top of each other at the other end of the plot. The difference due to this sample (from Site 7, lower Mooney Mooney Creek, Time 1) was because it was the only one that contained a large-mouth goby (*Redigobius macrostoma*) and no other species.

The greatly higher average abundance of glass gobies (*G. semivestita*) in inner South Sandbrook Inlet (90.1) and inner North Sandbrook Inlet (132.4) than in lower Mooney Mooney Creek (2.6) was the main contributor to their differences (according to SIMPER results). This species contributed over 53% to the overall average dissimilarity between the locations.

3.2.3 Univariate Analyses

Means and standard errors of each of the variables examined in the univariate analyses are graphed Figure 17, showing the variation between Sites and Times.

Changes over time in the abundance of fish significantly differed between Locations (Figure 18a,Table 6, Appendix 10). These differences were mainly attributed to the glass goby (*G. semivestita*), which increased greatly over time in inner South Sandbrook Inlet, upper Mooney Mooney Creek and Mullet Creek, but not in outer Sandbrook Inlet or lower Mooney Mooney Creek (Figure 18b,Table 6, Appendix 10).

Changes over time in the number of taxa, number of fish species, number of economic species, percent abundance of economic species and abundance of opossum shrimp (*R. brisbanensis*) significantly differed between sites, but not between Locations (Table 7a, Appendix 6).

There was an overall increase in the number of invertebrate species over time, which occurred at similar magnitudes across all Sites and Locations.

The total abundance of all individuals, invertebrates, economic species, pelagic shrimp (*A. sibogae australis* and *Lucifer sp*.), comb jellies, and Swan River goby (*P. olorum*) did not significantly differ between Locations or Sites or significantly change over time. The non-significant results of the three latter taxa are probably due to the low numbers of individuals recorded in this study.

3.3 Bioaccumulation in Oysters

Heavy metals were detected at all locations sampled in the Hawkesbury estuary and at all sites within each location (Appendix 11). However, mercury was only slightly above the limit of detection in all samples. Analysis of variance found significant differences in concentrations of heavy metals between locations for copper, arsenic, selenium and zinc (Table 7). The average concentrations of copper from oysters at Sandbrook Inlet and Brooklyn Harbour, and arsenic concentrations from oysters at Brooklyn Harbour exceeded the ANZFA food standards maximum permitted concentrations (ANZFA 2000).

Concentrations of zinc at Brooklyn Harbour (Location 2) were significantly greater than at all other locations, which were not significantly different from each other (Figure 19). High organic content of sediment samples can lower bioavailability of contaminants.

Significant differences between locations were detected for selenium and arsenic (Figure 20, Table 7). At time 1, Sandbrook Inlet (Location 1) showed a significantly greater concentration of selenium than other locations, which were not significantly different. At Time 2, Mooney Mooney Creek (Location 3) showed a significantly smaller concentration of selenium than other locations, which were non-significantly different (Table 7, Figure 20). Brooklyn Harbour showed significantly greater concentrations of arsenic at time 2 than other locations, which were not significantly different. There was not significant difference in arsenic concentration between locations at Time 1.

Although no significant difference in copper concentrations between locations was detected in the Analysis of Variance, graphical presentation (Figure 21a) suggests there may be a locational effect with Sandbrook Inlet and Brooklyn Harbour having greater concentrations of copper than both Mooney Mooney Creek and Mullet Creek. However this effect was not significant due to large difference between sites within location 2 (Brooklyn Harbour) (Table 7d).

Mercury concentrations at all locations were between 0.03 and 0.01 (mg/kg wet weight). This was only slightly above the limit of detection for heavy metal concentration in oysters of 0.01 mg/kg, wet weight.

Apart from differences among Locations, the results indicated some variability at the smaller spatial scale of Sites within Locations. Significant differences between sites were detected for selenium at Sandbrook Inlet, and for copper at Brooklyn Harbour (Figure 21).

A significant increase in zinc concentrations was observed over time from 285.94 mg/kg (S.E.= 11.6) at Time 1 to 348.44 mg/kg (S.E.= 14.75) at Time 2.

No detectable concentrations of PAH (>0.05 mg/kg) were measured in samples from Sandbrook Inlet at either times.

4.0 DISCUSSION & CONCLUSIONS

4.1 General Habitat Assessment

None of the aquatic fauna species recorded near Brooklyn Causeway are protected species under the Threatened Species Conservation Act, 1995 or Fisheries Management Act 1994. Marine vegetation, however, is protected and if harm to marine vegetation is imminent, a permit needs to be obtained from NSW Fisheries (under the NSW Fisheries Act, 1994).

In general, the flora and fauna communities observed were well represented throughout the Study area. The hillside vegetation, intertidal communities and riparian vegetation were similar throughout Mooney Mooney Creek, Mullet Creek, the main estuary and Sandbrook Inlet. More bird species were observed along Mullet Creek and Mooney Mooney Creeks compared to the rest of the Study area, although this is based only on qualitative observations.

Zostera capricorni was the dominant seagrass species in the Brooklyn area, although *Halophila* sp. was also present. Comparison of various maps indicates that seagrass beds in Mullet Creek and Brooklyn Harbour have increased while beds in Sandbrook Inlet and Dangar Island have remained unchanged.

The coverage of mangrove forests has remained relatively unchanged over the last 15 years, while the cover of seagrass appears to have increased in Brooklyn Harbour, Sandbrook Inlet and at the head of Mullet Creek. Although saltmarsh cover was recorded for the entire Hawkesbury River (West *et al.* 1985) no estimates were made of cover for smaller zones until recently (William & Waterford 1999) and (William & West 2001). Therefore, the change in cover for specific patches of saltmarsh cannot be estimated.

4.2 Intertidal Invertebrate Communities

The Brooklyn Harbour side and Sandbrook Inlet side of the causeway were different in terms of the number of species, abundances and distribution of intertidal organisms. Overall, significantly fewer individuals and species of intertidal invertebrates were present on the Sandbrook Inlet side of the causeway than the Brooklyn side. This may be due to the restricted flushing and water flow of the Sandbrook Inlet side compared to Brooklyn Harbour. However, a number of processes or factors could account for the differences observed. Further work involving experimental manipulation would need to be done to provide evidence supporting any specific model of distribution. Further studies could focus on the following processes that might be affecting the distribution of organisms on rocky shores: current regimes influencing the availability of larvae and nutrients on either side of the causeway; differences in the substratum such as differences in complexity, texture and orientation; variations in sunlight and wind; anthropogenic pressures; and effects of competition and predation between organisms.

Periodic sampling and assessment of soft-bottom intertidal invertebrates is recommended as a cost efficient and reliable strategy for detecting disturbances. However, the same sites should be sampled each time to eliminate variation due to location. Decreased tidal flushing in Sandbrook Inlet could possibly explain the different intertidal assemblages observed either side of the causeway. A more complex intertidal sampling design addressing other possible processes influencing the distribution and abundances of intertidal organisms on rocky shores is recommended.

4.3 Demersal Fish and Mobile Invertebrates

The assemblage of demersal fish and mobile invertebrates in Sandbrook Inlet were not unique and were well represented in other parts of the estuary. That is, the assemblages in Sandbrook Inlet were similar to those at Mullet Creek and upper Mooney Mooney Creek.

The species of economic significance (bream, leatherjacket, sandy sprat and 3 species of prawns) only represented 2.2% of the total catch in numbers.

At both sampling times, the location at the mouth of Mooney Mooney Creek contained quite different assemblages of demersal fish and mobile invertebrate to those of Mooney Mooney Creek Upper and Sandbrook Inlet. Most of the difference was due to variations in the abundance of widespread species such as the glass gobies (*G. semivestita*). It is recommended that, should impacts studies be envisaged that a location at the mouth of Mooney Mooney Creek, the lower Creek might not be appropriate to use as a reference because of its large differences compared to other locations.

In the scientific literature, there have been many factors suggested to explain the variability among fish and mobile invertebrate assemblages, including microhabitat preferences, influence of adjacent habitats, distance from mouth of estuary, predation pressure, larval settlement patterns and fish behaviour to mention a few (summarised in Bell and Pollard, 1989). Without experimental studies, it is not possible to assess further the contribution of these factors to the spatial pattern of fish and invertebrate assemblages in Brooklyn area.

The overall increase in numbers of invertebrate species over time at all sites and locations suggest a large-scale process affected the whole estuary, such as a larvae recruitment episode or factors related to seasonal variations in abundances.

The numbers of species of both invertebrates and fish were significantly different between sites within locations, while their abundances were not. This indicated the presence of significant medium-scale variability in species diversity. Significant variability between sites could hide variation between locations.

The other three survey locations (the entrance to Sandbrook Inlet, Mullet Creek, and upper Mooney Mooney Creek) were not significantly different from each other. This suggests that demersal fish assemblages across the Brooklyn area were similar.

Information on demersal fish abundances and distributions in the Brooklyn region was gained through beam trawl sampling. Demersal fish targeted using beam trawl sampling are likely to remain in the same area as they are less mobile than open water schooling fish caught with different sampling gear. Beam trawling studies have collected consistent numbers of fish, suggesting stable populations (The Ecology Lab 1988, 2002). Therefore reduced tidal flushing in Sandbrook Inlet does not affect the type of demersal fish species and their abundances. It is likely that fishing and possibly assemblages of economically valuable fishes would have been previously affected by changes to habitat, boating activities and fishing pressure. However, given the large swimming range of many fish and the number of factors that can influence fish distributions, it is believed further sampling might not provide additional information.

4.4 Bioaccumulation in Oysters

The following conclusions are made regarding the investigation of bioaccumulation in wild oysters from different locations in the Hawkesbury estuary.

Similar concentrations of most heavy metals except for arsenic, copper, zinc and selenium were detected at locations near Brooklyn (Sandbrook Inlet and Brooklyn Harbour) compared to more remote locations (Mooney Mooney Creek and Mullet Creek).

Bivalves use small amounts of copper in the oxygen carrier hemocyanin. However, the non-significant but greater concentrations of copper found at locations nearer the causeway suggest an anthropogenic effect. Since copper is used in antifouling paints found on boat hulls, extensive boating and maintenance activities are likely to have contributed to increased copper concentration in Brooklyn Harbour and Sandbrook Inlet. The significant difference between sites in Brooklyn Harbour could indicate a large variability at the small scale or insufficient power in the analysis. Recommendations for future studies include greater numbers of replicates to increase the power of the analysis.

Increased arsenic and selenium concentration occurred near Brooklyn, although these were not consistent in time and over small scales. The concentrations of arsenic found in the Brooklyn region overall were similar to those found by Lincoln Smith & Cooper (in prep.) in the Hawkesbury River and were significantly greater than concentrations found in the Hunter River. Although the source of arsenic in the Hawkesbury River is not confirmed, arsenate treated timber used in oyster leases, has been suggested as a possible source.

The increases in zinc concentrations at all locations over times combined with its consistently greater concentrations at location 2 (Brooklyn Harbour) supports the model that Brooklyn Harbour is affected by contaminants. A number of models could explain the increased concentrations in remote locations including the greater diffusion range of zinc compared to other metals. The scope of this study did not provide for further work to examine possible explanations for the results. However many factors could be affecting the distribution of heavy metals in the estuary including some large scale ‘process’ acting on the system such as seasonal variations in water temperature and currents.

In urban areas, sources of heavy metals include storm water canals, industrial discharges and other point sources; however the ultimate source is from contaminated sites and road run-off. Road and rail runoff is a complex mixture of litter, dust, heavy metals such as lead and zinc and organic matter (refer to section 3.3.3 of the EPS).

Scanes & Roach (1999) found similar results at sites in the Hawkesbury in 1998 for concentrations of chromium, lead and arsenic and these were significantly different to industrial sites in the Hunter estuary (Lincoln Smith & Cooper, 2001). Concentrations of zinc and nickel were smaller in the present study compared to sites in the Hawkesbury in 1988 (Scanes & Roach (1999) and were significantly different to sites in the Hunter River (Lincoln Smith & Cooper, 2001).

PAHs are potentially carcinogenic chemicals that are formed during the incomplete burning of coal, oil and gas, garbage, or other organic substances like tobacco or charbroiled meat. The absence of detectable levels of PAHs at the Sandbrook Inlet location corresponds to the non-industrial status of the study area.

Brooklyn Harbour and Sandbrook Inlet locations accounted for most of the significant increases in heavy metals detected in oysters. This supports the conclusion that locations nearer the causeway were more contaminated than remote locations. However, small scale and temporal variation suggested no consistent pattern in results. Recommendations for further investigations of ecosystem health included maintaining consistency of sampling methods and choice of locations so that different times can be compared and trends can be more accurately interpreted. It is recommended that the potential sources of heavy metal contamination be investigated and for periodic monitoring of heavy metal bioaccumulation.

This report contains no discussion of water quality for the Brooklyn region because this assessment was outside the scope of this study.

5.0 ECOSYSTEM HEALTH

The Brooklyn region is part of the expansive Hawkesbury River estuary system with a water body greater than 100 km^2 and a large opening to the sea. Estuarine health in the Brooklyn region is influenced by a variety of factors ranging from urban development, such as loss of habitat, sewage seepage from septic tanks, and storm water runoff, to inputs from agriculture, coal mining and industrial discharges (Mercer *et al.*, 1993).

The medium level urban foreshore development at Brooklyn Harbour, Sandbrook Inlet and Dangar Island are likely to have a negative effect on the estuarine health of the region. In contrast, the undeveloped aspect of Mullet Creek and Mooney Mooney Creek would have a low negative impact on estuarine health (Table 8).

Most of the foreshore development consisted of private hillside residences with jetties, slipways and moorings. A consequence of residential development is the potential for sewage seepage from septic tanks into the estuary following heavy rainfall. This study did not assess indicators of sewage contamination.

Mangrove forests are abundant throughout the study area and have increased over the last 15 years since the construction of the freeway bridge near Mooney Mooney Creek and land reclamation. Mangrove stands near the west fringe of Spectacle Island and at Mooney Mooney Point have increased in size significantly (Table 8). The leaf biomass for common grey mangroves in the Hawkesbury River of 40 kg/m^2 is the highest recorded for temperate forest communities. The distribution of mangrove forest in the study area and their general state of health are stable and positive

Seagrass beds were present in the study area at a number of locations including Sandbrook Inlet, Brooklyn Harbour, Dangar Island and the Head of Mullet Creek. The dominant seagrass was *Zostera capricorni* (eelgrass). The cover of seagrasses has increased over the 16 years of available data (Table 12). Additional beds were recorded east of Kangaroo Point and south of Dangar Island by William & West (2001) not recorded by West et al. (1985). The seagrass bed in Brooklyn Harbour appeared healthy with a low epiphyte load (The Ecology Lab 2002) while the beds in Mullet Creek had some epiphyte load. No other information exists on the health of seagrass beds. A better understanding of the health of seagrass beds could be gained through studying the maximum depth of beds, shoot density, shoot morphology and epiphyte cover of each bed. Decreases in water clarity affect the vertical distribution of seagrass. Seagrasses also require minimum concentrations of nutrients for growth. However, excessive levels of nutrients increase water turbidity and causes significant growth of epiphytic algae on seagrass leaves which reduces the surface available for photosynthesis.

Only recent information from 1999 and 2001 is available on the distribution of salt marsh habitat in the Brooklyn study area. The largest stands of saltmarsh were located at the head of Mooney Mooney Creek although small stands exist on both banks in Sandbrook Inlet (Table 12). No conclusions can be drawn regarding the stability of saltmarsh distribution without earlier data. The saltmarsh species present were typical for the area. No information exists on the state of health of these saltmarsh communities.

In summary, the area of wetland vegetation has remained constant of showed some increase in different parts of the study area, suggesting that the habitats are being maintained.

Intertidal benthic assemblages from mangrove habitats were different between the eastern and the western ends of Sandbrook Inlet (Lasiak & Underwood 2002). Both these locations were also different to locations in Mooney Mooney Creek and Mullet Creek. Different taxa rather than lower abundances accounted for most of this difference. A study by Jones *et al.* (1986) found the benthos of Sandbrook Inlet to be depauperate compared to other locations in the Hawkesbury River. Lasiak & Underwood (2002) did not sample Brooklyn Harbour, which was found to be depauperate compared to locations further from human disturbances (Jones 1986, The ecology Lab 2002). Many factors could be influencing the abundance and distribution of benthic animals such as the level of anthropogenic disturbance, decreased tidal flushing, larvae availability and predation. Generally, low species diversity is typical of highly disturbed environments.

The intertidal rocky shore invertebrate communities were significantly different either side of the causeway. This difference could be the result of a number of natural factor as well as anthropogenic pressures. To better understand what influences the distribution of animals on intertidal rocky shores in the Brooklyn area, further studies involving more locations having similar natural aspects (rock type, wave, wind and exposure) could be done.

The state of the Brooklyn region in terms of demersal fish species distributions and abundances is difficult to assess given the highly variable catch rates from beam trawling and beach seines studies (Table 8). The Ecology Lab did, however, find similar species of fish in this study and in 1988 suggesting some stability in populations. The assemblages of demersal fish and mobile invertebrates found in Sandbrook Inlet and Brooklyn Harbour in the present study were not different to other parts of the estuary. Therefore, factors other than proximity to Sandbrook Inlet (e.g. habitat cover or food availability) could be affecting the distribution of demersal fish and mobile invertebrates in the Brooklyn area. No information is available on the health of fish populations in the region. Information on the size and age of individual fish as well as the size of whole populations and their movements through time would be required to assess fish stock health.

Gobies were the most abundant group of fishes (Gehrke & Harris 1996; The Ecology Lab 1988), while shrimps were the most abundant demersal invertebrate group (The Ecology Lab 1988 & 2002). Fishes of economic importance collected in the Brooklyn area included mullet, bream, whiting, tailor, flounder, leatherjacket, mulloway and sandy sprat (Booth & Schultz 1997; Gehrke & Harris 1996; The Ecology Lab 2002). Demersal invertebrates of economic importance included eastern king prawns, school prawns, greasyback prawns and king prawns (The Ecology Lab 1988 & 2002).

The study of bioaccumulation in wild oysters found significantly greater concentrations of arsenic, copper and zinc in Brooklyn Harbour and selenium and copper in Sandbrook Inlet compared to Mooney Mooney Creek and Mullet Creek, while PAHs were not detected in the study area. The proximity of Sandbrook Inlet and Brooklyn Harbour to the Brooklyn urban area and associated roads and railways could explain the higher concentrations of heavy metals detected in oysters.

Copper is used in antifouling paints on the hulls of boats. The significantly higher concentration of copper found in oysters from Brooklyn Harbour indicates that boating in Brooklyn Harbour is probably having an impact on copper concentration in the water. A previous study on water quality in the Sandbrook Inlet found levels of copper and arsenic to be exceeding ANZECC guideline (The Ecology Lab 1997).

Boat traffic is probably greater during the weekends and holiday seasons when the number of recreational boat users increases. The significantly higher concentrations of zinc in Brooklyn Harbour detected after the summer holiday period could be explained by the increased boat and car traffic during that period.

Copper and arsenic concentrations in oysters from Sandbrook Inlet and Brooklyn Harbour exceeded maximum ANZFA food standards. The reduced tidal flushing in Sandbrook Inlet could increase the residence time of pollutants within the inlet. Further studies are recommended to assess long term trends in pollutants. It is likely that environmental threats to aquaculture have decreased since TBT was partially banned.

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PLATES

Plate 1. Oyster leases, Mullet Creek.

Plate 2. Mangroves in the foreground, backed by typical hillside vegetation in the Brooklyn Estuary.

Plate 3. Railway Causeway, Sandbrook Inlet (inner) side.

Plate 4: Railway Causeway, Brooklyn Harbour (outer) side.

Plate 1. Oyster leases, Mullet Creek.

Plate 2. Mangroves in the foreground, backed by typical hillside vegetation in the Brooklyn Estuary.

Plate 3. Railway Causeway, Sandbrook Inlet side

Plate 4. Railway Causeway, Brooklyn Harbour side.

TABLES

Table 1: Summary of studies on riparian and aquatic flora relevant to the Brooklyn area of the Hawkesbury River estuary.

Sp. Surveyed	Year	Study Location	Comments	Author
Mangrove and saltmarsh species	1977	Sandbrook Inlet	Aerial photographs (1941-1970) were used to assess changes in mangrove distribution.	Hutchings *et al.*
Mangrove communities	1988,& 1997	Sandbrook Inlet	Changes in mangrove communities were assessed using a time series of aerial photographs Field assessment of the composition of intertidal algal and the distribution of subtidal seagrass communities	The Ecology Lab
Vegetation communities	1990	Hornsby Shire	Mapped and identified	Smith & Smith at Hornsby Shire
Mangrove, saltmarsh and seagrass communities	2000	McKell Park, Brooklyn	Environmental Impact Study used field inspections and aerial photographs to examine the extent of vegetation.	Nexus 2000
Mangrove, saltmarsh and seagrass communities	2000	Brooklyn Estuary and Dangar Island	Mapped vegetation combining aerial photographs and fields surveys.	SMEC
Estuarine habitats	1985	Brooklyn estuary	Mapped from aerial photographs taken in 1979 and field surveys in February 1982	West *et al*.
Estuarine habitats	1999	Sandbrook Inlet, Spectacle Island & Mooney Mooney Point.	GIS mapping of West 1985 maps and field surveys in 1999	Williams & Watford
Estuarine habitats	2001	rest of Brooklyn Estuary	GIS mapping	Williams & West
Avicennia marina and *Aegiceras corniculatum*	1997	several sites Hawkesbury River	Above and below-ground biomasses of A.M. and A.C. & their relation to soil water salinity	Saintilan
Seagrass	1997	adjacent estuaries	information on seagrass health	Silberschneider
Flora	1996	Hawkesbury estuary	Searched 'Atlas of NSW Wildlife' for flora records and species protected under the *Threatened Species Conservation* (*TSC*) Act, 1995	NSW National Parks and Wildlife,

Table 2: Summary of studies on aquatic fauna relevant to the Brooklyn area of the Hawkesbury River estuary.

Component Surveyed	Year	Study Location	Comments	Author
Estuarine zooplankton	1979	Brooklyn estuary	Ecology	Bugler
Estuarine zooplankton	1995	adjacent Hawkesbury estuaries.	Ecology	AWT Ensight
Fauna	1996	Hawkesbury estuary	Searched 'Atlas of NSW Wildlife' for flora records and species protected under the *Threatened Species Conservation* (*TSC*) Act, 1995	NSW NPWS
Invertebrates and fishes	1977	Sandbrook Inlet	Four transects laid through mangrove forests.	Hutchings *et al*.
Mangrove fauna	1988, 1997	Sandbrook Inlet	Sampling subtidal benthos, mobile invertebrates and birds.	The Ecology Lab
Semaphore crab, *Heloecius cordiformis*	2000	Sandbrook Inlet	Bio-indicator tests	MacFarlane *et al*.
Subtidal benthic invertebrates	1986	Brooklyn Estuary	Sampled pre-and post-maintenance dredging and spoil disposal	Jones
Soft-sediment zoobenthos	1986	Brooklyn Estuary	Iidentified from replicate grabs taken in the estuary to examine spatial patterns in macrobenthos	Jones *et al*.
Soft-sediment zoobenthos	1987	Brooklyn Estuary	Identified from replicate grabs taken in the estuary to examine temporal patterns in macrobenthos	Jones
Soft-sediment zoobenthos	1988	Brooklyn Estuary	Examined patterns associated with salinity and sediment grade	Jones
Corophid amphipod	1998	Brooklyn Estuary	Bio-indicator test	Hyne & Everett
Notospisula trigonella	1988	Brooklyn Estuary	Spatial and temporal patterns in populations of a dominant bivalve collected in the estuary	Jones *et al*
Polychaetes	1984	Hawkesbury River and other central NSW estuaries	Compiled taxonomic key	Hutchings & Murray
Fishes	1996	entire Hawkesbury-Nepean River	identified and recorded	Gehrke & Harris
Prawn trawl by-catch	1990	several locations along the Hawkesbury River	Composition, distribution and abundance	Gray *et al*.
Subtidal fish assemblages	1997	Hawkesbury River estuaries	Beach seines	Booth & Schultz
Commercially important fishes	1997	Hawkesbury River estuaries	Ecological data: growth, distribution and diet	Silberschneider
Common birds	2000	Brooklyn estuary	Inventory	Powell & Powell
Birds	1977	Brooklyn	Summarised casual observations of birds over 8yrs	Hutchings *et al*.
Threatened terrestrial fauna	2000	Brooklyn and Dangar Island	Database searches supplemented by field inspections	Nexus 2000; SMEC 2000

Table 3. Results of three factor ANOVAs on selected intertidal species. Factors were: Zone (High or

Total Abundance Transform: None

Source	df	MS	F	F versus
Zo	1	210924.67	114.69	Zo x Si(Lo)
Lo	1	199349.008	4.22	Si(Lo)
Si(Lo)	4	47262.7917	**14.41***	Res
Zo x Lo	1	71394.4083	**38.82***	Zo x Si(Lo)
Zo x Si(Lo)	4	1839.1417	0.56	Res
Tot	108	3280.0009		

SNK tests. Zo x Lo: Low zone; outer > inner, High zone: outer >> inner. Si(Lo): Outer 1>>2, 2=3, 1>>3.
Cochran's test: C = 0.3725 (P<0.01)

Total taxa Transform: None

Source	df	MS	F	F versus
Zo	1	177.63	48.23	Zo x Si(Lo)
Lo	1	145.20	5.67	Si(Lo)
Si(Lo)	4	25.60	18.43	Res
Zo x Lo	1	32.03	**8.7***	Zo x Si(Lo)
Zo x Si(Lo)	4	3.68	**2.65***	Res
Tot	108	24.79		

SNK tests. Zo x Si(Lo): High zone; Outer 1=2=3, Inner 1=2<<3. Low zone; Outer 1<2=3, Inner 1>2<<3. Zo
Cochran's test: C = 0.2160 (P<0.05)

Saccostrea commercialis (live) Transform: None

Source	df	MS	F	F versus
Zo	1	11781.01	78.68	Zo x Si(Lo)
Lo	1	10735.21	77.94	Si(Lo)
Si(Lo)	4	137.73	0.63	Res
Zo x Lo	1	10028.41	**66.98***	Zo x Si(Lo)
Zo x Si(Lo)	4	149.73	0.68	Res
Tot	108	219.95		

SNK tests. Zo x Lo: High zone; Outer = Inner, Low zone; Outer>> Inner
Cochran's test: C = 0.4583 (P<0.01)

Saccostrea commercialis (dead) Transform: None

Source	df	MS	F	F versus
Zo	1	1353.41	28.94	Zo x Si(Lo)
Lo	1	1209.68	24.19	Si(Lo)
Si(Lo)	4	50.02	1.85	Res
Zo x Lo	1	891.08	**19.05***	Zo x Si(Lo)
Zo x Si(Lo)	4	46.77	1.73	Res
Tot	108	27.08		

SNK tests. Zo x Lo: High zone; Outer = Inner, Low zone; Inner > Outer.
Cochran's test: C = 0.4826 (P<0.01)

Table 3, con't. Results of three factor ANOVAs on selected intertidal species. Factors were: Zone (High or Low), Location (Brooklyn or Sandbrook), and Site within Location. * = significant at P<0.05. "<" or ">" = signifcant at 0.05, "<<" or ">>" =significant at 0.01.

Bembcium nanum Transform: None

Source	df	MS	F	F versus
Zo	1	9.08	0.10	Zo x Si(Lo)
Lo	1	285.21	4.66	Si(Lo)
Si(Lo)	4	61.16	2.82	Res
Zo x Lo	1	33.08	0.36	Zo x Si(Lo)
Zo x Si(Lo)	4	92.53	**4.26***	Res
Tot	108	21.70		

SNK tests. Zo x Si(Lo): High zone; outer 1>>2=3, inner 1=2=3. Low zone; outer1=2 2<<3 1<3, inner 1=2=3

Cochran's test: C = 0.6110 (P<0.01)

Bembicium auratum Transform: None

Source	df	MS	F	F versus
Zo	1	48200.21	29.72	Zo x Si(Lo)
Lo	1	11574.41	6.21	Si(Lo)
Si(Lo)	4	18643.13	**21.41***	Res
Zo x Lo	1	59185.21	**36.5***	Zo x Si(Lo)
Zo x Si(Lo)	4	1621.63	1.86	Res
Tot	108	870.88		

SNK tests. Zo x Lo: High zone; outer = inner, low zone: outer >>inner. Si(Lo): Outer 1>>2<<3, Inner 1=2=3.

Cochran's test: C = 0.3621 (P<0.01)

Mytilus edulis

Source	df	MS	F	F versus
Zo	1	252.30	2.59	Zo x Si(Lo)
Lo	1	464.13	2	Si(Lo)
Si(Lo)	4	231.56	9.34	Res
Zo x Lo	1	252.30	2.59	Zo x Si(Lo)
Zo x Si(Lo)	4	97.28	**3.92***	Res
Tot	108	1.39		

SNK tests. Zo x Si(Lo): High zone; outer 1=2=3, inner 1=2<3. Low zone; outer 1=2=3, inner1=2<<3.

Cochran's test: C = 0.6300 (P<0.01)

Table 4. Results of two factor ANOVAs on selected intertidal species. Factors were: Location (Brooklyn or Sandbrook), and Site within Location. * = significant at P<0.05. "<" or ">" = signifcant at 0.05, "<<" or ">>" =significant at 0.01.

Chamaesipho tasmanica (low zone) Tranform: Ln(X+1)

Source	df	MS	F	F versus
Lo	1	33.61	2.44	Si(Lo)
Si(Lo)	4	13.80	**7.1***	Res
Tot	54	1.9429		

SNK tests. Si(Lo): outer 1=2=3, inner 1=2<<3
Cochrans test: C = 0.3626 (Not Significant)

Patelloida mimula (low zone) Transform: None

Source	df	MS	F	F versus
Lo	1	37.89	**19.83***	Si(Lo)
Si(Lo)	4	1.91	**2.76***	Res
Tot	54	0.6926		

SNK tests. Si(Lo): outer 1<2=3, inner 1=2=3. Lo: outer>inner.
Cochrans test: C = 0.3415 (Not Significant)

Noddilitorina unifasicata (high zone) Transform: None

Source	df	MS	F	F versus
Lo	1	21.60	**9.00***	Si(Lo)
Si(Lo)	4	2.40	0.68	Res
Tot	54	3.5037		

SNK tests. Lo: outer > inner.
Cochrans test: C= 0.3911 (P<0.05)

"<" or ">" = signifcant at 0.05, "<<" or ">>" =significant at 0.01.

Table 5: SIMPER results for those ANOSIM pairwise comparisons of fish and mobile invertebrates that showed strong differences in community structure (i.e. those that had pairwise R-values ≥ 0.75). Species are listed in descending order of their Dissimilarity Index ("Diss/SD"). The higher the Dissimilarity Index of a species, the better that species is at discriminating between the samples. Diss/SD cut-off for species listed = 1.4. The "% Contribution" indicates the percent contribution that a particular species made to the total average dissimilarity.

Comparison	Species	Diss/SD	% Contribution
SIIS vs MMCL	*Favonigobius exquisitus*	6.57	5.39
	Pseudogobius olorum	2.2	10.08
	Gobiopterus semivestita	1.89	8.98
	Favonigobius tamarensis	1.5	3.28
	Lucifer sp.	1.47	2.39
MMCL vs MMCU	*Favonigobius exquisitus*	5.52	5.04
	Pseudogobius olorum	1.74	7.91
	Hyperlohus vittatus	1.49	4.96
	Rhopalopthalmus brisbanensis	1.45	5.86
	Gobiopterus semivestita	1.41	4.77
Time 1 vs Time 2	*Penaeus plebejus*	3.38	6.69
	Spisula trigonella	1.94	5.08
	Metapenaeus macleayi	1.66	4.00
	Gobiopterus semivestita	1.55	7.76
	Rhopalopthalmus brisbanensis	1.45	7.12

Table 6: Summary of the three-way partially hierarchical ANOVA results for the beam trawl results.
* = Significance at Alpha = 0.05
** = Significance at Alpha = 0.01
__ = Redundant term due to significant interactive term

Total Abundance

Source	
Ti	NS
Lo	NS
Si(Lo)	NS
TiXLo	NS
TiXSi(Lo)	NS

No. of Invertebrate Species

Source	
Ti	*
Lo	NS
Si(Lo)	NS
TiXLo	NS
TiXSi(Lo)	NS

Abundance of Invertebrates

Source	
Ti	NS
Lo	NS
Si(Lo)	NS
TiXLo	NS
TiXSi(Lo)	NS

No. of Fish Species

Source	
Ti	__
Lo	__
Si(Lo)	__
TiXLo	NS
TiXSi(Lo)	*

No. of Economic Species

Source	
Ti	__
Lo	__
Si(Lo)	__
TiXLo	
TiXSi(Lo)	*

Abundance of Economic Species

Source	
Ti	NS
Lo	NS
Si(Lo)	NS
TiXLo	NS
TiXSi(Lo)	NS

Total Number of Taxa

Source	
Ti	__
Lo	__
Si(Lo)	__
TiXLo	NS
TiXSi(Lo)	*

Abundance of *A. sibogae australis*

Source	
Ti	NS
Lo	NS
Si(Lo)	NS
TiXLo	NS
TiXSi(Lo)	NS

% Abundance of Economic Species

Source	
Ti	__
Lo	__
Si(Lo)	__
TiXLo	NS
TiXSi(Lo)	*

Abundance of Fish

Source	
Ti	__
Lo	__
Si(Lo)	__
TiXLo	*
TiXSi(Lo)	NS

Abundance of *Lucifer sp.*

Source	
Ti	NS
Lo	NS
Si(Lo)	NS
TiXLo	NS
TiXSi(Lo)	NS

Abundance of *R. brisbanensis*

Source	
Ti	__
Lo	__
Si(Lo)	__
TiXLo	NS
TiXSi(Lo)	**

Abundance of *G. semivestita*

Source	
Ti	__
Lo	__
Si(Lo)	__
TiXLo	**
TiXSi(Lo)	NS

Abundance of *P. olorum*

Source	
Ti	NS
Lo	NS
Si(Lo)	NS
TiXLo	NS
TiXSi(Lo)	NS

Abundance of Comb Jellies

Source	
Ti	NS
Lo	NS
Si(Lo)	NS
TiXLo	NS
TiXSi(Lo)	NS

Table 7. ANOVA of heavy metals bioaccumulation in oysters sampled at 2 sites nested in 4 locations at 2 times within the Hawksbury estuary, n=4. The analysis did not provide for a test of location. For some metals, the elimination of non-significant interactions (when P>0.25) , did result in a test for location.

A) **Arsenic** No transform, Cochran's C = 0.1619 (not significant)

Source of Variation	df	SS	MS	F	P	F vs.
ti	1	0.078	0.078	4.690	0.035	RES
lo	3	0.529	0.176	Re	Re	NO TEST
si(lo)	4	0.055	0.014	0.830	0.515	RES
tiXlo	3	0.170	0.057	3.380	0.026	RES
*tiXsi(lo)	4	0.040	0.010	0.600	0.666	RES
Residual	48	0.801	0.017			
SNK Test:		time(location):			location(time):	
Times x location		L1: T1=T2	L2: T1<T2		T1: L3=L4=L2=L1	
		L3: T1=T2	L4: T1=T2		T2: L3=L1=L4<L2	

B) **Cadmium** No transform, Cochran's C = 0.2352 (not significant)

Source of Variation	df	SS	MS	F	P	F vs.
Source	1	0.002	0.002	3.400	0.071	RES
ti	3	0.018	0.006	Re	Re	NO TEST
lo	4	0.003	0.001	1.600	0.190	RES
si(lo)	3	0.003	0.001	1.800	0.160	RES
tiXlo	4	0.002	0.001	0.980	0.426	RES
*tiXsi(lo)	Re	48	0.023	0.001		

C) **Chromium** No transform, Cochran's C = 0.4283 (P < 0.01)

Source of Variation	df	SS	MS	F	P	F vs.
Source	1	0.001	0.001	0.41	0.524	RES
ti	3	0.014	0.005	2.65	0.060	RES
lo	4	0.006	0.001	0.82	0.517	RES
*si(lo)	3	0.006	0.002	1.12	0.351	RES
*tiXlo	4	0.005	0.001	0.77	0.552	RES
*tiXsi(lo)	RES	48	0.082	0.002		

Table 7, continued.

D) **Copper** No transform, Cochran's C = 0.2392 (not significant)

Source of Variation	df	SS	MS	F	P	F vs.
ti	1	64.0	64.0	0.29	0.618	tiXsi(lo)
lo	3	37039.3	12346.4	5.25	0.072	si(lo)
si(lo)	4	9407.3	2351.8	10.72	0.021	tiXsi(lo)
*tiXlo	3	743.5	247.8	1.13	0.437	tiXsi(lo)
tiXsi(lo)	4	877.8	219.4	2.28	0.075	RES
RES	48	4628.0	0.02			
SNK Test:		Site (location):				
Site (location)		L1: S1=S2	L3: S1=S2			
		L2: S1<S2	L4: S1=S2			

E) **Lead** Ln(X) transformed, Cochran's C = 0.1783 (not significant)

Source of Variation	df	SS	MS	F	P	F vs.
Source	1	0.001	0.001	1.61	0.273	tiXsi(lo)
ti	3	0.008	0.003	2.08	0.246	si(lo)
lo	4	0.005	0.001	2.87	0.166	tiXsi(lo)
si(lo)	3	0.001	0.000	0.33	0.803	tiXsi(lo)
*tiXlo	4	0.002	0.001	1.92	0.122	RES
tiXsi(lo)	RES	48	0.012	0.000		

F) **Mercury** No transform, Cochran's C = 0.3793 (P < 0.01)

Source of Variation	df	SS	MS	F	P	F vs.
Source	1	0.0001	0.0001	1.96	0.234	tiXsi(lo)
ti	3	0.0006	0.0002	Re	Re	NO TEST
lo	4	0.0001	0.00	0.84	0.565	tiXsi(lo)
si(lo)	3	0.0001	0.00	1.11	0.444	tiXsi(lo)
*tiXlo	4	0.0002	0.00	2.59	0.049	RES
tiXsi(lo)	RES	48	0.0007	0.00		

Table 7, continued.

G) **Nickel** Ln(X) transformed, Cochran's C = 0.2589 (not significant)

Source of Variation	df	SS	MS	F	P	F vs.
Source	1	0.267	0.267	3.73	0.059	RES
ti	3	0.602	0.201	1.57	0.328	si(lo)
lo	4	0.509	0.127	1.78	0.148	RES
si(lo)	3	0.104	0.035	0.48	0.696	RES
*tiXlo	4	0.204	0.051	0.71	0.588	RES
*tiXsi(lo)	RES	48	3.437	0.072		

H) **Selenium** No transform, Cochran's C = 0.1777 (not significant)

Source of Variation	df	SS	MS	F	P	F vs.
Source	1	0.007	0.007	1.33	0.254	RES
ti	3	0.153	0.051	Re	**Re**	NO TEST
lo	4	0.058	0.015	2.69	0.042	RES
si(lo)	3	0.062	0.021	3.81	0.016	RES
tiXlo	4	0.025	0.006	1.16	0.342	RES
*tiXsi(lo)	RES	48	0.257	0.005		

SNK Test:	time(location):	location(time):
Times x location	L1: T1=T2 L3: T1=T2	T1: L1>L2=L3=L4
	L2: T1<T2 L4: T1=T2	T2: L3<L1=L2=L4
Site(location)	L1: S1>S2 L3: S1=S2	
	L2: S1=S2 L4: S1=S2	

I) **Zinc** No transform, Cochran's C = 0.1595 (not significant)

Source of Variation	df	SS	MS	F	P	F vs.
ti	1	62500.0	62500.0	19.51	0.012	tiXsi(lo)
lo	3	238781.3	79593.8	24.85	0.005	tiXsi(lo)
*si(lo)	4	7962.5	1990.6	0.62	0.672	tiXsi(lo)
*tiXlo	3	14337.5	4779.2	1.49	0.345	tiXsi(lo)
tiXsi(lo)	4	12812.5	3203.1	2.03	0.105	RES
RES	48	75700.0	1577.1			

SNK Test:	Times	Location
	T1<T2	L3=L4=L1<L2

Table 8: Summary of Brooklyn Estuary ecosystem health using biotic indicators and pressure factors. Trends have been given using one of the following four values:

⇔ = stable, ↑↓ = variable 👍 = improving, 👎 = worsening, ? = insufficient data.

Indicator **Habitat Integrity Index**	**Value**	**Comment**	**Trend**
Seagrass species present	Eelgrass - *Zostera capricorni* (most abundant) Strap weed - *Posidonia australis* paddleweed - *Halophila* sp	Eelgrass dominated. paddleweed present in Mullet Creek only.	👍
Seagrass coverage	Sandbrook Inlet 0.64 ha (TEL 1997), 0.74 ha (William & Watford 1999) Brooklyn Harbour 1.7 ha (Nexus 2000), 2.37 ha (TEL 2002) Dangar Island 9.4 ha (Fisheries 1994), Mullet Creek 2.1 ha - increased from (West *et al*. 1985) to (William & West 2001)		👍
Mangrove species present	grey mangroves - *Avicennia marina* (most common) river mangroves - *Aegiceras corniculatum*	Shoot biomass: (40kg/m^{2}) - highest recorded for temperate forest.	
Mangrove coverage	Sandbrook Inlet – 12.3 ha (West *et al*. 1985; Williams & Watford,1999) West Spectacle I. & Mooney Mooney Pt. – 9.6 ha. Mooney Mooney Creek 54.29 ha & Mullet Creek - 6.68 ha	new patches Spectacle I. unchanged 16 yrs	👍 ⇔
Saltmarsh species present	Samphire – *Sarcacornia quinqueflora* Sea rush - *Juncus kraussii*) Sand couch - *Sporobolus virginicus* Native reed - *Phragmites australis* Swamp oak - *Casuarina glauca* Broad-leafed paper-bark - *Maleleuca quinquenervia*	widespread decline in saltmarsh communities is often associated with invasion by grey mangroves (Saintilan 2000).	
Saltmarsh coverage	Long Island – 0.91 ha (Williams & Watford 1999) Sandbrook Inlet South – 0.53 ha (Williams & Watford 1999) Sandbrook Inlet west – 0.37 ha Head of Mooney Mooney Creek, (Williams & West 2001) North West arm – 0.5 ha East arm – 2.5 ha Patches North West totaling – 0.7 ha		?

Table 8: Continued

Indicator Aquatic Fauna	Value	Comment	Trends
Demersal Fish	Beam trawl– inundated mudflat habitat: 14 fish species (Brooklyn EPS, TEL 2002), 14 fish species - Sandbrook Inlet (TEL 1988) Beach seines: 27 fish species Sandbrook Inlet (TEL 1988) 31 fish species – Sandbrook Inlet (Booth & Schultz, 1997) Beam trawl & beach seines: demersal & pelagic fish 90 fish species – Broken Bay (Gehrke & Harris 1996)	Number of fish species caught highly variable. Beam trawling & beach seines best catch methods. Gill netting ineffective method. Gobies most abundant fish.	↑↓ ?
Demersal Macroinvertebrate	Beam trawl 32 invertebrate species (Brooklyn EPS, TEL 2002) – inundated mudflat habitat. Beam trawl 21 invertebrate species – Sandbrook Inlet (TEL 1988)	Number of invertebrate species caught highly variable. Mysid and pelagic shrimp most abundant group.	↑↓ ?
Intertidal hard substratum invertebrates	Causeway at Brooklyn Harbour – 9 species (Brooklyn EPS, TEL 2002) Causeway on Sandbrook Inlet – 4 species (Brooklyn EPS, TEL 2002)	Few studies on rocky shores in Brooklyn area. Species found common to Sydney. Sandbrook Inlet depauperate compared to Brooklyn Harbour.	?
Intertidal (1) and subtidal (2) soft substratum invertebrates	1Brooklyn Harbour - 27 species (Hutchings et al. 1977) Seymour Creek – more specious than south of inlet 2 Brooklyn Harbour & Sandbrook Inlet – 26 species (TEL 1988) 1&2 Hawkesbury River Survey - taxonomic key (Hutchings & Murray 1984)	Brooklyn Harbour relatively depauperate compared to rest of Brooklyn region.	⇔
Heavy Metals Bioccumulation in oysters	Zinc, copper, arsenic and selenium were present in Brooklyn Harbour and Sandbrook Inlet in greater concentration than in Mooney Mooney Creek and Mullet Creek locations. Consistent with Hardiman and Pearson (1995) findings.	Elevated copper concentration likely due to boating. Monitoring recommended.	⇔ ?
PAH bioaccumulation	Polycyclic aromatic hydrocarbons (PAH) were below detectable levels.	Corresponding with non-industrial status of Brooklyn area	👍👍

Table 8 Continued.

Pressure component	Description	Value
Oyster Leases	Larger leases in Sandbrook Inlet and Brooklyn Harbour. Most leases in Mullet Creek and Mooney Creek.	Total area: 399 ha
Foreshore Development		**Level of urbanisation**
Main Estuary	Foreshore between Brooklyn Wharf and Parsley Bay developed with a marina and public boat ramp. Little Wobby Beach had private hillside residences, sandstone seawalls, jetties, private boat harbour.	Medium
Brooklyn Harbour	Highly developed: Artificial rock walls, extensive marina, jetties and about 50 moorings.	Medium/High
Dangar Island	The entire foreshore had private hillside residences with jetties and moorings.	Medium
Mullet Creek	Less then 12 private residences along entire foreshore concentrated at Wondabyn Station.	Low
Mooney Mooney Creek	Foreshore development along creek scattered. Entire headland covered with hillside residences, seawalls, jetties, slipways and moorings.	Low
Sandbrook Inlet	Around 300 boats moored. Entire foreshore along Brooklyn had private hillside residences. Inlet permanently blocked at eastern end by Rail causeway. Remainder underdeveloped.	Medium/High

FIGURES

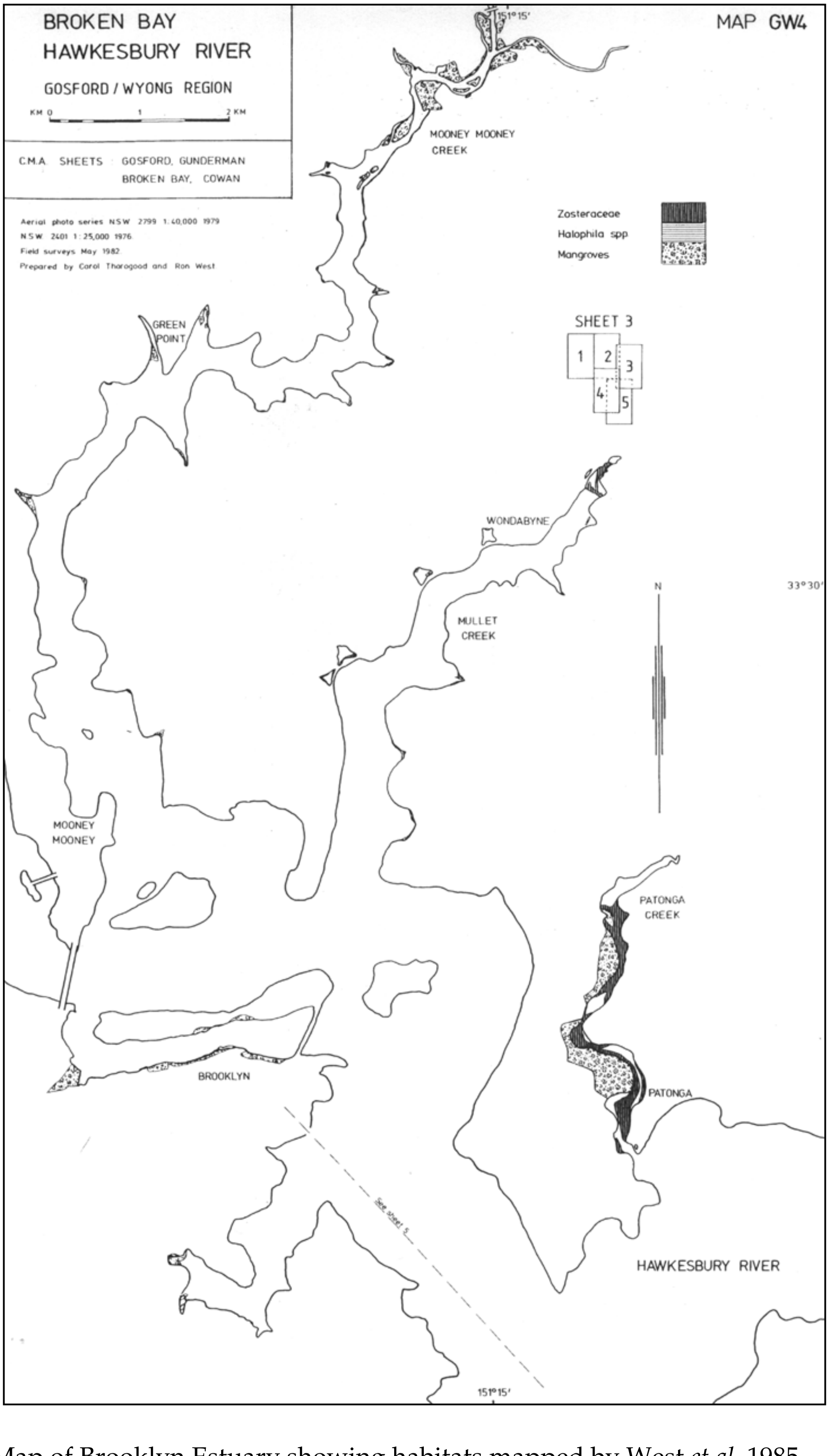


Figure 1: Map of Brooklyn Estuary showing habitats mapped by West *et al*. 1985.

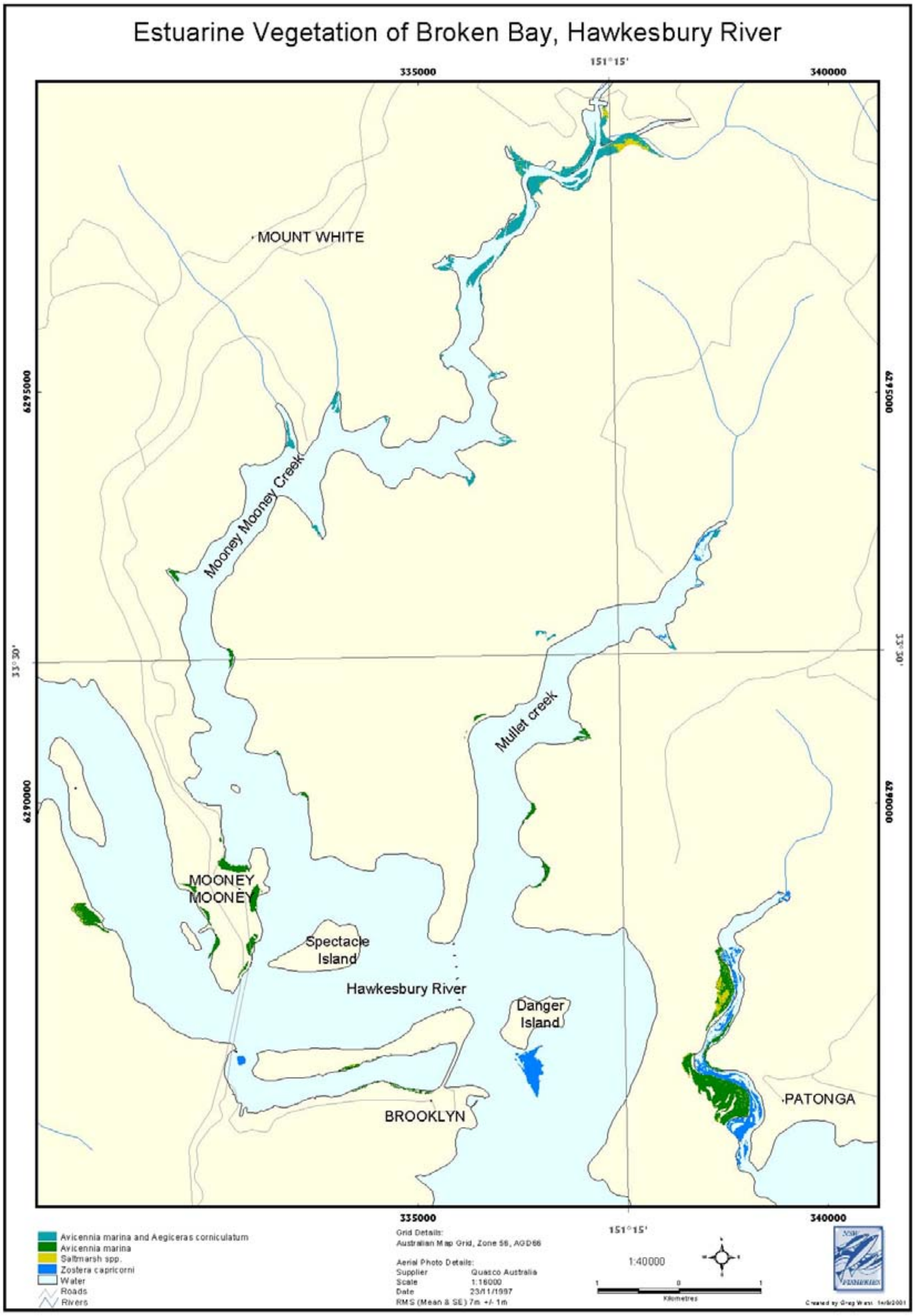


Figure 2. Map of Brooklyn Estuary showing habitats mapped by Williams & West 2001.

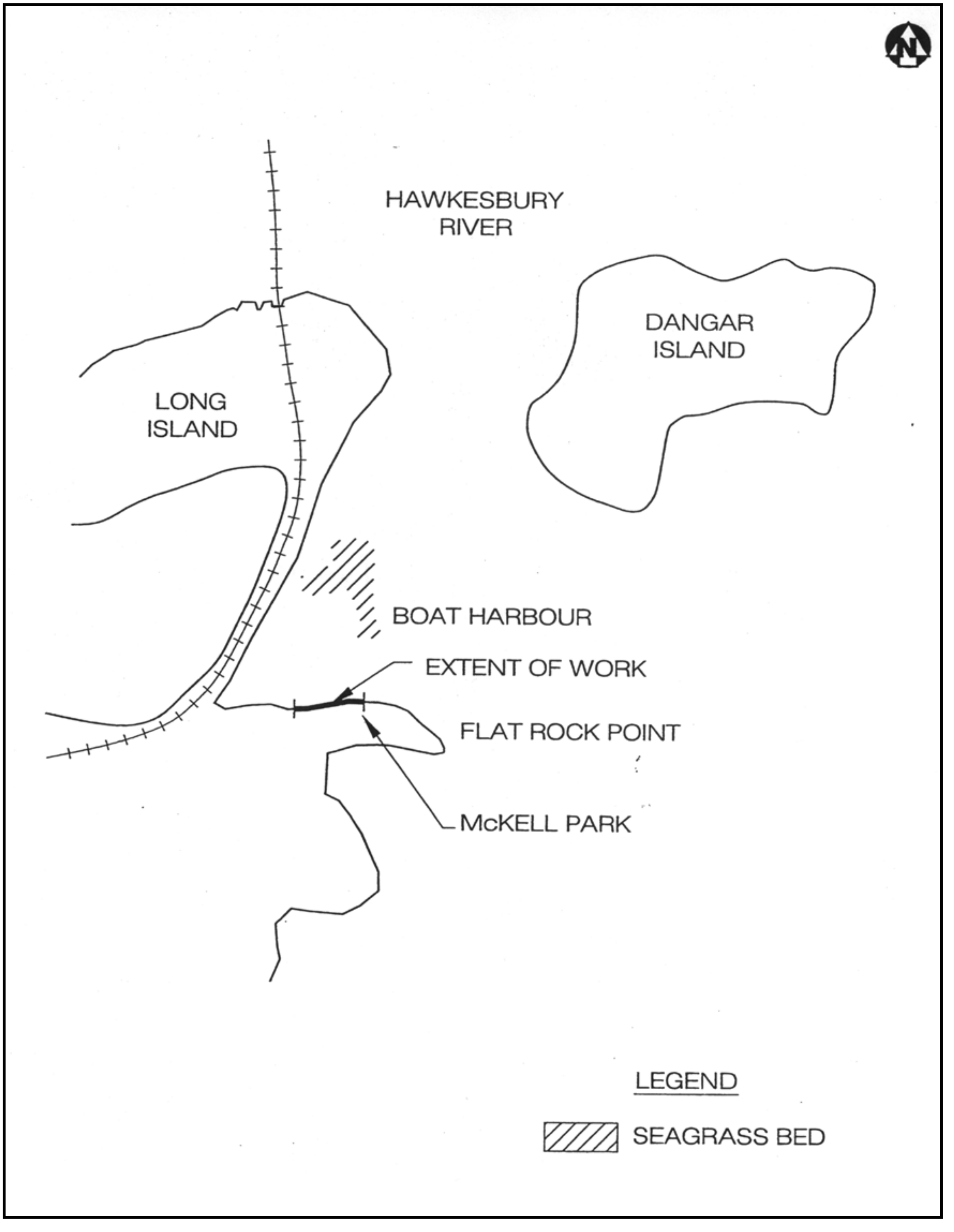


Figure 3. Map of Brooklyn Estuary showing habitats mapped by Nexus 2000 and SMEC 2000 (Source: Nexus 2000).

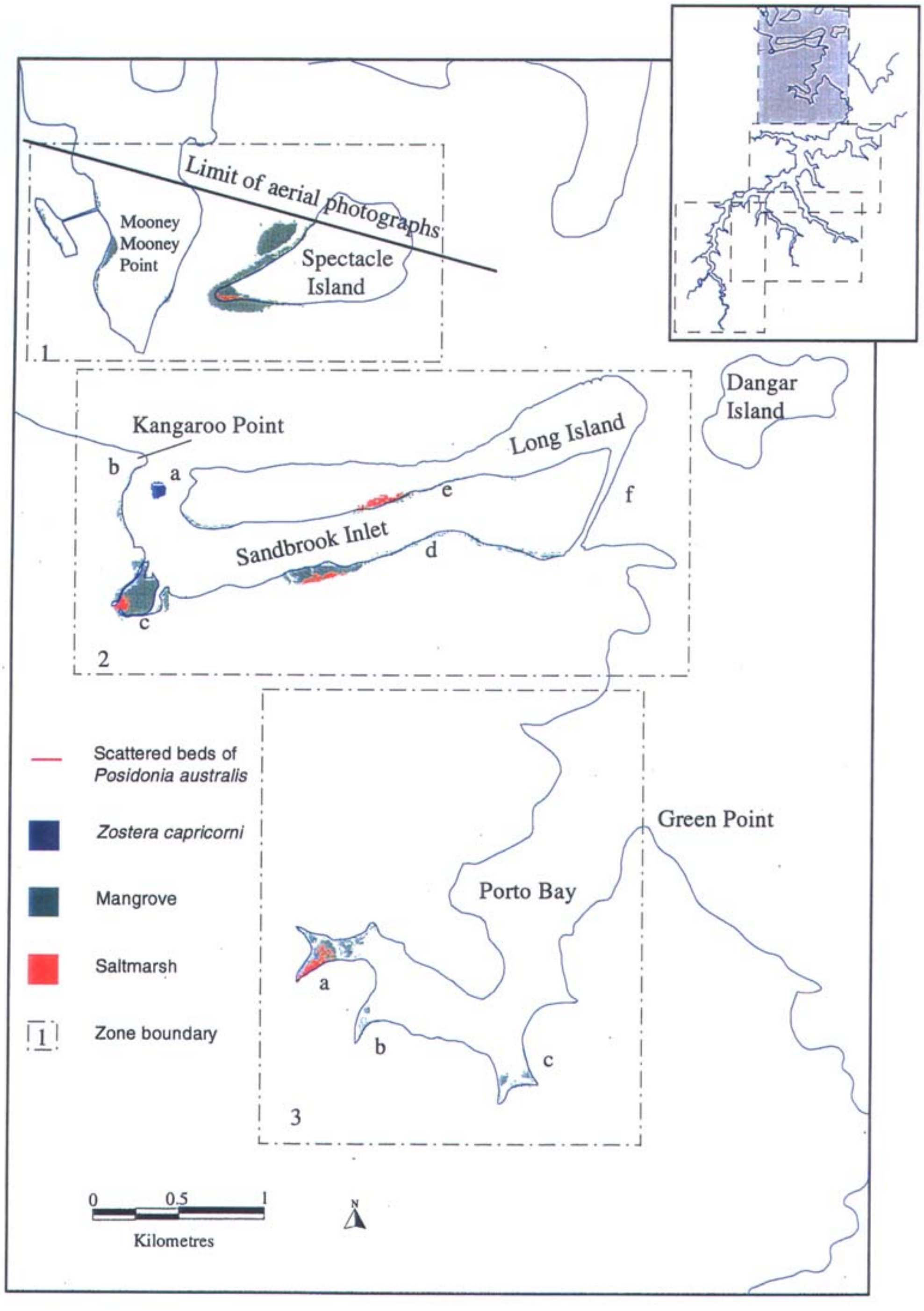


Figure 4. Map of Brooklyn Estuary showing habitats mapped by Williams & Watford 1999.

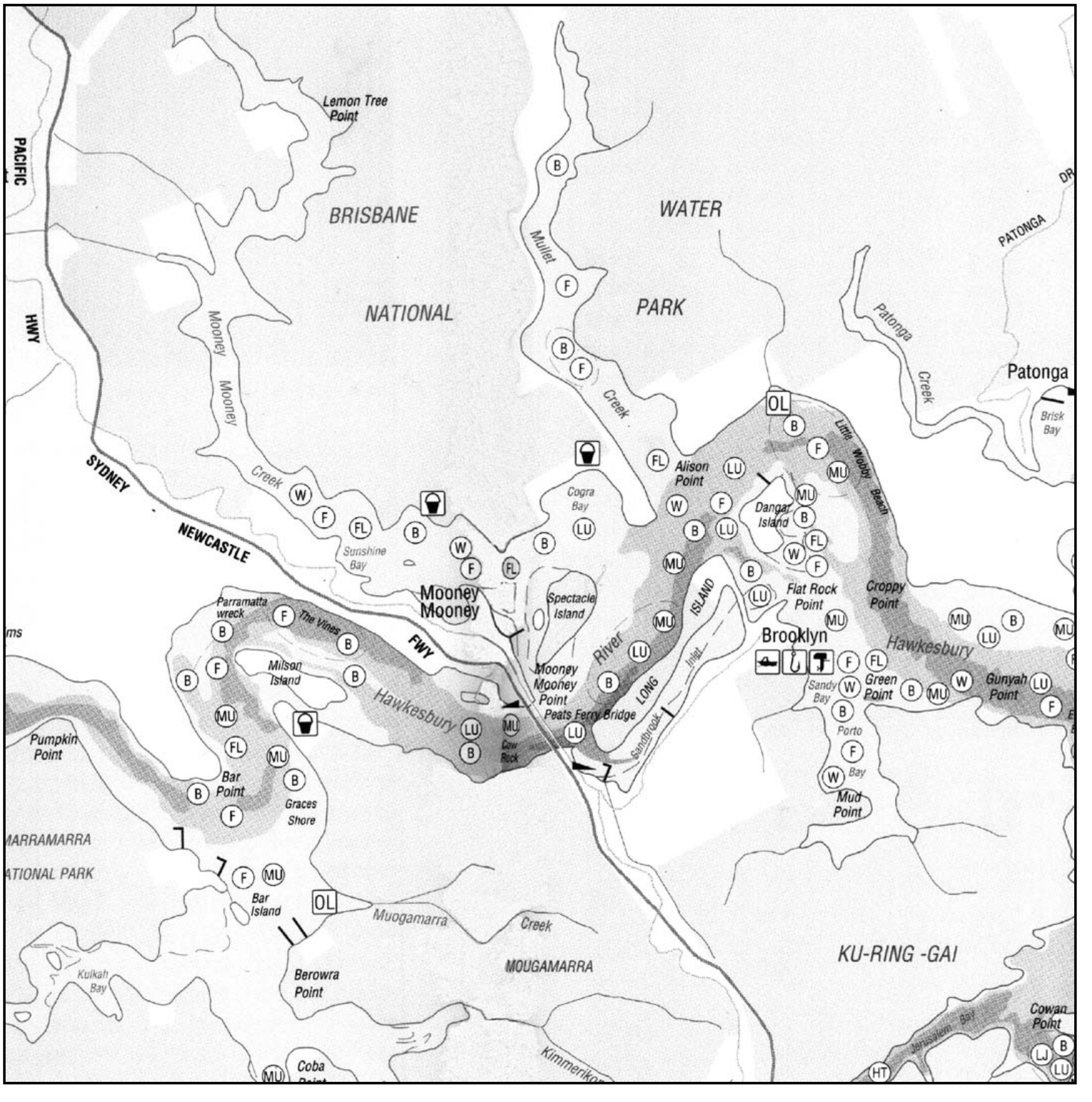


Figure 5. Map showing recreational fishing locations of target species in the Brooklyn Estuary. B = bream, F = flathead, FL = flounder, LU = luderick, MU = mulloway, W = whiting (Source: Ross 1995).

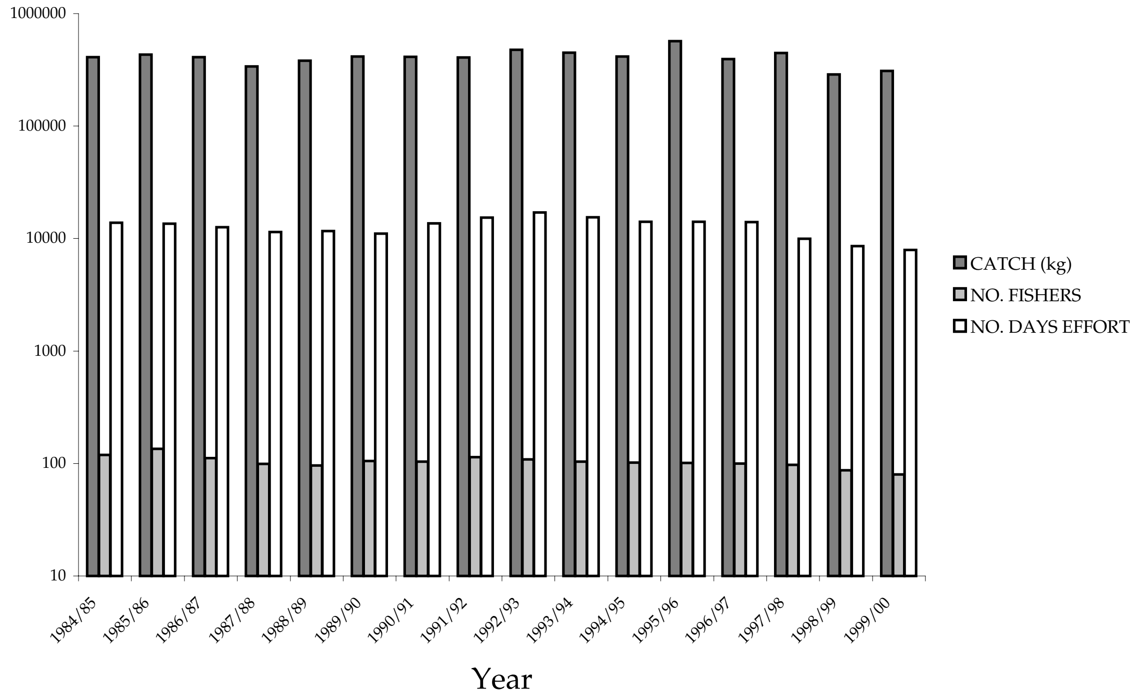


Figure 6. Total catch, no of fishers and number of days effort for the Hawkesbury River by year in log form. Data source: Tanner & Liggins 2001

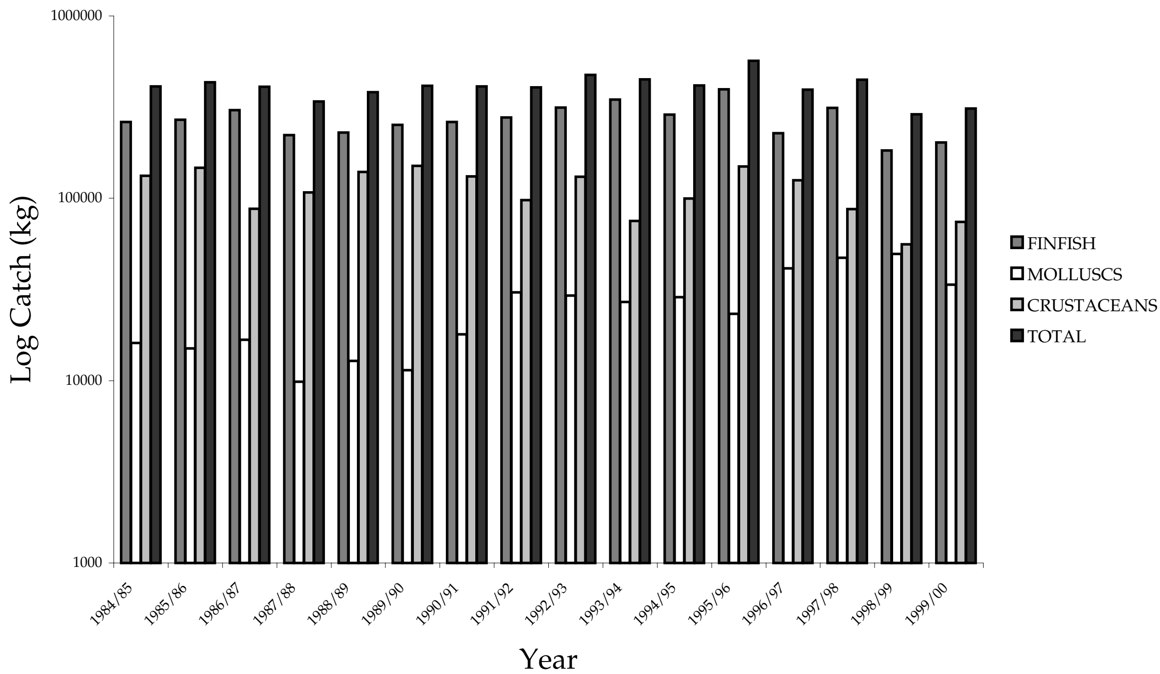


Figure 7. Hawkesbury commercial catch (kg) by year in log form. Data source: Tanner & Liggins 2001

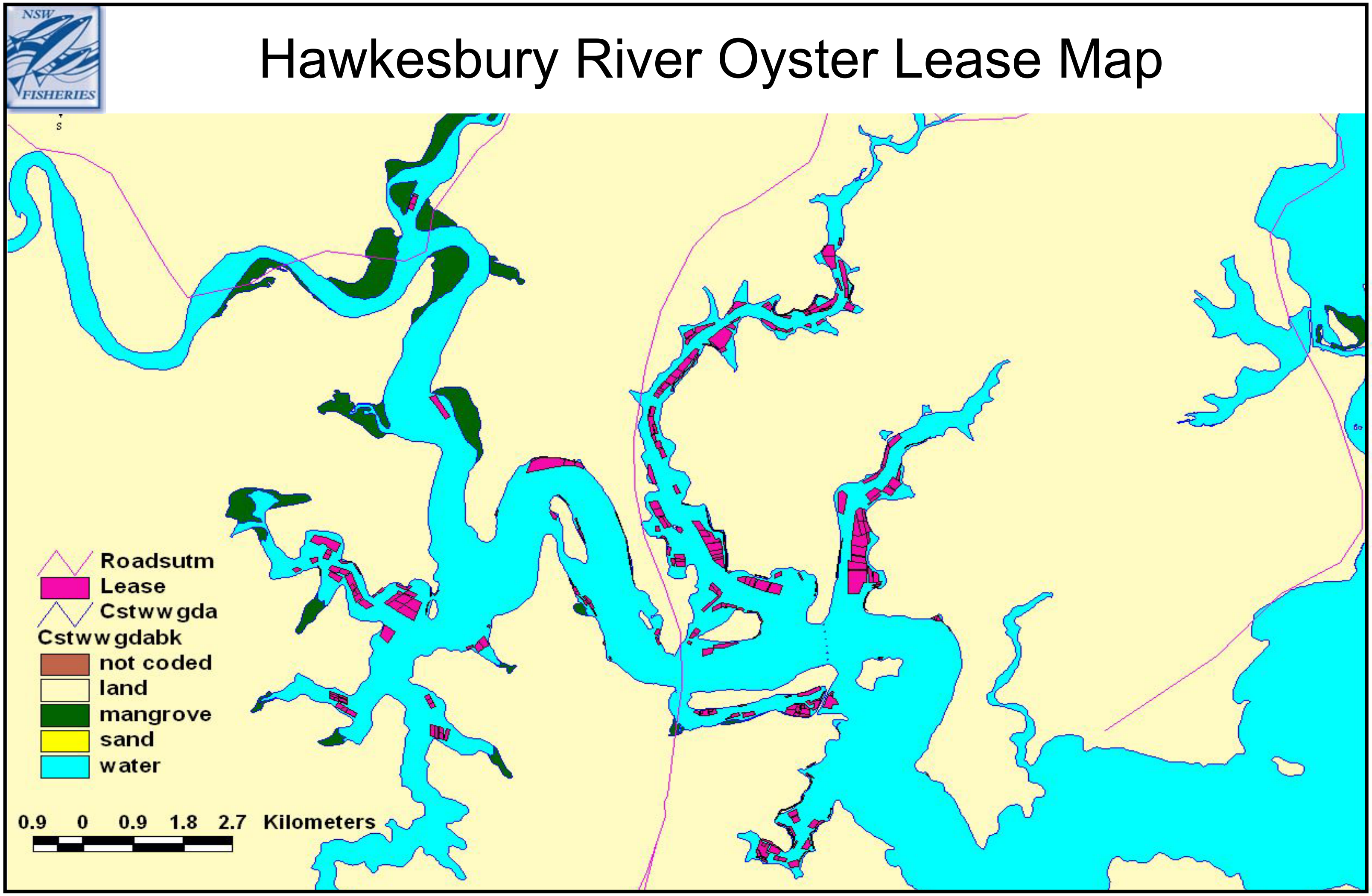


Figure 8. Map of oyster leases in the Hawkesbury River. (Source: : T. Zheng, NSW Fisheries).

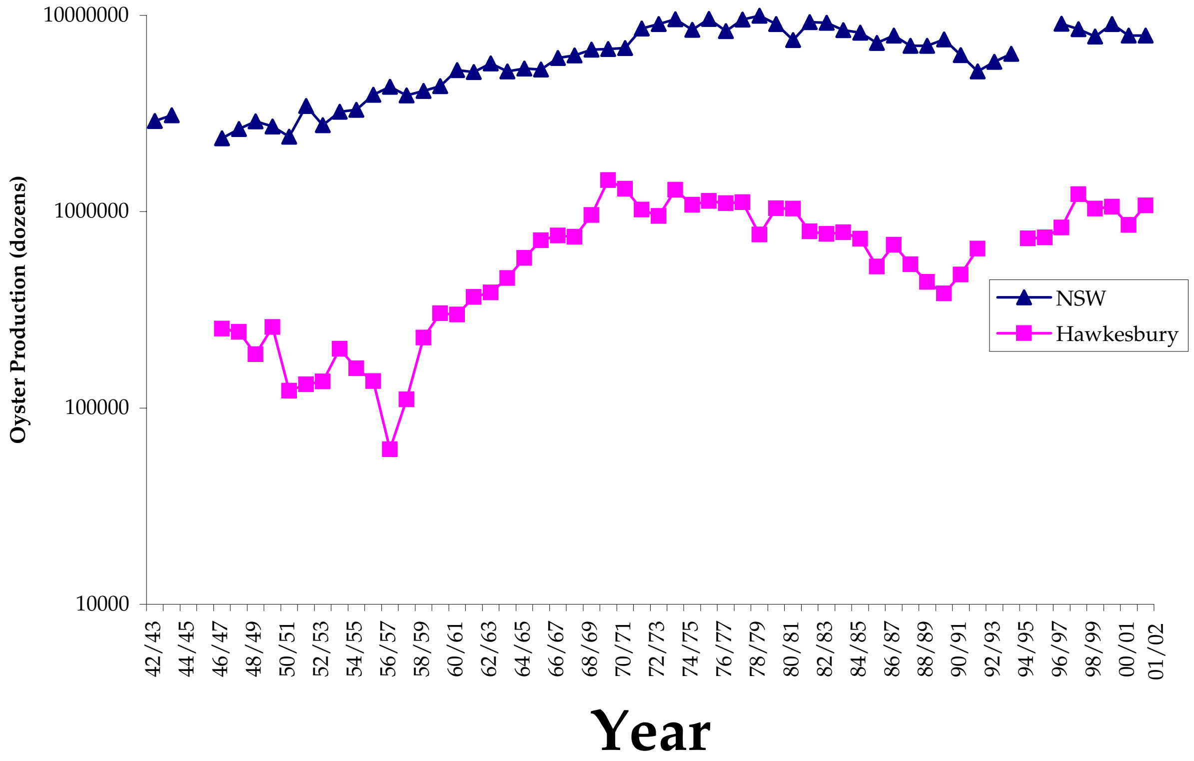


Figure 9. Production (dozens) of Sydney rock oysters between 1940 and 2002 for NSW and the Hawkesbury in log form. There were no data available for the 1942/43, 1943/44 or 1993/94 financial years. Data source: NSW Fisheries Commercial Fisheries Statistics.

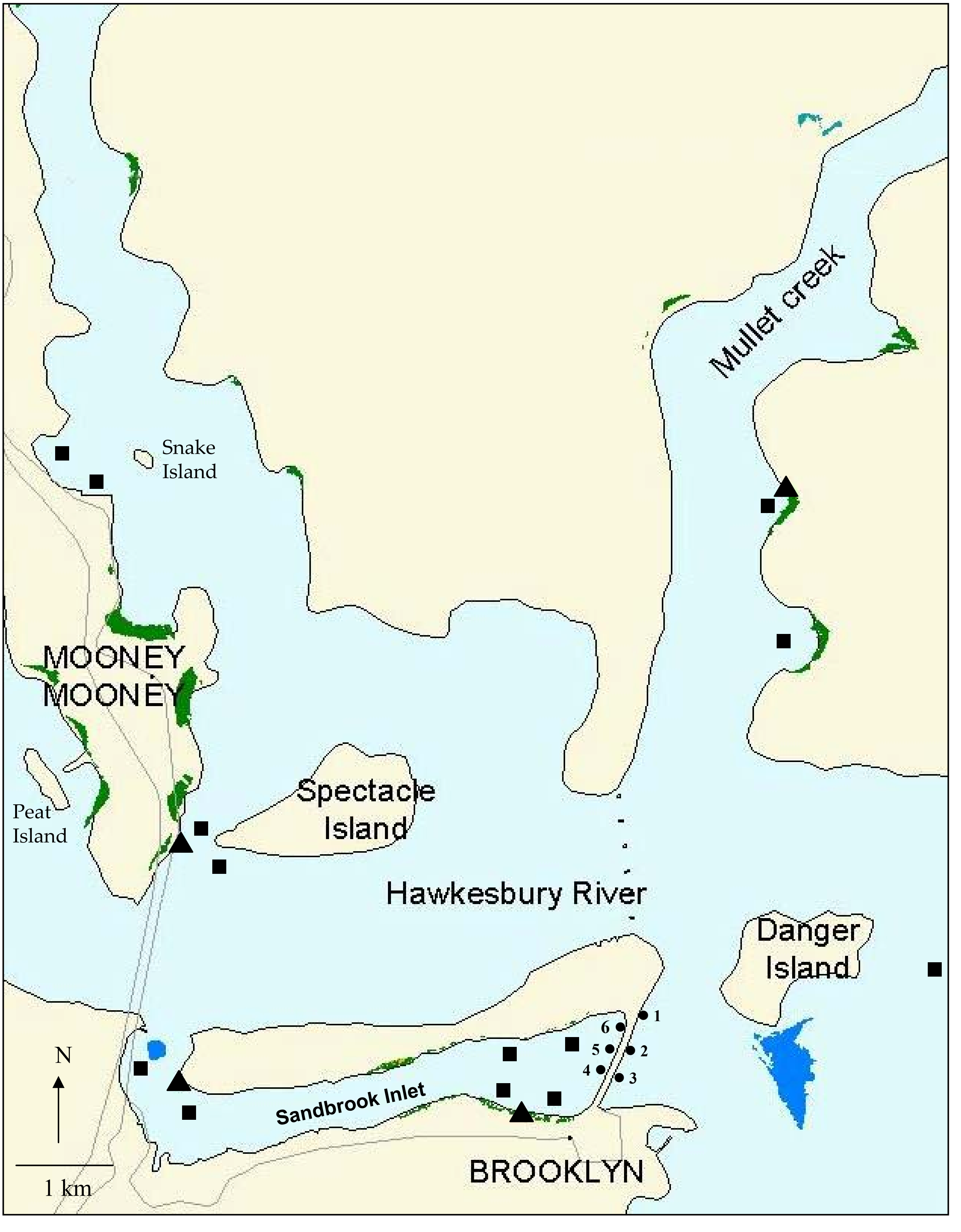


Figure 10. Map of Brooklyn Estuary showing location of sites for beam trawl samples (■), rocky shore intertidal samples (●),soft sediment intertidal benthos samples (▲), and oyster bioaccumulation samples (★). (Source: base map from Williams & West, 2001).

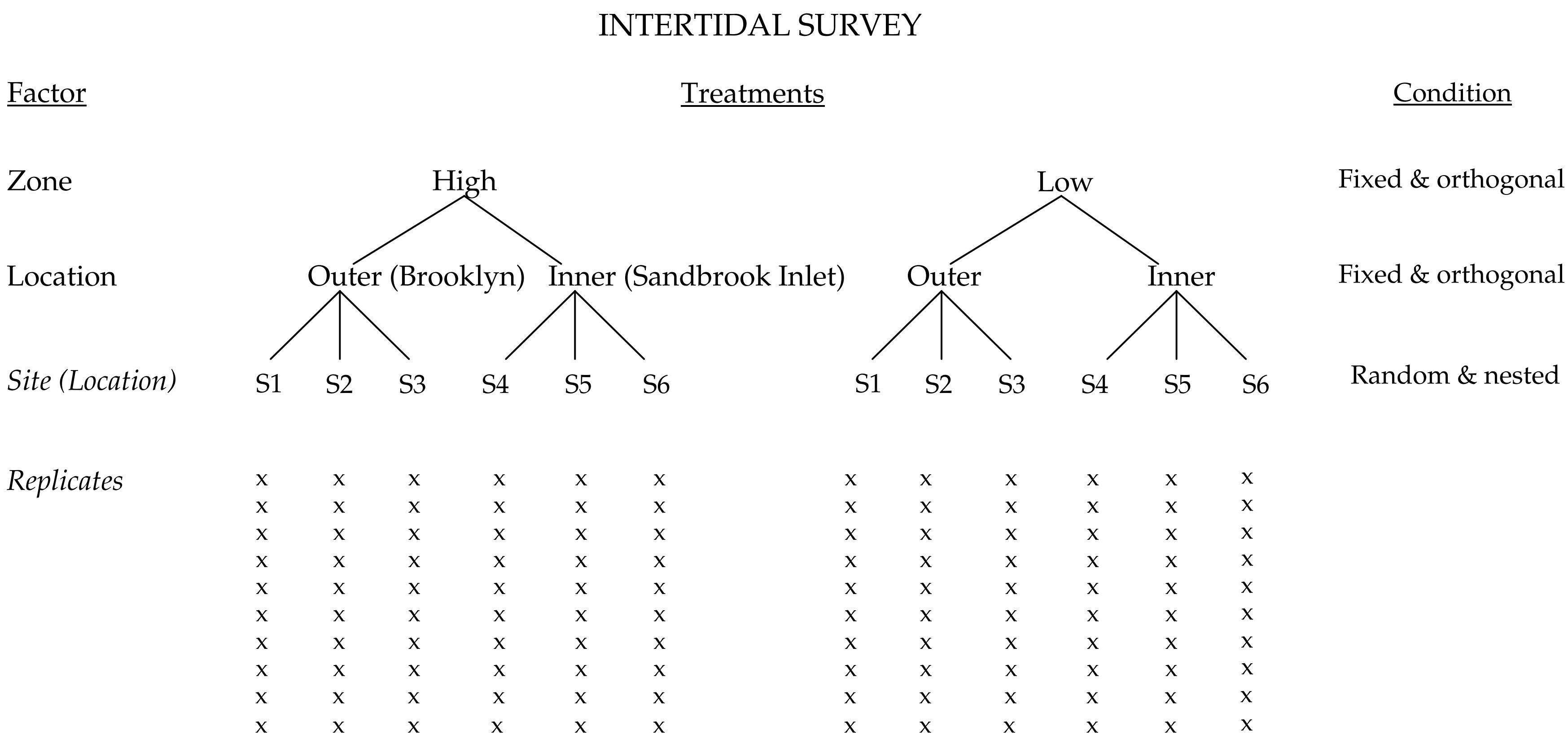


Figure 11: Sampling design for the intertidal survey (n = 120).

BEAM TRAWLS

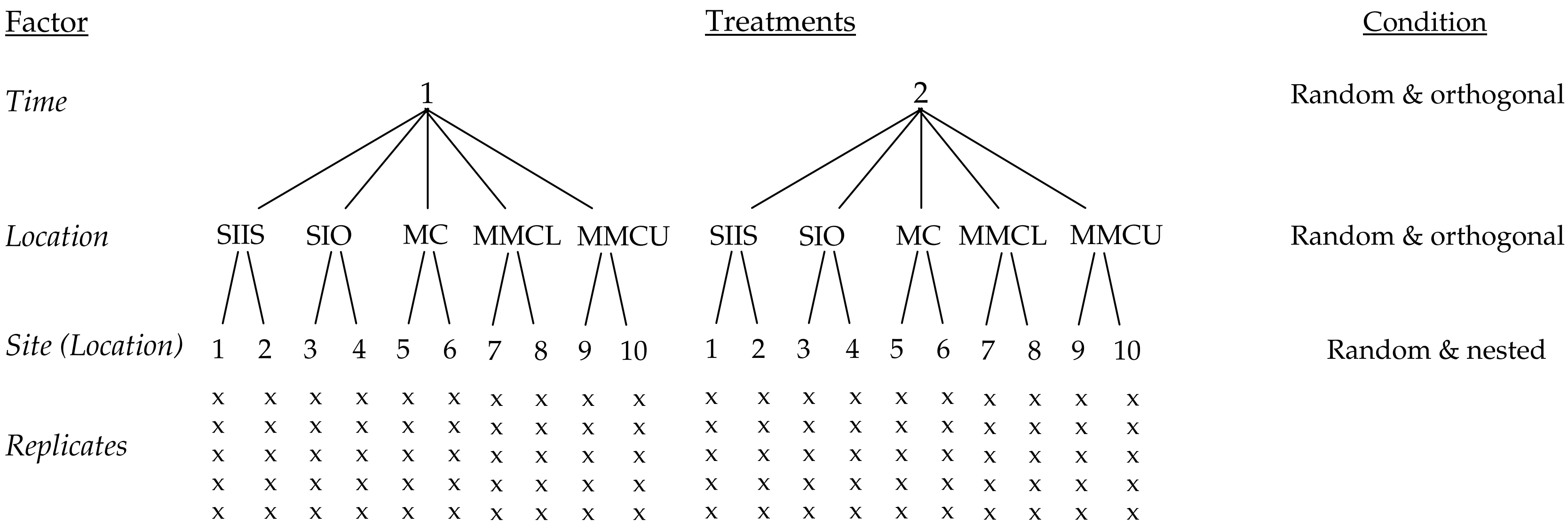


Figure 12: Sampling Design 1 for the beam trawl. SIIS = Sandbrook Inlet Inner South; SIO = Sandbrook Inlet Outer; MC = Mullet Creek; Moonie Moonie Creek Lower; Moonie Moonie Creek Upper; Sandbrook Inlet Inner North. (n = 110).

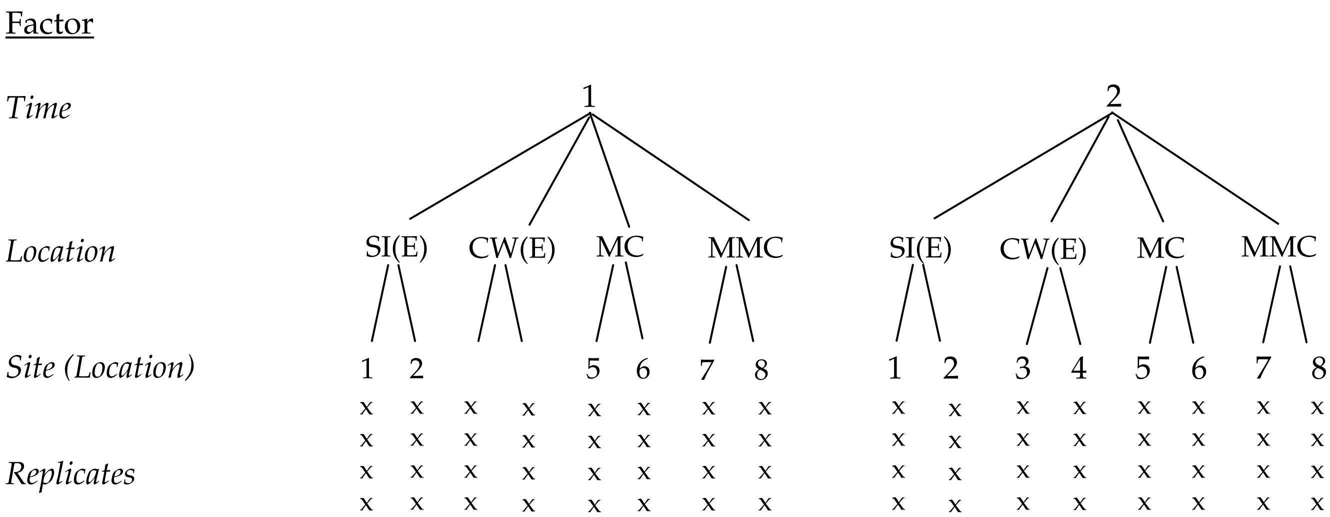


Figure 13: Sampling Design for the Bioaccumulation in Oysters. SI(E) = Sandbrook Inlet, East; CW(E) = Causeway, East; MC = Mullet Creek; MMC = Moonie Moonie Creek. (n = 64).

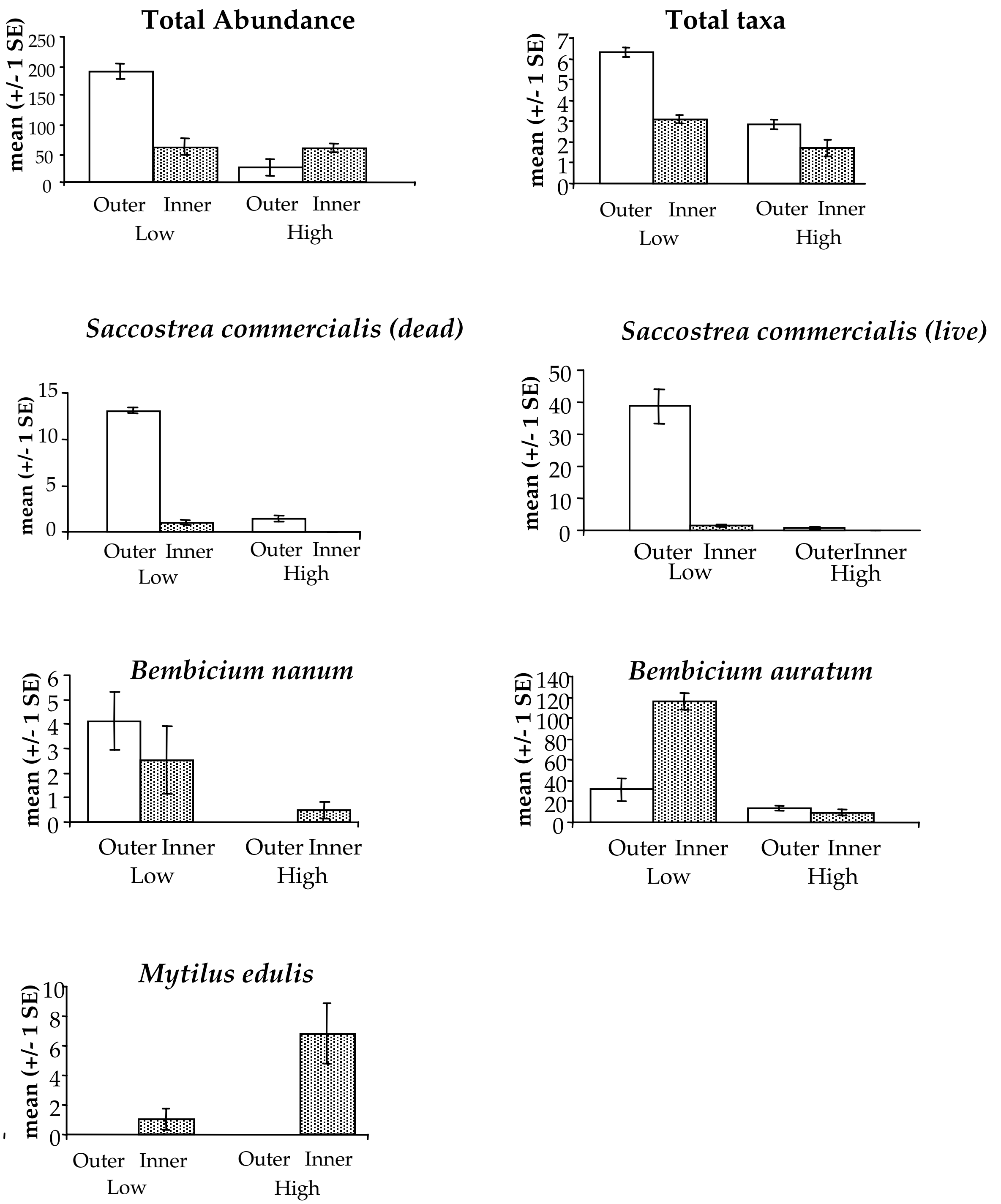


Figure 14: Mean (+ /- standard error) for total number of taxa, total abundance and four taxa from survey of intertidal organisms on Hawkesbury River causeway. Outer sites 1 - 3 were sampled on the Brooklyn Harbour side of the causeway; Inner sites 4 - 6 were sampled on the Sandbrook Inlet side of the causeway. Low = sampled at low intertidal zone, High = sampled at higher intertidal zone.

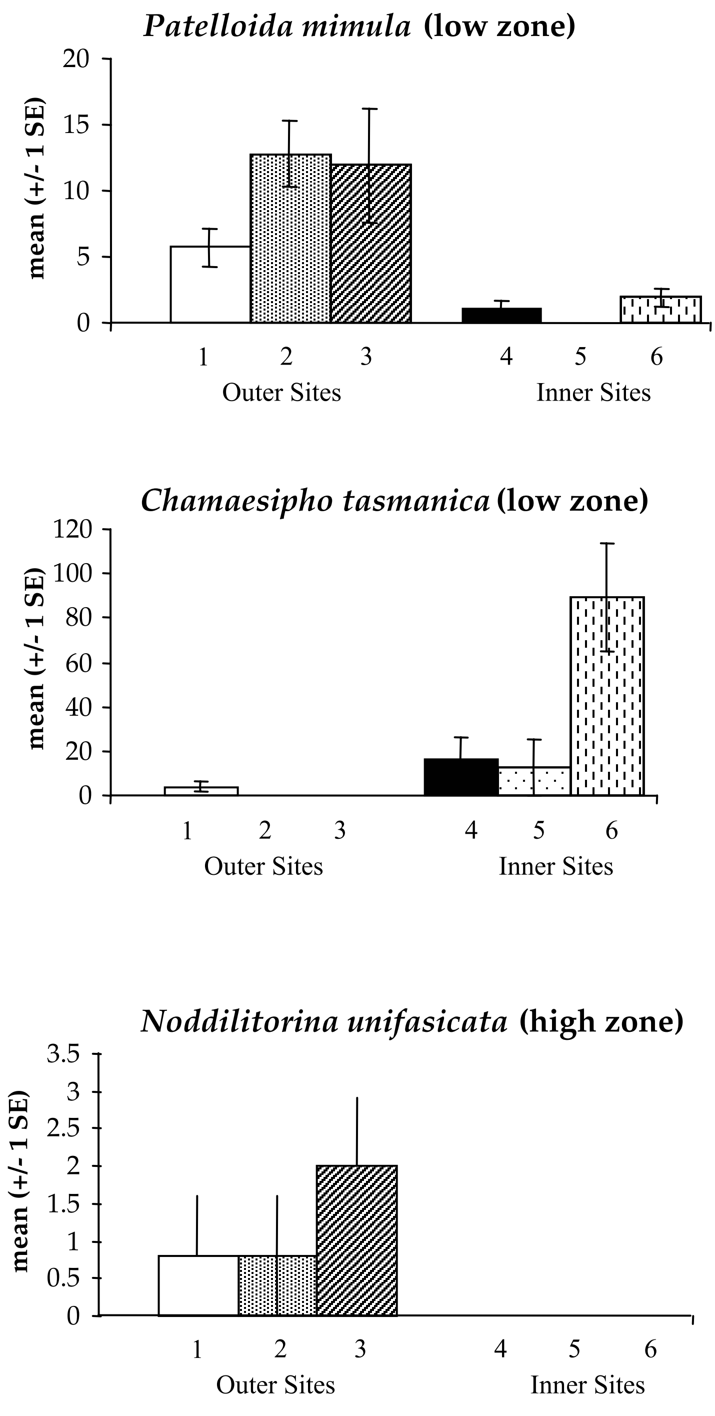


Figure 15:. Mean (+ /- standard error) for three taxa from survey of intertidal organisms on the Hawkesbury River causeway. Outer sites 1 - 3 were sampled on the Brooklyn Harbour side of the causeway; Inner sites 4 - 6 were sampled on the Sandbrook Inlet side of the causeway. Low = sample at low intertidal zone, High = sampled at higher intertidal zone.

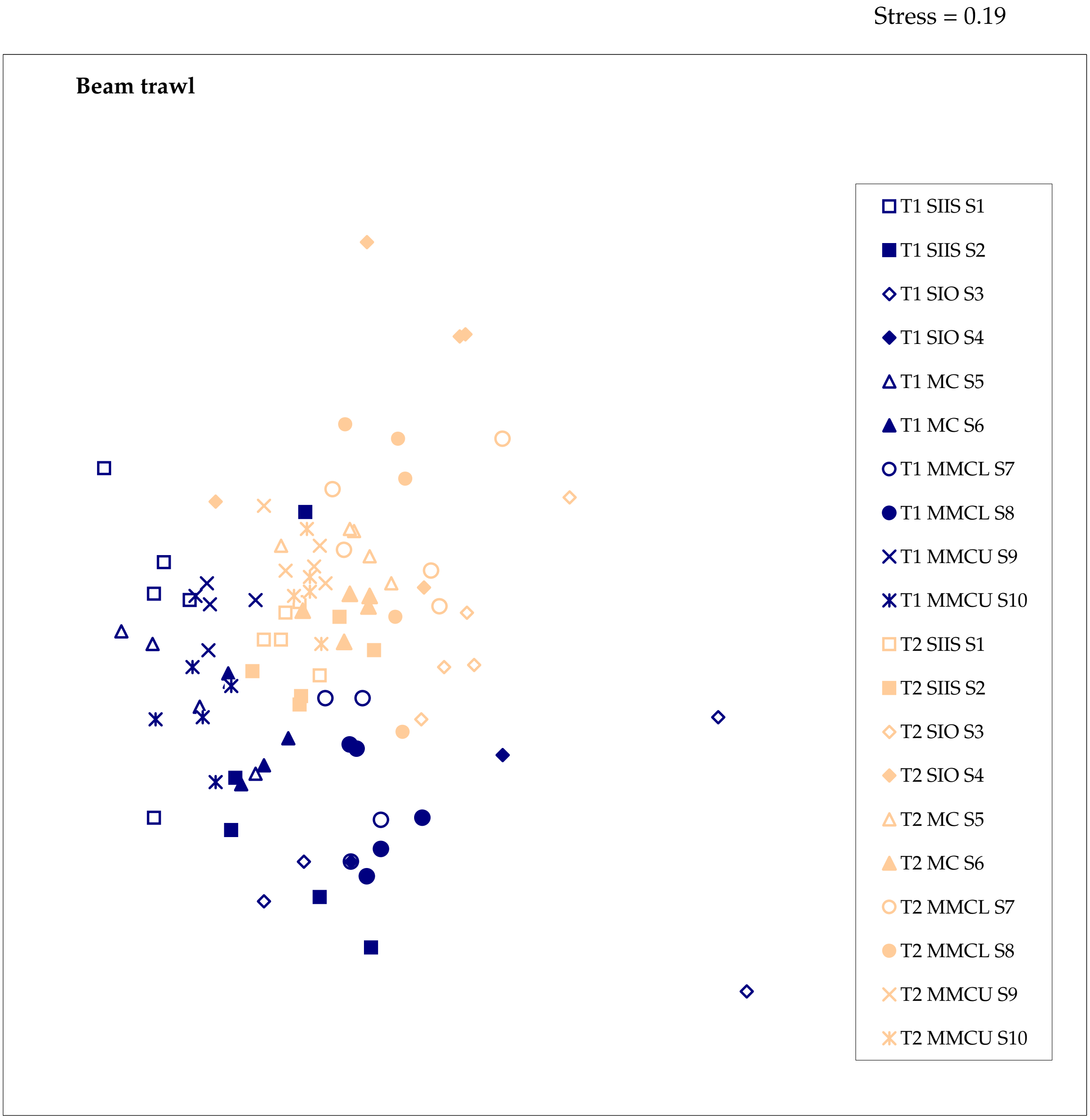


Figure 16: Two dimensional nMDS of the Beam Trawl samples (5 locations and 2 times) showing relative similarity between samples.

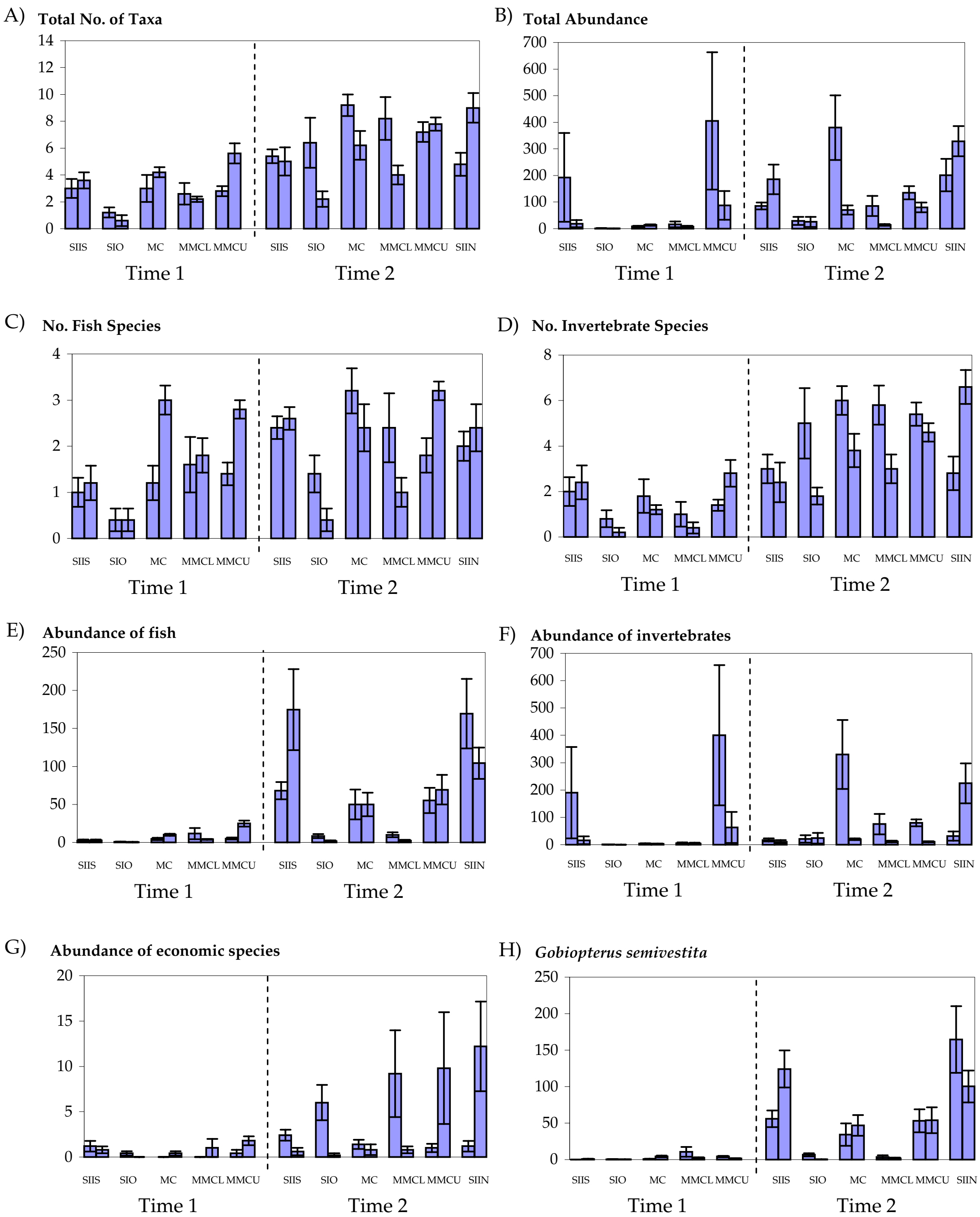
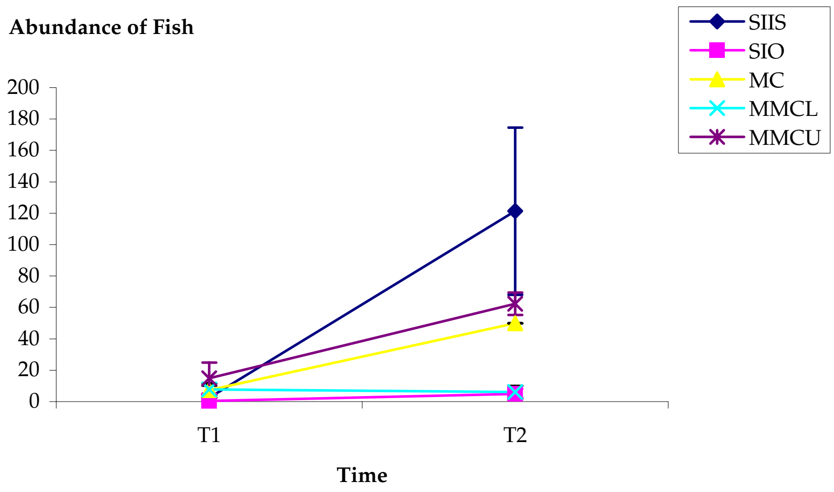


Figure 17: Means (+/- SE) for the two Sites at each Location and Time. A) Total number of taxa B) Total abundance C) Number of fish species D) Number of invertebrates species E) Abundance of fish F) Abundance of invertebrates G) Abundance of economic species H) Abundance of *G. semivestita* . n = 5.

A)



B)

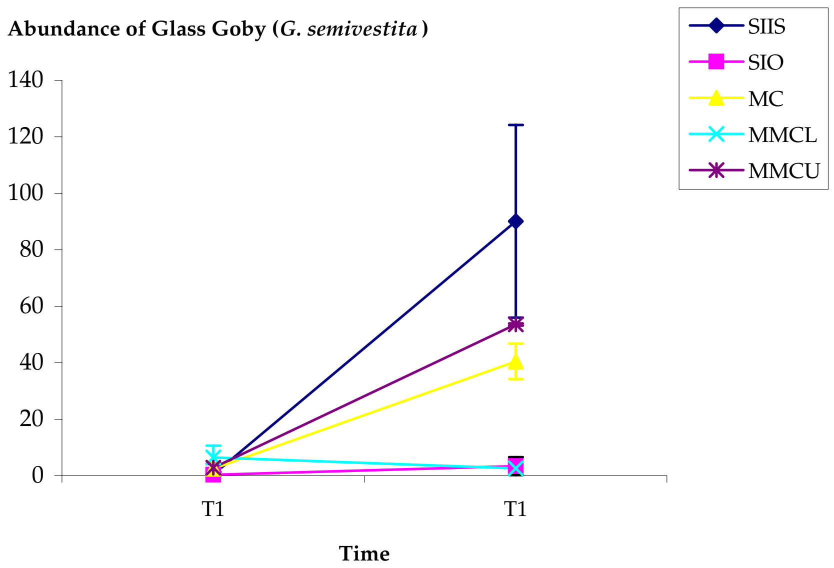


Figure 18: Changes (mean & SE) over time in the abundance of A) fish and B) glass goby (G. semivestita) at each location.

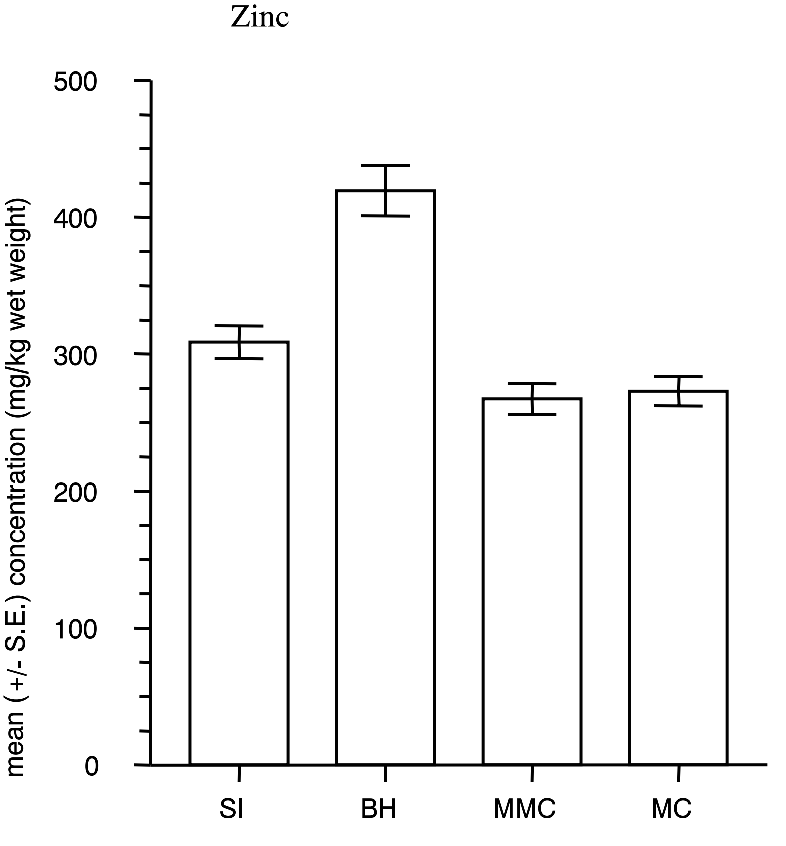


Figure 19: Mean concentration of Zinc in oysters from 4 locations in the Hawkesbury, n= 16 (sites and times are pooled). SI= Sandbrook Inlet, BH= Brooklyn Harbour, MMC = Mooney Mooney Creek, MC = Mullet Creek.

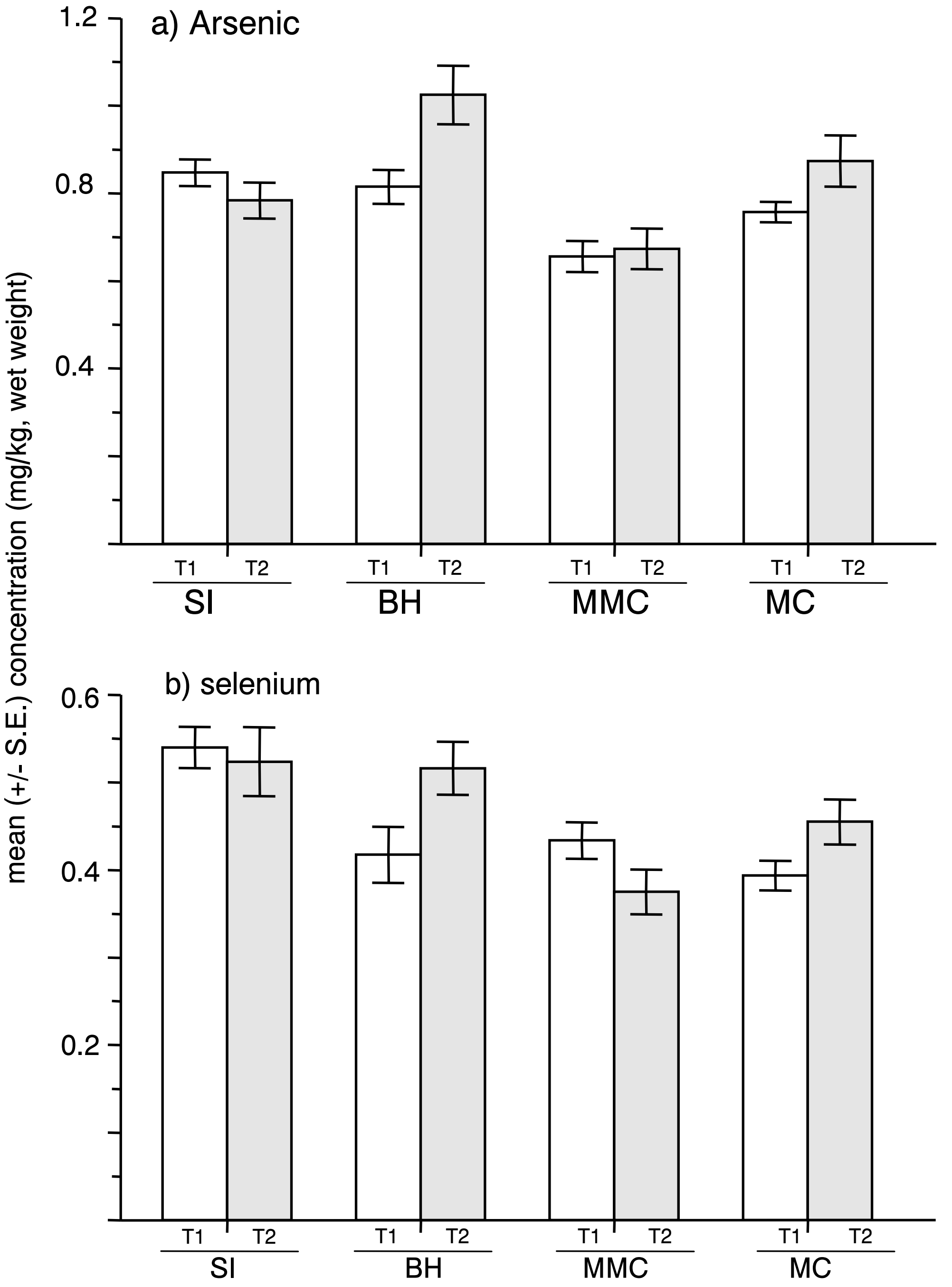


Figure 20: Mean concentration of a) arsenic and b) selenium in oysters from 4 locations in the Hawkesbury at 2 times, n= 8. T1 = Time 1, T2 = Time 2, SI= Sandbrook Inlet, BH= Brooklyn Harbour, MMC = Mooney Mooney Creek, MC = Mullet Creek.

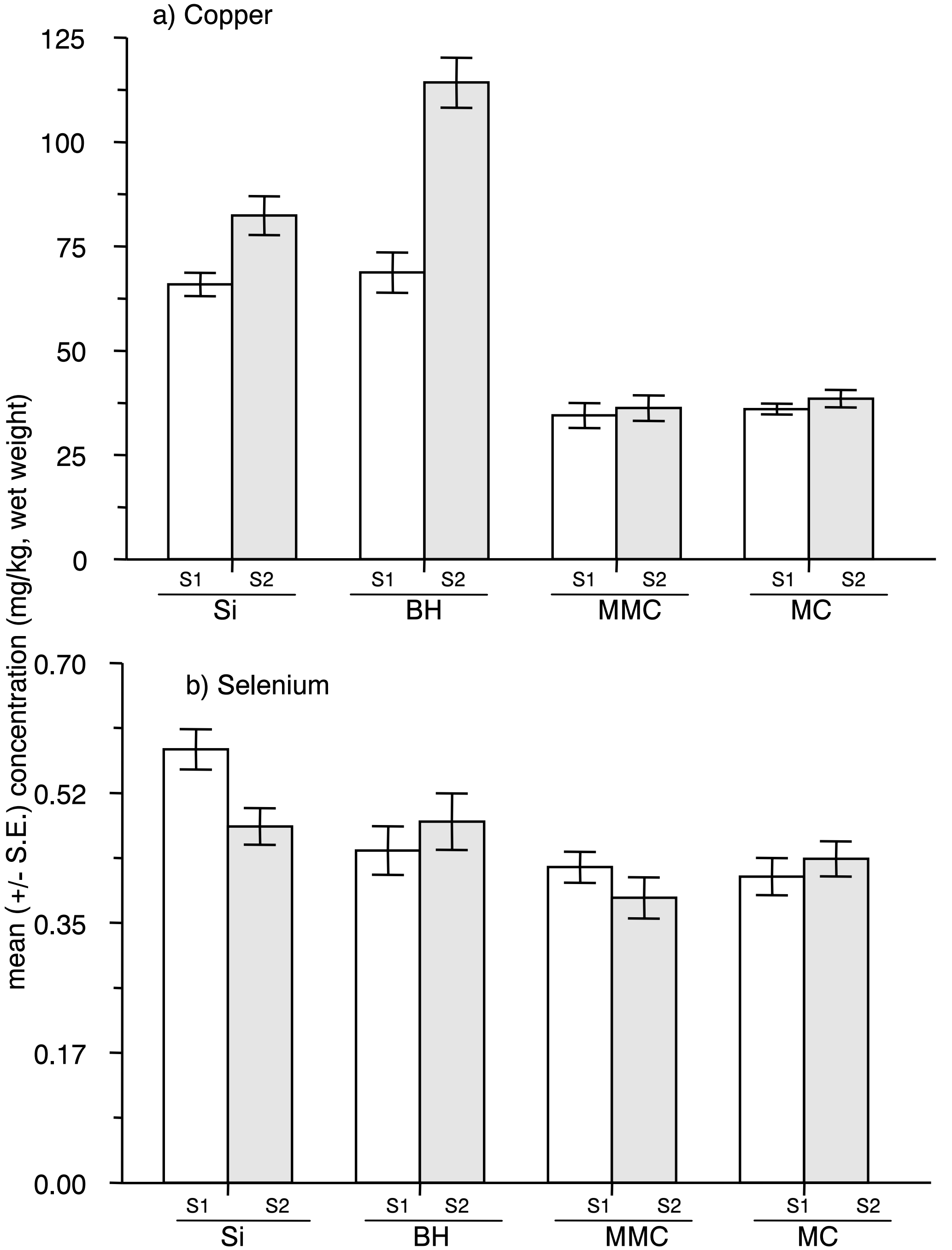


Figure 21: Mean concentration of a) copper and b) selenium in oysters from 2 sites at each of 4 locations in the Brooklyn region, n= 8. S1 = Site 1, S2 = Site 2, SI= Sandbrook Inlet, BH= Brooklyn Harbour, MMC = Mooney Mooney Creek, MC = Mullet Creek.

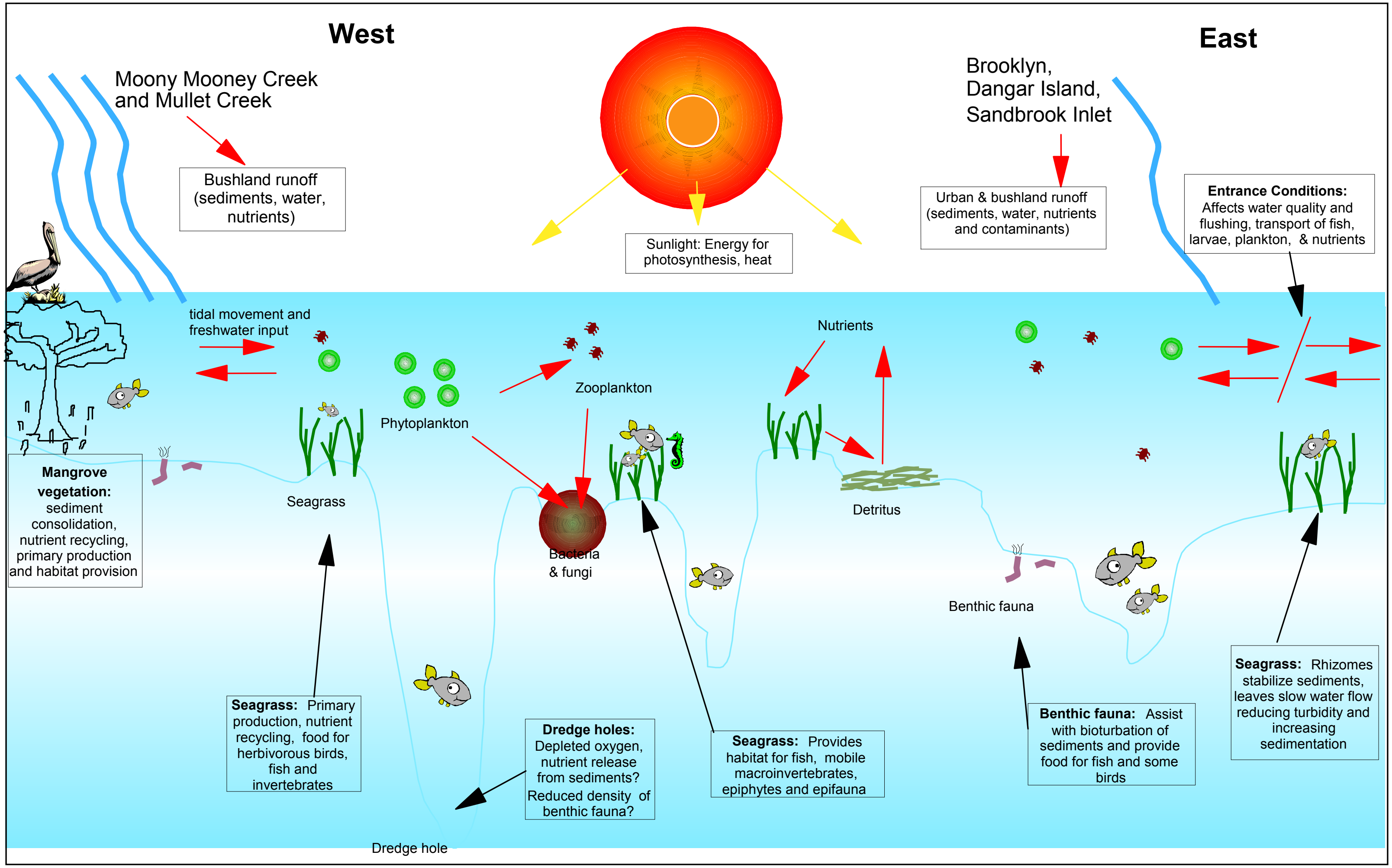
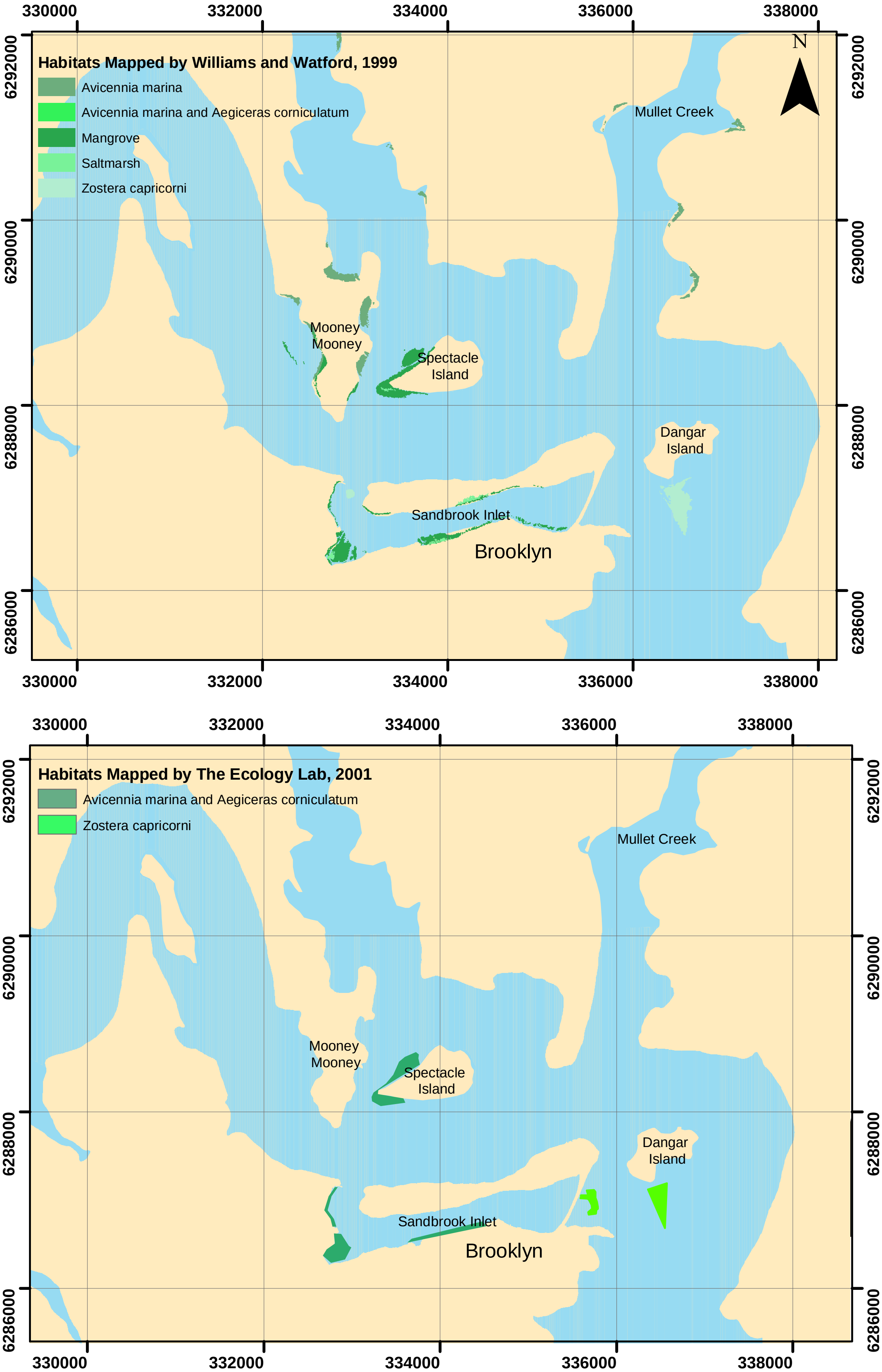


Figure 22: Conceptual model of Brooklyn Estuary in profile showing some of the processes which occur within the water column, aquatic vegetation and benthos.



WRL Report No. 2002/20	MAP OF BROOKLYN ESTUARY SHOWING HABITATS MAPPED BY WILLIAMS & WATFORD 1999 AND THE ECOLOGY LAB 2001	Figure 6.4

fig6_4.mxd

APPENDICES

Appendix 1: List of plants observed within approximately 5 km of the Brooklyn region (NSW NPWS Wildlife Atlas) and their protected status under the TSC Act.

Appendix 2: List of birds, amphibians, mammals and reptiles observed within approximately 5 km of the Brooklyn region (NSW NPWS Wildlife Atlas) and their protected status under the TSC Act.

Appendix 3: List of fish, birds, amphibians, mammals, reptiles and plants likely to occur within approximately 5 km of the Brooklyn region protected under the EPBC Act (1999). The list includes species classed as threatened ecological communities, threatened species, marine protected species and migratory species.

Appendix 4: The number of days fished by methods by year (NSW Fisheries 2001).

Appendix 5: Field GPS readings for intertidal sampling sites recorded between 30/01/02 and 01/02/02.

Appendix 6: Summary of statistical procedures.

Appendix 7: Mean and standard errors for intertidal organisms counted between 30/01/02 and 01/02/02.

Appendix 8: Field GPS readings for beam trawl sampling sites recorded 17-19/09/01 and 29-31/01/02.

Appendix 9: Mean and standard errors for beam trawl organisms sampled 17-19/09/01 and 29-31/01/02.

Appendix 10: Three-way partially hierarchical ANOVA results examining variations in the beam trawl samples.

Appendix 11: Mean and standard errors for heavy metal bioaccumulation in oysters.

Appendix 1. List of plants observed within approximately 5 km of the Brooklyn Estuary (NSW NPWS Wildlife Atlas) and their protected status under the TSC Act. E1 = Endangered, V= Vulnerable, I = Introduced, P13 = Protected Plants (NSW Wildlife Act, 1974) U = Unprotected. (nb: These data are only indicative and cannot be considered a comprehensive inventory, and may contain errors). Vulnerable and endangered species have been shaded.

	Scientific Name	Common Name	Legal Status	Count
Adiantaceae	*Adiantum aethiopicum*	Common Maidenhair	P13	1
	Adiantum hispidulum	Rough Maidenhair	P13	1
	Cheilanthes sieberi ssp sieberi		U	2
Aizoaceae	*Carpobrotus glaucescens*		U	1
	Tetragonia tetragonoides	New Zealand Spinach	U	1
Anthericaceae	*Alania endlicheri*		U	1
	Laxmannia gracilis		U	2
Apiaceae	*Actinotus helianthi*	Flannel Flower	P13	2
	Actinotus minor	Lesser Flannel Flower	U	4
	Apium prostratum	Sea Celery	U	1
	Platysace lanceolata		U	1
	Platysace linearifolia		U	5
	Xanthosia pilosa		U	6
	Xanthosia tridentata		U	3
Araceae	*Gymnostachys anceps*	Settler's Flax	U	1
	Typhonium eliosurum		U	1
Araliaceae	*Astrotricha crassifolia*		V	2
	Astrotricha floccosa		U	4
	Astrotricha latifolia		U	2
Asteraceae	*Helichrysum elatum*		U	1
	Ozothamnus diosmifolius	White Dogwood	U	1
Baueraceae	*Bauera microphylla*		U	1
Bignoniaceae	*Pandorea pandorana*	Wonga Wonga Vine	U	1
Blechnaceae	*Blechnum cartilagineum*	Gristle Fern	U	3
	Doodia aspera		U	2
Casuarinaceae	*Allocasuarina littoralis*	Black Sheoak	U	1
	Allocasuarina torulosa	Forest Oak	U	3
Chenopodiaceae	*Rhagodia candolleana ssp candolleana*		U	1
Commelinaceae	*Commelina cyanea*		U	1
Cunoniaceae	*Callicoma serratifolia*	Black Wattle	U	4
	Ceratopetalum apetalum	Coachwood	U	2
	Ceratopetalum gummiferum	Christmas Bush	P13	2
	Schizomeria ovata	Crabapple	U	1
Cyperaceae	*Caustis flexuosa*	Curly Wig	P13	2
	Caustis recurvata		P13	1
	Cyathochaeta diandra		U	1
	Gahnia spp.		U	2
	Isolepis nodosa	Knobby Club-rush	U	2
	Schoenus imberbis		U	2
Dennstaedtiaceae	*Histiopteris incisa*	Bat's Wing Fern	U	1
	Hypolepis muelleri	Harsh Ground Fern	U	1
	Pteridium esculentum	Bracken	U	3
Dicksoniaceae	*Calochlaena dubia*	Common Ground Fern	U	2
Dilleniaceae	*Hibbertia aspera*		U	1
	Hibbertia bracteata		U	2
	Hibbertia dentata	Twining Guinea Flower	U	3
	Hibbertia diffusa		U	1
	Hibbertia fasciculata		U	1
	Hibbertia monogyna		U	2
	Hibbertia obtusifolia		U	3
	Hibbertia scandens	Climbing Guinea Flower	U	1
Doryanthaceae	*Doryanthes excelsa*	Gymea/Giant Lily	P13	5
Droseraceae	*Drosera binata*		U	1
	Drosera peltata		U	3
Epacridaceae	*Leucopogon ericoides*		U	3
	Leucopogon microphyllus		U	2
	Monotoca scoparia		U	2
	Sprengelia incarnata		P13	1
	Sprengelia sprengelioides		U	1
	Trochocarpa laurina	Tree Heath	U	4
Euphorbiaceae	*Amperea xiphoclada var papillata*		U	1
	Micrantheum ericoides		U	1
	Phyllanthus hirtellus		U	2

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	Scientific Name	Common Name	Legal Status	Count
	Poranthera ericifolia		U	1
Fabaceae (Faboideae)	*Bossiaea scolopendria*		U	2
	Bossiaea stephensonii		U	1
	Dillwynia floribunda		U	3
	Dillwynia retorta		U	1
	Gompholobium grandiflorum	Large Wedge Pea	U	3
	Gompholobium latifolium	Golden Glory Pea	U	2
	Gompholobium pinnatum	Pinnate Wedge Pea	U	1
	Hardenbergia violacea	False Sarsaparilla	U	1
	Hovea linearis		U	2
	Phyllota phylicoides	Heath Phyllota	U	4
	Podolobium ilicifolium	Prickly Shaggy Pea	U	1
	Pultenaea daphnoides		U	1
	Pultenaea elliptica		U	1
	Pultenaea rosmarinifolia		U	3
Fabaceae (Mimosoideae	*Acacia echinula*		U	1
	Acacia elata	Mountain Cedar Wattle	U	3
	Acacia linifolia	Flax-leaved Wattle	U	5
	Acacia mearnsii	Black Wattle	U	1
	Acacia oxycedrus	Spike Wattle	U	6
	Acacia schinoides		U	1
	Acacia suaveolens	Sweet Wattle	U	3
	Acacia terminalis	Sunshine Wattle	U	2
	Acacia ulicifolia	Prickly Moses	U	1
Flagellariaceae	*Flagellaria indica*	Whip Vine	U	1
Gleicheniaceae	*Gleichenia dicarpa*		U	1
	Gleichenia rupestris		U	1
Goodeniaceae	*Dampiera stricta*		U	2
	Scaevola ramosissima		U	1
Grammitaceae	*Grammitis billardierei*	Finger Fern	U	1
Haloragaceae	*Gonocarpus salsoloides*		U	4
	Gonocarpus teucrioides		U	2
Hymenophyllaceae	*Hymenophyllum cupressiforme*	Common Filmy Fern	U	2
Iridaceae	*Libertia paniculata*		U	1
	Patersonia sericea		U	4
Lamiaceae	*Hemigenia purpurea*		U	1
	Prostanthera askania		E1	1
	Prostanthera junonis		E1	2
	Westringia fruticosa	Coastal Rosemary	U	1
Lauraceae	*Cassytha glabella*		U	3
Lindsaeaceae	*Lindsaea linearis*	Screw Fern	U	2
	Lindsaea microphylla	Lacy Wedge Fern	U	1
Lobeliaceae	*Lobelia alata*	Angled Lobelia	U	1
Loganiaceae	*Mitrasacme pilosa*		U	1
	Mitrasacme polymorpha		U	3
Lomandraceae	*Lomandra filiformis*	Wattle Matt-rush	U	2
	Lomandra glauca	Pale Mat-rush	U	3
	Lomandra longifolia	Spiny-headed Mat-rush	U	7
	Lomandra obliqua		U	3
Luzuriagaceae	*Eustrephus latifolius*	Wombat Berry	U	2
Monimiaceae	*Wilkiea huegeliana*	Veiny Wilkiea	U	1
Moraceae	*Ficus coronata*	Creek Sandpaper Fig	U	1
Myrsinaceae	*Rapanea variabilis*	Muttonwood	U	1
Myrtaceae	*Acmena smithii*	Lilly Pilly	U	1
	Angophora costata	Sydney Red/Rusty Gum	U	7
	Angophora floribunda	Rough-barked Apple	U	1
	Angophora hispida	Dwarf Apple	U	2
	Backhousia myrtifolia	Grey Myrtle	U	2
	Baeckea imbricata		U	1
	Baeckea linifolia		U	1
	Callistemon linearifolius		V	4
	Callistemon shiressii		U	2
	Corymbia eximia	Yellow Bloodwood	U	4

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	Scientific Name	Common Name	Legal Status	Count
	Corymbia gummifera	Red Bloodwood	U	4
	Darwinia fascicularis		U	4
	Darwinia glaucophylla		U	22
	Darwinia peduncularis		V	2
	Darwinia procera		U	9
	Eucalyptus botryoides	Bangalay	U	1
	Eucalyptus camfieldii	Hear-leaved Stringybark	V	1
	Eucalyptus deanei	Mountain Blue Gum	U	1
	Eucalyptus haemastoma	Broad-leaved Scribbly Gum	U	1
	Eucalyptus pilularis	Blackbutt	U	1
	Eucalyptus piperita	Sydney Peppermint	U	4
	Eucalyptus punctata		U	1
	Kunzea ambigua	Tick Bush	U	1
	Kunzea capitata		U	4
	Leptospermum arachnoides		U	1
	Leptospermum parvifolium		U	1
	Leptospermum polygalifolium		U	3
	Leptospermum trinervium		U	3
	Melaleuca deanei		V	2
	Micromyrtus blakelyi		V	1
	Micromyrtus ciliata		U	1
	Syncarpia glomulifera	Turpentine	U	2
	Syzygium paniculatum		V	3
	Tristaniopsis laurina	Kanuka	U	2
Orchidaceae	*Acianthus spp.*		U	1
	Bulbophyllum shepherdii	Wheat-leaved Orchid	P13	1
	Caleana major	Large Duck Orchid	U	1
	Calochilus gracillimus	Slender Beard Orchid	U	1
	Calochilus paludosus	Red Beard Orchid	U	1
	Cryptostylis subulata	Large Tongue Orchid	U	1
	Genoplesium fimbriatum	Fringed Midge Orchid	U	1
Osmundaceae	*Todea barbara*	King Fern	P13	2
Peperomiaceae	*Peperomia tetraphylla*		U	1
Phormiaceae	*Dianella caerulea*		U	3
Pittosporaceae	*Billardiera scandens*	Appleberry	U	1
	Pittosporum undulatum	Pittosporum	U	1
Poaceae	*Andropogon virginicus*	Whisky Grass	U	1
	Entolasia stricta	Wiry Panic	U	5
	Microlaena stipoides		U	1
	Themeda australis	Kangaroo Grass	U	3
Polygonaceae	*Rumex brownii*	Swamp Dock	U	1
Polypodiaceae	*Pyrrosia rupestris*	Rock Felt Fern	U	1
Portulacaceae	*Calandrinia pickeringii*		U	1
Proteaceae	*Banksia integrifolia*		U	1
	Banksia oblongifolia		U	4
	Banksia paludosa		U	1
	Banksia robur		U	1
	Banksia serrata		U	5
	Banksia spinulosa		U	5
	Conospermum ericifolium		U	2
	Conospermum longifolium		U	6
	Grevillea buxifolia	Grey Spider Flower	U	3
	Grevillea diffusa		U	4
	Grevillea diffusa ssp filipendula		U	1
	Grevillea linearifolia		U	1
	Grevillea shiressii		V	11
	Hakea dactyloides		U	1
	Hakea sericea		U	2
	Hakea teretifolia		U	4
	Isopogon anemonifolius		U	2
	Lambertia formosa	Mountain Devil	U	6
	Lomatia myricoides	River Lomatia	U	1
	Lomatia silaifolia	Crinkle Bush	P13	3

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	Scientific Name	Common Name	Legal Status	Count
	Persoonia isophylla		U	2
	Persoonia lanceolata		U	2
	Persoonia levis	Broad-leaved Geebung	U	2
	Persoonia linearis	Narrow-leaved Geebung	U	4
	Petrophile pulchella		U	1
Ranunculaceae	*Clematis glycinoides*	Headache Vine	U	1
Restionaceae	*Empodisma minus*		U	3
	Guringalia dimorpha		U	1
	Hypolaena fastigiata		U	1
	Leptocarpus tenax		U	1
	Lepyrodia scariosa		U	2
Rubiaceae	*Morinda jasminoides*		U	1
	Psychotria loniceroides	Hairy Psychotria	U	1
Rutaceae	*Asterolasia correifolia*		U	1
	Boronia fraseri		P13	7
	Boronia ledifolia	Sydney Boronia	P13	5
	Boronia pinnata		P13	1
	Boronia serrulata	Rose Boronia	P13	5
	Eriostemon australasius		P13	2
	Phebalium squamulosum	Scaly Phebalium	U	1
Santalaceae	*Exocarpos cupressiformis*	Native Cherry	U	1
	Leptomeria acida	Sour Currant Bush	U	1
Sapindaceae	*Dodonaea camfieldii*		U	1
	Dodonaea triquetra		U	4
Selaginellaceae	*Selaginella uliginosa*		U	3
Smilacaceae	*Smilax australis*	Sarsaparilla	U	1
	Smilax glyciphylla	Sweet Sarsparilla	U	1
Solanaceae	*Solanum nodiflorum*		U	1
	Solanum pungetium	Eastern Nightshade	U	1
Sterculiaceae	*Lasiopetalum macrophyllum*		U	2
Stylidiaceae	*Stylidium spp.*		U	2
Thymelaeaceae	*Pimelea linifolia*		U	3
	Wikstroemia indica		U	1
Tremandraceae	*Tetratheca ericifolia*		U	1
	Tetratheca glandulosa		V	6
	Tetratheca shiressii		U	4
	Tetratheca thymifolia	Black-eyed Susan	U	2
Verbenaceae	*Lantana camara*	Lantana	U	2
Vitaceae	*Cissus antarctica*	Water Vine	U	1
	Cissus hypoglauca	Giant Water Vine	U	1
Winteraceae	*Tasmannia insipida*	Brush Pepperwood	U	2
Xanthorrhoeaceae	*Xanthorrhoea arborea*		U	1
	Xanthorrhoea spp.		U	6

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		Scientific Name	Common Name	Legal Status	Count
Amphibia	Hylidae	*Litoria aurea*	Green and Golden Bell Frog	E1	2
		Litoria ewingii	Brown Tree Frog	P	1
		Litoria fallax	Eastern Dwarf Tree Frog	P	2
		Litoria freycineti	Freycinet's Frog	P	3
		Litoria jervisiensis	Jervis Bay Tree Frog	P	1
		Litoria phyllochroa	Leaf Green Tree Frog	P	5
	Myobatrachidae	*Crinia signifera*	Common Eastern Froglet	P	19
		Heleioporus australiacus	Giant Burrowing Frog	V	23
		Limnodynastes dorsalis	Western Banjo Frog	P	1
		Limnodynastes dumerilii	Eastern Banjo Frog	P	1
		Limnodynastes peronii	Brown-striped Frog	P	6
		Mixophyes iteratus	Giant Barred Frog	E1	1
		Pseudophryne australis	Red-crowned Toadlet	V	46
Aves	Accipitridae	*Accipiter cirrhocephalus*	Collared Sparrowhawk	P	3
		Accipiter fasciatus	Brown Goshawk	P	3
		Accipiter novaehollandiae	Grey Goshawk	P	2
		Aquila audax	Wedge-tailed Eagle	P	4
		Aviceda subcristata	Pacific Baza	P	4
		Circus approximans	Swamp Harrier	P	1
		Elanus axillaris	Black-shouldered Kite	P	3
		Haliaeetus leucogaster	White-bellied Sea-Eagle	P	24
		Haliastur sphenurus	Whistling Kite	P	26
		Hamirostra melanosternon	Black-breasted Buzzard	V	1
		Hieraaetus morphnoides	Little Eagle	P	3
		Pandion haliaetus	Osprey	V	11
	Aegothelidae	*Aegotheles cristatus*	Australian Owlet-nightjar	P	2
	Alcedinidae	*Alcedo azurea*	Azure Kingfisher	P	5
	Anatidae	*Anas castanea*	Chestnut Teal	P	11
		Anas gracilis	Grey Teal	P	4
		Anas platyrhynchos	Mallard	U	12
		Anas superciliosa	Pacific Black Duck	P	14
		Biziura lobata	Musk Duck	P	1
		Chenonetta jubata	Australian Wood Duck	P	10
		Cygnus atratus	Black Swan	P	1
	Apodidae	*Apus pacificus*	Fork-tailed Swift	P	4
		Hirundapus caudacutus	White-throated Needletail	P	6
	Ardeidae	*Ardea alba*	Great Egret	P	11
		Ardea ibis	Cattle Egret	P	1
		Ardea intermedia	Intermediate Egret	P	2
		Ardea pacifica	White-necked Heron	P	2
		Butorides striatus	Striated Heron	P	9
		Egretta garzetta	Little Egret	P	7
		Egretta novaehollandiae	White-faced Heron	P	21
		Ixobrychus flavicollis	Black Bittern	V	2
		Nycticorax caledonicus	Nankeen Night Heron	P	1
	Artamidae	*Artamus cyanopterus*	Dusky Woodswallow	P	4
		Cracticus nigrogularis	Pied Butcherbird	P	3
		Cracticus torquatus	Grey Butcherbird	P	37
		Gymnorhina tibicen	Australian Magpie	P	32
		Strepera graculina	Pied Currawong	P	49
	Burhinidae	*Burhinus grallarius*	Bush Stone-curlew	E1	23
	Cacatuidae	*Cacatua galerita*	Sulphur-crested Cockatoo	P	7
		Cacatua roseicapilla	Galah	P	5
		Cacatua sanguinea	Little Corella	P	1
		Cacatua tenuirostris	Long-billed Corella	P	1

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	Scientific Name	Common Name	Legal Status	Count
	Callocephalon fimbriatum	Gang-gang Cockatoo	P	1
	Calyptorhynchus funereus	Yellow-tailed Black-Cockatoo	P	13
	Calyptorhynchus lathami	Glossy Black-Cockatoo	V	66
Campephagidae	*Coracina novaehollandiae*	Black-faced Cuckoo-shrike	P	16
	Coracina tenuirostris	Cicadabird	P	1
	Lalage leucomela	Varied Triller	P	1
Caprimulgidae	*Eurostopodus argus*	Spotted Nightjar	P	1
	Eurostopodus mystacalis	White-throated Nightjar	P	3
Centropodidae	*Centropus phasianinus*	Pheasant Coucal	P	3
Charadriidae	*Elseyornis melanops*	Black-fronted Dotterel	P	1
	Vanellus miles	Masked Lapwing	P	19
Cinclosomatidae	*Cinclosoma punctatum*	Spotted Quail-thrush	P	2
	Psophodes olivaceus	Eastern Whipbird	P	32
Climacteridae	*Cormobates leucophaeus*	White-throated Treecreeper	P	15
Columbidae	*Columba leucomela*	White-headed Pigeon	P	2
	Columba livia	Rock Dove	U	1
	Geopelia humeralis	Bar-shouldered Dove	P	2
	Geopelia striata	Peaceful Dove	P	3
	Leucosarcia melanoleuca	Wonga Pigeon	P	4
	Lopholaimus antarcticus	Topknot Pigeon	P	5
	Macropygia amboinensis	Brown Cuckoo-Dove	P	3
	Ocyphaps lophotes	Crested Pigeon	P	11
	Phaps elegans	Brush Bronzewing	P	4
	Ptilinopus regina	Rose-crowned Fruit-Dove	V	1
	Ptilinopus superbus	Superb Fruit-Dove	V	3
	Streptopelia chinensis	Spotted Turtle-Dove	U	7
Coraciidae	*Eurystomus orientalis*	Dollarbird	P	5
Corvidae	*Corvus coronoides*	Australian Raven	P	45
	Corvus splendens	House Crow	U	1
Cuculidae	*Cacomantis flabelliformis*	Fan-tailed Cuckoo	P	11
	Cacomantis variolosus	Brush Cuckoo	P	2
	Chrysococcyx basalis	Horsfield's Bronze-Cuckoo	P	1
	Chrysococcyx lucidus	Shining Bronze-Cuckoo	P	1
	Cuculus pallidus	Pallid Cuckoo	P	1
	Eudynamys scolopacea	Common Koel	P	6
	Scythrops novaehollandiae	Channel-billed Cuckoo	P	6
Dicaeidae	*Dicaeum hirundinaceum*	Mistletoebird	P	9
Dicruridae	*Dicrurus bracteatus*	Spangled Drongo	P	1
	Grallina cyanoleuca	Magpie-lark	P	5
	Monarcha melanopsis	Black-faced Monarch	P	1
	Myiagra cyanoleuca	Satin Flycatcher	P	1
	Myiagra rubecula	Leaden Flycatcher	P	1
	Rhipidura fuliginosa	Grey Fantail	P	30
	Rhipidura leucophrys	Willie Wagtail	P	8
	Rhipidura rufifrons	Rufous Fantail	P	5
Falconidae	*Falco berigora*	Brown Falcon	P	2
	Falco cenchroides	Nankeen Kestrel	P	2
	Falco peregrinus	Peregrine Falcon	P	11
Fringillidae	*Carduelis carduelis*	European Goldfinch	U	1
Haematopodidae	*Haematopus fuliginosus*	Sooty Oystercatcher	V	1
	Haematopus longirostris	Pied Oystercatcher	V	35
Halcyonidae	*Dacelo novaeguineae*	Laughing Kookaburra	P	31
	Todiramphus sanctus	Sacred Kingfisher	P	15
Hirundinidae	*Hirundo neoxena*	Welcome Swallow	P	18
	Hirundo nigricans	Tree Martin	P	1

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	Scientific Name	Common Name	Legal Status	Count
Laridae	*Larus novaehollandiae*	Silver Gull	P	23
	Sterna albifrons	Little Tern	E1	1
	Sterna bergii	Crested Tern	P	16
	Sterna caspia	Caspian Tern	P	4
	Sterna fuscata	Sooty Tern	V	1
	Sterna hirundo	Common Tern	P	3
Maluridae	*Malurus cyaneus*	Superb Fairy-wren	P	30
	Malurus lamberti	Variegated Fairy-wren	P	18
	Malurus melanocephalus	Red-backed Fairy-wren	P	1
	Stipiturus malachurus	Southern Emu-wren	P	1
Megapodiidae	*Alectura lathami*	Australian Brush-turkey	P	11
Meliphagidae	*Acanthorhynchus tenuirostris*	Eastern Spinebill	P	41
	Anthochaera carunculata	Red Wattlebird	P	23
	Anthochaera chrysoptera	Little Wattlebird	P	53
	Epthianura albifrons	White-fronted Chat	P	1
	Lichenostomus chrysops	Yellow-faced Honeyeater	P	20
	Lichenostomus fuscus	Fuscous Honeyeater	P	3
	Lichenostomus leucotis	White-eared Honeyeater	P	39
	Manorina melanocephala	Noisy Miner	P	26
	Manorina melanophrys	Bell Miner	P	1
	Meliphaga lewinii	Lewin's Honeyeater	P	24
	Melithreptus brevirostris	Brown-headed Honeyeater	P	3
	Melithreptus lunatus	White-naped Honeyeater	P	2
	Myzomela sanguinolenta	Scarlet Honeyeater	P	3
	Philemon corniculatus	Noisy Friarbird	P	21
	Phylidonyris melanops	Tawny-crowned Honeyeater	P	4
	Phylidonyris nigra	White-cheeked Honeyeater	P	41
	Phylidonyris novaehollandiae	New Holland Honeyeater	P	31
	Phylidonyris pyrrhoptera	Crescent Honeyeater	P	1
	Xanthomyza phrygia	Regent Honeyeater	E1	4
Menuridae	*Menura novaehollandiae*	Superb Lyrebird	P	17
Motacillidae	*Anthus novaeseelandiae*	Richard's Pipit	P	1
Muscicapidae	*Zoothera dauma*	Unindentified Ground Thrush	P	5
Neosittidae	*Daphoenositta chrysoptera*	Varied Sittella	P	1
Pachycephalidae	*Colluricincla harmonica*	Grey Shrike-thrush	P	32
	Pachycephala pectoralis	Golden Whistler	P	33
	Pachycephala rufiventris	Rufous Whistler	P	8
Pardalotidae	*Acanthiza chrysorrhoa*	Yellow-rumped Thornbill	P	5
	Acanthiza lineata	Striated Thornbill	P	12
	Acanthiza nana	Yellow Thornbill	P	11
	Acanthiza pusilla	Brown Thornbill	P	32
	Acanthiza reguloides	Buff-rumped Thornbill	P	2
	Gerygone levigaster	Mangrove Gerygone	P	6
	Gerygone mouki	Brown Gerygone	P	5
	Gerygone olivacea	White-throated Gerygone	P	1
	Hylacola pyrrhopygia	Chestnut-rumped Heathwren	P	6
	Origma solitaria	Rockwarbler	P	4
	Pardalotus punctatus	Spotted Pardalote	P	33
	Pardalotus striatus	Striated Pardalote	P	1
	Sericornis citreogularis	Yellow-throated Scrubwren	P	2
	Sericornis frontalis	White-browed Scrubwren	P	32
	Sericornis magnirostris	Large-billed Scrubwren	P	2
Passeridae	*Neochmia temporalis*	Red-browed Finch	P	22
	Passer domesticus	House Sparrow	U	1
Pelecanidae	*Pelecanus conspicillatus*	Australian Pelican	P	32

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	Scientific Name	Common Name	Legal Status	Count
Petroicidae	*Eopsaltria australis*	Eastern Yellow Robin	P	21
	Microeca fascinans	Jacky Winter	P	1
	Petroica multicolor	Scarlet Robin	P	5
Phalacrocoracidae	*Phalacrocorax carbo*	Great Cormorant	P	18
	Phalacrocorax melanoleucos	Little Pied Cormorant	P	30
	Phalacrocorax sulcirostris	Little Black Cormorant	P	20
	Phalacrocorax varius	Pied Cormorant	P	11
Phasianidae	*Coturnix ypsilophora*	Brown Quail	P	3
Pittidae	*Pitta versicolor*	Noisy Pitta	P	1
Podargidae	*Podargus strigoides*	Tawny Frogmouth	P	10
Podicipedidae	*Tachybaptus novaehollandiae*	Australasian Grebe	P	1
Procellariidae	*Halobaena caerulea*	Blue Petrel	P	3
	Pterodroma leucoptera	Gould's Petrel	E1	3
	Puffinus gavia	Fluttering Shearwater	P	1
	Puffinus griseus	Sooty Shearwater	P	4
	Puffinus pacificus	Wedge-tailed Shearwater	P	6
	Puffinus tenuirostris	Short-tailed Shearwater	P	2
Psittacidae	*Alisterus scapularis*	Australian King-Parrot	P	10
	Barnardius zonarius	Australian Ringneck	P	1
	Glossopsitta concinna	Musk Lorikeet	P	3
	Glossopsitta pusilla	Little Lorikeet	P	1
	Lathamus discolor	Swift Parrot	E1	7
	Neophema pulchella	Turquoise Parrot	V	9
	Platycercus elegans	Crimson Rosella	P	22
	Platycercus eximius	Eastern Rosella	P	28
	Psephotus haematonotus	Red-rumped Parrot	P	1
	Purpureicephalus spurius	Red-capped Parrot	P	1
	Trichoglossus chlorolepidotus	Scaly-breasted Lorikeet	P	2
	Trichoglossus haematodus	Rainbow Lorikeet	P	33
Ptilonorhynchidae	*Ptilonorhynchus violaceus*	Satin Bowerbird	P	6
	Sericulus chrysocephalus	Regent Bowerbird	P	2
Pycnonotidae	*Pycnonotus jocosus*	Red-whiskered Bulbul	U	3
Rallidae	*Gallirallus philippensis*	Buff-banded Rail	P	2
	Rallus pectoralis	Lewin's Rail	P	1
Scolopacidae	*Calidris acuminata*	Sharp-tailed Sandpiper	P	1
	Heteroscelus brevipes	Grey-tailed Tattler	P	1
	Limosa lapponica	Bar-tailed Godwit	P	6
	Numenius madagascariensis	Eastern Curlew	P	20
	Numenius phaeopus	Whimbrel	P	9
	Tringa nebularia	Common Greenshank	P	1
	Xenus cinereus	Terek Sandpiper	V	1
Spheniscidae	*Eudyptula minor*	Little Penguin	P	9
Strigidae	*Ninox connivens*	Barking Owl	V	1
	Ninox novaeseelandiae	Southern Boobook	P	18
	Ninox strenua	Powerful Owl	V	12
Sturnidae	*Acridotheres tristis*	Common Myna	U	2
	Sturnus vulgaris	Common Starling	U	1
Threskiornithidae	*Platalea regia*	Royal Spoonbill	P	7
	Threskiornis molucca	Australian White Ibis	P	19
	Threskiornis spinicollis	Straw-necked Ibis	P	2
Turnicidae	*Turnix varia*	Painted Button-quail	P	2
Tytonidae	*Tyto alba*	Barn Owl	P	1
	Tyto novaehollandiae	Masked Owl	V	7
	Tyto tenebricosa	Sooty Owl	V	4
Zosteropidae	*Zosterops lateralis*	Silvereye	P	25

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		Scientific Name	Common Name	Legal Status	Count
Mammalia	Balaenidae	*Eubalaena australis*	Southern Right Whale	V	3
	Balaenopteridae	*Megaptera novaeangliae*	Humpback Whale	V	2
	Bovidae	*Capra hircus*	Goat (feral)	U	1
	Burramyidae	*Acrobates pygmaeus*	Feathertail Glider	P	1
		Cercartetus nanus	Eastern Pygmy-possum	P	4
	Canidae	*Canis familiaris*	Dingo and Dog (feral)	U	9
		Vulpes vulpes	Fox	U	11
	Dasyuridae	*Antechinus stuartii*	Brown Antechinus	P	16
		Antechinus swainsonii	Dusky Antechinus	P	5
		Dasyurus maculatus	Spotted-tailed Quoll	V	25
		Sminthopsis murina	Common Dunnart	P	2
	Delphinidae	*Delphinus delphis*	Common Dolphin	P	4
		Tursiops truncatus	Bottlenose Dolphin	P	2
	Dugongidae	*Dugong dugon*	Dugong	P	1
	Felidae	*Felis catus*	Cat (feral)	U	3
	Leporidae	*Lepus capensis*	Brown Hare	U	1
	Macropodidae	*Macropus giganteus*	Eastern Grey Kangaroo	P	1
		Macropus rufogriseus	Red-necked Wallaby	P	2
		Wallabia bicolor	Swamp Wallaby	P	31
	Molossidae	*Mormopterus sp 1*	undescribed mastiff-bat	P	2
	Muridae	*Hydromys chrysogaster*	Water-rat	P	3
		Melomys cervinipes	Fawn-footed Melomys	P	2
		Mus musculus	House Mouse	U	4
		Pseudomys gracilicaudatus	Eastern Chestnut Mouse	V	2
		Rattus fuscipes	Bush Rat	P	14
		Rattus lutreolus	Swamp Rat	P	3
	Ornithorhynchidae	*Ornithorhynchus anatinus*	Platypus	P	1
	Otariidae	*Arctocephalus forsteri*	New Zealand Fur-seal	P	2
		Arctocephalus sp.	Unidentified Fur-seal	P	2
		Seal sp.	Unidentified Seal	P	1
	Peramelidae	*Isoodon macrourus*	Northern Brown Bandicoot	P	3
		Isoodon obesulus	Southern Brown Bandicoot	E1	4
		Perameles nasuta	Long-nosed Bandicoot	P	11
	Petauridae	*Petauroides volans*	Greater Glider	P	3
		Petaurus australis	Yellow-bellied Glider	V	1
		Petaurus breviceps	Sugar Glider	P	10
		Petaurus norfolcensis	Squirrel Glider	V	9
		Pseudocheirus peregrinus	Common Ringtail Possum	P	10
	Phalangeridae	*Trichosurus vulpecula*	Common Brushtail Possum	P	9
	Phascolarctidae	*Phascolarctos cinereus*	Koala	V	90
	Physeteridae	*Kogia breviceps*	Pygmy Sperm Whale	P	2
		Physeter macrocephalus	Sperm Whale	V	1
	Potoroidae	*Potorous tridactylus*	Long-nosed Potoroo	V	2
	Pteropodidae	*Pteropus poliocephalus*	Grey-headed Flying-fox	P	1
	Rhinolophidae	*Rhinolophus megaphyllus*	Eastern Horseshoe-bat	P	1
	Tachyglossidae	*Tachyglossus aculeatus*	Short-beaked Echidna	P	9
	Vespertilionidae	*Chalinolobus gouldii*	Gould's Wattled Bat	P	2
		Falsistrellus tasmaniensis	Eastern False Pipistrelle	V	1
		Miniopterus australis	Little Bent-wing Bat	V	2
		Miniopterus schreibersii	Common Bent-wing Bat	V	9
		Myotis adversus	Large-footed Myotis	V	2
		Scoteanax rueppellii	Greater Broad-nosed Bat	V	1
		Vespadelus darlingtoni	Large Forest Bat	P	1
		Vespadelus vulturnus	Little Forest Bat	P	12
	Vombatidae	*Vombatus ursinus*	Common Wombat	P	5

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		Scientific Name	Common Name	Legal Status	Count
Reptilia	Agamidae	*Amphibolurus muricatus*	Jacky Lizard	P	1
		Physignathus lesueurii	Eastern Water Dragon	P	17
		Pogona barbata	Bearded Dragon	P	2
		Tympanocryptis diemensis	Mountain Dragon	P	1
	Boidae	*Morelia spilota spilota*	Diamond Python	P	1
	Cheloniidae	*Chelonia mydas*	Green Turtle	V	2
	Colubridae	*Boiga irregularis*	Brown Tree Snake	P	2
		Dendrelaphis punctulata	Green Tree Snake	P	3
	Elapidae	*Acanthophis antarcticus*	Common Death Adder	P	4
		Cacophis krefftii	Krefft's Dwarf Snake	P	1
		Cacophis squamulosus	Golden Crowned Snake	P	1
		Demansia psammophis	Yellow-faced Whip Snake	P	3
		Furina diadema	Red-naped Snake	P	2
		Notechis scutatus	Eastern Tiger Snake	P	2
		Pseudonaja textilis	Eastern Brown Snake	P	4
		Rhinoplocephalus nigrescens	Eastern Small-eyed Snake	P	1
		Vermicella annulata	Bandy Bandy	P	3
	Gekkonidae	*Oedura lesueurii*	Lesueur's Velvet Gecko	P	8
		Phyllurus platurus	Southern Leaf-tailed Gecko	P	5
	Hydrophiidae	*Hydrophis elegans*		P	1
	Pygopodidae	*Lialis burtonis*	Burton's Legless Lizard	P	4
		Pygopus lepidopodus	Common Scaly-foot	P	4
	Scincidae	*Bassiana platynota*	Red-throated Skink	P	6
		Cryptoblepharus virgatus	Wall Lizard	P	7
		Ctenotus robustus	Striped Skink	P	6
		Ctenotus taeniolatus	Copper-tailed Skink	P	22
		Cyclodomorphus michaeli		P	1
		Egernia cunninghami	Cunningham's Skink	P	3
		Egernia whitii	White's Skink	P	13
		Eulamprus quoyii	Eastern Water Skink	P	13
		Lampropholis delicata	Grass Skink	P	17
		Lampropholis guichenoti	Garden Skink	P	2
		Lampropholis sp.	unidentified grass skink	P	3
		Lygisaurus foliorum		P	2
		Saiphos equalis	Three-toed Skink	P	6
		Saproscincus mustelinus	Weasel Skink	P	4
		Tiliqua scincoides	Eastern Blue-tongued Lizard	P	6
	Typhlopidae	*Ramphotyphlops nigrescens*		P	4
	Varanidae	*Varanus rosenbergi*	Heath Monitor	V	1
		Varanus varius	Lace Monitor	P	11

Appendix 3. List of fish, birds, amphibians, mammals, reptiles and plants likely to occur within the vicinity of Brooklyn Estuary protected under the EPBC Act (1999). The list includes species classed as threatened ecological communities, threatened species, marine protected species and migratory species.

	Scientific Name	Common Name	Legal Status
Threatened Species			
Amphibia	*Heleioporus australiacus*	Giant Burrowing Frog	Vulnerable
	Litoria aurea	Green and Golden Bell Frog	Vulnerable
	Mixophyes balbus	Stuttering Frog	Vulnerable
	Mixophyes iteratus	Southern Barred Frog	Endangered
Aves	*Lathamus discolor*	Swift Parrot	Endangered
	Macronectes giganteus	Southern Giant-Petrel	Endangered
	Macronectes halli	Northern Giant-Petrel	Vulnerable
	Thalassarche cauta	Shy Albatross	Vulnerable
	Xanthomyza phrygia	Regent Honeyeater	Endangered
Chondrichthyes	*Carcharias taurus*	Grey Nurse Shark	Vulnerable
	Carcharodon carcharias	Great White Shark	Vulnerable
Mammalia	*Chalinolobus dwyeri*	Large-eared Pied Bat, Large Pied Bat	Vulnerable
	Dasyurus maculatus maculatus	Spot-tailed Quoll, Spotted-tail Quoll, Tiger Quo	Vulnerable
	Eubalaena australis	Southern Right Whale	Endangered
	Isoodon obesulus obesulus	Southern Brown Bandicoot	Endangered
	Megaptera novaeangliae	Humpback Whale	Vulnerable
	Petrogale penicillata	Brush-tailed Rock-wallaby	Vulnerable
	Potorous tridactylus tridactylus	Long-nosed Potoroo (SE mainland)	Vulnerable
Osteichthyes	*Macquaria australasica*	Macquarie Perch	Endangered
	Prototroctes maraena	Australian Grayling	Vulnerable
Plant	*Acacia bynoeana*	-	Vulnerable
	Astrotricha crassifolia	-	Vulnerable
	Caladenia tessellata	Thick-lipped Spider-orchid, Daddy Long-legs	Vulnerable
	Cryptostylis hunteriana	Leafless Tongue-orchid	Vulnerable
	Darwinia biflora	-	Vulnerable
	Eucalyptus camfieldii	Camfields Gum	Vulnerable
	Grevillea shiressii	-	Vulnerable
	Haloragodendron lucasii	Hal	Endangered
	Kunzea rupestris	-	Vulnerable
	Leptospermum deanei	-	Vulnerable
	Melaleuca deanei	Deane's Melaleuca	Vulnerable
	Micromyrtus blakelyi	-	Vulnerable
	Olearia cordata	-	Vulnerable
	Prostanthera junonis	Somersby Mintbush	Endangered
	Tetratheca glandulosa	-	Vulnerable
Reptilia	*Chelonia mydas*	Green Turtle	Vulnerable
	Dermochelys coriacea	Leathery Turtle, Luth	Vulnerable
	Hoplocephalus bungaroides	Broad-headed Snake	Vulnerable
Marine birds covered by migratory provisions of the EPBC Act, 1999			
Aves	*Macronectes giganteus*	Southern Giant-Petrel	
	Macronectes halli	Northern Giant-Petrel	
	Thalassarche cauta	Shy Albatross	
Marine species covered by migratory provisions of the EPBC Act, 1999			
Chondrichthyes	*Rhincodon typus*	Whale Shark	
Mammalia	*Eubalaena australis*	Southern Right Whale	
	Megaptera novaeangliae	Humpback Whale	
Reptilia	*Chelonia mydas*	Green Turtle	
	Dermochelys coriacea	Leathery Turtle, Luth	

Appendix 3. List of fish, birds, amphibians, mammals, reptiles and plants likely to occur within the vicinity of Brooklyn Estuary protected under the EPBC Act (1999). The list includes species classed as threatened ecological communities, threatened species, marine protected species and migratory species.

	Scientific Name	Common Name	Legal Status
Terrestrial species covered by migratory provisions of the EPBC Act, 1999			
Aves	*Haliaeetus leucogaster*	White-bellied Sea-Eagle	
	Hirundapus caudacutus	White-throated Needletail	
	Monarcha melanopsis	Black-faced Monarch	
	Myiagra cyanoleuca	Satin Flycatcher	
	Rhipidura rufifrons	Rufous Fantail	
	Xanthomyza phrygia	Regent Honeyeater	
Wetland species covered by migratory provisions of the EPBC Act, 1999			
Aves	*Gallinago hardwickii*	Latham's Snipe, Japanese Snipe	
	Rostratula benghalensis	Painted Snipe	
Species covered by marine provisions of the EPBC Act, 1999			
Aves	*Gallinago hardwickii*	Latham's Snipe, Japanese Snipe	Listed
	Haliaeetus leucogaster	White-bellied Sea-Eagle	Listed
	Hirundapus caudacutus	White-throated Needletail	Listed
	Lathamus discolor	Swift Parrot	*
	Macronectes giganteus	Southern Giant-Petrel	Listed
	Macronectes halli	Northern Giant-Petrel	Listed
	Monarcha melanopsis	Black-faced Monarch	Listed
	Myiagra cyanoleuca	Satin Flycatcher	Listed
	Rhipidura rufifrons	Rufous Fantail	Listed
	Rostratula benghalensis	Painted Snipe	Listed
	Thalassarche cauta	Shy Albatross	Listed
Osteichthyes	*Acentronura tentaculata*	Pipehorse	Listed
	Festucalex cinctus	Girdled Pipefish	Listed
	Filicampus tigris	Tiger Pipefish	Listed
	Heraldia nocturna	-	Listed
	Hippichthys penicillus	Steep-nosed Pipefish	Listed
	Hippocampus abdominalis	Eastern Potbelly Seahorse	Listed
	Hippocampus whitei	Crowned Seahorse	Listed
	Histiogamphelus briggsii	Briggs' Pipefish	Listed
	Lissocampus runa	Javelin Pipefish	Listed
	Maroubra perserrata	Sawtooth Pipefish	Listed
	Notiocampus ruber	Red Pipefish	Listed
	Phyllopteryx taeniolatus	Weedy Seadragon, Common Seadragon	Listed
	Solegnathus spinosissimus	Spiny Pipehorse	Listed
	Solenostomus cyanopterus	Blue-finned Ghost Pipefish	Listed
	Solenostomus paradoxus	Harlequin Ghost Pipefish	Listed
	Stigmatopora argus	Spotted Pipefish	Listed
	Stigmatopora nigra	Black Pipefish	Listed
	Syngnathoides biaculeatus	Alligator Pipefish	Listed
	Trachyrhamphus bicoarctatus	Short-tailed Pipefish	Listed
	Urocampus carinirostris	Hairy Pipefish	Listed
	Vanacampus margaritifer	Mother-of-pearl Pipefish	Listed
Reptilia	*Chelonia mydas*	Green Turtle	Listed
	Dermochelys coriacea	Leathery Turtle, Luth	Listed
	Pelamis platurus	Yellow-bellied Sea Snake	Listed

Appendix 4: Number of days fished by method by year (NSW Fisheries, 2001)

Method Name	84/85	85/86	86/87	87/88	88/89	89/90	90/91	91/92	92/93	93/94	94/95	95/96	96/97	97/98	98/99	99/00
Bait net		30	6			46	166	239	186	206	139	192	285	23	10	12
Bait trap																10
Bullringing (garfish)										3	3	16	18		1	17
Crab pot	13	7	48	21	73	39	310	722	710	1011	1133	950	351	73	124	270
Dropline	2			7		31										
Eel trap				18	12	28		317	1340	1446	1199	1151	921	618	883	856
Estuarine prawn trawl	5990	6312	5419	4765	4914	4893	6333	6640	7457	5670	5881	6679	6951	5622	4706	2798
Estuary prawn trawl (squid)															27	1357
Fish trap (bottom/demersal)	1094	1232	809	970	1255	1186	781	968	890	665	312	581	433	170	122	88
Fish trawl	242	181	71	8		1										
Hand gathering		9			8			46	43	58		20		4	76	6
Handline		20	29	88	25	48	325	506	707	832	664	559	457	192	186	167
Hauling net, general purpose														585	271	356
Hauling net (beach haul)	736	912	988	728	593	595	1165	1113	1176	1155	782	839	1094			
Hoop netting				6	31	10										
Hoop or lift netting						9	62	92	7	41			25	90	86	78
Jigging								12	32	31	5					
Lobster/crayfish pot	93	138	148	155	80	56	187	346	623	725	455	358	224	76		
Longline (midwater/pelagic)	28															
Mesh net (flathead)						25		10	48	81	40	10	36	6		15
Mesh net, bottom set								85	683	728	901	990	1158			
Mesh net, splashing			12	33	19	26		251	883	1531	1513	1371	1656			
Mesh net, top set	4180	3338	4292	3776	3641	3345	4019	3604	2057	1145	635	325	285			
Mesh net, top set, bottom set or splashing														1793	1880	1813
Other or ambiguous	1181	1060	709	762	878	675	209	409	207	94	364	42	73	638	108	
Pilchard, anchovy or bait net														63	30	48
Pound net (figure six)							20									
Prawn haul net	41	94	3	30	41	12	15	1		34						
Prawn running net	53	53		4	41	31	16			8		7		0	2	
Prawn seine	27		35			5	7						16		15	
Prawn set pocket set	13	24	27	18	45	8	7		7	22	23	3				
Purse seine		13														
Setlining						6									3	10
Skindiving	35	58	52	53	27	9	14									
Trolling	34	33													17	6
Trotline (bottom set)	35	49						6	10	1	5	4	2			
Hawkesbury River Total	13797	13563	12648	11442	11683	11084	13636	15367	17066	15487	14054	14097	13985	9953	8547	7907

Appendix 5. Field GPS readings for intertidal sampling sites on the causeway between Brooklyn Harbour and Sandbrook Inlet. Recorded between 30/01/02 and 01/02/02. See Figure 10 for map of locations. Map datum: AGM 84.

Location	Site	Easting	Northing	Easting	Northing
Brooklyn Harbour	1	0335493	6286924	0335493	6286971
Brooklyn Harbour	2	0335598	6287177	0335626	6287217
Brooklyn Harbour	3	0335561	6287105	0335558	6287060
Sandbrook Inlet	4	0335250	6286530	0335294	6286564
Sandbrook Inlet	5	0335319	6286624	0335338	6286674
Sandbrook Inlet	6	0335362	6286719	0335380	6286765

Appendix 6: Summary of Statistical Procedures

Data were analysed statistically using two broad procedures, multivariate and univariate analysis. Multivariate analysis allows us to examine differences among sites, locations, times and depth for all species or taxa present (commonly called “the assemblage”). Univariate analysis allows us to examine differences for a single species or factor among sites, locations, times and depth.

Variation in the assemblage of species between sites and among locations was assessed using multivariate procedures such as Bray-Curtis similarity matrix with the statistical program PRIMER (Clarke, 1993). Spatial variation in assemblages was examined using analysis of similarities (ANOSIM). The null hypothesis tested was one of no difference between sites and among locations. The significance levels in pairwise tests were adjusted to allow for multiple comparisons using the Bonferroni correction (Winer *et al.*, 1991). Variation in assemblages was presented graphically using multi-dimensional scaling (MDS) plots, based on Bray-Curtis similarity measures. The adequacy of the three dimensional representations of the similarities among samples is assessed by examining the stress value. This value is in no way connected to any measure of “environmental stress”. Stress values of < 0.1 indicate a good representation which may be easily interpreted and plots with < 0.2 indicate reasonable representation of the data. Plots where stress values exceed 0.2 indicate a poor representation of the relationship among samples in three dimensions and are of little value (Clarke, 1993). If variation in assemblages was detected, the species that contributed most to the dissimilarity among places or times was identified using similarity of percentage (SIMPER) analyses.

Species richness, total abundance and individual taxa that were identified as contributing substantially to the dissimilarity in assemblages among locations was analysed using asymmetrical analyses of variance (ANOVA). Variances was tested for homogeneity using Cochran's C-Test ($\alpha = 0.05$). Data was transformed where necessary to stabilise variances if the Cochran’s C-Test was significant. If transformations fail, untransformed data was used but the level of significance, α, was reduced from 0.05 to 0.01 to reduce the chance of making a Type 1 error (Underwood, 1981). When the ANOVAs were significant, means were compared using planned comparisons among locations. To enable a test of the factor location, non-significant interactions at $P>0.25$ were eliminated (Underwood 1981).

Appendix 7. Mean number and standard error (SE) of intertidal organisms counted in quadrats on existing rail causeway.
Location: **Outer Causeway** (Brooklyn Harbour side).

Site	1	1	1	1	2	2	2	2	3	3	3	3
Shore Height (Zone)	HIGH	HIGH	LOW	LOW	HIGH	HIGH	LOW	LOW	HIGH	HIGH	LOW	LOW
Species Name	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Saccostrea commercialis (live)	0.40	0.40	47.30	9.86	1.50	1.02	35.40	6.62	0.20	0.20	33.70	11.00
Saccostrea commercialis (dead)	0.80	0.70	10.80	3.08	1.00	0.45	17.80	3.96	1.00	0.54	10.70	2.44
Mytilus edulis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Bembicium nanum	9.00	2.90	0.60	0.50	0.30	0.21	0.70	0.30	3.10	0.53	6.30	3.99
Bembicium auratum	69.90	19.45	169.90	12.10	7.10	2.14	65.40	12.08	17.80	3.71	113.00	16.00
Austrocochlea porcarta	0.00	0.00	1.10	0.50	0.00	0.00	1.10	0.60	0.00	0.00	1.20	0.55
Austrocochlea concamerata	0.00	0.00	0.10	0.10	0.00	0.00	0.30	0.21	0.00	0.00	0.30	0.21
Morula marginalba	0.30	0.30	0.10	0.10	0.10	0.10	0.00	0.00	0.10	0.10	0.20	0.13
Nerita atramentosa	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.20	0.13	0.00	0.00
Nodilittorina unifasciata	0.80	0.80	0.00	0.00	0.80	0.80	0.00	0.00	2.00	0.91	0.00	0.00
Ophicardelus natus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Melosidula zonata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Patelloida mimula	0.00	0.00	5.70	1.45	1.70	0.87	12.80	2.48	0.00	0.00	11.90	4.28
Patelloida insignis	0.00	0.00	8.20	2.92	0.10	0.10	3.60	0.72	0.00	0.00	2.30	0.65
Siphonaria denticulata	0.00	0.00	0.70	0.52	0.20	0.13	5.20	1.32	0.00	0.00	1.20	0.55
Chamaesipho tasmanica	36.00	36.00	4.00	2.61	5.00	5.00	0.00	0.00	14.50	8.76	0.00	0.00
Ischnochiton variegatus	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10	0.00	0.00	0.00	0.00
Serpulidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Species recorded as present or absent												
Ligia australiensis	P		P		P		P		P		P	
Metapograpsus spp.	P		A		A		A		A		A	
Heloecius cordiformis	A		A		A		A		A		A	
Macropthalmus spp	A		A		A		A		A		A	
Algae												
Hildenbrandia rubra	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.60	2.57
Codium fragilis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.10	0.10

Appendix 7, continued. Mean number and standard error of intertidal organisms counted in quadrats on existing rail causeway.
Location: **Inner Causeway** (Sandbrook Inlet side).

Site	4	4	4	4	5	5	5	5	6	6	6	6
Shore Height	HIGH	HIGH	LOW	LOW	HIGH	HIGH	LOW	LOW	HIGH	HIGH	LOW	LOW
Species Name	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE	Mean	SE
Saccostrea commercialis (live)	0.00	0.00	1.20	0.51	0.00	0.00	0.40	0.22	0.20	0.13	3.20	0.55
Saccostrea commercialis (dead)	0.00	0.00	0.60	0.27	0.00	0.00	0.10	0.10	0.10	0.10	3.20	0.57
Mytilus edulis	0.10	0.10	3.40	2.32	0.00	0.00	1.20	1.00	3.00	2.14	15.90	4.33
Bembicium nanum	0.00	0.00	0.20	0.20	0.00	0.00	1.20	1.00	0.00	0.00	0.10	0.10
Bembicium auratum	9.40	1.76	15.10	6.78	4.70	1.55	2.60	1.95	27.60	6.20	11.00	2.50
Austrocochlea porcarta	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Austrocochlea concamerata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Morula marginalba	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nerita atromentosa	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.30	1.30	0.00	0.00
Nodilittorina unifasciata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ophicardelus natus	0.00	0.00	0.00	0.00	0.10	0.10	0.00	0.00	7.30	3.27	0.00	0.00
Melosidula zonata	0.10	0.10	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Patelloida mimula	0.00	0.00	1.10	0.57	0.00	0.00	0.00	0.00	0.00	0.00	1.90	0.69
Patelloida insignis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Siphonaria denticulata	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Chamaesipho tasmanica	0.00	0.00	16.20	10.14	0.00	0.00	12.80	12.80	21.80	10.32	89.50	24.25
Ischnochiton variegatus	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Serpulidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Species recorded as present or absent												
Ligia australiensis	P		A		P		P		A		P	
Metapograpsus spp.	P		P		A		P		P		P	
Heloecius cordiformis	A		P		A		P		A		P	
Macropthalmus spp	P		A		A		P		A		A	
Algae												
Hildenbrandia rubra	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Codium fragilis	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 8. Field GPS readings for beam trawl sampling sites in the Hawkesbury River. Recorded on 17-19/09/01 and 29-31/01/02. See Figure 10 for map of locations. Map datum: AGM 84.

Location	Site	Easting	Northing
Sandbrook Inner (L1)	1	0334859	6286525
Sandbrook Inner (L1)	2	0335109	6286486
Sandbrook Outer (L2)	1	0332641	6286710
Sandbrook Outer (L2)	2	0333023	6286635
Mullet Creek (L3)	1	0336276	6289914
Mullet Creek (L3)	2	0364710	6289259
Freeway (L4)	1	0332968	6288154
Spectacle (L4)	2	0333545	6287922
Bay 22 (L5)	1	0332370	6290013
Bay 22 (L5)	2	0332303	6290296
Sandbrook inlet north(L6)	1	0335154	6286965
Sandbrook inlet north(L6)	2	0334792	6286903

Appendix 9: Means and standard errors for biota collected using beam trawls at two times in the Hawkesbury River. Time 1 = 17-19/09/01, Time 2 = 29-31/01/02.

Family name	Common name	Species or taxon name	Time 1 SIIS S1 Mean	Time 1 SIIS S1 SE	Time 1 SIIS S2 Mean	Time 1 SIIS S2 SE	Time 1 SIO S3 Mean	Time 1 SIO S3 SE	Time 1 SIO S4 Mean	Time 1 SIO S4 SE	Time 1 MC S5 Mean	Time 1 MC S5 SE	Time 1 MC S6 Mean	Time 1 MC S6 SE	Time 1 MMCL S7 Mean	Time 1 MMCL S7 SE
FISH																
Sparidae	Yellow-finned bream	*Acanthopagrus australis*	0.20	0.20	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monacanthidae	Leatherjacket	Monacanthidae	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.00	0.00
Tetraodontidae	Common toadfish	*Tetractenos hamiltoni*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gobiidae	Swan River Goby	*Pseudogobius olorum*	2.20	1.07	1.60	1.17	0.00	0.00	0.00	0.00	3.80	1.36	4.80	1.50	0.40	0.40
Gobiidae	Large-mouth goby	*Redigobius macrostoma*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20
Gobiidae	Glass goby	*Gobiopterus semivestita*	0.00	0.00	0.80	0.37	0.40	0.40	0.20	0.20	0.60	0.40	4.40	1.17	10.60	6.79
Gobiidae	Exquisite goby	*Favonigobius exquisitus*	0.00	0.00	0.00	0.00	0.20	0.20	0.20	0.20	0.00	0.00	0.00	0.00	0.20	0.20
Gobiidae	Tamar River goby	*Favonigobius tamarensis*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.24	0.20	0.20
Gobiidae	Half-bridled goby	*Arenigobius frenatus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gobiidae	Juvenile bridled	*Arenigobius sp.*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gobiidae	Mangrove goby	*Mugilogobius stigmaticus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Clupeidae	Sandy sprat	*Hyperlophus vittatus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Platycephalidae	Larval flathead	Unidentified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unidentified	Larval fish	Unidentified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.00	0.00
INVERTEBRATES																
Penaeidae	Eastern king prawn	*Penaeus plebejus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Penaeidae	School prawn	*Metapenaeus macleayi*	1.00	0.55	0.60	0.40	0.40	0.24	0.00	0.00	0.00	0.00	0.20	0.20	0.00	0.00
Penaeidae	Greasyback prawn	*Metapenaeus bennettae*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Palaemonidae	Carid shrimp	*Palaemon sp.*	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.60	0.00	0.00
Palaemonidae	Carid shrimp	*Macrobrachium intermedium*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crangonidae	Carid shrimp	*Pontophilis angustirostris*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alpheidae	Pistol shrimp	*Alpheus richardsoni*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.24	0.20	0.20	0.00	0.00
Mysidae	Opossum shrimp	*Rhopalopthalmus brisbanensis*	0.00	0.00	1.80	1.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.40
Sergestidae	Pelagic shrimp	*Lucifer sp.*	0.80	0.58	10.00	9.75	0.20	0.20	0.20	0.20	0.00	0.00	0.20	0.20	4.00	3.52
Sergestidae	Pelagic shrimp	*Acetes sibogae australis*	188.20	166.71	2.20	2.20	0.00	0.00	0.00	0.00	1.60	0.93	2.20	1.36	0.00	0.00
Diogenidae	Hermit crab	Unidentified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hymenosomatidae	False spider crab	*Hymenosoma hodgkini*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Grapsidae	Shore crab	*Metapograpsus sp.*	0.00	0.00	0.20	0.20	0.00	0.00	0.00	0.00	1.60	1.17	0.00	0.00	0.20	0.20
Ocypodidae	Sentinel crab	*Macropthalmus sp.*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.24	0.00	0.00	0.00	0.00
Ocypodidae	Semaphpore crab	*Heloecius cordiformis*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Idiosepiidae	Southern pygmy squid	*Idiosepius notoides*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nassariidae	Dog whelk	*Nassarius burchardi*	0.00	0.00	0.20	0.20	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nassariidae	Dog whelk	*Nassarius jonasi*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nassariidae	Dog whelk	*Nassarius pauperatus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Naticidae	Moon snail	*Conuber sordida*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Naticidae	Moon snail eggs	*Conuber sordida*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trochiidae	Snail	Unidentified	0.00	0.00	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mytilidae	Mussel	*Xenostrobus securis*	0.00	0.00	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mactridae	Surf clam	*Spisula trigonella*	0.00	0.00	0.80	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Laternulidae	Lantern shell	*Laternula sp.*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Semelidae	Semelid bivalve	*Theora fragilis*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Cardiidae	Strawberry cockle	Snail	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haminoeidae	Opisthobranch	*Nipponatys tunida*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Phylum Chaetognatha	Arrow worm	Unidentified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Phylum Ctenophora	Comb jellies	Unidentified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Class Cubozoa	Box jellyfish	Unidentified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Class Insecta	Insect	Unidentified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 9 cont.. Means and standard errors for biota collected using beam trawls at two times in the Hawkesbury River. Time 1 = 17-19/09/01, Time 2 = 29-31/01/02.

			Time 1	**Time 1**	**Time 1**	**Time 1**	**Time 1**	**Time 1**	**Time 2**	**Time 2**	**Time 2**	**Time 2**	**Time 2**	**Time 2**	**Time 2**	**Time 2**
			MMCL	**MMCL**	**MMCU**	**MMCU**	**MMCU**	**MMCU**	**SIIS**	**SIIS**	**SIIS**	**SIIS**	**SIO**	**SIO**	**SIO**	**SIO**
			S8	**S8**	**S9**	**S9**	**S10**	**S10**	**S1**	**S1**	**S2**	**S2**	**S3**	**S3**	**S4**	**S4**
Family name	**Common name**	**Species or taxon name**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**	**Mean**	**SE**
FISH																
Sparidae	Yellow-finned bream	*Acanthopagrus australis*	0.00	0.00	0.00	0.00	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monacanthidae	Leatherjacket	*Acanthaluteres sp.*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tetraodontidae	Common toadfish	*Tetractenos hamiltoni*	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gobiidae	Swan River Goby	*Pseudogobius olorum*	0.00	0.00	0.80	0.58	21.80	4.04	10.40	3.40	49.80	41.01	0.00	0.00	1.20	1.20
Gobiidae	Large-mouth goby	*Redigobius macrostoma*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gobiidae	Glass goby	*Gobiopterus semivestita*	2.40	0.75	4.20	1.11	1.40	0.40	56.00	11.34	124.20	25.44	6.60	2.23	0.20	0.20
Gobiidae	Exquisite goby	*Favonigobius exquisitus*	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.60	1.12	0.00	0.00
Gobiidae	Tamar River goby	*Favonigobius tamarensis*	0.00	0.00	0.00	0.00	1.20	0.73	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gobiidae	Half-bridled goby	*Arenigobius frenatus*	0.20	0.20	0.00	0.00	0.20	0.20	0.00	0.00	0.20	0.20	0.00	0.00	0.00	0.00
Gobiidae	Juvenile bridled	*Arenigobius sp.*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.00	0.00	0.00	0.00
Gobiidae	Mangrove goby	*Mugilogobius stigmaticus*	0.00	0.00	0.00	0.00	0.00	0.00	1.00	1.00	0.00	0.00	0.00	0.00	0.00	0.00
Clupeidae	Sandy sprat	*Hyperlophus vittatus*	1.00	1.00	0.00	0.00	0.00	0.00	0.60	0.60	0.00	0.00	0.00	0.00	0.00	0.00
Platycephalidae	Larval flathead	Unidentified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.00	0.00	0.00	0.00
Unidentified	Larval fish	Unidentified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
INVERTEBRATES																
Penaeidae	Eastern king prawn	*Penaeus plebejus*	0.00	0.00	0.00	0.00	0.00	0.00	1.80	0.73	0.60	0.40	6.00	1.95	0.20	0.20
Penaeidae	School prawn	*Metapenaeus macleayi*	0.00	0.00	0.40	0.40	1.20	0.49	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Penaeidae	Greasyback prawn	*Metapenaeus bennettae*	0.00	0.00	0.00	0.00	0.40	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Palaemonidae	Carid shrimp	*Palaemon sp.*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Palaemonidae	Carid shrimp	*Macrobrachium intermedium*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.00	0.00
Crangonidae	Carid shrimp	*Pontophilis angustirostris*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.80	0.00	0.00
Alpheidae	Pistol shrimp	*Alpheus richardsoni*	0.00	0.00	0.00	0.00	2.00	0.84	0.00	0.00	0.00	0.00	0.40	0.24	0.00	0.00
Mysidae	Opossum shrimp	*Rhopalopthalmus brisbanensis*	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.40	4.00	4.00	6.40	6.40	0.20	0.20
Sergestidae	Pelagic shrimp	*Lucifer sp.*	4.00	2.92	0.80	0.80	0.00	0.00	4.80	1.93	1.60	0.68	0.00	0.00	0.00	0.00
Sergestidae	Pelagic shrimp	*Acetes sibogae australis*	0.00	0.00	399.20	257.21	59.20	56.95	9.40	5.16	0.20	0.20	0.00	0.00	0.20	0.20
Diogenidae	Hermit crab	Unidentified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hymenosomatidae	False spider crab	*Hymenosoma hodgkini*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.00	0.00
Grapsidae	Shore crab	*Metapograpsus sp.*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ocypodidae	Sentinel crab	*Macropthalmus sp.*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.40	0.00	0.00	0.00	0.00
Ocypodidae	Semaphpore crab	*Heloecius cordiformis*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Idiosepiidae	Southern pygmy squid	*Idiosepius notoides*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.24	0.00	0.00
Nassariidae	Dog whelk	*Nassarius burchardi*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.40	0.20	0.20	0.00	0.00
Nassariidae	Dog whelk	*Nassarius jonasi*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.00	0.00
Nassariidae	Dog whelk	*Nassarius pauperatus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Naticidae	Moon snail	*Conuber sordida*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Naticidae	Moon snail eggs	*Conuber sordida*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	20.00	20.00
Trochiidae	Snail	Unidentified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mytilidae	Mussel	*Xenostrobus securis*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mactridae	Surf clam	*Spisula trigonella*	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.40	3.60	3.36	4.20	3.25	0.40	0.40
Laternulidae	Lantern shell	*Laternula sp.*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.40	0.00	0.00
Semelidae	Semelid bivalve	*Theora fragilis*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.00	0.45	0.00	0.00
Cardiidae	Strawberry cockle	Snail	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.00	0.00
Haminoeidae	Opisthobranch	*Nipponatys tunida*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.00	0.00
Phylum Chaetognatha	Arrow worm	Unidentified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Phylum Ctenophora	Comb jellies	Unidentified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	3.00	1.00
Class Cubozoa	Box jellyfish	Unidentified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Class Insecta	Insect	Unidentified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Appendix 9 cont. Means and standard errors for biota collected using beam trawls at two times in the Hawkesbury River. Time 1 = 17-19/09/01, Time 2 = 29-31/01/02.

Family name	Common name	Species or taxon name	Time 2 MC S5 Mean	Time 2 MC S5 SE	Time 2 MC S6 Mean	Time 2 MC S6 SE	Time 2 MMCL S7 Mean	Time 2 MMCL S7 SE	Time 2 MMCL S8 Mean	Time 2 MMCL S8 SE	Time 2 MMCU S9 Mean	Time 2 MMCU S9 SE	Time 2 MMCU S10 Mean	Time 2 MMCU S10 SE	Time 2 SIIN S11 Mean	Time 2 SIIN S11 SE	Time 2 SIIN S12 Mean	Time 2 SIIN S12 SE
FISH																		
Sparidae	Yellow-finned bream	*Acanthopagrus australis*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Monacanthidae	Leatherjacket	*Acanthaluteres sp.*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Tetraodontidae	Common toadfish	*Tetractenos hamiltoni*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gobiidae	Swan River Goby	*Pseudogobius olorum*	11.00	5.31	2.60	1.44	0.00	0.00	0.00	0.00	1.80	0.97	4.00	1.05	4.40	2.04	3.40	2.01
Gobiidae	Large-mouth goby	*Redigobius macrostoma*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.40	0.20	0.20
Gobiidae	Glass goby	*Gobiopterus semivestita*	34.20	15.27	46.80	14.08	3.60	2.38	1.60	1.17	53.20	15.76	54.00	17.64	164.60	45.83	100.20	21.66
Gobiidae	Exquisite goby	*Favonigobius exquisitus*	0.00	0.00	0.20	0.20	2.20	1.56	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20
Gobiidae	Tamar River goby	*Favonigobius tamarensis*	0.00	0.00	0.00	0.00	0.20	0.20	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gobiidae	Half-bridled goby	*Arenigobius frenatus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Gobiidae	Juvenile bridled	*Arenigobius sp.*	0.80	0.58	0.40	0.24	2.40	1.75	0.00	0.00	0.20	0.20	0.00	0.00	0.00	0.00	0.20	0.20
Gobiidae	Mangrove goby	*Mugilogobius stigmaticus*	2.00	1.76	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	2.00	1.26	0.00	0.00	0.00	0.00
Clupeidae	Sandy sprat	*Hyperlophus vittatus*	0.80	0.49	0.00	0.00	1.40	1.17	0.20	0.20	0.00	0.00	9.40	6.28	0.00	0.00	0.00	0.00
Platycephalidae	Larval flathead	Unidentified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Unidentified	Larval fish	Unidentified	1.00	0.63	0.00	0.00	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
INVERTEBRATES																		
Penaeidae	Eastern king prawn	*Penaeus plebejus*	0.60	0.24	0.80	0.58	7.80	5.18	0.60	0.40	1.00	0.45	0.40	0.24	1.20	0.58	12.20	4.94
Penaeidae	School prawn	*Metapenaeus macleayi*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Penaeidae	Greasyback prawn	*Metapenaeus bennettae*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Palaemonidae	Carid shrimp	*Palaemon sp.*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Palaemonidae	Carid shrimp	*Macrobrachium intermedium*	0.20	0.20	0.00	0.00	0.40	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Crangonidae	Carid shrimp	*Pontophilis angustirostris*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Alpheidae	Pistol shrimp	*Alpheus richardsoni*	0.40	0.40	0.00	0.00	0.40	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.60	0.40
Mysidae	Opossum shrimp	*Rhopalopthalmus brisbanensis*	295.40	121.08	0.00	0.00	9.40	3.56	0.20	0.20	24.20	5.11	3.60	1.86	16.40	9.77	183.40	68.24
Sergestidae	Pelagic shrimp	*Lucifer sp.*	5.20	3.12	4.60	0.93	10.40	6.77	4.60	2.01	1.80	0.66	1.00	0.32	13.00	9.55	14.60	5.72
Sergestidae	Pelagic shrimp	*Acetes sibogae australis*	1.20	0.58	0.20	0.20	1.60	1.36	0.20	0.20	48.40	11.12	2.80	1.16	0.20	0.20	8.80	4.60
Diogenidae	Hermit crab	Unidentified	0.00	0.00	0.00	0.00	0.40	0.24	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Hymenosomatidae	False spider crab	*Hymenosoma hodgkini*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20
Grapsidae	Shore crab	*Metapograpsus sp.*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Ocypodidae	Sentinel crab	*Macropthalmus sp.*	0.20	0.20	0.40	0.40	0.00	0.00	0.00	0.00	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00
Ocypodidae	Semaphpore crab	*Heloecius cordiformis*	0.00	0.00	0.20	0.20	0.00	0.00	0.00	0.00	0.20	0.20	0.20	0.20	0.00	0.00	0.00	0.00
Idiosepiidae	Southern pygmy squid	*Idiosepius notoides*	0.20	0.20	0.00	0.00	0.00	0.00	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nassariidae	Dog whelk	*Nassarius burchardi*	0.40	0.40	0.00	0.00	0.00	0.00	0.00	0.00	0.40	0.40	0.20	0.20	0.00	0.00	0.80	0.80
Nassariidae	Dog whelk	*Nassarius jonasi*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Nassariidae	Dog whelk	*Nassarius pauperatus*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.20	0.20	0.00	0.00	0.20	0.20
Naticidae	Moon snail	*Conuber sordida*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20	0.00	0.00	0.00	0.00
Naticidae	Moon snail eggs	*Conuber sordida*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Trochiidae	Snail	Unidentified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mytilidae	Mussel	*Xenostrobus securis*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Mactridae	Surf clam	*Spisula trigonella*	2.00	0.55	1.40	0.75	1.60	0.68	0.00	0.00	0.40	0.24	0.80	0.37	1.00	0.63	1.80	0.80
Laternulidae	Lantern shell	*Laternula sp.*	0.80	0.58	0.00	0.00	0.20	0.20	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Semelidae	Semelid bivalve	*Theora fragilis*	0.00	0.00	0.00	0.00	1.80	1.56	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20
Cardiidae	Strawberry cockle	Snail	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Haminoeidae	Opisthobranch	*Nipponatys tunida*	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Phylum Chaetognatha	Arrow worm	Unidentified	0.00	0.00	0.20	0.20	0.80	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20
Phylum Ctenophora	Comb jellies	Unidentified	23.40	6.77	12.60	3.14	40.40	38.90	4.80	1.32	3.20	1.36	1.00	0.55	0.00	0.00	1.40	0.68
Class Cubozoa	Box jellyfish	Unidentified	0.00	0.00	0.00	0.00	0.00	0.00	0.80	0.80	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Class Insecta	Insect	Unidentified	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.20	0.20

Appendix 10: Three-way partially hierarchical ANOVA results for Beam Trawl study.

Total Number of Taxa Transform: Sqrt(X+1)

Source	SS	DF	MS	F	P	F versus
Ti	12.4738	1	12.47	80.86	0.001	TiXLo
Lo	8.1165	4	2.03	0.00	_	NO TEST
Si(Lo)	3.0619	5	0.61	1.22	0.415	TiXSi(Lo)
TiXLo	0.6171	4	0.15	0.31	0.862	TiXSi(Lo)
TiXSi(Lo)	2.5038	5	0.50	3.14	**0.012**	RES
RES	12.7748	80	0.16			
TOT	39.5479	99				

Cochran's Test
C = 0.1909 (Not Significant)

No. of Fish Species Transform: Sqrt(X+1)

Source	SS	DF	MS	F	P	F versus
Ti	0.8146	1	0.81	5.62	0.077	TiXLo
Lo	4.1822	4	1.05	0.00	_	NO TEST
Si(Lo)	1.2148	5	0.24	1.07	0.472	TiXSi(Lo)
TiXLo	0.5794	4	0.14	0.64	0.659	TiXSi(Lo)
TiXSi(Lo)	1.1384	5	0.23	3.29	**0.010**	RES
RES	5.5416	80	0.07			
TOT	13.471	99				

Cochran's Test
C = 0.1856 (Not Significant)

No. of Invertebrates Species Transform: Sqrt(X+1)

Source	SS	DF	MS	F	P	F versus
Ti	12.4149	1	12.41	21.72	**0.010**	TiXLo
Lo	2.7623	4	0.69	0.00	_	NO TEST
Si(Lo)	2.4579	5	0.49	2.19	0.205	TiXSi(Lo)
TiXLo	2.2867	4	0.57	2.54	0.167	TiXSi(Lo)
TiXSi(Lo)	1.1241	5	0.22	1.70	0.144	RES
RES	10.5844	80	0.13			
TOT	31.6303	99				

Cochran's Test
C = 0.1831 (Not Significant)

No. of Economic Species Transform: ArcSin(%)

Source	SS	DF	MS	F	P	F versus
Ti	86.9749	1	86.97	14.35	0.019	TiXLo
Lo	37.2001	4	9.30	0.00	_	NO TEST
Si(Lo)	47.5411	5	9.51	0.84	0.576	TiXSi(Lo)
TiXLo	24.2447	4	6.06	0.53	0.719	TiXSi(Lo)
TiXSi(Lo)	56.8731	5	11.37	3.06	**0.014**	RES
RES	296.8929	80	3.71			
TOT	549.7268	99				

Cochran's Test
C = 0.1855 (Not Significant)

Appendix 10, Cont.

Total Abundance Transform: None

Source	SS	DF	MS	F	P	F versus
Ti	28257.61	1	28257.61	0.36	0.580	TiXLo
Lo	370380.54	4	92595.14	0.00	_	NO TEST
Si(Lo)	304530.75	5	60906.15	0.99	0.506	TiXSi(Lo)
TiXLo	312270.34	4	78067.59	1.26	0.393	TiXSi(Lo)
TiXSi(Lo)	308769.75	5	61753.95	2.08	0.077	RES
RES	2380449.2	80	29755.62			
TOT	3704658.19	99				

Cochran's Test
C = 0.5591 (P < 0.01)
Therefore Alpha = 0.01

Abundance of Fish Transform: Ln(X+1)

Source	SS	DF	MS	F	P	F versus
Ti	55.9654	1	55.97	6.08	0.069	TiXLo
Lo	81.2277	4	20.31	0.00	_	NO TEST
Si(Lo)	11.3712	5	2.27	1.83	0.263	TiXSi(Lo)
TiXLo	36.8092	4	9.20	7.39	**0.025**	TiXSi(Lo)
TiXSi(Lo)	6.2292	5	1.25	1.88	0.107	RES
RES	52.9713	80	0.66			
TOT	244.574	99				

Cochran's Test
C = 0.1563 (Not Significant)

Abundance of Invertebrates Transform: None

Source	SS	DF	MS	F	P	F versus
Ti	1874.89	1	1874.89	0.02	0.894	TiXLo
Lo	211608.5	4	52902.13	0.00	_	NO TEST
Si(Lo)	373358.55	5	74671.71	1.50	0.334	TiXSi(Lo)
TiXLo	368769.66	4	92192.42	1.85	0.258	TiXSi(Lo)
TiXSi(Lo)	249304.75	5	49860.95	1.73	0.138	RES
RES	2310770.4	80	28884.63			
TOT	3515686.75	99				

Cochran's Test
C = 0.5711 (P < 0.01)

Abundance of Economic Species Transform: None

Source	SS	DF	MS	F	P	F versus
Ti	171.61	1	171.61	9.89	0.035	TiXLo
Lo	91.84	4	22.96	0.00	_	NO TEST
Si(Lo)	252.65	5	50.53	1.15	0.440	TiXSi(Lo)
TiXLo	69.44	4	17.36	0.40	0.805	TiXSi(Lo)
TiXSi(Lo)	219.05	5	43.81	2.57	0.033	RES
RES	1365.6	80	17.07			
TOT	2170.19	99				

Cochran's Test
C = 0.5571 (P < 0.01)
Therefore Alpha = 0.01

Appendix 10, Cont.

% Abundance of economic species Transform: Ln(X+1)

Source	SS	DF	MS	F	P	F versus
Ti	6.5447	1	6.54	1.62	0.272	TiXLo
Lo	10.666	4	2.67	0.00	_	NO TEST
Si(Lo)	33.0466	5	6.61	2.19	0.205	TiXSi(Lo)
TiXLo	16.1313	4	4.03	1.34	0.372	TiXSi(Lo)
TiXSi(Lo)	15.085	5	3.02	2.63	**0.030**	RES
RES	91.8837	80	1.15			
TOT	173.3573	99				

Cochran's Test
C = 0.1829 (Not Significant)

Abundance of *A. sibogae australis* Transform: None

Source	SS	DF	MS	F	P	F versus
Ti	86553.64	1	86553.64	2.14	0.217	TiXLo
Lo	246202.54	4	61550.64	0.00	_	NO TEST
Si(Lo)	233490.7	5	46698.14	1.58	0.313	TiXSi(Lo)
TiXLo	161583.26	4	40395.82	1.37	0.363	TiXSi(Lo)
TiXSi(Lo)	147417.7	5	29483.54	1.21	0.311	RES
RES	1947061.6	80	24338.27			
TOT	2822309.44	99				

Cochran's Test
C = 0.6795 (P < 0.01)

Abundance of Comb Jellies Transform: None

Source	SS	DF	MS	F	P	F versus
Ti	1953.64	1	1953.64	3.47	0.136	TiXLo
Lo	2253.46	4	563.37	0.00	_	NO TEST
Si(Lo)	1747.3	5	349.46	1.00	0.500	TiXSi(Lo)
TiXLo	2253.46	4	563.37	1.61	0.304	TiXSi(Lo)
TiXSi(Lo)	1747.3	5	349.46	0.89	0.493	RES
RES	31481.2	80	393.52			
TOT	41436.36	99				

Cochran's Test
C = 0.9615 (P < 0.01)

Abundance of *G. semivestita* Transform: Sqrt(X+1)

Source	SS	DF	MS	F	P	F versus
Ti	304.8528	1	304.85	5.10	0.087	TiXLo
Lo	199.8317	4	49.96	0.00	_	NO TEST
Si(Lo)	30.2807	5	6.06	1.80	0.267	TiXSi(Lo)
TiXLo	238.8957	4	59.72	17.75	**0.004**	TiXSi(Lo)
TiXSi(Lo)	16.8283	5	3.37	1.40	0.232	RES
RES	191.6978	80	2.40			
TOT	982.387	99				

Cochran's Test
C = 0.1882 (Not Significant)

Appendix 10, Cont.

Abundance of *Lucifer sp.* Transform: None

Source	SS	DF	MS	F	P	F versus
Ti	47.61	1	47.61	1.20	0.334	TiXLo
Lo	438.04	4	109.51	0.00	_	NO TEST
Si(Lo)	90.45	5	18.09	0.38	0.841	TiXSi(Lo)
TiXLo	158.24	4	39.56	0.84	0.554	TiXSi(Lo)
TiXSi(Lo)	235.05	5	47.01	1.03	0.405	RES
RES	3647.2	80	45.59			
TOT	4616.59	99				

Cochran's Test
C = 0.5215 (P < 0.01)

Abundance of *P. olorum* Transform: None

Source	SS	DF	MS	F	P	F versus
Ti	515.29	1	515.29	0.54	0.505	TiXLo
Lo	3370.64	4	842.66	0.00	_	NO TEST
Si(Lo)	2625.05	5	525.01	1.03	0.488	TiXSi(Lo)
TiXLo	3846.96	4	961.74	1.88	0.252	TiXSi(Lo)
TiXSi(Lo)	2554.25	5	510.85	1.17	0.333	RES
RES	35017.2	80	437.72			
TOT	47929.39	99				

Cochran's Test
C = 0.9608 (P < 0.01)

Abundance of *R. brisbanensis* Transform: None

Source	SS	DF	MS	F	P	F versus
Ti	29138.49	1	29138.49	1.44	0.297	TiXLo
Lo	80311.44	4	20077.86	0.00	_	NO TEST
Si(Lo)	109811.45	5	21962.29	1.00	0.500	TiXSi(Lo)
TiXLo	81068.16	4	20267.04	0.92	0.517	TiXSi(Lo)
TiXSi(Lo)	109751.45	5	21950.29	5.95	**0.000**	RES
RES	295246.4	80	3690.58			
TOT	705327.39	99				

Cochran's Test
C = 0.9930 (P < 0.01)
Therefore Alpha = 0.01

Appendix 11: Average concentrations of heavy metals bioaccumulated in oysters.

Locations: Sandbrook Inlet = 1; Brooklyn Harbour = 2; Mooney Mooney Creek = 3; Mullet Creek = 4. N = 4.

Time	Location	Site		Arsenic	Cadmium	Chromium	Copper	Lead	Mercury	Nickel	Selenium	Zinc
1	1	1	Mean	0.865	0.175	0.048	64.25	0.048	0.018	0.158	0.565	272.50
			SE	0.061	0.010	0.010	3.77	0.011	0.003	0.012	0.045	16.52
		2	Mean	0.830	0.173	0.048	90.50	0.060	0.020	0.193	0.515	275.00
			SE	0.019	0.010	0.007	6.84	0.007	0.000	0.026	0.012	21.79
	2	3	Mean	0.758	0.185	0.097	57.50	0.053	0.020	0.198	0.380	335.00
			SE	0.031	0.010	0.008	2.72	0.006	0.000	0.005	0.009	18.48
		4	Mean	0.873	0.178	0.070	113.50	0.063	0.020	0.198	0.455	402.50
			SE	0.062	0.005	0.004	9.60	0.009	0.000	0.002	0.062	27.20
	3	5	Mean	0.638	0.170	0.076	33.25	0.038	0.023	0.208	0.433	237.50
			SE	0.049	0.014	0.004	5.76	0.003	0.002	0.019	0.034	31.72
		6	Mean	0.675	0.168	0.079	38.75	0.040	0.020	0.220	0.435	280.00
			SE	0.057	0.005	0.008	3.35	0.004	0.000	0.015	0.030	21.21
	4	7	Mean	0.715	0.163	0.077	34.25	0.030	0.017	0.238	0.378	252.50
			SE	0.021	0.013	0.018	1.75	0.000	0.003	0.028	0.017	10.31
		8	Mean	0.800	0.128	0.085	36.50	0.028	0.010	0.193	0.410	232.50
			SE	0.029	0.003	0.015	3.66	0.002	0.000	0.010	0.029	14.36
2	1	1	Mean	0.818	0.188	0.030	67.50	0.035	0.020	0.123	0.603	345.00
			SE	0.045	0.011	0.000	4.48	0.003	0.000	0.013	0.034	17.08
		2	Mean	0.750	0.178	0.098	74.25	0.090	0.023	0.198	0.445	342.50
			SE	0.072	0.021	0.054	3.09	0.020	0.002	0.057	0.043	11.09
	2	3	Mean	1.013	0.188	0.103	80.00	0.055	0.028	0.250	0.515	460.00
			SE	0.100	0.009	0.036	4.04	0.005	0.002	0.065	0.044	23.45
		4	Mean	1.038	0.160	0.095	115.00	0.073	0.020	0.168	0.518	480.00
			SE	0.104	0.000	0.020	8.66	0.009	0.000	0.034	0.048	29.72
	3	5	Mean	0.740	0.150	0.100	35.75	0.038	0.020	0.203	0.418	297.50
			SE	0.066	0.014	0.028	2.59	0.003	0.000	0.023	0.030	11.81
		6	Mean	0.608	0.133	0.098	33.75	0.038	0.018	0.205	0.333	255.00
			SE	0.052	0.017	0.023	5.39	0.003	0.003	0.027	0.031	15.55
	4	7	Mean	0.853	0.130	0.060	37.75	0.045	0.013	0.170	0.448	285.00
			SE	0.095	0.009	0.007	1.60	0.010	0.003	0.016	0.042	15.55
		8	Mean	0.895	0.130	0.050	40.50	0.040	0.020	0.163	0.463	322.50
			SE	0.084	0.004	0.004	2.18	0.004	0.000	0.002	0.035	15.48

Appendix F

Sedimentological Methods

APPENDIX F – METHOD FOR DETERMINING FLUVIAL SEDIMENTATION

F1.1 Sedimentology

F.1.1.1 Introduction

An important characteristic of an estuary is the sediment quantity and quality. An analysis of the sediments of a river or estuary can reveal important information as to how the system reacts to changes in the catchment. A quantitative analysis of the bulk sediments present on the estuary bed was conducted for this study by comparing bathymetric surveys from 1872, 1952 and the most current data. This analysis was carried out using ArcInfo Geographical Information System (GIS) software.

F.1.1.2 Bathymetry Data

Hydrographic surveys of the Brooklyn study area were obtained from three periods in history in order to get a historical record of bathymetry and to identify changes in the bathymetry over time. The three periods chosen were 1872, 1952 and 1980.

The 1872 data was measured using triangulation and leadline from the sea to Peat Island, Cottage Rk and Pittwater (Royal Navy, 1868-1872) and data from 1952 was measured by triangulation and echosounder by the Royal Australian Navy (RAN, 1952). The most recent set of bathymetry data for the study region was obtained from the Lower Hawkesbury River Flood Study model mapfile. This data was from the 1978-1980 hydrographic survey of the Hawkesbury River and was obtained in digital form, however, as the data was used in RMA modelling, some transformations had to be made to convert it to AMG66 coordinates. As the hydrographic surveys mentioned did not have detailed bathymetry data in the Sandbrook Inlet, additional bathymetry data measured in Sandbrook Inlet by the Public Works Department in 1975 (PWD, 1975) was also used. This data not in any predefined co-ordinate system however, the data was overlain on registered aerial photographs.

F.1.1.3Projections

To make comparisons between the hydrographic surveys used for the sediment analysis the digital data had to be projected into the same co-ordinate system. MGA94 was used as requested by Hornsby Shire Council (HSC). Due to the datasets being in different co-ordinate systems the methods used to project them into MGA94 were varied.

F.1.1.3.1 1872 Data

The data from 1872 was not in any predefined projection, so, when digitised, a nominal data frame was used. ArcInfo GIS is able to transform data to an existing projection using a number of ‘tics’ (points that will be matched in the original dataset and the projected dataset). In order to find reasonable points to use to perform the transformation, GIS layers from the Hornsby Shire Council were used to find landmarks that were common to both datasets and that were not likely to have changed over time. Hornsby Shire Council GIS layers were projected in either ISG66 or AGD66 and so these layers had to be projected to MGA94.

Once the HSC GIS layers were in MGA94, both the 1872 hydrographic survey and layers from HSC were reviewed to identify suitable points for the transformation. Eleven points were used in transforming the data, which resulted in a reasonable match between shorelines.

F.1.1.3.2 1952 Data

The bathymetry data from 1952 was in a gnomonic projection and the datum was Clarke 1858. Unfortunately, ArcInfo GIS was unable to covert this projection to MGA94 and it was advised that reasonable method of converting Clarke 1858 to GDA94 was by using a block shift. Therefore, it was decided that the method of using 'tics' would also be used to project that data in this case. Nine points were used to project the data. To determine what the eastings and northings of the nine points would be in MGA94, the block shift was applied to the points and then GEOD was used to convert the points from GDA94 to MGA94. These nine points provided a reasonable match of the 1952 shoreline with that of the Hornsby Shire Council GIS layers.

F.1.1.3.3 1980 Data

The 1980 data from the Lower Hawkesbury Flood Study map file had been modified to be used in RMA modelling and had to be converted to AMG66.

A block shift translation was determined by locating six points at easily identifiable river features on a 1:25000 topographic map of Lower Portland. AMG coordinates were determined by scaling from a ruler with 1mm spacing. The differences between eastings and northings for RMA and AMG coordinates for the six sites was then averaged and rounded off as the translation would be the same for all points and would be a whole number. The resulting conversion from RMA to AMG (E,N) was equal to +290000, +6270000.

Some possible sources of inaccuracy which are inherent from this method include; the accuracy of reading from ruler ~ 12.5m, the accuracy of map enlargement ~ 18.25m and the accuracy of map ~ 6.25m.

Once the data was in AMG66, ArcInfo was used to convert the data to GDA94.

F.1.1.3.4 Sandbrook Inlet

The data digitised for Sandbrook Inlet, was also not in a predefined projection so the methodology used to transform the 1872 data was utilised in this case as well. The data was divided into four separate sheets and was overlaid on aerial photography. This aerial photography was used to determine landmarks that could be used as 'tics' to perform the transformation. For each of the four sheets approximately three points were found. The orthogonal transformation was used.

F.1.1.4 Height Datums

To perform a comparative analysis, the height datums for the datasets had to be in a common datum, which was AHD (Australian Height Datum). Table F.1 shows the shifts that were applied to the datasets to covert them to AHD.

Table F.1 – Translations used to convert data to AHD

Dataset	Original Datum	Shift to AHD

1872	Local Low Water	-
1952	Indian Springs Low Water (approx)	0.925
Sandbrook Inlet	Local Indian Springs Low Water	0.925
1980	AHD	-

F.1.1.5 Comparing Bathymetry using ArcInfo

Triangulated Irregular Networks (TINs) are an easily interpretable way of representing height data. Surfaces generated by way of a TIN surface can be clipped to prevent data being interpolated beyond physical boundaries of the data, or where data doesn't exist. Furthermore, the TIN surface can be used to generate lattices, which can then be used to perform surface analyses. To create lattices from the point data, ArcInfo Workstation was utilised do convert the TIN surfaces to lattices using the TINLATTICE command available at ARC. Lattices with cellsizes of 10m, 50m and 100m were created, using the default extents set by the tin.

To determine areas of accretion and erosion, the lattices created from the different datasets were subtracted from each other, using GRID in ArcInfo Workstation. Grid sizes of 20m, 50m and 100m were used to determine which gridsize presents the final data most successfully.

Due to the fact that the extents of the lattices were derived from the extents of the point data, the results from the subtraction of one lattice from another around the perimeter of the polygons could not be ascertained correctly. Therefore the resulting lattices were clipped to a polygon created by the intersection of the two dataset boundary polygons. This resulted in some data along the perimeter of the study area not being utilised.

F.1.2 Bedshear Stress Calculations

The bedshear stress is the force per unit area exerted by flowing water on the stream bed or soil surface. Calculations of bedshear stress were determined so as to identify areas that may be prone to accretion and erosion. This information can then be coupled with the analysis of sediments (Section ?.?) to determine the zones where erosion is more likely.

The formula used to determine the bedshear stress is shown below. It was assumed that the river was wide enough to make the assumption that the hydraulics radius is approximately equal to the depth of the river. This assumption is probably reasonable for the main river, however, the assumption would lead to slightly lower estimates of bedshear stress in narrow sections of the river (ie. Sandbrook Inlet and the section of the river between Long Island and Dangar Island).

$$\tau_b = \rho_w u_*^2$$

$$\textit{where (for wide channels)}$$

$$u_* = \frac{nu\sqrt{g}}{d^{\frac{1}{6}}}$$

and

$\tau_b = bed\ shear\ stress$

$u_* = shear\ velocity$

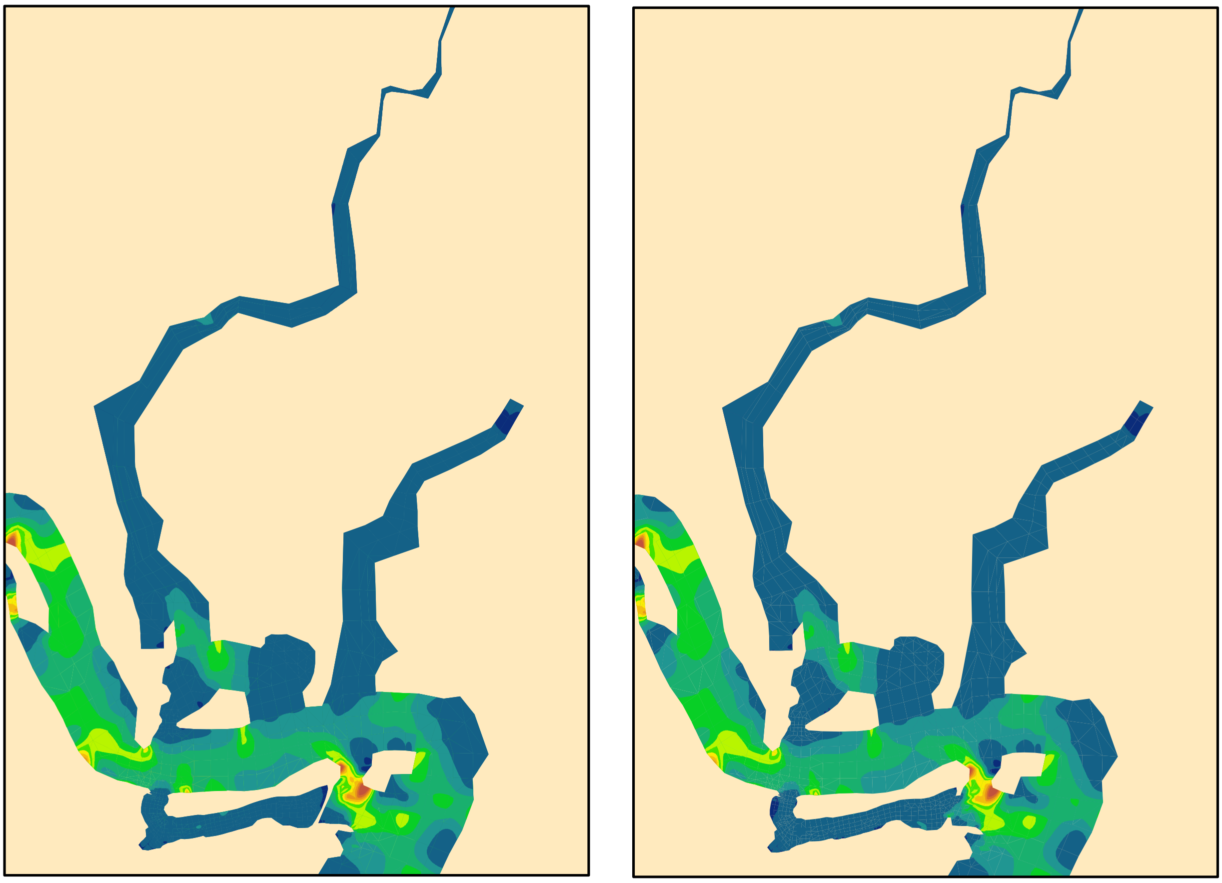
$u = velocity$

$n = Mannings\ n$

$d = depth$

$\rho_w = density\ of\ water$

Bedshear was calculated using the velocity and water stage results from the RMA2 modelling. Bedshear was the calculated for each element in the finite element mesh. It was assumed that Mannings n was constant across the study area.



Bed Shear Stress (Pa)

- <0.0
- 0.0 to 0.20
- 0.20 to 0.40
- 0.40 to 0.60
- 0.60 to 0.80
- 0.80 to 1.0
- 1.0 to 1.2
- 1.2 to 1.4
- 1.4 to 1.6
- 1.6 to 1.8
- 1.8 to 2.0
- >2.0

N

WRL Report No. 2002/20	TYPICAL PEAK BED SHEAR STRESSES WITH BASE FLOWS WITH AND WITHOUT CAUSEWAY	Figure F1

fig5.mxd