Appendix A. Raw data used for LOLA analyses.

Chlorophyll *a* uncorrected for phaeophytin, LOLA 2003

Date	Station	Rep	US chl a (ug/L)	Canada chl a (ug/L)
4/28/2003	8	1	0.80	0.81
4/28/2003	8	2	1.10	0.82
4/28/2003	8	3	1.34	0.77
4/28/2003	9	1	1.34	0.82
4/28/2003	9	2	0.80	0.99
4/28/2003	9	3	1.34	0.91
4/28/2003	12-1	1	1.07	1.33
4/28/2003	12-1	2	1.87	1.24
4/28/2003	12-1	3	1.60	1.32
4/28/2003	12-2	1	1.34	1.18
4/28/2003	12-2	2	1.60	1.31
4/28/2003	12-2	3	1.60	1.01
4/28/2003	19	1	2.94	1.37
4/28/2003	19	2	1.87	1.30
4/28/2003	19	3	1.87	1.37
4/28/2003	18	1	2.14	1.32
4/28/2003	18	2	1.87	2.32
4/28/2003	18	3	4.81	2.05
4/28/2003	17	1	2.40	3.16
4/28/2003	17	2	2.67	2.55
4/28/2003	17	3	2.67	3.15
4/29/2003	33	1	2.40	1.86
4/29/2003	33	2	2.67	1.48
4/29/2003	33	3	2.94	2.04
4/29/2003	38	1	0.53	0.77
4/29/2003	38	2	0.53	0.84
4/29/2003	38	3	.	1.00
4/29/2003	39	1	1.60	1.21
4/29/2003	39	2	0.80	1.26
4/29/2003	39	3	0.80	1.12
4/29/2003	40	1	1.07	1.12
4/29/2003	40	2	0.53	1.78
4/29/2003	40	3	1.87	1.13
4/29/2003	41-1	1	0.80	1.49
4/29/2003	41-1	2	1.07	1.57
4/29/2003	41-1	3	1.34	1.40
4/29/2003	41-2	1	1.34	1.09
4/29/2003	41-2	2	1.87	1.28
4/29/2003	41-2	3	1.34	1.38
4/29/2003	42	1	0.53	0.69
4/29/2003	42	2	0.80	0.72
4/29/2003	42	3	0.53	0.63
4/29/2003	43	1	0.80	0.80
4/29/2003	43	2	0.80	0.95
4/29/2003	43	3	1.60	0.87
4/29/2003	62	1	0.80	0.74
4/29/2003	62	2	1.34	0.90
4/29/2003	62	3	1.34	0.77
4/29/2003	63	1	1.34	1.13
4/29/2003	63	2	1.34	1.41
4/29/2003	63	3	2.14	1.55
4/29/2003	715	1	1.60	1.58
4/29/2003	715	2	1.34	1.27
4/29/2003	715	3	1.34	1.23
4/29/2003	64	1	.	0.91
4/29/2003	64	2	4.81	1.48
4/29/2003	64	3	1.07	1.35
4/30/2003	65-1	1	0.83	1.33
4/30/2003	65-1	2	0.27	1.82
4/30/2003	65-1	3	.	1.18
4/30/2003	65-2	1	1.07	1.21
4/30/2003	65-2	2	0.32	1.21
4/30/2003	65-2	3	1.07	1.23
4/30/2003	66	1	0.53	1.08
4/30/2003	66	2	0.80	1.12
4/30/2003	66	3	0.53	1.12
4/30/2003	84	1	0.80	1.06
4/30/2003	84	2	1.07	0.96
4/30/2003	84	3	0.80	0.94
4/30/2003	77	1	0.80	0.86
4/30/2003	77	2	0.53	1.05
4/30/2003	77	3	1.12	0.85
4/30/2003	81	1	0.30	1.15
4/30/2003	81	2	0.90	1.53
4/30/2003	81	3	0.80	1.02
4/30/2003	80	1	0.53	0.95
4/30/2003	80	2	0.80	1.03
4/30/2003	80	3	1.15	1.02
4/30/2003	74	1	0.84	1.27
4/30/2003	74	2	1.65	1.33
4/30/2003	74	3	1.34	1.78
4/30/2003	89	1	1.87	1.12
4/30/2003	89	2	1.34	1.34
4/30/2003	89	3	1.34	1.61
4/30/2003	72	1	.	0.98
4/30/2003	72	2	1.34	0.81
4/30/2003	72	3	0.27	0.97
4/30/2003	71	1	0.84	0.76
4/30/2003	71	2	0.80	0.91
4/30/2003	71	3	1.07	0.78
4/30/2003	49	1	1.34	0.84
4/30/2003	49	2	1.07	0.92
4/30/2003	49	3	1.34	1.12

Date	Station	Rep	US chl a (ug/L)	Canada chl a (ug/L)
8/10/2003	8	1	2.40	1.87
8/10/2003	8	2	2.40	2.31
8/10/2003	8	3	2.64	2.22
8/10/2003	9	1	0.79	1.89
8/10/2003	9	2	0.81	2.16
8/10/2003	9	3	0.62	2.63
8/11/2003	12	1	1.00	0.97
8/11/2003	12	2	0.49	1.02
8/11/2003	12	3	0.84	1.02
8/11/2003	19	1	1.23	1.16
8/11/2003	19	2	1.29	0.83
8/11/2003	19	3	1.51	1.09
8/11/2003	17	1	2.14	2.89
8/11/2003	17	2	2.49	2.80
8/11/2003	17	3	.	3.16
8/11/2003	18	1	0.97	0.83
8/11/2003	18	2	1.28	0.79
8/11/2003	18	3	1.12	0.97
8/19/2003	66	1	2.08	1.84
8/19/2003	66	2	1.47	1.85
8/19/2003	66	3	1.76	2.10
8/19/2003	65-1	1	1.60	1.67
8/19/2003	65-1	2	2.09	1.43
8/19/2003	65-1	3	1.79	1.29
8/19/2003	65-2	1	1.50	1.73
8/19/2003	65-2	2	1.60	1.90
8/19/2003	65-2	3	1.17	1.27
8/19/2003	64	1	1.00	1.52
8/19/2003	64	2	1.08	1.69
8/19/2003	64	3	1.79	1.53
8/19/2003	715	1	1.22	1.55
8/19/2003	715	2	0.95	1.63
8/19/2003	715	3	1.07	1.58
8/19/2003	63	1	2.10	1.25
8/19/2003	63	2	1.20	1.69
8/19/2003	63	3	1.07	0.89
8/19/2003	62	1	1.10	1.01
8/19/2003	62	2	0.88	0.99
8/19/2003	62	3	1.74	1.03
8/19/2003	80	1	2.93	2.48
8/19/2003	80	2	2.67	2.65
8/19/2003	80	3	2.64	2.29
8/19/2003	81	1	1.59	1.34
8/19/2003	81	2	1.63	1.30
8/19/2003	81	3	1.24	1.18
8/19/2003	84	1	1.28	1.62
8/19/2003	84	2	1.47	1.34
8/19/2003	84	3	1.47	1.50

Date	Station	Rep	US chl a (ug/L)	Canada chl a (ug/L)
8/19/2003	74	1	1.60	1.35
8/19/2003	74	2	1.71	1.24
8/19/2003	74	3	1.31	1.32
8/20/2003	89	1	2.00	1.65
8/20/2003	89	2	0.98	1.53
8/20/2003	89	3	1.68	1.80
8/20/2003	72	1	3.47	3.49
8/20/2003	72	2	3.92	3.83
8/20/2003	72	3	3.52	3.28
8/20/2003	71	1	7.05	6.98
8/20/2003	71	2	7.50	6.99
8/20/2003	71	3	7.34	6.51
8/20/2003	38	1	5.08	3.01
8/20/2003	38	2	3.84	3.10
8/20/2003	38	3	.	3.19
8/20/2003	39	1	1.40	1.97
8/20/2003	39	2	1.17	1.69
8/20/2003	39	3	1.87	1.99
8/20/2003	40	1	0.34	0.92
8/20/2003	40	2	0.32	1.02
8/20/2003	40	3	0.26	1.18
8/20/2003	41-1	1	0.93	1.76
8/20/2003	41-1	2	0.89	1.79
8/20/2003	41-1	3	1.12	1.73
8/20/2003	41-2	1	1.48	0.78
8/20/2003	41-2	2	1.29	0.91
8/20/2003	41-2	3	1.60	0.91
8/21/2003	42	1	1.17	0.73
8/21/2003	42	2	2.28	0.83
8/21/2003	42	3	1.89	0.98
8/21/2003	43	1	1.10	0.95
8/21/2003	43	2	1.13	0.61
8/21/2003	43	3	1.11	0.95
8/21/2003	33	1	0.32	0.84
8/21/2003	33	2	0.91	0.91
8/21/2003	33	3	0.97	0.86

Date	Station	Rep	US chl a (ug/L)	Canada chl a (ug/L)	Date	Station	Rep	US chl a (ug/L)	Canada chl a (ug/L)
9/21/2003	80	1	1.70	2.62	9/23/2003	39	1	2.20	2.33
9/21/2003	80	2	1.70	2.53	9/23/2003	39	2	2.30	2.46
9/21/2003	80	3	1.74	2.66	9/23/2003	39	3	2.29	2.03
9/21/2003	81	1	2.40	2.40	9/23/2003	40	1	2.59	2.19
9/21/2003	81	2	1.87	3.03	9/23/2003	40	2	2.79	3.11
9/21/2003	81	3	2.27	2.88	9/23/2003	40	3	2.83	1.98
9/21/2003	77	1	2.80	3.03	9/23/2003	41	1	2.80	3.63
9/21/2003	77	2	3.60	2.50	9/23/2003	41	2	3.47	3.23
9/21/2003	77	3	2.66	2.71	9/23/2003	41	3	3.47	3.85
9/21/2003	84	1	1.81	1.79	9/24/2003	33	1	1.74	2.09
9/21/2003	84	2	1.62	1.65	9/24/2003	33	2	2.60	2.30
9/21/2003	84	3	1.74	1.78	9/24/2003	33	3	2.54	2.49
9/21/2003	74	1	2.79	3.39	9/25/2003	29-1	1	3.34	3.27
9/21/2003	74	2	2.37	3.37	9/25/2003	29-1	2	2.62	3.13
9/21/2003	74	3	3.78	3.32	9/25/2003	29-1	3	2.94	3.22
9/21/2003	89	1	2.40	3.71	9/25/2003	29-2	1	.	2.90
9/21/2003	89	2	2.24	3.70	9/25/2003	29-2	2	.	2.91
9/21/2003	89	3	2.26	3.62	9/25/2003	29-2	3	.	3.15
9/21/2003	72	1	2.14	2.97	9/25/2003	28	1	2.83	2.06
9/21/2003	72	2	2.00	2.56	9/25/2003	28	2	2.27	2.72
9/21/2003	72	3	1.87	2.72	9/25/2003	28	3	2.97	3.54
9/21/2003	71	1	1.48	1.61	9/25/2003	8	1	0.68	1.67
9/21/2003	71	2	1.83	1.72	9/25/2003	8	2	1.20	1.83
9/21/2003	71	3	1.74	2.14	9/25/2003	8	3	1.33	2.60
9/22/2003	66	1	1.00	1.51	9/25/2003	9	1	7.76	1.71
9/22/2003	66	2	1.44	1.74	9/25/2003	9	2	2.02	2.73
9/22/2003	66	3	.	2.21	9/25/2003	9	3	2.67	2.83
9/22/2003	65	1	2.56	3.46	9/25/2003	12-1	1	3.40	3.69
9/22/2003	65	2	2.22	3.23	9/25/2003	12-1	2	3.39	3.83
9/22/2003	65	3	2.83	3.59	9/25/2003	12-1	3	3.62	3.93
9/22/2003	64-1	1	3.85	4.18	9/25/2003	12-2	1	3.81	3.65
9/22/2003	64-1	2	3.71	3.94	9/25/2003	12-2	2	3.52	3.94
9/22/2003	64-1	3	3.27	4.70	9/25/2003	12-2	3	3.38	3.86
9/22/2003	64-2	1	1.87	3.92	9/25/2003	19	1	3.04	3.23
9/22/2003	64-2	2	1.51	3.95	9/25/2003	19	2	2.36	3.19
9/22/2003	64-2	3	1.82	4.07	9/25/2003	19	3	2.94	.
9/22/2003	715	1	2.56	2.51	9/25/2003	18	1	3.24	3.01
9/22/2003	715	2	0.13	2.32	9/25/2003	18	2	3.22	2.90
9/22/2003	715	3	2.14	2.98	9/25/2003	18	3	3.07	3.00
9/22/2003	63	1	2.14	3.30	9/25/2003	17	1	0.69	1.93
9/22/2003	63	2	2.27	3.12	9/25/2003	17	2	1.04	1.32
9/22/2003	63	3	2.40	3.21	9/25/2003	17	3	0.40	1.43
9/22/2003	62	1	1.74	2.13					
9/22/2003	62	2	1.47	1.82					
9/22/2003	62	3	.	1.73					
9/23/2003	38	1	3.30	2.34					
9/23/2003	38	2	3.15	2.82					
9/23/2003	38	3	2.92	2.38					

Nutrient data: LOLA 2003

Season	Date	Station	Si (ug/L)	SRP (ug/L)	TFP (ug/L)	TP (ug/L)
April	4/28/2003	8	820	0.9	4.2	7.3
April	4/28/2003	9	780	0.7	4.7	4.8
April	4/28/2003	12	755	0.6	4.4	6.7
April	4/28/2003	17	660	0.8	5.3	14.7
April	4/28/2003	18	810	0.7	3.7	8.9
April	4/28/2003	19	800	0.7	3.5	6.1
April	4/29/2003	33	780	2.3	3.6	7.1
April	4/29/2003	38	620	1.2	8.0	7.6
April	4/29/2003	39	800	1.0	3.7	6.3
April	4/29/2003	40	790	1.0	4.0	5.8
April	4/29/2003	41	815	0.9	4.5	5.5
April	4/29/2003	42	730	0.9	3.7	7.5
April	4/29/2003	43	510	0.8	.	5.1
April	4/29/2003	62	350	0.8	5.1	6.2
April	4/29/2003	63	800	0.6	4.1	6.8
April	4/29/2003	64	820	.	.	.
April	4/29/2003	715	810	0.7	4.2	6.8
April	4/30/2003	49	750	1.1	4.3	6.7
April	4/30/2003	65	845	0.8	4.2	6.9
April	4/30/2003	66	830	1.0	5.7	7.8
April	4/30/2003	71	570	0.9	5.3	7.6
April	4/30/2003	72	870	1.2	4.2	7.3
April	4/30/2003	74	770	1.0	3.9	6.1
April	4/30/2003	77	780	0.8	3.1	5.2
April	4/30/2003	80	580	0.8	5.1	6.3
April	4/30/2003	81	610	0.9	5.8	17.1
April	4/30/2003	84	670	0.8	4.0	5.4
April	4/30/2003	89	750	1.3	4.0	6.4
August	8/10/2003	8	340	3.8	8.0	15.0
August	8/10/2003	9	100	0.4	10.8	18.0
August	8/11/2003	12	270	.	14.9	18.3
August	8/11/2003	17	310	0.8	4.8	11.5
August	8/11/2003	18	170	0.2	4.2	7.5
August	8/11/2003	19	300	0.2	4.0	26.3
August	8/19/2003	62	310	0.2	0.2	1.8
August	8/19/2003	63	200	0.2	4.4	6.9
August	8/19/2003	64	180	0.2	5.2	8.3
August	8/19/2003	65	190	0.2	2.5	3.5
August	8/19/2003	66	260	0.2	5.4	8.2
August	8/19/2003	74	190	0.2	3.6	7.3
August	8/19/2003	80	400	0.2	5.1	7.6
August	8/19/2003	81	240	0.2	6.7	12.0
August	8/19/2003	84	220	0.2	6.5	8.5
August	8/19/2003	715	190	0.2	5.3	8.2

Nutrient data continued

Season	Date	Station	Si (ug/L)	SRP (ug/L)	TFP (ug/L)	TP (ug/L)
August	8/20/2003	38	290	0.2	7.4	12.4
August	8/20/2003	39	130	0.2	4.4	7.1
August	8/20/2003	40	200	0.2	0.6	.
August	8/20/2003	41	160	0.2	4.8	6.9
August	8/20/2003	71	1020	0.2	4.5	8.9
August	8/20/2003	72	280	0.2	0.4	4.6
August	8/20/2003	89	180	0.2	4.5	7.2
August	8/21/2003	33	130	0.2	.	.
August	8/21/2003	42	170	0.2	5.3	7.8
August	8/21/2003	43	240	0.2	4.4	6.7
September	9/21/2003	71	410	1.5	4.4	8.8
September	9/21/2003	72	380	0.2	6.5	28.0
September	9/21/2003	74	240	0.2	5.7	9.8
September	9/21/2003	77	250	0.4	4.8	8.7
September	9/21/2003	80	530	2.0	4.7	8.8
September	9/21/2003	81	330	0.2	4.4	8.4
September	9/21/2003	84	530	0.2	4.7	10.3
September	9/21/2003	89	390	0.2	5.1	14.5
September	9/22/2003	62	610	0.2	3.4	7.4
September	9/22/2003	63	130	0.2	3.8	7.2
September	9/22/2003	64	175	0.3	6.1	7.5
September	9/22/2003	65	310	0.2	4.1	10.2
September	9/22/2003	66	570	0.2	3.6	7.2
September	9/22/2003	715	140	0.2	3.9	9.3
September	9/23/2003	38	430	2.4	4.8	7.3
September	9/23/2003	39	500	0.2	4.4	11.5
September	9/23/2003	40	160	.	4.4	11.5
September	9/24/2003	33	152.5	0.5	5.5	12.2
September	9/25/2003	8	460	4.9	15.0	20.0
September	9/25/2003	9	390	0.6	6.6	13.6
September	9/25/2003	12	230	0.3	5.3	12.1
September	9/25/2003	17	480	.	7.0	13.7
September	9/25/2003	18	140	0.2	4.1	10.2
September	9/25/2003	19	215	0.5	4.5	10.9
September	9/25/2003	28	290	3.1	5.3	18.4
September	9/25/2003	29	300	0.2	6.9	10.9

Benthos, LOLA 2003

* indicates community assessment sample (average of 3 PONARS)

[a] indicates sites where only one PONAR was retrieved due to hard substrate

Station	Date	Depth	latitude	longitude	*Diporeia spp.*	*D. bugensis*	*D. polymorpha*
		m	N	E	$\#/m^2$	$\#/m^2$	$\#/m^2$
0-30 m depth							
62	19-Aug-03	9.9	43.88	-77.00	0	1600.2	0
17	11-Aug-03	10.5	43.22	-79.27	0	2765.7	396.9
8	10-Aug-03	14.6	43.62	-79.45	0	7868.7	0
66[a]	19-Aug-03	18.3	43.33	-76.84	0	1134.0	18.9
38	20-Aug-03	18.7	43.38	-77.99	0	2104.2	0
80	21-Sep-03	22	44.14	-76.61	0	1978.2	0
71B	20-Aug-03 *	27	43.50	-76.51	0	31033.8	6.3
77	21-Sep-03	28	43.96	-76.41	0	20412.0	0
29[a]	25-Sep-03	30	43.82	-78.87	0	3213.0	0
				AVERAGE	**0**	**9146.2**	**46.9**
				SE		**3428.3**	**438**
30-90 m depth							
81	19-Aug-03 *	35	44.02	-76.68	0	6356.7	0
84	19-Aug-03	35	43.89	-76.73	0	30044.7	0
35	24-Sep-03	37	43.36	-78.73	0	2979.9	0
717	24-Sep-03	38	43.30	-77.44	6.3	13563.9	0
43A	21-Aug-03	38.1	43.93	-77.97	0	1801.8	0
61	22-Sep-03	53	43.79	-77.16	0	4006.8	0
9	10-Aug-03 *	60	43.59	-79.39	0	504.0	6.3
28	25-Sep-03	61	43.78	-78.85	81.9	18440.1	0
42	21-Aug-03	65.5	43.84	-78.04	6.3	13986.0	0
74	21-Sep-03	68	43.75	-76.52	0	6816.6	0
6	25-Sep-03 *	71	43.47	-79.53	0	4693.5	0
93A	24-Sep-03	74	43.36	-78.86	0	6627.6	0
18	11-Aug-03	86.9	43.30	-79.28	781.2	25.2	0
63	19-Aug-03 *	87.1	43.73	-77.02	6.3	3628.8	0
				AVERAGE	**63.0**	**8105.4**	**0.5**
				SE	**55.5**	**819.5**	
>90 m depth							
58	24-Sep-03	99	43.37	-77.44	0	6904.8	0
12	11-Aug-03	106	43.50	-79.35	283.5	0	0
72	20-Aug-03	108.5	43.55	-76.53	0	3143.7	0
19	11-Aug-03	108.7	43.38	-79.29	472.5	0	0
41	20-Aug-03 *	129.1	43.72	-78.03	945	6.3	0
33	21-Aug-03	137.4	43.60	-78.80	963.9	0	0
65	19-Aug-03	147.5	43.42	-76.88	0	50.4	0
715	22-Sep-03	151	43.64	-76.97	447.3	0	0
39	23-Sep-03	153	43.49	-78.00	478.8	0	0
34	24-Sep-03	174	43.46	-78.76	636.3	4113.9	0
40	23-Sep-03	182	43.59	-78.01	1159.2	0	0
55	24-Sep-03	190	43.44	-77.44	724.5	12.6	0
64	22-Sep-03	219	43.53	-76.93	976.5	50.4	0
				AVERAGE	**545.2**	**1099.6**	**0**
				SE	**110.9**	**613.8**	

Epilimnetic Zooplankton Indicators (64-um mesh net)

Date	Station	Latitude	Longitude	Mean Length	Density	Biomass
		N	E	um	$\#/m^3$	mg/m^3
April						
28-Apr-03	12	43.50	-79.35	676.3	3109.8	8.22
28-Apr-03	17	43.22	-79.27	519.5	458.5	0.81
28-Apr-03	18	43.30	-79.28	615.0	1551.6	2.79
28-Apr-03	19	43.38	-79.29	568.3	1792.4	2.44
28-Apr-03	8	43.62	-79.45	612.1	393.5	0.97
28-Apr-03	9	43.59	-79.39	700.1	1177.6	3.13
29-Apr-03	33	43.60	-78.80	683.6	4371.2	12.41
29-Apr-03	39	43.49	-78.00	655.0	1798.2	4.46
29-Apr-03	40	43.59	-78.01	625.3	1612.1	3.32
29-Apr-03	41	43.72	-78.03	614.2	1489.7	3.63
29-Apr-03	42	43.84	-78.04	642.6	1013.5	2.29
29-Apr-03	43	43.95	-78.05	611.8	162.6	0.42
29-Apr-03	63	43.73	-77.02	718.0	2236.5	6.47
29-Apr-03	64	43.53	-76.93	755.8	2372.6	7.38
29-Apr-03	715	43.64	-76.97	604.5	2841.2	5.91
30-Apr-03	65	43.42	-76.88	686.4	1871.5	4.77
30-Apr-03	66	43.33	-76.84	713.2	2556.2	7.51
30-Apr-03	72	43.55	-76.53	715.2	1494.1	4.57
30-Apr-03	74	43.75	-76.52	713.6	1694.9	4.71
30-Apr-03	77	43.96	-76.41	728.9	553.1	1.59
30-Apr-03	80	44.14	-76.61	686.6	373.2	0.96
30-Apr-03	81	44.02	-76.68	728.9	201.1	0.60
30-Apr-03	84	43.89	-76.73	804.5	2586.5	13.20
30-Apr-03	89	43.70	-76.42	682.1	578.6	1.53
1-May-03	49	43.77	-77.44	678.4	1474.3	3.77
August						
10-Aug-03	12	43.50	-79.35	256.8	63348.3	30.58
10-Aug-03	19	43.38	-79.29	213.6	163864.5	45.94
10-Aug-03	8	43.62	-79.45	345.1	11523.2	4.76
10-Aug-03	9	43.59	-79.39	483.0	6374.9	9.96
11-Aug-03	17	43.22	-79.27	711.9	12637.7	51.17
11-Aug-03	18	43.30	-79.28	410.2	7824.0	8.17
19-Aug-03	62	43.88	-77.00	402.3	20068.4	18.37
19-Aug-03	63	43.73	-77.02	491.7	9164.5	11.09
19-Aug-03	64	43.53	-76.93	634.5	19920.8	37.06
19-Aug-03	65	43.42	-76.88	655.2	13363.1	29.81
19-Aug-03	66	43.33	-76.84	683.4	20027.1	37.06
19-Aug-03	715	43.64	-76.97	584.0	17346.7	28.06
19-Aug-03	74	43.75	-76.52	588.7	19939.6	39.16
19-Aug-03	80	44.14	-76.61	366.4	56202.1	56.05
19-Aug-03	81	44.02	-76.68	414.9	11454.2	11.42
19-Aug-03	84	43.89	-76.73	515.9	11443.6	16.99
19-Aug-03	89	43.70	-76.42	647.5	13355.7	29.87
20-Aug-03	38	43.38	-77.99	500.5	12576.9	28.67
20-Aug-03	39	43.49	-78.00	525.8	12672.3	20.55
20-Aug-03	40	43.59	-78.01	608.5	14535.6	26.32

Date	Station	Latitude	Longitude	Mean Length	Density	Biomass
		N	E	um	#/m^3	mg/m^3
20-Aug-03	41	43.72	-78.03	693.1	13054.8	27.51
20-Aug-03	42	43.84	-78.04	601.4	23814.7	40.36
20-Aug-03	71	43.48	-76.53	563.1	19409.5	39.88
20-Aug-03	72	43.55	-76.53	773.7	16303.3	50.99
21-Aug-03	33	43.60	-78.80	557.7	15752.1	31.26
21-Aug-03	43	43.95	-78.05	614.0	58076.6	79.58
September						
21-Sep-03	71	43.48	-76.53	524.8	141014.9	318.63
21-Sep-03	72	43.55	-76.53	532.1	155165.2	312.54
21-Sep-03	74	43.75	-76.52	545.4	54109.2	141.96
21-Sep-03	77	43.96	-76.41	705.1	18391.4	51.50
21-Sep-03	80	44.14	-76.61	501.2	55130.3	118.24
21-Sep-03	81	44.02	-76.68	473.4	73635.6	165.02
21-Sep-03	84	43.89	-76.73	600.9	14835.4	70.91
21-Sep-03	89	43.70	-76.42	645.2	11393.3	29.62
22-Sep-03	62	43.88	-77.00	527.2	74250.9	192.90
22-Sep-03	63	43.73	-77.02	621.7	31128.3	80.13
22-Sep-03	64	43.53	-76.93	518.9	19154.4	36.84
22-Sep-03	65	43.42	-76.88	398.3	75566.1	68.84
22-Sep-03	66	43.33	-76.84	287.8	155752.2	75.08
22-Sep-03	715	43.64	-76.97	557.0	62819.7	149.11
23-Sep-03	38	43.38	-77.99	322.9	76220.9	68.54
23-Sep-03	39	43.49	-78.00	258.5	37134.3	14.47
23-Sep-03	40	43.59	-78.01	536.1	28798.0	54.43
24-Sep-03	12	43.50	-79.35	489.0	41345.1	50.94
24-Sep-03	29	43.82	-78.87	549.5	178978.7	297.71
24-Sep-03	33	43.60	-78.80	602.4	79130.7	216.14
25-Sep-03	17	43.22	-79.27	449.1	9604.9	7.98
25-Sep-03	18	43.30	-79.28	286.8	39097.5	22.85
25-Sep-03	19	43.38	-79.29	439.4	39468.9	88.94
25-Sep-03	28	43.78	-78.85	584.6	72431.6	136.39
25-Sep-03	8	43.62	-79.45	251.4	70456.9	24.46
25-Sep-03	9	43.59	-79.39	428.3	18310.4	8.84

Total Water Column Zooplankton Indicators (153-um mesh net)

Date	Station	Latitude N	Longitude E	Mean Length um	Density #/m^3	Biomass mg/m^3
April						
28-Apr-03	12	43.50	-79.35	778.6	3170.3	11.10
28-Apr-03	18	43.30	-79.28	685.7	708.9	1.79
28-Apr-03	9	43.59	-79.39	659.2	96.6	0.23
29-Apr-03	19	43.38	-79.29	683.8	1963.3	5.10
29-Apr-03	33	43.60	-78.80	706.7	2082.4	5.55
29-Apr-03	38	43.38	-77.99	771.1	688.5	2.27
29-Apr-03	39	43.49	-78.00	795.0	1838.0	6.37
29-Apr-03	40	43.59	-78.01	774.0	1512.1	4.96
29-Apr-03	41	43.72	-78.03	770.0	1571.0	5.32
29-Apr-03	42	43.84	-78.04	758.4	957.1	3.23
29-Apr-03	62	43.88	-77.00	753.6	687.0	2.07
29-Apr-03	63	43.73	-77.02	798.9	2501.9	8.54
29-Apr-03	64	43.53	-76.93	734.6	2029.9	5.67
29-Apr-03	715	43.64	-76.97	690.1	2035.9	5.14
30-Apr-03	65	43.42	-76.88	749.8	1246.7	3.91
30-Apr-03	71	43.48	-76.53	668.3	592.4	1.43
30-Apr-03	72	43.55	-76.53	799.9	826.8	3.11
30-Apr-03	74	43.75	-76.52	808.6	1724.1	6.26
30-Apr-03	81	44.02	-76.68	779.4	317.1	1.11
30-Apr-03	84	43.89	-76.73	815.6	2356.9	8.13
30-Apr-03	89	43.70	-76.42	782.2	1261.7	4.19
1-May-03	49	43.77	-77.44	747.7	2463.3	7.27
August						
10-Aug-03	12	43.50	-79.35	514.9	15876.3	35.00
10-Aug-03	19	43.38	-79.29	451.7	15723.0	22.57
10-Aug-03	9	43.59	-79.39	599.0	19093.8	39.63
11-Aug-03	18	43.30	-79.28	504.4	14735.7	24.22
19-Aug-03	62	43.88	-77.00	487.6	25419.5	36.41
19-Aug-03	63	43.73	-77.02	663.5	13150.0	33.19
19-Aug-03	64	43.53	-76.93	736.4	2645.4	8.17
19-Aug-03	65	43.42	-76.88	428.6	3820.9	6.63
19-Aug-03	66	43.33	-76.84	769.4	14344.7	38.47
19-Aug-03	715	43.64	-76.97	706.2	15944.8	39.97
19-Aug-03	74	43.75	-76.52	590.3	8167.3	175.95
19-Aug-03	80	44.14	-76.61	368.6	37413.0	38.58
19-Aug-03	81	44.02	-76.68	472.0	17906.8	27.89
19-Aug-03	84	43.89	-76.73	692.8	69275.5	172.91
20-Aug-03	38	43.38	-77.99	407.1	14027.5	18.30
20-Aug-03	39	43.49	-78.00	647.2	6595.0	18.34
20-Aug-03	40	43.59	-78.01	709.9	9528.1	29.11
20-Aug-03	41	43.72	-78.03	673.5	10765.4	27.48
20-Aug-03	42	43.84	-78.04	647.5	13080.8	31.17
20-Aug-03	71	43.48	-76.53	602.5	23314.1	48.65
20-Aug-03	72	43.55	-76.53	508.3	8292.1	75.05
21-Aug-03	33	43.60	-78.80	576.8	10695.5	23.96
21-Aug-03	43	43.95	-78.05	669.6	43268.2	89.78

Date	Station	Latitude N	Longitude E	Mean Length um	Density #/m^3	Biomass mg/m^3
September						
21-Sep-03	72	43.55	-76.53	622.8	20938.6	53.95
21-Sep-03	74	43.75	-76.52	655.2	38662.4	113.93
21-Sep-03	77	43.96	-76.41	635.4	93927.4	285.64
21-Sep-03	80	44.14	-76.61	647.4	39250.7	117.78
21-Sep-03	81	44.02	-76.68	726.6	13911.4	45.36
21-Sep-03	84	43.89	-76.73	666.6	34897.2	104.26
21-Sep-03	89	43.70	-76.42	698.8	7369.2	25.65
22-Sep-03	63	43.73	-77.02	665.5	27460.9	82.85
22-Sep-03	64	43.53	-76.93	751.3	3926.6	13.64
22-Sep-03	65	43.42	-76.88	622.6	16056.8	38.87
22-Sep-03	715	43.64	-76.97	684.2	19702.1	58.29
23-Sep-03	39	43.49	-78.00	503.4	8007.0	11.12
23-Sep-03	40	43.59	-78.01	654.3	11993.3	28.45
24-Sep-03	12	43.50	-79.35	595.8	44301.7	84.02
24-Sep-03	29	43.82	-78.87	596.4	106309.0	212.02
24-Sep-03	33	43.60	-78.80	650.0	7933.7	23.16
25-Sep-03	18	43.30	-79.28	528.6	48660.0	93.82
25-Sep-03	19	43.38	-79.29	530.5	34548.0	58.44
25-Sep-03	28	43.78	-78.85	661.4	12882.4	34.70
25-Sep-03	9	43.59	-79.39	590.3	60372.2	105.69

Microbial Food Web, LOLA 2003

April

Station	Transect	Bacteria (x10^5) per mL	HNF (x10^3) per mL	APP (x10^3) per mL	ANF (x10^3) per mL
Stn8	**1**	5.97	3.09	1.86	4.46
Stn12	**1**	5.94	2.32	5.09	0.93
Stn19	**1**	4.35	9.28	2.40	0.31
Stn17	**1**	4.87	1.16	0.90	5.57
Stn43	**3**	3.61	0.46	0.93	10.68
Stn41	**3**	4.54	4.22	1.16	0.62
Stn40	**3**	3.89	0.31	0.93	0.62
Stn38	**3**	3.62	0.93	1.55	2.17
Stn62	**5**	2.29	1.39	0.31	8.82
Stn715	**5**	3.71	6.19	0.31	0.31
Stn66	**5**	3.66	2.32	1.24	2.48
Stn81	**6**	4.61	0.31	0.93	7.12
Stn74	**6**	2.90	1.16	0.62	1.24
Stn71	**6**	7.95	2.65	0.27	4.24
Stn77	**6**	4.69	0.31	0.31	2.48
	Average	4.44	2.41	1.25	3.47
	S.E	0.36	0.65	0.32	0.85

August

Station	Transect	Bacteria (x10^5) per mL	HNF (x10^3) per mL	APP (x10^3) per mL	ANF (x10^3) per mL
Stn8	**1**	26.90	5.06	14.24	1.86
Stn12	**1**	18.63	6.75	37.14	0.58
Stn19	**1**	8.89	11.82	14.85	0.62
Stn17	**1**	23.81	10.13	32.80	1.86
Stn43	**3**	21.38	18.57	52.61	0.62
Stn41	**3**	18.71	5.31	35.34	0.60
Stn40	**3**	19.06	4.13	53.23	0.62
Stn38	**3**	21.64	10.32	63.75	1.24
Stn62	**5**	24.60	7.43	22.41	0.62
Stn715	**5**	19.06	16.50	81.08	1.86
Stn66	**5**	16.81	4.64	119.76	2.79
Stn81	**6**	18.61	7.43	51.37	0.62
Stn74	**6**	27.35	26.53	22.28	1.86
Stn71	**6**	17.25	2.65	76.13	2.48
Stn84	**6**	22.06	10.32	47.04	1.86
	Average	20.32	9.84	48.27	1.34
	S.E	1.18	1.66	7.37	0.20

Phytoplankton abundance (cells/L)

Date	Station	Cyanophyta	Chlorophyta	Euglenophyta	Chrysophyceae	Haptophyta	Diatomeae	Cryptophyceae	Peridineae
4/28/2003	8	26400	7938795	0	74124	82054	173459	995334	275
4/28/2003	12	5018	12675167	0	646329	443423	322317	139785	12738
4/28/2003	17	0	3846715	0	0	13129	178373	79652	220
4/28/2003	19	2583632	297098	0	1340377	356504	757883	240197	26301
4/29/2003	38	0	14589944	59676	32838	387894	153352	657436	3000
4/29/2003	40	4669	1496513	2030	836491	351313	273645	124829	5278
4/29/2003	41	1236	295038	1030	405677	227425	117810	173136	24620
4/29/2003	43	0	13568092	0	24169	0	55628	105001	540
4/29/2003	62	0	11038906	0	18977	88559	1484	57143	0
4/30/2003	66	0	11038906	0	18977	88559	1484	57143	0
4/29/2003	715	1015	9305	0	417941	224113	88958	140971	5278
4/30/2003	71	0	25103903	0	0	27451	28601	13725	230
4/30/2003	74	454	1847992	0	718416	426713	132587	213412	4540
4/30/2003	81	0	23632696	0	179028	0	119352	60676	0
8/10/2003	8	323790	389407	0	2297276	141134	352294	1596552	31681
8/11/2003	12	54250221	992693	0	2454268	691197	586491	214531	4100
8/11/2003	19	11157920	191154	0	4964001	3625317	835403	428414	31054
8/11/2003	17	0	1928523	0	268840	1779091	207704	1695293	114674
8/20/2003	38	59640	23255572	0	462667	119054	18798	2287117	53278
8/20/2003	40	16727404	13725977	0	974751	250639	357315	399862	6800
8/20/2003	41	17615779	435151	210	1737776	156649	410263	223509	2100
8/21/2003	43	760000	998825	0	228479	62361	233511	136061	4180
8/19/2003	62	27915	5036144	1925	1049902	161871	149063	806816	9100
8/19/2003	66	14727668	7525841	0	2739128	179028	64806	425132	1800
8/19/2003	715	82612	1407652	197	2627701	188099	205174	514348	3546
8/20/2003	71	80412642	12069675	0	20740	1700	81017	472249	340
8/19/2003	74	63949045	10898417	0	645267	87724	1069847	53614	5684
8/19/2003	81	19163785	894172	0	1700766	1277066	1850556	498176	49773
8/19/2003	84	22895749	604973	0	837119	265319	616689	601983	5472

Phytoplankton biomass (mg/m^3)

Date	Station	Cyanophyta	Chlorophyta	Euglenophyta	Chrysophyceae	Haptophyta	Diatomeae	Cryptophyceae	Peridineae
4/28/2003	8	0	18.2	0	4.2	1.3	21.8	81.3	0.5
4/28/2003	12	1	14.6	0	40.7	5.1	282.7	15.9	23.6
4/28/2003	17	0	14.6	0	0	0.2	17.5	7.8	0.1
4/28/2003	19	3.4	13.4	0	27.1	5.8	1082	49.3	45.1
4/29/2003	38	0	44.2	9.8	1.9	4.5	72.2	66.3	22.3
4/29/2003	40	0.8	3.3	7.9	39.7	4	65.8	34.8	8.1
4/29/2003	41	0.1	3.3	10.1	7.5	2.6	35.3	13.9	13.5
4/29/2003	43	0	119.6	0	0.9	0	11.5	9.7	0.7
4/29/2003	62	0	150.4	0	0.5	0	0	0.1	0
4/30/2003	66	0	38.9	0	0.2	1	1.7	3.4	0
4/29/2003	715	0.2	0.4	0	17.6	2.6	24.9	21.3	28.1
4/30/2003	71	0	115.4	0	0	0.3	10	3.1	1.6
4/30/2003	74	13.1	5.2	0	21.7	5.3	19.5	34.1	13.7
4/30/2003	81	0	29.4	0	8.5	0	4.4	10	0
8/10/2003	8	6.8	31.2	0	31.2	1.2	19.4	71.2	30.3
8/11/2003	12	21	12.5	0	23	5.7	24.9	20	6.4
8/11/2003	19	22	7.8	0	49.3	29.8	47.2	50.8	22.3
8/11/2003	17	0	7.4	0	15.2	20.4	11.1	74.6	31.5
8/20/2003	38	7.5	51.2	0	12.3	1.4	0.9	108.3	22
8/20/2003	40	16	43.6	0	30.1	2.9	25.2	103.4	30.5
8/20/2003	41	181.1	25	0.7	17.9	1.8	12.7	14.4	13
8/21/2003	43	0.2	11.4	0	2.9	0.5	8.5	5.9	111.3
8/19/2003	62	1.4	11.9	2.1	10.2	1.3	6.6	46.9	20
8/19/2003	66	41.7	39.9	0	37.5	2.1	8.2	35.4	25.8
8/19/2003	715	6.3	59.2	0.3	18.3	1.5	5.6	23.2	9.2
8/20/2003	71	1338.7	41.7	0	1.4	0	4.2	20.5	0.3
8/19/2003	74	49.5	91.5	0	13.5	1	78	3	29.9
8/19/2003	81	48.2	48	0	20.4	10.5	58	33.9	150.5
8/19/2003	84	18.2	17.7	0	29.1	3.5	21.3	107.4	17.8

Appendix B. Agenda for the LOLA workshop held at the Cornell Biological Field Station.

LOLA WORKSHOP AGENDA
November 16 - 17, 2005

Developing the next generation of long-term lower food web assessment tools for Lake Ontario

Wednesday, November 16

11:15	Arrival	
11:30	Lunch	
12:30	Welcome and Introductions	Luckey and Richardson
12:45	What is LOLA?	Luckey and Kelly
1:15	LaMP-Lake Ontario Management Issues	del Vicario
1:45	Status of Lake Ontario 2003	Mills
2:15	The Lake Ontario Lower Food Web: A nutritionist's view	Schulz
2:45	Break	
3:00	Lake Ontario Lower Food Web Assessment	
	Nearshore vs Offshore habitat	Stewart
	Spatial and Temporal Variability-Field Reality	Watkins
	Sampling Strategies	Sullivan
	Meshing Field Assessment with Mechanistic Studies	Watkins and Schulz
4:45	Pulse of Lake Ontario	Munawar
5:00	Group Discussion	
5:30	Tour of CBFS	
6:00	Dinner and Ponder the Day's Discussions among Friends	

Thursday, November 17

8:30	New Technologies-	
	Stable Isotopes and Fatty Acids	Johannsson
	Hydroacoustics	Rudstam
	Optical Plankton Counter	Yurista
	Remote Sensing	Becker
	Phytoplankton Fluorometry	Twiss
10:30	Break	

10:45 Bioassessment costs and funding — Luckey

11:00 A Strategy for Monitoring Lake Ontario's Lower Food Web

Three breakout groups*

Facilitators: Johannsson, Luckey, and MacNeill

You will be asked to design a sampling program to best assess the lower food web at funding levels of $200K annually and $500K at 5-year intervals.

- Lower food web parameters to be monitored must include:
  - Nutrients
  - Chlorophyll
  - Zooplankton
  - Benthos
- Description of sampling design must include minimally:
  - Sampling frequency
  - Spatial and temporal coverage
- Additional aspects to be considered:
  - Meshing with experimental studies
  - Links to existing programs
  - New technologies (may be used in addition to or in place of traditional sampling)

12:15 Discussion: Summary of breakout groups, next steps, and final remarks

1:00 Lunch

*breakout group assignments

	Group 1	**Group 2**	**Group 3**
Facilitator:	**Johannsson**	**MacNeill**	**Luckey**
	de Barros	Del Vicario	Fynn-Aikins
	Kalinauskas	O'Neill	Raeburn-Gibson
	Townsend	Zelazny	Scharold
	Johnson	Kelly	LaPan
	Culligan	O'Gorman	Marsden
	Schaner	Dittman	Morrison
	McKenna	Bowen	Dermott
	Holeck	Mills	Connerton
	Becker	Twiss	Schulz
	Stewart	Watkins	Rudstam
	Yurista	Bertram	Whittle

Appendix C. LOLA Workshop Participants

Mohi Munawar, Department of Fisheries and Oceans Canada
Heather Niblock, Department of Fisheries and Oceans Canada
Kelly Bowen, Department of Fisheries and Oceans Canada
Mike Whittle, Department of Fisheries and Oceans Canada
Ora Johannsson, Department of Fisheries and Oceans Canada
Ron Dermott, Department of Fisheries and Oceans Canada
Joe Makarewicz, SUNY Brockport
Don Zelazny, NYSDEC
Steve Lapan, NYSDEC
Bill Culligan, NYSDEC
Bob Townsend, NYSDEC
Richard Raeburn-Gibson, Ontario Ministry of the Environment
Conrad deBarros, Ontario Ministry of the Environment
Bruce Morrison, OMNR
Tim Johnson, OMNR
Ted Schaner, OMNR
Tom Stewart, OMNR and University of Toronto
Peder Yurista, USEPA
Mario Del Vicario, USEPA
Jack Kelly, USEPA
Jill Scharold, USEPA
Fred Luckey, USEPA
Paul Bertram, USEPA, GLNPO
Kim Schulz, SUNY ESF
Mike Connerton, SUNY ESF
Michael Twiss, Clarkson University
Richard Becker, Western Michigan University
Bob O'Gorman, USGS
Dawn Dittman, USGS
Jim McKenna, USGS
Kofi Fynn-Aikins, USFWS
Carolyn O'Neill, Environment Canada
Rimi Kalinauskas, Environment Canada
John Marsden, Environment Canada
Ed Mills, Cornell University
Lars Rudstam, Cornell University
Kristen Holeck, Cornell University
Jim Watkins, Cornell University
Pat Sullivan, Cornell University
Dave MacNeill, Cornell University

Appendix D. Variability of Lower Food Web Components

The evaluation of change in lower food web components requires a consideration of variability. The lake-wide LOLA sampling provides a snapshot of spatial variability at three times in 2003. Variability is expected to change from nearshore to offshore habitats because of different fauna and processes. Nearshore habitats are thought to be generally more heterogeneous because of interaction with land, river inputs, and benthos. Physical conditions such as water temperature play a role in the spatial variability of organisms as an important control of plankton growth. Temperature can also trace specific water masses including warm coastal water defined by thermal bars, river plumes, and upwelled deep water. Physical forcing may affect the distribution of food web components differently because of the different time scales of phytoplankton and zooplankton life cycles. In this section we describe the extent of spatial variability in temperature, nutrients, phytoplankton, and zooplankton within ship collected LOLA data. We also compare the station data to lake-wide patterns apparent in satellite imagery collected at the same time periods.

Surface Temperature

The water column was well mixed during the spring cruise (April 28-May 2, 2003). Nearshore temperatures were significantly warmer than offshore by 2˚C (Table 1, Figure 12A). This temperature contrast signaled the early onset of thermal bar conditions. Satellite imagery tracked the development of the thermal bar through June, 2003.

By August, the water column had stratified leading to the highest surface temperatures of the year and low spatial variability (Table 1, Figure 1B). Satellite imagery suggests that the lake was warmest from August 13-18, 2003. Summer LOLA sampling included cruises on the western transect from August 10-11, 2003 and another cruise from August 19-August 21, 2003. By August 27, 2003 strong westerly winds had initiated a major upwelling event along the northwest coast.

One month later, mixing had cooled surface water and resulted in greater overall temperature variability (Table 1). However there was no significant difference in temperature or its variability for nearshore and offshore habitats, suggesting a similar breakdown in stratification in both habitats. Cool water from coastal upwelling events on the northwest and southern coasts was advected to offshore regions (Figure 1C-E). Lake Ontario's thermal structure was dynamic during the fall LOLA cruise (September 19-September 25, 2003) and included the passage of Hurricane Isabel on September 19, 2003. Gale force easterly winds led to strong upwelling on the south coast (Figure 1D).

Table 1. Mean epilimnion temperature, standard deviation, and coefficient of variation (cv) at nearshore, offshore, and all sites (overall) in Lake Ontario during spring, summer, and fall, 2003.

	Nearshore				Offshore				Overall			
Season	n	avg	sd	cv	n	avg	sd	cv	n	avg	sd	cv
Spring	8	4.3	1.0	23%	18	2.3	0.3	12%	26	2.9	1.1	38%
Summer	6	22.6	1.3	6%	12	22.4	1.6	7%	18	22.5	1.5	7%
Fall	9	17.4	2.6	15%	13	17.4	3.0	17%	22	17.4	2.8	16%

Figure 1. Lake Ontario surface water temperatures May – September, 2003. Images created using SEADAS (SeaWIFS data analysis system) from MODIS satellite data (http://oceancolor.gsfc.nasa.gov/).

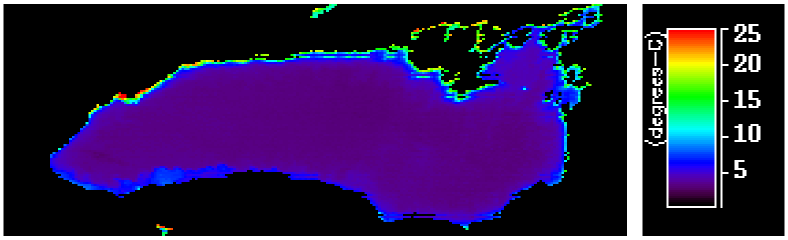


Figure 1A. May 3, 2003

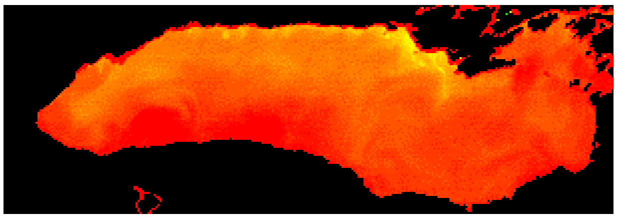


Figure 1B. August 18, 2003

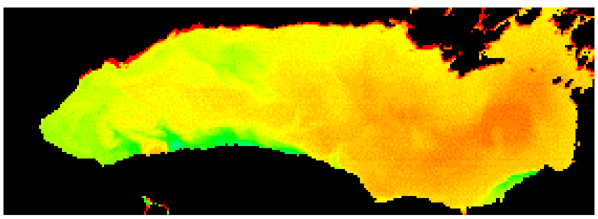


Figure 1C. September 10, 2003

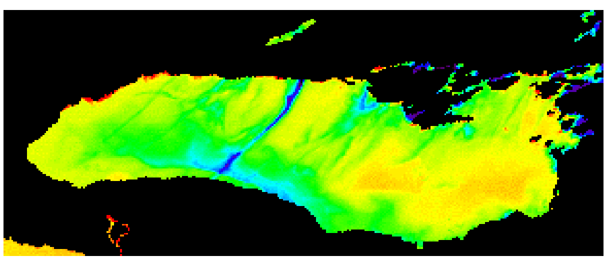


Figure 1D. September 21, 2003

* NE-SW oriented blue line is a cloud streak

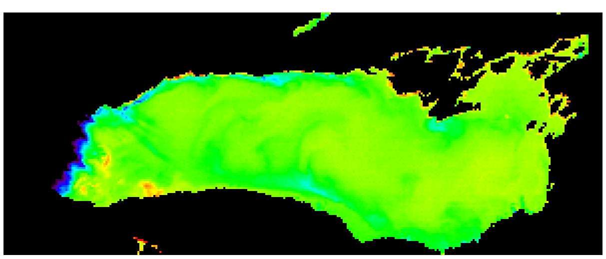


Figure 1E. September 26, 2003

* Cloud cover in far western coast

Nutrients (Total Phosphorus)

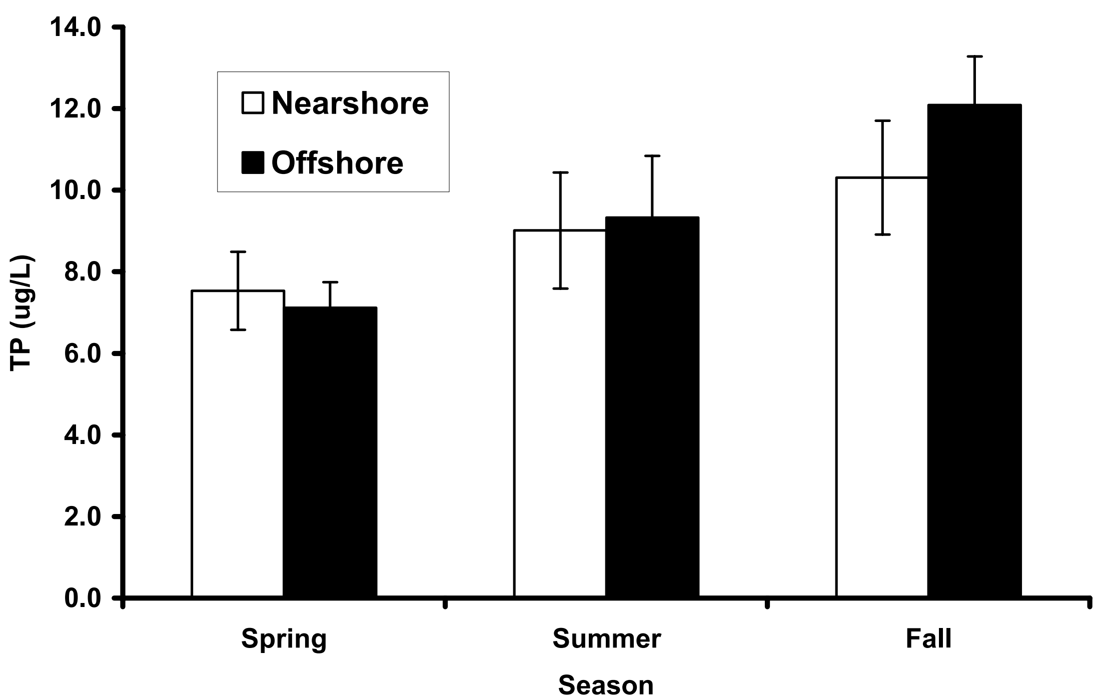
Variability of TP was consistent (c.v. 40%) throughout the year except for the very high variability in the offshore habitat during summer (Table 2). The high variability of TP in summer occurred during conditions of low temperature variability, and may be the result of sampling variability or biological processes. Although variability of temperature had increased from summer to fall, the variability of TP decreased or was stable during the same time period.

Table 2. Mean TP, standard deviation (sd), and coefficient of variation (cv) at nearshore, offshore, and all sites (overall) in Lake Ontario during spring, summer, and fall, 2003.

	Nearshore				Offshore				Overall			
Season	n	avg	sd	cv	n	avg	sd	cv	n	avg	sd	cv
Spring	9	7.5	2.9	38%	18	7.1	2.7	37%	27	7.3	2.7	37%
Summer	8	9.0	4.0	45%	17	9.3	6.2	67%	25	9.2	5.5	60%
Fall	9	10.3	4.2	41%	17	12.1	4.9	41%	26	11.5	4.7	41%

There was no significant difference in TP between nearshore and offshore habitats in any season (Figure 2). Although variability was high, lake-wide fall TP was significantly higher than spring TP (ANOVA; $p<0.0001$).

Figure 2. Mean total phosphorus concentrations at nearshore and offshore locations in Lake Ontario during spring, summer, and fall 2003. Error bars represent +/- 1SE.



Phytoplankton (Chlorophyll)

The distribution of phytoplankton is expected to reflect physical and nutrient gradients. Although the nearshore habitat was slightly warmer than offshore in the spring, there was no significant difference in chlorophyll levels for the two habitats (Table 3, Figure 3). Nearshore values were more variable (60-70% c.v.). This pattern suggests that the spring LOLA cruise was earlier than the spring nearshore phytoplankton bloom characteristic of thermal bar conditions. Satellite images confirm that this bloom did not occur until June.

In the summer, chlorophyll was significantly higher in nearshore habitats than in the offshore although there was little difference in temperature or TP concentration (Table 3, Figure 4B). Offshore chl a in the summer was not significantly higher than spring levels. The variability of chl *a* for nearshore sites was very high (70%). Satellite images confirm that high and variable phytoplankton production was limited to a narrow nearshore band (Figure 4B). Phytoplankton production may have been high nearshore because of river inputs and the role of the benthos in shallow regions.

The pattern reversed in the fall, with offshore chlorophyll significantly higher than nearshore chlorophyll. Overall variability of chlorophyll decreased from 69% to 25% between the summer and fall sampling, a trend opposite to that of temperature. Mixing may have reduced phytoplankton variability.

Satellite images suggest that peaks in lake-wide phytoplankton production occurred in June, 2003 (associated with the thermal bar) and early September, 2003 (associated with early thermal breakdown, Figure 4C), both events falling in between LOLA sampling cruises. Strong upwelling on the south coast was associated with low chlorophyll on satellite imagery from September 21, 2003 (Figures 1D, 4D).

Table 3. Mean chlorophyll *a*, standard deviation (sd), and coefficient of variation (cv) at nearshore, offshore, and all sites (overall) in Lake Ontario during spring, summer, and fall, 2003.

	Nearshore				**Offshore**				**Overall**			
Season	n	avg	sd	cv	n	avg	sd	cv	n	avg	sd	cv
Spring	9	1.13	0.69	61%	19	1.26	0.29	23%	28	1.22	0.45	37%
Summer	8	2.66	1.87	70%	18	1.46	0.64	44%	26	1.83	1.25	69%
Fall	9	2.23	0.52	23%	18	2.97	0.63	21%	27	2.72	0.68	25%

Figure 3. Mean chlorophyll *a* concentrations at nearshore and offshore locations in Lake Ontario during spring, summer, and fall, 2003. Error bars represent +/-1SE.

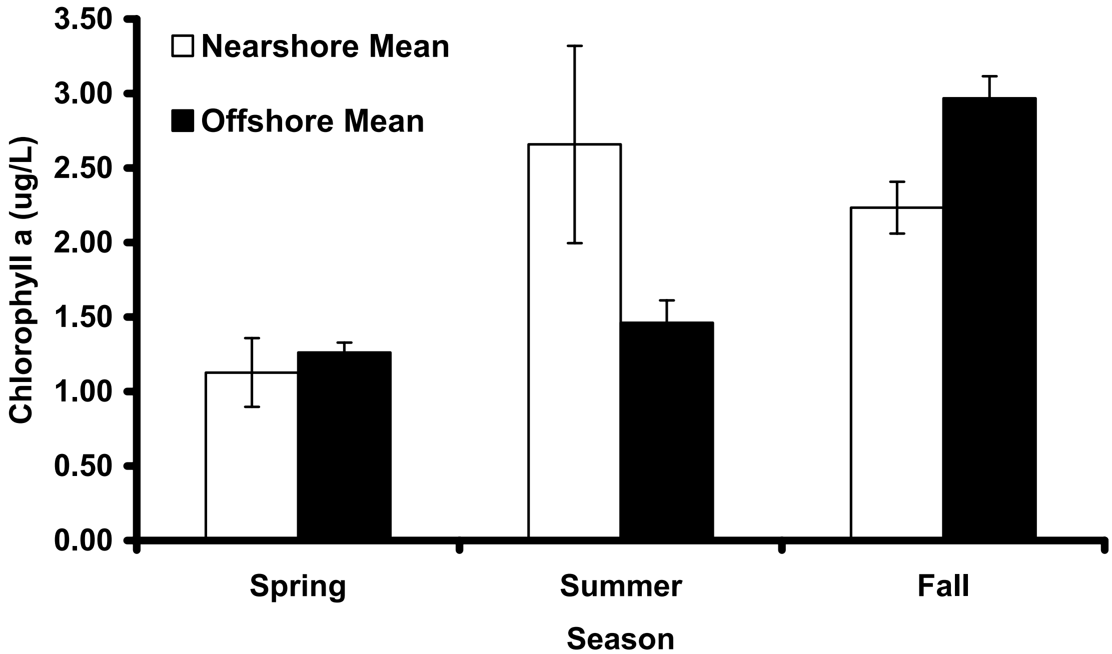


Figure 4. Lake Ontario surface chlorophyll a concentrations May – September, 2003. Images created using SEADAS (SeaWIFS data analysis system) from MODIS satellite data (http://oceancolor.gsfc.nasa.gov/).

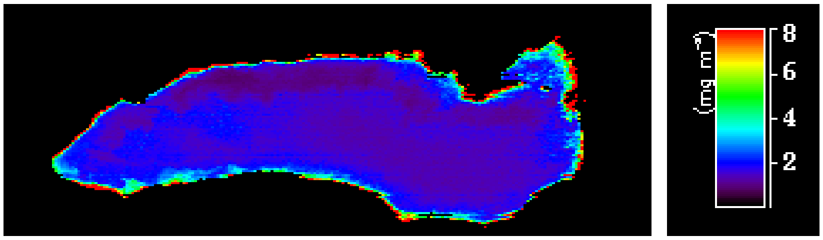


Figure 4A. May 3, 2003

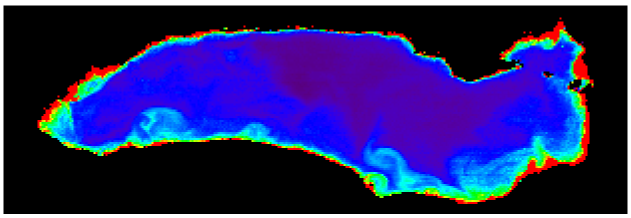


Figure 4B. August 18, 2003

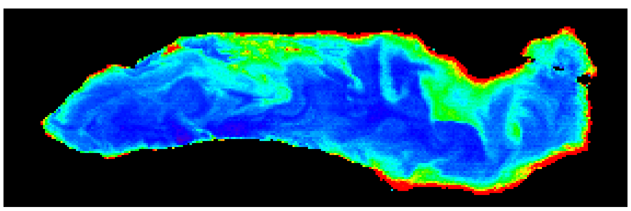


Figure 4C. September 10, 2003

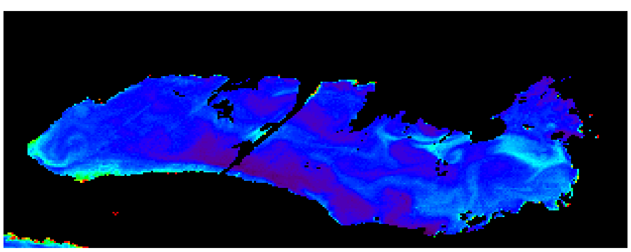


Figure 4D. September 21, 2003

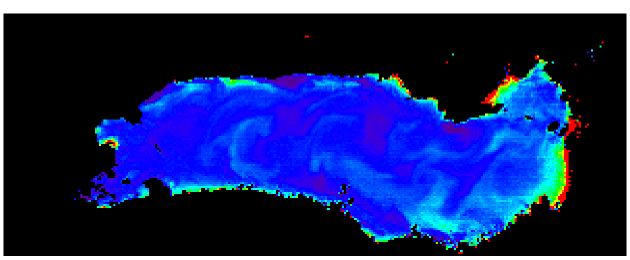
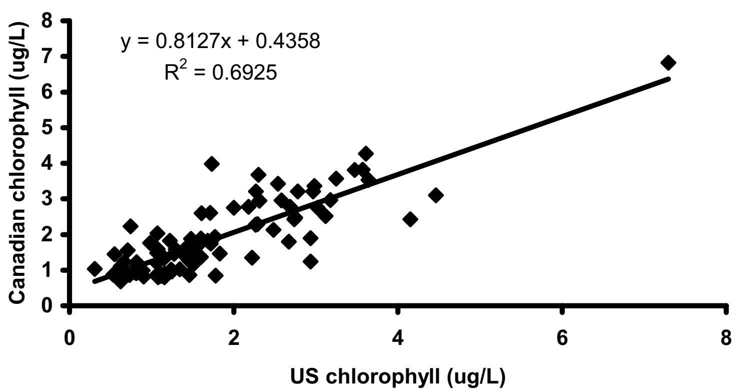


Figure 4E. September 26, 2003

Lab Comparison

Both U.S. and Canada have conducted long-term monitoring programs. Therefore, a laboratory comparison was included for all chlorophyll measurements. Chlorophyll values for the U.S. lab ranged from 0.13 – 7.76ug/L. Canadian values ranged from 0.61 – 6.99 ug/L. Regression of US vs Canadian chlorophyll values showed a positive relationship (r^2=0.69) with a slope of 0.81 (Figure 5). The slope was determined to be significantly different from one (t*=6.3; p<0.001 where t*=observed slope-specified slope/standard deviation of the observed slope), and only Canadian data were used for further analyses.

Figure 5. Comparison of US and Canadian chlorophyll values for samples collected during LOLA, 2003. Values are unadjusted for phaeophytin.



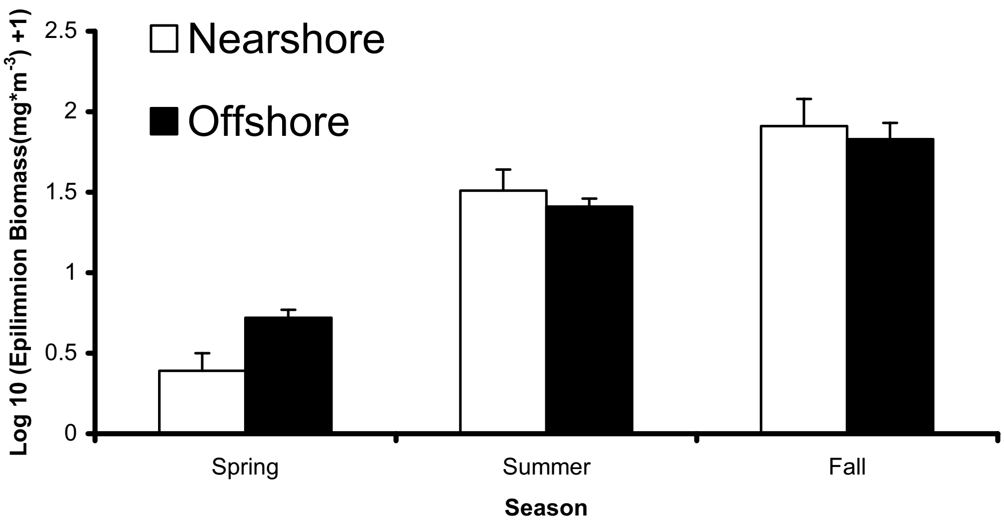
Zooplankton (biomass)

Zooplankton biomass dramatically increased between spring and summer, consistent with the typical summer peak in zooplankton production (Table 4, Figure 6). Variability of zooplankton biomass was highest with low spring abundances. Zooplankton biomass in each season was not normally distributed, and therefore was logarithmically transformed in the calculation of lake-wide averages. There was no significant difference in biomass between nearshore and offshore habitats, although there were higher levels of phytoplankton food (reflected by chl *a*) in the nearshore region in summer and offshore in the fall. The increase of epilimnetic zooplankton biomass between August and September suggests that zooplankton growth and reproduction was rapid enough to respond to the increase in phytoplankton food supply between August and September. This increase occurred because of a phytoplankton bloom in early September, 2003 associated with the onset of thermal breakdown.

Table 4. Mean $\log_{10}$ transformed zooplankton biomass (mg/m^3 +1), standard deviation (sd), and coefficient of variation (cv) at nearshore, offshore, and all sites (overall) in Lake Ontario during spring, summer, and fall, 2003.

	Nearshore				Offshore				Overall			
Season	n	avg	sd	cv	n	avg	sd	cv	n	avg	sd	cv
Spring	6	0.39	0.28	72%	19	0.72	0.23	32%	25	0.64	0.28	44%
Summer	8	1.51	0.36	24%	18	1.41	0.23	16%	26	1.44	0.27	19%
Fall	9	1.91	0.51	27%	17	1.83	0.41	22%	26	1.86	0.44	24%

Figure 6. Mean $\log_{10}$ transformed zooplankton biomass (mg/m^3 +1) at nearshore and offshore locations in Lake Ontario during spring, summer, and fall, 2003. Error bars represent + 1SE.



Appendix E. Meshing Field Assessment with Experimental Studies

Introduction

Annual monitoring has been valuable in identifying environmental change in the Great Lakes. This includes documenting changes in physical conditions as well as biological communities (declines of specific organisms or the arrival or spread of exotic invaders). Correlations of parameters within monitoring data often suggest cause and effect but need to be more closely investigated. Controlled experiments are a key way to uncover the mechanisms behind the observations.

Ideally there is interplay between monitoring and experimentation. Monitoring identifies an environmental problem. Mechanisms are proposed based on ecological relationships of organisms and observed correlations in field studies. Controlled experiments are then designed to test these hypotheses. Experimental results often point out associated effects in previously unconsidered parameters. Researchers can return to the monitoring database and look for trends of these parameters. Experimental results could also call for redesign of monitoring sampling design, particularly if important parameters are not included or not sampled at the right temporal resolution.

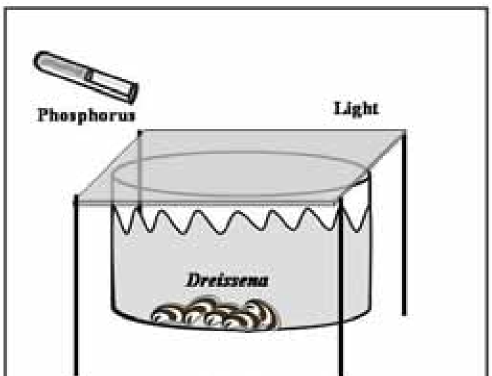
The Need for Field and Mechanistic Studies: *Dreissena* spp. and *Diporeia* spp. case studies

Monitoring history. Benthic surveys of Lake Ontario have been done since the 1960's. Monitoring quickly identified the introduction of dreissenids in the late 1980's and their rapid spread in the Great Lakes. The pervasiveness of zebra mussels on natural substrates and manmade structures was immediately clear. These observations raised the priority to identify potential positive and negative effects of dreissenids on benthic and planktonic communities.

A decline of populations of the native amphipod *Diporeia* was initially identified in Lake Erie in 1993 (Dermott and Kerec 1997), while declines in Lake Ontario were identified in sampling during 1995 and 1997 (Dermott 2001; Lozano et al. 2001). LOLA sampling in 2003 identified the continued decline of *Diporeia* as well as the expansion of *D. bugensis* to deep habitats.

Dreissenid research: predicting the effects of an invader. The rapid spread of zebra mussels in shallow habitats of the Great Lakes had immediate repercussions for benthic and planktonic ecosystems in the late 1980's. Scientists had to turn to the research base of Europe where the species is native to predict what effects it might have on freshwater ecosystems. A considerable amount of research on dreissenids has now been done within the Great Lakes. *Dreissena* introduction occurred simultaneously with phosphorus reduction, making it hard to tease apart the independent effects of each from monitoring data alone. In addition, these multiple stressors may have synergistic effects. For example, the phosphorus remediation and dreissenid filtration both work to reduce phytoplankton biomass, increase water clarity (Mills et al. 2003), and potentially decrease the nutrient content of pelagic and benthic primary producers, thereby altering *both the amount and quality* of food available to invertebrates and fish. In addition, higher light combined with benthic nutrient recycling and selective filtration by dreissenids may have the counterintuitive effect of promoting nuisance filamentous algae (NFA), despite lower water column nutrient availability.

Experiments with dreissenids have been done within microcosm and mesocosm settings. Microcosm (500 ml beakers) experiments have been successful for evaluating tolerances of the two species of *Dreissena* sp. to temperature, salinity, turbidity, and food levels (Baldwin et al. 2002). However, if you want to truly evaluate the effects of dreissenid beds on ecosystems, you have to turn to mesocosm experiments. You need the larger volume to assess the impacts on nutrients, phytoplankton (chl *a*, community, size), and zooplankton. A series of New York Sea Grant funded mesocosm experiments conducted by Mayer and Schulz at the Cornell Biological Field Station over the past two years set out to tease apart both the individual and synergistic effects of P remediation and dreissenid invasion. Specifically, we performed a fully factorial experiment to manipulate light, phosphorus and *Dreissena* to test effects on (1) benthic and pelagic primary production; (2) benthic and pelagic nutrient content and stoichiometry; (3) benthic and pelagic invertebrate composition and production; and (4) nuisance filamentous algal growth. We used large numbers (60 in 2002; 64 in 2003) of relatively large (600L, 1 m depth) mesocosms (filled with lake sediment, lake water, and natural levels of phytoplankton, benthic algae, and benthic and pelagic invertebrates) to enable us to separate the effects of nutrient remediation and zebra mussels, as well as the indirect effect of increased light penetration. Our phosphorus levels were set at pre- and post-remediation concentrations; light conditions at historic and modern (at 1-2 m depth) levels, and the mussel treatments were with and without zebra mussels. In the second year, we also included replicates of all treatments with and without other invertebrates (benthic and zooplankton) to look at direct grazer and recycling effects.



Mesocosm design showing three factors that will be independently manipulated in a full factorial design.

We are able to compare our results with the large amount of historic monitoring data available from Lakes Ontario and Oneida. While analysis is ongoing, we have been able to tease apart some of the direct light, zebra mussel and nutrient remediation effects on the lower food web. The strength of these interactions has informed an ongoing economic valuation of the zebra mussel invasion on homeowners and businesses that is part of this project (Limburg and Ludzadis). In addition to confirming some widely accepted ideas about these stressors (e.g., that dreissenids increase water clarity, decrease phytoplankton biomass, and increase benthic algal biomass and production), we were also able to observe that dreissenids increased ecosystem P retention (as suggested by Hecky et al. 2004), and that under conditions of high nutrient loading, zebra mussels can exacerbate nearshore phosphorus problems through accelerated P excretion. We were also able to confirm dramatic direct and indirect effects of P remediation and dreissenid invasion on invertebrates and nuisance filamentous algae. Many of these direct causal links would have been difficult to establish with monitoring alone, but can inform our future monitoring. For example, the study suggests that very nearshore sites might need to be sampled for nutrients and filamentous algae.

***Diporeia* Research: A search for a solution to stem the decline**

Knowledge base of *Diporeia*. As a major (60-80%) component of the benthic community and an important fish food, the physiology and ecology of *Diporeia* in the Great Lakes has been closely studied since the 1950's. Therefore there was a considerable knowledge base built up prior to the observation of the decline. There has also been abundant research of the European genus *Monoporeia* (separated from *Diporeia* in 1989). Much of the research has focused on the diet of *Diporeia,* particularly the importance of settling material from diatom blooms and its incorporation as lipids. Seasonal measurements of density, age structure, and body composition (lipid and proteins) have clarified the importance of the spring bloom, quantified growth rates, and documented the life cycle for this species. Toxicology studies of *Diporeia* have found bioaccumulation and sensitivity to environmental contaminants such as PCBs.

Experimental set-up. A recent NOAA/EPA workshop on the *Diporeia* decline identified the three most supported hypotheses for the decline of *Diporeia*.

1) dreissenids intercept food of *Diporeia*
2) dreissenid pseudofeces are toxic to *Diporeia*
3) an unknown pathogen or environmental contaminant is involved

Experiments have been set up to test the first two hypothesis. These typically track mortality or growth over a 2-3 month time period within a microcosm (e.g. 750ml flask). Testing the first hypothesis has proven difficult because food has not been limiting to *Diporeia* within laboratory conditions. Numerous food materials from natural and cultured phytoplankton have been offered at varying concentrations. Even "starved" *Diporeia* populations survive over several months. The incorporation of phytodetritus can be assessed through tracking the uptake of ^{14}C-labeled phytoplankton (van de Bund et al. 2001). Stable isotope analysis may also be an important tool to assess the diets of *Diporeia* and dreissenids. *Diporeia* are lipid rich, so stable isotope signatures should be corrected (lipids are enriched in ^{12}C).

Diporeia have also been exposed to dreissenid pseudofeces and various sediments in laboratory conditions. There is an early indication that dreissenid pseudofeces may be toxic to *Diporeia.* No experiments have exposed *Diporeia* to live dreissenids. Experiments which evaluate dreissenid effects are often conducted within macrocosms (hundreds of liters of water). Macrocosms would require a large number of *Diporeia* and considerably increase the difficulty of the experiments. Potential factors such as substrate surface coverage by dreissenids (e.g. inhibiting O_2 levels for burrowing *Diporeia*) have not been evaluated.

The third hypothesis has spurred an extensive search for biological pathogens. Hundreds of *Diporeia* were collected from healthy and declining populations. Infection rates were very low, and no clear pathogen candidate has emerged. There is interest in developing genetic bioassays to identify stressors, but genetic variability of *Diporeia* needs to be addressed. The decline of *Diporeia* has become an important research priority for EPA, which may make a call for research proposals in early 2006.

There has also been considerable research investigating competition for food between age classes and its role in population fluctuations of *Monoporeia* (Elmgren et al.2001, Wenngren and Olafsson

2002). These experiments are done in microcosms with different food levels, population densities, and age structure.

Experimental approaches have been used to evaluate the interaction of dreissenid mussels with other organisms. For example, field experiments have tested whether *Gammarus fasciatus* prefers a complex mussel substrate (Gonzalez and Downing, 1999). Laboratory experiments have then evaluated whether the habitat complexity reduced predation rates by fish on the amphipods. Laboratory experiments have also tested the effect that turbidity levels induced by the burrowing activity of the mayfly *Hexagenia* have on dreissenid filter feeding (Bergman et al. submitted)

Recent monitoring findings. *Dreissena bugensis* has largely replaced *D. polymorpha* in shallow habitats in Lake Ontario. This dreissenid has also been able to expand to deep habitats, which it was not expected to do based on its native distribution. Lake Superior appears to be the only Great Lakes ecosystem where dreissenids are not able to become established.

Continued Great Lakes monitoring has uncovered several important exceptions to the pattern of *Diporeia* decline. Whether the decline has expanded to Lake Superior, where dreissenids haven't spread, is not completely clear. There is also evidence that the problem is restricted to the Great Lakes. In the Finger Lakes of New York State and Canadian lakes *Diporeia* populations are not declining although they coexist with large dreissenid populations.

The negative association of *Diporeia* and dreissenids is clear in the affected Great Lakes, but the onset of *Diporeia* decline often preceded direct contact with dreissenids. This suggests that the effects of dreissenids are transported, perhaps by offshore sediment transport.

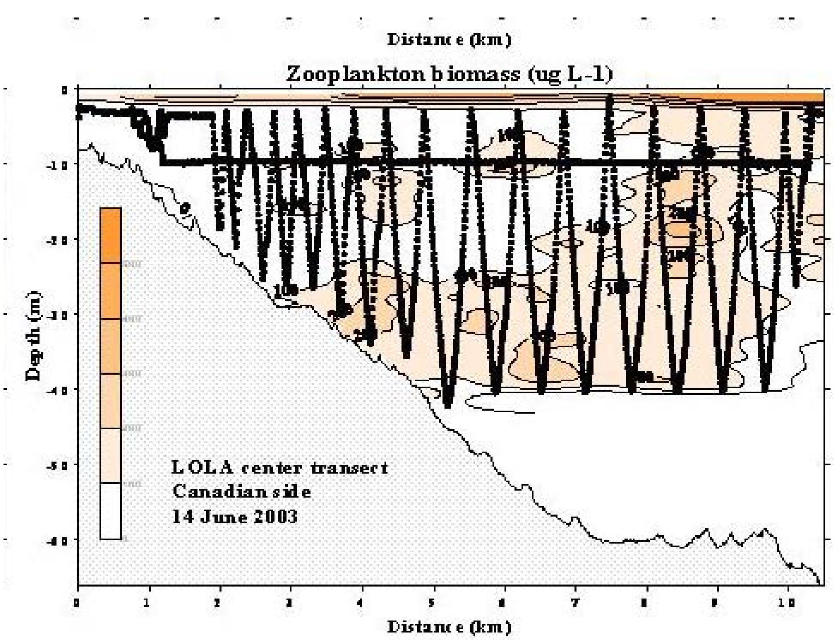
An early look at genetics has found that *Diporeia* populations in Lake Superior are different from populations in the lower Great Lakes (Lake Michigan and Lake Ontario) and the Finger Lakes. A better knowledge of the genetic diversity of *Diporeia* will be a key in developing genetic bioassays in evaluating stressors.

Appendix F. Bioassessment and Technology

Bioassessment programs should undergo periodic evaluation, not only to reconsider modifications to historic sampling regimes, but also to determine the appropriateness of new technologies. Technological advances have the potential to enhance bioassessment programs by reducing sampling costs and providing new and/or more comprehensive data. Several technological advances related to the assessment of lower food webs of freshwater ecosystems have been developing over the past two decades including optical plankton counters, hydroacoustics, stable isotope and fatty acid analysis, buoy systems, fluorometry, FlowCAM imaging, and remote sensing.

Optical Plankton Counters

Optical plankton counters (OPC) measure zooplankton biomass and size spectra. Additional sensors can be added to measure temperature, fluorescence, light transmittance, and conductivity. They provide a more detailed snapshot of patchiness in spatial distributions of plankton and can improve accuracy of biomass estimates compared to those of traditional net hauls. For example, the figure below shows a partial optical plankton counter transect taken on June 14, 2003. The distribution of zooplankton biomass is uneven both vertically (a condition that would be masked by use of a traditional net haul) and horizontally (a condition that could be masked depending on the number and location of traditional net tows on any given transect. The use of an OPC gives a more accurate picture of true conditions.



Optical Plankton Counter (contributed by Peder Yurista and Jack Kelly, US EPA Duluth)

Application:

-Zooplankton biomass and size spectrum
-other sensors include temperature, fluorescence, conductivity, light transmittance

Present Status:

-Lake Ontario sampling
-Gary Sprules LOTT study of 1995
-two cross-lake transects were done during the LOLA program in June, 2003.
-Additional paired nearshore sites in Lake Ontario (4 locations, 8 tows) June 2003
-Three embayments (with nearshore tows for two of them), 24-28 July 2004

other Great Lakes
-LETT (Lake Erie) survey of 1994 by Stockwell
-nearshore to ~8km offshore at approximately 20 sites (paired tows at 20 locations with shore parallel transects at nominally 5, 10, 20m); Yurista, et al. 2005, Also Yurista et al. in review.
-Lake Superior, 537 km of coast line Yurista and Kelly in review
-Lake Superior - Zhou et al. 2001
-Lake Superior - EPA-MED with US Canadian coalition in conjunction with fish acoustics. Extensive surveys in 2005.
-Lake Michigan - Hank Vanderploeg

Cost Estimate:

Equipment Costs

Equipment	dollars	additional notes
LOPC	46,000	
(OPC	25,000)	Older technology, smaller boats
CTD	8,250	
Fluorometer	3,000	
Transmissometer	3,500	
Tow platform	8,000	
(Mini Bat	20,000)	Smaller boats e.g. 26'
(Sea Cable	3,000)	
Computer	2,000	
Flow meter	1,500	

Processing

Processing time (OPC) can be streamlined provided the data structure needed/desired has been defined, metrics have been fully defined, and data templates constructed. Present processing is investigative to identify an appropriate analysis format and to identify useful versus peripheral data or metadata and more than might be needed for an assessment program. In general, under good conditions I expect one week of data processing for a season's worth of sampling to final analysis.

Groundtruthing:

Transects are accompanied by plankton tows (153 um total water column or 63 um epilimnion.

Potential Expansion:

What is your dream monitoring program using OPC in Lake Ontario?

LOPC at 20 m contour around lake with multiple (EMAP) on/off shore (20 km?) transects.

What is the minimum useful monitoring program using OPC?

EMAP style sample location selection (randomized from lake area).

Seasonal coverage?

For assessments no– define monitoring sample frame (e.g. stable conditions – July-August). For research questions yes.

Any new sensors to add?

Currently use CTDs, fluorometers, and transmissometers. Oxygen sensors are becoming faster and might be incorporated into a tow package. Oxygen may be appropriate for "dead zone" questions. NOx by UV spectrophotometry is a potential addition in near future.

Stick to transects or switch to nearshore or offshore coverage?

Presently exploring various tow strategies (local grids, alongshore contour transects, on/off shore transects).

Any needs for groundtruthing project?

There is considerable reluctance to accept OPC data as zooplankton monitoring tool, which will require good correlations to expected zooplankton community and demonstrations that it measures zooplankton as effectively as net sampling does (or does not).

Is there a need to convert static biomass to production?

Probably not for assessment but maybe for fisheries management.

Hydroacoustics (contributed by Lars Rudstam, Cornell University)

Hydroacoustic technology can been used to estimate fish, mysid, and zooplankton biomass. Currently, the Ontario Ministry of Natural Resources (OMNR) and NY Department of Environmental Conservation (NYDEC) conduct surveys of pelagic fish abundance along 7 transects and an area around Cape Vincent (figure below) in the end of July or beginning of August. Frequencies used in the past include 420kHx and 120kHz. Currently, the survey uses a Biosonics Dt-X digital 120kHz split beam scientific echosounder. Concurrent with the acoustic surveys, the agencies collect midwater trawl samples targeting aggregations observed with acoustics, and do occasional temperature profiles.

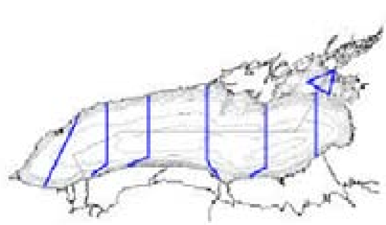


Figure 1. Lake Ontario map showing locations of transects ran by the NYDEC R/V Seth Green during hydroacoutistics surveys.

Estimates of current ship costs are US $2,000 per day, for a total of $20,000 (8 areas plus transportation time. The equipment is a one-time cost of 35-45K (either Biosonics or Simrad). Cost for software to analyze data varies. Both Biosonics and Simrad supply their units with a program package that can analyze fish density. Another software package (EchoView) is used by many of the agencies around the Great Lakes and cost 10K for fish and an additional 10K for multifrequency analysis. The software for multifrequency is presently at Cornell (Rudstam and Sullivan), USGS-Great Lakes lab in Ann Arbor (Warner) and is being purchased by DFO in Burlington (Koops and Doka). The fish analysis versions are available at NYSDEC (Region 8 and Lake Erie Unit) and OMNR (Glenora – Schaner and Port Dover – Witzel). Processing is time consuming and not automated at this point. For fish, we anticipate a processing time of at least 1 month. We do not know the time necessary for multifrequency analysis.

In addition**,** USGS and NYSDEC conduct bottom trawl surveys as part of the Lake Ontario Forage Base Assessment Program. These were initiated in 1978 and formalized in 1980. This covers the US side of the lake. Trawling is timed to coincide with maximum availability of prey fish. Alewife are assessed in April-May, rainbow smelt in May-June, and slimy sculpin in October. This sampling program was recently reviewed by an expert panel and several changes to the program implemented as a result. The panel suggestions are summarized by MacNeill (2005). So far, the acoustics and trawl surveys have not been compared directly.

Potential Expansion:

Schaner, Rudstam and Gal are funded by New York Sea Grant to develop the analysis techniques required to also assess mysids using the existing data collection. We are building on previous work by Gal et al. (1999). By constructing various thresholds, it is possible to remove most fish echoes from the data collected and estimate biomass of *Mysis relicta*.

Smaller zooplankton can also be visible with acoustics, but the smaller the targets of interest, the higher the frequency that should be used (Smith et al. 1992, Foote and Stanton 2000). 120kHz may not be sufficiently high to assess zooplankton, although it has been used in marine systems and 200kHz has been used in Lake Superior (Megard et al. 1997). Fish echoes are more of a problem when assessing zooplankton distribution in shallow water than when assessing mysids in deeper water because fish are more abundant in shallow water and zooplankton returns smaller and therefore more sensitive to contamination by fish echoes. The presence of a mysid layer in deeper water will likely prevent assessment of smaller zooplankton in deep water. Although routine use of acoustics to estimate mysids abundance and whole lake distribution are within reach, similar use for smaller zooplankton will require additional development and possibly the use of higher frequencies. We are looking at 430kHz as a potential additional frequency to add to 120kHz for routine sampling. Up to 10 frequencies are sometimes used in marine applications, but not presently during routine surveys. Multifrequency responses are sometimes surprising as small animals may be resonating at intermediate frequencies (Knudsen et al. in press). More work is required on the response of Great Lakes zooplankton to different frequencies before such systems can be used for monitoring.

An alternative to acoustic surveys is to deploy automated buoys. Rudstam, Bove (Univ Buffalo) and Kremer (Rochester Institute of Technology) have applied for funding to test this concept using inexpensive fish finder and data transfer systems developed at RIT. Because they are potentially relatively inexpensive ($5000 per buoy), several of these sampling stations can be deployed. However, use of such units requires funds for maintenance of the buoy and equipment, and ship time is costly. Automated systems using more expensive equipment including Acoustic Doppler Current Profilers (ADCP) have been used in the Great Lakes and yield information on mysids migration patterns (Miller 2003) and show promise also for smaller zooplankton (Lorke et al. 2004). They have been used for some time in the marine systems (Flagg and Smith 1989).

Stable Isotopes (contributed by Ora Johannsson, Department of Fisheries and Oceans Canada)

Application and Background:

- stable isotopic signatures ($\delta^{15}N$ and $\delta^{13}C$) of organisms are used in food web studies to determine the relative source of energy (nearshore versus offshore: $\delta^{13}C$) and the trophic structure of the food web ($\delta^{15}N$).
- The ability to use isotopes to infer these properties is based on the fractionation of isotopes of carbon and nitrogen during photosynthesis and of nitrogen during assimilation and excretion. The fractionation of carbon within the food chain is slight and animals reflect the base carbon source of their food.
- Fractionation depends on the pool-size of the carbon or nitrogen source (is it limiting), and the selectivities of the enzyme systems. Thus fractionation can be affected by temperature (concentration of CO_2 in water, rates of diffusion, and enzyme reaction rates), pH of the medium (speciation of CO_2), and physical restrictions on diffusion and enzyme concentrations.
- The higher $\delta^{13}C$ of carbon in nearshore areas is due to allochthanous inputs from terrestrial, emergent and surface-leafed submergent plants which obtain their CO_2 from the air. These systems have a higher fractionation of carbon during photosynthesis than do aquatic and marine plants and algae which obtain their CO_2 from HCO_3^- dissolved in the water. Most aquatic plants have some membrane-bound pumps for dissolved inorganic carbons (DIC) to help transfer HCO_3^- into the cells. In more acid waters, dissolved CO^2 becomes more abundant and some algae can utilize this source. In this situation, carbon fractionation by photosynthesis is similar to that in terrestrial plants.
- The nitrogen isotopic signature at the base of the food chain is seasonally variable and can change across sites and years depending on the sources of nitrogen (sewage, atmospheric, decomposed organic matter). The base sources of nitrogen are N_2, NO_3, NO_2, NH_3, and NH_4^+. These tend toward equilibrium concentrations depending on pH, and the supply and removal of nitrogen from the system, but in some instances there is a fractionation cost. For instance, there is a -19‰ equilibrium fractionation in the conversion between NH_3 and NH_4^+. Fractionations of 0‰ to -20‰ occur with the assimilation by algae of NH_4^+ and of 0‰ to -24‰ with the assimilation of NH_3.
- Once incorporated at the base of the food web, nitrogen fractionates at each step up the food chain by 2‰ to 4‰ on average. Therefore, $\delta^{15}N$ reflects the relative trophic position of organisms within the food web.
- Stable isotope analysis can be combined with gut content analysis to estimate the roles of different prey in the diet of specific species or to try to ground truth a food web model.

Current sampling. There was a major study of the carbon and nitrogen stable isotope patterns in Lake Ontario in the mid-1990s by Dr. Michael Leggett (Ph. D. thesis) which resulted in a number of definitive publications on the signatures of geochemical sources, seasonal and spatial patterns in sources and the base components of the food web, food web structure up to and including fish, and spatial patterns in some fish species (Leggett et al. 1999, 2000; Johannsson et al. 2001). The data on fish still need to be published but can be found in his thesis.

The work by Mike Leggett can be considered a baseline against which change in the food web due to management actions or unexpected events, such as the invasion of a new species, can be compared. He looked at conditions in the offshore (28 km south of Cobourg, ON) and in the centre of the Kingston Basin. At that time, impacts of exotics were not felt in the offshore and phosphorus concentrations had been stable since 1987, the end of the decline due to phosphorus management. In the Kingston Basin, some effects of dreissenids were beginning to be seen at that time: phosphorus concentrations and diatom biomass had started to decline.

Mark Teece and Kim Schulz (SUNY College of Environmental Science and Forestry) have extensive isotope data for benthos, seston, zooplankton (by species), alewife, and smelt for 2002 and 2003. Analyses of these data will be presented in two forthcoming manuscripts.

Cost of SI. Work on SI can be labor intensive and for that reason can be expensive. If the samples are prepared by the researcher, then the University of Waterloo charges about $12/sample for carbon and nitrogen analyses for members of the university. Samples need to be collected, sorted to component (zooplankton/phytoplankton size or functional groups: muscle of fish etc), frozen, dried, pulverized, weighed, and submitted for analysis. Number of samples will depend on the question and group analyzed. It is essential to monitor a baseline consistently in all years so that differences in trophic position can be corrected when making comparisons with past data.

Monitoring tool. A baseline is essential and should be based on annual sampling of a generalist feeding herbivore. One might propose dreissenids on offshore buoys for the offshore pelagia, and dreissenids on the bottom for both the offshore benthic and nearshore. Depending on what is meant by nearshore, one should collect samples from around the lake to characterize the nearshore as the nutrient sources at the base of the food chain will vary around the lake. The first assessment might be extensive and then reduced depending on the results of the initial survey. If one were looking at dreissenids then one would want to sample them in fall and to be selecting for young of the year that settled in the first batch of reproduction to maximize the signature for that year and eliminate signatures carried over from previous years.

If one were rich and wanted to monitor key organisms in the food web to keep an eye on food web shifts and the potential impact of stressors, then one should determine which are the key management species. In Lake Ontario, lake trout and white fish are two species which come to mind, but others such as walleye might be considered important locally.

Otherwise, one should do stable isotope studies when regular monitoring suggests that the system might be changing due to new or additional stresses. These considerations should guide a targeted survey. The organisms to measure in a targeted survey would depend on the trends observed in the lake in community composition and biomass and any hypotheses of how present stresses may have been altering the system. If the targeted survey indicates significant changes than a follow up survey can assess how these changes emanate through the food web.

All questions of spatial coverage, age of organism, etc will be determined by the questions being asked. Sample sizes are usually small (3-5) as stable isotopes integrate over groups of prey organisms (i.e. herbivores, predatory cladocerans) and time. If the targeted species tends to include animals that specialize on different types of dietary groups then one needs to increase the sample size.

Buoy Systems (contributed by Jim Watkins, Cornell Biological Field Station)

Application. Buoys are remote environmental observatories capable of providing real-time observations of chemical, biological, and physical parameters, even during extreme weather events. Data can be transmitted wirelessly from buoys to stations on shore, so that boats are only necessary for routine maintenance.

Current status. Planning new buoy monitoring systems in the Great Lakes falls under the jurisdiction of the Great Lakes Observing System (GLOS) program. This program is a regional branch of the Integrated Ocean Observing System (IOOS), a primary source for observation system research funds. The NOAA Great Lakes Environmental Research Laboratory (GLERL) is leading the development of a buoy observation network. Currently they have started demonstration projects using three buoys in Lake Erie in collaboration with the International Field Years on Lake Erie (IFYLE). There are also projects on Lake Huron at the Thunder Bay National Marine Sanctuary and on Lake Michigan collaborating with University of Wisconsin-Milwaukee.

These demonstration projects have considerably advanced buoy technology, sensor capability and communication. Design improvements have made buoys stronger, more stable, easier to maintain, and better able to run on solar power. Sensors for temperature, oxygen, chlorophyll a, PAR, turbidity, conductivity and currents (ADCP) have been tested successfully.
Data including high resolution images have been successfully relayed from buoys to shore based stations using wireless technology. None of these projects have been tested very far from shore.

There are currently no long-term buoys on Lake Ontario with profiling capability. Environment Canada maintains meteorological buoys at Grimsby, West Lake Ontario, 16 Mile Creek, and Prince Edward Point. NOAA has a meteorological buoy 20 nm NNE of Rochester NY. These stations measure surface water temperature, wind speed and direction, and wave height. The National Water Research Institute (NWRI) of Canada has a field program which set up seasonal transects of current meter and thermistor moorings offshore of Toronto (Yerubandi Rao).

Costs. Buoy costs can easily exceed $300,000 per buoy (with instruments installed for profiling capability). Another configuration includes a "base station" buoy ($500,000) surrounded by lower cost buoys ($50,000). Data processing and buoy maintenance are not included. Existing National Data Buoy Center (NDBC) meteorological buoys cost $165,000 for the first year of operation (including purchase, installation, and equipment) and $36,000 per year to operate and maintain.

Using buoys as monitoring tools. GLOS intends to improve existing buoys and deploy 3-4 new ones per lake over the 2007-2011 time period. IOOS intends to provide funding to support Great Lakes open water observing starting in 2007 on a seven year timeline. It is not currently clear when or where the buoys for Lake Ontario would be.

Key questions are-

- -where would the buoys be?
- -which institution(s) would provide support as collaborator with GLERL?
  - -maintenance
  - -data download processing
  - -scientific goals
- -what sensors would be included?

A buoy workshop (Future of Open Water Observation Technology for Great Lakes Research) in 2004 developed a sensor wish list. These include

- physical
  - -meteorological data
  - -temperature loggers
  - -acoustic doppler current profilers (ADCP)
  - -pressure
- chemical
  - -nutrients by sensor or flow injection analyzers
  - -dissolved oxygen
  - -carbon dioxide
  - -contaminants
- biological
  - -light and turbidity
  - -fluorometry for chl a and DOC
  - -time series sediment traps
  - -benthic habitat mapping
  - -multifrequency acoustics for fish and zooplankton

Fluorometry (contributed by Michael Twiss, Clarkson University)

Application. Traditional methods to establish the health of a phytoplankton community require intensive water sampling efforts and labor-intensive sample analysis (phytoplankton identification, pigment analysis) and experimentation , e.g. use of light:dark dissolved oxygen method or radioactive carbon method to measure gross photosynthesis (Ostrom et al. 2005), and techniques establish photosynthetic efficiency. Recent advances in fluorometry enable aquatic scientists to establish qualitative and quantitative assessments of phytoplankton community composition (Gregor and Maršálek 2004) and photosynthesis (Smyth et al. 2004) in situ. The Great Rivers Center at Clarkson University possesses several instruments that are able to assess to map phytoplankton community composition and health of the community.

Instrument/Platform	Description	Endpoint/Purpose
FluoroProbe, (bbe Moldaenke GmbH, Series 7)	Submersible fluorometer that uses several excitation wavelengths of light to simultaneously detect algal and cyanobacterial pigments	• Phytoplankton division pigment concentrations • Water temperature • Depth
Fast Repetition Rate Fluorometer (FRRF; Chelsea Instruments, Mk I)	Submersible fluorometer that uses light utilization by photosynthetic apparatus in phytoplankton	• Photosynthetic efficiency • Photosynthetically Active Radiation (PAR) • Primary productivity (photosynthesis)
Flow cytometer (Guava Tech., model PCA)	Analytical flow cytometer (to be purchased)	• Measure size and count phytoplankton and bacteria
Field fluorometer, (Turner Designs, model 10-AU)	Ruggedized instrument with flow-through cell	• Colored Dissolved Organic Matter (CDOM)
Field computer (Panasonic, CF-29)	Fully ruggedized computer	• Integrates water quality data from sensors with geographic positioning
R/V *Lavinia*	25' Boston Whaler-Challenger, 2 × 150 HP, DGPS, 25 mile radar, marine radio, navigational software	• Stable research platform for coastal transects

Present sampling strategies. Two sampling methods can be employed: (i) vertical sampling at fixed stations using FRRF and FluoroProbe, and (ii) horizontal sampling uses a towed fish at depth, trace metal clean pumping system, and Ferrybox with in line sampling (in a laminar flow hood) for discrete sampling. The Ferrybox is a 9 L chamber in which water collected during underway sampling is collected, and passed though the fluorometers. Data are collected at 3-30 seconds intervals. Spatial resolution is 0.5 km at a hull speed of 12 knots.

Equipment costs: FluoroProbe, $35k; FRRF Mk I, $60k; flow cytometer, $40k; 10-AU, $20k; CF-29, $5k. Operating costs are limited to replacement of sampling tubing, laminar flow hoods, ancillary chemical measurements, and cartridge filters.

Ship time requirements: We have used the R/V *Lake Guardian* and CCGS *Limnos* platforms on three lake wide transects in Lake Erie in 2005. A speed of 12 knots allows sampling at 1 m depth; slower speeds will provide greater depth. An ideal sampling depth for the epilimnion would be 5 m.

R/V *Lavinia*: surface (0.4 m depth) sampling is possible at 20 knots. Vertical profiling is feasible (100 m cable with FluoroProbe; autonomous sampling using FRRF); a heavier winch on the davit would be required.

Sampling efforts to assess phytoplankton community composition and health:
- Minimum: summer pelagic survey of the USEPA GLNPO, plus seasonal nearshore to offshore (40 km) transects.
- Maximum: seasonal pelagic surveys, multiple nearshore to offshore transects, routine station survey, coordinated with remote sensing (aircraft and satellite imaging).

Goundtruthing exercises. Two research cruises (June, September) were conducted on Lake Erie during 2005, as part of the International Field Year (IFYLE) – Lake Erie program. During these cruises, satellite imagery was collected and information of water quality was determined by G. Leshkevitch (NOAA GLERL). In July 2005, surface water transects were conducted in fluvial Lake St. Lawrence in conjunction with a fly-over by aircraft borne hyperspectral instruments. This information was collected in collaboration with A. Vodacek (RIT). Exercises in 2005 wait processing of data using light extinction parameters measured during each exercise.

Investigative survey scheme for Lake Ontario. This array of instruments will allow investigative mapping exercises to be conducted. These maps will increase our ability to visualize spatial and temporal changes in phytoplankton communities. Such investigative mapping will allow the detection of the onset and movement of phytoplankton blooms, including harmful algal blooms (HABS). In conjunction with measurements of physical (e.g. light penetration, thermal profile of the water column, currents), chemical (e.g. water color, nutrients), and biological (e.g. zooplankton community, bacteria, viruses) parameters, this information can be used to decipher the dominant forces affecting phytoplankton community structures, health and productivity.

Full potential of this instrumentation can be realized from the use of a large stable platform (ship) on fixed transects and in a mode that will allow identified features, such as the apparent peak in cyanobacteria in the west basin of Lake Erie (Fig. 1), to be followed or sampled at a higher degree of spatial resolution. A robust coastal vessel such as the R/V *Lavinia* can provide a low cost supplement for coastal transects.

Seasonal lake-wide surveys are needed to assess seasonal changes on phytoplankton, sources of cyanobacterial blooms, and functional changes in community composition and health.

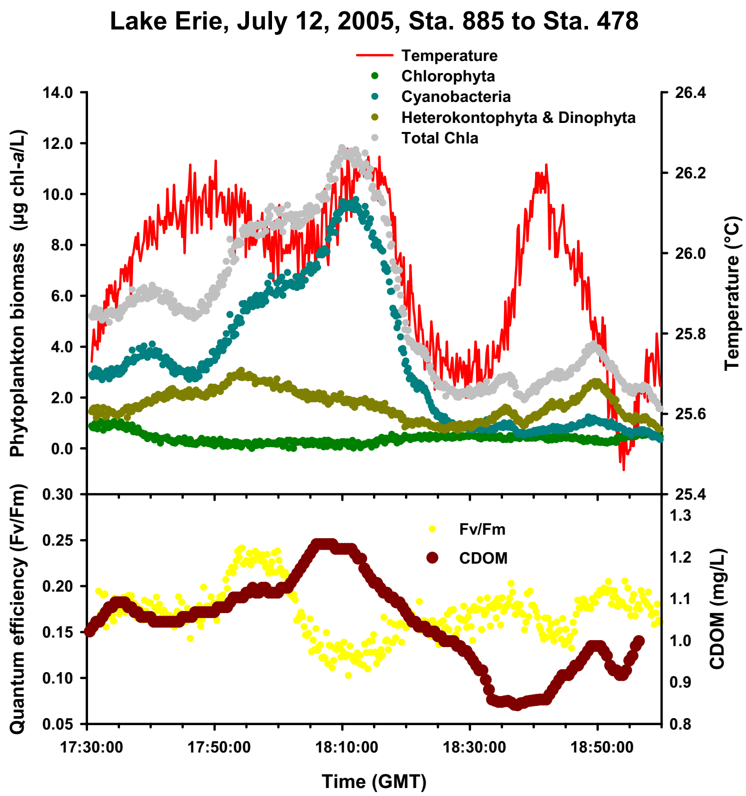


Figure 1. Phytoplankton community composition, photosynthetic health, and water color along a 27.3 km transect that was sampled continuously from a depth of 1 m onboard the CCGS Limnos. The transect began offshore of Sandusky Bay (41° 31.156 N, 82° 38.884) to offshore of Put-in-Bay, South Bass Island (41° 39.578 N, 82° 48.993).

FlowCAM II Fluid Imaging System (contributed by Mohi Munawar, Department of Fisheries and Oceans Canada)

The microbial and planktonic food web in aquatic ecosystems can be assessed using state-of-the-art FlowCAM II fluid imaging system. The FlowCAM combines flow cytometry, microscopy, and imaging techniques to provide rapid imaging and recording of micro-particles in a fluid stream (Fig. 1). This emerging technology should be tested and evaluated against standard microscopic techniques for the enumeration of phytoplankton and microbial food web components. This new technique has considerable potential in the planktonic surveys in the Great Lakes and would be an excellent tool to add to the battery of emerging techniques recommended for Lake Ontario and other Great Lakes.

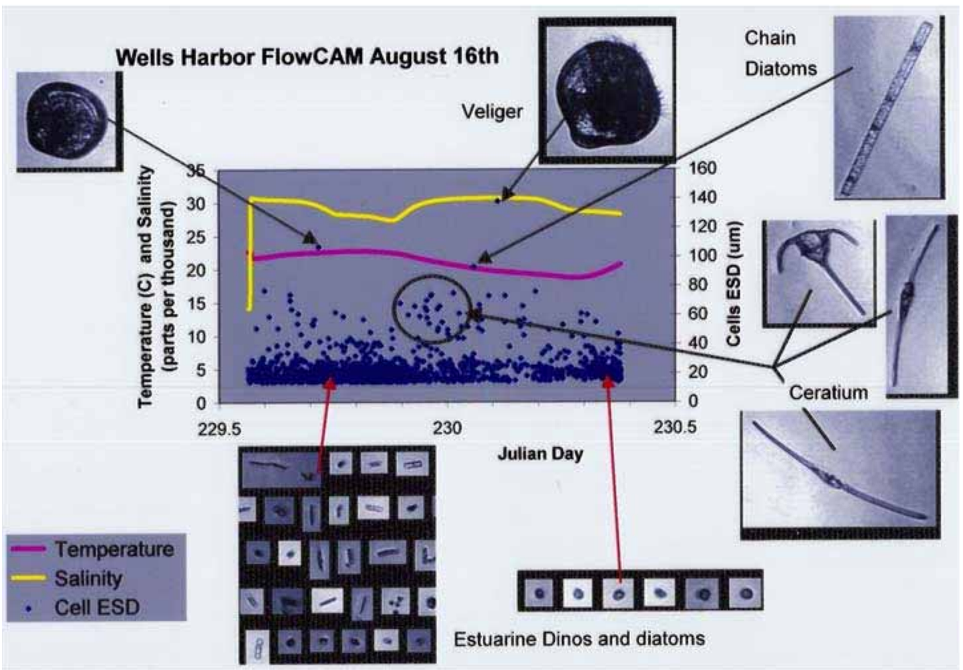


Figure 1. An example of application of FlowCAM in Wells Harbor.

Remote Sensing (contributed by Ricky Becker, Western Michigan University)

Application. Remote sensing technology can provide lake-wide coverage of surface temperature, lake color (chlorophyll), and whiting (calcium carbonate precipitation) events. Satellite imagery provides a temperature regime context for LOLA 2003 sampling (see images at bottom of page).

Present status. There are a suite of satellite sensors which provide data for Lake Ontario on a daily or more frequent basis. These include: the MODIS instrument on the Aqua and Terra platforms, the SeaWiFS sensor on the Orbview -2 platform, the NOAA AVHRR sensor on POES (polar orbiting), imager on GOES (geostationary) satellites, and TMI on the TRMM platform. All of these have a resolution of 1km^2 pixels, or larger. In addition to these, Landsat TM/ETM has a much higher spatial resolution (30m pixel spacing), but only a 14 day repeat cycle, and cannot cover the entire lake at one time. The ESA sensor MERIS also has good potential for being used for ocean color parameters, as it has 300m pixels, and improved spectral resolution.

Visible – near infra-red sensors (used for ocean color parameters) include: MODIS on Aqua and Terra - these images are available once per day for each satellite, and SeaWifs – available once per day. MODIS and SeaWifs have a nominal resolution of 1km^2 at full resolution.

Thermal data sets (for SST) include: Aqua and Terra (2 times each per day total), AVHRR (roughly 8 times per day), GOES imager (every 3 hours), and TMI is available once per day. These products have spatial resolutions ranging from 1km to 6km on a side.

Most of these datasets are available at no cost shortly after acquisition from the NASA Oceancolor website: http://oceancolor.gsfc.nasa.gov and NOAA Coastwatch website: http://coastwatch.noaa.gov. Delayed-mode, low resolution SeaWiFS data is available through the NASA oceancolor website to authorized users, as well as historical full resolution data (pre Dec. 2004). Full resolution data can be acquired through separate agreements with Orbview. MERIS data is only obtainable through the ESA, as part of a cat-1 proposal through their website: http://eopi.esa.int/esa/esa.

Cloud cover can obscure a significant portion of or all data for indefinite periods (frequently 1-7 days).

NASA and the NOAA Coast Watch have developed software programs such as CDAT for displaying coast watch images and SeaDAS for displaying and analyzing MODIS and SEAWIFS temperature and color data. These programs are free and available on the web. Cruise data can be compared to satellite data easily using SeaDAS for both temperature and chlorophyll *a*.

Groundtruthing. Surface temperature images are accurate to 1.5^{o}C RMS, with a bias ranging from 0.2 to 1.0^{o}C (Li et al. 2001; Schwab et al. 1999). Upwelling events, thermal bars, and stratification are clear features. The thermal bar's influence on nearshore/offshore chlorophyll *a* gradients is evident in lake color.

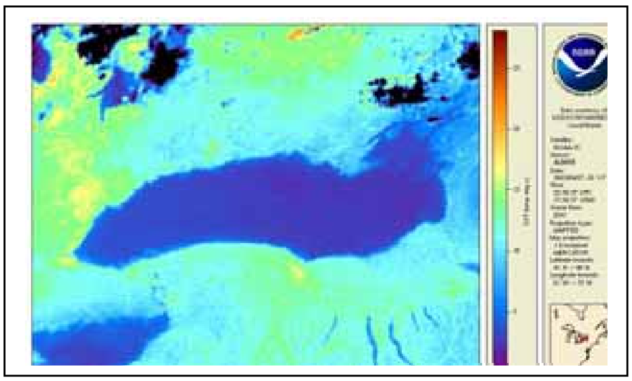
The standard chlorophyll *a* algorithms used for MODIS and SeaWiFS data were derived from, and works well for non-polar Case I (open ocean) waters (Gregg and Casey, 2004; O'Reilly et al., 1998). They are still very useful in showing chlorophyll distribution, but are less accurate when used for the more optically complex Case II (inland and coastal waters), where they tend to overestimate the concentration of chlorophyll *a* in areas dominated by inorganic sediments (Lavender et al., 2004). Several models have been used to overcome this for case II waters. These include an algorithm developed by Carder et. al. included in SeaDAS (Carder et al., 1999). This semi-analytic model has been found to improve the accuracy of estimates of the chlorophyll *a* concentrations in Lake Erie and Lake Ontario based on a limited data set acquired in the summer of 2004 (Becker et al., 2005). This is currently being expanded to include data acquired from cruises in 2005. In addition, a bio-optical model has been developed specifically for Lake Ontario (Bukata et al., 1991; Bukata et al., 2001), and compares favorably with the in-situ data.

Potential expansion:

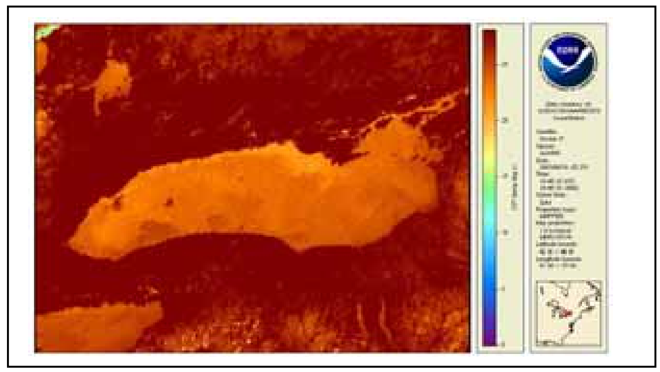
How do we incorporate this technology into a real time monitoring system?
We can design a web based GIS interface (ArcIMS or an open standard interface)
-images to provide context
-updated automatically from NASA, NOAA ftp data pulls
-links to station data
-ability to extract data either spatially or temporally
add calculated indices such as
-average lake wide temperature
-average lake wide chlorophyll *a*
-make line graphs of these parameters over season
-upwelling indices (areal coverage)
-whiting alerts
-harmful algal bloom alerts

<u>Context for LOLA - satellite imagery</u>. The spring cruise on the *Limnos* was from April 28 to April 30, 2003. At this time there was little surface temperature variability, and the water column was completely mixed. The lake was isothermal until June 1, when a thermal bar formed (warming and stratification nearshore) and was maintained for the month of June. Upwelling developed on the NW coast during the entire month of July, but a warm lake-wide epilimnion was set up by August 1. The summer Lake Guardian cruise in western Lake Ontario was August 10-11. The summer *Limnos* cruise was August 19-21. The stable epilimnion was existent throughout this period. The fall *Lake Guardian* cruise was September 19-26. By August 27 upwelling had developed on the NW coast from strong winds from the west. By September 9, the winds had shifted to coming from the east and localized upwelling developed on the south coast. On September 18-20, the passage of a storm system related to Hurricane Isabel passed over the Great Lakes. On September 19, sustained winds of 65 km/hr with gusts to 80 km/hr were reported. This wind event intensified upwelling on the south shore.

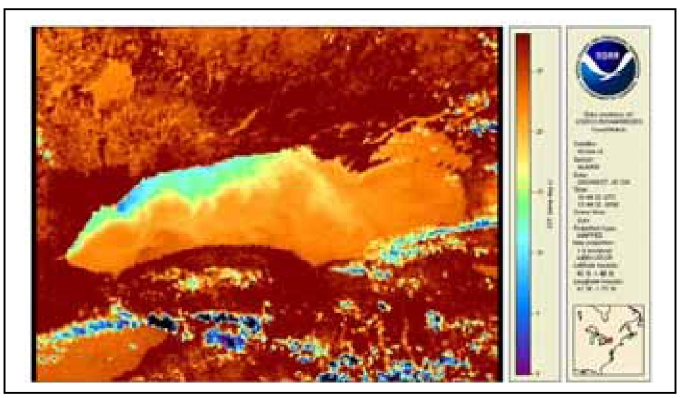
April 27, 2003



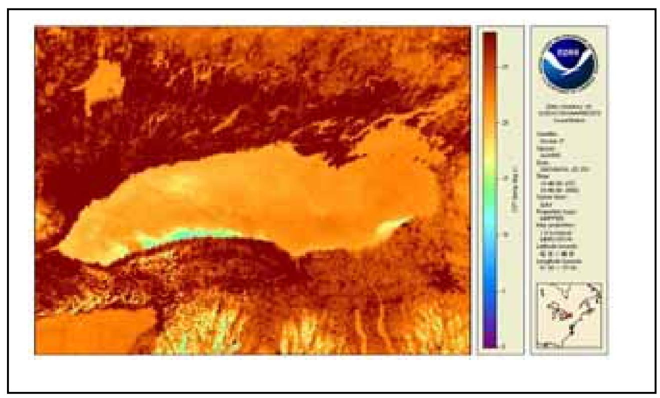
August 18, 2003



August 27, 2003

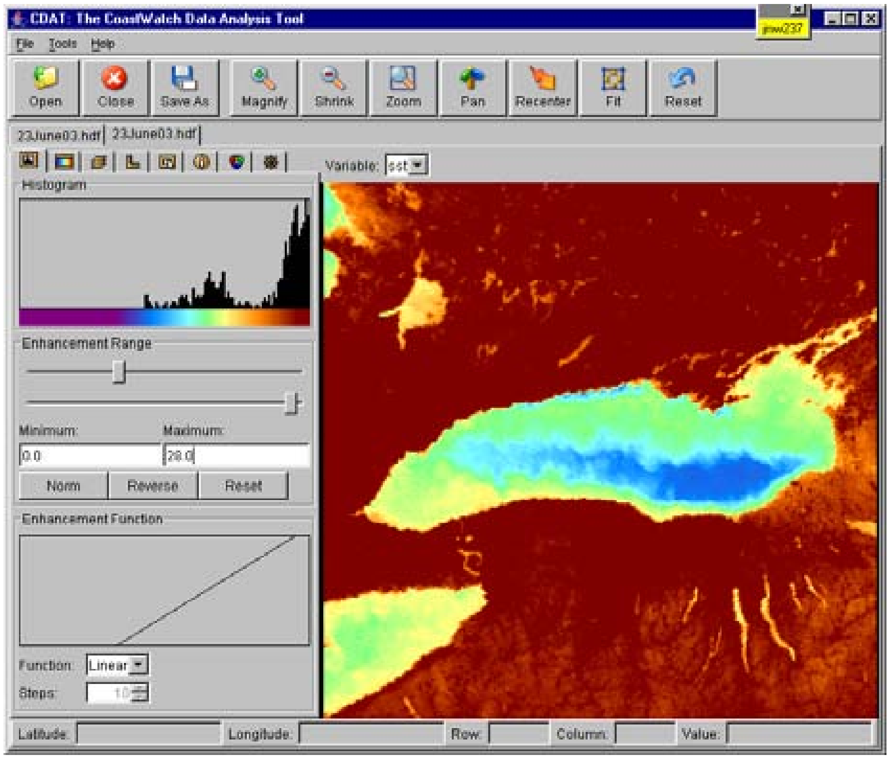


September 10, 2003



September 20, 2003 Hurricane Isabel passage

These images were produced using CDAT 3.1.9 (see below) software available from the Coastwatch program. It is only usable for temperature images and has limited potential for comparison to cruise data. The NASA Ocean Color Page has another free software package called SeaDas that is extremely useful and easy for comparison of temperature and color images to temperature and chl a data from cruises.

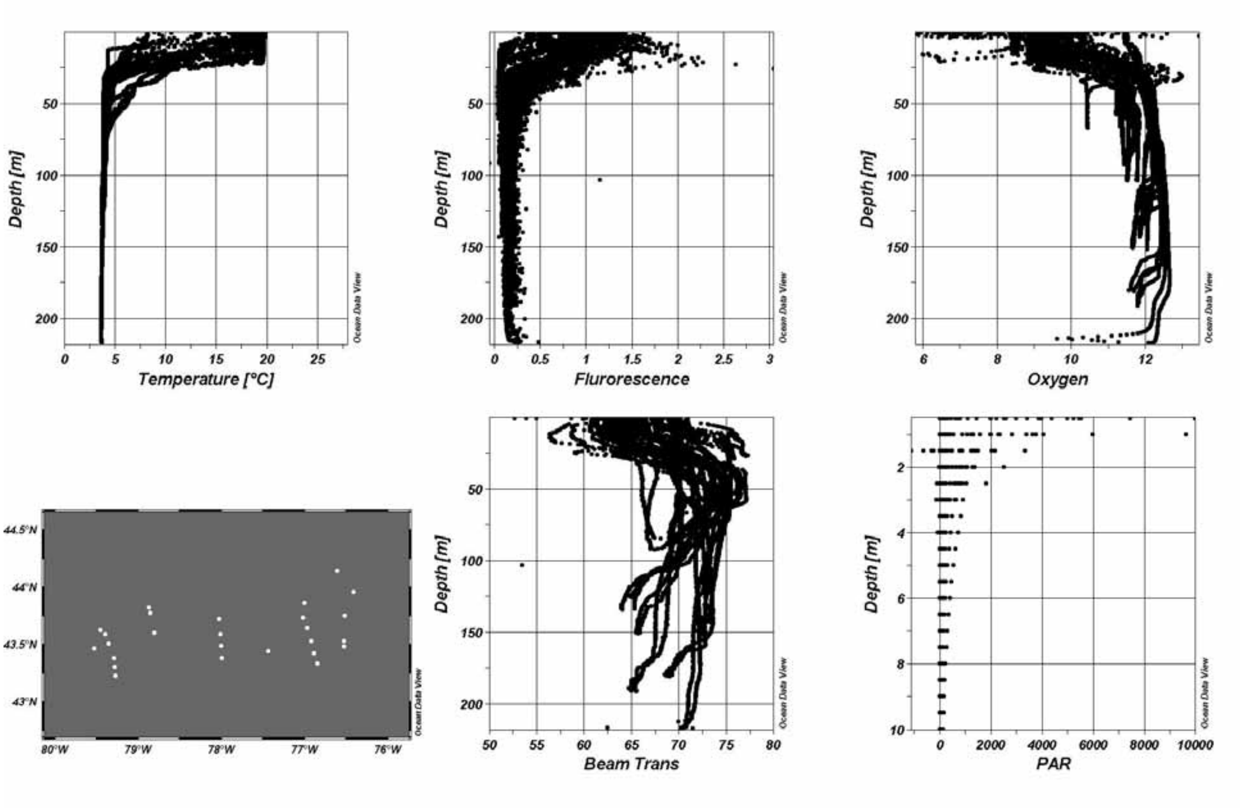


<u>Hydrography</u> (contributed by Jim Watkins, Cornell Biological Field Station)

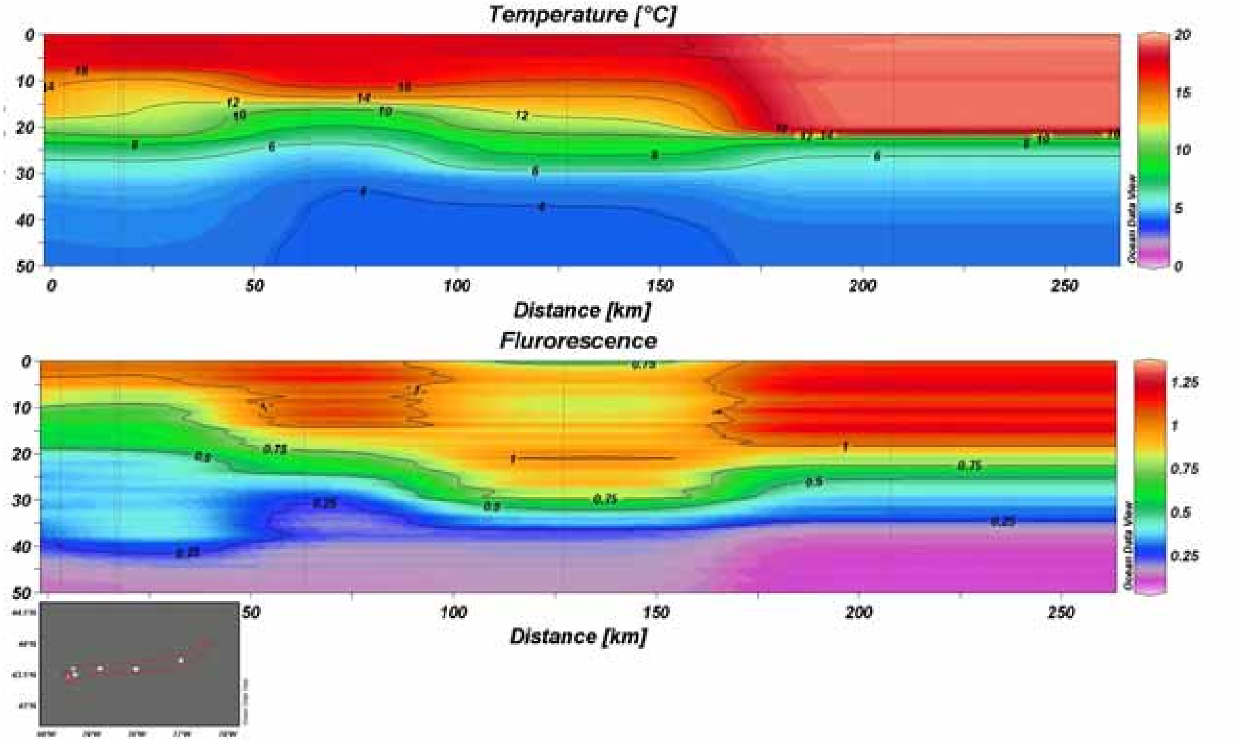
The EPA *Lake Guardian* has collected hundreds of hydrographical profiles in the Great Lakes over the past 10 years. These include data for temperature, fluorescence, oxygen, light transmittance (particle concentration), ph, conductivity, and PAR. This data collection has the potential to reveal a considerable amount on the status of Lake Ontario. It could potentially document subtle changes (e.g. changes of water temperature <1C is often significant) over time to pinpoint effects of climate change or oligotrophication. There is a need to access this information in an easy, interactive platform.

We have such data for the entire lake in September and only western Lake Ontario for August 10-11. The April and August cruises on the Limnos only have temperature data. We have put this data (and an EPA data set from 1994) into a data viewing software named Ocean Data View. This freely distributed software program is a good way to organize and plot hydrography data. Its usefulness includes property-property plots and sections. Below is an example of two hydrography sections from the September, 2003 cruise, one N-S transect and an E-W section across transects. Parameters can be easily plotted with custom ranges.

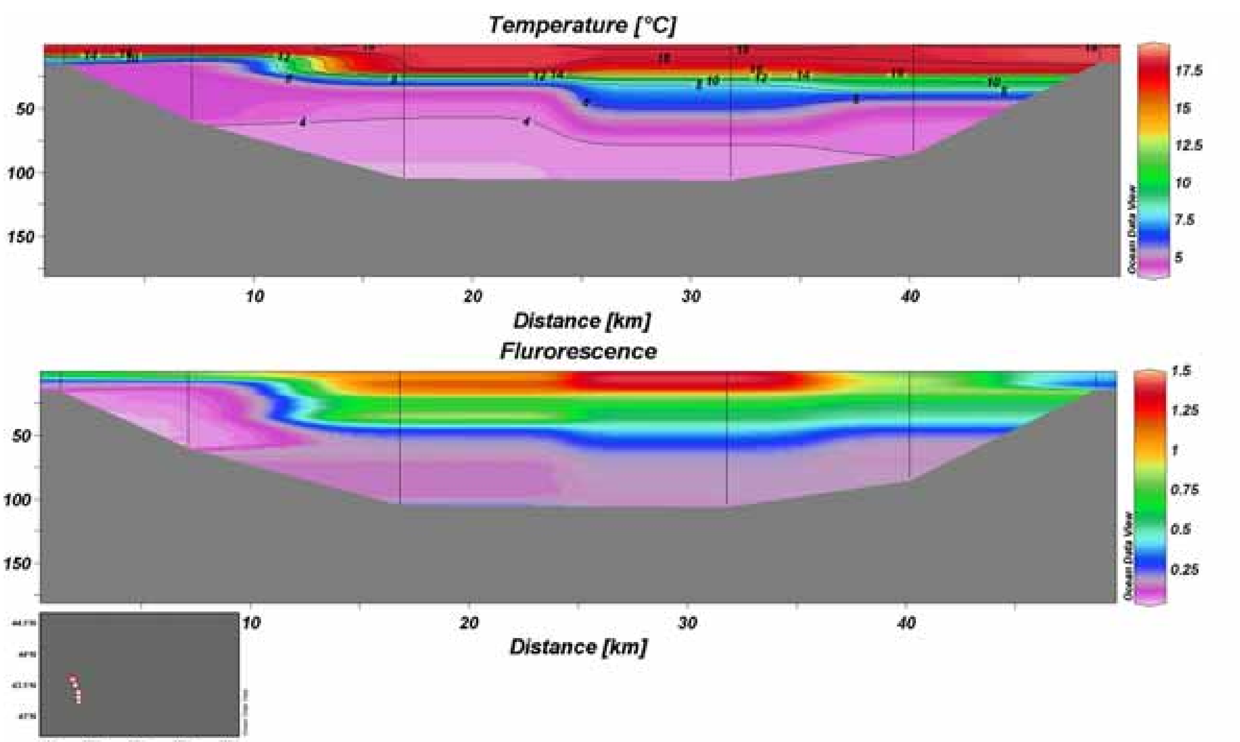
__Scatter Plots of all the September 2003 Profiles__



E-W Section Across All transects



Far West Transect



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