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Bottom Currents At The Stoney Creek Reef, Lake Ontario, 1999

By:
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BOTTOM CURRENTS AT THE STONEY CREEK REEF, LAKE ONTARIO, 1999

Michael Skafel

Management Perspective

Improved knowledge of flow conditions at lake trout spawning sites will contribute to sustainable fishery management strategies in the Great Lakes through the development of more realistic exposure systems in the lab for testing the influence of flow factors on shock sensitivity of eggs.

High egg mortality occurs even over fetches as short as 75 km suggesting that sensitivity to stresses caused by large bottom currents may be a major factor limiting lake trout restoration and limiting the habitat in which spawning might be successful.

This report represents the second data set of wave induced currents obtained at a site in Lake Ontario. The data will be provided to DFO, to be integrated with the mortality data and correlations sought. Further data collection may be indicated.

Courants de fond au récif de Stoney Creek, lac Ontario, 1999

Michael Skafel

Sommaire à l'intention de la direction

Une meilleure connaissance des conditions de flux d'un lieu de fraye de touladis sera utile pour les stratégies de gestion des pêches durables dans les Grands Lacs en permettant le développement de systèmes d'exposition en laboratoire à conditions plus réalistes, pour vérifier l'effet de facteurs liés au flux sur la sensibilité aux chocs des oeufs.

Une forte mortalité des œufs, observée même sur des zones de génération de vagues de seulement 75 km, semble indiquer que la sensibilité aux stress causés par les grands courants de fond peut être un important facteur limitant le rétablissement des touladis, ainsi que l'habitat dans lequel le frai peut donner un bon rendement.

Ce rapport présente les résultats du deuxième ensemble de données sur les courants causés par les vagues à un site du lac Ontario. Elles seront envoyées au MPO, qui doit les intégrer aux données sur la mortalité et rechercher des corrélations. D'autres collectes de données pourraient être nécessaires.

ABSTRACT

Mortality of Lake Ontario lake trout eggs appears to have a higher sensitivity to physical shock than other stocks in laboratory tests. How these differences relate to survival in the wild is unclear. Bottom currents are one factor that may induce shock causing egg mortality. These currents were monitored at a lake trout spawning reef off Stoney Creek in Lake Ontario from September to December, 1999 to determine the duration and magnitude of high currents that could lead to physical shock. The reef is relatively flat topped, narrow, oriented approximately north-east south-west and about 2 hectares in aerial extent, with an average lakeward slope of about 1:40. The surficial material is cobble and boulder sized. The site is exposed to the full force of north-easterly storms, common in the fall and winter months, when eggs are incubating. Mean currents and storm induced oscillatory flow are documented, and wave conditions inferred from the current data. The expected interstitial flows induced by the bottom currents are explored using a numerical model.

Résumé

Lors d'essais en laboratoire, la mortalité d'oeufs de touladi du lac Ontario semblait présenter une plus grande sensibilité aux chocs physiques que celle d'autres stocks. On n'a pu établir clairement les rapports entre ces différences et la survie de l'espèce dans la nature. Les courants de fond sont l'un des facteurs qui pourraient provoquer un choc causant la mortalité des oeufs. De septembre à décembre 1999, on a surveillé des courants sur le site d'un récif du lac Ontario utilisé comme lieu de fraye par les touladis, près de Stoney Creek, afin de déterminer la durée et l'importance des forts courants pouvant causer un choc physique. Ce récif à sommet relativement plat est étroit et orienté approximativent du nord-est au sud-ouest; sa superficie est d'environ 2 hectares, et sa pente moyenne en direction du lac est d'environ 1:40. Les matériaux qui le recouvrent vont de la taille des cailloux à celle des blocs de roche. Ce site est exposé à la pleine force des tempêtes du nord-est, qui sont courantes en automne et en hiver, pendant l'incubation des oeufs. On a documenté les courants moyens et les flux oscillants causés par les tempêtes, et on peut déduire les conditions des vagues à partir des données courantométriques. On étudie, à l'aide d'un modèle numérique, les flux interstitiels prévus provoqués par les courants de fond.

BOTTOM CURRENTS AT THE STONEY CREEK REEF, LAKE ONTARIO, 1999

by

M G Skafel

1.0 INTRODUCTION

Restoration of lake trout (*Salvelinus namaycush*) in the Great Lakes has been successful in establishing populations of adult fish. On the other hand, reproduction in the wild has not been successful except in Lake Superior. At present mortality of Lake Ontario lake trout eggs appears to be higher than that of other stocks although the factors responsible are not clear. Mortality has been correlated with fetch, and even over fetches as short as 75 km, was 80% prior to hatch (Fitzsimons, 1995), suggesting that shock sensitivity may be a major factor limiting lake trout restoration. Shock sensitivity of lake trout eggs from Lakes Erie and Ontario was found to be elevated over that of a control stock (Fitzsimons, 1994). Consequently, the habitat that would support successful spawning could be reduced considerably from what it was historically.

The current monitoring program initiated in 1998 (Skafel and Fitzsimons, 1999) was continued in 1999 as a precursor to developing more realistic exposure models in the laboratory for testing the influence of factors that may lead to physical shock of eggs. The reef off Stoney Creek in Lake Ontario has been monitored for a number of years to determine patterns of egg deposition and mortality of lake trout eggs. The reef is exposed to nearly the full length of Lake Ontario during typical fall and winter storms with winds out of the north-east and east (Figure 1). The reef is approximately 3 km offshore and the depth on the relatively flat top ranges from 9 to 10 m (Figure 2). The aerial extent of the flat top is about 2 hectares, but the spawning area is limited to about one fifth of that. The spawning area is defined by Fitzsimons (1995) to be a 2 m strip, with suitable surficial material, along the top of the slope. The mean lakeward slope drops off at about 1:40 to about 15 m, thereafter the general lake bottom drops off at about 1:300, in a northerly direction. Incubators have been deployed at the site in several previous years, and used to explore the mortality of the eggs through the incubation period. The deployment in the autumn of 1999 provided the second opportunity to make concurrent bottom flow measurements.

2.0 INSTRUMENTATION

A three axis acoustic Doppler current meter, with pressure transducer and temperature sensor (SonTek Hydra) was deployed on the top of the reef from 9 September (Julian day 252) to 9 December 1999 (Julian day 343). The water depth was steady at about 9 m. The current meter was programmed to sample in bursts every three hours. Data from each record consisted of 2560 scans of the three velocity components (east, north and up) sampled at 4 Hz, along with mean temperature and pressure. The meter was oriented to be upward looking, so that the measurement volume was 0.6 m above the lake bottom, at 8.4 m below the surface.

3.0 DATA

3.1 Meteorology

Wind speed and direction were monitored by NWRI at a site on the lakeward side of the Burlington Ship Canal. All wind events important for this study are onshore at this site, so that there is no influence of the bridge and buildings to the southwest of the station. The wind rose (plotted as direction <u>to</u>, rather than direction from, for easier comparison to the current data) is shown in Figure 3. Most of the winds are either offshore or from the short northwest fetch. Nevertheless, there are occurrences of higher wind speeds onshore (to the S through to the W). This is explored in Figure 4 where winds greater than 6 m/s coming from 337.5° through to 112.5° (NNW to ESE) are marked with an asterisk. This direction range includes all winds that would produce significant wave events at the spawning reef. There were 140 ten minute averages that met these criteria, amounting to 1% of the time.

3.2 Mean Bottom Conditions

The mean bottom water temperature on the reef is plotted in Figure 5a. Two major short duration upwelling events occurred, on Julian day (JD) 268 (25 September) and JD 286 (13 October). The temperature was relatively steady just under 10°C from JD 290 (17 October) to JD 307 (3 November). Thereafter it dropped rapidly, reaching near 5°C on JD313 (9 November). The corresponding mean bottom currents are shown in Figure 5b. The largest mean flows, over 0.3 m/s, occurred on Julian day 307 (3 November), the same day the water temperature dropped to around 5° C and remained there. These flows were similar in magnitude to the largest wave induced flows, which occurred on day 315 (sec. 3.4). Flow events after this date had speeds less than half this value.

The current rose for the means of each burst of data from the current meter are shown in Figure 6 (the directions are 'towards'). The mean currents are predominately shore parallel, southeasterly, and easterly and so cut across the bottom contours on the reef, which are aligned nearly SW-NE. They mirror to some extent the winds. Most of the time the currents are modest, 0.05 to 0.10 m/s, but 12.4% of the measurements were between 0.10 to 0.20 and 0.7% between 0.20 to 0.50 m/s.

3.3 Wave Component of Bottom Currents

3.3.1 Measured Bottom Velocity

Wave induced bottom velocities were responsible for a significant portion of the energy on the bottom at the reef and were episodic. All of the records from the deployment were examined for evidence of wave induced velocities. This was done by computing the standard deviations and spectra of the three velocity components (east, north and up) for each burst of data, and inspecting them. In all, 53 records contained wave energy well above the background noise level. Of these records, only 24 occurred after the first significant event recorded concerning trout eggs on the reef (Julian day 300: 44 % of natural spawning). The events are summarized in Table 1 and are indicated in Figure 5b. The wave induced bottom velocity was small after the incubators were deployed on 22 November, until the current meter was retrieved on 9 December.

Table 1. Summary of significant events related to trout eggs on the reef off Stoney Creek, 1999 (John Fitzsimons, personal communication).

Date	Julian Day	Event
27 October	300	44% of natural spawning
3 November	307	49% of natural spawning
8 November	312	Seeding of nets occurs
20 November	324	6% of natural spawning
22 November	326	First set of incubators put out (68.8% survival)
29 November	333	Second set of incubators put out (62.7% survival)
3 December	337	Egg nets retrieved – survival of naturally deposited eggs 70%/ average of 50% of seeded eggs recovered

Using the method of Longuet-Higgins et al. (1963), the mean direction of the peak of the bottom velocity spectra was found and used to characterize each record. The number of records showing waves is plotted as a function of wave direction (to) in Figure 7. All but two of the records show waves travelling towards 210 to 250° True, with the peak at 240°. All of the 24 wave records from Julian day 300 onwards were travelling towards 210 through 250°. The longest fetches are from 60 to 80° T, corresponding to wave directions of 240 to 260° T. The differences between the local wave directions and the directions of longest fetches can most likely be explained by refraction effects due to the regional bathymetry and the local effects of the reef.

The directions of the more energetic waves on or after Julian day 300 were screened by adding a magnitude threshold to the standard deviation of the bottom velocity. When the threshold was set at 0.1 m/s, the number of records was reduced to 11 from 24, all in the direction range of 210 to 240° T. Using a threshold of 0.2 m/s only one record remained, with direction towards 230° T. Thus, all of the largest waves were travelling in a direction consistent with the largest fetch. These results are similar to those obtained in 1998 (Skafel and Fitzsimons, 1999).

The bottom velocities for the 24 records that showed wave activity from Julian day 300 onward are summarized in Table 2. The variable U_{br} is the bottom representative velocity, following Madsen (1994), and is a simplified representation of the wave induced horizontal bottom velocity, aligned in the dominant direction of the wave motion.

Table 2. Summary of records from Julian day 300 onwards that had wave-like spectra. The variables in the middle set of columns were computed from the bottom velocity time series and are the bottom representative velocities (U_{br}), the mean wave direction and the peak wave period. The variables in the right hand set of columns, computed from ODIFLOCS, are the average bottom velocities, filter and pore velocities within the cobble matrix. The highlighted records indicate wave events on or after the day of a significant event related to the trout eggs (refer to Table 1).

Julian Day	Record Number	U_{br} [m/s]	Dir to [°]	T_p [s]	U_{av}	U_f	U_p
		(from velocity time series)			[m/s]	(from ODIFLOCS)	
307	313	0.22	220	4.76	0.23	0.06	0.15
307.125	314	0.25	214	6.12	0.25	0.07	0.18
315.375	380	0.24	243	5.14	0.24	0.06	0.15
315.5	381	0.23	232	6.77	0.23	0.06	0.15
315.625	382	0.29	235	5.59	0.30	0.08	0.20
315.75	383	0.24	229	6.77	0.23	0.06	0.15
315.875	384	0.17	240	5.59	0.17	0.05	0.13
330.375	500	0.11	239	5.14	0.11	0.03	0.08
330.5	501	0.23	237	5.59	0.23	0.06	0.15
330.625	502	0.22	224	5.59	0.23	0.06	0.15
330.75	503	0.22	234	5.59	0.23	0.06	0.15
330.875	504	0.23	239	6.12	0.23	0.06	0.15
331	505	0.10	238	5.59	0.10	0.03	0.08
334.125	530	0.04	222	3.67	-	-	-
334.25	531	0.06	232	2.85	-	-	-
334.375	532	0.05	230	3.67	-	-	-
334.5	533	0.05	232	3.47	-	-	-
334.625	534	0.07	237	4.43	0.07	0.02	0.05
334.75	535	0.09	230	4.43	0.09	0.02	0.05
334.875	536	0.09	243	4.76	0.10	0.02	0.05
335	537	0.05	243	4.14	-	-	-
335.125	538	0.05	247	4.76	0.05	0.01	0.03
335.25	539	0.04	246	5.14	0.04	0.01	0.03
335.375	540	0.03	245	4.76	0.03	0.01	0.03

There were storms on Julian days 307, 315 and 330, after three of the 'egg' events on Julian days 307, 312, 324/326. The records on days 334 and 335 (following the egg event on day 333) indicated wave like spectra, but they were all rather small compared to the above mentioned storms. There was a major storm on Julian day 348 (see Figure 3.2), unfortunately the current meter had been recovered for the season on 9 December (Julian day 343). The wave conditions for this storm were hindcasted (see below).

3.3.2 Interstitial Flow

The flow affecting the trout eggs is the flow amongst the stones on the bottom. This flow is extremely complex, depending on the details of the stone shapes and sizes, amongst other factors. At present, it can only be described in terms of its mean value, based on an estimate of the mean stone size and porosity, and on the orbital velocities of the waves at the bottom. A numerical model ODIFLOCS was used to estimate the flow within the cobble layer, based on the bottom flow. ODIFLOCS (One Dimensional Flow on and in Coastal Structures) was developed at the Delft University of Technology (See van Gent, 1994). Input to the model was selected to be representative of the top of the reef off Stoney Creek: median bottom stone size (D_{50})= 0.2 m; water depth = 9 m; lakeward slope = 0.027, porosity = 0.4. The model was run with the peak wave periods, and by trial and error, input wave heights (H_o) selected that produced mean bottom velocities (U_{av}) that matched the bottom representative velocities computed from the measured data (U_{br}). Then the corresponding computed model filter (also called discharge) velocities (U_f) and the pore velocities (U_p) within the cobble were tabulated. The pore velocities (equal to the filter velocities divided by the porosity), are average velocities within the interstitial spaces, and are the best available representation of the flow that is imposed on any trout eggs that lie within the cobbles. It must be re-emphasized that the pore velocity is a spatial average velocity (at the maximum of the corresponding wave period) and that the actual velocity will vary considerably within the cobble layer.

During the storms on Julian days 307, 315 and 330, the pore velocities peaked at 0.18, 0.20 and 0.15 m/s. These values are smaller than the values estimated for the storms encountered in 1998. Then, the pore velocities were 0.20 to 0.25 m/s (Skafel and Fitzsimons, 1999). The storm on days 334 and 335 produced quite modest pore velocities, the larger of which were from 0.03 to 0.05 m/s.

3.4 Modeling Waves

The deployment of the current meter on the reef provided excellent data to estimate the interstitial flow within the cobble layer. However, it is not always possible to have the reef instrumented. However, it is possible to get meteorological data from a nearby site (in this case the NWRI Burlington pier data is usually available). Wave conditions can then be hindcasted. From them, estimates of bottom velocity and then pore velocity can be made. How well do these hindcasted data stand up against the measured data?

To examine this question, the measured wave induced bottom velocity spectra, aligned in the direction of the maximum, were converted to surface elevation spectra using spectral techniques and linear wave theory (Isobe et al 1984). The significant wave heights (H_{mo}) and peak periods were then computed from the surface spectra. The waves for the corresponding times were also hindcasted using the NWRI meteorological data from the Burlington Pier site and a hindcasting program, PHEW-wave fetch (See Skafel and Bishop, 1991). These two sets of wave characteristics are compared in Table 3 and Figures 8 and 9.

Table 3. Wave conditions estimated from the bottom velocities and by hindcasting. The velocity summary set of columns (U_{br},...) are repeated from Table1, the first set of wave summary columns were derived by transforming the bottom velocities to surface elevations using spectral techniques, the last set of wave summary columns were computed by hindcasting the wave data from wind data. The highlighted records indicate wave events on or after the day of a significant event related to the trout eggs (refer to Table 1).

Julian Day	Record Number	U_{br} [m/s]	Dir to [°]	T_p [s]	T_p [s]	H_{mo} [m]	Dir to [°]	T [s]	H [m]	Dir to [°]
		(from velocity time series)			(from bottom velocity spectra)			(hindcast from PHEW)		
307	313	0.22	220	4.76	4.76	1.23	220	3.58	0.97	223
307.125	314	0.25	214	6.12	6.12	1.19	214	3.58	0.78	208

315.375	380	0.24	243	5.14	5.14	1.32	243	3.95	0.91	247
315.5	381	0.23	232	6.77	6.77	1.12	232	4.36	1.10	217
315.625	382	0.29	235	5.59	5.59	1.37	235	4.68	1.25	247
315.75	383	0.24	229	6.77	6.77	1.11	229	4.81	1.29	247
315.875	384	0.17	240	5.59	5.59	0.92	240	4.99	1.36	247
330.375	500	0.11	239	5.14	5.14	0.77	239	2.99	0.52	251
330.5	501	0.23	237	5.59	5.59	1.14	237	3.28	0.60	250
330.625	502	0.22	224	5.59	5.59	1.03	224	3.61	0.71	248
330.75	503	0.22	234	5.59	5.59	1.00	234	3.55	0.64	246
330.875	504	0.23	239	6.12	6.12	1.01	239	3.55	0.54	247
331	505	0.10	238	5.59	5.59	0.50	238	3.55	0.45	256
334.125	530	0.04	222	3.67	3.67	0.44	222	2.34	0.26	211
334.25	531	0.06	232	2.85	2.85	0.55	232	2.27	0.28	247
334.375	532	0.05	230	3.67	3.67	0.45	230	2.27	0.29	247
334.5	533	0.05	232	3.47	3.47	0.47	232	3.04	0.46	234
334.625	534	0.07	237	4.43	4.43	0.54	237	3.07	0.47	234
334.75	535	0.09	230	4.43	4.43	0.61	230	2.57	0.39	232
334.875	536	0.09	243	4.76	4.76	0.55	243	2.77	0.38	231
335	537	0.05	243	4.14	4.14	0.38	243	2.77	0.31	231
335.125	538	0.05	247	4.76	4.76	0.30	247	2.72	0.30	231
335.25	539	0.04	246	5.14	5.14	0.27	246	2.77	0.20	231
335.375	540	0.03	245	4.76	4.76	0.17	245	2.72	0.12	231

From the start of the deployment until the current meter was removed on Julian day 346, both the velocity data and the hindcasted wave data indicated storm events at the same times (Figure 8). However, the hindcasted values of height and period are lower than those estimated from the current data (Figure 9). This finding is consistent with, although more accentuated than, earlier work that found this hindcasting method tends to underestimate the larger heights and longer periods (Skafel and Bishop, 1991). The measured directions are turned to the left, when viewed in the direction of wave travel, compared to the hindcasted directions, although there is considerable scatter. This latter observation is consistent with the general orientation of the bottom contours, which should cause some refraction of the waves to the left, which was not modeled in the hindcast waves.

The hindcast waves show a large storm on day 343, with the height peaking at about 2 m and the period at about 6 s. This was the largest storm of the season. Based on the limited comparison of hindcasted and measured wave conditions herein, the measured wave height would have been about 2.2 m and the period about 7 or 8 s. The corresponding bottom representative would have been about 0.4 m/s and the pore velocity about 0.25 m/s.

4.O DISCUSSION and CONCLUSIONS

The Sontek Hydra current meter was successfully deployed on the Stoney Creek reef in Lake Ontario during the 1999 lake trout spawning season. There was 100% data recovery from the deployment. With its capability to collect large sample records at a high sampling rate, it is a valuable tool for monitoring flow in adverse conditions. The mean flows were typically modest and shore parallel. However, 0.7% of the records had mean flows in the range of 0.2 to 0.5 m/s, which would cause pore velocities as high as or higher than those caused by the largest waves recorded during the deployment. The highest mean flow occurred on Day 307 (3 November), the day it was noted that 49% of natural spawning was completed. The magnitude was about as large as largest bottom representative velocity found from the wave induced flow.

Several storms causing waves up to nearly 1.4 m were monitored. The resulting pore velocities ranged from around 0.03 up to 0.2 m/s. The pore velocities were at the low end of the range after the incubators were deployed on 22 November. The storm on 9 December, after the current meter was recovered, was estimated by hindcasting techniques to be the most severe of the season, resulting in the highest pore velocities, likely about 0.25 m/s.

The hindcasting technique reproduced the storm events recorded during the deployment. Unfortunately, it under predicted both the height and period. It nevertheless is a useful tool in providing guidance as to the order of magnitude of the wave conditions in the absence of measurements. No readily applicable tool is at hand to estimate the mean currents, which were shown to be about as strong as the wave induced flow during this deployment.

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FIGURES

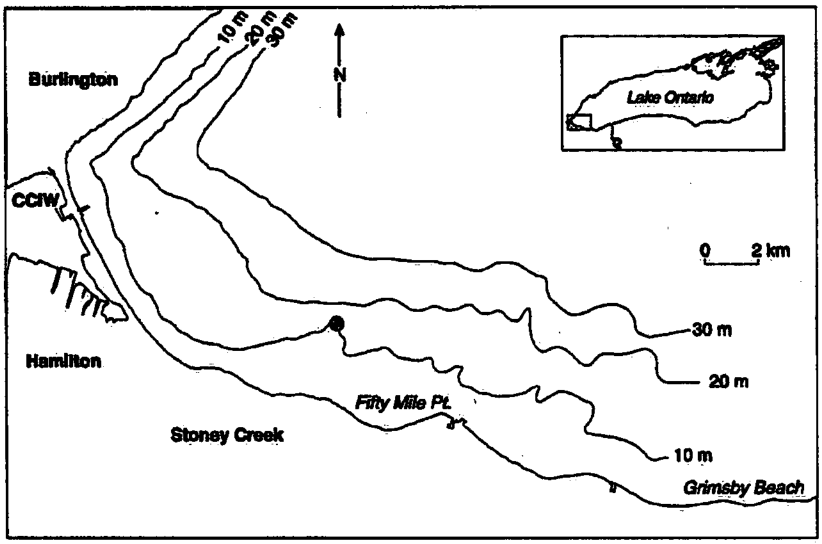


Figure 1. Site location off Stoney Creek (•).

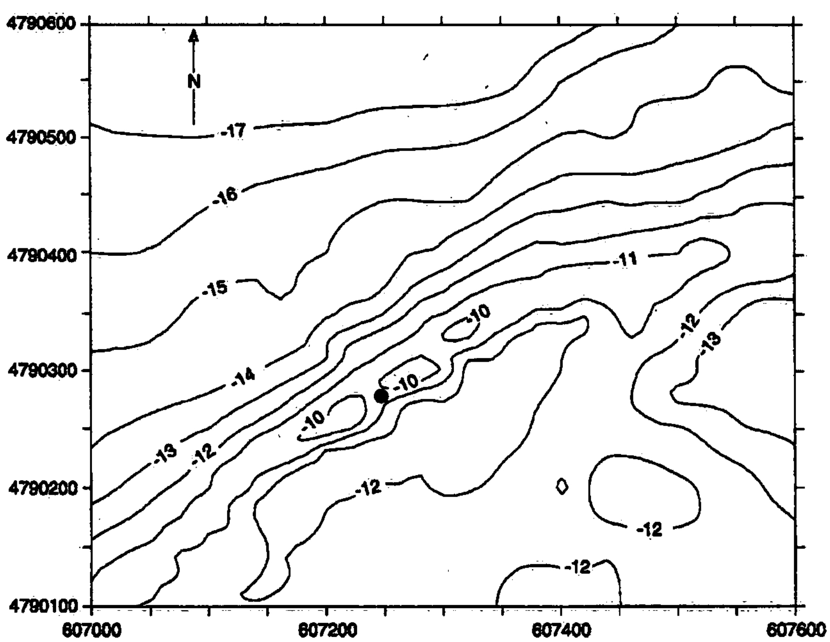


Figure 2. Details of bathymetry at site (•), UTM grid in metres, elevations in metres below IGLD.

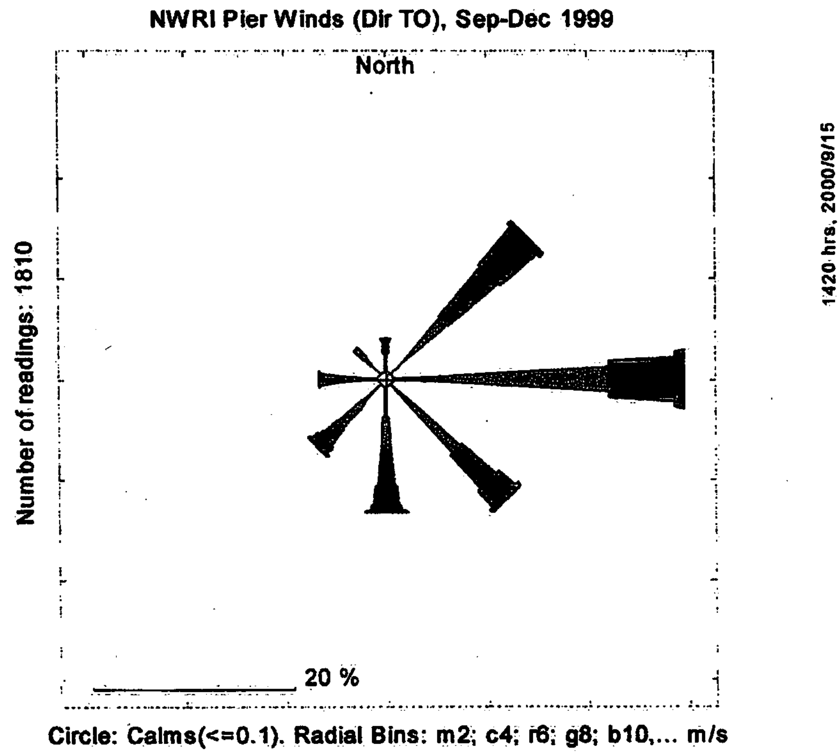


Figure 3. Wind rose for the winds from the Burlington Pier (NWRI) meteorological station during the current meter deployment, September to December 1999. Note the directions are reported as towards, for ease in comparison to the current data. The letter before the upper limit of each speed bin is the colour code. For example, m2 refers to the bin from 0.1 to 2 m/s, and it is mauve coloured.

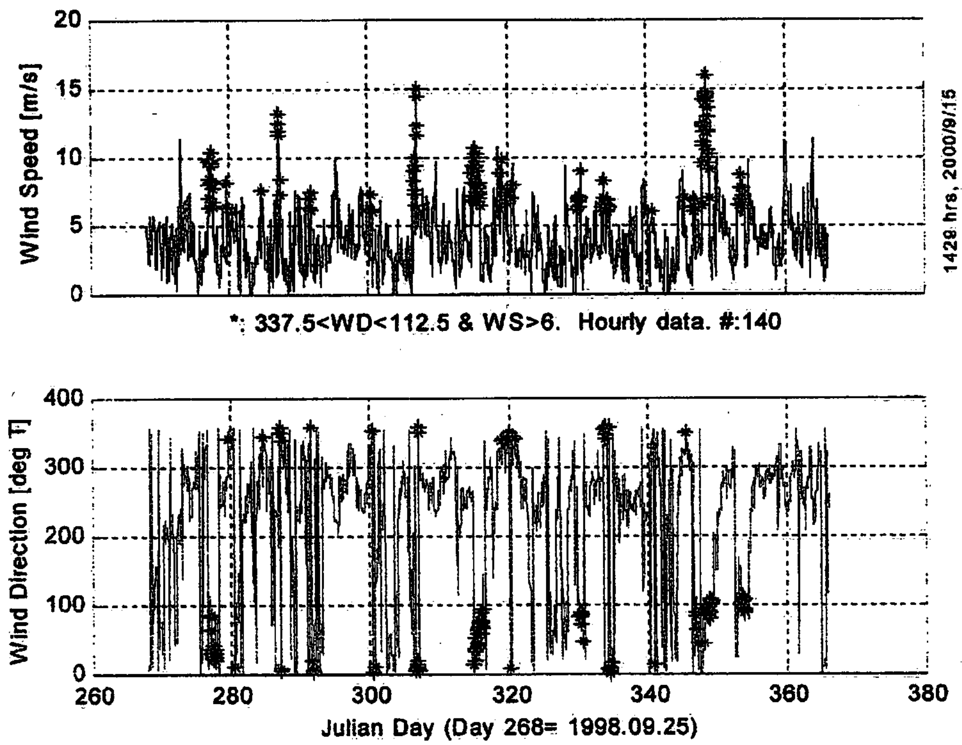


Figure 4. Time series of wind speed and direction from the NWRI Burlington Pier meteorological station. Events marker with the cross are likely to cause waves at the Stoney Creek Reef.

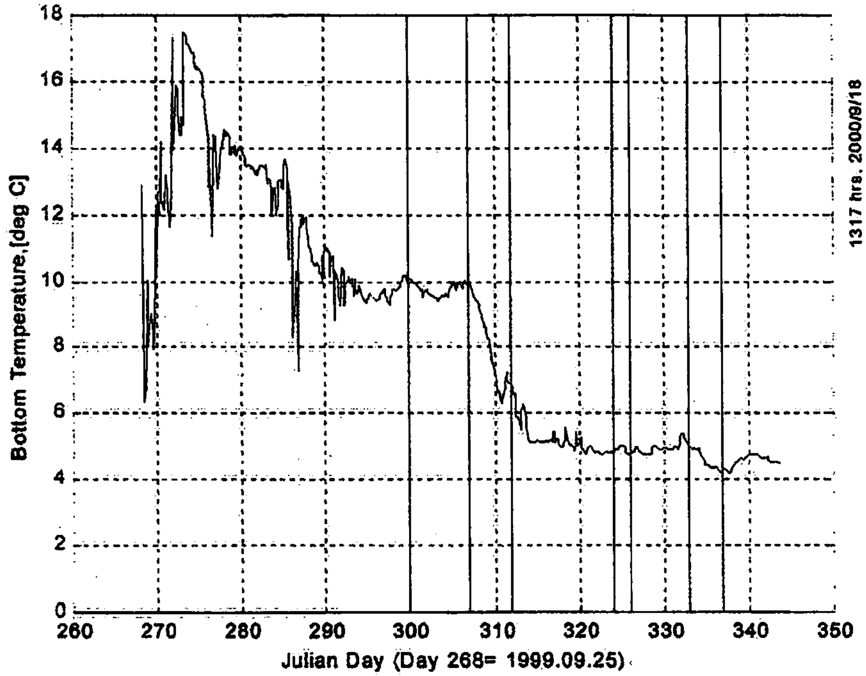
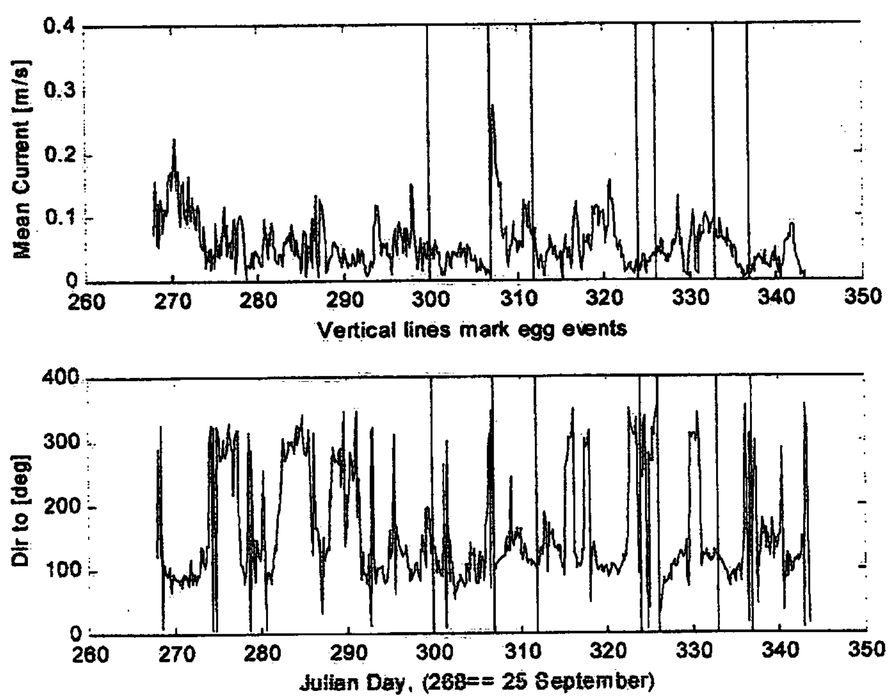


Figure 5a. Bottom water temperature during the 1999 deployment on the Stoney Creek Reef, Lake Ontario. Vertical lines mark the significant events for the trout eggs.

Figure 5b. Mean bottom current during the 1999 deployment on the Stoney Creek Reef. Vertical lines



mark the significant events for the trout eggs (See Table 1).

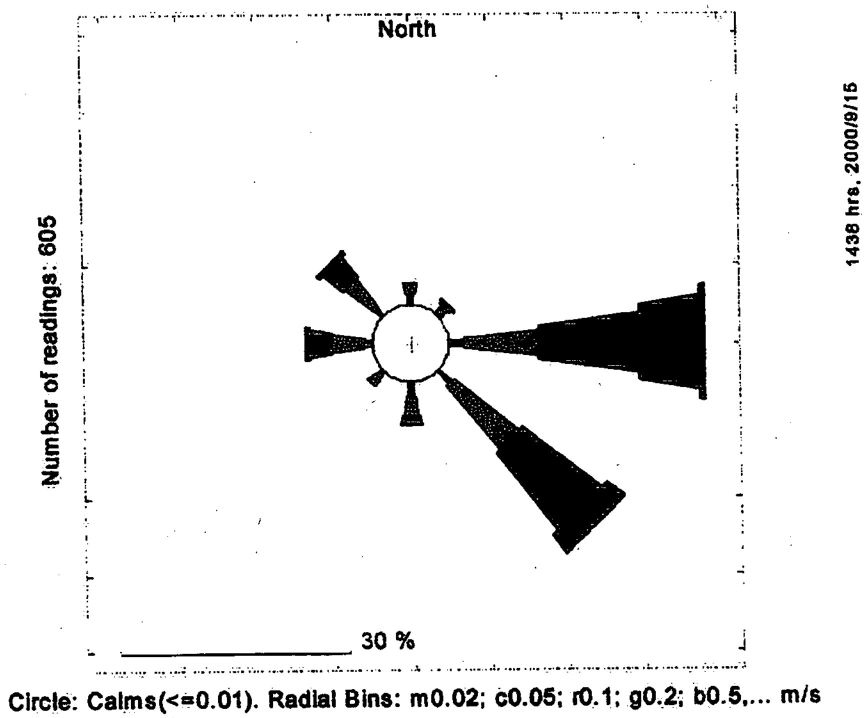


Figure 6. Bottom current rose on the Stoney Creek Reef, September to December 1999.

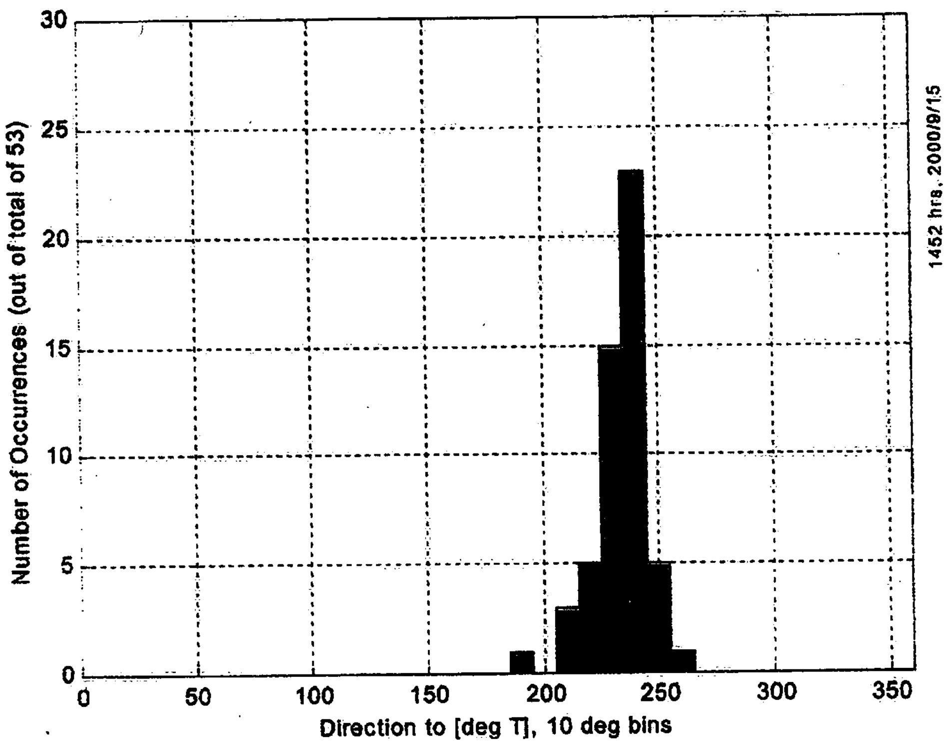


Figure 7. Stoney Creek Reef, 1999. Current records showing wave characteristics, plotted as a function of direction of travel.

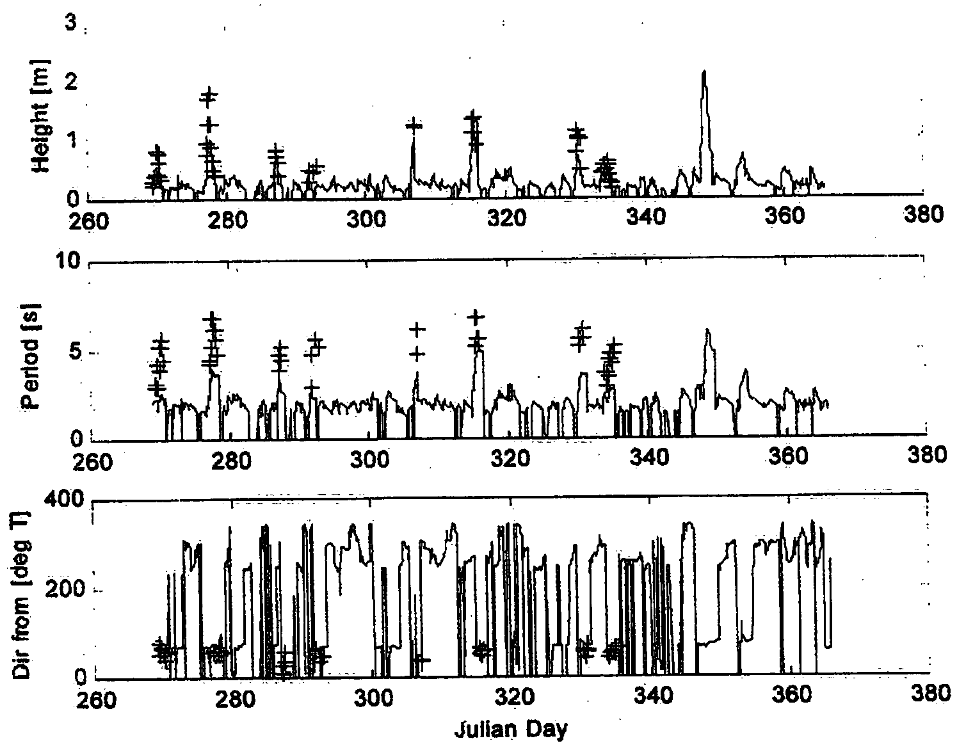


Figure 8. Stoney Creek Reef, 1999. Hindcast wave parameters (continuous plot), and wave parameters estimated from the bottom velocities (+).

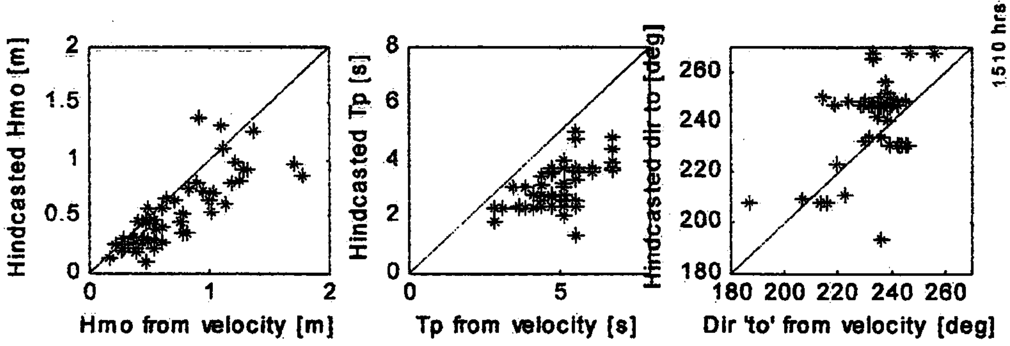


Figure 9. Stoney Creek Reef, 1999. Hindcast wave parameters versus those estimated from the bottom velocities.

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