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Bottom Currents at a Lake Trout SpawningReef

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Management Perspective

Title:
BOTTOM CURRENTS AT A LAKE TROUT SPAWNING REEF

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

Background:
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.

Next Steps
Additional monitoring will be done at the same site to capture enough data on significant storms to develop suitable statistics on the bottom currents.

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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 October to December, 1998 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.

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). As a result the habitat that would support successful spawning could be reduced considerably from what it was historically.

A current monitoring program was undertaken 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. A 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.

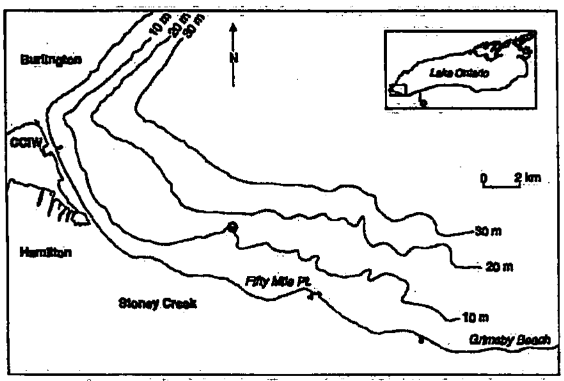

Figure 1. Site location off Stoney Creek (•).

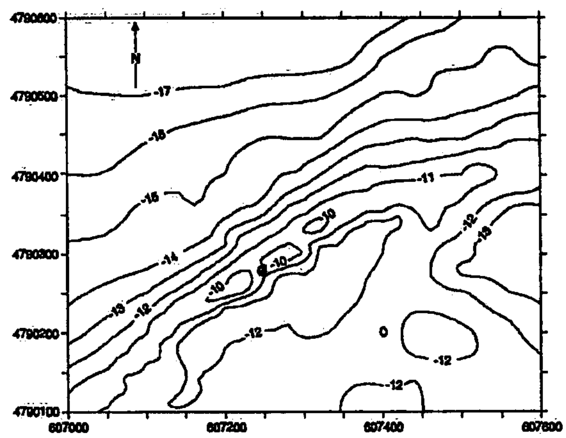

Figure 2. Details of bathymetry at site (•), UTM grid in metres, elevations in metres below IGLD.

Incubators have been deployed at the site in several previous years, and used to explore the mortality of the eggs through the incubation period. However, the deployment in the autumn of 1998 was the first opportunity to make concurrent bottom flow measurements.

A three axis acoustic Doppler current meter, with pressure transducer and temperature sensor (SonTek Hydra) was deployed on the top of the reef from 1 October (Julian day 274) to 7 December 1998 (Julian day 341). The depth at the beginning of the deployment was 9.6 m, decreasing to 9.4 m by the end of the deployment. The 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 bottom.

MEAN CONDITIONS

The mean temperature and pressure for the deployment are shown in figure 3. The temperature record shows three distinct upwelling events, on days 274, 277, and 299. On day 310 there appears to be an upwelling event that is followed by more or less continuously lower temperatures, around 6° C. The pressure record, showing the water depth, reflected very closely the water level data recorded at the Burlington ship canal by the Canadian Hydrographic Service, some 12 km to the WNW.

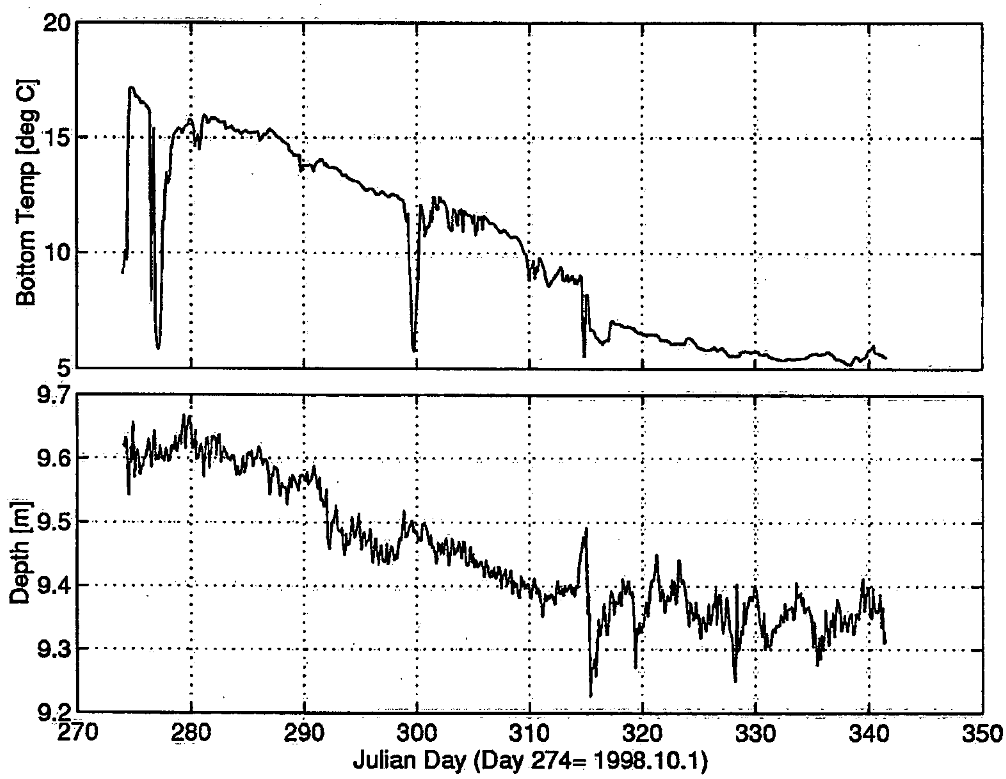

Figure 3. Mean bottom temperature (upper panel) and mean depth (lower panel) for each record. The depth is corrected for barometric pressure and temperature effect.

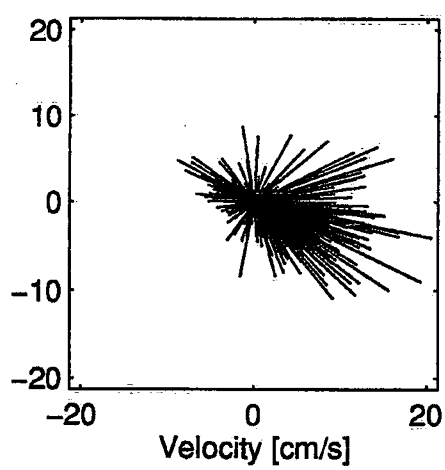

Figure 4. Mean bottom flow vectors for all records (north is up).

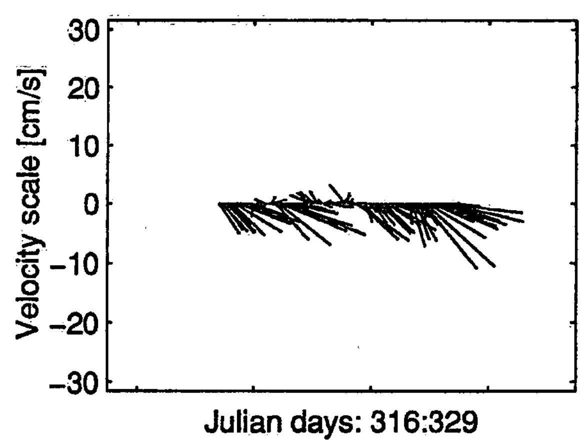

Figure 5. Mean bottom flow vector time series for a two week period (north is up).

The mean flow conditions at the site are summarized in the vector rose plot, figure 4. The means were typically less than 15 cm/s, and none exceeded 25 cm/s. Most of the flow was oriented towards the ESE, roughly parallel to the shoreline. There is a smaller lobe in the WNW direction, with few occurrences in the onshore-offshore direction. An example vector time series for a two week period is shown in figure 5. Here a persistent flow in the SE to ESE direction is well illustrated.

WAVE INDUCED FLOW

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), and inspecting them. Especially towards the end of the deployment, significant energy, as indicated by the standard deviation, was not always confirmed by inspection of the spectrum. The current meter requires particles in the water to reflect the acoustic signal; an inadequate number of particles result in an increase in the noise levels of the signals. It appears that the clearer water late in the year resulted in increased noise in the velocity signals, especially under relatively quiescent conditions. This noise level is reflected in the standard deviation measurements, and can be distinguished from wave activity by its spectral characteristics. When there was increased wave activity the noise level decreased. Evidently the wave action was resuspending sediment, providing more target particles for the acoustic pulses from the meter. In all, 64 records contained wave energy well above the background noise level. Using the method of Longuet-Higgins et al. (1963), the mean direction of the peak of the 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 6.

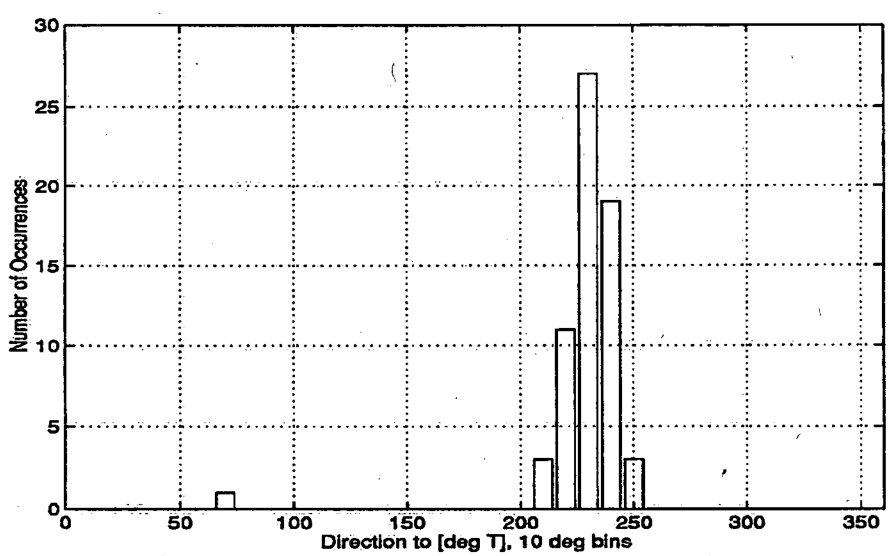

Figure 6. Records showing significant wave energy versus direction to.

All but one of the records show waves travelling towards 210 to 250° True. The longest fetches are from 60 to 80° T, corresponding to wave directions of 240 to 260° T. The 10 to 30° differences can likely be explained by refraction effects and actual wind directions. The single exception shows waves directed to 70° (preliminary data indicate strong WSW winds).

The directions of the more energetic waves were screened by adding a magnitude threshold to the standard deviation. When the threshold was set at 0.1 m/s, the number of records was reduced to 24, all but one in the direction range of 210 to 250° T. Using a threshold of 0.2 m/s only 4 records remained, with waves towards 210 to 220° T. Thus all of the largest waves were travelling in a direction consistent with the largest fetch.

These four records with standard deviations over 0.2 m/s are examined in some detail because they represent the largest forcing on the reef experienced during the deployment. The peak period and standard deviation of the velocity (U_{std}) are listed in table 1. The first three records are from a 6 hour period during a storm on 6-7 October, the fourth is from a storm on 17 November. The velocity spectra for the middle record of the 6-7 October storm is shown in figure 7a, that of the 17 November storm in 7b. The spectra are similar in that the peak frequencies are the same (0.15 Hz), the energy content is similar, the direction of the peak is similar, and the high frequency part of the spectra falls off at –5/3 rate (The straight line in the figure has a slope of –5/3). The component of velocity perpendicular to the peak direction, while an order of magnitude smaller, is still quite large. This is an indication that there is considerable spread in the wave directions, characteristic of a storm sea in contrast to swell, typical for waves on Lake Ontario.

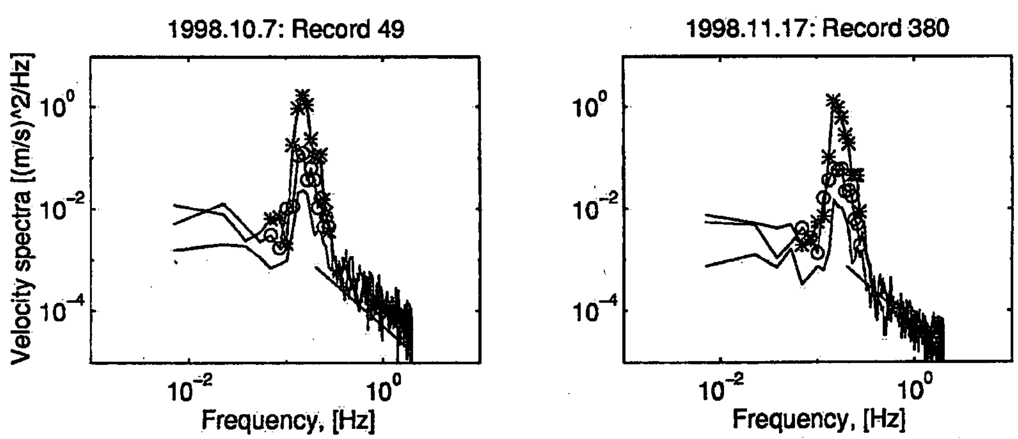

Figure 7. Spectra from two storms (*: horizontal velocity in the mean wave direction; o: horizontal velocity perpendicular to the mean direction; -; vertical velocity).

INTERSTITIAL FLOW

The bottom velocity data from the four records representing the largest storms during the deployment are used to gain insight into the interstitial flow, within the surficial cobble layer of the reef. The following approach was used. To simplify the analysis, the velocity standard deviation was replaced by the representative wave orbital velocity and corresponding representative periodic wave with the same peak period and direction as the spectrum, following Madsen (1988). A numerical model ODIFLOCS was then used to estimate the flow within the cobble layer. 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 to the top of the reef off Stoney Creek: median size (D_{50})= 0.2 m; water depth = 9.5 m; lakeward slope = 0.027, porosity = 0.4. The model was run with the representative wave period, and by trial and error, a wave height (H_o) determined that produced representative bottom velocities in the direction of the wave travel and in the reverse direction (U_{max}, U_{min}) that closely matched the representative velocity computed from the measured data (U_{rep}). The corresponding velocities within the cobble (U_{pmax}, U_{pmin}) were also computed by the model (These are filter or discharge velocities, from which the pore velocities can be found by dividing by the porosity). The resulting wave height and computed velocities are summarized in table 1. The maximum computed filter velocities in the cobble layer of the reef are all about 0.10 m/s, showing less variation than the measured bottom velocities. Effects of varying median cobble size and on thickness of the layer were tested by varying the particle size from 0.1 to 0.3 m and reducing thickness to 0.6 m. The maximum variation in the computed flow in the cobble was only 0.005 m, suggesting it is insensitive to changes in cobble size or layer thickness. Porosities of 0.2 and 0.5 were also used to test the influence on the velocity. The filter or discharge velocity, reported by the model showed significant differences, especially for the low porosity. However, the pore velocities were virtually the same for all three porosities. Indeed, the pore velocities for all cases lie in the range of 0.2 to 0.3 m/s. It must be re-emphasized that the pore velocity is an 'average' velocity and that the actual velocity will vary considerably within the cobble layer. Furthermore it is representative in the sense that the bottom velocity is representative, and is not the maximum velocity.

Table 1. Computed filter velocities derived from the peak period and standard deviation of the bottom velocity (U_{std}) measured for the four most severe wave records off Stoney Creek, 1998.

Record	Period [s]	U_{std} [m/s]	U_{rep} [m/s]	H_o [m]	U_{max} [m/s]	U_{min} [m/s]	U_{pmax} [m/s]	U_{pmin} [m/s]
48	6.12	0.23	0.33	0.67	0.36	-0.31	0.09	-0.08
49	6.77	0.27	0.38	0.75	0.41	-0.35	0.11	-0.10
50	7.56	0.21	0.30	0.60	0.34	-0.27	0.09	-0.08
380	6.77	0.24	0.34	0.67	0.36	-0.31	0.10	-0.09

CRITICAL TIME

What are the bottom velocities when the lake trout eggs are most susceptible? Temperature is an indicator or trigger for lake trout spawning (Fitzsimons, 1995), with a temperature in the range of 6 to 10°C being important. Furthermore, lake trout eggs appear to be most sensitive to shock within about 10 days post fertilization. Combining this information with the temperature record (figure 3), it would appear that a period starting at day 315 for about 10 days could have been critical. Record 380 occurred during this time. In addition, 5 more records immediately following 380 had bottom velocity standard deviations between 0.1 and 0.2 m/s. Thus the bottom velocities at this critical time were some of the most severe during the whole deployment. Whether or not the velocities were sufficient to cause elevated mortality must await examination of the eggs retrieved from incubators early in the spring, 1999.

DISCUSSION

Representative bottom velocities from the largest storms on the Stoney Creek reef during the 1998 deployment indicate moderate wave agitation. The pore velocity within the cobble surficial layer has been estimated for these storms. From here there are several steps needed to place these data in the context of shock loading on the lake trout eggs at the site. Firstly, the record is short, and from previous work on the western end of Lake Ontario, it is known that the autumn of 1998 was atypically calm. More field data are desirable to develop a realistic data base. More quantitative information about the characteristics of the cobble field would also be desirable, but as can be seen from the results here, the estimates of pore velocity are not particularly sensitive to these parameters. The wave induced flow is more important than the mean flow as the bottom representative velocities were significantly greater than any of the mean currents. An obvious step is to hindcast the wave conditions and compare the results with the measured velocities with the goal of eliminating the need for current measurements. Presently, the threshold velocity that causes shock stress on eggs has not been determined. Evidence of mortality this past autumn combined with the information on the velocities during the critical period will provide insight into this question.

With establishment of a threshold velocity, a relatively inexpensive test could be set up to predict if high mortality is likely for a given year. Deploy an inexpensive temperature logger at the site in question, and retrieve it late in the autumn. Using available wind data, hindcast the waves during the period when the eggs are sensitive (based on the temperature) and estimate the bottom velocities from the hindcasted waves for any storm events occurring during the critical period. If these estimated velocities exceed the threshold, high mortality is likely.

CONCLUSIONS

A current meter was successfully deployed on the Stoney Creek reef in Lake Ontario, known to be a lake trout spawning site. The mean flow and wave induced flow were characterized for the deployment period. A moderate storm inducing significant bottom velocities was observed during a period that lake trout eggs would likely be sensitive to physical shock. Avenues of further work are described which will help to define more closely levels of physical parameters that promote elevated mortality.

REFERENCES

Fitzsimons, JD 1994 Survival of lake trout embryos after receiving a physical shock. The Progressive Fish-Culturist, **56**, pp 149-151.

Fitzsimons, JD 1995 Assessment of lake trout spawning habitat and egg deposition and survival in Lake Ontario. J Great Lakes Res, **21** (Supplement 1), pp 337-347.

Longuet-Higgins, MS, Cartwright, DE, and Smith, ND 1963 Observations of the directional spectrum of sea waves using the motions of a floating buoy. Ocean Wave Spectra: Proc Conf, May 1-4 1991, Prentice-Hall, pp 111-132.

Madsen, OS 1994 Spectral wave-current bottom boundary layer flows. Proc 24st Internat. Conference on Coastal Engineering, pp 384-397.

Van Gent MRA 1994 The modelling of wave action on and in coastal structures. Coastal Engineering, **22**, pp 311-339.

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