Water quality observations near a

working cage-aquaculture farm in the North Channel,

Manitoulin Island, Ontario

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Abstract

Cage-aquaculture in Ontario has the potential to expand to meet the needs of a demanding market. Most cage-aquaculture farms in Ontario are located in Georgian Bay and northern Lake Huron. The predominant species farmed is rainbow trout *Oncorhynchus mykiss*. Environmental concerns are influencing the growth of the industry in Ontario while regulatory agencies are developing a policy framework aimed at creating a sustainable industry. The environmental concerns include the impact of farming activities on water quality, benthic communities (excess feed and feces), native fisheries, and fish health. We investigated potential near field and far field effects of a cage fish farm located near Eastern Island in the North Channel of Lake Huron, Ontario. On June 12, 2007 twenty-five stations were sampled from approximately 100 m to 5000 m of the fish farm. Data from these samples were compared to those of a large scale water quality survey completed on the North Channel around Manitoulin I. June 12 to 15, 2006. We found slightly elevated surface concentrations of nitrate plus nitrite ($NO_{3/2)}$ and bottom concentrations of total phosphorus (TP) near-field of the fish farm, however, $NO_{3/2}$ and TP surface and bottom averages were lower than average results of the large scale North Channel survey. Total phosphorus, total filtered phosphorus (TFP) and $NO_{3/2}$ surface and bottom averages both near and far-field were lower then average results of large scale North Channel survey. Average concentrations of soluble reactive phosphorus (SRP) were higher than results of the large scale North Channel survey at surface, however, not significantly elevated between near and far-field. Ammonia (NH_3N) concentrations were comparable to results of the large scale North Channel survey. Total phosphorus

remained below the Provincial Water Quality Objective (PWQO) and dissolved oxygen remained above the PWQO at all stations and depths.

Introduction

Aquaculture is one of the fastest growing food producing industries in the world. In Canada, there were 6598 licensed operations in 2004 (Department of Fisheries and Oceans 2007). Every province, including the Yukon Territory, practice aquaculture. In Ontario the Great Lakes provide a potential opportunity for growth in the fresh water sector. At present, possible environmental impacts are influencing growth of the industry in Ontario (Moccia and Hynes 1998). All cage-aquaculture is currently practiced in Lake Huron and Georgian Bay. The need for sustainable environmental management of cage-aquaculture farms is of utmost importance to preserve the ecological integrity of the Great Lakes. The environmental concerns include, but are not limited to, impact of farming activities on water quality, benthic communities (excess feed and feces) and native fisheries (Axler et al. 1996; Brooks et al. 2003; Brown et al. 1987). Industry, regulators, academic and other government agencies are striving to create a sustainable ecosystem approach. In the present study, we focus on water quality concerns. At a recent State of Lake Huron Conference (2006) a concern was raised regarding elevated Nitrite/Nitrate numbers in a wetland approximately 5 km east of a cage-aquaculture site in the North Channel, Ontario. It was suggested this may potentially be caused by far-field effects of the fish farm. The objectives of the following study are to 1.) determine spatial water quality concentrations from near-field to far-field of a working fish farm and 2.) compare near and far-field water quality concentrations to ambient North Channel water quality concentrations.

Methods

Study Site

The study site is a cage-culture farm located between High Island and Eastern Island in North Channel, Ontario (Fig. 1). The farm has been in operation since 1997 with an annual production of Rainbow Trout (*Oncorhynchus mykiss*) of 360 tonnes. The farm is located in a type II area as indicated in "Recommendations for Operational Water Quality Monitoring at Cage Aquaculture Operations" (Boyd et al. 2001). Type II sites are partially exposed "having good epilimnion/metalimnion flushing but limited or no hypolimnion exchange" (Boyd, et al. 2001). Sampling took place by boat on June 12, 2007. Water was collected at 25 stations located approximately 100m to 5000 m in an easterly direction from the farm (fig. 2). Samples were analysed of $NO_{3/2}$, NH_3N, SRP, TFP, and TP.

Fig. 1 The location of the fish farm for this study is located between High I. and Eastern I, North Channel, Ontario.

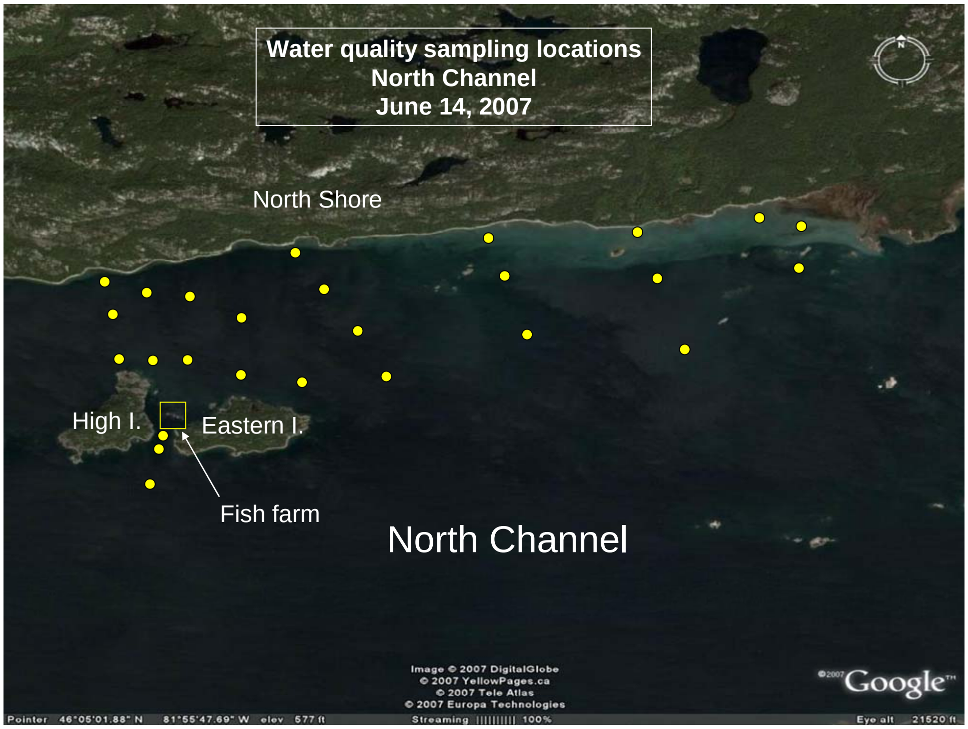

Fig. 2 Water quality sampling locations June 12, 2007, North Channel, Ontario.

Prevailing winds are from the west. Positions were recorded with a GPS, WAAS enabled (table 1).

Table 1 Water quality and YSI profile sampling positions near Eastern I. North Channel, Ontario.

Station #	Latitude	Longitude	YSI profile collected
EI 3	46° 04’ 54.72”	81° 57’ 28.68”	YES
EI 4	46° 05’ 04.50”	81° 57’ 49”.14”	NO
EI 5	46° 05’ 24.42”	81° 58’ 14.70”	YES
EI 6	46° 05’ 00.60”	81° 57’ 39.78“	YES
EI 7	46° 05’ 14.82”	81° 58’ 11.64”	YES
EI 8	46° 05’ 03.96”	81° 58’ 04.98”	YES
EI 9	46° 05’ 20.40”	81° 57’ 52.68”	NO
EI 10	46° 05’ 19.20”	81° 57’ 39.72”	YES
EI 11	46° 05’ 09.72”	81° 57’ 21.06”	NO
EI 12	46° 04’ 53.88”	81° 57’ 05.10”	YES
EI 13	46° 05’ 32.46”	81° 57’ 05.10”	NO
EI 14	46° 05’ 23.82”	81° 56’ 53.10”	NO
EI 15	46° 05’ 11.16”	81° 56’ 42.30”	NO

EI 16	46° 04' 57.12"	81° 56' 32.22"	YES
EI 17	46° 05' 38.22"	81° 55' 53.10"	NO
EI 18	46° 05' 26.10"	81° 55' 45.24"	NO
EI 19	46° 05' 11.76"	81° 55' 38.22"	YES
EI 21	46° 05' 35.34"	81° 54' 46.20"	NO
EI 22	46° 05' 20.94"	81° 54' 42.00"	YES
EI 23	46° 05' 02.82"	81° 54' 34.14"	NO
EI 24	46° 05' 39.90"	81° 54' 14.70"	YES
EI 26	46° 04' 44.76"	81° 57' 41.82"	NO
EI 27	46° 04' 36.48"	81° 57' 54.00"	YES
EI 28	46° 04' 28.74"	81° 57' 57.24"	NO
EI 29	46° 05' 16.62"	81° 53' 53.04"	YES

On June 12 to 15, 2006 a large scale water quality survey was conducted on the North Channel around Manitoulin Island on board the CCGS Samuel Risley (fig. 3). Positions were recorded with a GPS (table 2). Water was collected at 36 stations for analyses of $NO_{3/2}$, NH_3N, SRP, TFP, and TP.

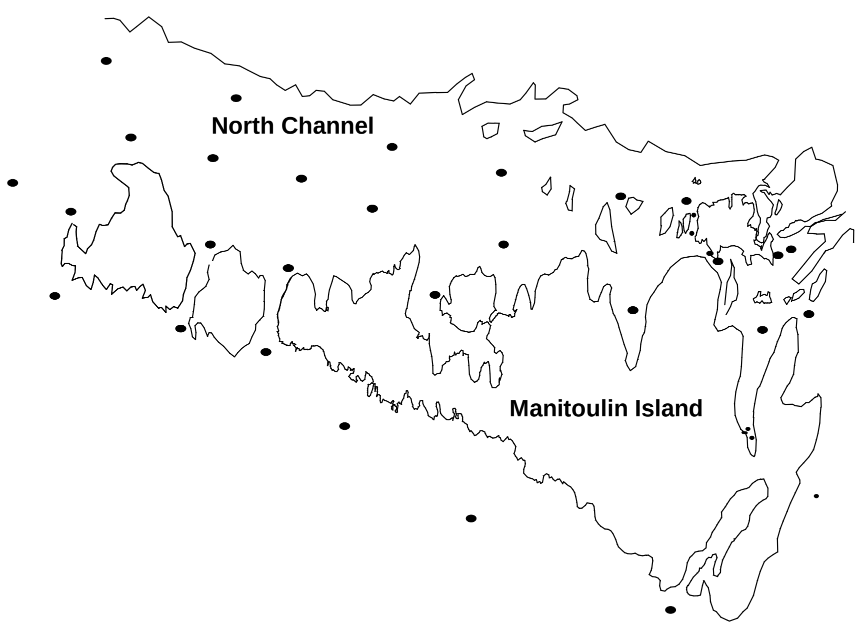

Fig 3. Thirty-six stations were sampled during the large scale water quality survey around Manitoulin I. Ontario June 12 to 25, 2006 .

Table 2. Water quality and profiling sampling positions for large scale survey around the Manitoulin I. June 12 to 15, 2006.

Station #	Latitude	Longtitude	YSI profile collected
18	46° 02' 35"	83° 07' 57"	YES
50	45° 32' 04"	82° 02' 54"	YES
52	45° 39' 03"	82° 39' 00"	YES
58	45° 51' 45"	83° 15' 31"	YES
59	45° 46' 09"	83° 01' 57"	YES
60	45° 53' 57"	83° 31' 23"	YES
67	45° 56' 02"	83° 53' 58"	NO
68	46° 02' 30"	83° 51' 13"	NO
69	46° 04' 38"	84° 01' 35"	NO
70	46° 08' 09"	83° 40' 25"	NO
71	46° 13' 52"	83° 44' 48"	NO
73	46° 11' 05"	83° 21' 27"	YES
75	46° 04' 52"	83° 25' 06"	YES
76	45° 59' 59"	83° 26' 12"	YES
77	45° 58' 18"	83° 11' 51"	YES
78	46° 01' 51"	82° 59' 47"	YES
79	46° 07' 25"	82° 53' 03"	YES
82	45° 56' 16"	82° 45' 30"	YES
83	45° 59' 57"	82° 33' 07"	YES
84	46° 05' 29"	82° 33' 21"	YES
87	46° 03' 42"	82° 11' 41"	YES
88	46° 03' 23"	82° 00' 06"	YES
89	45° 54' 59"	82° 09' 38"	NO
36	45° 42' 29"	81° 37' 09"	YES
42	45° 54' 58"	81° 36' 04"	NO
45	45° 53' 28"	81° 46' 17"	NO
46	45° 45' 49"	81° 48' 16"	NO
47	45° 59' 07"	81° 43' 27"	NO
50	45° 54' 32"	81° 40' 30"	YES
256	45° 45' 23"	81° 48' 15"	NO
457	45° 45' 24"	81° 48' 39"	NO
458	45° 45' 28"	81° 48' 59"	NO
102	45° 59' 13"	81° 55' 26"	YES
177	46° 02’ 26”	81° 58’ 37”	YES
178	46° 00’ 37”	81° 58’ 37”	YES
53	45° 57' 53"	81° 45' 43"	YES

Depth, temperature, pH, conductivity and dissolved oxygen were recorded with a YSI 6600 profiler at 15 stations on June 12, 2007 (table 1) and at 23 stations June 12 to 15, 2006 (the large scale North Channel survey) (table 2). A 3 litre VanDorn water sampler was used to collect discreet water samples at surface (1 m) and bottom (bottom-1 m) for both studies. Water was collected in 1 litre acid-washed HDPE bottles and kept cool until return to the lab. An aliquot of sample water was fixed with 30% sulphuric acid for analyses of Total Phosphorus (TP). A second aliquot of sample was filtered and fixed with 30% sulphuric acid for analyses of total filtered phosphorus (TFP) and the remainder of the sample was filtered and analyzed for nitrites/nitrates ($NO_{3/2}$), ammonia (NH_3N) and Soluble Reactive Phosphorus (SRP). Analyses of all parameters were performed by the National Laboratory of Environmental Testing (NLET) as per their protocols (CAEAL accredited) (Environment Canada 2007). The detection limit for TP, TFP, SRP, $NO_{3/2}$ and NH_3N are as follows: 0.5 ug L^{-1}, 0.5 ug L^{-1}, 0.2 ug L^{-1}, 0.005 mg L^{-1} and 0.005 mg L^{-1} respectively. For interpretation purposes, data was divided into near-field (100 m to 1000 m) from the fish farm) and far-field (>1000 m from the fish farm). Restricted access at our study site prevented sampling closer than 100 m of the fish farm, therefore more than half the samples were collected between 100 and 1000 m of the fish farm. The remainder of the stations were located between 1000 m and 5000 m. Differences in water quality parameters were assessed using a two-sample t-test.

Results

Temperature, specific conductance, dissolved oxygen and pH results for the near-field far-field study June 12, 2007 and the large scale survey June 12 to 15, 2006 are summarized in table 3. Depths at the 25 stations sampled June 12, 2007 ranged from <1m to 28m. Dissolved oxygen remained above 5 mg L^{-1} at all stations and depths. Temperature was 13 to 15 ^{o}C at the surface and 8 to 12 ^{o}C at the bottom indicating stratification at deep stations (>10 m). Specific conductance varied between 168 and 181 uS cm^{-1} and pH ranged between 7.8 and 8.25. Depths at the 23 stations sampled during the large scale North Channel study ranged from 17m to 66m. Dissolved oxygen remained above 5 mg L^{-1} at all stations and depths. Temperature ranged between 10 and 18 ^{o}C at the surface and 4 to $12^{o}C$ at the bottom. The lower average temperature for the larger survey bottom water probably reflects the larger number of deeper colder stations. Specific conductance ranged between 122 and 215 uS cm^{-1} and pH ranged from 7.7 to 8.5.

Table 4 shows average water quality parameters near and far-field. Included on the table are the averages of the large scale North Channel water quality survey, June 12 to 15, 2006, for background comparison purposes. Table 5 shows a comparison of water quality of data near and far-field assessed with a two-sample t-test (p=0.05).

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Table 3. Average surface and bottom concentrations with standard deviation (SD ±) of physical parameters collected with a YSI 6600 for near-field far-field study completed June 12, 2007 and a large scale study completed June 12 to 15, 2006 North Channel, Ontario.

	Near-field far-field study June 12, 2007				Large scale North Channel Study June 12 to 15, 2006			
	Ave surface	SD±	Ave bottom (>20m)	SD±	Ave surface	SD±	Ave bottom (>20m)	SD±
Temperature ^{o}C	14.7	0.82	9.9	0.63	14.3	1.71	5.8	1.29
Specific Conductance uS cm^{-1}	178.9	2.9	178.8	1.7	182.5	17.9	194.7	11.8
Dissolved Oxygen mg L^{-1}	12.6	0.57	13.0	0.11	10.4	1.05	11.6	0.16
pH	8.14	0.03	8.1	0.04	8.32	0.13	8.05	0.16

Table 4. Average water quality concentrations from near field far-field study, June 12, 2007. Large scale water quality averages of the North Channel, June 12 to 15, 2007, are also included for comparison purposes with standard deviation (SD±).

	Near-field		Far-field		Near-field		Far-field		Large scale North Channel survey			
	Surface		Surface		Bottom		Bottom		Surface		Bottom	
	Ave	SD±	Ave	SD±	Ave	SD±	Ave	SD±	Ave	SD±	Ave	SD±
TP (ug L^{-1})	4.16	1.22	3.20	1.17	3.68	1.29	2.18	1.36	4.59	1.49	4.53	0.71
TFP (ug L^{-1})	2.17	0.65	2.48	0.62	2.19	0.99	2.24	0.40	2.45	0.37	2.51	0.44
SRP(ug L^{-1})	0.45	0.07	0.39	0.09	0.45	0.10	0.40	0.10	0.27	0.11	0.28	0.16
$NO_{3/2}$ (mg L^{-1})	0.17	0.004	0.16	0.20	0.18	0.007	0.16	0.013	0.24	0.06	0.28	0.06
NH_3N (mg L^{-1})	0.010	0.009	0.006	0.001	0.006	0.003	0.007	0.003	0.007	0.003	0.006	0.001

TP and TFP near-field surface n=13; TP and TFP near-field bottom n=12; SRP , $NO_{3/2}$ and NH_3N near-field surface n=12; SRP , $NO_{3/2}$ and NH_3N near-field bottom n=11; TP,TFP, SRP , $NO_{3/2}$ and NH_3N far-field surface n=13; TP,TFP, SRP , $NO_{3/2}$ and NH_3N far-field bottom n=10; TP and TFP large scale North Channel study surface n=36; SRP , $NO_{3/2}$ and NH_3N n=33; TP and TFP large scale North Channel study bottom n=35; SRP , $NO_{3/2}$ and NH_3N n=30.

Table 5. Near-field vs far-field water quality concentrations, June 12, 2007. Comparison of data was assessed with a two-sample t-test ($p=0.05$).

Water Quality Parameters	Near-field vs far-field	p-value
Surface		
$NO_{3/2}$	slightly elevated	p=0.006
NH_3N	not different	p=0.112
SRP	not different	p=0.097
TFP	not different	p=0.252
TP	not different	p=0.057
Bottom		
$NO_{3/2}$	not different	p=0.462
NH_3N	not different	p=0.871
SRP	not different	p=0.299
TFP	not different	p=0.691
TP	slightly elevated	p=0.002

According to a two-tailed t-test $NO_{3/2}$ surface concentrations were slightly elevated in the near-field (table) compared to far-field, however, average concentrations near-field were 0.10 mg L^{-1} lower than large scale North Channel water (0.17 mg L^{-1} vs 0.27 mg L^{-1}) (table 4) . Bottom TP was slightly elevated in the near-field (table 5), however, the average TP was almost 1 ug L^{-1} lower than average large scale results of the North Channel water (3.68 ug L^{-1} vs 4.53 ug L^{-1}) (table 4). Near-field TFP average surface and bottom concentrations and far-field bottom concentrations were lower than surface and bottom averages of large scale North Channel water quality results (2.17 ug L^{-1}, 2.19 ug L^{-1}, and 2.24 ug L^{-1} vs 2.45 ug L^{-1} and 2.51 ug L^{-1}) (table 4). TFP average surface far-field concentrations were slightly higher than average results of the large scale North

Channel survey (2.48 ug L^{-1} vs 2.45 ug L^{-1}), however, we consider 0.03 ug L^{-1} difference as negligible. NH_3 average surface concentration was slightly elevated near-field compared to large scale North Channel survey results (0.010 mg L^{-1} vs 0.007 mg L^{-1}) (table 3), however, we consider a difference of 0.004 mg L^{-1} negligible. SRP average concentrations surface and bottom, near and far-field were not significantly different (table 5), however average concentrations were higher than large scale North Channel survey results (0.45 ug L^{-1},0.39 ug L^{-1}, 0.45 ug L^{-1} and 0.40 ug L^{-1} vs 0.27 ug L^{-1} and 0.28 ug L^{-1}) (table 4). Differences in SRP concentrations were noted between the near-field, far-field and large scale North Channel surveys. It should be noted, however, all concentrations of SRP were close to the detection limit (0.2 ug L^{-1}), therefore these results may not represent any influence from the fish farm.

Discussion

Near and far-field temperature, specific conductance, pH, and dissolved oxygen were comparable to the large scale North Channel survey June 12 to 25, 2006. The minimum Provincial Water Quality Objective (PWQO) (Ministry of Environment and Energy 1994) for dissolved oxygen at 25 ^{o}C is 5 mg L^{-1}. All dissolved oxygen results for both studies were above the PWQO indicating no direct deleterious influence of organic enrichment.

The interim PWQO for TP in lakes is 10 ug L^{-1} (MOEE 1994). The minimum TP for all data in this study was <0.5 ug L^{-1} and the maximum was 8.0 ug L^{-1}. Clearly, both near and far-field TP surface and bottom results are well below the PWQO therefore not likely to cause eutrophication given the current farming practices.

In a previous study conducted by Reid et al. 2006, the average TP near-field concentrations were 6.5 ug L^{-1} (+- 0.1 ug L^{-1}) at a comparable fish farm in the North Channel. These results are higher than TP results from the present study, however, near-field results were collected 30 m from the cage edge upstream and downstream whereas our near-field samples were collected between 100 and 1000 m from the cage edge. Reid et al's results of TP concentration from the reference sites, located 2.0 to 2.5 km from the farm, were 4.5 (+-0.1 ug L^{-1}). Our far-field and large scale North Channel average TP results (surface and bottom) were 2.5 ug L^{-1} and 4.2 ug L^{-1} respectively which are comparable to Reid et al.

Site selection is one of the most important factors to consider for sustainable aquaculture. This farm is a type II site with good flushing. As a result sufficient water exchange occurs between the farm and ambient water, therefore minimizing the localized effect of the fish farm (Boyd et al. 2001). Increase in production at this farm, however, may in turn increase nutrient concentrations. Current requirements for an aquaculture license include monitoring and reporting water quality parameters by the licencee (Boyd et al. 2001) which assists regulatory agencies determine any changes over time.

Increases in nutrient loading may lead to eutrophication of an otherwise nutrient limited ecosystem. Nitrate and nitrite can be released from uneaten fish food via microbial activity (Crab et al. 2007) and from the fish themselves (Pei-Yuan et al. 2001). Ammonia is excreted in the urine and gills of fish (Young Cho and Bureau 1997). Nitrifying bacteria under aerobic conditions will oxidize ammonia forming nitrite and nitrate (Sharma and Ahlert 1977; Kemp and Mudrochova 1972). SRP, bio-available phosphorus, is excreted in the urine of the fish (Bureau and Cho 1999). SRP is of particular concern in P limited lakes such as Lake Huron and Georgian Bay because excess SRP can lead to extensive algal blooms and decreased dissolved oxygen (Gowen and Bradbury 1987). Total phosphorus includes the particulate and the soluble form derived from waste feed, fish feces, plant and animal matter. The particulate fraction may settle out of the water column contributing to benthic organic enrichment. During anoxic conditions and through biochemical processes, P may be re-introduced to the water column in a bio-available form. This study was completed in June when TP concentrations tend to be higher due to intensive fish production (June, July and August) (Norvarg and Johansson 2002). Other exogenous variables that may potentially impact water quality in the vicinity of the farm are extensive colonial water bird colonies (Hughes 2006). The predominant species are Herring Gulls, Double Crested Cormorants, and Ring-billed Gulls comprising of approximately 591 colonies that line the shores of Georgian Bay, Lake Huron and North Channel (Hughes 2006). Birds can concentrate nutrients from food into their nesting areas, therefore localized nutrient enrichment may develop that could be confused with the effects of the fish farm. Extricating potential farm impacts from other sources needs to be investigated in order to assist regulators for making sound decisions regarding sustainable aquaculture practices.

Conclusion

In the present study we found slightly elevated surface concentrations of $NO_{3/2}$ and bottom concentrations of TP near-field of the fish farm. $NO_{3/2}$ and TP concentrations for surface and bottom samples were generally lower than results from a large scale North Channel survey completed June 12 to 15, 2006. SRP average concentrations were slightly higher than those found in our large scale North Channel survey. It appears from this study that near and far-field effects of the fish farm are minimal. Elevated concentrations of Nitrite/Nitrate in a nearby wetland may be caused by other exogenous sources of nutrient loadings such as extensive bird colonies and requires further investigation.

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References

Axler, R. P., Larsen, C. P., Tikkanen, C. A., McDonald, M., Yokom, S., and Aas, P. 1996. Water quality issues associated with aqauculture: a case study in mine pit lakes. Water Enivironment Research 68:995-1011.

Boyd, D., Wilson, M., and Howell, T. 2001. Recommendations of Operational Water Quality Monitoring at Cage Aquaculture Operations. Ontario Ministry of Environment.

Brooks, K. M., Stierns, A. R., and Mahnken, C. V. W. 2003. Chemicasl and biological remediation of the benthos near Atlantic salmon farms. Aquaculture 219:355-377.

Brown, J. R., Gowen, R. J., and McLusky, D. S. 1987. The effect salmon farming on the benthos of a Scottish sea loch. Journal of Experimental Marine Biology and Ecology 109:39-51.

Bureau, D. P. and Cho, Y. C. 1999. Phosphorus utilization by rainbow trout (*Oncorynchus mykiss*): estimation of dissolved phosphorus waste output. Aquaculture 179:127-140.

Crab, R., Avnimelech, Y., Defoirdt, T., Bossier, P., and Verstraete, W. 2007. Nitrogen removal techniques in aquaculture for a sustainable production. Aquaculture 270:1-14.

Department of Fisheries and Oceans 2007. Aquaculture.

Environment Canada 2007. The National Laboroatory for Environmental Testing schedule of services.

Gowen, R. J. and Bradbury, N. B. 1987. The ecological impact of salmonid farming in coastal waters: a review. Oceanography and Marine Biology an Annual Review 25:563-575.

Hughes, K. D. 2006. Current status, trends and distributions of aquatic wildlife along the Canadian shores of Lake Huron. Canadian Wildlife Service, Environment Canada, Toronto. Technical Report Series No. 441.

Kemp, A. L. W. and Mudrochova, A. 1972. Distribution and forms of nitrogen in a Lake Ontario sediment core. Limnology and Oceanography 17:855-867.

Ministry of Environment and Energy 1994. Water management policies guidelines of the Ministry of Environment and Energy. PIBS 3303B.

Moccia, R. D. and Hynes, J. 1998. Sustainability of Ontario's aquaculture industry: 1998 and beyond. AEC98-001.

Norvarg, L. and Johansson, T. 2002. The effects of fish farm effluents on the water quality in the Aland archipelago,Baltic Sea. Aquaculture Engineering 25:253-279.

Pei-Yuan, Q., Wu, C. S. M., and Ni, I.-H. 2001. Comparison of nutrients release among some maricultured animals. Aquaculture 200:305-316.

Sharma, B. and Ahlert, R. C. 1977. Nitirification and nitrogen removal. Water Research 11:897-925.

Young Cho, C. and Bureau, D. P. 1997. Reduction of waste output from salmonid aquaculture through feeds and feeding. The Progressive Fish-Culturist 59:155-160.