Composition of Fecal Waste from Commercial Trout Farms in Ontario: Macro and Micro Nutrient Analyses and Recommendations for Recycling

Final Report Submitted to the:

Ontario Sustainable Aquaculture Working Group
Environment Canada

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14th June 2007

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1. Introduction

The regulatory compliance for aquaculture in Ontario is based in part, on the potential of farm effluent, including the disposal of collected fecal wastes, to produce deleterious effects in both the receiving aquatic and terrestrial ecosystems. As such, concentrations of phosphorus, nitrogen, and suspended solids are central to effluent monitoring in Ontario (OME 1988, Boyd, Wilson and Howel, 2001). Recently, there has been evidence that elevated levels of certain trace metals might accumulate under fish cages (Chou, Haya, Paon and Moffatt, 2003 and 2004), which may warrant additional environmental concern. More recently, there has been discussion by the Ontario Ministry of the Environment, regarding the use of toxicity testing of benthic deposits (primarily fecal and feed wastes) below cage farms, as a possible means of assessing environmental impacts. Finally, ALL land-based fish farms in Ontario that require 'Certificates of Approval' for the collection and handling of effluent, need acceptable 'Standard Operating Procedures' (SOP's) for the disposal of materials collected in the licensed sewage treatment works. This disposal must be also compatible with the phased implementation of the Nutrient Management Act that will regulate the management of all agricultural livestock manure in Ontario. In all these cases, a detailed knowledge of the macro- and micronutrients, and trace metal characteristics of fish manure is required for the proper management and disposal of this aquaculture waste product.

A detailed chemical analysis of fish feces from Ontario aquaculture farms has been previously reported (Naylor, Moccia and Durant, 1999). However, the formulations and ingredients used in commercial fish feed in Ontario, have changed significantly over the last 15 years. Notably, there has been an increase towards higher energy diets, total phosphorus concentrations have been reduced, fish-meal and plant meal types have changed, and there has been a reduction of the nondigestible materials (mainly carbohydrates and fibre) to create ‘nutrient dense’ diets (Cho and Bureau, 2001, Bureau, Gunther and Cho, 2003, Jeff Mountjoy, Martin Mills Inc, ON. *personal communication*). Therefore, research on the composition of rainbow trout feces warrants updating of this previously published material in order to reflect present day feed standards and management practices. In addition, the implementation of Ontario’s Nutrient Management Act will require new, and refined, SOP’s for the disposal of all manure wastes that may be collected from either land-based, or open water cage aquaculture facilities.

Therefore, this study provides an updated chemical analysis of feces collected from Ontario rainbow trout fed contemporary commercial feeds and addresses the implications of these findings to the Ontario Nutrient Management Act and its regulatory compliance.

2. Methods

This study was conducted at the Alma Aquaculture Research Station of the University of Guelph between March and April 2006. A domestic strain of rainbow trout, *Onchorhyncus mykiss* (Walbum) was used, with an initial average weight of 400 grams. Fish were randomly allocated to six 1-metre semi-square fibreglass tanks (350 litres volume), 40 fish per tank (Figure 1). Each tank was supplied with aerated well water (8.5º C, 15 $L.min^{-1}$). Computer controlled incandescent lights provided a natural (ie. ambient) photoperiod and lighting regimen. The discharge water pipe from each tank was modified to permit the collection of feces into an acrylic plastic container with the minimum of physical disturbance (Figure 2). Fish were fed three commercial trout feeds, selected after consultation with industry participants, to reflect the principle feeds used in Ontario aquaculture. Fish were fed ca. 0.9% body weight daily. After ensuring that all feed had been consumed and tanks and discharge pipes were cleaned, fecal collections were made between 5pm and 9am on the sampling days. Feces samples were collected from each tank on three occasions and submitted to our Laboratory Services Division, University of Guelph for chemical analysis. Similarly, three separate feed samples from each lot were collected and similarly analysed. Each sample was analysed for N, P, Ca, Mg, carbon and various selected metals using standardised and accredited methods with results reported on a dry weight basis. Statistical differences were tested using the SAS system (SAS 9.1 for Windows). The level of significance was set at $P<0.05$.

Figure 1: Rearing tank set-up with overflow and fecal collection vessels.

Figure 2. Close-up of fecal collection vessel showing intact, and undisturbed fecal particles.

3. Results and Discussion

The chemical composition of rainbow trout feces fed commercial trout diets is given in Table 1. Levels of nitrogen ranged from 3.07 to 5.23 % dry weight, with an overall average of 3.97 % dry weight. Phosphorus levels ranged from 2.20 to 3.95%, with an overall average of 2.87 % dry weight. Potassium levels were less than 0.30 % dry weight, the minimum detection limit. These low values are attributed to the high solubility of potassium salts, thereby reducing the measurable level in the fecal solids fraction. The organic carbon content of fecal material ranged from 33.7 to 46.8 % dry weight, while the organic form was less than 1% dry weight (range 0.41 – 0.80). Many of the micronutrients (ie. trace metals) were below minimum detection limits, e.g. As, Cd, Co, Hg, Mo and Pb, and all metals measured were below MOE limits for waste (MOE 1996, reprinted in Appendix, Table 5). Levels for copper and zinc ranged from 19.0 to 78.3 $mg.kg^{-1}$ and 430 to 923 $mg.kg^{-1}$, respectively.

Generally, only small differences in macronutrient values between Feces 1 and Feces 3 were observed, with values for Feces 2 being significantly different for several elements (e.g. N, P, organic and inorganic carbon). Additionally, Feces 2 tended towards higher levels of metals, and significant differences between feces for the micronutrients Cu, Fe, Se and Zn were also observed (Table 1).

The chemical composition of the three commercial trout feeds used is given in Table 2. Levels of nitrogen, phosphorus and potassium averaged 5.26, 1.08 and 0.79 % dry weight, respectively. Many of the micronutrients (metals) were below minimum detection limits, e.g. As, Cd, Co, Hg, Mo, Ni and Pb. Copper and zinc averaged 22.2 and 160.0 $mg.kg^{-1}$, respectively. The respective feed analysis data is given in the Appendix, Table 8.

Table 1. Chemical composition of rainbow trout feces fed three commercial feeds. Data measured on a dry-weight basis. Values are means ± SD where means in each row with different letters are significantly different (P<0.05).

Element	Feces 1		Feces 2		Feces 3		Average	
	mean	± SD	mean	± SD	mean	± SD	mean	± SD
Elements measured as percent								
N	3.62 ^{b}	±0.28	5.20 ^{a}	±0.04	3.08 ^{b}	±0.01	**3.97**	±1.10
P	2.51 ^{b}	±0.13	3.86 ^{a}	±0.13	2.25 ^{b}	±0.07	**2.87**	±0.86
K	<0.30 ^{a}	±0.00	<0.30 ^{a}	±0.00	<0.30 ^{a}	±0.00	**<0.30**	±0.00
Ca	5.42 ^{a}	±0.35	6.36 ^{a}	±2.64	4.91 ^{a}	±0.05	**5.56**	±0.73
Mg	0.44 ^{a}	±0.01	0.50 ^{a}	±0.03	0.39 ^{b}	±0.00	**0.44**	±0.05
Inorganic C	0.47 ^{b}	±0.08	0.79 ^{a}	±0.01	0.49 ^{b}	±0.05	**0.58**	±0.18
Organic C	42.92 ^{a}	±0.18	33.76 ^{b}	±0.06	45.88 ^{a}	±1.27	**40.85**	±6.32
Total C	43.38 ^{a}	±0.26	34.55 ^{b}	±0.07	46.37 ^{a}	±1.23	**41.43**	±6.14
Elements measured as $mg.kg^{-1}$								
As	<1.0 ^{a}	±0.00	<1.0 ^{a}	±0.00	<1.0 ^{a}	±0.00	**<1.0**	±0.00
Cd	<1.0 ^{a}	±0.00	<1.0 ^{a}	±0.00	<1.0 ^{a}	±0.00	**<1.0**	±0.00
Co	<1.5 ^{a}	±0.00	<1.5 ^{a}	±0.00	<1.5 ^{a}	±0.00	**<1.5**	±0.00
Cr	3.98 ^{a}	±0.64	7.42 ^{b}	±1.25	3.63 ^{a}	±0.57	**5.01**	±2.09
Cu	29.83 ^{a}	±1.65	77.00 ^{b}	±1.89	19.83 ^{c}	±1.18	**42.22**	±30.53
Fe	704.17 ^{a}	±23.33	1,296.67 ^{b}	±29.70	1,009.83 ^{c}	±23.81	**1,003.56**	±296.30
Hg	<0.05 ^{a}	±0.00	0.05 ^{a}	±0.00	<0.05 ^{a}	±0.00	**<0.05**	±0.00
Mn	391.17 ^{b}	±3.06	755.50 ^{a}	±3.06	941.17 ^{a}	±117.62	**695.94**	±279.79
Mo	<2.5 ^{a}	±0.00	<2.5 ^{a}	±0.00	<2.5 ^{a}	±0.00	**<2.5**	±0.00
Ni	<4.0 ^{a}	±0.43	4.68 ^{a}	±0.99	<4.0 ^{a}	±0.58	**<4.0**	±0.00
Pb	<5.0 ^{a}	±0.00	<5.0 ^{a}	±0.00	<5.0 ^{a}	±0.00	**<5.0**	±0.00
Se	<1.0 ^{b}	±0.11	1.68 ^{a}	±0.02	<1.0 ^{b}	±0.01	**<1.0**	±0.00
Zn	535.00 ^{a}	±11.79	890.00 ^{a}	±47.14	436.67 ^{b}	±9.43	**620.56**	±238.47

< Method Detection Limit

Table 2. Chemical composition of three commercial rainbow trout feeds. Data measured on a dry-weight basis. Values are means ± SD where means in each row with different letters are significantly different (P<0.05).

Element	Feed 1		Feed 2		Feed 3		Average	
	mean	±SD	mean	±SD	mean	±SD	mean	±SD
				Elements measured as percent				
N	5.18 [a]	±0.99	6.09 [a]	±1.40	4.50 [a]	±1.38	**5.26**	±0.80
P	1.12 [a]	±0.07	1.21 [a]	±0.10	0.90 [b]	±0.02	**1.08**	±0.16
K	0.88 [a]	±0.04	0.68 [b]	±0.07	0.81 [a]	±0.03	**0.79**	±0.10
Ca	1.53 [b]	±0.14	2.00 [a]	±0.27	1.29 [b]	±0.03	**1.61**	±0.36
Mg	0.18 [a]	±0.04	0.17 [a]	±0.01	0.14 [a]	±0.02	**0.16**	±0.02
Inorganic C	0.03 [a]	±0.03	0.08 [b]	±0.01	0.00 [a]	±0.00	**0.04**	±0.04
Organic C	49.97 [a]	±0.33	48.22 [b]	±0.46	49.33 [a]	±0.12	**49.17**	±0.88
Total C	50.00 [a]	±0.36	48.30 [b]	±0.46	49.33 [a]	±0.12	**49.21**	±0.86
				Elements measured as mg.kg^{-1}				
As	<1.0 [a]	±0.00	<1.0 [a]	±0.00	<1.0 [a]	±0.00	**<1.0**	±0.00
Cd	<1.0 [a]	±0.00	<1.0 [a]	±0.00	<1.0 [a]	±0.00	**<1.0**	±0.00
Co	<1.5 [a]	±0.00	<1.5 [a]	±0.00	<1.5 [a]	±0.00	**<1.5**	±0.00
Cr	1.10 [a]	±0.45	1.70 [a]	±0.78	1.18 [a]	±0.24	**1.33**	±0.33
Cu	20.67 [ab]	±6.35	32.67 [a]	±6.43	13.33 [b]	±5.13	**22.22**	±9.76
Fe	186.00 [a]	±19.08	219.00 [a]	±20.52	206.67 [a]	±37.07	**203.89**	±16.67
Hg	<0.05 [a]	±0.00	<0.05 [a]	±0.00	<0.05 [a]	±0.00	**<0.05**	±0.00
Mn	78.00 [a]	±8.19	101.33 [a]	±3.51	116.67 [a]	±45.35	**98.67**	±19.47
Mo	<2.5 [a]	±0.00	<2.5 [a]	±0.00	<2.5 [a]	±0.00	**<2.5**	±0.00
Ni	<4.0 [a]	±0.00	<4.0 [a]	±0.00	<4.0 [a]	±0.00	**<4.0**	±0.00
Pb	<5.0 [a]	±0.00	<5.0 [a]	±0.00	<5.0 [a]	±0.00	**<5.0**	±0.00
Se	<1.0 [a]	±0.00	1.25 [b]	±0.05	<1.0 [a]	±0.00	**<1.0**	±0.00
Zn	156.67 [a]	±5.77	176.67 [a]	±5.77	146.67 [a]	±80.83	**160.00**	±15.28

< Method Detection Limit

Comparison of macro-nutrient levels between the three trout feeds and their respective feces shows that nitrogen, potassium and total carbon levels decreased by 1.3%, 0.5% and 7.8%, respectively and phosphorus, calcium and magnesium levels increased by 1.8%, 4.0% and 0.3%, respectively (Tables 1 and 2, and Figure 3). Comparison of the micro-nutrients (metals) shows a general increase in levels between the feeds and their corresponding feces, i.e. copper, chromium, iron manganese and zinc showed no differences as the levels were below the Method Detection Limit (Tables 1 and 2 and Figure 4).

A comparison of data on the fecal composition measured during this study was made with those reported in the earlier research by Naylor et al. (1999) (see Table 3). Most elements showed similar concentrations, with only nitrogen levels being significantly different between the two studies ($p = 0.01$), although there is a greater coefficient of variation in values obtained from the farm-collected fecal material by Naylor et al. (1999) as compared to the in-tank collection of feces used in this study.

Similarly, a comparison of feed composition in this study with those reported in the earlier study by Naylor et al. (1999) is given in Table 4. The present study shows a reduction in the concentration of most elements measured, notably the macronutrients nitrogen and phosphorus. Also, several of the metals, notably copper and zinc were reduced in comparison to the earlier work. This is probably the result of improved ingredient digestibility, and refinement of the trace elements added in current diets.

Figure 3. A comparison of selected macronutrients levels in three commercial trout feeds and their corresponding feces. (Grey bars show the diet (feed) levels and black bars show the feces levels. Data measured on a dry weight basis. Values are means and standard errors.)

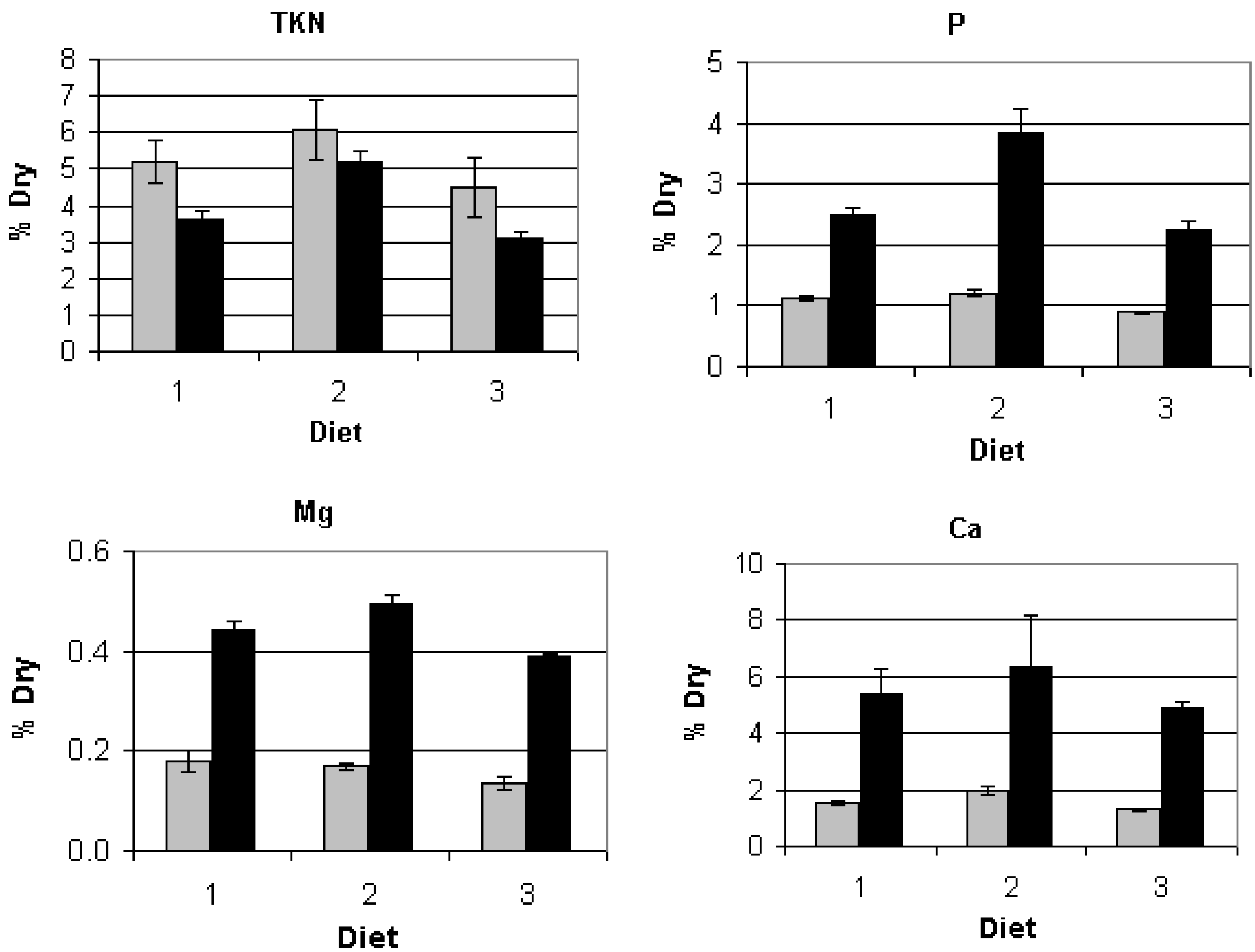

Figure 4. A comparison of selected micronutrients levels in three commercial trout feeds and their corresponding feces. (Grey bars show the diet (feed) levels and black bars show the feces levels. Data measured on a dry weight basis. Values are means and standard errors.)

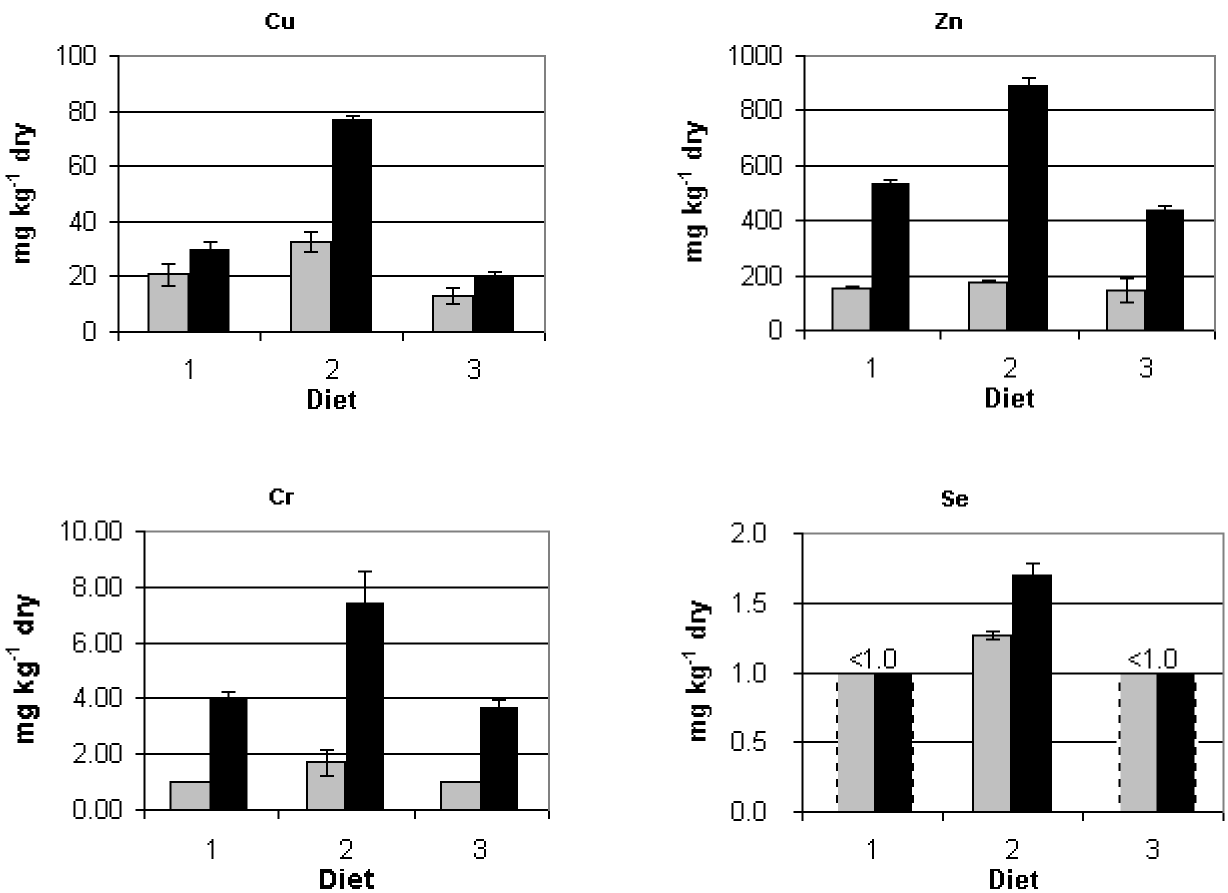

Table 3. Chemical composition of rainbow trout feces (this study) compared to values reported by Naylor et al. (1999). Data reported on a dry-weight basis. Values are means and coefficient of variation (CV).

Element	Ave. this study		Naylor et al.	
	mean	CV	mean	CV
Elements measured as percent				
N	3.97	27.8	2.83	23.3
P	2.87	30.1	2.54	47.2
K	<0.30	0.0	0.10	50.0
Ca	5.56	13.2	6.99	38.8
Mg	0.44	12.1	0.53	111.3
Inorganic C	0.58	30.9	NA	NA
Organic C	40.85	15.5	NA	NA
Total C	41.43	14.8	NA	NA
Elements measured as mg.kg^{-1}				
As	<1.0	0.0	2.20	52.7
Cd	<1.0	0.0	1.13	68.1
Co	<1.5	0.0	1.82	70.9
Cr	5.01	41.7	3.86	101.6
Cu	42.22	72.3	33.40	37.4
Fe	1,004	29.5	1,942	57.8
Hg	<0.05	0.0	0.05	100.0
Mn	695.9	40.2	487.8	83.7
Mo	<2.5	0.0	NA	NA
Ni	<4.0	26.5	4.94	92.5
Pb	<5.0	0.0	5.54	139.2
Se	<1.0	0.0	0.50	62.0
Zn	620.6	38.4	604.9	34.2

< Method Detection Limit, NA : Not Available.

Table 4. Chemical composition of rainbow trout feeds (this study) compared to values reported by Naylor et al. (1999). (Data reported on a dry-weight basis. Values are means and coefficient of variation (CV)).

Element	Ave. this study		Naylor et al.	
	mean	CV	mean	CV
Elements measured as percent				
N	5.26	15.15	7.19	12.10
P	1.08	14.77	1.15	24.35
K	0.79	12.46	0.91	28.57
Ca	1.61	22.52	1.43	27.27
Mg	0.16	13.99	0.27	7.41
Inorganic C	0.04	104.84	NA	NA
Organic C	49.17	1.79	NA	NA
Total C	49.21	1.74	NA	NA
Elements measured as $mg.kg^{-1}$				
As	<1.0	0.00	1.49	12.08
Cd	<1.0	0.00	2.26	115.93
Co	<1.5	0.00	0.99	14.14
Cr	1.33	0.33	1.00	117.00
Cu	22.22	9.76	74.50	92.07
Fe	203.89	16.67	354.00	28.76
Hg	<0.05	0.00	0.03	33.33
Mn	98.67	19.47	194.50	47.62
Mo	<2.5	0.00	NA	NA
Ni	<4.0	0.00	2.37	14.77
Pb	<5.0	0.00	1.40	53.57
Se	<1.0	0.00	0.50	62.0
Zn	160.00	38.4	604.9	34.2

< Method Detection Limit, NA : Not Available.

Summary and Conclusion

There is a growing awareness that aquaculture has an important part to play in the Ontario agrifood sector. A detailed knowledge of manure composition is important for assessing potential environmental impacts for siteing purposes, and for managing both cage and land-based aquaculture facilities in Ontario. As such, fish manure has been included in the Nutrient Management Act (Annon. 2002) for regulatory compliance purposes. While the specifics of exactly what components of the Act will be specifically applied to aquaculture are still being determined, details on fish manure composition are important for regulatory compliance, either through the NM Act itself, or within existing regulatory compliance mechanisms such as the Certificate of Approval. Guidelines for the utilization of biosolids and other wastes on Agricultural Land (MOE 1996) and the study results for the composition of trout feces can be used for an initial estimate of fish manure application rates for Ontario soils (Appendix, Table 7). These results show that the concentration of zinc may be a potentially limiting factor for application (approximately 530 tonnes per hectare), with the next limiting factors being cadmium and molybdenum at more than three times this quantity. For example, a farm producing 100 tonnes of fish annually, and assuming complete recovery of the 32% solid waste produced (Bureau et al. 2003), the minimum land area required for manure application is only 0.06 hectares (600 m^2).

Currently, the regulations controlling cage aquaculture in Ontario are also under review. The importance of the sediment as a complex ecosystem is recognized, and efforts are being made to provide science-based criteria to support a comprehensive and credible regulatory process. The chemical composition of feces and feed provided in this study will assist in the development of models which can be used to predict the assimilative capacity of the receiving watershed for solid waste from cage aquaculture. Of particular importance will be the determination of the impact of certain metals present in the waste (e.g. copper and zinc) and their bioavailability to the benthic community.

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4. Appendices

Table 5. Criteria for Metal Content in Sewage Biosolids for Ontario (Reprinted from Ontario Ministry of Environment 1996).

1	2	3	4	5
Metals	Anaerobic Biosolids		Aerobic, Dewatered and Dried Biosolids and Other Wastes	
	Minimum Ammonium + Nitrate Nitrogen (NH_4^+-N + NO_3^--N) to Metal Ratios		Maximum Permissible Metal Concentrations (mg/kg of solids)	
	Present Requirements	Long-term Targets	Present Requirements	Long-term Targets
ARSENIC	100	480	170	35
CADMIUM	500	4200	34	4
COBALT	50	220	340	77
CHROMIUM	6	32	2800	530
COPPER	10	45	1700	380
MERCURY	1500	8400	11	1.4
MOLYBDENUM	180	1700	94	1.2
NICKEL	40	210	420	80
LEAD	15	75	1100	220
SELENIUM	500	2800	34	6
ZINC	4	20	4200	840

a. Acceptability of biosolids will be judged on the basis of the average concentrations of nitrogen, metals and solids during the preceding 12 months. B. All dewatered and dried biosolids must meet the appropriate biosolid criteria before dewatering and drying. C. The long term targets are based on the assumption that metal additions to soil from waste materials is undesirable and that application rates of metals should be reduced in the future.
b. All dewatered and dried biosolids must meet the appropriate biosolid criteria before dewatering and drying.
c. The long term targets are based on the assumption that metal additions to soil from waste materials is undesirable and that application rates of metal should be reduced in future.

Table 6. Criteria for Metal Content in Soils for Ontario (Reprinted from Ontario Ministry of Environment 1996).

1	2	3	4	5	6
Metal	Mean Metal Content in Uncontaminated Ontario Soils[a] (mg/kg)	Maximum Permissible Metal Content in Soils Receiving Waste Materials[a] (mg/kg)	Maximum Permissible Metal Addition to Uncontaminated Soil[b] (kg/ha)	Maximum Permissible Metal Application per 5 years[d] (kg/ha)	Minimum Number of Years to Reach Max. Recommended Metal Content in Soil[b&c]
ARSENIC	7	14	14	1.40	50
CADMIUM	0.8	1.6	1.6	0.27	30
COBALT	5	20	30	2.70	55
CHROMIUM	15	120	210	23.30	45
COPPER	25	100	150	13.60	55
MERCURY	0.1	0.5	0.8	0.09	45
MOLYBDENUM	2	4	4	0.80	25
NICKEL	16	32	32	3.56	45
LEAD	15	60	90	9.0	50
SELENIUM	0.4	1.6	2.4	0.27	45
ZINC	55	220	330	33.00	50

a. Based on dry weight at 105°C.
b. Columns 4 and 6 take into account the mean metal content of uncontaminated soils (see column 2). These numbers are examples because most soils are unlikely to have exactly the mean metal contents listed in column 2.
c. Based on anaerobic biosolid applications providing 135 kg/ha of ammonium plus nitrate nitrogen, or aerobic biosolid applications providing 8 tonnes of dry solids per hectare per 5 years, as outlined in these Guidelines. The number of years is rounded to the nearest five. See sample calculation in Figure 4
d. Column 4 divided by column 6 will give metal application for one year. To obtain the figures in column 5 the yearly metal application figures are multiplied by 5.

Table 7. Estimation of fish manure application rates based upon average metal levels in rainbow trout feces and typical metal levels in Ontario soils.

Metal	Maximum permissible metal addition in soil ($kg.ha^{-1}$) [a]	Average concentration in trout feces ($mg.kg^{-1}$)	Dry weight of solids applied ($tonnes.ha^{-1}$)
Arsenic	14	1.0	14,000
Cadmium	1.6	1.0	1,600
Cobalt	30	1.5	20,000
Chromium	210	5.0	42,000
Copper	150	42.2	3,555
Mercury	0.8	0.05	16,000
Molybdenum	4	2.5	1,600
Nickel	32	4.0	8,000
Lead	90	5.0	18,000
Selenium	2.4	1.0	2,400
Zinc	330	621	531

[a] Based on mean metal content of uncontaminated Ontario soils (see MOE 1996 and Appendix, Table 6, Column 2).

Table 8. Feed analysis data for the three commercial rainbow trout feeds used (as reported on the product labels).

	FEED 1	FEED 2	FEED 3
Crude protein (min.)	41.0%	45.0%	41.0%
Crude fat (min.)	23.0%	22.0%	24.0%
Crude fibre (min.)	2.1%	1.5%	4.0%
Calcium (actual)	1.3%	1.4%	1.0%
Phosphorus (actual)	1.1%	1.15%	0.9%
Sodium (actual)	0.6	0.4%	0.55%