

Composition of Feed and Fecal Waste from Commercial
Trout Farms in Ontario:
Physical Characterization and Relationship to Dispersion
and Depositional Modelling

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Table of Contents

1. Introduction.....	3
2. Methods	4
3. Results and Discussion	7
4. References	18
5. Appendix	21

1. Introduction

The physical characteristics of feed and fecal waste products (manure) from trout aquaculture are important to the development of improved effluent treatment methods, and for the regulatory control of ‘open’ system technologies (e.g. cage farming), which is based in part, on the dispersal characteristics of wastes in the receiving ecosystem. The physical characteristics of primary interest include the size distribution of particles of fecal matter, along with their corresponding settling characteristics. These characteristics provide the fundamentals for wastewater treatment design in land-based aquaculture facilities (e.g. predicting pipe size, flow rates and gravitational clarifier size etc.) and also for the modelling of waste particle dispersion and the benthic ‘footprint’ of cage-based aquaculture facilities.

The present theoretical basis for the design of wastewater treatment methods is founded on studies that were done 15 or more years ago (e.g. Cho, Hynes, Wood and Yoshida 1990, MOE 1990, Westers 1990). During the intervening period, there have been considerable advances in both diet formulation and fish management, such that present day fecal products from fish are quite different in both their consistency and physical characteristics. Additionally, an area of growing interest is in the improvement of wastewater management through the use of increasingly complex treatment systems (e.g. swirl separators, drum & screen filtration and tube settlers etc.) and these technologies require improved estimates of the physical characteristics of fish waste in order to optimize their design, application use (Cripps and Bergheim 2000, Stechey 2003).

The current study provides an update of the main physical characteristics of fecal waste produced by rainbow trout fed modern commercial diets.

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, *Onchorhynchus mykiss* (Walbaum) were used, with an initial average weight 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 (8.5° C, 15 L.min⁻¹). Computer controlled incandescent lights provided a natural, ambient photoperiod and lighting regimen. The discharge pipe from each tank was modified to permit the collection of feces into an acrylic plastic container with the minimum of physical



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

disturbance (Figure 2). Fish were fed three commercial trout feeds, selected after consultation with several industry participants, in order to reflect the principle feeds used in Ontario aquaculture. Each feed was 5 mm diameter, sinking pellets. Fish were fed ca. 0.9% body weight daily. After ensuring that all feed had been consumed and tanks and discharge pipes were

clean, fecal collections were made between 5pm and 9am on sampling days. At 0900 hrs. on each sampling day, the acrylic container was removed from the discharge pipe, excess water was carefully siphoned off to leave approximately 300 ml of undisturbed and intact feces.



Figure 2. Close-up of fecal collection vessel showing intact trout fecal pellets.

A settling column was manufactured from a vertically mounted acrylic tube (152 cm height, 10.6 cm diameter) with a conical discharge port controlled with a ball valve (Figure 3). It was filled with aerated well water (8.5° C). A portion of the collected feces was then gently introduced into the top of the settling column, and 11 sequential samples of settled feces were collected from the discharge port over a 60 minute period. The sampling time, duration and volume collected were recorded. Each sample volume was filtered (Whatman glass fibre filter,

type 934/AH) and dried (103 – 105° C) to determine the dry weight of the settled feces. The sum of the dry weights of the 11 fecal samples was taken as the total mass, from which the individual sample mass-fraction was then determined. Fecal settling velocity was calculated knowing the distance travelled and the time taken, using the method described by Wong and Piedrahita (2000) to adjust for changes in distance travelled (i.e. water column height) as sequential sample volumes were removed. The mass-based settling velocity curve was produced by plotting fecal settling velocity against (1-cumulative mass-fraction) and fitting a quadratic equation to the results. Fecal samples were collected from each tank (6) on three separate occasions to provide a mean value for each replicate tank. The mean % mass-fraction of feces settled at each sample period was compared using Tukey's Honestly Significant Difference (HSD) test (SAS 9.1 for Windows). The level of significance was set at $P < 0.05$.



Figure 3. Settling column

The efficiency of the fecal collection system was evaluated by sampling the overflow water using a Sigma 900 Standard Portable Sampler. Samples of 200 ml were taken at 30 minute intervals from 1700 until 0900 hrs. (ie. overnight). The composite samples were then analysed for particle size distribution using a Mastersizer 2000 operated by the Engineering Department, University of Guelph.

The settling velocity of individual fecal and feed pellets were determined by recording the time taken to travel 100 cm of free-fall distance in the acrylic settling column previously described. Individual fecal pellets were selected to maximize the range of fecal pellet weight.

Fecal density was determined by placing individual fecal pellets in sucrose solutions of known specific gravity (range 1.015 – 1.057 g.cm⁻³) and determining buoyancy.

3. Results and Discussion

Particle size analysis of the overflow water failed to produce any meaningful results because the particle size of material collected was smaller than the detection limit of the apparatus used (Mastersizer 2000). Nevertheless, this lack of data supports the observation that the vast majority of the feces produced was deposited in the collection vessels and thus available for the evaluation of fecal settling velocity.

Mass-based settling velocity curves of individual fecal collections from rainbow trout fed three commercial feeds are presented in Figures 4a, 4b and 4c, respectively. The data are plotted on a semi-log scale and a quadratic equation provided a best fit to the curve. Each figure shows the data of two replicate tanks of fish, sampled on three separate occasions. The corresponding feed analysis data is given in the Appendix, Table 4.

Figure 4a. Mass-based settling curve for Feces 1 (rainbow trout fed Feed 1).

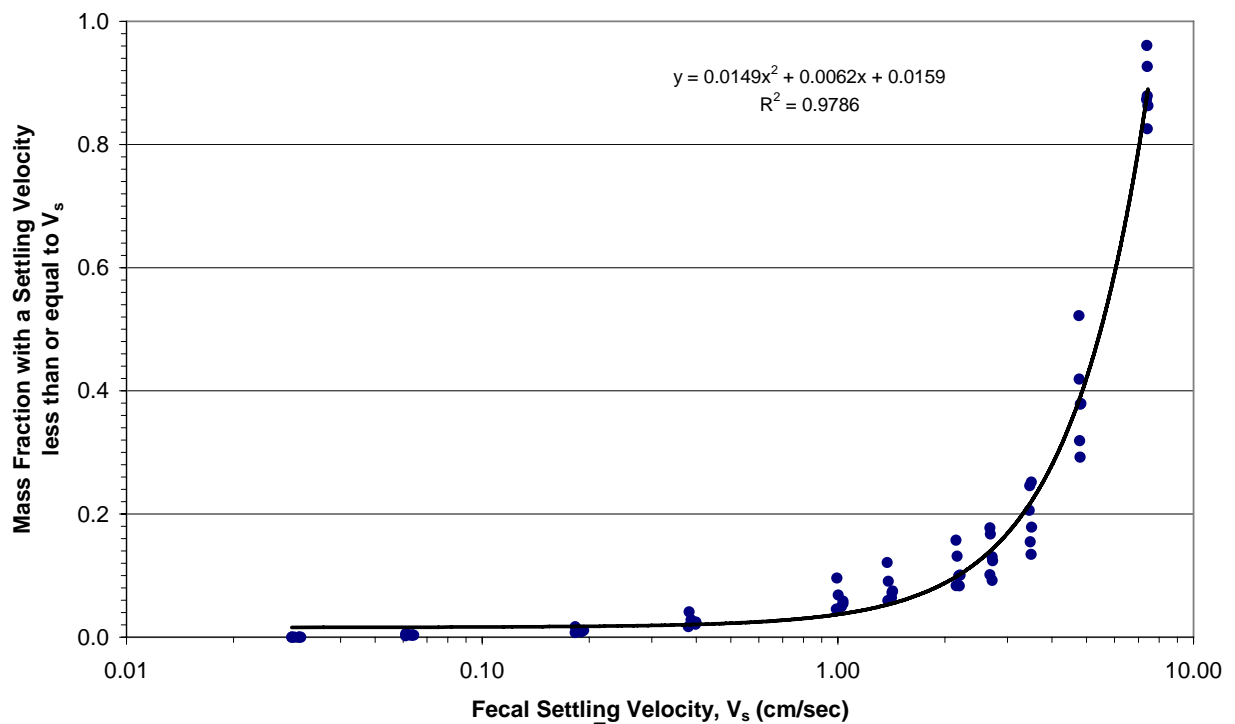


Figure 4b. Mass-based settling curve for Feces 2 (rainbow trout fed Feed 2).

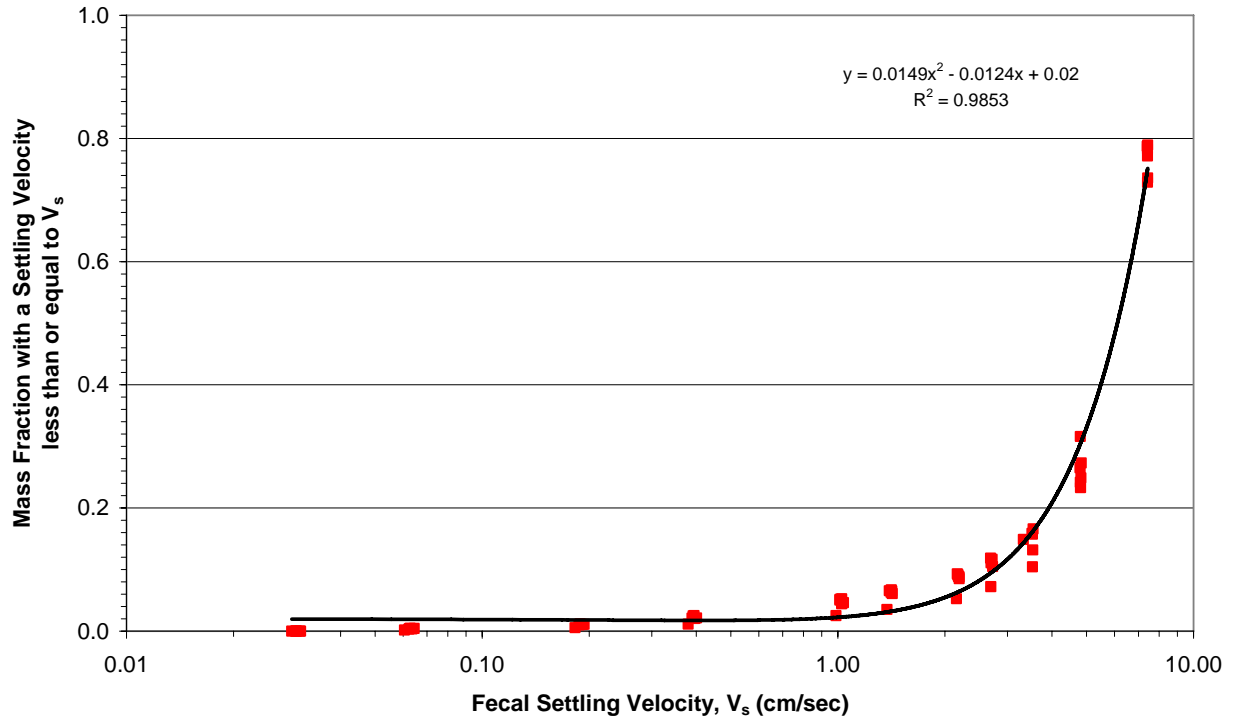
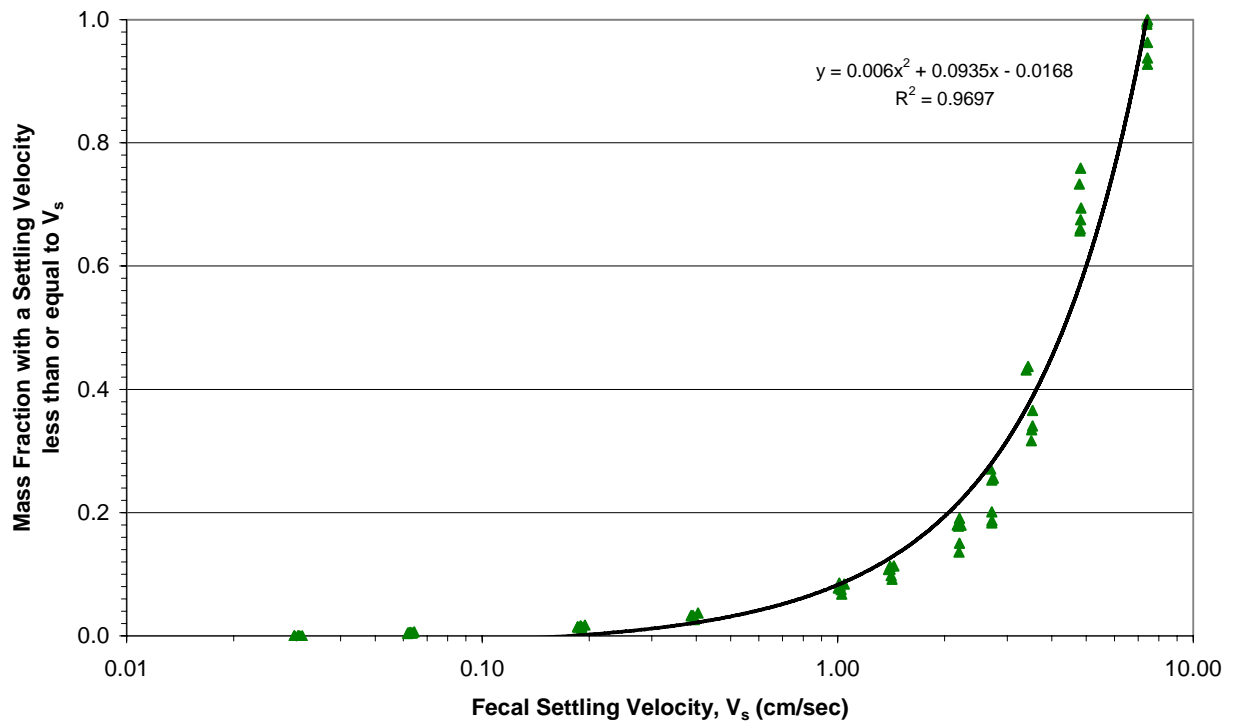


Figure 4c. Mass-based settling curve for Feces 3 (rainbow trout fed Feed 3).



The average mass-based settling velocity curves for each feces is provided in Figure 5. The settling velocity of Feces 3 lies to the left of Feces 1 and 2 indicating a slower rate of settling. For example, 50% of Feces 3 had a settling velocity of $\leq 4.33 \text{ cm}\cdot\text{sec}^{-1}$, compared to Feces 1 and 2 which had settling velocities ≤ 5.48 and $6.08 \text{ cm}\cdot\text{sec}^{-1}$, respectively (Table 1).

Figure 5. Mass based settling velocity curves for trout feces. Data points are the average from two tanks of fish sampled on three occasions.

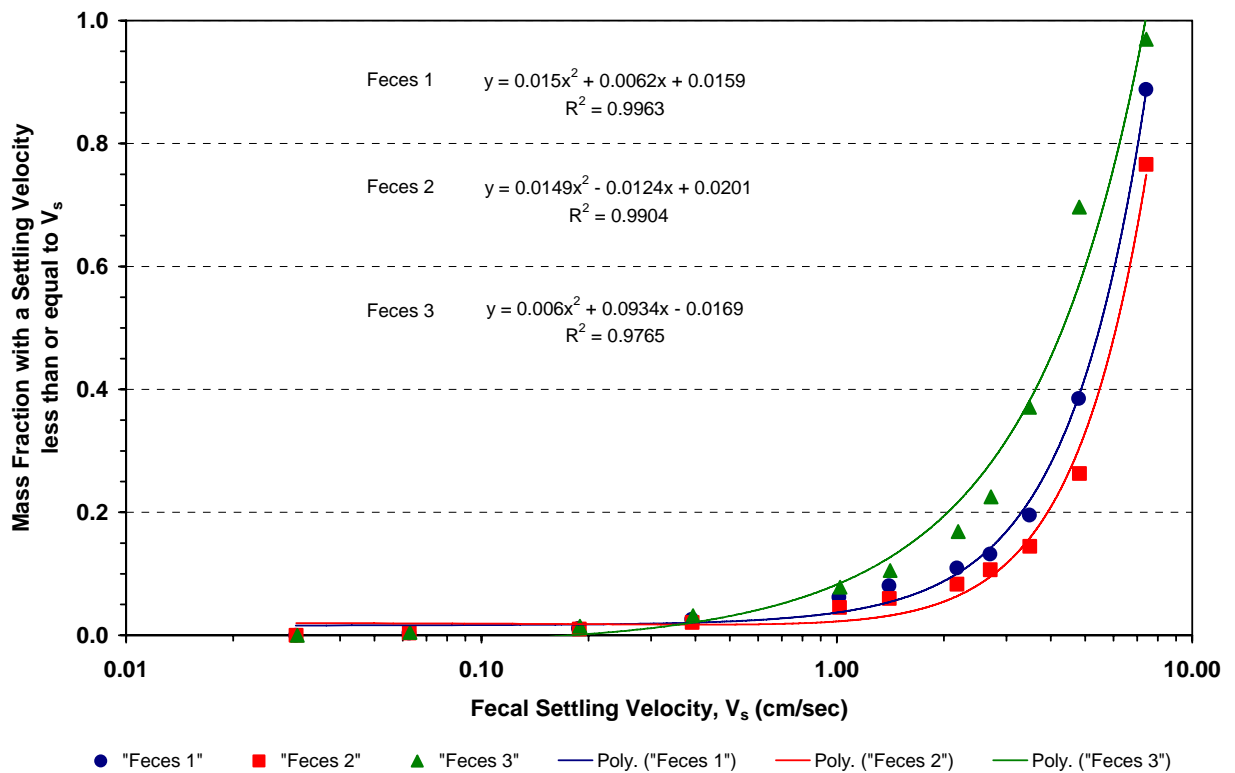


Table 1. Average settling velocity of rainbow trout feces for selected mass fractions.

Fecal mass fraction	Feces 1 Settling Velocity (cm.sec⁻¹)	Feces 2 Settling Velocity (cm.sec⁻¹)	Feces 3 Settling Velocity (cm.sec⁻¹)
0.2	3.30	3.92	2.05
0.5	5.48	6.08	4.33
0.8	7.03	7.66	6.24

The percentage mass fraction of feces that settled for each of the eleven sampling periods is given in Table 2 and Figure 6. A comparison of the mean percentage mass fraction shows that Feces 3 was significantly different from Feces 1 and Feces 2 at all periods except 600, 1800 and 3600 seconds. For example, after 30 seconds, 61% and 73% of Feces 1 and Feces 2 settled-out, respectively; compared to only 30% for Feces 3. The lack of a difference at the longer time periods (over 10 minutes) shows that all fecal samples contained similar proportions of slow settling material, but this accounts for only 2 – 3% of the total produced (Feces1: 2.7%, Feces 2: 2.1%, Feces 3: 3.2%).

The cohesiveness of the feces was not specifically examined in this study. However, the labile nature of the feces was apparent and Feces 3 appeared softer and fractured more easily than Feces 1 and Feces 2. It is known that differences in feed formulation can affect fecal cohesiveness. Ogunkoya et al. (2006) showed that fecal cohesiveness was reduced with the inclusion of soybean meal and an enzyme cocktail (Superzyme CS), whereas the addition of guar gum increases

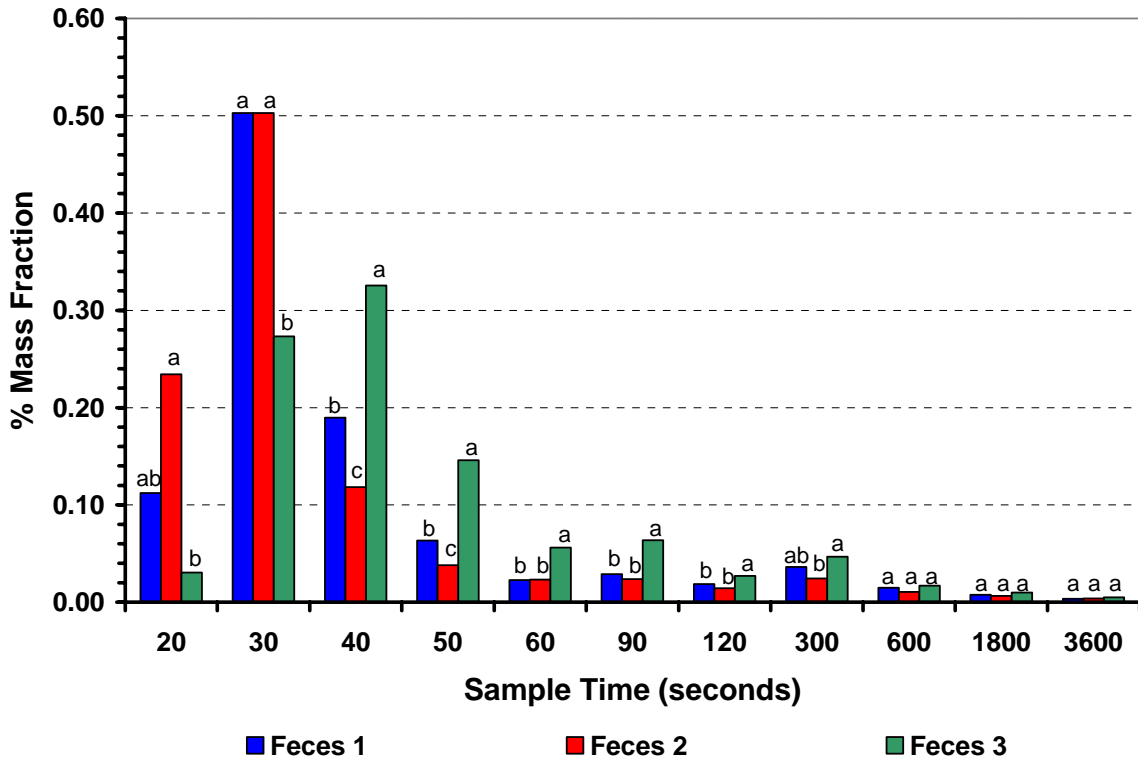
cohesiveness (Jeff Montjoy, Martins Mills Inc. ON. *Personal communication*). In land-based aquaculture, an increase in cohesiveness could increase the efficiency of waste transportation from rearing facility via pipes and channels to the waste treatment facility (e.g. settling tanks and/or mechanical filtration). In open water culture, a less cohesive fecal pellet may expand the benthic, waste deposition footprint, especially in deep water situations.

Table 2. Comparison of mean % mass fraction of rainbow trout feces that settled over different sampling periods.

Sample Time	Feces 1	Feces 2	Feces 3
(seconds)	% Mass Fraction	% Mass Fraction	% Mass Fraction
20	11.2 ^{ab}	23.4 ^a	3.0 ^b
30	50.3 ^a	50.3 ^a	27.3 ^b
40	19.0 ^b	11.8 ^c	32.6 ^a
50	6.3 ^b	3.8 ^c	14.6 ^a
60	2.3 ^b	2.3 ^b	5.6 ^a
90	2.9 ^b	2.4 ^b	6.4 ^a
120	1.8 ^b	1.4 ^b	2.7 ^a
300	3.6 ^{ab}	2.4 ^b	4.7 ^a
600	1.5 ^a	1.1 ^a	1.7 ^a
1800	0.8 ^a	0.6 ^a	1.0 ^a
3600	0.4 ^a	0.4 ^a	0.5 ^a

Note: Values in the same row that do not share common superscript letters are significantly different ($P < 0.05$).

Figure 6. Comparison of mean % mass fraction of rainbow trout feces that settled over different sampling periods. Data points are the average from two tanks of fish sampled on three occasions.



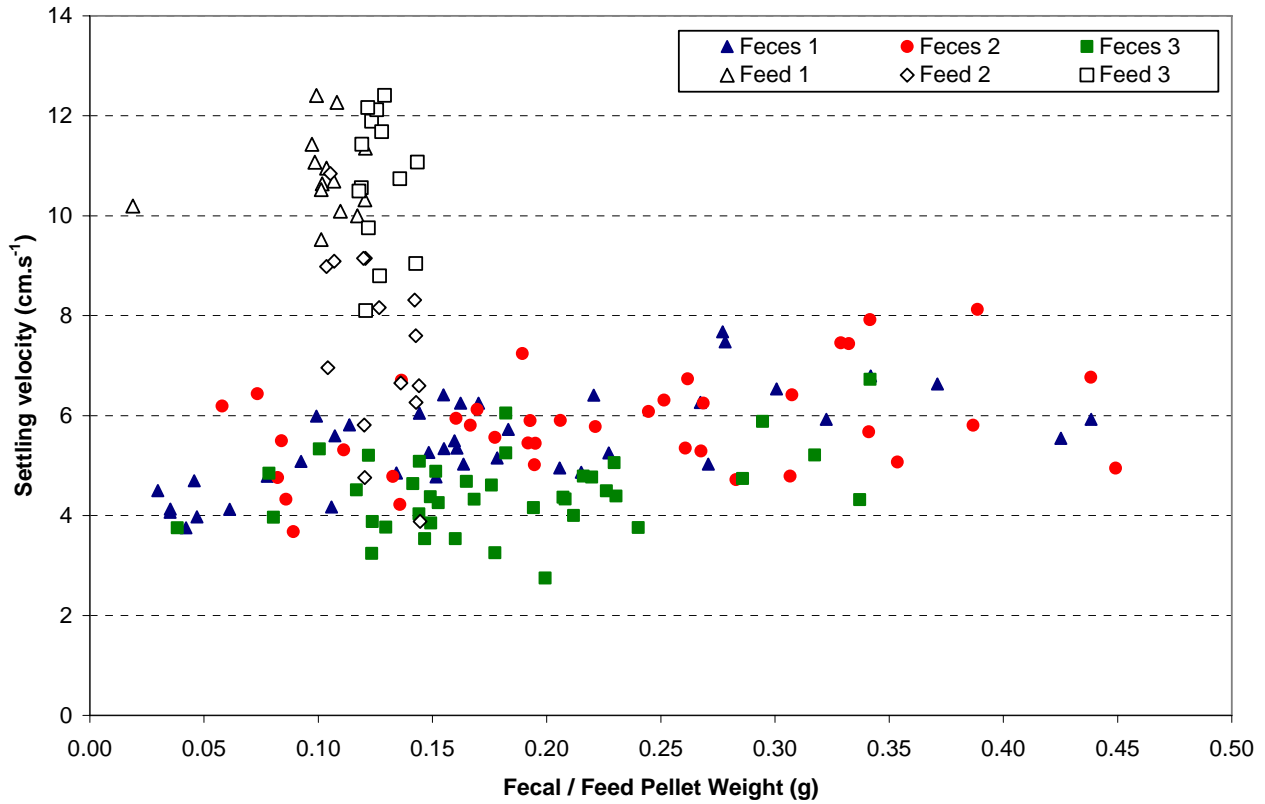
Note: Values at the same sample time that do not share common letters are significantly different ($P < 0.05$).

The settling velocity of individual fecal pellets and feed pellets are given in Figure 7. The median settling velocity of Feces 1, 2 and 3 was 5.4, 5.8 and 4.4 $\text{cm}\cdot\text{sec}^{-1}$, respectively. There was a weak correlation between pellet weight and settling velocity for Feces 1 ($R^2 = 0.56$), but no correlation for Feces 2 and Feces 3, over the range examined. The overall settling velocity ranged from 2.8 – 8.1 $\text{cm}\cdot\text{sec}^{-1}$ with a mean of 5.2 $\text{cm}\cdot\text{sec}^{-1}$.

There are few studies reporting individual fecal pellet settling velocity, partially because of the difficulty in obtaining “undisturbed fecal samples” as opposed to waste material deposited within the rearing system (e.g. Elberizon and Kelly, 1998, Wong and Piedrahita, 2000, Brinker, Koppe and Rösch, 2005). Chen et al. (1999) collected newly evacuated and stripped feces from salmon (700 - 1000 g.) with mean fecal settling velocities values of 5.8 and 6.0 cm.sec⁻¹, respectively and Cromey et al. (2002) report fecal settling velocities ranging from 1.5 to 6.3 cm.sec⁻¹ (mean 3.2 cm.sec⁻¹) for salmon averaging 3.4 kg. In a study of rainbow trout (approximately 100 grams), Ogunkoya et al. (2006) report fecal settling velocities ranging from 2.7 to 3.9 cm.sec⁻¹ (mean 3.3 cm.sec⁻¹).

The settling velocity of trout feed greatly exceeds that of the corresponding feces generated using this feed, with observed values ranging from 3.9 – 12.4 cm.sec⁻¹ (Figure 7). The median settling velocity of Feeds 1, 2 and 3 was 10.7, 7.6 and 10.9 cm.sec⁻¹, respectively. These observed settling velocities are very similar to those reported by Cromey et al (2002) who found a positive correlation between pellet diameter (2 – 13 mm) and settling velocity (mean settling velocity 10.8 cm.sec⁻¹ for 7 mm feed).

Figure 7. Settling velocity of individual trout fecal and feed pellets (5 mm diameter).



The specific density of individual trout fecal pellets ranged from 1.022 to 1.052 g.cm⁻³. Samples of Feces 3 had the lowest density, while samples of Feces 2 had the highest (Table 3). The pattern of specific density follows that observed for the settling velocity, where Feces 3 had lower values than those for Feces 2 (Figure 5 and Table 1). The values in this study are similar to the values of 1.023 – 1.038 g.cm⁻³ reported by Ogunkoya et al. (2006) for rainbow trout of approximately 100 g.

Table 3. Specific density of rainbow trout fecal pellets fed three commercial diets, as determined by observing buoyancy in sucrose solutions with different specific gravities.

	Minimum Specific Density (g.cm⁻³)	Maximum Specific Density (g.cm⁻³)	Median Specific Density (g.cm⁻³)
Feces 1	1.024	1.048	1.036
Feces 2	1.027	1.052	1.040
Feces 3	1.022	1.044	1.033

As aquaculture fish production increases, there is a growing concern about the environmental impact of the waste products which are generated as a result of these production systems. Consequently, technology for waste treatment is being refined and new methods investigated. Waste treatment methods generally focus on a reduction in the solids produced (e.g. improved digestibility of diets, reduced feed wastage etc.) and/or the removal of solids that are produced. Techniques to reduce and remove soluble waste are also available, and are of great importance in recirculating aquaculture system designs.

Sedimentation and mechanical filtration are the principle methods used for solids removal in land-based aquacultural systems. The fundamental design of sedimentation systems depends upon knowing the settling velocity of the particles and the basin overflow rate (MOE 1990, Stechey

2003). This study's estimate of fecal settling velocity for the various mass-fractions permits the opportunity to refine the design basis.

In cage-culture systems, the management of solid waste is typically addressed by allowing the solids to be dispersed, with some efforts being made to adopt sedimentation techniques (e.g. contained bag production and under-cage collection systems). The development of predictive waste dispersion models (e.g. DEPOMOD) for managing the environmental impacts of cage culture depend, in part, upon knowing the precise settling characteristics of the waste outputs – both feces and uneaten feed (Cromeey et al. 2002). In these models, settling velocity of waste particles can either be approximated as a single mean value, or assigned a more accurate probability distribution accounting for the different mass fractions that exist. The results from the present study provide significant input for this second refinement in the modelling approach.

Salmonid fecal settling velocity values of $2 \text{ cm}\cdot\text{sec}^{-1}$ that are typically used in predictive models, and are probably way too low based on our data. The median values in this study suggest that a value of $4 \text{ cm}\cdot\text{sec}^{-1}$ is a better estimate for intact rainbow trout fecal pellets (Figure 8). This would result in a reduction in the foot print surface area of 50% with a corresponding doubling in the depth of the deposition zone (Figure 9). The settling velocity of uneaten feed is considerably higher than that of the feces. In this study, the overall median value for the three feeds was $10 \text{ cm}\cdot\text{sec}^{-1}$, and therefore uneaten feed will be deposited within a smaller area than that of the fecal footprint. A secondary consequence of the rapid settling of fecal material and uneaten feed, are the steep contours of benthic deposits which in turn will influence selection of appropriate sediment sampling methods.

Figure 8. Average settling velocity of rainbow trout feces for selected mass fractions. Reference line at $2 \text{ cm}\cdot\text{sec}^{-1}$ shown for comparison to widely accepted settling velocity value.

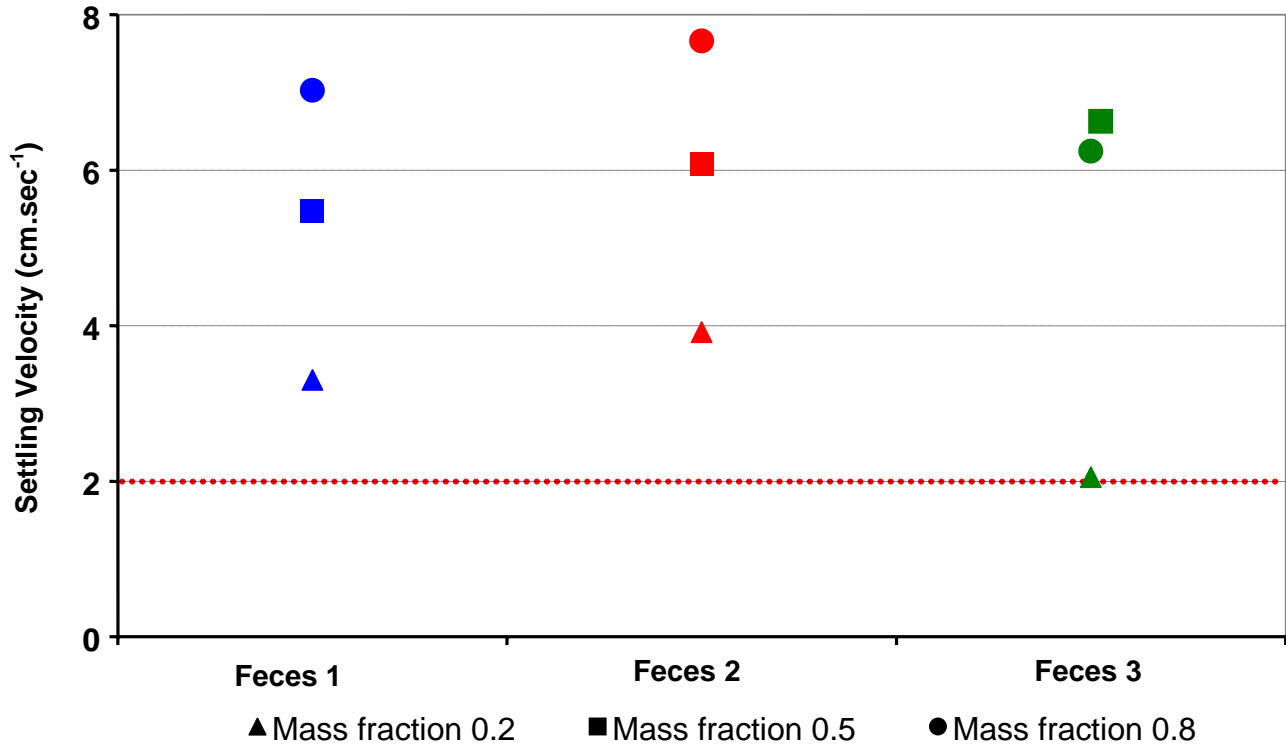
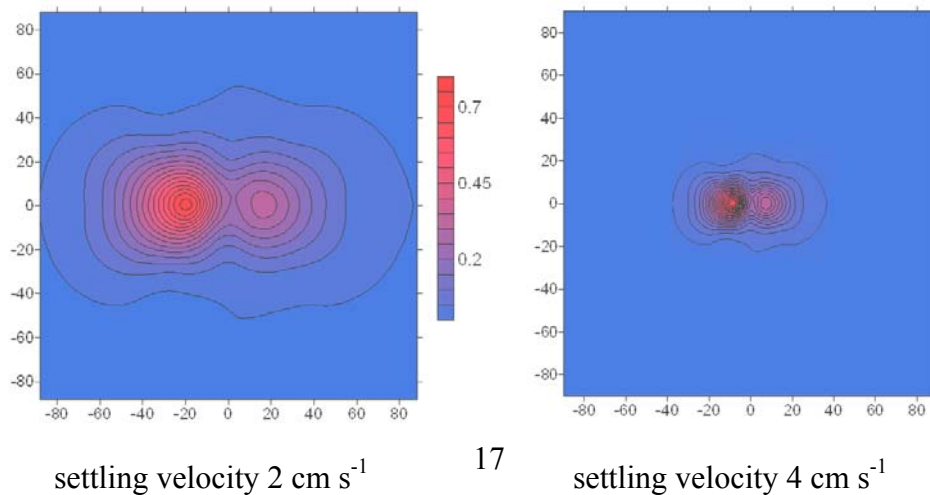


Figure 9. Rudimentary deposition simulation of fecal particles showing accumulation contours (kg m^{-2}) for two averaged settling velocities and 8 directional vectors.



Further areas of research include:

(i) Quantifying the cohesiveness of feces and its influence on the break up of material during transportation either between the rearing tank and treatment centre or during deposition to the sediment in open water. Changes in water temperature, feeding regimen and diet composition are also expected to influence fecal cohesiveness.

(ii) Determining the size distribution of fecal waste as it pertains to filtration membrane selection and pipe size selection in recirculation systems. Of concern is the design conflict between reduced pipe size to increase scouring velocity and increase solids removal efficiency and the potential problems that can result from biofilm accumulation.

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5. Appendix

Table 4. 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%