WASTES/EFFLUENTS[9]

Project Component Termination Report for the Period
September 1, 1996 to August 31, 1999

NCRAC FUNDING LEVEL: $10,000 (September 1, 1996 to August 31, 1999)

PARTICIPANT:

Fred P. Binkowski	University of Wisconsin-Milwaukee	Wisconsin
Industry Advisory Council Liaison:		
Harry Westers	Aquaculture Bioengineering Corporation, Rives Junction	Michigan
Extension Liaison:		
LaDon Swann	Purdue University	Illinois/Indiana

REASON FOR TERMINATION

The objective for this work on Wastes/Effluents has been completed.

PROJECT OBJECTIVE

(1) Develop a report that:

(a) describes the potential benefits of aquacultural by-products (effluents and solids) in the context of Integrated Resource Management and Sustainable Development,

(b) characterizes the differences between the aquacultural discharges and other agricultural and industrial discharges, and

(c) identifies case studies of previous controversies highlighting real versus perceived impacts of aquaculture.

PRINCIPAL ACCOMPLISHMENTS

Selected references specifically on aquacultural wastes and on related agricultural, municipal, and industrial waste management and recovery techniques were compiled into a 96-page report. The report is divided into a number of sections each containing a list of references and summarizing comments. The sections cover a variety of topics and subject areas including: a general overview; different rearing systems (e.g., ponds, flow through, etc.); sources of aquaculture by-products and waste generation including the role of fish bioenergetics, feed formulation, microbial content, and antibiotics; potential utilization and recovery of solids and nutrients from aquaculture effluents by irrigation, wetlands, vegetative buffers, and hydroponics; waste solids and sludge utilization by land application and composting, including aquaculture examples in comparison to agricultural manure and sewage sludge utilization, along with coverage of water quality, soil, health and toxicity issues associated with sludge usage; and a comparison of aquaculture waste production with alternative land use practices. Available regional cases were highlighted as examples of various effluent issues and practices.

IMPACTS

The report summarizes scattered information on aquacultural wastes and effluents which could be used by regional aquaculturists, researchers, and resource agency personnel to locate information on potential recovery and reuse of aquaculture effluents and waste solids when planning waste management strategies or policies.

RECOMMENDED FOLLOW-UP ACTIVITIES

Several topical extension fact sheets or technical bulletins concerned with aquaculture waste management could be developed from sections of this report.

PUBLICATIONS, MANUSCRIPTS, OR PAPERS PRESENTED
See Appendix A for a cumulative output for all NCRAC-funded Wastes/Effluents activities.

SUPPORT

YEARS	NCRAC-USDA FUNDING	OTHER SUPPORT					TOTAL SUPPORT
		UNIVERSITY	INDUSTRY	OTHER FEDERAL	OTHER	TOTAL	
1996-99	$10,000						$10,000
TOTAL	$10,000						$10,000

WASTES/EFFLUENTS[10]

Progress Report for the Period
September 1, 1996 to August 31, 1999

NCRAC FUNDING LEVEL: $90,000 (September 1, 1996 to June 30, 1999)

PARTICIPANTS:

Ira R. Adelman	University of Minnesota	Minnesota
Fred P. Binkowski	University of Wisconsin-Milwaukee	Wisconsin
Christopher C. Kohler	Southern Illinois University-Carbondale	Illinois
Industry Advisory Council Liaison:		
Harry Westers	Aquaculture Bioengineering Corporation, Rives Junction	Michigan
Extension Liaison:		
LaDon Swann	Purdue University	Illinois/Indiana
Non-Funded Collaborators:		
Antony Grabowski	Milwaukee County House of Correction Fish Hatchery	Wisconsin
John Hyink	Glacial Hills, Inc./Alpine Farms, Sheboygan Falls	Wisconsin
Jeffrey A. Malison	University of Wisconsin-Madison	Wisconsin
John Wolf	Glacial Hills, Inc./Alpine Farms, Sheboygan Falls	Wisconsin

PROJECT OBJECTIVE
(1) Study and evaluate solid waste management by:

(a) describing the relevant physical characteristics of fecal material from fish fed commonly used commercial feeds,

(b) developing diets to maximize integrity of fecal pellets without loss of fish performance and compare the physical characteristics of these pellets to those in subobjective a, and

(c) developing operational and engineering solutions to minimize destruction of larger particles and to remove all particulates.

ANTICIPATED BENEFITS

Characterization of the possible differences in fecal waste properties of important regional alternative species will assist in the engineering design and operation of rearing systems for waste removal.

Faster and more complete separation of structurally intact fish fecal material from the culture water could greatly reduce biological activity associated with fecal breakdown. Removal of organic fecal components could reduce biological and chemical oxygen demands associated with their breakdown as well as reduce the need for water oxygenation/aeration. Controlling levels of fecal material could also deprive potentially pathogenic bacteria of favorable environments that could promote epizootics. Improving fecal structural integrity could also control leaching of nitrogenous waste that increases requirements on biofilters for nitrification activity.

PROGRESS AND PRINCIPAL ACCOMPLISHMENTS

OBJECTIVE 1A

University of Wisconsin-Milwaukee (UW-Milwaukee)

Researchers investigated the physical properties of freshly deposited feces generated through intensive tank culture of yellow perch fed commercial feeds at various phases of the production cycle at commercial rearing densities and grow-out temperature (18–23°C; 64.4–73.4°F). The phases examined to date include: (1) perch approaching market size (approximately 100–150 mm [3.9–5.9 in] total length) and fed Zeigler Bros. trout grower, (2) mature perch at marketable sizes (>150 mm; >5.9 in) fed Zeigler Bros. trout grower, (3) advanced fingerlings (50–100 mm; 2.0–3.9 in) fed Zeigler Bros. salmon starter, and (4) young fingerlings (25–75 mm; 1.0–3.0 in) habituated to feed exclusively on Biodiet #2 starter feed.

Initial attempts at individually isolating or anesthetizing fish to collect freshly egested fecal material were found to be unreliable in obtaining enough material to conduct investigations of specific gravity and fecal friability. Therefore, a low-head, side-stream siphoning device was constructed and installed on circular rearing tanks so that freshly settled fecal materials and uneaten food could be collected from the sump of the rearing tanks. The collecting basin (a 18.9-L [5.0-gal] pail) for the siphoned material was raised so that the water surface in the collection basin was just below that of the rearing tank. For 2.44-m (8.0-ft) diameter tanks, a smooth semi-flexible clear vinyl tube (approximately 28-mm [1.1-in] diameter) and a side-stream flow of around 4–7 L/min (1.1–1.8 gal/min) was used to siphon waste. In this way the water velocity within the siphon was low enough (adjustable in the range of <1–15 cm/sec; <0.4–5.9 in/sec) to collect the fecal material with minimal handling and disturbance. The clear tube allowed visual monitoring of the condition of the waste during collection. To insure freshly deposited material, the rearing tank was cleaned at the start of each collection period. By arranging for the inflow to the tank to rotate the water, solid material would rapidly settle and collect in the sump at the base of the central standpipe of the circular rearing tanks. By attaching the siphon tube to collars mounted on the outer diameter of the standpipe and holding the collecting end at a narrow fixed height above the bottom in the central collecting sump, settled solids could be continuously removed from the rearing tank. For perch larger than approximately 100 mm (3.9 in) in size this collection device could be left unattended even over night without fish entering the waste collection stream. Small fingerlings tended to enter the waste collector even though the opening was positioned very close to the tank bottom and feces from these fish were collected by hand-directing the low-head siphon hose.

In a tank of adult perch at a rearing density of 84 kg/m^3 (5.2 lb/ft^3) fed a ration of 2.4% (approximately 2 kg; 4.4 lb) this low-head siphon device would collect 4–5 kg (8.8–11.0 lb) of sludge that was 8–10% solid on a dry weight basis (320–500 g; 0.7–1.1 lb). This represents a recovery of 17–26% of the food solids entering the tank on a dry weight basis. The literature reports that for salmonids, 25–30% of the dried weight of food is converted to feces on a dry weight basis. Therefore, between 69 to nearly 100% of the excreted solids produced in the rearing tank were removed by this simple device that concentrates the recovered waste in a side-stream of 4–5% of the tank's water inflow. In effect, with only a few pieces of inexpensive hardware, the rearing tank itself acts like a “swirl concentrator.” With improvement this device could be incorporated as an inexpensive initial clarifier component, prior to further fine solids removal, in recirculating aquaculture systems (RAS). Fecal waste and uneaten food particles are removed directly from the rearing tank relatively intact before they are further broken up by more turbulent components of RAS.

Overall, freshly deposited feces (*N* = 887) ranged from 0.4–6.2 mm (0.02–0.24 in) in diameter and 0.6–23 mm (0.02–0.91 in) in length. Median fecal pellet diameters were 0.7 mm (0.03 in) (*N* = 344), 1.6 mm (0.06 in) (*N* = 240), 2.6 mm (0.10 in) (*N* = 182), and 3.2 mm (0.13 in) (*N* = 121) for perch in the size categories of 25–75 mm (1.0–3.0 in), 50–100 mm (2.0–3.9 in), 100–150 mm (3.9–5.9 in), and >150 mm (>5.9 in) total length, respectively. The corresponding median lengths of intact fecal particles for these size categories were 4.8 mm (0.19 in), 4.0 mm (0.16), 6.7 mm (0.26 in), and 5.4 mm (0.21 in), respectively. Fingerling perch on the Biodiet feeds tended to have longer feces in relation to their diameter and the feces tended to lack the multifolded rough character of the pellets of larger sized perch fed the Zeigler feeds.

Settling velocities of individual fecal and food particles were determined in a 180 cm (70.9 in) high settling column (10-cm [3.9-in] diameter). As anticipated by Stoke’s law, settling velocities increased with increasing particle size and density. Settling velocities for feces increased gradually over a range of 0.4–5.0 cm/sec (0.16–1.97 in/sec) (*N* = 204) with increasing fish size. The settling velocities of the intact food granules and pellets were higher (5.0–6.0 cm/sec; 1.97–6.30 in/sec) than settling velocities of feces of similar diameter, except for the smaller granules of Biodiet #2 starter and feces of the fingerling perch with diameters <1 mm (<0.004 in) and settling velocities from 0.7–3.2 cm/sec (0.28–1.26 in/sec) and 0.4–1.8 cm/sec (0.16–0.71 in/sec), respectively. This difference mainly reflects the higher density of the pelletized food compared to the less dense fecal material after passage through the digestive tract.

Specific gravity measurements of freshly collected fecal solids were made before and after uniformly compressing the water from approximately 50 mL (1.7 oz) of collected sludge by centrifugation for 5 min at 2,500 rpm, pouring off the water, determining the resulting volume and weight of solid material and comparing it to the weight of an equal volume of deionized water and correcting for temperature. The overall mean specific gravity by this method was 1.055 (SD = 0.019; *N* = 36) after centrifugation and 1.029 (SD = 0.013; *N* = 24) without centrifugation. Differences in specific gravity of feces based on the type of food used were not detectable. It appeared that these mass techniques might create uniform conditions due to consistent packing of the material, while individual fecal particles can vary considerably in compactness and durability. Perhaps measuring settling velocities directly will be more expedient than using a representative value for specific gravity, that may be influenced by collecting and compaction techniques, to infer settling rates using Stoke’s law. It may be better to measure the settling velocity and calculate specific gravity using Stoke’s law and to use these values to make further estimates of settling velocities.

Initial attempts to examine the friability of feces of larger perch fed Zeigler grower diets using direct observation of small numbers of fecal particles in water in Erlenmeyer flasks were unsuccessful due to the heterogeneous nature of the fecal particles. Some of the larger fecal pellets appeared to consist of fine solid material approximately the size of the finely milled material in the formulated diet, encased in an outer more durable mucus-like shell that either was a solid smooth-surfaced stream of material or became folded on itself and compressed into a larger diameter rough surface pellet. In some fecal pellets the proportion and durability of the outer casing appeared to vary in thickness and a relatively small proportion of fine material was inside this casing. These fecal pellets were extremely compressed and durable and tended to have a grayish to white color compared to the less durable brownish type encasing large amounts of finely milled material. Some fecal pellets tapered along their length from wide easily friable character to the more durable grayish cast. This complicated the visual determination of when the pellet was completely broken down. For this reason it seemed better to use a larger (45–70 mL; 1.5–2.4 oz), more representative sample of fecal material to quantify fecal friability. Samples of intact settled fecal material collected by low-head siphoning and an approximate settled volume of 45–70 mL (1.5–2.4 oz) of material was scooped into a 150 mL (5.1 oz) graduated beaker, the contents of this beaker were poured into a 250 mL (8.5 oz) Erlenmeyer flask capped with parafilm and subjected to mechanical agitation of 0, 5, 15, 30, 60, 120, and 240 sec duration at 300 rpm on an orbital rotary shaker. The contents of the flasks were then poured into Imhoff cones and the settleable solids determined along with the volume of intact particles by visually determining the boundary between the fine broken settled solids (less than the diameter of intact fecal material) and the more rapidly settled mainly intact fecal material. The difference in settled volume of the intact feces versus the fines as a percent of the settled solids in the cone was used to express the degree of breakdown. Four or five repeated samples at each time duration were used to express the breakdown of fecal material over time.

Using this technique it was found that the feces of the larger perch fed Zeigler grower and salmon starter diets rapidly decreases from 60–80% intact material to around only 20% of the durable type of intact fecal material after only 5–60 sec of agitation at 300 rpm, while fecal material of fingerling perch fed Biodiet #2 starter also started out 70–80% intact and tended to remain around >60% intact even after 240 sec at 300 rpm. The fineness of the milling of the various components appeared to influence the durability of the fresh fecal material. The coarser “fines” in the grower diet fed to the larger sized perch appeared to give the fecal material a more friable consistency.

The smaller diameter and proportionately greater length of the intact fecal particle of fingerling perch fed semi-moist starter diet contributes to a slower rate of settling. This proportionately greater length suggests a greater resistance to mechanical agitation and further breakdown.

<u>Southern Illinois University-Carbondale (SIUC)</u>
Comparisons of fecal characteristics using commercial feeds are awaiting completion of Objective 1b so that experimental diets can be included in the trials.

OBJECTIVE 1B
<u>UW-Milwaukee</u>
In order to examine the influence of variations in composition of commercial diets, the effect of a “high-energy” versus a “grower” type commercial diet formulation on the physical properties of yellow perch wastes was compared.

Wastes from a 2.44-m (8.0-ft) diameter tank with approximately 3,000 perch that were 227 to 286 days post hatch were collected with the low-head siphon device used for Objective 1a. This group of fish was fed a typical “grower” diet (38.2 % protein and 8.2% lipid) for an approximate two-week period during which the size distribution and physical characteristics of freshly collected “intact” perch feces were evaluated with the same techniques used for Objective 1a. During a subsequent two-week period, a “high-energy” diet (42% protein and 15% lipid) was fed to this same group of fish and the fecal characteristics evaluated.

The size distributions of fecal diameters and lengths of feces from fish fed either the “high-energy” diet or the grower diet overlapped considerably. The settling velocities of individual feces produced by fish fed the “high-energy” diet were slightly but consistently lower than those produced by fish fed the “grower” diet. No difference was demonstrated in the specific gravity of the gathered and centrifuged fecal sludge samples, using the techniques employed in this investigation.

During agitation at 300 rpm feces produced from fish fed the “high-energy” diet generated a higher proportion of total suspended solids than did feces from the "grower" diet. Also, at least during the first 10 min of agitation, the “high-energy diet” feces appeared to remain slightly less intact as a percentage of the settleable material in the Imhoff cones.

These differences in fecal characteristics suggest that feces produced by fish fed the “high-energy” diet are more likely to be resuspended by turbulence in the fish rearing tanks and break up to small-sized suspended particles slightly more readily than those produced from the “grower” diet.

Engineering strategies aimed at removal or recovery of biosolids from aquaculture rearing facilities must aim to separate solids before they are further broken up. Given the fragility of these particles, it seems that using the fish rearing tank itself as a settling unit is the most rapid means of accomplishing this with minimal mechanical disturbance.

The settling velocities of fecal material are important for rapid collection and removal.

Interestingly, by using highly digestible nutrient dense formulations to reduce waste output by the fish, fecal properties might also be altered in ways that make them more readily broken down and consequently more difficult to settle and remove. Strategies to reduce the output of waste by increasing the digestibility and incorporation of dietary nutrients into fish flesh may have trade-offs in the characteristics of the fecal material produced. A combined strategy considering feed formulation and resulting fecal properties that influence engineered removal of biosolids may result in more effective waste removal.

<u>SIUC</u>
The growth trial with Nile tilapia indicates dietary fiber level manipulation in the range of 0 to 18%, using semi-purified formulations, does not affect growth rates, regardless of fiber type.

Tilapia, yellow perch, and largemouth bass have been fed fiber-manipulated diets (cellulose or beet pulp) for fecal collection. Yellow perch and hybrid striped bass had a poor acceptance rate for the prescribed formulations (<0.5% body weight/day, <2% body weight/day). A modified semi-purified basal diet with more menhaden fishmeal and without casein was adopted for the more carnivorous species and gave satisfactory results. Trials with the modified diets have been completed for yellow perch and largemouth bass. Hybrid striped bass were tested but intake rates of the prescribed diets were inadequate to promote formation of representative feces and rates needed to run integrity tests.

Fish species, fiber source and fiber level can affect feces in the ability to endure mechanical stress. Nile tilapia feces did not respond favorably to the highest fiber levels (18%), particularly beet pulp. The mucous strands were prone to break and spill their contents when distended with large amounts of fiber. Yellow perch and largemouth bass produce fecal masses that are considerably different from those of tilapia. The yellow perch and largemouth bass produce feces which are generally made of smaller round pellets that are excreted either singly or attached as pellet masses. Individual pellets are very resistant to mechanical stress but the break up of bunches often results in many individual pellets breaking into smaller particles. Largemouth bass fecal integrity appears to be enhanced by the addition of beat pulp (8 and 18%) and decreased by 18% cellulose or no added fiber. Yellow perch fecal integrity appears to be enhanced by modest amounts of beet pulp (8%). Hybrid striped bass trials to date present a picture with a highly variable fecal structure that is difficult to manipulate due to its fragility.

A problem that has been identified deals with quantitative collection of feces. Much of the feces, particularly that promoted by feeds without fiber, disintegrates immediately upon exiting the anus. The resulting feces retained by the collector is often considerably more durable than the feces excreted as a whole.

OBJECTIVES 1A AND 1C
<u>University of Minnesota (UM)</u>
A break in the production cycle at the UM facility occurred while adult tilapia, which became infected with *Aeromonas hydrophila*, were treated, held for a withdrawal period, and marketed. The stress from this disease limited the ability of the fish to tolerate decreased water quality and

thus the degree to which the tanks could be loaded. During this time the fish were fed a maintenance ration. This lessened the nutrient input and resulted in better water quality and a lower suspended solids load than would normally be experienced in a production system. The disease problems necessitated a complete shutdown of the production system tanks. The shutdown afforded an opportunity to rework system configurations and make repairs and improvements. In preliminary work with the tilapia production systems before the disease outbreak, total suspended solids levels in the three system types ranged from approximately 10–45 ppm. These values correspond well to average values reported in the literature.

WORK PLANNED

OBJECTIVES 1A-C

SIUC

A growth trial using hybrid striped bass is underway using a modified basal diet and should be completed by the end of January 2000. Rainbow trout and hybrid striped bass will be tested using the more palatable basal diet. If possible, the use of a more finely ground beet pulp will be tested on Nile tilapia. The comparison of commercial feeds and resulting fecal characteristics will be conducted following completion of all experimental trials using beet pulp.

UM

UM participants will continue to complete Objectives 1a and 1b.

IMPACTS

- ● Provide a broad base of information with regard to alternative species for rearing system design.
- ● System design of settling basins and clarifiers will be improved through the use of data gathered during this project.
- ● Fiber sources of alpha-cellulose and sugar beet pulp, when supplied at levels of 0, 8, or 18% , do not appear to affect growth of Nile tilapia and may thus enable variations in dietary fiber levels to promote waste management without negatively impacting production.
- ● The use of modest amounts of beet pulp in some carnivorous fish diets may be useful in enhancing fecal integrity, thus promoting solid waste removal from culture waters and waste effluents.

PUBLICATIONS, MANUSCRIPTS, OR PAPERS PRESENTED

See Appendix A for a cumulative output for all NCRAC-funded Wastes/Effluents activities.

SUPPORT

YEARS	NCRAC-USDA FUNDING	OTHER SUPPORT					TOTAL SUPPORT
		UNIVERSITY	INDUSTRY	OTHER FEDERAL	OTHER	TOTAL	
1996-99	$90,000	$79,968				$79,968	$169,968
TOTAL	$90,000	$79,968				$79,968	$169,968

WASTES/EFFLUENTS

Publication in Print

Rosati, R., P.D. O'Rourke, K. Tudor, and R.D. Henry. 1993. Performance of a raceway and vertical screen filter while growing *Tilapia nilotica* under commercial conditions. Pages 303-214 *in* J-K. Wang, editor. Techniques for modern aquaculture. Publication No. P-0293, American Society of Agricultural Engineering, St. Joseph, Michigan.

Report

Yeo, S.E., and F.P. Binkowski. 1999. Beneficial utilization of aquaculture effluents and solids. Report submitted to NCRAC, Michigan State University, East Lansing.

Papers Presented

Hinrichs, D., J. Webb, R. Rosati, and P. Foley. 1994. Effluent characterization from the production of *Oreochromis niloticus* in a modified Red Ewald-style recirculating system. 25th Annual Meeting of the World Aquaculture Society, New Orleans, Louisiana, January 12-18, 1994.

Rosati, R., D. Hinrichs, and J. Webb. 1994. Biofilter performance during the production of *Oreochromis niloticus* in a modified Red Ewald-style recirculating system. 124th Annual Meeting of the American Fisheries Society, Halifax, Nova Scotia, August 21-25, 1994.

Rosati, R., P.D. O'Rourke, K. Tudor, and R.D. Henry. 1993. Performance of a raceway and vertical screen filter while growing *Tilapia nilotica* under commercial conditions. Techniques for Modern Aquaculture, Special Session at the Annual Meeting of the American Society of Agricultural Engineering, Spokane, Washington, June 21-23, 1993.

Rosati, R., J. Webb, D. Hinrichs, and P. Foley. 1993. Characteristics of the effluent from a recirculating aquaculture system. U.S. Chapter of the World Aquaculture Society, Hilton Head, South Carolina, January 27-30, 1993.

Smydra, T.M., and J.E. Morris. 1994. Characterization of aquaculture effluents from two Iowa hatcheries. Iowa Chapter, American Fisheries Society, Council Bluffs, Iowa, February 15-16, 1994.

Smydra, T.M., and J.E. Morris. 1994. Characterization of aquaculture effluents. 56th Midwest Fish and Wildlife Conference, Indianapolis, Indiana, December 4-7, 1994.