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Project Summary

An Evaluation of Filter Feeding Fishes for Removing Excessive Nutrients and Algae from Wastewater

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This study was instituted to determine the feasibility of utilizing certain species of finfish for the removal and recycling of excessive nutrients and algae from wastewater. The silver carp *(Hypopthalmichthyes molitrix)* and the bighead carp *(Aristichthyes nobilis)* were chosen as the central species due to their specifically adapted filter feeding mechanism. An existing wastewater treatment plant with six lagoons served as the project site. Since the results from previous controlled field trials were available, this project utilized the entire facility as a pilot scale system. No attempt was made to alter or influence the waste load normally received by the lagoons.

It can be said unequivocally that the presence of the fish had a beneficial effect on the aquatic system. Because of the many variables involved in such a dynamic, stressed ecosystem it is difficult, if not impossible, to quantify a direct relationship between the standing crop of fish and any one water quality parameter. In all, 14 water quality parameters along with selected heavy metals, pesticides, pathogenic bacteria, and viruses were monitored during the project.

Analysis of the data shows that the presence of the fish improves the treatment capability of the conventional lagoon system. There are tradeoffs to be made among some parameters and some liabilities resulting from the presence of the fish. All are within acceptable limits and, when considered, still tip the scales in favor of the benefits gained. In the final analysis, the real determining factor in deciding to use a finfish-aquaculture-treatment system is the capability of using the more than 7,200 kg/ha annual production of fish as a revenue producer to sufficiently offset or pay for water treatment costs.

This Project Summary was developed by EPA's Robert S. Kerr Environmental Research Laboratory, Ada, OK, to announce key findings of the research project that is fully documented in a separate report of the same title (see Project Report ordering information at back).

Introduction

The passage of the Federal Water Pollution Control Act of 1972 (PL 92-500) generated considerable interest and concern for the development of wastewater treatment methods that would meet the more stringent standards at a reasonable cost. The emphasis on re-use of wastewater and the recycling of nutrients into useful products brought about a new look at old biological treatment methods. The biological production capability of nutrient-laden wastewaters is obvious. However, directing the energy and raw materials into useful products has proven difficult.

Often the emphasis has been on developing new products and uses for the mostly invertebrate species that grow naturally in wastewater. With an already growing demand and a decreasing world supply of fish and fisheries products, many investigators have attempted to rear fish in wastewaters. This has been largely unsuccessful in the United States due to the lack of a native species with a high production capability utilizing primary production from ponds or lagoons as a food source. The importation of the silver and bighead carp into Arkansas in 1973 by a private fish farmer provided the opportunity for experimentation with fish species uniquely adapted for the job.

Initial interest in the silver and bighead carp resulted from an extensive amount of literature reporting the many characteristics they possess that make them a seemingly ideal fish for culture. A fish that could be added to the species in Arkansas' large fish farming industry to increase production was an attractive possibility. It became apparent that these filter feeders had quite an impact on water quality and this became an increasingly important subject of subsequent studies. All preliminary work corroborated reports in the literature concerning production and growth rate potential of these fish. By the time this project was designed and implemented, the major emphasis was on the use of these fish to improve the quality of wastewater. This was somewhat unique in that previous work had been concerned with the optimum nutrient loads to add to ponds to maximize their production. The ability of the fish to withstand heavy wastewater loads and their concomitant impact on water quality is relatively unexplored territory.

Fertilization of fish ponds has long been recognized by the fish culturist as a method of increasing production. The production of finfish as a method of reducing fertility is a relatively new approach that has been stimulated by the increasing need for effective, low cost treatment of wastewater by small municipalities. The recent realization of the need to conserve energy and to recycle what has previously been regarded as a troublesome waste product has provided the impetus for exploring alternative methods. The Arkansas Game and Fish Commission's interest in this project evolved from the fact that they were an unknown, exotic species being imported into the state and the need to evaluate the possible dangers as well as the beneficial uses of the fish.

The fact that X pounds of fish are produced without supplemental feeding obviously shows that in one fashion or another, energy and nutrients are transformed into the very stable form of fish flesh. The fish culturist may draw on a rather large body of literature in determining the proper type and amount of fertilizer to add to a culture pond. If, on the other hand, the objective is to utilize available nutrients, little is known about the effectiveness of finfish in general or any species in particular. Common sense dictates that those fishes that have adapted to feeding at the lower trophic levels would be most efficient at converting nutrients. The filter feeding silver and bighead carps meet these criterion and are the key species in this study.

Project Site

An existing wastewater treatment plant of the Benton Services Center in Benton, Arkansas was chosen as the location for the study. Other than the collective individual wastes of approximately 1,000 residents and employees of the center, the largest contributors to the center's treatment plant are a laundry and full-time food services section.

The physical facilities of the treatment plant are the same as many small municipalities in Arkansas and consist of (1) bar screen and grinder, (2) clarifier, (3) aerobic digestor, and (4) six lagoons. Minor alterations were made to the plant before initiating the study, but for the most part it functioned on a day-to-day basis the same as other lagoon type treatment facilities. At no time was the normal wastewater load coming to the plant altered during the two year project period.

Monitoring Program

Water Quality

Grab samples were taken regularly at the effluent of each of the six ponds. All sampling was done according to the APHA Standard Methods with analysis being conducted by the Arkansas Department of Pollution Control and Ecology. Parameters monitored were:

- Air Temperature
- H_2O Temperature
- Carbon dioxide
- Dissolved oxygen
- BOD_5
- Turbidity
- Ammonia
- Nitrite - N
- Nitrate - N
- pH
- Total Suspended Solids
- Total Phosphorus
- Fecal Coliform
- Plankton Enumeration

Toxic Substances

Due to the need to utilize the fish to provide an economic return as well as maintain an expanding population for optimum efficiency, samples were taken to look for the presumed most likely toxic substances. These samples of both fish and water were analyzed by an independent testing laboratory for:

- Aldrin
- Dieldrin
- Endrin
- Mirex
- DDT
- Toxaphene
- Kepone
- PCB
- Lead
- Copper
- Cadmium
- Mercury
- Arsenic

Biological Contaminants

Since human consumption is considered the ultimate use of the fish produced, the Baylor College of Medicine was contracted to provide analysis of bacterial and viral contamination. Regular samples were taken of the water and bottom mud as well as various portions of the fish. All samples were assayed for common viral and bacterial pathogens associated with municipal wastewaters.

Fish Production

To monitor the growth rate of fish within the system, monthly samples were taken throughout the growing season and individual fish weighed, measured and returned to the ponds. It was difficult to obtain adequate samples of species other than the silver carp due to relatively low stocking densities and the inefficiency of sampling techniques in the 1.5-1.8 hectare ponds.

Ponds 1 and 2 were considered to be plankton culture ponds necessary to accept the initial shock of the BOD loads and stabilize dissolved oxygen levels. As would be expected, the serial arrangement of the ponds provided successively better water quality in each successive pond. Pond 3 was extremely fertile with a heavy plankton bloom and typically minimum dissolved oxygen levels. Pond 4 exhibited wide fluctuations in DO levels but other water quality parameters began to stabilize over time. Ponds 5 and 6 remained in near optimum conditions for pond fish culture throughout the project period.

Economic Design Considerations

Since the project was conducted in a full scale functioning sewage treatment system, the experience provided the ability to make certain realistic projections regarding economic and design considerations. This type of finfish wastewater treatment system has shown the capability of upgrading the effluent of conventionally designed and operated lagoon treatment plants. However, the level of treatment is somewhat limited compared with other types of advanced treatment systems. Only when the fish produced from recycling the wastes can be utilized, can the true advantages of this method of treatment be realized. If a true profit or even supplemental income to offset treatment costs can be generated, the production of fish becomes a more attractive treatment method or a viable addition to more advanced treatment practices.

Results and Discussion

Water Quality

The wastewater entering the plant had an average BOD_5 of 251.4 mg/l and a suspended solids concentration averaging 97 mg/l. During the two year project period, the system has reduced the BOD_5 by 96.01% and the TSS by 78.22%. Also, the effluent has been within the criteria established for secondary wastewater treatment and many parameters were at levels associated with advanced secondary treatment.

Toxic Substances

With the exception of the metals, copper and mercury, all samples have contained less than the standard detection limits or have been negative. In no instance has any sample contained the listed contaminants at levels above action guidelines established by the FDA or the Arkansas Department of Health.

Biological Contaminants

From the influent to Pond 6, there was an average 2.6-fold decrease per pond for fecal coliforms (FC) and an average 2.4-fold decrease per pond for fecal streptococci (FS). Bacterial concentrations in the sediments followed a different pattern than in the overlying waters. There was an average 4.7-fold decrease per pond for FC in the last four ponds. The decrease in FS in the sediments from pond to pond was substantially less than the decrease in FS in the water.

The concentrations of FC and FS in the fish guts were on the average greater than in the surrounding water and sediments. Mean concentrations of FC and FS in the fish skin were lower than in the gut. Levels of bacteria detected in the fish flesh are shown in Table 1.

Two methods were used for sampling the fish muscle. The samples in August and September were taken by a normal fillet procedure using a decontaminated fillet knife. Samples taken during these two months yielded sporadically high levels of FC and FS in the muscle tissue, probably due to contamination by bacteria from the fish skin. Beginning in October, all muscle samples were taken aseptically to avoid contamination from the skin. Three of nine samples of muscle tissue obtained from October through December were positive for either FC or FS at low levels.

Salmonella spp. was detected in 2 of 4 influent samples at levels of 0.4 and 2.3 MPN (most probable number)/100 ml using dulcitol selenite enrichment. Salmonella spp. was also isolated from a single water sample from Pond 2 in December. No salmonella was isolated from any of the other pond water, sediment, or fish samples.

Six of the 90 samples tested for enteric viruses yielded at least 1 PFU (plaque-forming unit) on BGM (buffalo green monkey kidney cells) monolayers (Table 2). Three of five influent samples were positive at low levels with concentrations ranging from 7.5 to 20 PFU/liter. Two of 15 sediment samples and one water sample from Pond 2 also yielded 1-2 PFU per sample of 500 g or 20 liters. All other pond water samples were negative for virus. No viruses were detected in any of the 45 fish samples processed.

The sewage entering the Benton fish ponds was atypical from a virological standpoint. The levels of virus in the sewage were much lower than would be expected for untreated sewage from a larger and more diverse community. For example, concentrations in raw sewage from treatment plants in St. Petersburg, Florida, averaged 90 PFU/liter and, at a larger treatment plant in Tampa, Florida, concentrations of over 2,000 PFU/liter were found. The sewage entering the Benton ponds had an average concentration of $<$9 PFU/liter for the 5 samples tested.

Because of the low levels of virus found in the influent, the results cannot be extrapolated to make conclusions or predictions about the survival and transport of viruses in other fish pond systems that may have a much higher input of viruses. The lack of virus isolates from the fish and pond water in this study does not preclude the possibility of viruses surviving in the fish ponds and being accumulated by the fish if the initial levels of virus were higher. In fact, since relatively high levels of FC and FS were found in the ponds and fish, it is likely that viruses would also be present if the input rate were higher, since viruses generally survive inactivation processes better than do indicator bacteria.

Fish Production

Ponds 1 and 2 were considered to be plankton culture ponds necessary to accept the initial shock of the BOD loads and stabilize dissolved oxygen levels. Fish were stocked in Ponds 3, 4, 5, and 6. Other than the initial regrading of the pond bottoms to facilitate harvesting, no supplemental aeration or fresh water was provided to any of the fish ponds. All were left in series accepting the full flow volume and waste load as it passed through the plant. As long as the entire system functioned normally, all four of the fish ponds maintained adequate water quality for survival and growth.

As would be expected, the serial arrangement of the ponds provided increasingly better water quality in each successive pond. Pond 3 was extremely

Table 1. *Concentrations of FC and FS in Fish Flesh*

	MPN/100 g fish flesh					
	Pond 4		Pond 5		Pond 6	
Month	*FC*	*FS*	*FC*	*FS*	*FC*	*FS*
*Aug.**	<30	140	<30	140	40	860
*Sept.**	230	80	430	22,000	<30	<60
Oct.	<11	25	<11	<11	<6.6	15
Nov.	11	<11	<11	<11	<11	<11
Dec.	<11	<15	<11	<15	<11	<15

**August and September samples were taken by a normal fillet procedure with possible contamination from the skin. All other flesh samples were taken aseptically.*

Table 2. *List of Samples which Yielded Plaque-Forming Units (PFU) on Cell Monolayers*

Sample	*Month*	*Total PFU counted**	*Estimated concentration***
Influent	*Aug.*	*5*	*20 PFU/liter*
Influent	*Nov.*	*3*	*15 PFU/liter*
Influent	*Dec.*	*2*	*7.5 PFU/liter*
Pond 2 sediment	*Sept.*	*2*	*2 PFU/500 g*
Pond 4 sediment	*Nov.*	*1*	*1 PFU/500 g*
Pond 2 water	*Dec.*	*1*	*0.05 PFU/liter*

* *Unidentified.*
** *Dilution factors varied for influent samples.*

fertile with a heavy plankton bloom and typically minimum dissolved oxygen levels. Pond 4 exhibited wide fluctuations in DO levels and other water quality parameters began to stabilize. Ponds 5 and 6 remained in near optimum conditions for pond fish culture throughout the project period.

In May of 1980 after the system had been operational for 1 1/2 years, a delivery line collapsed necessitating the flow of the total raw waste load directly into Pond 2 until repairs could be made. In the six weeks required for these repairs, the already marginal water quality in Pond 3 deteriorated until a total oxygen depletion and fish kill occurred on July 1, 1980. Recovery of the fish from Pond 3 after the kill showed that the original stocking biomass of 374.8 kg/ha had increased to 7,165.1 kg/ha in the 18 months the fish had been in the pond.

The plant breakdown and resulting short-circuiting of the water also had a visual impact on Pond 4. The period of decreased retention time greatly added to the fertility in Pond 4. In essence, Pond 4 became Pond 3 during that period of time. The diminished water quality coupled with extremely hot, dry late summer weather and a period of cloudy days resulted in a major fish kill occurring in this pond on September 4, 1980. A total of 7,691.9 kg/ha of silver carp were removed from Pond 4 as a result of this kill. This is a considerable production in the 21 months since initial stocking with 40.6 kg/ha.

The fish in Ponds 5 and 6 survived the full 24 month experimental period. Stocking and harvesting data for these ponds are listed in Tables 3 and 4. Water quality remained good and no problems with the survival and growth of the fish were noted.

Table 3. *Growth of Silver and Bighead Carps in Pond 5 During Project Period*

Date	*Time from stocking*	*Silver carp, standing crop (kg/ha)*	*Bighead carp, standing crop (kg/ha)*
Jan., 1979	*0*	*293.2*	*39.1*
March, 1979	*3 mos.*	*900.0*	
June, 1979	*6 mos.*	*1,871.9*	
Sept., 1979	*9 mos.*	*4,098.9*	*425.6*
Dec., 1979	*12 mos.*	*4,650.0*	
March, 1980	*15 mos.*	*5,350.5*	*560.0*
June, 1980	*18 mos.*	*6,075.0*	
Sept., 1980	*21 mos.*	*7,260.0*	
Dec., 1980	*24 mos.*	*7,634.4*	*1,510.4*

Table 4. *Growth of Silver and Bighead Carps in Pond 6 During Project Period*

Date	*Time from stocking*	*Silver carp, standing crop (kg/ha)*	*Bighead carp, standing crop (kg/ha)*
Jan., 1979	*0*	*210.6*	*12.24*
March, 1979	*3 mos.*	*1,029.6*	*15.4*
June, 1979	*6 mos.*	*1,745.0*	
Sept., 1979	*9 mos.*	*2,480.5*	
Dec., 1979	*12 mos.*	*2,475.0*	
March, 1980	*15 mos.*	*3,441.3*	*248.2*
June, 1980	*18 mos.*	*3,650.5*	
Sept., 1980	*21 mos.*	*4,255.0*	
Dec., 1980	*24 mos.*	*4,454.7**	*589.0*

**Channel catfish, grass carp, and smallmouth buffalo were also initially stocked in Pond 6. Due to low stocking rates, difficulty of sampling, etc., no interim growth estimates were made. Also, the buffalo spawned during the spring of 1979 further complicating matters. At harvest, the final standing crop for each species was found to be: channel catfish = 832 kg/ha, buffalo = 562 kg/ha, grass carp = 262 kg/ha.*

Economic Considerations

This type finfish wastewater treatment system has shown the capability of upgrading the effluent of conventionally designed and operated lagoon treatment plants. However, the level of treatment is somewhat limited compared with other types of advanced treatment systems. Only when the fish produced from recycling the waste can be utilized can the true advantages of this method of treatment be realized. If a true profit or even supplemental income to offset treatment costs can be generated, the production of fish becomes a more attractive treatment method or a viable addition to more advanced treatment practices.

Silver and bighead carp from a preliminary hatchery study were rendered into fish meal which assayed at a crude protein content of a minimum 55-57%. This is compared to 62% crude protein for Menhaden meal considered the best product now available. Oil and fat content were not considered. There was an estimated 18% return of meal from fresh fish by weight. Current market prices for pure fish meal, FOB Little Rock, vary from $400-500 per ton in bulk quantities depending on season and harvest source. Based on a price of 7-9 cents per kg (3-4 cents per lb.) for live fish and an annual production rate of approximately 5,000 kg/ha as demonstrated in this study, a gross return of $350-450 per ha/yr could be realized by processing the fish in this way.

If, on the other hand, human health considerations could be mollified and the product sold for direct human consumption, the economic picture could be quite different. Hatchery reared silver and bighead carp have been tested organoleptically for two different methods of preparation. As a fresh fish fillet product, the silver carp has a white, lightly oily meat that is excellent in a variety of preparations with the subjective taste test yielding comments ranging from excellent flavor to barely acceptable. However, the problem is boniness. The silver carp has many floating bones that do not increase in size proportionately as the fish grows. This is a major problem for American tastes even with larger sized fish. Canning the fish, however, makes the small bones unnoticeable and the heat involved could overcome some of the health effects problems. If the fish were marketed in either manner (fresh or canned), a conservative price of 55-65 cents per kg would be reasonable. The gross amount return based on these assumptions and the demonstrated production potential would be $2,750-3,250 per ha per year. Whatever the market, any income realized would certainly be welcomed to offset treatment costs.

Design Considerations

In general, the factors involved in the selection, design, and construction of a finfish wastewater treatment system are the same as those historically used for conventional aerobic lagoon treatment plants. Prime consideration should be given to climate, availability of land area, and the treatment level desired or necessary. The results of this study have shown that the additions of controlled stocking of certain species and numbers of fish can increase the efficiency of lagoon treatment. Therefore, in instances where conventional lagoon design criteria indicate the system would be marginal, either due to space or treatment level, the incorporation of finfish into the design could make this the method of choice.

Since the fish must survive to do the job, the most obvious criterion is that the wastewater contain no contaminants lethal to the organism. This could limit use to specific circumstances or, more likely, require in-house removal of these substances prior to treatment. Because of the flexibility needed to insure proper operation, a finfish treatment system requires a multiple lagoon design with generally a serial flow pattern. The initial impact of the BOD load from raw wastewater must be lessened by some method prior to entering the pond containing fish. Short-term peaks in loading rate are no major problem, but generally the concentration of BOD_5 entering the first pond containing fish should be no more than 50 ppm annual average.

There must be the capability of draining each pond individually for maintenance and harvest of the fish while allowing continued operation of the plant. Typical pond construction is applicable with the probable need for a more carefully graded bottom with a catch basin to facilitate harvest of the fish. Little effect on water quality is seen until the standing crop of fish reaches 1,000 kg/ha. Also, larger numbers of smaller, younger fish are more efficient than fewer larger fish even though biomass may be the same. A method of harvest and replacement of the fish should be established to maintain a total standing crop between 1,000-5,000 kg/ha at all times and to have a high percentage of small growing fish. Harvest and restocking should be done annually to provide maximum fish production or should be done at least every three years to prevent decreased water treatment capability.

Conclusions and Recommendations

The addition of silver and bighead carp to a lagoon wastewater treatment system increases the efficiency of that system. Depending on climatic and other operational conditions, the inclusion of these natural filters can increase treatment levels by as much as 25-30%. From a practical standpoint, this could decrease the amount of land area needed or improve the quality of water leaving the facility, or both. When used as the sole method of treatment, an aquaculture system using silver carp is limited in capability. Properly designed and operated, the system could provide advanced secondary treatment and consistently meet discharge requirements of 10 ppm BOD_5 and 20 ppm total suspended solids. Though nutrient removal is improved and both total phosphate and nitrogen levels were decreased by more than 90% in this system, total removal would require such a lengthy retention time as to be impractical. However, where finfish treatment level requirements do not exceed the capability of the system, finfish aquaculture in wastewater lagoons is a viable and reasonable method of upgrading treatment and recycling wastes into a stable and useful form.

Aquaculture treatment systems are competitive with other conventional methods from a cost effectiveness standpoint at the present time. Recycling wastes into useful products is certainly the ultimate goal of waste disposal. This method achieves that goal in theory since fishery products are in high demand. At the present time, however, product utilization possibilities range from being limited to virtually impossible. The development of quality control standards to allow the use of fish products grown in wastewater is the most pressing need. If that could be accomplished, there is little doubt that a treatment system that could potentially produce a profit would be available.

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