

Stirring Ponds as a Possible Means of Increasing Aquaculture Production*

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Introduction

Gross inefficiencies of nutrient conversion in pond, tank and cage aquaculture are commonplace. As little as 6.5% of the organic carbon in freshwater prawn (*Macrobrachium rosenbergii*) feeds added to ponds in Hawaii is harvested as prawn biomass (Weisburd and Laws 1986). Phillips and Beveridge (1986) estimated that 5-40% of the feeds given to caged fish is lost to the environment. Merican and Phillips (1985) actually measured a mean loss to the environment of 35.6%, 21.8% and 65.9%, respectively of the carbon, nitrogen and phosphorus contained in feeds given to caged rainbow trout.

Such inefficiencies are different in different environments and have rarely been closely examined in the tropics. Cages, tanks and raceways have little scope for nutrient recycling because they are essentially single pass or flow-through systems. In earthen ponds, however, detrital pathways could be harnessed to recycle nutrients to cultured fishes that feed low in the food web. This was the topic of a conference organized by ICLARM (Moriarty and Pullin 1987).

The recycling of nutrients from fish-pond sediments and benthic detritus appears attractive, but overloading of a pond with suspended organic matter can lead to dramatic increases in microbial respiration and anoxic/anaerobic conditions that can overwhelm the aerobic processes essential for good fish growth and survival. When organic matter builds up in a pond the food web can change from being mainly phototrophic to mesotrophic and there is partitioning of

energy and nutrients between and within the water column and sediments.

It is well known in limnology and oceanography that natural waters are stratified. Temperature stratification also occurs in earthen ponds, even those as shallow as 0.5 to 1.0 m. Stratification can isolate waters near the sediment-water interface from surface waters (the photic zone). Therefore, nutrients and energy at the sediment-water interface may become unavailable to microorganisms in the upper water column. In the tropics, there is stronger pond stratification than in temperate zones because to mix waters with a 1°C difference between the surface and bottom layers requires more energy (e.g., wind) at 25°C than at 15°C (Hutchinson 1957).

Schroeder (1978) pointed out that Israeli earthen ponds, 1.0-1.5 m deep, with a 1% sediment organic matter content, were temperature - and highly nutrient stratified. Nutrients and bacteria were 100-1,000 times more concentrated at the sediment-water interface than at the surface. Costa-Pierce and Laws (1985) studied the effects of vertical mixing on microbial activity in freshwater prawn ponds in Hawaii. The suspended material during stratified conditions (temperature differences between surface and bottom water = $1.9 \pm 0.8^\circ\text{C}$) had a higher C:N ratio (8.2 ± 1.2 vs. 4.0 ± 0.6) and a lower C:chlorophyll *a* ratio (27 ± 4 vs. 80 ± 55): all data here are means \pm S.D.s. These 1-m stratified ponds also showed very pronounced vertical gradients in protein concentration, microbial cell division (DNA synthesis) and cell growth (RNA synthesis) in the water just above the sediment-water interface (Fig. 1).

Other quantitative data on stirred vs. unstirred ponds are rare, but Costa-Pierce

(unpublished data from work in Hawaii) obtained higher extrapolated net annual yields from two stirred tilapia (*Oreochromis mossambicus*) culture ponds (5.1 t/ha/year) than from two unstirred controls (2.1 t/ha/year). The ponds were stirred by workers wading through them at 1400 hours (on sunny days only) until the water became a turbid brown color. These extrapolations are based on 120-day culture periods after stocking fingerlings of average weight 10 g at 20,000/ha and feeding them three times a day with 25% protein chicken feed. Despite the lack of statistically analyzable data from this trial, it is indicative of the possible benefits of pond stirring.

How Can Pond Stirring Be Done?

Pond stirring can be done either mechanically or by aquatic organisms (bioturbation). The former could be expensive in terms of equipment and labor. Pullin (1987) mentions a 'hydrocultivator' (an expensive machine) used to turn over the mud of mullet ponds in Italy. This situation might be thought analogous to that of pond aeration i.e., expensive mechanical devices vs. biological aerators (phytoplankton). However, as Pullin (1987) points out, a farmer could disturb pond sediments simply and cheaply by periodically towing a weighted line or an old large mesh net through the pond. Merely walking in the pond is another option. None of these simple ideas has been adequately researched.

For bioturbation, there are several fish species that could be used. The best known is the common carp (*Cyprinus*

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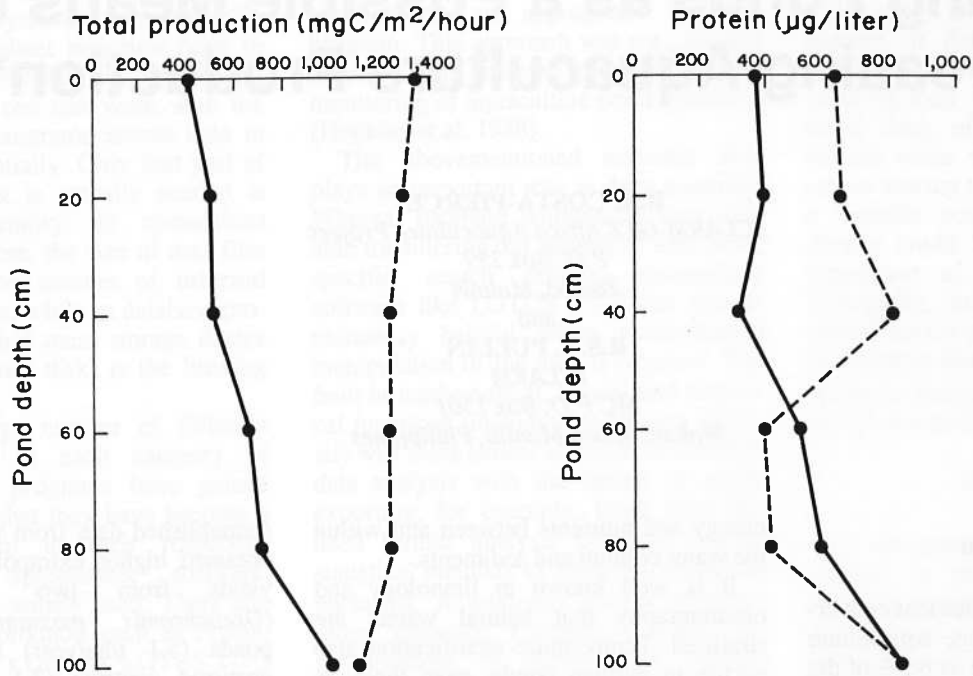


Fig. 1. Stratification of microbial production and protein in 1-m deep Hawaiian *Macrobrachium* ponds on calm (solid line) and windy (dotted line) days: based on recalculation of data from Costa-Pierce and Laws (1985) using the DNA to carbon conversion assumptions of Karl and Winn (1984).

carpio). Its role as a benthic feeder in many polyculture systems is assured. Its effect on mobilizing benthic materials into the water column has been studied; for example, Lamarra (1975) states that a carp population of 200 kg/ha can internally load a lake with orthophosphate at 0.52 mgP/m²/day. This is from excreta as well as stirring. Common carp do produce brown water conditions in fishponds and their sediment-disturbing activities need more study in terms of recycling of benthic nutrients. Information on bioturbation by other species relevant to fish culture is rare. Pauly et al. (1988) state that the tilapia (*Sarotherodon melanotheron*) population (3.65 t biomass) in the Sakumo Lagoon, Ghana stirs up 1.3 t of bottom sediments per day, corresponding to a bioturbation rate (Clifton and Hunter 1973) of 470 g/m²/year. This is almost analogous to earthworms turning over soil and contributing to terrestrial productivity.

Potential Impacts of Pond Stirring

Conventional wisdom among aquaculture scientists has been that a fertilized

pond should have a healthy algal bloom. Behind this management objective is an implied food chain (based on grazing of phytoplankton) and an implied water quality goal [coping with large diurnal swings in dissolved oxygen concentrations (DO)]. All semi-intensive pond systems are sunlit and organically-driven, but management systems vary. Many traditional fish farmers in Indonesia and China prefer brown water pond conditions. Thus, they encourage the detrital food web and their fish (principally carps) do without very high oxygen concentrations during the day and avoid the large diurnal DO swings of green water situations.

Costa-Pierce and Laws (1985) found no significant differences between chlorophyll *a*, surface photosynthetic indices and primary productivity between stratified and well-mixed ponds; although well-mixed ponds were a deep chocolate brown color and stratified ponds a deep green. Brown ponds were dominated by diatoms; green ponds by green algae.

We conclude that still very little is known about the interrelationships of the autotrophic and heterotrophic food webs

and how to optimize these for efficient fish production. Would brown water be better than green water for fish that can utilize detrital aggregates and bacteria? What would this do to the abundance and diversity of algal species that are essential for maintaining water quality (adequate DO and low ammonia)? Probably the best of all options is a healthy 'green-brown' compromise.

Table 1 lists some of the possible benefits and disadvantages of pond stirring. A critical research approach is needed. However, we can speculate that pond total microbial production (in g/m²/day) could be greatly increased by pond stirring. Costa-Pierce and Craven (1987) estimated total production in aquaculture ponds over a period from May 1981 to April 1982. On two of these dates field observations recorded "green water, calm wind" (8 June and 18 June 1981), and on two other dates, 25 August 1981 and 14 April 1982, notes were made: "brown water, strong winds, heavy rains in the past 2 days". In these 1-m deep ponds, Costa-Pierce and Craven (1987) measured total microbial production (bacteria, algae and fungi in the

Table 1. Some testable hypotheses on the effects of stirring fishpond sediments.

Possible benefits	Possible disadvantages
1. Increases nutrients (soluble and particulate organic matter) in the water column, thereby increasing total production of microorganisms (plankton, bacteria, fungi)	Pond production is not just limited by nutrient supply; release of toxic concentrations of sulfides and/or ammonia may occur
2. Supplies foods and surfaces for microbial colonization (bacteria, protozoa, microbenthos, detrital particles) directly to the water column for consumption by fish	These foods are of limited use to some fish species; settled detritus may be of poor nutrient quality because it has been leached and/or contains refractory compounds; stirring may encourage pathogens such as fungi
3. Regular aeration of pond soils increases benthic productivity	Pond soils may become more compact and less productive with repeated disturbance; stirring may disrupt life cycles of zoobenthos that are important fish foods, e.g., <i>Tubifex</i>
4. Mobilization of clays and reduced compounds assists the decomposition of organic matter and dampens diurnal swings in dissolved oxygen concentrations	Dissolved oxygen may decrease quickly to critical levels due to lowered light for phytoplankton, threatening fish survival and hindering growth; clays may clog fish gills and increase disease risks
5. Compaction of ponds muds may assist in pond sealing and reduce seepage	
6. Regular stirring may disrupt tilapia nesting thereby decreasing prolific breeding and consequent stunting	Stirring may stress the fish; footprints may encourage tilapia nesting

water column were included by estimating rates of DNA synthesis) of 85.7-92.2 gC/m²/day during the windy days, and 6.8-14.9 gC/m²/day during calm days. Ponds had approximately the same species combinations and inputs. One implication is that stirring could possibly increase total microbial production by nearly an order of magnitude.

Current and Future Experimentation

At the Domasi Experimental Fish Farm of the Malaŵi Fisheries Department (FD), ICLARM, FD and the University of Malaŵi are working together to develop and improve pond aquaculture systems for the rural African farmer. The team is investigating pond inputs available on-farm (composts, ash and green vegetation) to culture tilapias (*Oreochromis shiranus* spp. and *Tilapia rendalli*). Initially, chopped napier grass was added to ponds at 100 kg dry matter/ha/day. This rate was too high. The pond bottoms became covered by a mat of poorly decomposed grass up to 10 cm deep that supported a large population of benthic worms. These were not eaten by the tilapias. Apart from stocking benthic feeding species, one clear option is to mobilize benthic nutrients into the water column by stirring. This is now being investigated.

Clearly there is much research to be done on mechanical stirring and bioturbation in fishponds. However, researchers should be cautious and remember the water quality as well as the food needs of the fish.

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