Verh. Internat. Verein. Limnol. | 26 | 2220–2227 | Stuttgart, Juni 1998

Use of a subsurface plankton layer to benefit a cage-culture fishery in Lake Phewa, Nepal

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Introduction

The Nepalese government and some 225 families in the private sector are engaged in an expanding aquaculture program in lakes Phewa, Begnas and Rupa in the Pokhara Valley, Nepal (Swar & Pradhan 1992). Bighead carp (*Aristichthys nobilis*) and silver carp (*Hypopthalmichthys molitrix*) are propagated in hatchery ponds and are raised to market size in mesh enclosures (having sides, tops and bottoms) suspended to a depth of 2 m. Some 300 cages are presently in use, with annual production varying from 3.4 kg/m^3 in Lake Phewa to about 5 kg/m^3 in lakes Begnas and Rupa (Swar & Pradhan 1992). These cage-reared fish are an important source of animal protein and revenue (Swar 1981). Tourism in the region provides growers a continuous market for their fish.

A problem with this fishery is that fish grow poorly during the summer monsoon in Lake Phewa, the largest and most centrally-located lake. Intense monsoon rains in the Pokhara Valley typically measure 3.2 m between May and September. The decline in growth of caged fish may be due to food limitation associated with the monsoon. Bighead and silver carp are planktivorous, feeding directly on invertebrates and algae (Cremer & Smitherman 1980). Lake Phewa often supports algal chlorophyll levels of >10 µg/L (Jones et al. 1989) but these are diluted by monsoon runoff from its extensive watershed (Lohman et al. 1988). Swar (1981) has shown that zooplankton abundance also declines during the monsoon and attributes the seasonal decline to a low food availability.

Concurrent with decreased fertility of Lake Phewa surface water, a subsurface layer of phytoplankton develops in the metalimnion and upper hypolimnion in spring and persists until fall turnover. The size of this algal peak differs from year-to-year, but 1985 measurements made prior to destratification showed that algal biomass within this layer was some 20- to 30 times greater than at the surface and that zooplankton were most abundant with in this zone (Lohman et al. 1988, unpubl. data). Algae and zooplankton occurring within this zone are sizes that bighead carp and silver carp can use. Oxygen values in the top half of this layer were between 5 and 8 mg/L (Lohman et al. 1988) suggesting this stratum was suitable for fish.

This study was designed to test experimentally whether cage-culture fishery in Lake Phewa could be improved by placing the cages in contact with the subsurface plankton-rich layer to exploit these food resources. The hypothesis underlying this study is that growth of these cage-reared fish is limited by food availability and that yields will improve with access to locations where food is more more abundant. We also predicted that increased food intake would outweigh the consequences of exposing fish to lower water temperatures in subsurface water.

Experimental design and methods

Limnology data: In this papers, our evaluation of Lake Phewa limnology is limited to samples from near the experimental cages, but unpublished data from other lake sites suggest this information represents conditions within the lake. Analyses were performed at the University of Missouri using standard methodology. Samples for chlorophyll (Chl) and solids were filtered onto glass fiber filters and were transported in desiccated containers. We passed some samples through nets to measure the nanno (<34 µm) fraction of the phytoplankton. Subsamples (10 mL) for TP and TN analyses were transferred to acid-cleaned culture tubes; TN samples were acidified to stop bacterial activity. Digestion and analysis of TP and TN were performed in the original culture tube. Zooplankton samples were collected with a 16 L Schindler-Patalas trap fitted with a 64 µm net were weighed to estimate biomass (as volatile suspended solids).

Cages: Experiments were conducted during the monsoons of 1989–91 in cages with 25 mm nylon mesh suspended from bamboo floats at a government facility near the western shore of Lake Phewa. In 1989–90, the experimental design consisted of a Control and two experimental treatments, each with three cages. Cages used for the Control and Horizontal treatment had dimensions of 4.3 m × 4.3 m × 2.2 m (L × W × H) and were suspended horizontally in the water column. The Vertical cages had dimensions

0368-0770/98/0026-2220 $ 2.00

of 2.2 m × 4.3 m × 4.3 m. In 1989 the Control cages extended into the water column to a depth of 2.2 m – thereby mimicking the typical placement of fish cages within the lake. Three Horizontal treatment cages were lowered into the water column until the bottom of each cage reached 5 m depth, as dictated by the location of the plankton layer and oxic water (Lohman et al. 1988, and unpubl. data). Vertical cages were suspended so the bottom of each reached a depth of 6 m. Our reasoning for this configuration was that fish in Control cages would be positioned in the surface waters and serve as a reference to the existing aquaculture practice. In terms of cage volume, fish in the Horizontal cages would potentially have optimum exposure to the plankton layer but there was a concern that, without direct access to surface water, they might undergo periodic oxygen stress. Fish in the Vertical cages had access to both the subsurface plankton layer in the lower zone of the cage and continuously oxygenated water in surface layer.

During 1990, our placement of the cages was more conservative; Horizontal cages were suspended to a depth of 4.2 m and the Vertical cages extended down to 4.8 m. During 1991, the Horizontal cages were eliminated and growth was compared between Control and Vertical cages (three each). Control cages extended 2.2 m into the water column and Vertical cages extended to 5 m.

Stocking: On 10 July 1989, each cage was stocked with 350 bighead carp. Average stocking weights ranged from 46.1 to 50.3 gm for the Control, 44.4 to 45.9 gm for the Horizontal cages and 42.4 to 46.3 gm in the Vertical cages. No silver carp were available. The experiment ended on 4 October (87 days).

In 1990, 210 bighead and 75 silver carp were added to each cage on 19 June. Also, 15 Rohu (*Labeo rohita*), an endemic attached algal grazer, were added to reduce the growth of attached algae and promote water movement through the cages. Average stocking weights for the Control cages were 19.0 to 21.0 gm for bighead and 21.0 to 24.0 gm for silver carp. Average weights were 19.0 to 26.2 gm for bighead and 17.0 to 20.0 gm for silver carp added to the Horizontal cages. In the Vertical cages bighead averaged 20.5 to 27.6 gm and silver carp averaged 17.0 to 20.0 gm. The experiment ended on 25 October (129 days).

In 1991, cages were stocked on 27 May with 300 bighead carp and 15 Rohu. Bighead carp averaged 13.3 to 14.7 gm in each cage. Silver carp fingerlings were not available. The experiment ended on 24 November (182 days).

Differences in stocking weights among the various treatments were not significant in any of the experiments.

Fish growth: Average fish weight was determined by biologists employed at the Fisheries Development Centre, Pokhara one-to-two times per month until harvest. Fish were removed from each cage and weighed en mass in mesh bags before being replaced. Averages were calculated and recorded based on these group weighings. The number of survivors in each cage was recorded at harvest. Growth data was analyzed using average weight gains from stocking to harvest. Treatments were statistically analyzed using Analysis of Variance followed by a Duncan's Multiple Range Test (alpha = 0.05). Statements of significance are based on this analysis.

Results

Limnology

During the monsoon we observed several patterns in the distribution of algal biomass, temperature, and oxygen within the water column of Lake Phewa that were tied to inflow (Figs. 1, 2 and 3). In most samples, algal biomass was

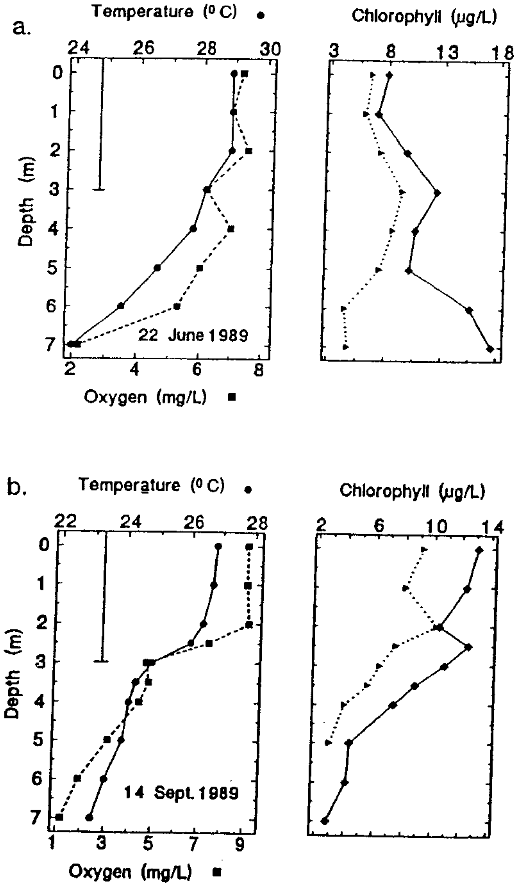

Fig. 1. Limnology data from Lake Phewa in 1989. Vertical line represents Secchi depth. Total chlorophyll (solid line) and the chlorophyll fraction <34 µm (dotted line with triangles) shown in the right panel.

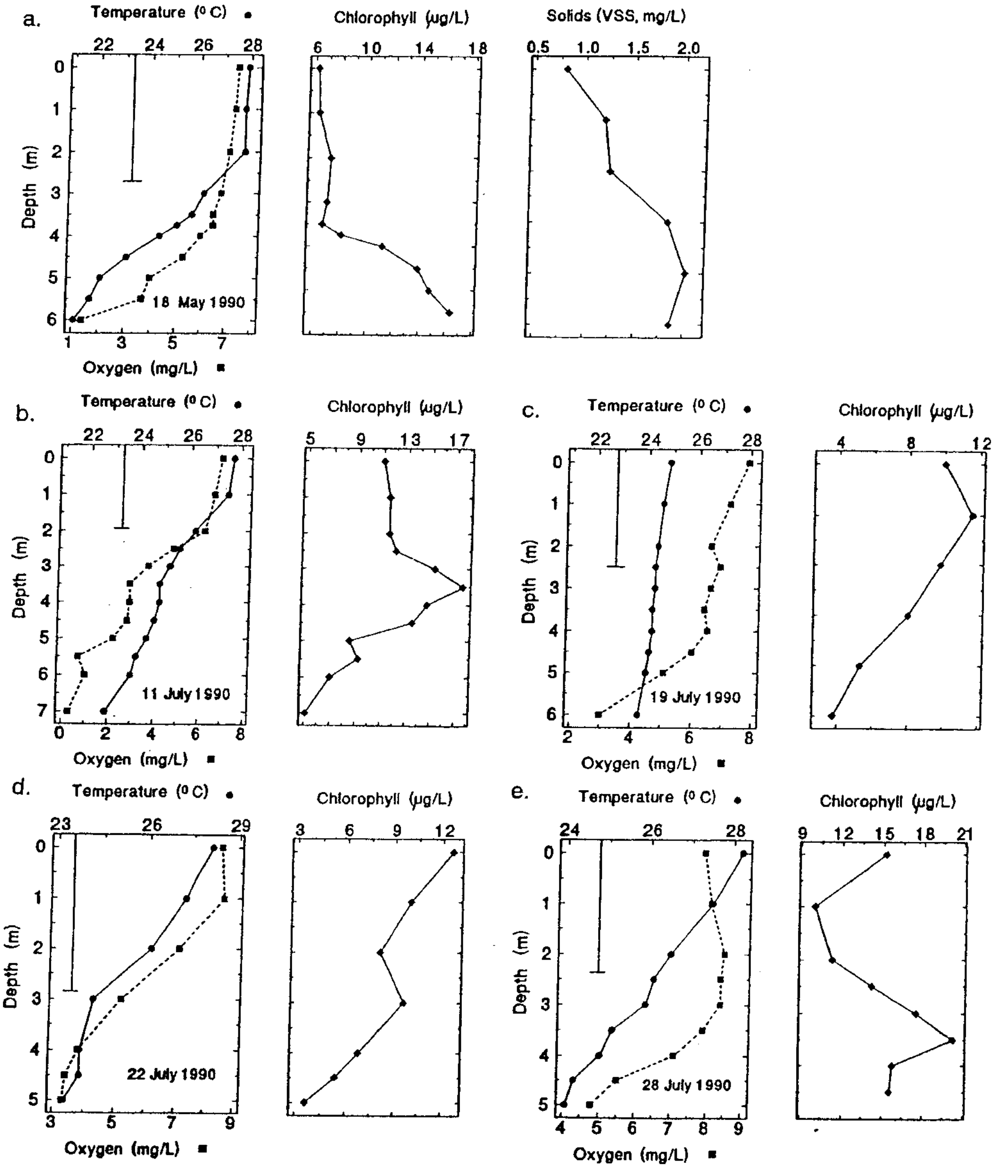

Fig. 2.

greater in the metalimnion than the epilimnion, but this was not always the case. Our samples from May, early in the monsoon, show subsurface metalimnetic Chl peaks occurring within <25 C water (at 4–4.5 m, Figs. 2 a and 3 a). During mid-summer, the monsoon inflow enters the lake as an underflow, cooling the water column and diluting the metalimnion. This pattern was shown best in 1990 (Fig. 2). Data from 11 July show a Chl peak in the metalimnion (Fig. 2 b); some 180 mm of rain were measured in the preceding four days. By 19 July, there was an additional 250 mm of rain and the top 6 m of the water column was nearly homothermal (Fig. 2 c). Subsequently, the lake restratified and the sub-surface Chl peak re-

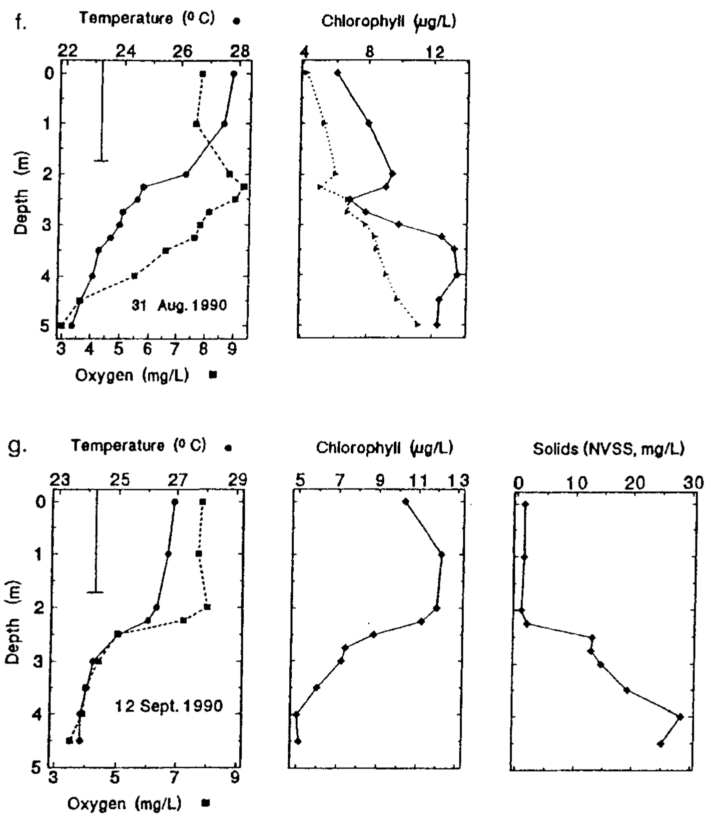

Fig. 2. Limnology data from Lake Phewa in 1990. Vertical line represents Secchi depth. Total chlorophyll (solid line) and in panel f. the chlorophyll fraction <34 µm (dotted line with triangles) is shown. In panel a. the volatile suspended solids (VSS) fraction was measured in samples collected with a 64 µm net as an estimate of zooplankton biomass. In panel g. non-volatile suspended solids (NVSS) was measured as an estimate of inorganic turbidity in interflow water.

formed (Figs. 2 d and 2 e). Rainfall was modest for the 11 day period prior to 31 August (0 to 20 mm), and profile data show a complex pattern with two sub-surface Chl peaks (Fig. 2 f). Some 225 mm of rain fell during the three days before the 12 September 1990 collection (Fig. 2 g); the interflow created a sharp oxycline associated with a nearly 30-fold increase in non-volatile suspended solids. We also measured an interflow of turbid water on 16 July 1991, after some 125 mm of rainfall (Fig. 3 b). Modest rainfall occurred prior to the 1 September 1991 sample; the metalimnion was on that date was irregular, suggesting the influence of another interflow (Fig. 3 c).

Our algae size fraction data suggest that the sub-surface biomass was occasionally composed of larger cells than at the surface, thereby benefitting plankton-feeding fish with access to this layer (e.g., Figs. 1 a and 2 f). Oxygen was usually greater than 5 mg/L within the upper zone of the algal peak, but declined rapidly with increasing depth. Occasionally, however, low oxygen values within the 3 to 5 m zone would have stressed fish (e.g., Fig. 2 d). Our gravimetric measurements of zooplankton suggested peak biomass occurred within the sub-surface plankton layer (Fig. 2 a) but not in all cases.

Fish growth – Bighead carp

Our work in 1989 was exploratory. Growth of bighead carp was parallel in each treatment

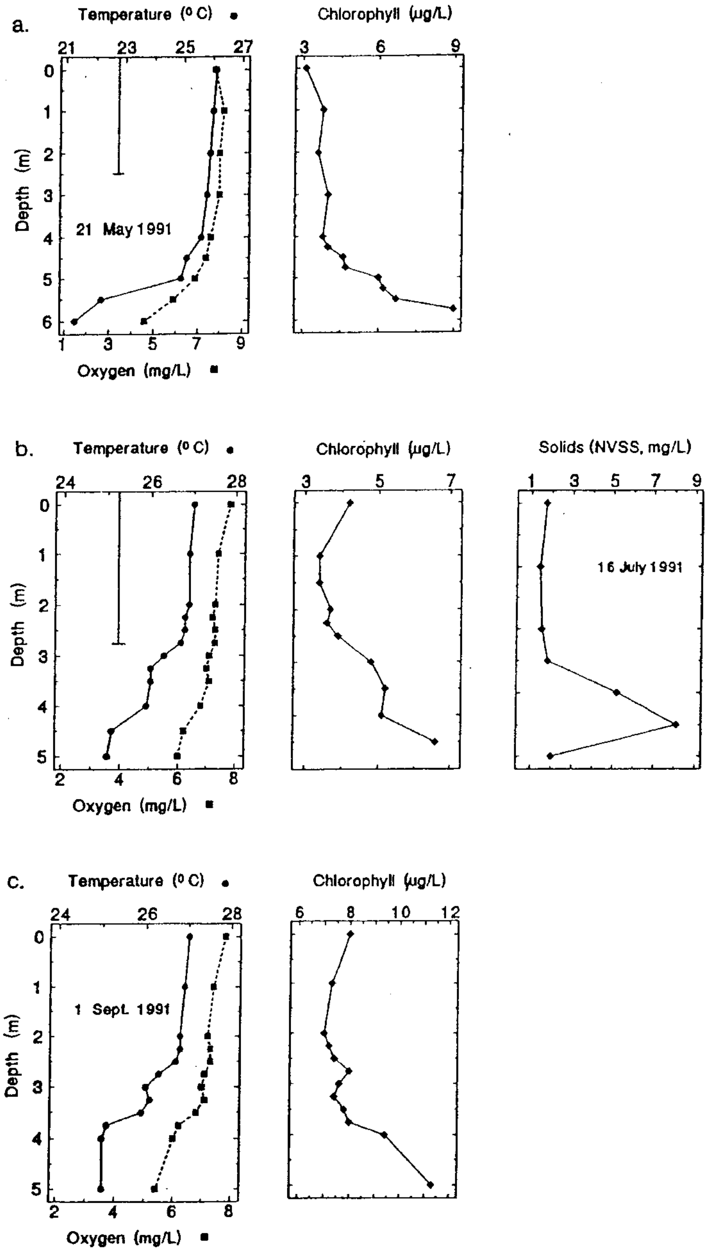

Fig. 3. Limnology data from Lake Phewa in 1991. Vertical line represents Secchi depth. In panel b. non-volatile suspended solids (NVSS) was measured on whole water as an estimate of inorganic turbidity in interflow water.

during most of the study (Fig. 4 a). However, by the final sampling fish in the Horizontal and Vertical cages, with access to the subsurface layer, gained about 75 % more weight than the Controls (some 27 gm/fish in the treatments versus 15 gm/fish). This difference was signifi-

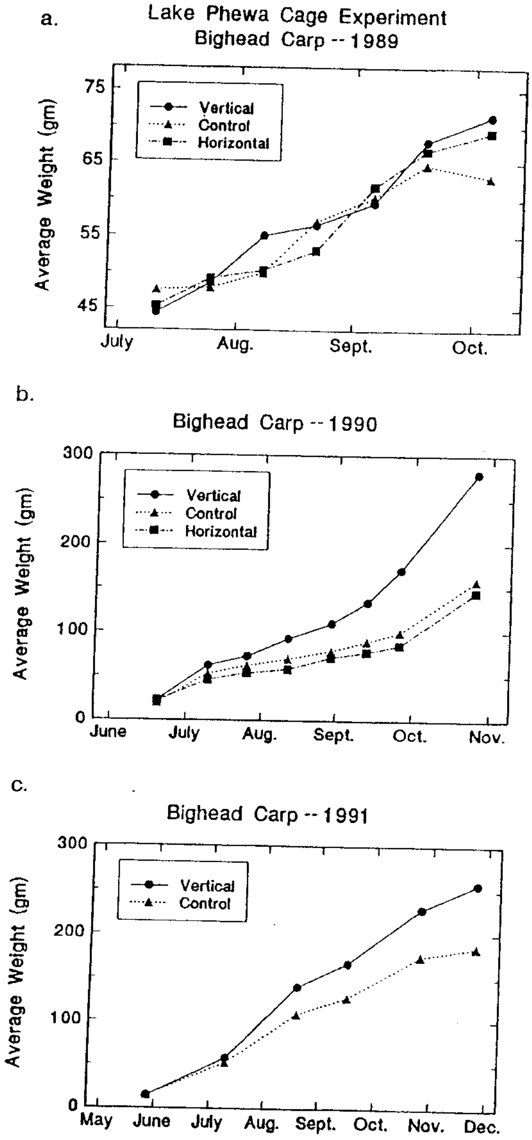

Fig. 4. Growth of bighead carp in cage experiments in Lake Phewa during 1989 (panel a.), 1990 (panel b.) and 1991 (panel c.). Error bars not shown on the panels in order to simplify the presentation. The coefficient of variation within individual treatments varied from 0.8 to 3.3 with an overall average of 1.96.

cant and supported our original hypothesis. During this pilot study one Vertical cage detached from its float and partially settled into anoxic water; mortality resulted and this cage was excluded from the analysis.

In 1990, the average weight gain by bighead carp in the Vertical treatment (257 gm/fish) was 87 % greater than the Control (Fig. 4 b), a significant difference. Despite access to the subsurface plankton layer, growth in the Horizontal cages was on par or slightly lower than the Control (not significant). We suspect that fish in Horizontal cages were stressed by hypoxic interflow during storms (e.g., Figs. 1 b and 2 b). Horizontal cages did not allow access to surface water. Survival in all treatments was about 92 % (no significant differences) so that production (weight gain × survivorship/volume) was about 1.2 kg/m^3 in Vertical cages and about half that amount in the others.

Another interesting feature of the 1990 data is that growth of bighead carp was greatest in the Vertical cage adjacent to the open lake, intermediate in the cage closest to the shore and

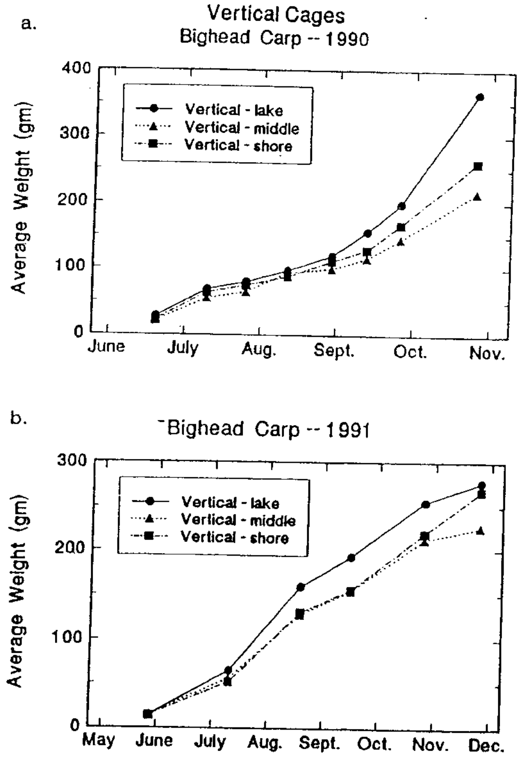

Fig. 5. Growth of bighead carp in three Vertical cages in Lake Phewa during 1990 (panel a.) and 1991 (panel b.). The cage designated "lake" was nearest the open water, the "shore" cage closest to the shore and the "middle" cage was between the others.

least in the cage located in the middle of our experimental floats (Fig. 5 a). We suspect that this growth pattern reflects differences in water circulation through the cages and, therefore, the supply of plankton. Among the Vertical cages growth seemed to diverge after the fish were greater than 100 g (Fig. 5 a); this may represent the point where food resources became limiting. Growth and survival of Rohu, an attached algal grazer, was similar among these three cages.

In 1991, bighead carp in the Vertical cages gained 243 gm/fish; this was some 42 % greater than weight gains in the Control (a significant difference, Fig. 4 c). Survival averaged 82.5 % in the Vertical cages and 78 % in the Controls (not significant). Based on these values production was 1.5 kg/m^3 in the Vertical cages versus 1.0 kg/m^3 in the Control.

Excluding the Horizontal treatment in 1991 left space between individual cages such that relative position had less influence on growth (Fig. 5 b). Growth was somewhat greater in the Vertical cage next to the open water; it likely had the best water exchange. Among the Control cages, growth was also consistently greater in the cage adjacent to the open lake.

Fish growth – Silver carp

Silver carp fingerlings were available only in 1990. In each treatment, initial growth occurred immediately after stocking, followed by several months of weight loss or little gain, and then a period of growth in final month of the study (Fig. 6). At the end of the experiment, weight gain in the Vertical cages was some 25 % greater than the Controls and about double that in the Horizontal treatment (a significant difference). Survival was significantly greater in the Vertical cages (83 %) as compared to the Control (53 %) and Horizontal cages (66 %). Production in the Vertical cages averaged 63 g/m^3, double the other treatments. Propagation of silver carp, a known phytoplankton feeder, has never been particularly successful in Lake Phewa compared with other lakes in the valley. This experiment suggests weight gain and survival can be improved by providing fish access to the sub-surface plankton layer.

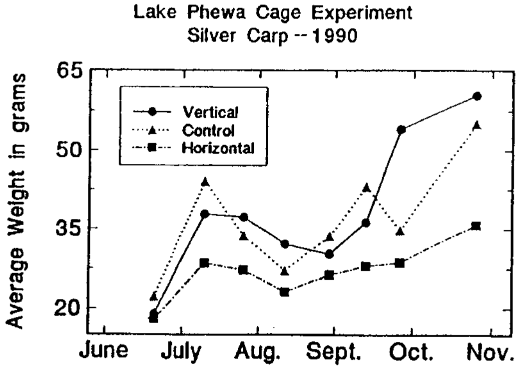

Fig. 6. Growth of silver carp in cage experiments in Lake Phewa during 1990.

Discussion

The most important outcome of this study is that positioning culture cages vertically in Lake Phewa increased fish production. It provided fingerlings with access to a sub-surface plankton layer and benefits were greatest when the top of the cage was in surface water. This modification takes advantage of natural fertility without negatively impacting the environment. Optimal use of natural fertility is especially important to aquaculture in Nepal because supplemental feeding programs are cost prohibitive for private fish farmers. This adjustment is practical because floats and cages currently in use can be adapted easily with locally available materials (rope and weights) making it simple and inexpensive to modify existing production methods.

Our data suggested growth of bighead carp could be improved by 40 to 85 + %. The actual level of improvement will vary with stocking regime (weight, number.and species composition), weather conditions that influence the location and concentration of the plankton layer, position of cages in the water column relative to both the plankton layer and oxygen, and water movement through individual cages. Lake conditions will vary from year-to-year but, despite this variance, our data suggest that access to the sub-surface plankton layer will improve the growth of caged fish. The algal layer within the metalimnion of Lake Phewa was dynamic; it was disrupted by storms and reformed during the monsoon (Fig. 2). The magnitude and frequency of storms determined this pattern and its occurrence. Available data suggest that Lake Phewa stratifies by March (Ferro 1981/82) and that the sub-surface plankton layer develops shortly thereafter and lasts until fall turnover (November). Fish grow during much of this period (Swar & Pradhan 1992) and the fishery should benefit from maximum temporal exposure to the plankton layer.

The local fish farmers are aware of our study and have adjusted their cages accordingly. Some have added material to increase the height of their cages (from 2 m to about 5 m) while others have rotated their cages to maximize their depth within the water column. Biologists estimate there are some 20,000 ha of water in Nepal in which cage culture might be practiced without supplemental feed. Many of these waterbodies likely stratify and may support a subsurface plankton layer. We hope our work in Lake Phewa will be considered in these locations as a simple mechanism to increase fish harvest. The practice may have widespread application in much of Asia and in other places where a cage fishery depends on ambient fertility.

Acknowledgements

This material is based on work supported by the US Agency for International Development and the National Science Foundation under Grant No INT-8407884. We thank B. P. Sharma, P. L. Joshi, and all employees of the Fisheries Development Centre, Pokahara for help with this study, particularly for weight measurements. We thank Prem B. Nepali for invaluable help collecting the limnology data. We thank Drs. Doug Noltie, Art Witt, Aaron Delonay, and James Fairchild for reviewing this manuscript. This paper is a contribution from the Missouri Agricultural Experiment Station, Journal series number 12,366.

References

Cremer, M. C. & Smitherman, R. O., 1980: Food habits and growth of silver and bighead carp in cages and ponds. – *Aquaculture* 20: 57–64.

Ferro, W., 1981/82: Limnology of the Pokhara Valley lakes (Himalayan region, Nepal) and its implications for the fishery and fish culture. – *J. Nepal Res. Centre* 5/6: 27–52.

Jones, J. R., Knowlton, M. F. & Swar, D. B., 1989: Limnological reconnaissance of waterbodies in central and southern Nepal. – *Hydrobiol.* 184: 171–189.

Lohman, K. L., Jones, J. R., Knowlton, M. F., Swar, D. B., Pamperl, M. A. & Brazos, B. J., 1988: Pre- and postmonsoon limnological characteristics of lakes in the Pokhara and Kathmandu valleys, Nepal. – *Verh. Internat. Verein. Limnol.* 23: 558–565.

Swar, D. B., 1981: Seasonal abundance of limnetic crustacean zooplankton in Lake Phewa, Pokhara Valley, Nepal. – *Verh. Internat. Verein. Limnol.* 21: 535–538.

Swar, D. B. & Pradhan, B. R., 1992: Cage fish culture in the lake of Pokhara Valley, Nepal, and its impact on local fishers. – *Asian Fish. Science* 5: 1–13.

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