Nutrient Dynamics of Seasonal Tanks in the Dry Zone of Sri Lanka in relation to their hydrological regimes

B.V.P.L. Jayakody[1]
Francis J. Murray[2]
David C. Little[2]
M.I.M. Mowjood[3]

ABSTRACT

Village tanks are put to a wide range of uses by the rural communities that depend on them for their survival. As the primacy of irrigation has decreased under these tanks due to a variety of climatic and economic reasons there is a need to re-evaluate their use for other productive functions. The research presented in this paper is part of a programme investigating the potential to improve the management of living aquatic resources in order to bring benefits to the most marginal groups identified in upper watershed areas.

Based on an improved typology of seasonal tanks, the seasonal changes and dynamics of various water quality parameters indicative of nutrient status and fisheries carrying capacity are compared over a period of one year. Indicators of Net (Primary) Productivity (NP): Rates of Dissolved Oxygen (DO) change, Total Suspended Solids (TSS): Total Suspended Volatile solids (TVSS) ratios are the parameters of principle interest. Based on these results a comparative analysis is made on two classes of 'seasonal' and 'semi-seasonal' tanks.

Results indicate a broad correlation in each of these parameters with seasonal trends in tank hydrology. Highest productivity levels are associated with periods of declining water storage, whilst the lowest levels are associated with the periods of

[1] **PGIA, University of Peradeniya**
[2] **Institute of Aquaculture, University of Stirling, United Kingdom**

maximum water storage shortly after the NW monsoon. This variation is primarily attributed to dilution effects associated with depth and storage area. During the *yala* period, encroachment of the surface layer by several species of aquatic macrophyte also has progressively negative impacts on productivity.

The most seasonal tanks show wider extremes in seasonal nutrient dynamics, overall, with less favourable conditions than the 'semi-seasonal' tanks. Never the less all the tanks can be considered as being highly productive with NP levels comparable to fertilised pond systems for much of the year. This indicates that nutrient status is not likely to be amongst the most important constraints to enhancing fish production. Other potential management improvements based on these results are discussed.

INTRODUCTION

Traditionally, the livelihoods of communities in the Dry Zone of Sri Lanka have revolved around the village tank system. Primarily constructed as irrigation systems, these resources are put to a range of ancillary uses that include bathing / domestic uses, livestock watering, and the harvesting of fish and aquatic plants for household consumption. Village tanks are also integrated components of the wider eco-system understanding of which requires a watershed-based approach (Murray and Little 2000). In recent times the primacy of irrigation under seasonal tanks has decreased due to the increasingly erratic nature of rainfall distribution and the availability of lower risk livelihood options (Murray and Little 2001).

Work in this paper is part of a wider DFID/CARE funded research project (Fish in Irrigation Systems Technology - FIrST), which seeks to understand the potential to integrate aquaculture options in the most seasonal tanks in upper

[3] **Dept. of Agricultural Engineering, Faculty of Agriculture, University of**

watershed areas, often the only resources accessible to many of the most marginal rural communities (Murray and Little 2000). Critically the work aims to define such potentials through a holistic approach considering the preferences, priorities and collective management capacities of these groups. This is in contrast to most traditional water management interventions with their focus on technical optimisation of the resource often considering a single use.

This paper examines the seasonal variation in selected water quality parameters indicative of the nutritive status and natural carrying capacity of these water bodies for fish stocks. The indicators of principle interest are rates of Dissolved Oxygen (DO) Change, Total Solids (TSS) and Total Volatile Suspended Solids (TVSS) levels. An attempt is made to relate observed trends to the broader hydrological regime of tanks related to their position in the watershed (Murray and Little 2001). Finally, options for enhancing fisheries production are evaluated based on these findings.

Collaborating institutions include the University of Stirling in the United Kingdom and the AgriBusiness Center (ABC) of Peradeniya University and CARE International Sri Lanka. The study took place in just over a one-year period, from April 2000 to May 2001.

MATERIALS AND METHODS

- **The research area**

Research was undertaken in adjacent watersheds of Giribawa and Nawagaththegama Divisional Secretariats of North West Province (Fig 1). The area belongs to the DL1 agro-climatological region of the Dry Zone, which receives 1300

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mm rainfall per annum (75% probability). Along with Anuradhapura District to the North, the area benefits from one of the highest densities of seasonal tank resources in the country.

- **Tank selection**

Seventy-one tanks, comprising 7 cascade systems were screened according to hydrological and poverty criteria (Murray and Little 2001). Subsequently four tanks from adjacent cascade systems, representing two seasonal typologies were selected for the study as shown in Table 1. The position of the tanks in their respective watersheds is shown in Fig 1.

- ***In-situ* measurement of Dissolved Oxygen (DO) and temperature**

DO ($mg.l^{-1}$) and temperature were measured *in-situ* on a weekly basis using a portable DO meter (Yellow Springs Instruments, Model 85), once in the early morning (6:00 - 7:30 hrs) and again in the afternoon (13:00 - 15:00 hrs). Measurements were taken at depths of 0.1m and 1m whilst there was sufficient depth to assess any vertical stratification. Measurements of these and the other reported parameters were taken concurrently from a single site near the sluice gate, deeper areas likely to hold water for the longest period. Areas of dense macrophyte coverage and sites of intense human/animal activity including bathing spots and heavily overcast days were avoided as far as possible.

- ***Ex-situ* Measurement of Total Suspended Solids (TSS), Total Volatile Suspended Solids (TVSS)**

Replicate water samples were collected for laboratory analysis on a weekly to fortnightly basis (at the same time as *in-situ* measurements) using an improvised column sampler (100cm, 3.5cm Diameter PVC pipe) to account for any turbidity stratification.

TSS levels were assessed by filtering 100-150mls of sample (depending on solids loads) followed by oven drying at 105oC for 1hrs.

TVSS was assessed by evaporating 100-150mls of unprocessed and filtered water sample at 105oC for 8hrs and combusting the resulting residues at 550 ^{o}C for 30 min. in a muffle furnace. The resulting filtrate value was then subtracted from that of the unprocessed sample.

Start and end weights for each of these parameters were measured on a microbalance accurate to 0.1mg. Experimental error was minimized through periodic analysis of distilled water samples and rejection of replicate values differing by more than 25%. Otherwise the mean replicate value is presented (Fig 5).

- **Measurement of rainfall, tank water levels and aquatic encroachment**

Daily rainfall levels were recorded by farmers supplied with non-recording rainfall gauges at three sites around the tank (Figs 1 and 2) and results averaged.

Depths of water in the tanks were measured in the deepest areas close to the sluice on a weekly basis. Measurements were related to two datum; Full Supply Level (FSL) marked on the sluice during tank spill events and Dead Storage Level (DSL) at lowest point of the sluice gate (Fig 3 and Table 1).

Surface encroachment by rooted and floating macrophytes was estimated visually as the percentage of the total surface tank area covered by the weeds.

RESULTS AND DISCUSSION

- **Tank Hydrology**

Broad correlations with other water quality parameters were made possible using daily tank water level and rainfall data (Figs. 2 & 3).

The seasonal hydrological regime of man-made tanks in the dry zone reflects two principle factors; the monsoon cycle and irrigation demand. Sixty to seventy percent of this annual total falls during the main (*Maha)* cultivation season (October to February) when most tanks reach their maximum storage level. The secondary cultivation season (*yala*) runs from May to September and tanks typically reach their lowest water levels or dry completely between July and September. However within these broader trends rainfall distribution is highly erratic. A total of only 810mm rain fell between April 2000 and March 2001 only 62% of the mean 75% annual probability level, making this a drought year (Fig 2). Consequently cultivation only took place under IMK at 50% cropping intensity during the period of the study (Murray and Little 2001). Meanwhile tank water levels continued to fall right up to the middle of November 2000, some 2-3 months beyond the anticipated period.

Although none of the four tanks dried completely, both MAD and LHG were reduced to muddy pools less than 0.1Ha in size and no more than 5cm in depth, conditions in which only resilient air-breathing fish varieties were likely to survive.

- **Seasonal variation of net DO evolution rates**

Algal productivities are most readily measured by measuring rates of change in DO (i.e. $mg.l^{-1}.hr^{-1}$ – Boyd 1990). This gives an estimate of Net Productivity (NP), the amount of organic matter produced over a given time accounting for losses to respiration. The net yield of tilapias raised on natural foods in fertilised ponds has been shown to be well correlated to the rate of NP estimated from diel DO rate changes (McConnell et al., 1977; Knud-Hansen and Batterson, 1994).

The net rate of DO evolution ($mg.l^{-1}.hr^{-1}$) was calculated between first light and mid afternoon at the surface (0.1m) and depth (1m) and these weekly values averaged for each month of the study (Fig. 4). The rate and direction of these changes is the net result of a number of closely inter-related physical and biological processes that produce and consume oxygen: photosynthesis, reaeration / deaeration, Biological and Chemical Oxygen Demand (BOD & COD), Dilution arising from water inflows (Lewis and Whiteman, 1924, Mowjood, 1998). Despite this complexity, three broad seasonal trends correlated with changes in tank depth and water-spread are observed.

- Inter-monsoon periods of low storage (Oct to Nov 2000 and Mar to Apr 2001)

Net DO production rates reached their seasonal maxima between October and November. Uniform levels of 1.2 $mg.l^{-1}.hr^{-1}$ were recorded at 0.1m depth, whilst values at 1m ranged from 0.75 to 1.15 $mg.l^{-1}.hr^{-1}$. These are the months of minimal water storage and depth, accompanied by a progressive concentration of organic material originating from livestock and human activity in the tank bed. The period also experienced a high proportion of cloudless days. A minor secondary peak also occurred during the second inter-monsoon period (March to April) a dry period when water levels retreat partially prior to the onset of the SW monsoon.

- Inundation periods (Nov 2000 to Jan 2001 and April 2001)

The peak production levels described above fall rapidly to between 0.17 to 0.25 $mg.l^{-1}.hr^{-1}$ and 0.4 to 0.2 $mg.l^{-1}.hr^{-1}$ at 0.1 and 1m depth respectively. This is due to massive dilution as the tanks rapidly begin to fill from their lowest levels with the onset of the NW monsoon, heavy cloud cover and BOD created by the decomposition of vegetation and other organic matter in newly inundated areas.

- Periods of intermediate water storage (Apr to Sept 2000, Feb to Mar 2001)

DO production rates recover sharply only 1-2 weeks after inundation, presumably due to algal blooms and continue to increase progressively in the months thereafter as water levels fall again. Median levels between 0.4 to 0.6 $mg. l^{-1}. hr^{-1}$ (0.1m depth) and 0.1 to 0.25 $mg.l^{-1}.hr^{-1}$ (1m depth) during April / May double by September. However, the increase is punctuated by frequent and wide fluctuations (no depth measurements were possible in the shallow residual storage of MAD and LHG from Mid July to early November). This oscillation is a consequence of a number of site-specific factors discussed below.

- **Water Temperature and DO**

Results indicate wide seasonal, diel and to a lesser extent, depth fluctuations in temperature. Over the course of year temperatures fall as low as 23 ^{o}C (1m depth) in the semi-seasonal tanks in May rising as high as 36 ^{o}C (0.1m depth) in seasonal tanks during November. Except for periods of inundation, all tanks show a marked diurnal (AM/PM) temperature fluctuation, with most of the variability accounted for in the afternoon readings. The variation can be as high as 6 and 11^{o}C in the seasonal and semi-seasonal tanks respectively during the dry season.

Although non of these shallow systems appeared to experience persistent thermal stratification (normally a feature of deeper tanks), a surface/ depth divergence of 1 to 3.5 ^{o}C by mid afternoon is a feature of the shallowest 'seasonal' tanks for much of the year whilst depths are greater than 0.5m. Lack of persistent stratification indicates nightly mixing of upper and lower water layers with positive impacts for internal nutrient cycling and NP. The afternoon thermal stratification observed in the seasonal tanks is probably due to greater shelter from prevailing winds and sunlight as a result of their smaller size and location within forested areas in addition to high levels of aquatic emergent macrophyte encroachment. Levels in the shallower 'seasonal' tanks reached some 85-95% of total surface area by September, compared to only 60-70% in the two larger tanks.

During the dry season surface layers become supersaturated in the afternoon due to high water temperature and productivity levels. Levels reach as high as 200% in the semi-seasonal tanks and 130% in the seasonal tanks.

- **Inter-tank variation in DO profiles**

'Seasonal tanks' DO profiles in the two smaller 'seasonal' tanks though relatively erratic show some broadly similar trends. Out with periods of good water mixing such as inundation a wide disparity exists between surface and depth measurements (Fig 4). This is most marked in MAD, the smallest tank, where conditions at depth are close to anoxic for much of the year whilst elevated levels persist at the surface. This is consistent with observations of fish regularly 'taking air' at the surface during morning periods. Such conditions, normally a feature of persistent thermal stratification in deeper tanks, are instead probably due to heavy weed encroachment that creates both shading effects and BOD at depth through build up of decaying vegetation. In addition even modest bio-perturbation in shrinking water spreads (i.e. bathing activity) can increase inorganic turbidity. These conditions result in net losses to primary productivity.

'*Semi-seasonal tanks*' Overall levels of DO production and by inference NP are substantially higher in the two larger 'semi-seasonal' tanks considering the net contribution at 0.1m and 1m depths (Fig. 4). Seasonal cycles are also more clearly defined including the progressive increase in production levels from April to Nov.

Absolute DO levels both at the surface and depth also show higher seasonal maxima with increasing tank size and depth. Between August and October PM surface levels of 9, 11, 12 and 15 $mg.l^{-1}$ in MAD, LHG, IMK and GUR respectively, rose from 3-5 $mg.l^{-1}$ in the morning (data not shown). Little variation exists between surface and depth readings in the larger tanks at this time again indicating good water mixing. Seasonal minima at the surface range from 0.5 (AM) to mg. l^{-1} (PM) and 1 (AM) to 5 mg.l^{-1} (PM) in the seasonal and semi-seasonal tanks respectively during the *maha* season (data not shown).

Aquatic macrophyte encroachment: Such encroachment has impacts on large and small tanks. Most significant in terms of shading were two species of water lillies (*Nymphaea sp.*) and one of lotus (*Nelumbo nucifera)*, present in all the tanks. A more serious weed, *Salvenia infestans,* resulted in dense areas of blanket coverage in GUR, creating anaerobic conditions beneath. As floating surface macrophytes, salvinia patches were moved by winds creating shifting windows for gaseous exchange and primary production. Finally, dense growth in the nutrient rich littoral areas was concentrated by run-off during the inundation period into the deeper bund area. This was probably responsible for the lack of a marked post inundation DO peak, experienced in all the other tanks during December.

- **Seasonal variation of TSS and TVSS**

TSS refers to the total concentration of particulate organic and inorganic matter suspended in the water column also sometimes referred to as organic and inorganic turbidity. The organic / volatile component consists primarily of phytoplankton and algae-derived detritus, whilst the inorganic component consists of fine clays and silts entering the tank from surface runoff, rainfall, bund erosion or bio-perturbation (i.e. cattle incursions, fishing activity or the nest building activities of tilapia). TSS levels up to 80 mg.l^{-1} are acceptable for most grow-out purposes, whilst optimal levels are below 25 mg.l^{-1} (Boyd 1990). Figure. 5 shows the seasonal variation of TSS, TVSS and the TVSS: TSS ratio in each of the tanks.

TSS profiles: TSS levels rise steadily from April onwards as water levels fall, rising to abrupt peaks between October and November. These peaks are highest in the smallest tanks, where they correlate with periods of major cattle incursions in the residual water spreads for watering purposes. The largest peak (1,300 $mg.l^{-1}$) recorded in LHG is a combined result of such incursions and a period of intense collective 'mud' fishing lasting 5 days.

Secondary peaks occurring in three of the tanks in the third week of November (170 – 200 $mg.l^{-1}$) were a result of runoff associated with the first heavy, consecutive *maha* rain days. The highest such peak in GUR reflects its poor catchment characteristics consisting of the command area of its immediately superior tank in the cascade. After the inundation period levels fluctuate less dramatically between basal levels of 15 – 50 $mg.l^{-1}$ from Jan to May 2001, levels more suited for fish growth. The negative impacts of Inorganic turbidity events on DO level therefore appear to be short-lived compared to the impacts of aquatic weed encroachment.

TVSS Profiles: TVSS levels though much lower follow a similar trend with peaks of 25-60 in October (300 $mg.l^{-1}$ in LHG during the September collective fishing event) whilst basal values fluctuate between 5 to 25 $mg.l^{-1}$ during the rest of the year. The inorganic turbidity will settle much more rapidly than the organic load which enters the tank simultaneously. The Total Volatile Dissolved Solid (TVDS) load that also persists in the water column follows a similar trend and also contributes a sizeable part of the total organic load, contributing nutrients for primary productivity (data not shown).

TVSS: TSS ratios and NP: After brief episodes of oxygen depletion due to a combination of solar interception associated with inorganic turbidity, dilution and elevated BOD/COD during both January and April, there follow rapid increases in net DO production rates, presumably as a result of algal blooms utilizing the more persistent organic load in the water column.

Correspondingly in the ‘semi-seasonal’ tanks the highest TVSS: TSS ratios and those most favourable to primary productivity occur during the two periods of lowest water storage (September to November and February to March). Knud – Hansen (1998) reports that high TSS concentrations are particularly undesirable when the TVSS: TSS ratio falls below 0.2, as aquatic organisms must contend energetically with reduced concentrations of digestible matter in the filtered material. Seasonally, ratios in the current study ranged from 0.1 to 0.9 with the lowest sub-optimal ratios corresponding with periods of inundation run-off (Dec-Jan). Ratios in the ‘seasonal’ tanks are more erratic as they respond more dramatically to site-specific factors such as bio-perturbation. Overall ratios remain more favourable in the larger tanks for most of the year.

CONCLUSIONS

The tilapiines of the genera *Oreochromis* (*O. mossambicus* and *O. niloticus*) constitute as much as 95% of the yield in shallow reservoir fisheries of Sri Lanka. Although highly adaptive omnivores they are predominantly herbivorous, feeding low in the food chain grazing and filtering algae and algal derived detritus. Fish yields in seasonal tanks consisting primarily of tilapias can therefore be expected to correlate closely with their primary productivity, a measure of the total organic production of plant mass through photosynthesis

The results presented here clearly indicate that regional climatic factors through their effects on tank hydrology play the major role in the overall seasonal variation of D0 and primary productivity. The highest levels and consequently most favourable periods for fish growth occur from February onwards, for as long as sufficient water storage remains in the system. The least favourable periods occur after inundation from December to January when buffering capacity is low and inorganic turbidity frequently elevated.

The results also clearly indicate NP levels are correlated closely with tank water spread and depth, with greater production potentials in the larger 'semi-seasonal' tanks. Loss of productivity in the 'seasonal' tanks is related in large part to their shallow depth and attendant problems of aquatic macrophyte encroachment resulting in high levels of BOD and anoxic conditions at depth. In addition the effects of bio-perturbation and run-off events are more marked in smaller tanks, resulting in more erratic seasonal trends.

Knud-Hansen (1998) reported that mean net primary productivity levels were strongly correlated with net *O. niloticus* yields in fertilised earthen pond experiments. Levels ranged from 0.7 to 1.35 $mg.l^{-1}.hr^{-1}$ In other words for much of the current year, conditions particularly in the larger semi-seasonal tanks approximate to fertilised pond conditions albeit at the lower end of this scale. Were levels to be maintained at 0.7 $mg.l^{-1}.hr^{-1}$ throughout the season this would be equivalent to a Net Fish Yield (NFY) potential of 1,280kg over 5 months. In reality although the observed NP trend in the current study indicates a good correlation with increasing fish biomass and carrying capacity, the sub-optimal concentrations recorded during the first months of the seasonal production cycle are likely to result in reduced growth of at the critical fry and juvenile stages with loss of 'cumulative growth interest' throughout the rest of the production cycle. This is of significance when a goal is to achieve rapid growth within a short seasonal window of opportunity using early season / advanced stocking options.

Never the less these results indicate extremely high production potential, particularly remembering that these are natural production systems. Seasonal variations in nutrient availability due to various climatic, hydrological factors and weed encroachment rather than nutrient concentrations *per se*, appear to be the main constraints to further productivity enhancement. Consequently Interventions designed to increase organic nutrient are likely to have little application and greater emphasis should be given to other management factors, particularly relating to weed management and refuge excavation. Such options must be fully integrated with other uses considering the primary seasonal requirements of the tank, particularly for irrigation and bathing.

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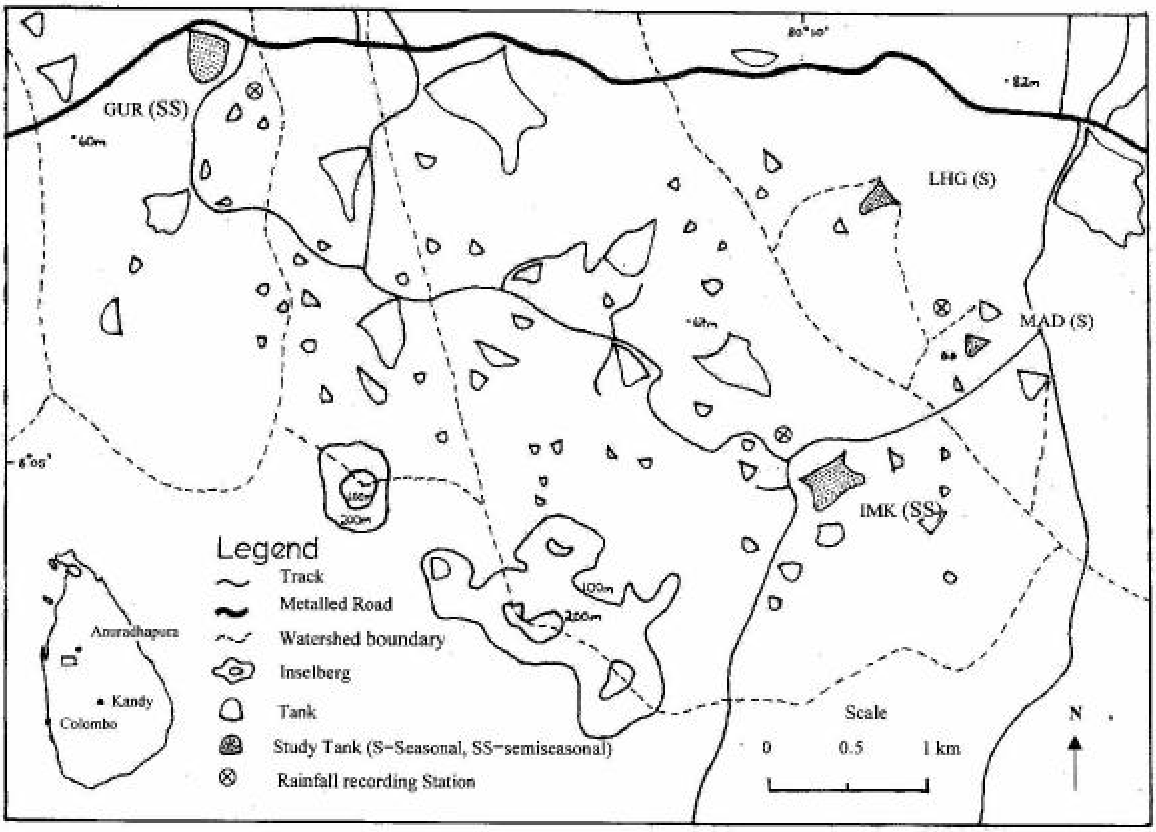

Figure 1. The research area, showing location of the study within watershed boundaries (Source: Survey Dept. of Sri Lanka 1984 and field survey)

	Maduragama (MAD)	**Lokahettiyagama (LHG)**	**Ihala Maradan kadawela (IMK)**	**Gurulu-pitigama (GUR)**
Typology[1]	Seasonal Radial / Axial 1		Semi-seasonal Axial 1	
Max Water Spread (Ha)	3-4	6-7	12-15	15-20
Full Supply Storage Depth (m)	1.48	2.5	2.5b	2.5
Dead Storage Max Depth (m)	0.5	1	1	1.5
Households / Community	49	43	128	120

[1] **Seasonal tanks:** Dry 1 or more times / 5 years with complete loss of fish stocks.
Semi-seasonal tanks: Drying frequency less than once every 5 years – retain stocks.
Radial tank: Receives water only from it's own micro-catchment
Axial 1 tank : 1st order: receives water from own micro-catchment & spills/returns from 1 radial tank
Axial 2 tank: 2nd order: receives water from own micro-catchment and spills/returns from other axial tanks or more than 1 radial tank.

Table 1. Typology of seasonal tanks in the study (After Murray and Little 2001)

Tank Name	Parameter	Max	Min	Mean	STD	CV[1] %	Tot No of Cloudy Days [2]
MAD	DO 0.1m	10.8	0.07	4.16	3.04	73.2	6
	DO 1m	6.21	0	2.27	1.67	73.5	
	TVSS	286	2	44.2	65.4	147.9	
	TSS	1365	9.25	150.9	270	179	
LHG	DO 0.1m	9.65	0.07	259	2.44	94.2	6
	DO 1m	6.52	0	0.87	1.4	160.0	
	TVSS	61.5	1.3	13.3	13	102	
	TSS	174.5	1.4	41.68	42.2	101	
IMK	DO 0.1m	12.24	0.91	5.61	3.11	55.4	6
	DO 1m	11.33	0.14	4.03	2.82	70.0	
	TVSS	58	2	19	13.9	73	
	TSS	71.5	6.6	33.4	18.4	55	
GUR	DO 0.1m	14.68	0.06	4.62	3.95	85.5	5
	DO 1m	13.29	0	3.46	3.53	101.9	
	TVSS	28.5	1.35	12.29	8.2	66	
	TSS	155.5	3	29.4	30.6	104.2	

[1] Coefficient of variation.
[2] Days with over 60% cloud cover.

Table 2. Summary statistics for D0 ($mg/l^{-1}/hr^{-1}$) TVS (mg/l^{-1}) and TS (mg/l^{-1}), all tanks

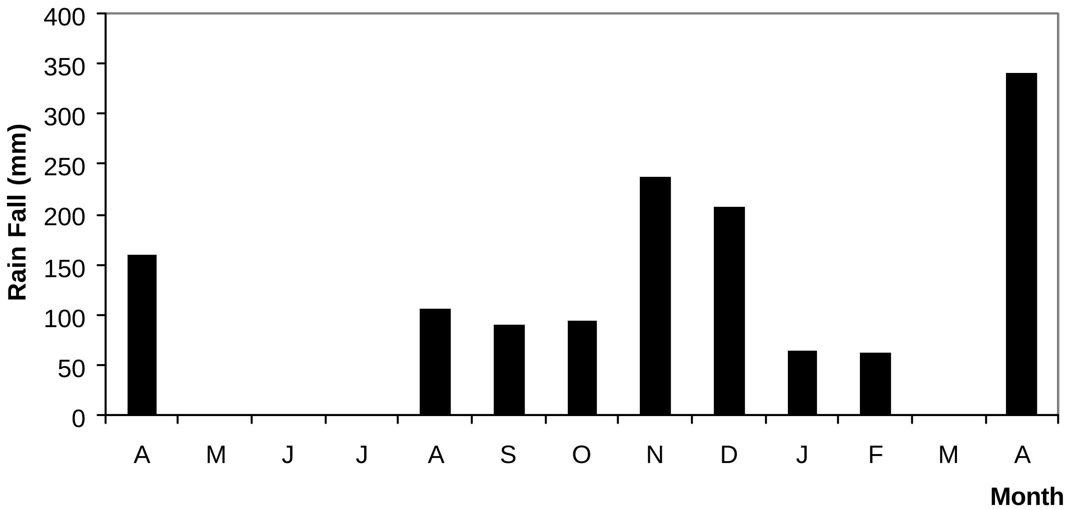

Figure 2. Mean monthly rainfall, averaged over three recording sites: MAD , IMK, GUR (see Fig 1).

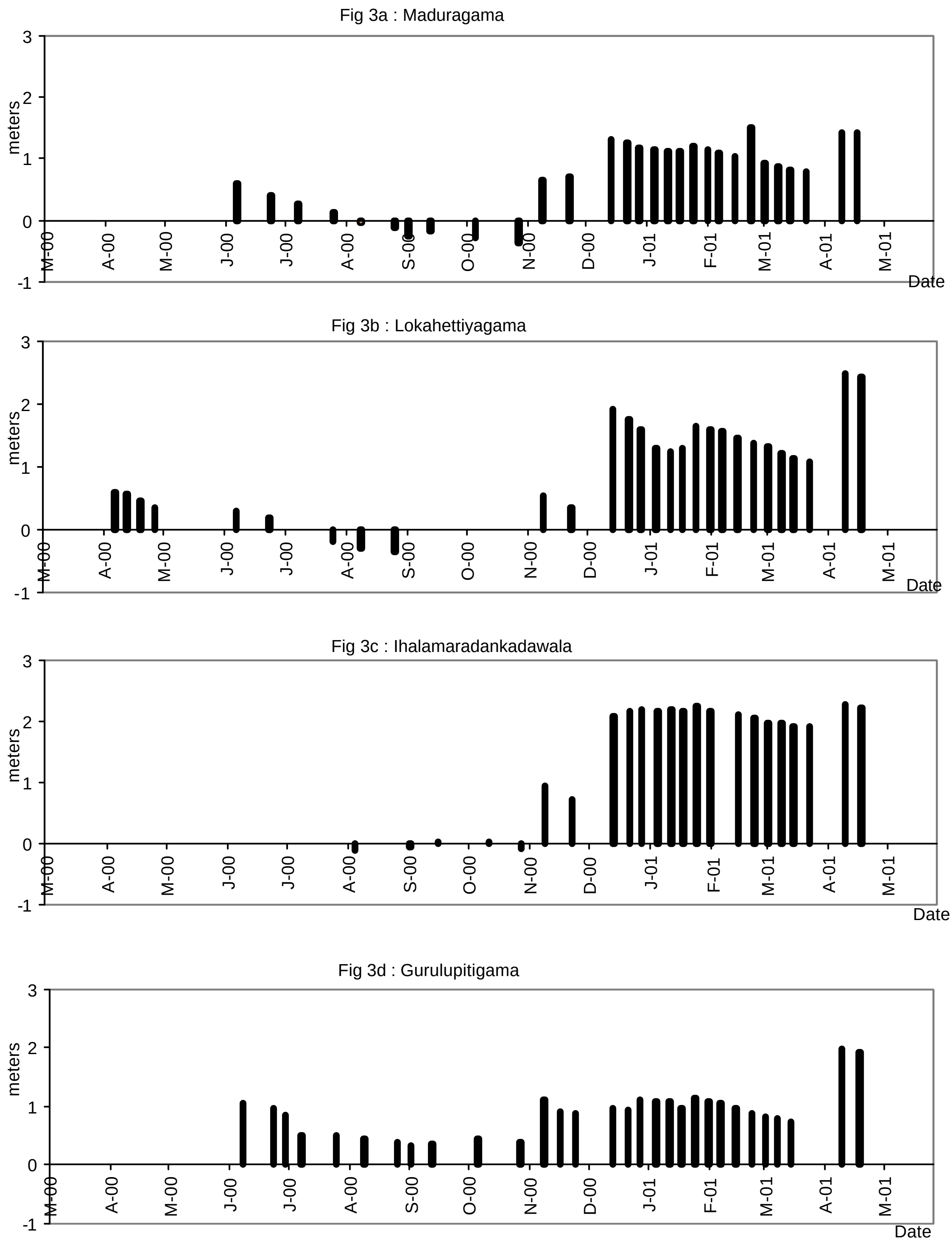

Fig 3. Weekly tank water level, above and below Dead Storage Level (DSL) April 2000 to April 2001. (No data shown for IMK and GUR to July and June respectively. MAD dried completely during October)

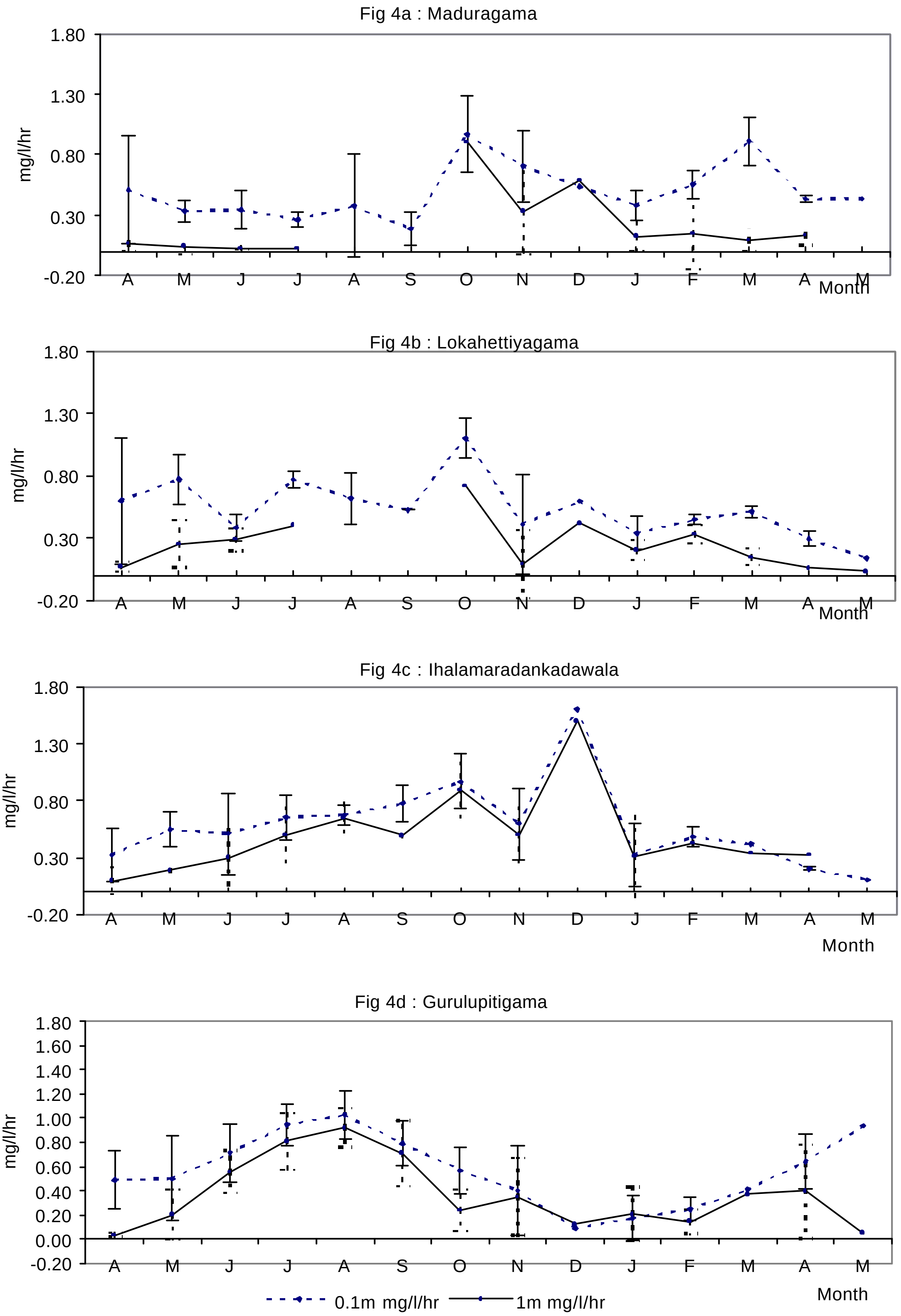

Figure 4. Mean monthly net oxygen production rates, April 2000 to May 2000. (Standard deviation bars shown for 0.1m and 1m depth).

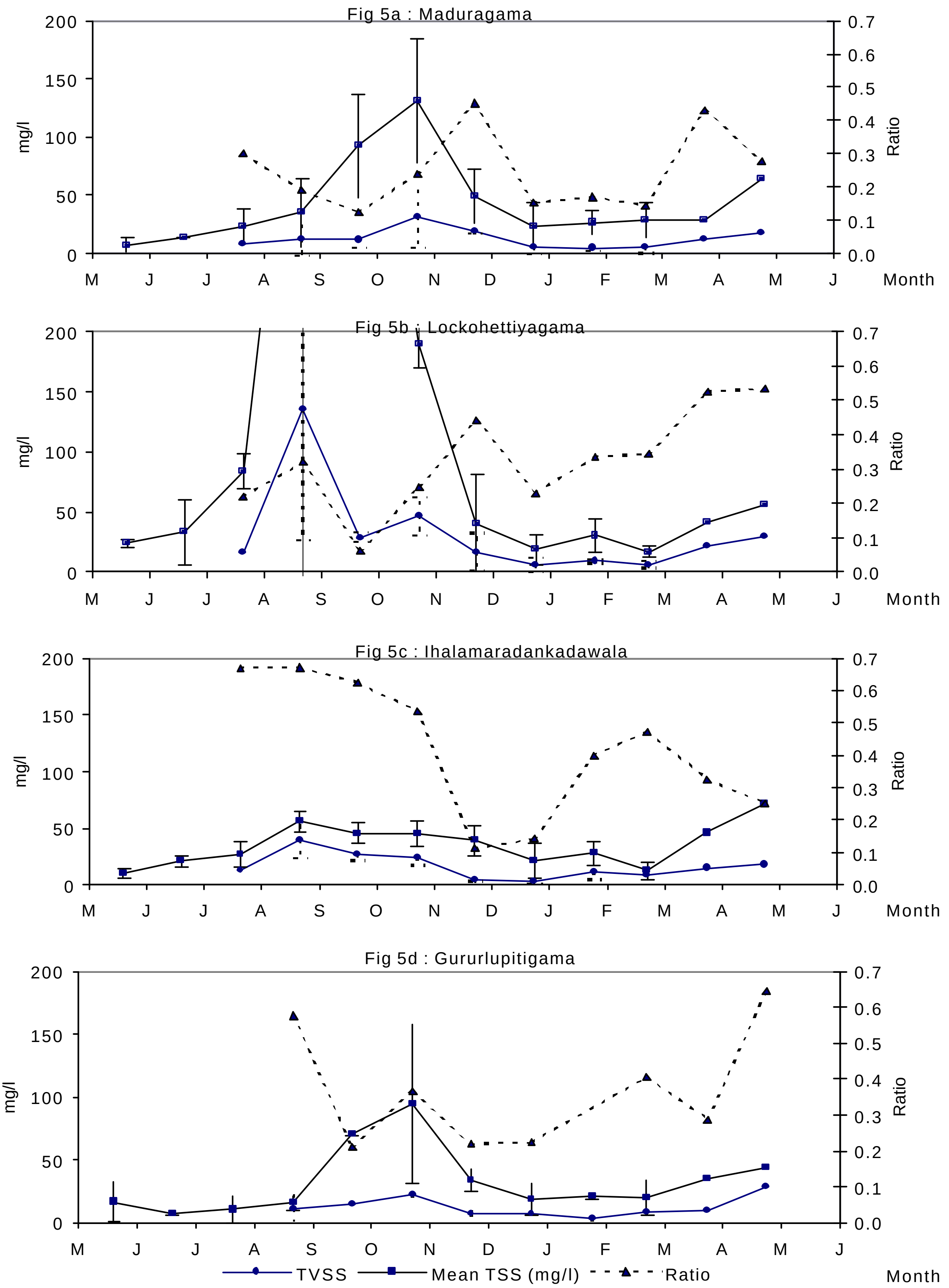

Fig 5: Mean Monthly Total Suspe nded Solids (TSS), Total Volatile Suspended Solids (TVSS) and TVSS: TSS ratio, April 2000 to May 2001
(Standard deviation bars shown for TSS and TVSS)