Parakrama Samudra Project — a summary of main results

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19. Parakrama Samudra Project – a summary of main results

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Abstract

The following chapter provides a short synopsis of main results obtained during two research visits (August/September 1979, February/April 1980). It summarizes the major physiographical characteristics of the lake and outlines its trophic structure. Emphasis has been given to factors governing production processes.

1. Physiography

The physiographical and hydrological features of the Parakrama Samudra reservoir (PS) have been discussed in Schiemer (1983). PS consists of three well-separated basins, the northern (PSN) and southern (PSS) being smaller and shallower than the middle part (PSM) (6.5, 3.6 vs 15.4 km^2 at full supply level; maximal depth, $z_m = 8.2$ vs 12.7 m). The lake forms a flow-through system from the artificial inflow channel of the Amban Ganga into PSS to outflow channels situated in PSS (one) and PSN (two). Most water is passing from the inflow channel to the northernmost outflow at PSN.

Due to the monsoonal cycle in the 'dry zone' of Sri Lanka (rains from October–December) and due to the seasonal usage of the reservoir for irrigation of rice fields, the hydrological regime is characterized by high water levels from December to April and low water levels from June to August, with an average annual amplitude of 3.7 m. As a consequence of the seasonality of inflow, outflow and water storage, the water renewal rates exhibits strong seasonal differences with highest relative rates in July and low ones from December to May.

The temperature regime is characterized by a strong diurnal cycle (e.g. from 28–34 °C in September), expressed either over the whole water column during windy periods or in form of strong thermal stratification patterns building up during the day. Under calm conditions, the stability of this stratification prevents mixing of the whole column by even strong afternoon thunderstorms.

The kinetic energy released by the breakdown of thermal gradients in the course of the night, however, results in homeothermy plus an erosional effect on the bottom sediments which lead to resuspension of bottom material during night and in the early morning hours. In the course of the day, differences in heating and cooling between littoral and offshore areas lead to considerable advective currents (Bauer 1983). The underwater light conditions are considered in connection with the primary production processes in the lake (see below).

The ionic composition of the lake water is discussed by Gunatilaka & Senaratne (1981). The ratio of anions (in % of mequ sum), HCO_3^-: Ce^-: SO_4^{--} is 74 : 14 : 13; that of cations, Ca^{++}: Mg^{++}: Na^+: K^+ is 48 : 34 : 15 : 3. pH ranged from 8.7–9.6 in September 1979 and from 8.3–8.9 in March 1980. A higher ionic concentration in March (218–243 μS compared to 130–180 μS in September is likely to

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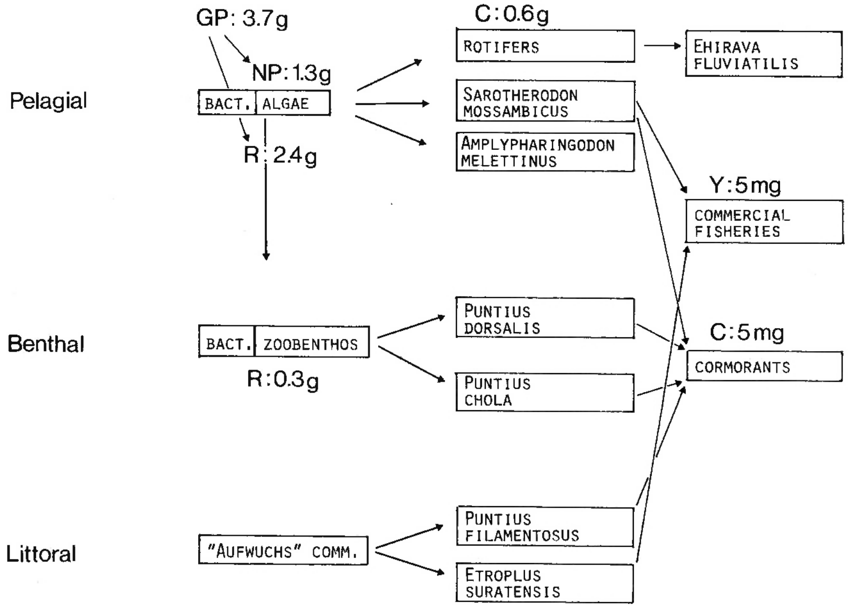

Fig. 1. Main trophic interrelationship of the PS ecosystem with some data on carbon transfer. The data refer to the offshore region of PSN on 1 September 1979, except for the commercial fisheries yield (Y) and food consumption (C) of cormorants, which are based on annual averages for the whole lake area. Data in g (or mg) C per m² lake area per day. GP, NP gross, respectively, net primary production, R = community respiration of the limnetic and benthic zone.

be associated with leaching of soluble ions and slow seepage after monsoonal rains.

The lake water is characterized by a high content of nutrients (e.g. phosphorus and nitrogen), present mainly in particulate organic form and thus not readily available to algal growth. The main components of an input-output budget have been discussed in Schiemer (1980, 1981) and Gunatilaka & Senaratne (1981). Dissolved inorganic nutrients other than silica (5.5–11.8 $\mu g\ l^{-1}$) are present only in low concentrations (e.g. soluble reactive phosphate – SRP – 0–6 $\mu g\ l^{-1}$ in September 1979, 2.5–13 $\mu g\ l^{-1}$ in March 1980.

2. Trophic structure of the lake

In PSN where most research work was carried out, three main habitat types can be distinguished (a) a shallow limnetic zone, (b) soft mud sediments in the deeper parts of the lake and (c) a littoral zone mostly with sandy bottoms, to a minor extent with gravel and rocks. Aquatic macrophytes are only at a few locations of periodic importance. Flooded terrestrial vegetation is generally of higher importance as food and substrate of an epiphytic community.

Ad (a) The limnetic zone is characterized by a highly diverse phytoplankton assemblage (83 taxa acc. to Rott 1983). Blue-green algae and diatoms predominated almost everywhere.

In August/September 1979 *Microcystis* spp., *Anabaenopsis raciborskii* Wol. and the diatom *Melosira granulata* (Ehrb.) Ralfs were most abundant in PSN. In March/April 1980 the dinoflagellates *Peridiniopsis* spp. were additionally of importance. Thus, phytoplankton consists to some extent of large colonial and filamentous forms, considered to be unsuitable as food, especially for small-sized zooplankton. However, a high proportion of the limnetic algal biomass (57–94% measured as chlorophyll-a < 94% measured as sestonic carbon) is contained in the filter size-fraction < 33 μm. This suggests that small algal forms contribute considerably to the algal biomass and its production. The concentration of the < 33 μm fraction of sestonic carbon was high in comparison to temperate lakes (e.g. 11 mg.C l^{-1} in 1979; 3 mg C l^{-1} in 1980), (Duncan & Gulati 1983).

The zooplankton consisted of very small sized rotifers (14 ssp) and protozoans. Crustaceans and large-sized rotifers were virtually absent. A considerable amount of indirect evidence (Duncan 1983) indicate that fish predation is the most important of several factors affecting the zooplankton, accounting both for the very low abundance of crustaceans and the size distribution of rotifers. Amongst the potential zooplanktivorous species are the clupeiform *Ehirava fluviatilis* Deraniyagala, larvae of a hemiramphid species, the smaller size classes of *Rasbora daniconius* (Ham.-Buch.) and *Sarotherodon mossambicus* (Peters). Gut analysis of the small sized *Ehirava fluviatilis* in 1980 revealed the presence of rotifers as well as crustaceans (Duncan 1983) and intensive sampling during the summer 1982 confirmed that this species was the most abundant zooplanktivorous fish in the lake. Potentially, *Rasbora daniconius* could be predatory on large-sized crustacean plankton, but the species has not been found to feed on rotifers. Small *S. mossambicus* (Tl 8–10 mm) capture zooplankton but their distribution in the shallow littoral precludes them to exert a major predatory pressure on the open water zooplankton.

Food limitation is a further factor which could influence body size and density of rotifer populations in the lake. Porriot (1973) suggests that small adults and eggs may arise from poor nutritive conditions during the juvenile phase. Although the concentration of sestonic particles less than 33 μm was quite high compared to temperate lakes (3–11 mg C l^{-1}), there is evidence from the rotifer feeding ecology that concentrations may be suboptimal, i.e. not allowing for maximal performances with respect to body growth and population dynamics.

Two common fish species feed on phytoplankton, either in form of suspended algae or on flocculant material on the sediment surface. These are *Sarotherodon mossambicus* and the small sized cyprinid *Amblypharyngodon melettinus* (Cuv. et Val.). *S. mossambicus* feeds continuously throughout the day diurnal changes in the vertical distribution of the species in the water column suggests a day-time feeding on the sedimented material and a night-time feeding in the open water (Hofer & Schiemer 1983). *A. melettinus*, the second common phytoplanktivorous species in the lake is filtering seston in the water column.

Ad (b) The zoobenthos living in soft mud in PSN is predominated by meiobenthos, especially the cladocerans *Macrothrix* spp. and *Alona* spp., and lower densities of cyclopids, ostracods and nematodes (Schiemer, in preparation). Macrobenthos is sparse, consisting of small-sized chironomid species and few oligochaetes (naididae mainly, *Branchiura sowerbyi* Beddard, very rare).

Heavy predation by zoobenthivorous fish viz. *Puntius chola* (Ham.-Buch.) and *Puntius dorsalis* (Jerdon) and to a lesser degree by *Mystus vittatus* (Bloch) is the cause for the dominance of small-sized zoobenthos. Gut analysis of mature *P. chola* and *P. dorsalis* showed a clear selectivity of larger sized prey. High food overlap values between the two species indicated food competition, which is relaxed by different diurnal feeding patterns (*P. chola* continuous, *P. dorsalis* during the night) and a tendency of spatial segregation by inshore migrations of *P. dorsalis* during the period of its highest feeding intensity (Schiemer & Hofer 1983).

Ad (c) The littoral zone with rocks and flooded terrestrial vegetation develop a dense and diverse Aufwuchs community with sponges, bryozoans, freshwater shrimps (*Caridina* sp.), entomostracans and various aquatic insects of quantitative importance. The nature of the marginal habitats is changing continually due to the water level fluctuations. Molluscs are restricted to a belt between the soft mud sediments and an upper border which appears to be mainly affected by the drawdown regime, and predation by mollusc-eating birds (Bretschko in litt.).

The mean width of the mollusc-belt is approximately 50 m. The following species, ranked according to their quantitative importance, have been recorded: *Parreysia corrugata* (Müll.), *Lamellidens marginalis* (Müll.), *Melanoides tuberculatus* (Müll.), *Bellamya dissimilis* (O.F. Müller) var. *ceylonica* (Dohrn), *Thiara scabra* (Müll.). The very low water level in 1979 accompanied by strong predation, e.g. by storks, lead to a strong reduction in the population density of the mollusc fauna. (In 1982 population densities had again increased.)

Several species of fish, some of them of economical importance, show a predominance of inshore sites and are feeding on animal and plant Aufwuchs organisms and macrophytes. The most important among them are *Etroplus suratensis* (Val.), *Puntius filamentosus* (Val.), *Puntius sarana* (Ham.-Buch.) and *Labeo dussumieri* (Val.). Areas with submerged trees (e.g. PSM) form good conditions for this fish assemblage. The littoral area is the breeding zone of *S. mossambicus* and the favoured habitat of its fry. Short-term water level fluctuations may result in severe disturbance of the breeding activity of the species. In summer 1982 we observed that receeding water level leeds to a considerable loss of *S. mossambicus* fry in marginal pools which are drying out. A strong predation effect on the fry is exerted by several species of fish, e.g. *Rasbora daniconius, Glossogobius giuris* Russell, *Ophiocephalus* sp., *Puntius sarana* and by fish-eating birds.

Cormorants by their high population densities (maximal numbers approximately 15 000 ind.) exert an overall important effect on the fish population of the lake (see below). They are represented by three species, the Large Cormorant *Phalacrocorax carbo sinensis* (Shaw), the Indian Shag *P. fuscicollis* Stephens and the Little Cormorant *P. niger* (Vieillot). These three species differ in size, foraging behaviour, fishing distance from the shore and diving depth. Little Cormorants have the most diverse diet including many species of fish, insect larvae and crustaceans. Indian Shag and even more so Large Cormorants have a less variable diet. The size range of their food species is correlated with the size of the three species. Large Cormorants hunt fishes of an average size of 130 mm (standard length), Indian Shag of 60–120 mm, Little Cormorants of 30–70 mm.

Cichlids (*Sarotherodon mossambicus* and *Etroplus suratensis*) seem to form the main prey of all three species. Little Cormorants hunt within the littoral zone, Indian Shag along the edge of macrophytic vegetation and Large Cormorants at the open water.

Winkler (1983) calculated the mean fish consumption by cormorants as 969 kg fish per day, which roughly converts to 0.5 mg C m^{-2} d^{-1}. It is of significance to note that these values approximately corresponded to the daily catch of the commercial fisheries. In order to assess the overall effects of cormorants on the lake ecosystem this data can also be used to evaluate their role in the nutrient budget and nutrient recycling. Cormorants will cause a nutrient loss from the lake since part of the defecation occurs when birds leave the lake for roosting. Part of the feces with high fractions of soluble nutrients, however, will be deposited in the lake and should be of significance in accelerating nutrient recycling.

3. Factors governing production processes

The phytoplankton biomass of PSN was generally high. The mean areal biomass figures recorded were 95 mg chlorophyll-a m^{-2} ($n = 8$) for September 1979 and 59 mg chl-a m^{-2} ($n = 18$) for March 1980 (mean concentrations were 47 and 15 μg chl-a l^{-1} for the two periods, respectively). These seasonal differences in areal algal biomass have to be contrasted with differences in light extinction and water level. In September 79 at low water level the light extinction coefficient for the photosynthetical active radiation (ϵ_{phar} m^{-1}) ranged from 2.9–4.4, which corresponded with a Secchi disc depth (z_{SD}) of 0.4–0.6 m and a depth of the euphotic zone (z_{eu}, taken as the 1% level of the incoming irradiance) of 1.05–1.66 m. In March/April 1980, at higher water level and less wind, light penetration was higher ($\epsilon_{phar} = 0.9$–1.3; $z_{SD} = 1.1$–1.4 m; $z_{eu} = 3.1$–4.3 m). The mean compensation depth was coinciding in both seasons roughly with the mean depth of PSN ($z = 1.5$ m in 1979 and 2.9 m in 1980), i.e. the lake was optically shallow during both visits (Dokulil *et al.* 1983).

Applying Steele's (1975) general considerations of algal productivity in reservoirs and assuming no nutrient limitation, a B_{max} (maximal sustainable areal algal biomass) of 150 and 100 mg chl-a m^{-2} respectively for the two seasons can be predicted, based on extinction coefficients and the depth of the mixed water column. The predicted value of B_{max} is depressed by higher levels of 'r' (respiration per unit chl-a as a fraction of photosynthesis per unit chl-a) (see also Dokulil *et al.* 1983). Since 'r' is based on community respiration the model may have its limitations for eutrophic, tropical lakes with high bacterial and zooplanktic respiration.

The differences between the predicted B_{max} and the realized values can be due to (a) nutrient limitations of photosynthesis (CO_2 and/or nutrients), (b) biomass losses due to outflow, grazing and sedimentation.

Although areal gross primary production values are comparatively high (7.5–14.7 g O_2 m^{-2} d^{-1} in 1979; 3.8–8.6 g O_2 m^{-2} d^{-1} in 1980), there is indication that the productivity of the lake is to some extent nutrient limited. For example, nutrient deficiency indicators such as phosphatase activity and the stored algae phosphorous content showed strong diurnal dynamics, indicating nutrient limitations in the course of the day (Gunatilaka & Seneratna 1981; Gunatilaka 1983). Further, P_{max} values (light saturated chlorophyll specific production) calculated for different periods of the day showed a positive correlation with the diurnally changing SRP levels (Dokulil *et al.* 1983).

Effects of hydrological flushing and dilution on the limnetic biomass were mainly observed during periods of low water level and times of strong changes in water throughput rates (e.g. from 2–40% daily throughput rates of the PSN volume). Periods of decline in phytoplankton biomass were associated with high water inflow from PSM resulting in a dilution effect (lower phytoplankton concentration in this part) and high biomass losses due to the outflow at PSN. When flushing rates decreased, the concentrations increased within a few days. Exactly the same pattern was observed in zooplankton densities (Duncan & Gulati 1981). The importance of flushing became also apparent from the spatial pattern of biomass distribution in the southern and northern part of PSN, which at low water level in 1979 were separated by a peninsula (represented by PSN 8 and PSN 3, see map in Schiemer 1983). Due to the more direct exposure of flushing phytoplankton (Dokulil *et al.* 1983), zooplankton (Duncan & Gulati 1981) and meiobenthos (Schiemer, in preparation) occurred at significantly lower densities in the southern bay. In March/April 1980, at a higher water volume and generally lower flushing rates (%) no similar effects were recognized.

Grazing effects on algal biomass are severe. Studies were conducted on planktonic rotifers (*Brachionus* ssp.), using a C_{14}-technique with 33 μm lake seston as food source. At the food densities prevailing in the PS reservoir, a mean grazing rate of 0.013 μg C ind^{-1} h^{-1} (Duncan & Gulati, 1983) was determined. Assuming continuous feeding, the grazing rate of the total *Brachionus* population was calculated as 0.6 g C m^{-2} d^{-1} for September 1979. Under the assumption that all rotifer species encountered in the limnetic zone have similar feeding rates, a total areal grazing rate of 2.4 g C m^{-2} d^{-1} is estimated for the period of high rotifer abundance in September 1979 and 0.6 g C m^{-2}d^{-1} for March 1980 (mean population densities of 7.5×10^6 and 2.4×10^6 ind m^{-2}, respectively). This is a high portion of the areal primary production of the lake. A carbon budget has been calculated for 1 September 1979 and according to above values the net primary production would not even balance the total rotifer grazing rate.

Feeding rates have also been established for one size class of *Sarotherodon mossambicus* (19 g fresh weight) which was abundant in the open lake in 1980. Daily food consumption was estimated as 0.8 g dry weight ind^{-1} d^{-1} (or roughly 0.4 g C ind^{-1} d^{-1}) which roughly equals a third of the net primary production per m^2 lake area.

The role of the herbivorous grazers is controlling primary production processes in the lake will have to be considered in more detail both with regard to its effects on algal biomass and with regard to nutrient recycling in the open lake.

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