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EFFECT OF PREDATION AND ZOOPLANKTON-MORTALITY ON THE OVERALL ECOSYSTEM-HEALTH OF UDAIPUR LAKES IN INDIA: A CASE STUDY APPLICATION OF FIVE COMPARTMENT ECOLOGICAL FOOD-WEB INTERACTION MODEL

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ABSTRACT

Pichola and Fatehsagar lakes of Udaipur city in India are presently experiencing very high levels of algal eutrophication due mainly to instability in the relevant ecological food-webs that resulted from inter-species predation and mortality at various trophic levels. In both lakes, very low zooplankton levels were observed, indicating high mortality and associated predation rates. We studied the impacts of varying zooplankton-mortality-coefficients on the dynamics of other ecological state variables—phytoplankton, pelagic fish, benthic fauna, and demersal fish—using a five-compartment aquatic ecosystem computer simulation model. The software (UDAIPUR.C) quantified the most and least perturbed state variables. Analysis reveals, *inter alia,* that phytoplankton levels show a strongly rising trend, especially in the case of Pichola lake, while most of the other variables exhibit a declining trend. Ecological dynamics of the two lakes were found to be quite dissimilar. The most perturbed compartments were pelagic fish and demersal fish.

INTRODUCTION

Udaipur city (Figure 1) in Rajasthan state is known as the “lake city” of India. Pichola and Fatehsagar lakes in this city are presently experiencing very high levels of algal eutrophication. Therefore, their ecorestoration is of very great importance, especially from the standpoint of tourism and meeting the city’s drinking water requirements. These lakes have been accorded high priority by the National Lake Conservation Programme (NLCP) of the Ministry of Environment and Forests, India.

Roughly 60,000 families live around these lakes, and nearly 150 hotels are situated on their periphery. Sewage from the private homes and hotel wastes are continuously dumped into lake-waters. Solid waste is also dumped close to the waterfront only to be washed into the lakes during the rainy season. As a result, the capacities of these lakes have shrunk almost by one-fifth of their original size. Added to this is the problem posed by deforestation of the adjacent hills, due to which enormous amounts of silt are washed down during the rainy season. Then there is the further problem of nearly continuous inflows containing excessive nutrients and other chemicals reaching and polluting these water bodies [1, 2]. Consequently, these lakes show the symptoms of severe environmental stress [3, 4].

This ecological instability is reflected in interspecies predation and mortality at various trophic levels. In both lakes, very low zooplankton levels were observed, indicating high mortality and associated predation. We studied the impacts of varying zooplankton mortality coefficients on the dynamics of other ecological state variables involving phytoplankton, zooplankton, pelagic fish, benthic fauna, and demersal fish, using a five-compartment aquatic ecosystem computer simulation model [5], based on aquatic foodweb interactions [6]. Although the model (developed earlier [5]) was for marine ecosystems, the premise on which it was developed covered ecological food-web interactions generally. For the kind of processes analyzed, the roles of currents, winds, and hydrodynamics were ignored. In the absence of any hydrodynamic parameters, the model can be applied to any wetland ecosystem; naturally, the values of mortality, respiration, and energy-feeding rates will be different in different situations. However, the chief objective of the present exercise was to study the behavioral patterns of different state variables by just varying the zooplankton-mortality-coefficient. The values of other parameters were kept fixed. Software (UDAIPUR.C, written in “Turbo C”) was used to quantify the most and least perturbed state variables. The analysis of relative shifts observed with respect to the initial values of the state variables reveals that phytoplankton levels show a strongly rising trend, especially in the case of Pichola lake, while most of the other variables exhibit a declining trend. These results were found to be consonant with what was actually observed.

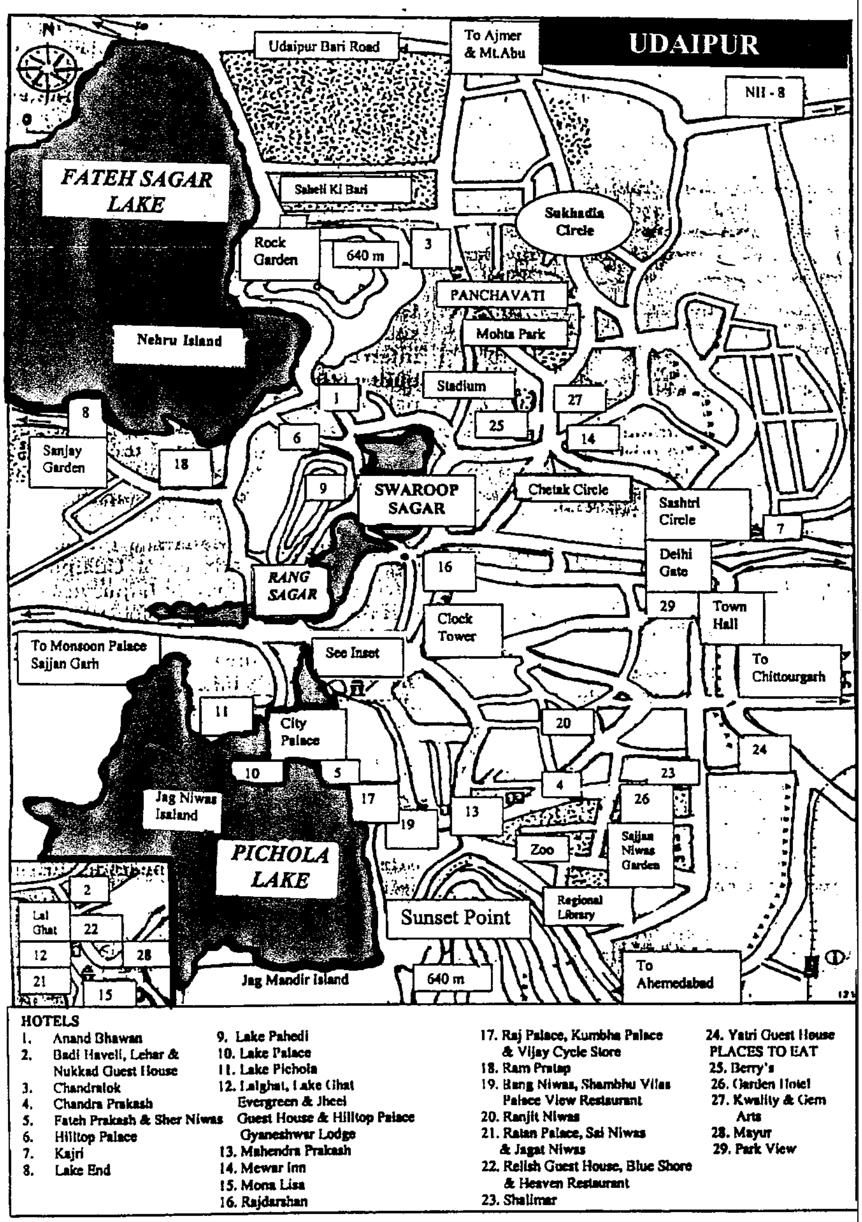

Figure 1. Udaipur City.

UDAIPUR LAKES AND THEIR BACKGROUND

Udaipur city (Figure 1) lies at an altitude of 578 m on the eastern flanks of the Aravalli Mountains south of Rajasthan at 24° 35' N latitude and 73° 42' E longitude. It is regarded as one of the most important tourist places in India mainly because of the lakes in the city; nearly 0.8 million tourists arrive annually. Although on the surface Udaipur looks as beautiful as ever, the heavy siltation due to excessive deforestation of the surrounding hills and of the catchment area has reduced the depth of water bodies to almost a quarter of their levels four decades ago. Arising out of river Berach and its tributaries, the lake system consists of six lakes within Udaipur's municipal territory. The river Berach forms a part of the Ganga-river-system, joining it through the rivers Banas, Chambal and Yamuna. Pichola and Fateh Sagar are the most important lakes of the city.

Pichola Lake

Pichola lake (Figure 2) was initially constructed by a Banjara chieftain toward the end of the 14th century. Its embankment was further raised by Rana Udai Singh in 1560 A.D. The water spread of its present area is 6.96 km^2; maximum depth is 10.5 m. Constructed primarily for irrigation purposes, this lake is the main source of drinking water in the city.

Fateh Sagar Lake

This medium sized perennial reservoir (Figure 3) situated in the north of Udaipur city as a part of the western lake frontage, was constructed in the year 1678 A.D., and modified in 1889 by Maharana Fateh Singh. The lake occupies 4 km^2 with a maximum depth of 13.4 m. The main feeder canal for the lake comes from the Madar reservoir some 15 km distant. Several drains and runoffs also contribute to the impoundment of the lake.

FOOD-CHAIN INTERACTIONS AND BIORESTORATION

Both lakes, especially Pichola, suffer from severe algal blooms that cause serious taste, odor, and water quality problems. If, as an ecological engineering intervention, algae-grazing fishes are introduced in the bloom-afflicted water body, eutrophication may be reduced substantially. These fishes can then be harvested as a rich source of protein. For example, blue tilapia (*Tilapia aurea*) can ingest and assimilate green algae, blue-green algae, and detrital bacteria. They prefer eutrophic waters and are relatively disease-free. They can also tolerate extreme levels of dissolved oxygen and salinity. This technique, therefore, also has very low energy requirements, is inexpensive, and serves the purpose of recycling waste resources into a usable commodity [7, 8].

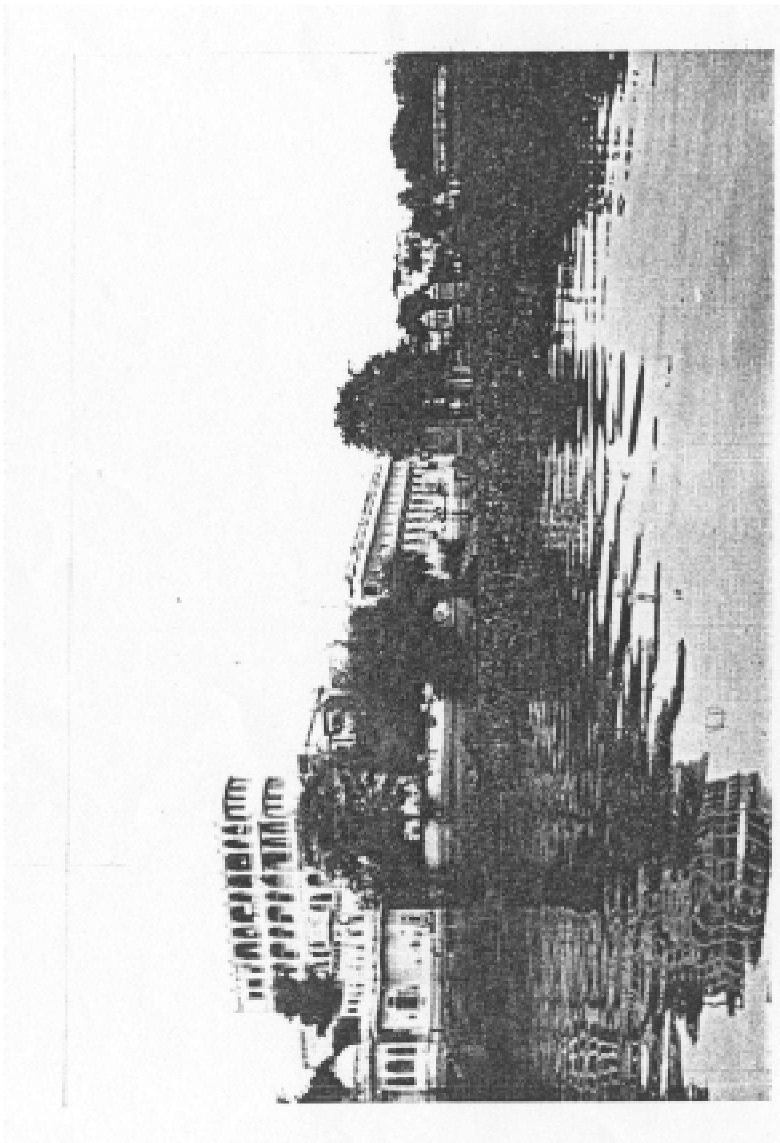

Figure 2. Pichola Lake

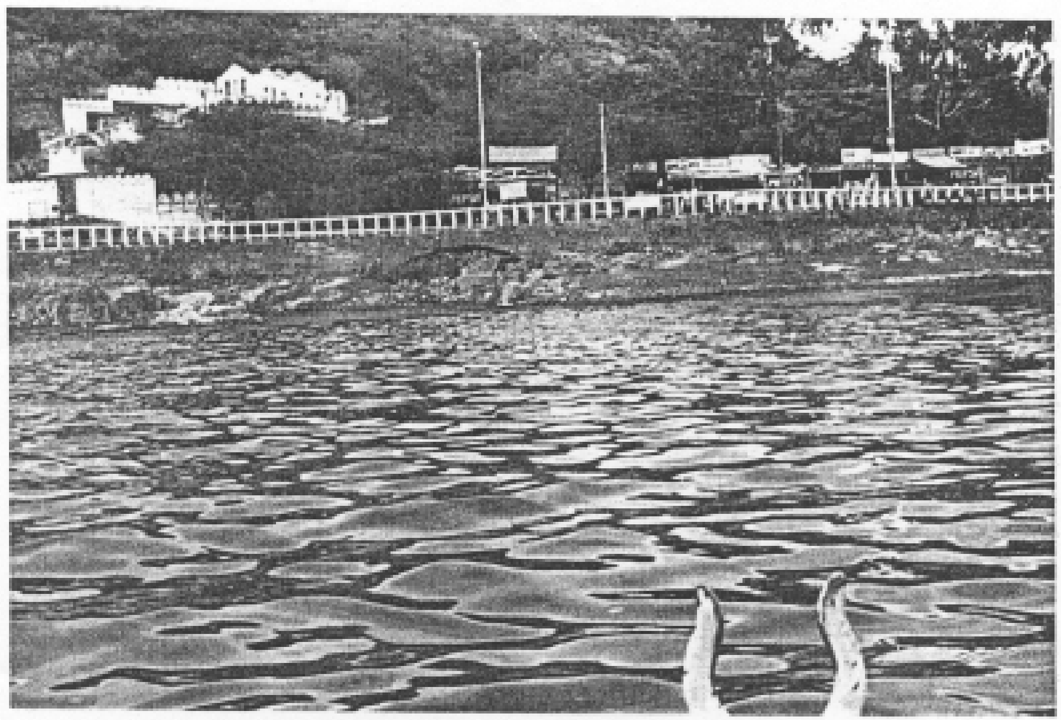

Figure 3. Fateh Sagar Lake

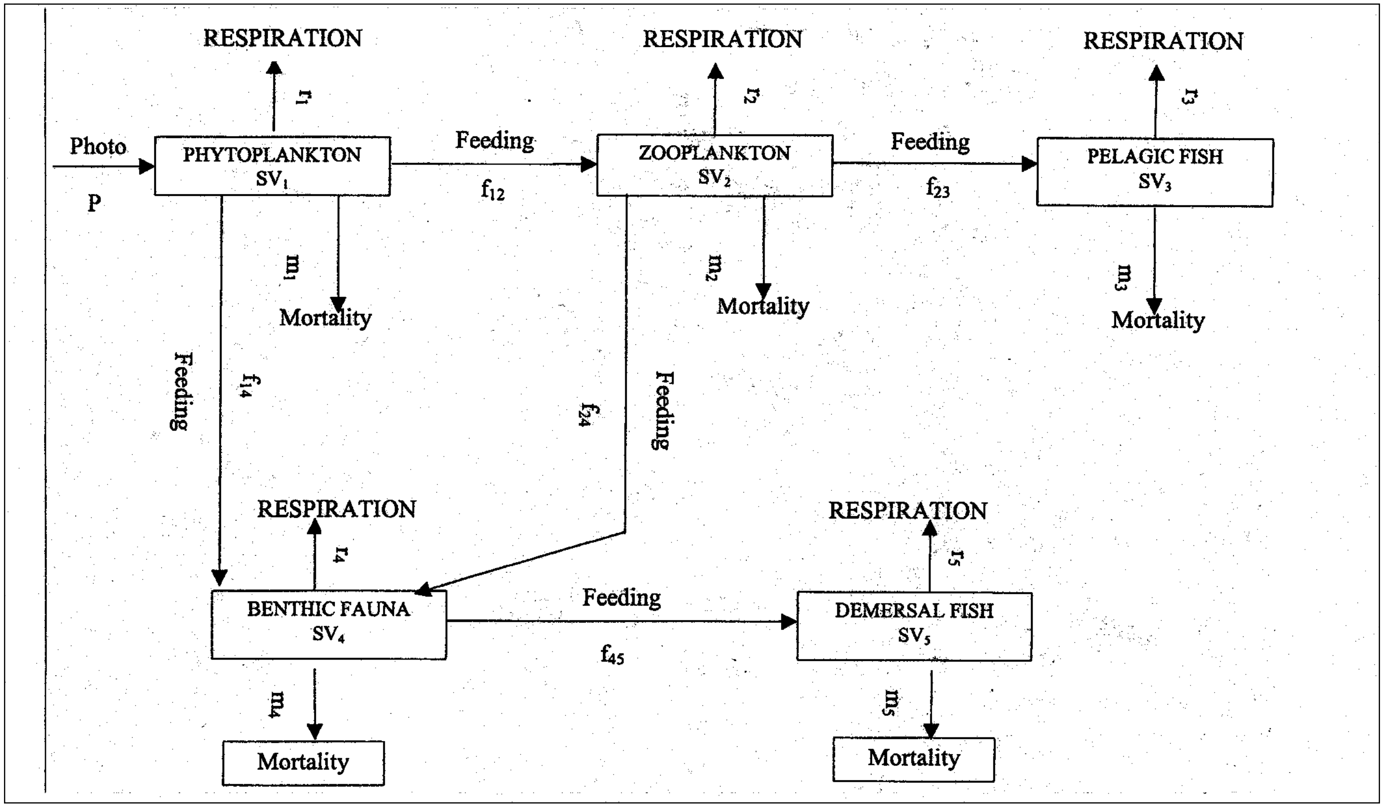

Figure 4. Five compartment aquatic model (after Pandey et al. [5]).

However, lake ecosystem response at any trophic level is a net result of growth and grazing loss, and lake productivity is regulated hierarchically through both biotic and abiotic factors jointly [4, 7]. Such engineering approaches as nutrient removal, sediment pumping, hypolimnion oxygenation, and alum treatment are appropriate for deep lakes, but do not always give the desired results for shallow ones, where biomanipulation may be the essential biorestoration measure. A critical role is played by predation [8]; highly selective predation by fish zooplankton together determine which species of primary producer and consumer can persist in aquatic ecosystems. It is in this context that the role of the zooplankton-mortality-coefficient becomes important.

THE MODEL

In the Five Compartment Aquatic Ecosystem Model [5] (Figure 4),

$$\frac{d(SV)_i}{dt} \quad P \quad (SV)_i[\, f_{ij}(SV)_j \quad f_{ji}(SV)_j] \quad (SV)_i(r_i \quad m_i) \tag{1}$$

where, i, j = 1, 2, . . . , 5.

Steady-state values of phytoplankton $(SV)_1$, zooplankton $(SV)_2$, pelagic fish $(SV)_3$, benthic fauna $(SV)_4$, and demersal fish $(SV)_5$ are expressed as:

$$(SV)_i \quad \frac{(SV)_{i1}}{(SV)_{i2}} \tag{2}$$

where

$$i = 1, 2, \ldots, 5$$

$$(SV)_{11} = P(f_{23})(f_{45}) \tag{3}$$

$$(SV)_{12} = (f_{23})(f_{45})(r_1 + m_1) + (f_{12})(f_{45})(r_3 + m_3) + (f_{14})(f_{23})(r_5 + m_5) \tag{4}$$

$$(SV)_{21} = r_3 + m_3 \tag{5}$$

$$(SV)_{22} = f_{23} \tag{6}$$

$$(SV)_{31} = (f_{12}(SV)_{11}(SV)_{42}(r_2 + m_2)(SV)_{12}(SV)_{42}(f_{24})(SV)_{41}(SV)_{12} \tag{7}$$

$$(SV)_{32} = (f_{23})(SV)_{12}(SV)_{42} \tag{8}$$

$$(SV)_{41} = (r_5 + m_5) \tag{9}$$

$$(SV)_{42} = f_{45} \tag{10}$$

$$(SV)_{51} = (f_{14}(SV)_{11}(SV)_{22} + (f_{24})(SV)_{12}(SV)_{21} - (r_4 + m_4)(SV)_{12}(SV)_{22} \tag{11}$$

$$(SV)_{52} = (f_{45})(SV)_{12}(SV)_{22} \tag{12}$$

where F_{ij} (i,j = 1,2,3,4,5) denotes the energy-transfer coefficient from the i^{th} compartment to j^{th} compartment, r_i and m_i are, respectively, respiration and mortality coefficients, and P is the total photosynthetic energy.

Conditions for Ecological Feasibility [5]

These equations must be satisfied to ensure that this non-linear model is ecologically feasible:

$$(f_{12})(SV)_{11}(SV)_{42} - (SV)_{12}(SV)_{42}(r_2 + m_2) - (f_{24})(SV)_{41}(SV)_{12} > 0 \quad (13)$$

and,

$$(f_{14})(SV)_{11}(SV)_{22} + (f_{24})(SV)_{12}(SV)_{21} - (SV)_{12}(SV)_{22}(r_4 + m_4) > 0 \quad (14)$$

RESULTS AND DISCUSSION

The zooplankton-mortality-coefficient was varied from 0.0 to 25.0 per year (i.e., 0.0 to 0.068 per day), and the dynamics of phytoplankton, zooplankton, pelagic fish, benthic fauna, and demersal fish population was simulated over a time frame of ten weeks. The normalized relative shifts (NRS) from the initial states have been analyzed for these state variables (Figures 5 through 9). NRS values are given as (dS/S), where S is the initial value of the concerned variable and dS is the difference between the final and initial values. Positive or negative NRS indicates growth and decline respectively in the concerned state variable (Figures 5 through 9).

In the simulations, in general, as the zooplankton-mortality-coefficient rises, all other compartments except phytoplankton show a decline. An actual increase for phytoplankton has been observed in case of Udaipur lakes. As the zooplankton-mortality rises, phytoplankton-grazing drops, and consequently phytoplankton-biomass rises. Zooplankton population not only thus controls the primary productivity, but also regulates ecological dynamics at higher trophic levels [9]. Other coefficients were kept constant during the simulation period [5]; input variables used for the model are shown in Table 1.

Table 1. Input Values for the Model

S. No. Lake	State Variables ($Kcal/m^2$)	Pichola Lake	Fateh Sagar Lake
1.	Phytoplankton	76.50	24.00
2.	Zooplankton	22.50	11.50
3.	Pelagic fish	22.55	9.35
4.	Benthic fauana	1095.25	1092.25
5.	Demersal fish	12.50	5.20

Relationships between phytoplankton, nutrients, and zooplankton grazing are complex and intricate. Moreover, they depend very strongly on the initial trophic state of the system. Especially in case of eutrophic lakes [7], phytoplankton communities have been reported to be more sensitive to shifts in zooplankton biomass as predation plays a critical role. As noted, predation by fish and zooplankton together determine which species of primary producer and consumer can persist in an aquatic ecosystem. Heavy predation by fish means depressed zooplankton-biomass. Modeling results also corroborate this relationship. The ecological dynamics of the two lakes are quite dissimilar during the same simulation period, although the most perturbed compartments are the same for both lakes, i.e., the pelagic and demersal fish compartments. *Inter alia*, the model depicts how, through the non-linearity of energy transfer functions, zooplankton mortality can have a significant bearing on the growth and loss of pelagic and demersal fish species. As in this preliminary analysis, site-specific models improve our biorestoration strategies needed to be delineated by applying site-specific models that incorporate (*inter alia*) seasonal dynamics [10-12], followed by sensitivity studies [2, 13] that identify concerns requiring immediate attention, control, and regulation from the point of view of environmental management.

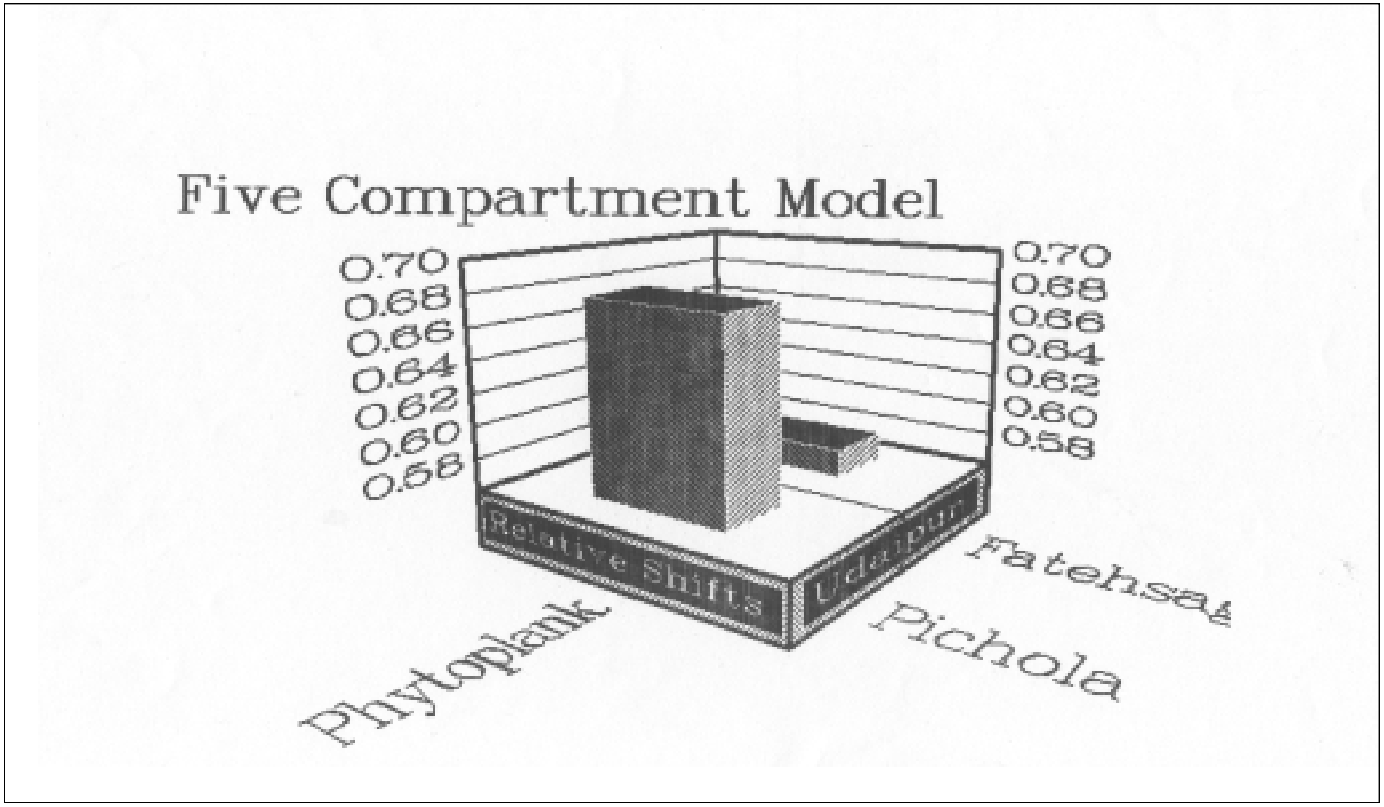

Figure 5. Normalized relative shifts (dimensionless) for phytoplankton: Pichola and Fateh Sagar Lakes.

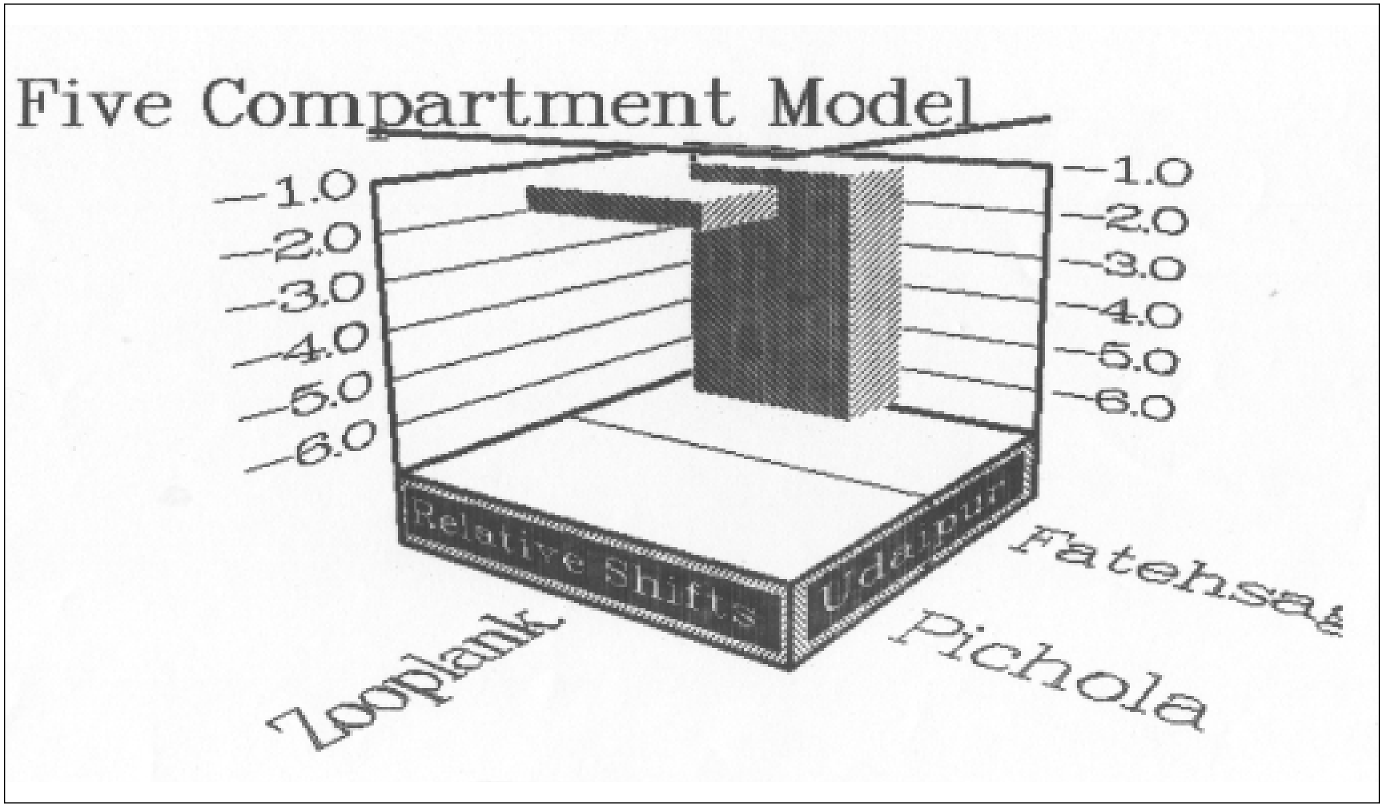

Figure 6. Normalized relative shifts (dimensionless) for zooplankton: Pichola and Fateh Sagar Lakes.

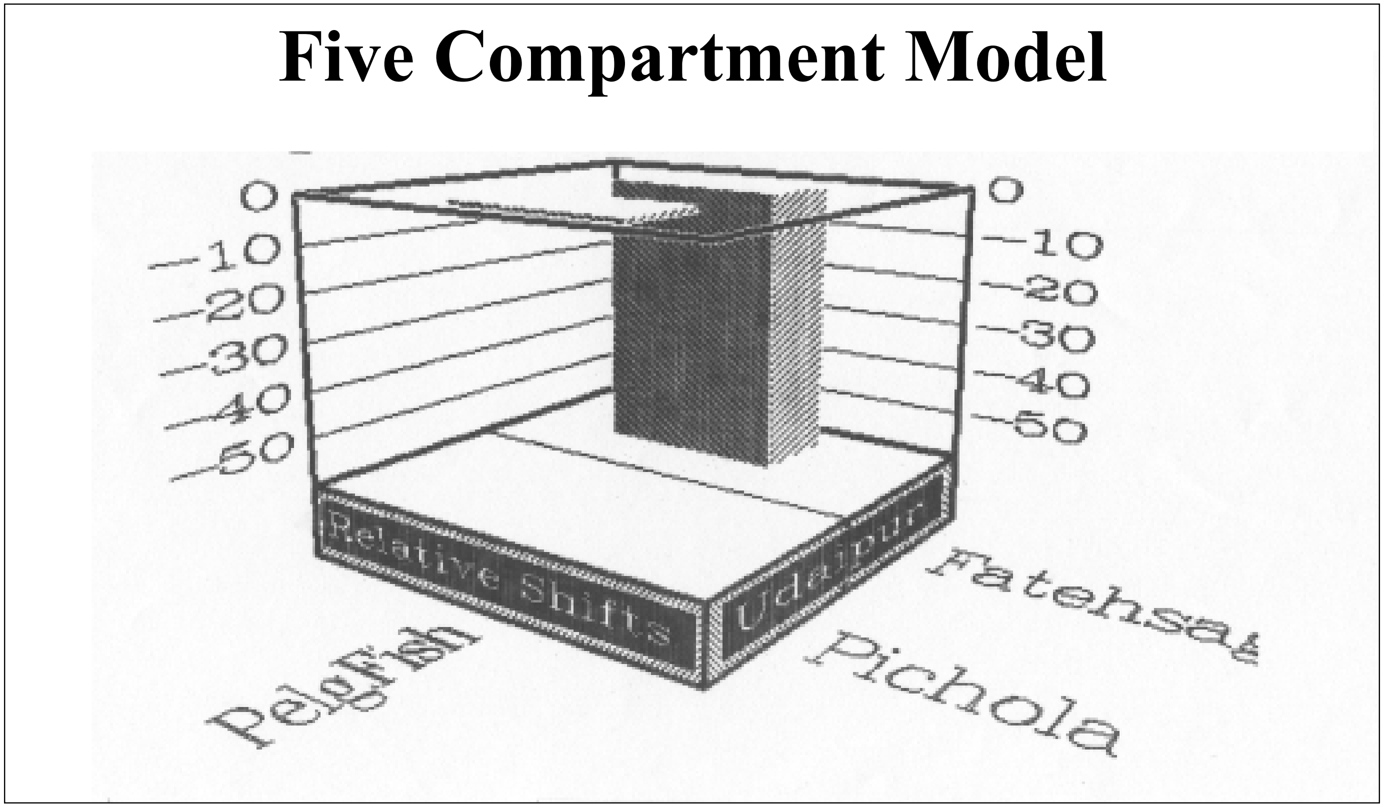

Figure 7. Normalized relative shifts (dimensionless) for pelagic fish: Pichola and Fateh Sagar Lakes.

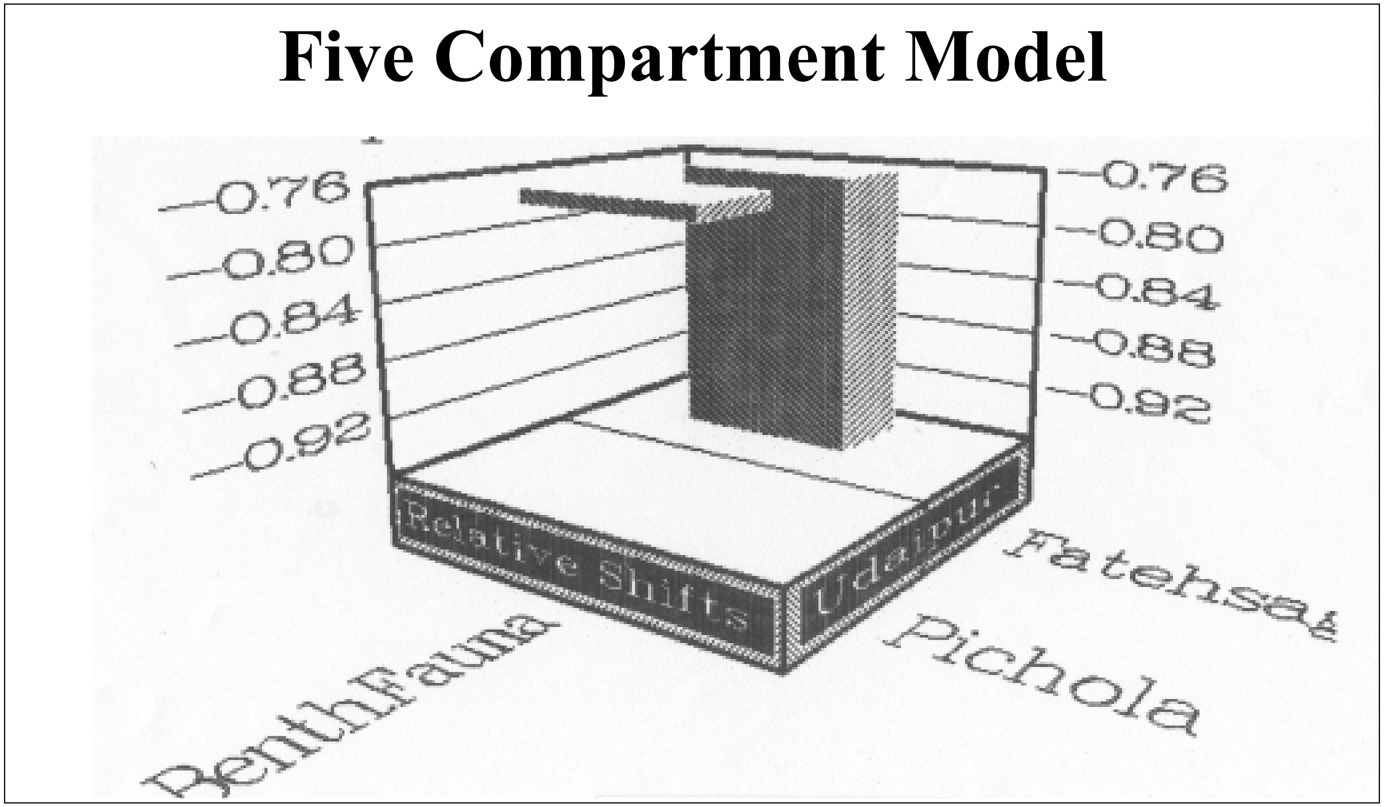

Figure 8. Normalized relative shifts (dimensionless) for bethnic fauna: Pichola and Fateh Sagar Lakes.

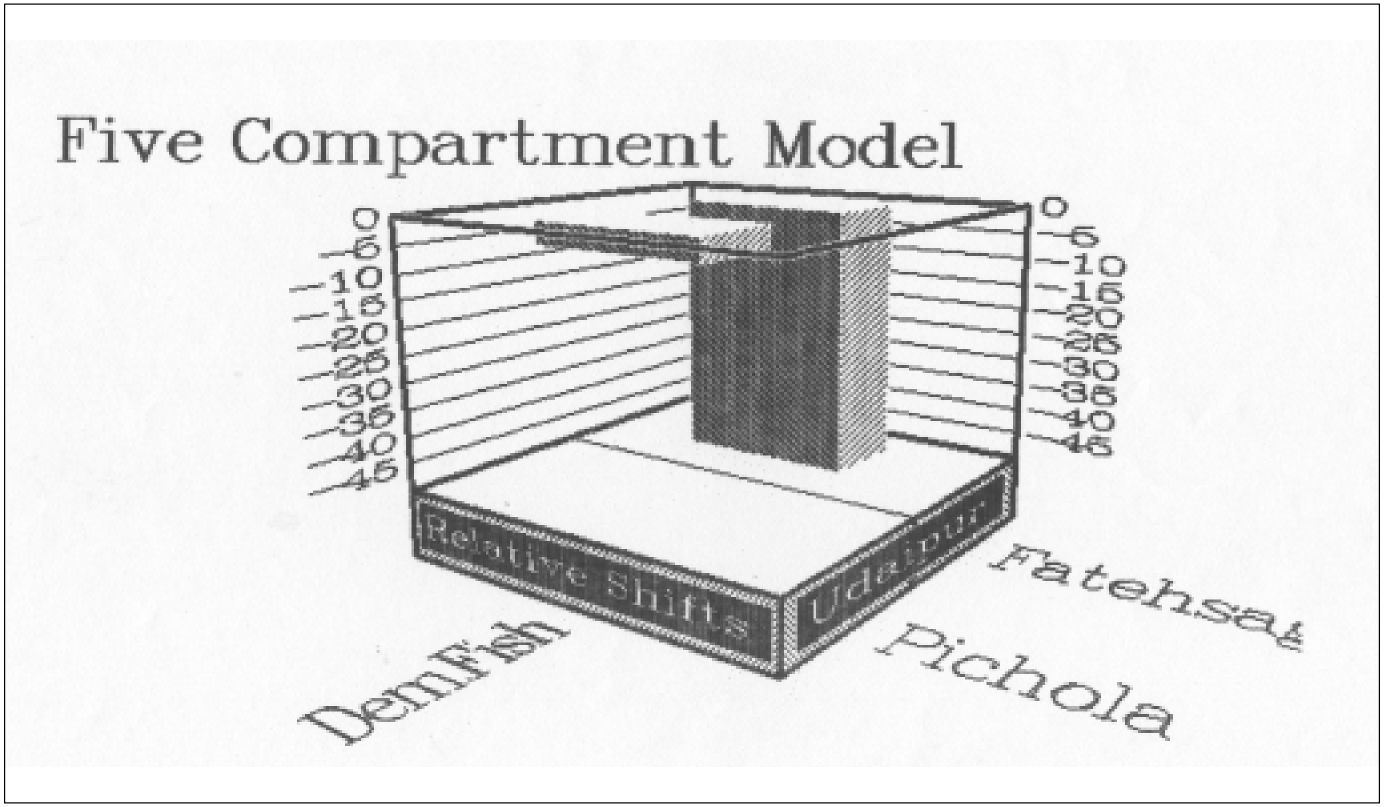

Figure 9. Normalized relative shifts (dimensionless) for demersal fish: Pichola and Fateh Sagar Lakes.

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