ECOLOGICAL STATUS AND PRODUCTION DYNAMICS OF WETLANDS OF UTTAR PRADESH

Central Inland Fisheries Research Institute
(Indian Council of Agricultural Research)

BARRACKPORE, KOLKATA 700 120
WEST BENGAL

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FOREWORD

The wetlands covering an area of 152,000 ha in Uttar Pradesh are very rich in nutrients and have diverse ecological features with tremendous fishery potential. These waters have high potential energy resource but unfortunately the actual energy harvest from them as fish is comparatively of very low order. The information regarding the ecological status, energy dynamics and energy conversion efficiencies in wetlands are lacking and practically nothing is known about them. To fill this gap in knowledge, Riverine Division of Central Inalnd Fisheries Research Institute, Barrackpore took up a detailed survey and in depth study of wetlands spread over sixteen districts of Uttar Pradesh. I am sure that the pioneering information collected and documented here will give an opportunity to have an in depth knowledge for the optimum utilization of this vast aquatic resource, hitherto unknown.

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Introduction

India has extensive freshwater wetlands in Uttar Pradesh, North Bihar, Assam and West Bengal. These waters cover an estimated water spread area of nearly 3.5 lakh hectares and are locally known as *chaurs*, *mauns* and *pats* in Bihar; *beels* and *baors* in West Bengal, Assam and North Eastern States. Large shallow lakes are called *tals*, *jheels* and *dah* in Uttar Pradesh and Madhya Pradesh and *sar* and *dal* in Jammu and Kashmir. Wetlands are integral part of river complex and should be identified and distinguished from other ecosystems for their proper utilization. Strengthening of river embankments as part of flood control measures or change in river courses have resulted in many of these water bodies getting permanently disconnected from the main stream, categorizing wetlands in two categories, open and closed. Open wetlands are wide and shallow with irregular contours and are connected with the river either throughout the year through channels or in some part of the year, especially during flood season. The feeding river regulates the water quality of such waters. Closed wetlands are dead zones of river or rivulets, which become disconnected permanently from the main river due to change in their course.

Wetlands are extremely rich in nutrients and have immense production potential as reflected by rich deposition of organic matter and available nutrients in the soil phase. Till recently these water bodies had the distinction of supporting high level of bio-production in general and fish yield in particular. But increased anthropogenic activities in the catchement areas and irrational modification of river basins, the ecological balance of these lakes have been affected. The rich nutrient status and shallow nature have led to excessive proliferation of aquatic macrophytes in almost all the wetlands. Loss of water due to evaporation by macrophytes, their death, decay and deposition at the bottom coupled with excessive silting are some of the factors responsible for the deterioration in condition of these water bodies. In recent years although there has been much concern over the rampant growth of macrophytes all over the world in natural lakes, streams, reservoirs and specially in shallow water lakes, swamps and wetlands, but there is amazing lack of interest in studying the ecological relationships which cause plant infestation and proper utilization of these aquatic resources for fish production.

In Uttar Pradesh (U.P.) alone the wetlands cover an area of nearly 152,000 ha, majority of which are situated in the basins of Ganga, Yamuna, Ramganga, Ghaghara, Gomti and Rapti rivers. Although vast water sheet is available under wetlands in the state but the average fish production from these waters is barley 100 kg ha^{-1} and there is a big gap between their potential and actual harvest. Although, some of these wetlands still maintain their connection with the parent rivers, many of them are permanently disconnected. The rich ecological status and vast production potential compel for evaluation of common management norms for the optimum utilization of these resources.

Limnology and productivity of macrophytes and macrophyte dominated water bodies have been studied by workers like Wilson (1939), Penfound (1956), Sculthrope (1967), Boyd (1968, 1969), Lind and Cottam (1969), Haniffa (1978), Haniffa and Pandiam (1978). Pathak *et ql* (1985), Pathak (1989, 1990), Sugunan (1995, 1997), Vass (1977), Jha (1989, 1997) have studied the ecology and productivity of wetlands in different parts of the country. These studies have suggested various management norms for the development of wetlands. Odem and Smalley (1959) suggested that even though macrophytes may not be utilized directly, they form very rich detritus pool after their death and decay and the best way to utilize these water bodies is through detritus chain to make the maximum utilization of this niche. Although many studies have been made on the ecology and development of wetlands in different parts of the country practically no attempt has been made on the wetlands of U.P. and still remain most neglected resource of the state.

Fisheries development in wetlands presupposes knowledge of the ecology and flow of energy in these water bodies. Lack of understanding of the ecological principles, especially productivity characteristics and improper management has resulted in rather low yield (100 to 200 kg ha^{-1}) from most of the wetlands of the country. In terms of potential these water bodies are capable of giving an annual fish crop of 1000 to 1500 kg ha^{-1}. Full implications of ecology, dynamics of physico-chemical constituents, flow of energy and nutrients in the system, aspects of fish culture and capture principles and various management measures in wetlands are examined here in order to bridge the gap between potential and actual production.

Study area

Ecological status, production potential and fisheries resources of thirty wetlands spread over sixteen districts of U.P. were taken for study in order to get clear picture of the entire state. Details of the studied wetlands are given in Tab 1. The abiotic and biotic variables, their role in production process, fisheries structure and yield and patterns and extent of energy utilization were critically examined in all the wetlands. Studies were made quarterly during the period 1999-2002.

Ecological parameters governing productivity

Sediment quality

It is rather unfortunate that in fishery science the study of underwater soil has not received much attention, in spite of the fact that fish like agricultural crops is mainly the product of the soil. The study of water without any relation with the underlying soil gives only an incomplete picture as the column of water standing is always in dynamic equilibrium with the soil on which it stands. Practically the under water soil works as a laboratory for the production of nutrients, from the raw material which consists of organic matter and the mineral constituents of the clay fraction of the soil. Thus, not only the total available quantity of the raw material but also the requirement of the organism as to the suitability of condition of existence and food supply is the essential components of a productive soil. The major chemical factors of importance are pH, available nitrogen and phosphorous and organic carbon apart from the physical composition.

The physico-chemical characteristics of soil in different wetlands have been presented in Tab 2. The physical composition of the sediment showed dominance of sand in all the wetlands (64.2 to 96.7%) with silt and clay ranging from 1.3 to 25.5% and 2.0 to 18.35% respectively. In general the soil texture varied between sandy to sandy loam. Except Devasi deval, which showed slightly acidic character (pH-6.5), sediment in all the wetlands showed neutral to alkaline, pH ranging from 7.0 to 8.2. Specific conductance was high in all the wetlands (136 to 972 µmhos), except Devasi deval that showed low conductance (98.0 µmhos). Free calcium carbonate was generally high in the wetlands connected with Ghaghra river, *viz.* Rewati and Mundiari in Ballia district and Ratoi tal in Mau district (11.7 to

14.3%). The high values in these wetlands are expected as the feeding river Ghaghra has also shown high values of free calcium carbonate in the sediment phase. The values ranged from 1.1 to 6.6% in others. Organic carbon, an index of productivity, was generally high (0.87 to 3.68%) in all the wetlands with few exceptions. Except Gagnikhera (0.87%) the organic carbon in all the wetlands was more than 1 %. The excessive growth of macrophytes, their death and decay resulted in constant loading of organic matter at the bottom and this may be the reason of high organic carbon in the sediment phase. Available nutrients, nitrogen and phosphorus were also quite high (298 to 635 ppm and 17 to 174 ppm, respectively).

Large number of observations has shown that a slightly alkaline pH (7.5) is optimum for production. Highly acidic soils (pH below 4.5) and highly alkaline soils (pH above 8.5) are generally unproductive. Similarly soils with available phosphorus below 30 ppm are poor, 30 to 60 are average and above 60 are highly productive. With respect to available nitrogen the values below 250 give poor results, and in the range of 250 to 750 ppm are productive and above 750 are highly productive. Organic carbon less than 0.5% could be considered too low for fishery soil; in the range 0.5 to 1.5% the productivity is average while in the range 1.5 to 2.5% soil appeared to be optimal. If these values are compared with the values observed in the wetlands under study it can be concluded that they can be put under productive class, with few exceptions.

Water quality

The biological productivity of any aquatic system depends on the quality of water. The process of energy fixation and utilization by the aquatic organisms and their whole life cycle depend on the characteristics of waters in which they live. Changes in the various water quality parameters and the dynamics of various physico-chemical constituents play vital role in the abundance and functioning of the aquatic organisms and the productivity as a whole. From the point of view of biological productivity the water is divided into two fundamentally different regions, one below the other, in which opposing processes take place. These are the regions of photosynthetic production (trophogenic zone) and the regions of breakdown (tropholytic zone). The kinetics of the processes taking place in these two different zones can be directly related with the productivity of the system, the greater the rate of production in the trophogenic zone (photosynthetic) and greater rate of decomposition in the tropholytic zone, greater is the productivity of the system. Both the production and decomposition processes bring about substantial changes in the water quality and the measurement of the rate of changes brought about by these processes can be used to evaluate productivity of the system. Among the physico-chemical factors influencing aquatic productivity, heat, light, turbidity, pH, alkalinity, conductance, dissolved solids, hardness and dissolved gases like oxygen and carbon dioxide and, dissolved nutrients like nitrogen, phosphorus, calcium, magnesium *etc.* are most important.

The important water quality parameters of different wetlands have been presented in Tab 3. Water temperature in all the wetlands varied within a very narrow range (23.7 to 27.3°C). Another important physical factor is the penetration of light on which the primary production or photo-chemical fixation of energy depends. The clarity of water was quite high in the wetlands ranging from 45.7 to 137.5 cm. In many of them the transparency was more than 100 cm and some of them were transparent even up to bottom. The penetration of light with sufficient intensity is one of the major causes of aquatic infestation in such systems. Among the chemical parameters the most important factor influencing productivity is pH, the index of hydrogen ion concentration. Observations made by many scientist in different aquatic systems have shown that slightly alkaline pH (7.0 to 8.0) indicates productive waters and accordingly all the wetlands where pH ranged between 7.0 to 8.4 can be classed as productive systems. The only exception is Devasi deval where pH was slightly lower (6.8).

Alkalinity or acid combining capacity of water is another important factor, which can be correlated with productivity and is generally caused by the carbonates and bicarbonates of calcium and magnesium. These along with dissolved carbon dioxide in water form an equilibrium system CO_2+CO_3+H_2O=$(HCO_3)_2$ which play a very important role in the ecology of the environment and acts as a buffer system for not allowing pH to fluctuate more. Moyle (1949), based on the study of a large number of lakes and ponds showed that alkalinity ranging from 40 to 90 mgl^{-1} gives medium productivity and highly productive waters have values more than 90 mgl^{-1}. Accordingly wetlands under study, where the alkalinity ranged between 56 to 284 mgl^{-1} can be put under high productive waters. Except Devasi deval, Bansidah, Bhagnaiya, Sangara, Bahusi and Ratanpur, which showed slightly lower alkalinity (56 to 87 mgl^{-1}), in all the other wetlands it was more than 100 mgl^{-1}. It is interesting to see that wetlands situated under different river basins have shown considerable variations in alkalinity, which reflects the impact of the feeding river. The clear examples are Naraini and Samaspur in Raibareli district and Loshar and Rainital in Pratapgarh district situated in Ganga basin, Alwar jheel in Yamuna and Bhadayal in Ramganga. Since the above rivers themselves have high values of alkalinity, wetlands under their basins have also reflected very high values of alkalinity (232 to 285 mgl^{-1}) whereas wetlands under other river basin have shown comparatively lower value of this parameter. Specific conductance and dissolved solids were also high in all the wetlands with few exceptions. Northcote and Larkin (1956) from the study of a number of lakes concluded that the dissolved salts in any sheet of water could be directly related with productivity. According to them the productive waters should have conductance greater than 200 µmhos and total dissolved solids more than 100 mgl^{-1}. Except Devasi deval (121 µmhos and 60 mgl^{-1}), Bhagnaiya (182 µmhos and 91 mgl^{-1}), Sangara (131 µmhos and 65 mgl^{-1}), Ratanpur (128 µmhos and 64 mgl^{-1}) and to some extent Rewati and Bansidah, the conductance and dissolved solids were much higher than the above limit of productive waters (211 to 706 µmhos and 105 to 353 mgl^{-1}). Like alkalinity these two parameters have also reflected the impact of feeding rivers. Wetlands in Ganga, Yamuna and Ramganga basins have shown comparatively much higher values of conductance (366 to 706 µmhos) and dissolved solids (183 to 352 mgl^{-1}) than those situated under other river basins.

Among the dissolved gases oxygen and carbon dioxide are more important from productivity point of view. Oxygen is a regulator of metabolic processes of plant and animal communities and an indicator of the condition of water. In fact dissolved oxygen provides much more information about water quality than any other chemical parameter. From large number of observations in different aquatic systems it has been found that a DO concentration of 5 mgl^{-1} is required for good growth of fauna. Dissolved oxygen in wetlands under investigation was generally more than 5.0 mgl^{-1} but in some wetlands like Devasi deval (2.6 mgl^{-1}), Chandutal and Sikandarpur (4.6 mgl^{-1}), Loshar (4.2 mgl^{-1}), Bhadayal and Mohane

($3.9\ mgl^{-1}$), Narainital ($4.8\ mgl^{-1}$), Dahital ($4.7\ mgl^{-1}$) and Sangara ($4.9\ mgl^{-1}$), the values were lower during morning hours but increased sharply with the progress of the day. Carbon dioxide dissolved in water, forms week carbonic acid, which remains held up by calcium as half bound calcium bicarbonate and completely bound calcium carbonate. This weak acid and its salts form a buffer system preventing the fluctuation in pH, the buffer capacity depending on the concentration of bicarbonate. A stable pH is essential for the aquatic productivity. Free carbon dioxide either absent or present in small amount is good for aquatic health but in high concentration it becomes harmful for the system. In all the wetlands under investigation, free carbon dioxide was either absent or present in small quantity (0.7 to $9.7\ mgl^{-1}$), excepting Devasi deval, Mohane, Bhadayal, Bhaghar, Sangara, Ratanpur, Sonari and Saman jheel, where the carbon dioxide was higher (14.6 to 21.6 mgl^{-1}).

Dissolved organic matter, which determines the chemical oxygen demand (COD) of the water is another important parameter to be related with productivity. It has been found that the productive waters should have dissolved organic matter more than $1\ mgl^{-1}$. In the wetlands under study the dissolved organic matter was quite high ranging between 1.6 to $4.3\ mgl^{-1}$. The high values of dissolved organic matter in such waters is expected due to constant loading of organic detritus following death and decay of the macrophytes. This is well supported by the high carbon content in the soil phase. But in contrast to the rich nutrient status of the sediment the nutrient status of water was poor in respect of both nitrate and phosphate, with concentrations ranging from 0.023 to $0.432\ mgl^{-1}$ and 0.012 to $0.378\ mgl^{-1}$, respectively. Moyle's observation on lake productivity indicated the optimal concentration of phosphate as more than $0.2\ mgl^{-1}$. But except in Rohua, Mohane, Dabri jheel, Ratanpur and Aheerwan, the concentration in other wetlands is generally much lower than the optimum limit. Similarly in respect of nitrate it has been found that a concentration of 0.2 to $0.5\ mgl^{-1}$ is favourable for fish production. However, the nitrate concentration in the wetlands was much below the production limit with few exceptions. It may be recalled that all the wetlands are infested with aquatic macrophytes and large amount of nutrients are used and locked by these macrophytes. Since macrophytes have longer life periods, the nutrients taken up by them are removed from circulation. Only after death and decay of macrophytes these nutrients are again released. Due to locking of nutrients by macrophytes and their removal from circulation the water gradually shows deficiency of nutrients. Calcium, magnesium and total hardness, essential for productive waters, ranged from 10.7 to 30.0; 7.2 to 33.0 and 57.0 to 218.0 mgl^{-1}, respectively. The high values of these parameters also reflected good productive character of the wetlands. Like alkalinity and conductance these parameters also showed considerable variation, reflecting the impact of the feeding rivers. In fact the high values of calcium, magnesium and hardness observed in the wetlands situated in Ganga, Yamuna and Ramganga basins may be due to the impact of the river on their water quality as the above rivers have themselves shown high values of these parameters. The variations in other wetlands also reflect the impact of the parent river especially in open ones. Other water quality parameters, silicate and chloride ranged from 2.0 to 9.7 and 7.1 to 23.3 mgl^{-1}. Although silicate concentration was medium to poor in almost all the wetlands but this does not seem to have much correlation with the diatom population, which remained the dominant component in almost all the wetlands.

Dynamics of chemical constituents and evaluation of productivity

In photosynthetic zone during daytime carbon dioxide is taken up from bicarbonate by the photosynthetic organisms resulting in decrease of bicarbonate and increase in carbonate and pH. Oxygen is liberated and increases in concentration.

$$2HCO_3 = CO_2 + CO_3 + H_2O$$

$$6CO_2 + 6H_2O = C_6H_{12}O_6 + 6O_2$$

During dark hours (night) oxygen is consumed, carbon dioxide is liberated, carbonate is converted into bicarbonate and pH decreases due to increase in hydrogen ion concentration.

$$C_6H_{12}O_6 + 6O_2 = 6CO_2 + 6H_2O$$

$$CO_2 + CO_3 + H_2O = 2(HCO_3)$$

$$CO_2 + H_2O \rightarrow H_2CO_3 \rightarrow H^+ + HCO_3$$

The kinetics of two opposite chemical processes during two phases of the day is reflected in the diel cycle of chemical parameters. In productive waters the rates of above reactions are high and hence the relative productivity of the aquatic ecosystem can be evaluated from the magnitude of diel change in chemical parameters. The diel cycle of chemical parameters in Sikandarpur and Ratoi tal, the two extremes has been depicted in Fig 1.

A sharp diel change in chemical parameters like dissolved oxygen, pH, free carbon dioxide, carbonate and bicarbonate have been observed in all the wetlands although with varying magnitude. The intensity of variations was minimum in Sikandarpur and maximum in Ratoital. Dissolved oxygen, the most important parameter directly related to the photosynthetic production, registered sharp increase with the progress of the day, reaching maximum in the noon or evening and then showed declining trend. In wetlands Ratoi and Rewati, oxygen showed an increase of 10 to 11 mgl^{-1} between morning and evening. Carbonate and pH also followed similar increasing trend but free carbon dioxide and bicarbonate showed opposite trend, being maximum in the morning and decreased with the progress of the day reaching minimum in the evening. Similar trend was observed in all the wetlands. Sharp diel changes in chemical parameters clearly suggest the productive nature of all the wetlands. From the variation in the magnitude of diel change (especially oxygen), the productivity trends in wetlands can easily be evaluated.

Rich sediment quality with high organic carbon and nutrients, optimum water quality parameters and sharp diel variation in chemical parameters, all reflect high production potential of the wetlands under study.

Biotic communities

Floodplain wetlands are highly productive ecosystem and present diverse ecological conditions. They support rich varieties of biotic communities like plankton, benthos, periphyton, macrovegetation and weed associated fauna and flora. The relative abundance and dominance of these groups vary from wetland to wetland and season to season, depending on their hydrodynamics and morpho-ecological conditions. However, one characteristic biological feature common to all wetlands in Uttar Pradesh, is the moderate to heavy infestation of macrophytes.

Plankton

Plankton includes those aquatic flora and fauna, which readily drift along the water current and move irresistantly by the wind action. This generally includes microscopic aquatic flora (phytoplankton) and fauna (zooplankton). Phytoplankton bearing photosynthetic pigments make use of the inorganic nutrients available in the wetland ecosystem and synthesize organic matter (autotrophs). On the other hand, zooplankton lives on huge reserve of organic matter of plants and animal origin. Both phyto and zooplankton sustain a substantial portion of planktophagus fishery of wetland resources.

Phytoplankton

Owing to the high rate of accumulation of nutrients, macrophytes compete with phytoplankton and under macrophyte dominated conditions phytoplankton do not get enough nutrients for their growth. The qualitative and quantitative abundance of phytoplankton in different wetlands have been presented in Tab 4. The group Chlorophyceae dominated in 14 wetlands (35.6 to 72.9%) while in others Bacillariophyceae showed superiority (35.3 to 57.3%). The possible dominance of these two groups may be facilitated by the rapid removal of plant nutrients by macrophytes from the soil water phase. The group Myxophyceae also showed higher percentage in about eight wetlands (35.2 to 74.5%). In Rewati and Rainital the bloom of *Microcystis* was observed during summer and winter months, indicating lower rate of absorption by macrophytes and enrichment of nutrients, which favoured blooming of blue green algae. Desmids were also recorded in some of the wetlands in the range of 10.7 to 31.7%, although being absent in many wetlands whereas Rodophyceae was present only in one wetland. A sum total of 74 species of phytoplankton were recorded in wetlands under study, comprising of 26 green algae, 17 diatoms, 18 blue greens algae, 12 desmids and one Rodophyceae. The species dominated in these wetlands were *Microspora, Ankistrodesmus, Mougeotia, Protococcus, Botryococcus, Synedra, Cymbella, Navicula, Fragilaria, Phormidium, Merismopedia, Anabaena, Microcystis, Tabellaria* and *Pediastrum*.

Total average phytoplankton population ranged from 59 to 17,734 ul^{-1}, being maximum in Rewati and minimum in Aheerwan. The highest density (17,734 ul^{-1}) recorded in Rewati was on account of *Microcystis* bloom.

Zooplankton

The quantitative and qualitative abundance of zooplankton have been shown in Tab 5. The group Rotifera dominated in 14 wetlands (35.1 to 88.6%), followed by cladocerans.

(35.3 to 70.1%) in nine wetlands and copepods (37.3 to 71.6%) in seven wetlands. Protozoans were dominant only in Sangara (43.7%). The other groups were either absent or contributed very low. A sum total of 48 species of zooplankton were recorded in these wetlands, which include 18 Rotifera; 2 Copepoda; 11 cladoceran; 13 Protozoa and one Ostracode. Dominant species encountered were *Keratella, Brachionus, Daphnia, Diaphanosoma, Bosmina, Moina, Asplancha, Synchaeta, Euglena, Nauplii, Cyclops, Dioptomus, Cypridopsis, Sida and Chydorus.* Average zooplankton ranged between 11 to 1609 ul^{-1}.

Benthos

The study of benthic communities in the wetlands helps in assessing the quantum of energy transformed through detritus as well as the trophic status of the system. The qualitative and quantitative abundance of benthos in different wetlands have been presented in Tab 6. The abundance of benthic communities varied considerably in various wetlands being minimum in Rohua (176 n m^{-2}) and maximum in Rewati (1617 n m^{-2}). All the wetlands being rich in detritus energy, the population of benthos was in general rich. Mollusc (mainly gastropds) remained the dominant component of almost all the wetlands (48.3 to 100%), except Bansidah, Bhaghar, Sangara, Bahausi, Aheerwan and Saman jheel, which were dominated by insects (36.5 to 50.0%). Oligochaets and crustaceans were absent on many occasions and if present their contribution was low (2.6 to 29.2%) and (4.8 to 13.8%), respectively (Tab 6). The dominant molluscan species observed during investigations were *Indoplanorbis exustus, Lymnaea accuminata, L. columella, Gyraulus sp., Pila globosa, Bellamya bengaloum.* Besides chinomomids, which was the next important component of benthic fauna, insects were represented by their nymphs, while *Macrobrachium lamarrei* and *Tubifex tubifex* were observed among crustacean and annelids (oligochaetes).

Periphyton

In wetlands periphytons are highly significant as primary producers, next only to macrophytes. Periphytons assume greater significance in weed choked impoundments as they tend to grow luxuriantly. The aquatic macrophytes act as sheet anchor for periphytic proliferation, either in terms of substrate or in terms of nutrients supplier. The abundance of periphyton in different wetlands has been presented in Tab 7. The population ranged between 1163 to 7101 u cm^{-2}, being minimum in Rohua and maximum in Dabri jheel. The monsoon month showed relatively poor abundance of periphyton that may be attributed to the influx of floodwater and highly turbid conditions.

Except Rewati, Sikandarpur, Bhagnaiya, Alwar jheel, Rohua, Gagnikhera and Bhadayal, the periphytic community in all other wetlands was dominated by Bacillariophyceae (40.8 to 85.1%). Myxophyceae was the major component in Rewati (60.9%), while others were dominated by Chlorophyceae (42.4 to 64.7%).

Among the animals' only rotifers, protozoans and crustaceans were the main representative but their contribution was of very low order.

Macrophytes

Wetlands of U.P. are highly infested with submerged, floating, emergent and marginal macrophytes. These macrophytes compete with phytoplankton and restrict their growth either by shading or locking of nutrients for longer duration. The evapotransition of water by macrophytes and constant accumulation of detritus also deteriorates the condition of the wetlands. The extent of infestation, biomass and dominant macrophytes in wetlands under study are presented in Tab 8. Various wetlands were chocked with macrophytes to the extent of 25 to 90%, in some of them the infestation rate being comparatively much higher (60 to 90%). The net wet biomass was within the range of 1.3 to 9.3 kg m^{-2}, maximum domination being in Narainital and minimum in Aheerwan. A sum total of 22 species have been encountered in the studied wetlands of which *Hydrilla, Cerratophyllum, Potomogoton, Eichhornia, Naja, Vallicnaria* and *Chara* were most dominant.

Energy dynamics of wetlands

The energy source for all living organisms on the earth is sun, a vast incandescent sphere of gas, which releases energy by nuclear transmutation of hydrogen to helium in the form of electromagnetic waves. Only a small fraction of this energy is transformed into chemical energy by producers and stored by them. The energy stored by the producers gives the potential energy resource of the system, as this is the available energy, which flows to consumers at various trophic levels. In fact the organisms in an aquatic system are interlinked with one another by energy chain and arranged at various trophic levels depending on their mode of obtaining energy. Thus for understanding the energy dynamics of any system two types of studies are essential:

1. Transformation and storage of solar energy into chemical energy by producers;
2. Flow of energy from producers to consumers at different levels (pattern of energy utilization).

Energy transformation through primary production

The process of energy transformation by producers is represented by the basic equations:

$$6CO_2+6H_2O \xrightarrow[\text{Solar energy}]{\text{709 cal}} C_6H_{12}O_6+6O_2$$

$$nCO_2+n(H.doner) \xrightarrow{\text{Solar energy}} (CH_2O)_n+n(oxidized\ doner)$$

This redox process is endergonic in nature requiring more than 100 calories of energy per mole of CO_2 reduced and consequently plants can store large amount of energy in the form of energy rich organic compounds. From the above equation the energy required to liberate one milligram of oxygen through algal photosynthesis is approximately 3.68 calories and hence the amount of oxygen liberated gives a measure of solar energy trapped as chemical energy by producers. The efficiency of energy transformation is known as photosynthetic efficiency and is equal to the energy fixed by producers during photosynthesis per unit light energy available in the system in any given time and space that is $F=H/S\times100$ where F is the efficiency, H the energy fixed by producers and S, the light energy available on the surface. H can easily be estimated from the amount of oxygen liberated. The productivity of any sheet of water directly depends on the efficiency with which producers convert light energy to chemical energy.

In wetland ecosystem, which are generally infested with aquatic macrophytes the primary production is contributed both by phytoplankton and macrophytes. In such cases the contribution of macrophytes is comparatively much higher than phytoplankton. The available light energy, rate of energy transformation by producers and photosynthetic efficiency in different wetlands have been presented in Tab 9.

The light energy penetrating the water surface of all wetlands was in the range of 17,88,000 to 19,45,000 in different parts of U.P. depending upon latitude and hence variation in incident light energy was of lower magnitude. But considerable variations were observed in respect of energy fixed by producers. The gross energy transformation rates including both phytoplankton and macarophytes was in the range of 26,170 to 63,879 cal $m^{-2} d^{-1}$. The rate was maximum in Ratoi and minimum in Sikandarpur. The photosynthetic efficiency in different wetlands ranged between 1.44 and 3.37%. When compared to many other aquatic systems the efficiency in the wetlands was found to be much higher. Studies have shown that nearly 59.0 to 78.1% energy fixed by producers was stored by them and the rest was lost as energy of respiration. The variation in the rate of energy transformation and photosynthetic efficiency in various wetlands was due to the variation in both water quality and producer population.

Between the two types of producer populations, the rate of energy transformation by phytoplankton ranged from 3,705 to 19,927 cal $m^{-2} d^{-1}$ and that by macrophytes from 17,908 to 60,174 cal $m^{-2} d^{-1}$. Thus, about 5.8 to 38.8% of total energy fixed through primary production was contributed by phytoplankton and the rest 61.2 to 94.2% was contributed by macrophytes in different wetlands. Considerable variations were observed in the rate of energy transformation by phytoplankton, being minimum in Ratoital and maximum in Rewati while macrophytes showed opposite trend. On average 25.5% of the energy fixed by producers was contributed by phytoplankton and the rest 74.5% by macrophytes. The rate of energy transformation by phytoplankton in wetlands can be well compared with other water bodies where phytoplankton is the main producer group. However, the energy represented by phytoplankton is only 25.5% of the total and therefore calculation of potential energy resource taking only this producer group into consideration gives an incomplete picture. Thus, for the estimation of fish production potential, the energy fixed by both the producer groups must be taken into consideration.

Dynamcis of macrophytes and detritus energy

A conceptual model of macrophyte dynamics in the wetland ecosystem is presented in Fig. 2.

The rate of input of energy to the living mcarophyte compartment (BL) is PG, the gross energy fixed by them through photosynthesis. Losses of energy occurs by respiration (RN), excretion (RX) of organic matter, grazing (G) and mortality (M) all expressed as rates and therefore

BL=PG-RN-M-G-RX→BD (Detritus pool)

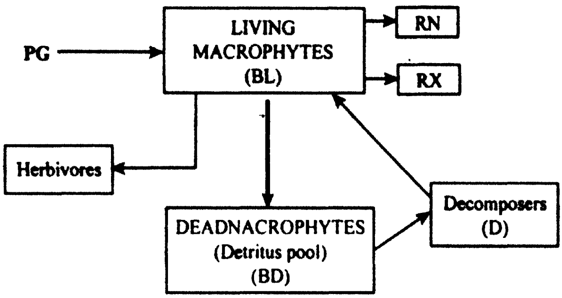

Fig 2. Dynamics of macrophytes in wetlands

PG = gross primary production RN = macrophyte respiration

RX = excretion of dissolved organic matter BD = dead macrophytes (detritus pool)

G = grazing; M = mortality; D =decomposition and N = nutrients.

Most of the macrophytes are not grazed directly by herbivores and the unused material gets deposited at the bottom after their death (BD). When decay occurs these macrophytes contribute to the organic detritus pool, which is very important in the aquatic food webs (Odem and Smalley, 1959). The dead macrophytes can be estimated by studying detritus availability, which reflect the energy available at the bottom.

The energy available as organic detritus in different wetlands have been presented in Tab 12. The detritus energy fluctuated between 10.16×10^5 to 28.00×10^5 K cal h^{-1}, being minimum in Bhadayal and maximum in Dabri jheel. Thus, the energy available as organic detritus was in general very high in all the wetlands, which if judiciously utilized can increase the energy harvest from them as fish manifold.

Evaluation of fish production potential in wetlands

The productivity potential of any water body directly depends on the efficiency with which producers convert and store light energy in the form of chemical energy, because this is the available energy, which flows to other higher trophic levels. Odem (1975) and Mann (1969) applied the energy flow approach for calculating fish production of lakes and reservoirs keeping in view that in passing from one trophic level to the other almost 90% of the energy is lost according to the second law of thermodynamics. Odum (1960, 1962) felt that in open water bodies, which have wide range of fish spectrum belonging to various trophic levels, the productivity potential can be taken as 1% of gross or 0.5% of net energy fixed at producer level. Natrajan and Pathak (1987) and Pathak (1990) estimated fish production potential of a number of reservoirs and wetlands by taking energy available at fish level as 0.5 of net energy fixed by producers. The wetlands under study have shown very high production potential.

The fish production potential (kg ha^{-1} y^{-1}) in different wetlands has been estimated as 1283.5 in Rewati; 756.7 in Mundiari; 680.0 in Rohua; 934.1 in Gujartal; 807.5 in Narainital; 663.0 in Lohsartal; 637.5 in Rainital; 965.1 in Chandutal; 817.7 in Sikandarpur; 760.0 in Bansidah; 1012.0 in Bhagnaiya; 858.0 in Gambhirban; 829.7 in Salona tal; 767.0 in Devasi deval; 1223.7 in Ratoital; 792.0 in Alwar jheel; 788.0 in Dahital; 669.2 in Gagnikhera, 828.7 in Mohane; 799.0 in Bhadayal; 1069.2 in Dabri jheel; 1309.0 in Bhaghar jheel; 843.2 in Sangara; 703.8 in Ratanpur; 881.5 in Sonari; 1258.3 in Kuthala; 1326.5 in Bahausi; 822.8 in Aheeravan and 898.3 in Saman jheel.

The potential energy resource as fish in wetlands of U.P. has been shown in Fig 3. In terms of energy these wetlands have the capacity of giving an energy output in the range of 765,000 to 159,1800 K cal ha^{-1} y^{-1}. On average these wetlands have a fish production potential of 913.3 kg ha^{-1} or 1,095,948 K cal ha^{-1} of energy. The fish production potential of these waters is of very high order and if the potential energy is properly utilized they can yield a good amount of fish without putting much effort.

Actual fish production from wetlands

The actual fish production and contribution of different fish groups have been presented in Tab 10. The fish production from various wetlands of U.P. ranged between 43.0 to 357.0 kg ha^{-1} being minimum in Rainital and maximum in Dabri jheel. Among the various groups miscellaneous were most dominant (31.0 to 59.3%) followed by carps (14.6 to 42.9%) and catfish (18.8 t o 39.5%). The average catch in the wetlands system under study was 160.4 kg ha^{-1}, mainly contributed by miscellaneous (39.1%), carps (33.8%) and catfish (27.1%). The dominant species encountered in catches were *C. mrigala, C. catla, L. rohita, L. calbasu, L. gonius, L. bata, P. ticto, P. sarana, P. sophore, R. daniconius, W. attu, A. seenghala, A. aor, A. mola, M. cavasius, O. bimaculatus, O. pabda, A. colia, C. ranga, C. nama, C. batrachus, H. fossilis, X. cancila, O. bacaila, O. gora, G. giuris, N. nandus, C. gachua, C. punctatus, C. garua, C. labuca, N. notopeterus, etc.* and small shrimps.

The energy harvest as fish from wetlands and contribution of various groups has been shown in Tab 11. The actual energy harvest ranged from 51,600 to 428,400 K cal ha^{-1} y^{-1}, being maximum in Dabri jheel and minimum in Rainital. Miscellaneous group (29,577 to 148,746 K cal ha^{-1} y^{-1}) remained the dominant contributor followed by tertiary consumers (13,519 to 93,391 K cal ha^{-1} y^{-1}). The contribution of secondary consumers was minimum. Between the two primary consumers, the contribution of detritivores (4,861 to 128,000 K cal $ha^{-1}y^{-1}$) was comparatively much higher than herbivores (1.660 27,418 K cal ha^{-1} y^{-1}). In some wetlands, *viz.*, Sikandarpur, Bansidah, Bhagnaiya, Salona tal, Kuthala, Gagnikhera, Mohane, Dabri jheel, Sangara, Sonari, Bhaghar and Bauhasi the contribution of detritivores was comparatively much better (51,122 to 128,000 K cal ha^{-1} y^{-1}) and together with herbivores they contributed 28.0 to 36.3% of the total energy harvest. As a result these wetlands have shown comparatively better harvest than others. The average energy harvest from all the wetlands was 192, 506 K cal ha^{-1} y^{-1}, contributed by primary consumers (28.6%), secondary consumers (95.2%), tertiary consumers (27.1%) and miscellaneous (39.1%). The variation in catch stucture and contribution of various groups has direct impact on the energy harvest from the wetlands of the state.

Flow of energy in wetland ecosystems

Energy chains interlink the biotic communities in any aquatic ecosystems with one another. The complex relationships of food chain and flow of energy in community metabolism are of great importance. A proper understanding of the trophic dynamics of the aquatic ecosystem help in formulating policies for stock manipulations and better utilization of potential energy resources. There are two main routes through which energy flows in any aquatic ecosystem, one of which has been emphasized much more than the other. The first involves grazing of green organisms (producers) by herbivores or plant feeders, which are in turn taken by predators; thereby the energy stored by photosynthesis is transferred to consumers at various levels. This is commonly known as the grazing food chain. The second pathway, involves flow of energy from dead organic matter deposited at the bottom through the detritus food chain. The two pathways are shown below:

Energy fixed at producer level → Herbivores → Predators → Grazing chain

Energy fixed at producer level → Organic detritus → Detritivores → Predators → Detritus chain

There are a number of restricting conditions for the transfer of energy from primary producers to secondary and tertiary consumers. Herbivorous fishes are distinctly selective in their feeding on phytoplankton and macrophytes. Similarly zooplankton organisms also show tendency for selective feeding on phytoplankton. Thus, consumers do not always utilize all the energy represented by primary producers directly and the unutilized energy reaches the bottom after the death of the organisms. This energy is utilized through detritus chain. Juday (1940), Lindemann (1942), Reiley (1956), Teal (1957), Odum (1957, 1962), Odem (1969, 1975), Ganapati (1970), Sreenivasan (1972), Natarajan and Pathak (1980, 1983, 1987), Pathak *et al* (1985), Pathak (1990) and Haniffa and Pandian (1978) have studied the flow of energy in different aquatic ecosystems and highlighted the importance of detritus chain. Generally the studies on energy flow through an aquatic ecosystem do take into account the different trophic levels but this approach although appears to be simple, has the disadvantage that many fishes are omnivorous and can not be assigned to a particular level. Simil rly the feeding habit of the fish also changes depending on the availability of food. It appears that the most important single channel of energy flow leading to fish production is through organic deritus complex, which consist of decaying plant material, sewage solids and decomposer organisms. In some aquatic systems, grazing path predominates while in others most of the energy flows through detritus chain. Functionally the distinction between grazing and detritus chain is of importance as there is a time lag between direct consumption of living plants and the ultimate utilization of dead organic matter through detritus chain.

A general energy flow model of the wetland ecosystem has been shown in Fig. 4.

The main primary producers in wetlands are macrophytes and almost 70 to 80% of the energy fixed through primary production in such systems is by them. But the energy fixed and stored by macrophytes is not utilized directly by the consumers. After their death and decay the energy is deposited at the bottom forming very rich detritus pool.

As shown in the model the best way to utilize this energy is through detritus chain. Pathak *et al* (1985) and Pathak (1990) studied the energy dynamics of a number of wetlands located in different geographical regions of India. It was observed that wetlands, which were dominated by detritus feeders and most of the available energy was utilized through detritus chain have shown much better production. But in wetlands where the available detritus energy is not utilized properly the production was of low order. The pattern of energy utilization from potential to fish in wetlands of U.P. has been presented in Fig 5. Studies in 29 wetlands spread over different districts have clearly shown that almost 60 to 80% of the available potential energy is utilized by tertiary and miscellaneous consumers. The contribution of secondary consumers was very low. In some wetlands, where the contribution of detritus feeders or primary consumers as a whole was more, the energy harvest from them was comparatively better.

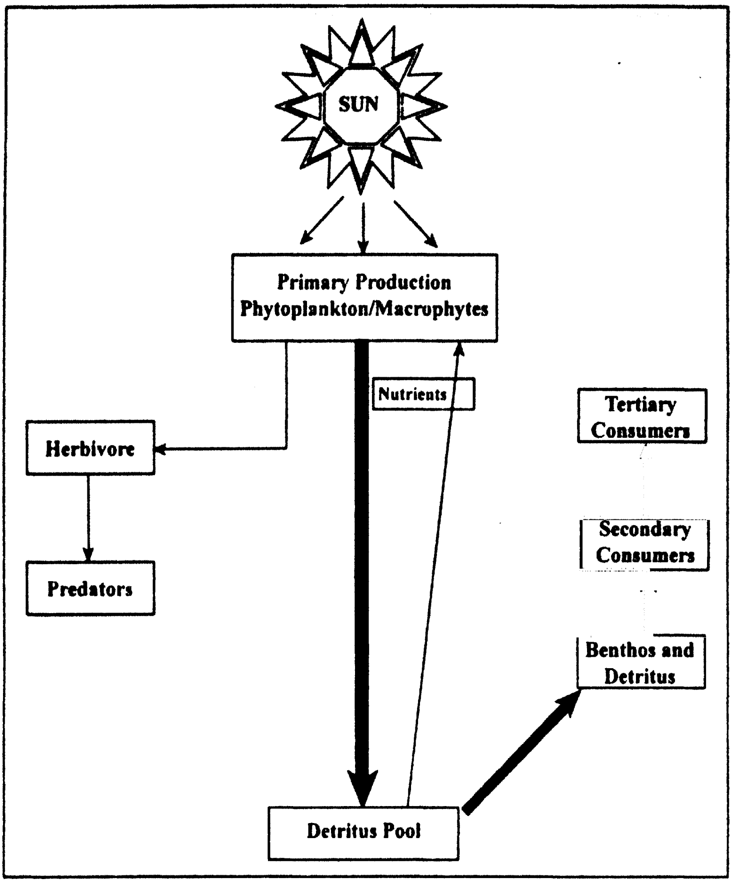

Fig 4. Flow of energy in wetlands (general model)

Comparison of production efficiencies

Comparison of available detritus energy and potential energy resources with actual fish harvest and the various conversion efficiencies are presented in Tab 12. Good conversion efficiency indicates better management and proper utilization of available energy resource. All the wetlands received almost similar light energy and showed high efficiency of energy transformation (1.44 to 3.37%), but the actual energy harvest, as fish was invariably low in almost all the wetlands. Energy transformation was maximum in Dabri jheel and minimum in Rainital. The energy conversion efficiencies from different sources to fish have been depicted in Fig 6. The conversion from primary fixed energy to fish ranged from 0.044 to 0.268%. Except some of the wetlands like Salona tal, Gagnikhera, Mohane, Dabri jheel and Sonari and to some extent Sikandarpur, Bansidah, Devasi.deval, Dahital and Sangara, the efficiency in others was very low. The poor conversion efficiencies in wetlands clearly reflect the failure of management and improper utilization of available energy.

Odum (1962) observed that fishes feeding directly on algae or macrophytes have shown maximum conversion from primary energy to fish. Nicolsky (1963) stated, "the nearer the useful end product stands to the fist link in food chain the higher is the yield from water mass". Odem and Smalley (1959) suggested that the best way of utilization of energy is through detritus as detritus feeders are the most efficient converter of energy. Pathak (1990, 1997) studied the energy conversion of efficiencies in a number of wetlands located in Assam, West Bengal and Bihar and found that the wetlands, in which almost 70 to 80% of the energy is utilized through detritus chain, have shown better conversion efficiency than those dominated by catfishes and weed fishes. These findings clearly confirm that the detritus feeders, which have shown maximum conversion efficiencies, are the most suitable species for the better utilization of energy in wetlands.

The wetlands of U.P. are very rich in detritus energy (10.16×10^5 to 28×10^5 K cal ha^{-1}) but dominated by catfishes and undesirable weed fishes. The non-utilization of vast detritus energy resource has resulted in poor yield and conversion efficiency from detritus to fish ranged from 4.6 to 17.2%. The wetlands, which have shown better energy harvest, have also shown the higher conversion efficiency (more than 10%). A comparison of the fish production potential and the actual yield clearly shows that only 6.5 to 33.4% of the potential is actually harvested from the wetlands of U.P. However, some wetlands have shown better conversion efficiencies (>20%) as the energy utilization in them was more through detritus chain. In most of the wetlands the potential remained unutilized. These observations clearly show that in order to enhance fish production from the wetlands, the vast energy resource, as detritus must be utilized properly.

Guidelines for fishery management of wetlands in U.P.

Biological productivity of water bodies depends on the efficiency with which the solar energy is trapped and stored as chemical energy in the system and the efficiency with which consumers at various trophic levels utilize this potential energy. The energy conversion efficiency at trophic levels of consumers differs from one water body to the other depending on their biotic communities structure. A well-managed system will show higher conversion efficiency from primary photosynthetic energy to fish or potential to fish but lower efficiency reflects poor management. Studies conducted in wetlands U.P. have proved beyond doubt that these water bodies have high-energy conversion efficiency at the producer level but the poor conversion efficiency at fish level indicating about non-utilization of potential energy and management failure. In an ideal situation, the commercial species should share the ecological niche in such a way that trophic resources are utilized to the optimum. At the same time the fishes should belong to shorter food chain in order to allow maximum efficiency in converting the primary food resources into harvestable material and thus reducing the loss of energy. Ecosystem-oriented management implies, increasing productivity by utilizing the natural ecosystem processes to the maximum extent. Some of the basic management norms for enhancement of fish production from wetlands in general are as under.

Weed management

The high incidence of macrophytes is a negative development in the wetlands, which needs to be tackled effectively for maximum sustainable fishery. The dense growth of macrophytes interferes with the fishing operation, reduces the phytoplankton population, restricts the living space and movement of the fishes and deteriorates the water quality by changing the amount of dissolved gases. Studies in Kulia beel (Pathak, 1990) have shown that the production potential of wetlands increased sharply after clearance of aquatic weeds. The management of wetlands, therefore, largely centers on the elimination of macrophyte cover. In some wetlands the formation of floating "islands" due to succession and piling of weeds is a common phenomenon. The floating island not only causes hindrance during fishing activities but also reduce the productive area of the wetland. There are three well-established methods for weed control:

(a) Mechanical (b) Chemical (c) Biological

In small wetlands manual clearance can be done but in large ones where the manual clearance is not possible the same can be carried out by the application of chemical weedicide like 2,4-D sodium salt at the rate of 10 kg h^{-1}. The weedicide kills the weed *in* *situ* and the released nutrients from the dead weeds fertilize the water to make it more productive. The random growth of macrophytes can also be checked with the help of biological agents. The most promising species for the consumption of macrophytes is grass carp, which is one of the fastest growing fish. The stocking of wetlands with grass carp will not only control macrophytes and contribute to fish production but it will also provide food for other species through its faecal matter as the fish is found to utilize only 50% of the consumed material and the rest is released. The grass carp in fact acts as a living manuring machine and its faeces lead to production of natural food. But the stocking of grass carp should be done only in closed wetlands in order to prevent its escapement in the riverine system. The quantum of macrophytes in wetlands has assumed such a proposition that no single method may be 100% effective and as such all the three methods will have to be attempted in phased manner although it is cost effective.

Stocking of wetlands

By nature wetlands are extremely rich in nutrients and have immense production potential as reflected by their rich soil quality. Hence, a proper understanding of the complex relationships of soil quality, food chain, pattern of energy utilization *etc.* will be of great help in formulating policies for stock manipulation. Any stocking program should take into consideration as far as possible the available food resources and their maximum utilization. In general these water bodies are very rich in organic detritus and the best way of using this resource is to strengthen the detritus chain. In fact the detritus feeders have shown maximum energy conversion efficiency. The wetland should, therefore, be stocked with fishes oriented to detritus like *C. mrigala*, *L. rohita* *L. calbasu*, *L. fimbriatus* and *C. carpio* (the last one however be stocked in closed wetlands), *C. catla* can also be stocked in proper combination, especially after clearance of aquatic weeds. Central Inland Fisheries Research Institute, Barrackpore, has successfully demonstrated in Kulia beel, West Bengal that fish production in terms of yield can be enhanced through stocking. It has been observed that the production of the beel increased from 320 kg h^{-1} to 1077 kg h^{-1} by cleaning of aquatic weeds and stocking with *L. rohita* and *C. mrigala* fingerlings @ 8000 h^{-1}. For better survival and growth the size of the stocking material should be bigger with an average weight of 16 g each and 3 to 6" in size. The technology developed by the institute may be extended in the wetlands of U.P. also. Molluscan population, forming more than 70% of the total biomass with few exceptions, dominates the benthic environment of wetlands in

U.P. It was found that this niche of the system was under exploited, to a larger extent causing substantial loss in total fish production. To utilize the vast population of molluscs some fishes like *Pangasius pangasius* may be introduced in selective wetlands. which feed upon molluscs extensively. The interaction should be watched carefully and if the results are positive further propagation should be advocated.

Culture based fisheries

One of the useful criteria for demarcating the capture and culture fisheries is the extent of human intervention in the management process. In capture fisheries the wild stock of fish is harvested with little intervention on either habitat variables or the biotic communities. On the other hand in culture fisheries the whole operation is based on captive stock with a high degree of effective human control over the water quality and other habitat variables. The main focus of management in culture-based fishery is stocking and recapture. The size of stocking, density, growth period and the size at capture are the important criteria in culture based fishery management.

Closed wetlands

Wetlands are the ideal water bodies for practicing culture based fisheries management, as they are very rich in nutrients and fish food organisms. which enable the stocked fishes to grow faster. They allow higher stocking density and better growth performance and there is no irrigation canals or spillways, which cause the stock to escape. In a culture-based fishery, the growth is dependent on stocking density and the survival is dependent on size of the stocked fish. Stocking of suitable species of proper size and density and their recapture at economic size are the determining factors. Therefore, the basic management strategies in closed wetlands should be centered on

- Eradication and control of predatory species;
- Selection of species depending on available food niche;
- Size of stocking material and species combination;
- Stocking density;
- Proper stocking and harvesting schedule allowing maximum growth period;
- Size at recapture and selection of proper fishing gears.

Capture fisheries of the open wetlands

Some of the wetlands retain their riverine connection for a reasonably longer period and are comparatively free from weed infestation. The basic approach in them is to allow recruitment by conserving and protecting the brooders and juveniles. These measures have advantage of both conserving the natural habitat as well as extending benefits for conserving the environment of the parent river. In capture fisheries management, the natural fish stock is managed and therefore, a thorough knowledge of population dynamics including recruitment, growth and mortality is very essential. In order to ensure recruitment the following measures are taken into consideration

- Identification and protection of breeding grounds;
- Allow free migration of brooders and juveniles from wetland to river and vice versa;
- Protection of brooders and juveniles by conservation measures, such as, observing closed season during breeding months, imposing restrictions on juvenile fishery and use of small mesh sized gears.

Adoption of capture and culture strategy

The ecological conditions of wetlands, their connection with rivers, vast extensions and proportionately large shallow water areas, all demand the adoption of a strategy to develop culture fisheries in shallow areas and capture fisheries in deeper areas. Any measure for exclusive development of only one of these fisheries may result in under utilization of the potential and also wasteful expenditure. Conversion of marginal areas into culture ponds and leaving the rest of the area for capture fisheries is most economical and feasible solution that can be thought of. The lake like (open) wetlands are extensive water spreads with irregular shorelines. From the margin towards the centre an extensive shallow area exist during summer. It is estimated that above 30% of these wetlands can be converted into culture ponds and the rest 70% can be utilized for capture fisheries. The strategy for the development of closed wetlands has also been on the same line as open wetlands but in most cases proportionately larger areas (even up to 60%) can be covered into ponds.

Pen culture

As a management measure, especially in the weed-chocked waters, culture of fishes and prawns in pen enclosures have drawn much attention in recent years. Pen culture offers scope for utilizing all available water resources, optimal utilization of fish food organisms for growth and complete harvest of the stock. In India pen culture has been successfully tested for raising carp fry and fingerlings in reservoirs and the culture of table size fish in wetlands. Pen preparation is based on food availability, depth of the water body, seed availability *etc*. The following aspects are to be taken into consideration before pen fabrication.

Site selection

Pen size and deign

Pen material

In exclusive carp culture, the suggested ratio of fish species is

Surface feeders	*Catla catla*	20-35%
	Silver carp	15%
Column feeders	*Labeo rohita*	20%
Bottom feeders	*Cirrhinus mrigala*	45%

It is generally preferred to stock larger size fingerlings for better survival (10 to 15 cm). The stocking rate of the pen is fixed on the carrying capacity of the pen, however, in carps monoculture the recommended density ranged between 4000 to 5000 no h^{-1}. while in mixed culture the density of carp and prawn could be 3000-4000 no h^{-1} and 1000 to 2000 no h^{-1}, respectively.

Other developmental priorities

The overall fisheries development of the wetlands requires both micro and macro planning. The major issues to be tackled under the development of sector approach are :

- Formation of cooperative societies
- Availability of finance
- Change in lease period
- Transfer of appropriate technology suiting local conditions
- Transport and marketing
- Employment generation
- Insurance scheme
- Socio-economic development

Conclusion

Studies in thirty wetlands spread over sixteen districts of Uttar Pradesh revealed that these water bodies are extremely rich in nutrients and have immense fish production potential. The energy resource of these wetlands both in the form of primary fixed energy and detritus are of very high order, on the contrary the actual energy harvest from them is comparatively much lower. The low values of conversion efficiencies clearly reflected that the available potential energy is not properly utilized in almost all the wetlands. In order to fill the gap between available potential energy and actual energy harvest in terms of fish, the various suggested management norms should be adopted for full utilization of this rich natural resource. This will not only enhance the fish production from these wetlands but also narrow the gap between demand and supply of fish in the state and ultimately improve the socio economic status of fishers dependent on these water bodies for their livelihood.

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Executive summary

- Ecological studies, fish production potential and energy dynamics were studied in thirty wetlands of Uttar Pradesh, spread over in sixteen districts of the state.
- Sediment from all the wetlands were rich in organic carbon (0.87 to 3.68%), available nitrogen (298 to 635 ppm) and phosphorous (17 to 174 ppm). Except Devasi deval (pH - 6.5) sediment was neutral to alkaline in reaction (pH – 7.0 to 8.2)
- Considerable variations were observed in respect of water quality parameters alkalinity, dissolved solids, hardness and conductance, *etc.*, all being minimum in Devasi deval (56, 60, 57 mgl^{-1} and 121 μmhos, respectively) and maximum in Bhadayal (285, 353, 218 mgl^{-1} and 706 μmhos, respectively).
- Water was rich in dissolved organic matter (1.6 to 4.3 mgl^{-1}) but poor in nutrients (nitrate – 0.023 to 0.432 mgl^{-1} and phosphate – 0.012 to 0.378 mgl^{-1}) with few exceptions.
- All the wetlands showed high degree of diel variations in chemical parameters.
- The biotic setup of the wetlands showed considerable variations in respect of quality and quantity. While 14 wetlands showed dominance of Chlorophyceae (35.6 to 72.9%), in others Bacillariophyceae showed superiority (35.3 to 57.3%). The group Myxophyceae was dominant only in Reawati and Rainital due to *Microcystis* bloom. Rotifers were most dominant component of zooplankton (35.1 to 88.6%) followed by cladocerans and copepods. In respect of benthic organisms, wetlands were quite rich (176 to 1617 n m^{-2}) and in general showed dominance of molluscs (34.8 to 100%). Periphyton was also rich in all the wetlands ranging between 1163 to 7101 u cm^{-2}.
- The rate of energy transformation by producers was high in all the wetlands (26,170 to 63,879 cal m^{-2} d^{-1}) with efficiency 1.44 to 3.37%. The contribution of phytoplankton in the total being only 5.8 to 38.8% and the rest by macrophytes (61.2 to 94.2%).
- All the wetlands were very rich in detritus energy (10.16×10^5 to 28.0×10^5 K cal ha^{-1}) and this resource must be properly utilized for enhancement in fish production.

- The fish production potential was very high in the wetlands ranging from 637.5 to 1326.5 kg ha^{-1}, but against this potential the actual fish production was comparatively much lower (43.0 to 357.0 kg ha^{-1}) and there is a big gap between potential and actual production.
- The energy harvest from studied wetlands varied from 51,600 to 428,400 K cal ha^{-1} y^{-1}, contributed mainly by miscellaneous group (29,577 to 148,746 K cal ha^{-1} y^{-1}). The contribution of detritus feeders ranged from 4,861 to 128,000 K cal ha^{-1} y^{-1}. In some wetlands the contribution of primary consumers was quite high (28.0 to 36.35) and resulted in better harvest.
- Studies have clearly reflected that the available energy is not properly utilized and the energy harvest from them was of very low order with few exceptions. In some wetlands where the contribution of detritus feeders was more, the energy harvest was comparatively better.
- The conversion efficiency from primary energy to fish in wetlands ranged from 0.044 to 0.268% and that from detritus to fish, 4.6 to 17.2%. Although wetlands have very high potential but only 6.5 to 33.4% of the potential is actually harvested from them. Except some wetlands, which have dominance of detritivores, the conversion efficiencies were very poor in general.
- In order to bridge the gap between the vast potential energy resource and the actual harvest, several management norms have been suggested. As most of the wetlands are heavily infested with weeds, the weed eradication and their utilization programmes should be given top priority. Other important measures are stocking with proper species of suitable size and density. The main focus should be on detritus feeders in order to utilize the vast detritus energy pool at the bottom. Adoption of culture and capture strategies and pen culture should also be given proper attention. Further, the fishermen should be educated to follow the proper harvesting practices and not to use the destructive gears.

Table 1. Morphometric features of wetlands

District	Wetland	Area (ha)	River basin
Ballia	Rewati	150	Ghagra
Ballia	Rewati	150	Ghagra
	Mundiari	250	Ghagra
Jaunpur	Rohuatal	47	Gomti
	Gujartal	88	Gomti
RaeBareilly	Narainital	45	Ganga
	Samaspur	800	Ganga
Pratapgarh	Lohsartal	80	Ganga
	Rainital	40	Ganga
Basti	Chandutal	230	Ghagra
	Sikandarpur	200	Ghagra
Sidharthnagar	Bansidah	49	Rapti
	Bhagnaiya	60	Rapti
Azamgarh	Salontal	200	Tons
	Gambhirban	43	Tons
Mau	Ratoital	800	Ghagra
	Devasi deval	140	Ghagra
Allahabad	Dahital	54	Yamuna
	Alwar jheel	250	Yamuna
Unnao	Mohane	48	Ganga
	Gagnikhera	80	Ganga
Hardoi	Bhadayal	200	Ganga
Bareilly	Dabri jheel	140	Ramganaga
Barabanki	Sangara	250	Ghagra
	Bhaghar jheel	80	Ghagra
Sitapur	Ratanpur	900	Ghagra
	Sonari	63	Ghagra
Farrukhabad	Kuthala	410	Ganga
	Bahausi	250	Ganga
Mainpuri	Aheerwan	110	Ganga
	Saman jheel	200	Ganga

Table 2. Sediment quality of wetlands

Wetland	Sand	Silt	Clay	pH	Cond.	Free $CaCO_3$	Organic carbon	Available nitrogen	Available phosphorous
	%	%	%		µmhos	%	%	ppm	ppm
Rewati	73.8	19.5	6.7	8.1	507	12.4	1.03	362	28
Mundiari	85.0	9.5	5.5	8.2	359	11.7	1.31	[redacted]	[redacted]
Rohua tal	72.0	18.5	9.5	7.7	306	3.2	2.03	327	20
Gujartal	71.8	20.2	8.0	7.5	388	2.2	1.88	427	36
Narainital	79.2	16.3	6.5	7.8	536	6.6	1.38	443	30
Samaspur	76.0	19.8	6.2	7.7	478	3.9	1.04	521	43
Lohsartal	75.2	20.8	4.0	7.8	464	4.3	1.79	470	38
Rainital	79.3	15.2	5.5	7.6	396	2.1	1.64	476	32
Chandutal	91.0	4.3	4.7	7.6	360	3.7	2.96	308	17
Sikandarpur	95.5	1.8	2.7	7.1	212	3.8	3.68	567	37
Bansidah	93.7	4.3	2.0	7.4	404	2.8	1.00	315	22
Bhagnaiya	96.7	1.3	2.0	7.4	308	1.2	1.76	523	34
Gambhirban	87.5	9.3	3.2	7.7	300	4.7	1.67	565	44
Salontal	88.2	9.0	2.8	7.6	418	5.3	1.61	494	36
Devasi deval	75.8	16.2	8.0	6.5	98	1.1	1.24	396	23
Ratoital	81.2	11.6	7.2	7.3	972	14.3	2.67	435	30
Alwar jheel	64.5	21.0	14.5	7.2	555	5.4	1.69	536	113
Dahital	87.0	9.0	4.0	7.3	289	5.8	1.09	488	102
Gagnikhera	70.5	21.7	7.8	7.4	325	4.5	0.87	298	50
Mohane	85.8	10.7	3.5	7.1	416	3.1	1.79	424	97
Bhadayal	79.8	15.7	4.5	7.3	788	3.3	1.11	618	174
Dabri jheel	85.0	12.0	3.0	7.4	455	2.0	1.54	548	78
Bhaghar jheel	89.5	5.7	4.8	7.6	136	3.5	2.91	510	63
Sangara	68.0	21.3	10.7	7.0	244	3.5	2.57	395	18
Ratanpur	87.8	9.2	3.0	7.0	212	3.2	1.20	466	32
Sonari	70.0	19.3	10.7	7.4	328	3.9	3.91	403	29
Kuthala	64.2	25.5	10.3	8.1	578	5.0	1.87	444	39
Bahausi	76.0	16.5	7.5	7.2	262	3.7	1.72	507	62
Aheerwan	66.5	18.3	15.2	8.1	478	4.4	1.25	565	69
Saman jheel	68.5	13.2	18.3	8.0	518	5.4	1.92	635	103

Table 3. Important hydrological features of wetlands

Wetland	Temp.	DO	pH	Free CO_2	Total alkalinity	Cond.	TDS	Total hardness	DOM	NO_3	PO_4
	°c	mgl^{-1}		mgl^{-1}	mgl^{-1}	μmhos	mgl^{-1}	mgl^{-1}	mgl^{-1}	mgl^{-1}	mgl^{-1}
Rewati	25.5	9.1	8.3	0.0	105	199	99	88	3.8	0.039	0.014
Mundiari	25.6	8.9	8.2	0.0	166	254	127	121	1.6	0.027	0.012
Rohuatal	24.7	6.4	7.8	1.5	139	211	105	96	4.3	0.235	0.213
Gujartal	24.7	6.1	7.6	3.2	140	224	112	103	1.8	0.023	0.012
Narainital	23.9	4.8	7.9	4.0	284	504	252	208	4.1	0.112	0.079
Samaspur	25.3	6.6	8.1	2.7	232	412	206	127	2.6	0.122	0.096
Lohsartal	24.1	4.2	7.8	3.6	269	454	227	153	3.3	0.058	0.034
Rainital	24.8	7.0	8.3	0.0	232	366	183	132	4.0	0.139	0.085
Chandu tal	24.7	4.6	8.0	2.8	130	266	132	119	2.4	0.085	0.060
Sikandarpur	26.2	4.6	7.5	6.3	100	224	112	104	1.8	0.090	0.050
Bansidah	26.0	5.9	8.0	6.0	87	199	100	89	1.8	0.160	0.080
Bhagnaiya	26.4	6.1	7.9	5.2	81	182	91	68	2.0	0.065	0.040
Gambhirban	24.2	5.3	8.3	0.0	158	357	179	123	2.9	0.125	0.100
Salontal	25.2	5.1	8.0	2.7	146	316	158	109	2.6	0.080	0.050
Devasi deval	25.4	2.6	6.8	19.5	56	121	60	57	1.9	0.135	0.095
Ratoital	25.6	6.2	8.4	0.0	196	480	240	145	3.7	0.135	0.095
Alwar jheel	24.7	7.0	8.2	0.7	240	552	276	158	3.2	0.250	0.136
Dahital	24.8	4.7	7.6	9.7	103	234	117	98	2.1	0.242	0.123
Gagnikhera	25.5	6.6	8.2	0.7	129	270	135	107	1.7	0.080	0.030
Mohane	25.7	3.9	7.7	17.8	192	351	185	141	4.1	0.142	0.290
Bhadayal	23.7	3.9	7.4	21.6	285	706	353	218	4.2	0.264	0.128
Dabri	23.7	9.7	8.4	0.0	194	457	228	154	2.4	0.432	0.378
Bhaghar jheel	27.0	6.0	7.1	15.0	216	438	219	144	3.6	0.178	0.114
Sangara	25.0	4.9	7.0	16.3	62	131	65	72	2.5	0.276	0.190
Ratanpur	27.0	6.8	7.0	14.6	60	128	64	61	2.0	0.340	0.360
Sonari	27.0	5.3	7.4	15.0	105	213	106	97	1.9	0.327	0.240
Kuthala	26.3	7.7	7.9	10.3	139	384	161	121	3.1	0.306	0.150
Bahausi	27.3	6.5	8.1	6.7	85	226	113	94	2.6	0.350	0.199
Aheerwan	27.0	5.1	7.7	8.3	134	349	176	150	2.3	0.285	0.255
Saman jheel	28.3	6.0	7.6	15.3	217	417	208	152	2.9	0.214	0.198

Table 4. Quantitative and qualitative composition of phytoplanton

Wetland	Abundance (ul^{-1})	Contribution (%) in total				
		Chlorophyceae	Myxophyceae	Bacillariophyceae	Desmids	[illegible]
Rewati	17734	5.5	94.5	0.0	0.0	0.0
Mundiari	129	40.1	0.0	59.9	0.0	0.0
Rohua tal	245	41.0	51.4	7.6	0.0	0.0
Gujartal	107	33.9	20.1	46.0	0.0	0.0
Narainital	105	18.4	70.2	11.4	0.0	0.0
Samaspur	129	13.5	26.4	57.3	2.7	0.0
Lohsar	197	56.5	24.8	17.9	0.9	0.0
Rainital	8545	17.7	61.6	20.1	0.2	0.4
Chandu tal	361	30.7	43.8	21.3	4.2	0.0
Sikandarpur	69	40.7	16.4	22.5	20.5	0.0
Bansidah	182	47.5	15.2	22.1	15.2	0.0
Bhagnaiya	293	72.9	13.6	9.3	4.1	0.0
Gambhirban	183	48.8	27.5	2.6	21.0	0.0
Salontal	325	34.2	14.6	35.3	15.9	0.0
Devasi deval	71	53.3	14.4	16.2	16.2	0.0
Ratoital	530	38.1	22.4	26.9	12.6	0.0
Alwar jheel	107	34.7	14.1	43.5	7.6	0.0
Dahital	115	61.3	12.8	26.0	0.0	0.0
Gagnikhera	94	19.1	8.5	40.6	31.7	0.0
Mohane	93	20.9	63.7	9.4	5.9	0.0
Bhadayal	89	29.5	18.9	40.9	10.7	0.0
Dabri	121	42.4	0.0	51.0	6.6	0.0
Bhaghar jheel	309	45.7	0.0	30.1	24.1	0.0
Sangara	138	38.1	6.5	34.5	20.8	0.0
Ratanpur	160	41.5	0.0	22.2	36.3	0.0
Sonari	93	33.4	5.3	42.9	18.4	0.0
Kuthala	947	35.6	35.2	22.8	6.4	0.0
Bahausi	266	48.4	47.6	4.0	0.0	0.0
Aheerwan	59	48.8	11.3	19.6	20.3	0.0
Saman jheel	126	28.8	36.5	12.4	22.3	0.0

Table 5. Quantitative and qualitative abundance of zoo plankton

Wetland	Abundance (ul⁻¹)	Contribution (%) in total					
		Rotifera	Protozoa	Cladocera	Copepoda	Ostracoda	Free living
Rewati	1607	62.7	0.0	0.0	37.3	0.0	0.0
Mundiari	11	38.4	0.0	0.0	61.6	0.0	0.0
Rohua tal	392	5.1	0.0	27.4	67.5	0.0	0.0
Gujartal	91	15.2	0.0	40.4	44.5	0.0	0.0
Narainital	111	21.1	0.0	7.3	71.6	0.0	0.0
Samaspur	62	18.7	0.0	24.0	55.1	2.2	0.0
Lohsar	214	35.0	0.0	30.4	31.3	3.4	0.0
Rainital	1336	18.8	5.0	23.7	52.5	0.0	0.0
Chandu tal	529	26.8	8.4	51.3	6.6	6.8	0.0
Sikandarpur	94	28.9	11.2	54.7	1.8	3.4	0.0
Bansidah	690	22.5	14.8	59.9	1.4	1.4	0.0
Bhagnaiya	497	10.2	13.0	59.6	15.3	1.9	0.0
Gambhirban	655	32.5	12.8	50.5	3.6	0.6	0.0
Salontal	767	28.1	9.5	5[illegible]8	0.3	3.3	0.0
Devasi deval	669	16.1	9.8	70.1	1.8	2.2	0.0
Ratoital	446	17.3	6.8	64.9	9.6	1.4	0.0
Alwar jheel	168	88.6	5.8	2.5	1.5	1.6	0.0
Dahital	144	54.1	19.0	10.1	16.8	0.0	0.0
Gagnikhera	249	66.0	30.0	4.0	0.0	0.0	0.0
Mohane	235	69.4	20.7	9.9	0.0	0.0	0.0
Bhadayal	191	76.8	16.9	1.1	5.2	0.0	0.0
Dabri	102	77.3	13.0	0.0	9.7	0.0	0.0
Bhaghar jheel	191	61.5	22.0	16.4	0.0	0.0	0.0
Sangara	142	35.1	43.7	9.4	6.9	0.0	4.9
Ratanpur	155	69.0	14.9	9.4	6.7	0.0	0.0
Sonari	127	65.1	17.0	15.9	0.0	0.0	1.9
Kuthala	486	32.6	16.0	35.3	11.2	0.0	4.9
Bahausi	94	47.2	21.4	5.6	25.8	0.0	0.0
Aheerwan	148	41.8	24.1	13.3	20.8	0.0	0.0
Saman jheel	104	60.4	12.5	27.1	0.0	0.0	0.0

Table 6. Quantitative and qualitative abundance of benthic communities

Wetland	Abundance (n m^2)	Contribution (%) in total				
		Gastropoda	Bivalves	[redacted]	[redacted]	Crustacea
Rewati	1617	100.0	0.0	0.0	0.0	0.0
Mundiari	1276	94.6	0.0	2.7	2.7	0.0
Rohua tal	176	80.0	7.5	12.5	0.0	0.0
Gujartal	594	91.3	8.7	0.0	0.0	0.0
Narainital	814	98.0	2.0	0.0	0.0	0.0
Samaspur	176	76.4	23.6	0.0	0.0	0.0
Lohsar	275	90.0	4.1	0.0	5.9	0.0
Rainital	308	76.2	0.0	4.8	19.0	0.0
Chandu tal	352	85.0	15.0	0.0	0.0	0.0
Sikanderpur	330	70.0	3.4	0.0	26.6	0.0
Bansidah	275	30.5	4.0	3.4	48.3	13.8
Bhagnaiya	572	52.5	10.0	0.0	25.0	12.5
Gambhirban	374	80.0	2.4	0.0	7.6	10.0
Salontal	418	60.0	5.8	0.0	34.2	0.0
Devasi deval	330	83.0	10.3	0.0	6.7	0.0
Ratoital	660	62.6	10.0	0.0	22.6	4.8
Alwar jheel	451	78.2	17.0	0.0	4.8	0.0
Dahital	365	86.0	14.0	0.0	0.0	0.0
Gagnikhera	1027	80.0	11.5	3.2	5.3	0.0
Mohane	344	79.0	21.0	0.0	0.0	0.0
Bhadayal	387	68.0	20.8	5.6	5.6	0.0
Dabri	831	77.4	14.4	4.1	4.1	0.0
Bhaghar jheel	572	38.5	3.8	7.7	50.0	0.0
Sangara	550	32.2	8.1	10.1	49.5	0.0
Ratanpur	396	48.2	4.8	8.6	38.4	0.0
Sonari	454	32.9	15.8	10.8	40.5	0.0
Kuthala	426	48.3	5.6	27.6	18.5	0.0
Bahausi	880	32.8	7.2	20.0	40.0	0.0
Aheerwan	748	37.3	4.6	17.8	40.3	0.0
Saman jheel	953	23.9	10.4	29.2	36.5	0.0

Table 7. Quantitative and qualitative abundance of periphytic communities

Wetland	[redacted] (u cm^{-2})	[redacted] on (%) in total					
		[redacted]	[redacted]	[redacted]	Protozoa	Rotifers	Crustacea
Rewati	1349	60.9	16.3	22.5	0.0	0.3	0.0
Mundiari	1549	8.1	6.5	85.1	0.0	0.3	0.0
Rohua tal	1163	25.5	47.7	25.5	0.0	1.3	0.0
Gujartal	3118	11.1	29.0	59.3	0.0	0.2	0.4
Narainital	[redacted]	[redacted]	[redacted]	[redacted]	0.0	0.0	0.8
Samaspur	5369	7.5	7.4	84.6	0.2	0.4	0.0
Lohsar	1681	11.6	21.4	66.5	0.0	0.5	0.1
Rainital	4816	44.1	11.4	44.3	0.0	0.2	0.0
Chandu tal	3373	18.9	37.7	35.4	4.5	1.8	1.6
Sikandarpur	3816	6.7	53.8	34.4	0.5	2.2	2.4
Bansidah	3299	9.1	35.3	52.5	0.8	1.6	0.6
Bhagnaiya	3451	15.7	45.7	36.2	0.9	1.0	0.5
Gambhirban	4911	13.3	34.8	49.3	0.7	1.5	0.4
Salontal	3114	15.8	20.6	60.9	0.6	2.0	0.0
Devasi deval	2714	8.3	26.2	59.8	1.0	1.4	3.4
Ratoital	3533	13.9	38.6	40.8	2.7	2.7	1.4
Alwar jheel	3890	11.0	64.7	18.1	1.6	2.2	2.4
Dahital	7101	27.3	37.4	33.9	0.6	0.5	0.3
Gagnikhera	3358	14.2	62.3	22.1	1.3	0.1	0.0
Mohane	4592	25.5	29.4	42.8	1.2	0.9	0.2
Bhadayal	5021	12.3	51.0	33.5	1.7	1.5	0.0
Dabri	2577	10.3	42.4	43.8	1.4	2.2	0.0
Bhaghar jheel	2560	11.2	16.2	71.6	0.4	0.6	0.0
Sangara	2036	10.8	20.4	67.8	0.4	0.2	0.4
Ratanpur	1960	12.4	19.8	66.2	0.8	0.4	0.4
Sonari	2462	32.4	20.6	46.0	0.0	1.0	0.0
Kuthala	2253	18.6	19.2	61.2	0.4	0.0	0.6
Bahausi	2940	21.0	18.6	60.2	0.0	0.0	0.2
Aheerwan	2670	32.4	20.8	46.2	0.3	0.3	0.0
Saman jheel	2966	30.8	19.8	48.4	0.6	0.0	0.4

Table 8. Quantitative infestation of macrophytes

Wetland	Extent of infestation (%)	Biomass wet wt. (kg m⁻²)	Dominant species
Rewati	60-90	8.9	H,C,S,P,EC
Mundiari	50-80	5.7	H,C,N,EC,P,NAJ
Rohua tal	40-80	7.3	C,N,EC,P,S
Gujartal	40-70	6.9	C,H,EC
Narainital	40-90	9.3	V,H,EC,IP,P,C,S
Samaspur	30-80	9.0	V,H,S,EC,P
Lohsar	40-70	4.1	EC,H,C,NAJ,P
Rainital	30-70	7.9	EC,C,H,P
Chandu tal	40-80	5.8	NAJ,H,CH,V,C,EC,N
Sikandarpur	30-70	4.3	H,CH,NAJ,L,EC
Bansidah	40-80	6.4	CH,P,L,V,T,NAJ,H,EC
Bhagnaiya	50-80	3.3	V,H,CH,NAJ
Gambhirban	40-80	5.6	NAJ,H,S,EC,L
Salontal	50-80	4.6	NAJ,H,C,H,IP,P,EC
Devasi deval	50-70	2.3	NAJ,H,CH,L,C,N,EC
Ratoital	70-80	4.2	H,P,CH,L,C
Alwar jheel	60-80	5.9	N,NAJ,V,EC,H,T,P
Dahital	25-60	2.8	C,NAJ,V,EC,H,N
Gagnikhera	40-70	8.0	H,P,EC,T,CH
Mohane	30-60	4.6	P,EC,T,NAJ,H
Bhadayal	60-80	6.8	EC,T,NAJ,V,H
Dabri	35-65	4.9	EC,NAJ,V,H
Bhaghar jheel	30-50	1.8	EC,C,H,P
Sangara	25-50	1.8	C,H,P,EC
Ratanpur	40-60	5.0	H,C,EC,P
Sonari	30-60	4.0	V,H,EC,CH,P
Kuthala	50-80	6.8	EC,P,IP,H
Bahausi	40-70	5.6	EC,H,P,CH
Aheerwan	25-40	1.3	P,C,H,EC
Saman jheel	35-55	3.0	EC,P,C,H

H - Hydrilla, C - Cerratophylum, S - Sagittaria, P - Potomegeton, EC - Eichornia, N - Nymphaea

NAJ - Najas, IP - Ipomea, L - Limnothelum, CH - Chara, T - Typha, V - Vallicnaria

Table 9. Energy transformation through primary production in wetlands

Wetland	Solar energy entering the system	Gross energy fixed by producers	Efficiency of transformation	Phytoplankton contribution	Macrophytes contribution	Energy assimilated by producers
	$Cal\ m^{-2}d^{-1}$	$Cal\ m^{-2}d^{-1}$	%	$Cal\ m^{-2}d^{-1}$	$Cal\ m^{-2}d^{-1}$	% of gross as net
Rewati	1,912,000	55,974	2.93	19,927	36,047	66.2
Mundiari	1,912,000	36,885	1.93	6,886	29,999	59.2
Rohua tal	1,892,000	34,941	1.85	11,899	23,042	56.2
Gujartal	1,892,000	32,938	1.74	8,498	24,440	60.0
Narainital	1,858,000	37,070	2.00	11,751	25,319	62.9
Samaspur	1,858,000	31,588	1.70	12,133	19,455	59.0
Lohsar	1,872,000	29,909	1.60	7,552	22,357	64.0
Rainital	1,872,000	30,687	1.64	11,907	18,780	60.0
Chandu tal	1,812,000	44,434	2.45	6,601	37,833	62.7
Sikandarpur	1,812,000	26,170	1.44	4,789	21,381	71.8
Bansidah	1,804,000	33,465	1.85	3,898	29,567	65.5
Bhagnaiya	1,804,000	42,471	2.35	6,965	35,506	68.7
Gambhirban	1,838,000	32,884	1.79	8,041	24,843	75.4
Salontal	1,838,000	27,636	1.50	9,728	17,908	69.3
Devasi deval	1,894,000	28,282	1.49	9,956	18,326	78.3
Ratoital	1,894,000	63,879	3.37	3,705	60,174	70.4
Alwar jheel	1,945,000	32,907	1.69	7,168	25,739	69.5
Dahital	1,945,000	33,476	1.72	11,382	22,094	67.9
Gagnikhera	1,842,000	27,187	1.47	8,592	18,595	71.2
Mohane	1,842,000	35,813	1.94	9,741	27,863	66.8
Bhadayal	1,792,000	31,007	1.73	6,667	24,340	74.4
Dabri	1,788,000	43,813	2.45	14,371	29,442	70.5
Bhaghar jheel	1,862,000	51,555	2.77	4,862	46,709	73.3
Sangara	1,862,000	36,702	1.97	5,285	31,417	72.9
Ratanpur	1,850,000	29,300	1.58	4,278	25,022	69.3
Sonari	1,850,000	33,005	1.78	6,040	26,965	77.1
Kuthala	1,868,000	51,442	2.75	7,871	43,520	70.7
Bahausi	1,850,000	57,815	3.12	12,113	45,701	66.2
Aheerwan	1,878,000	31,483	1.68	3,558	27,925	67.8
Saman jheel	1,878,000	36,437	1.94	9,838	26,599	71.2

Table 10. Actual fish production and contribution of different groups

Wetland	Actual fish production (kg ha^{-1})	Major and minor carps (%)	Catfish (%)	Miscellaneous species (%)
Rewati	112.7	18.6	24.0	57.4
Mundiari	49.4	14.6	28.2	57.2
Rohua tal	82.0	23.6	40.0	36.4
Gujartal	102.8	24.0	51.3	24.7
Narainital	58.3	19.0	35.0	46.0
Samaspur	No fishing			
Lohsar	62.0	20.7	38.4	40.9
Rainital	43.0	16.5	26.2	57.3
Chandu tal	150.0	27.2	32.6	40.2
Sikandarpur	175.0	37.6	28.5	33.9
Bansidah	179.0	31.2	26.4	42.4
Bhagnaiya	211.0	41.2	26.3	32.5
Gambhirban	160.0	32.5	30.2	27.3
Salontal	245.0	42.9	25.2	31.9
Devasi deval	158.3	32.2	29.8	38.0
Ratoital	142.0	24.4	28.5	47.1
Alwar jheel	142.0	25.2	28.2	46.4
Dahital	166.7	29.0	24.2	46.8
Gagnikhera	198.0	32.8	30.0	37.2
Mohane	220.0	38.9	26.2	34.9
Bhadayal	52.5	14.4	26.4	59.2
Dabri	357.0	43.5	21.8	34.7
Bhaghar jheel	190.0	32.6	29.4	38.0
Sangara	185.3	31.9	24.8	43.3
Ratanpur	126.8	22.3	39.5	38.2
Sonari	213.3	38.7	18.8	42.5
Kuthala	211.4	38.4	26.4	35.2
Bahausi	218.0	36.2	32.8	31.0
Aheerwan	166.4	33.6	28.0	38.4
Saman jheel	98.4	16.8	24.0	59.3
Average	**160.4**	**33.8**	**27.1**	**39.1**

Table 11. Energy harvest (K cal $ha^{-1}yr^{-1}$) and contribution of various groups of fishes in wetlands

Wetland	Energy harvest	Contribution (%) in total				
		Primary consumers		Secondary consumer	Tertiary consumer	Miscellaneous
		Herbivores	Detritus feedrs			
Rewati	135,240	4,328	17,312	3,516	32,459	77,626
Mundiari	59,280	1,660	4,861	2,134	16,717	33,908
Rohuatal	98,400	5,117	13,579	4,526	39,360	35,818
Gujartal	123,400	3,455	22,212	3,949	63,304	30,480
Narainital	70,000	2,960	8,260	2,100	25,060	31,640
Samaspur	No fishing					
Lohsar	74,400	3,422	8,854	3,125	28,570	30,430
Rainital	51,600	1,961	4,483	2,060	13,519	29,577
Chandu tal	180,000	6,840	32,760	9,360	58,680	72,360
Sikandarpur	210,000	10,920	55,000	13,020	59,850	71,210
Bansidah	214,800	9,022	51,122	6,874	56,707	91,075
Bhagnaiya	253,200	12,660	74,000	17,724	66,592	82,824
Gambhirban	192,000	11,328	41,856	9,216	57,984	52,416
Salontal	294,000	19,992	82,000	24,108	74,000	97,870
Devasi deval	190,000	9,120	41,800	10,260	56,620	72,200
Ratoital	170,400	6,475	28,000	7,157	61,855	86,913
Alwar jheel	170,400	6,475	29,650	6,816	48,053	79,066
Dahital	200,000	8,400	42,000	7,615	48,497	93,488
Gagnikhera	237,600	10,454	58,925	8,554	71,280	88,387
Mohane	264,000	12,672	79,000	11,088	69,168	92,072
Bhadayal	63,000	2,394	4,682	2,016	16,632	37,276
Dabri	428,400	27,418	128,000	30,845	93,391	148,746
Bhaghar jheel	228,000	8,208	55,176	10,944	67,032	86,640
Sangara	222,360	8,450	55,025	7,564	55,145	96,176
Ratanpur	152,160	4,260	24,345	5,478	60,170	57,907
Sonari	255,960	13,310	68,363	17,405	48,120	108,762
Kuthala	253,650	20,799	65,930	9,639	66,964	90,318
Bahausi	261,600	15,173	68,539	10,987	85,805	81,096
Aheerwan	199,680	12,380	43,930	10,783	55,910	76,677
Saman jheel	118,080	4,487	12,044	3,306	28,339	69,904
Average	**192,506**	**9,851**	**45,254**	**9,965**	**52,165**	**75,271**

Table 12. Utilization of potential energy resource and conversion efficiency

Wetland	Energy available as detritus (K cal ha⁻¹)	Potential energy resource (K cal ha⁻¹ y⁻¹)	Energy harvest as fish from the system (K cal ha⁻¹ y⁻¹)	Conversion efficiency (%)		
				Primary [illegible] to fish harvest	Potential to actual harvest	Detritus energy to fish
Rewati	2,000,000	1,540,200	135,240	0.066	8.8	6.8
Mundiari	1,280,000	908,040	59,280	0.044	6.5	4.6
Rohuatal	1,082,000	816,000	98,400	0.077	12.0	9.1
Gujartal	1,080,000	1,120,920	123,400	0.103	11.0	11.4
Narainital	1,422,000	969,000	70,000	0.052	7.2	4.9
Samaspur	1,426,000	No fishing				
Lohsar	1,584,000	795,600	74,400	0.068	9.4	4.7
Rainital	1,220,000	765,000	51,600	0.046	6.7	4.2
Chandu tal	1,428,000	1,158,000	180,000	0.110	15.5	12.6
Sikandarpur	2,010,000	981,200	210,000	0.199	21.4	10.4
Bansidah	1,284,000	912,000	214,800	0.170	23.5	16.7
Bhagnaiya	1,828,000	1,214,400	253,200	0.163	20.8	13.9
Gambhirban	1,648,000	1,029,600	192,000	0.160	18.6	11.7
Salontal	2,384,000	995,600	294,000	0.243	29.5	12.3
Devasi deval	1,189,000	920,400	190,000	0.180	20.6	16.0
Ratoital	2,600,000	1,468,400	170,400	0.073	11.6	6.6
Alwar jheel	1,724,000	950,400	170,400	0.140	17.9	9.9
Dahital	1,986,000	945,600	200,000	0.164	21.1	10.1
Gagnikhera	1,382,000	803,040	237,600	0.230	29.6	17.2
Mohane	2,428,000	994,440	264,000	0.202	26.5	10.9
Bhadayal	1,016,000	958,800	63,000	0.056	6.6	6.2
Dabri	2,800,000	1,283,040	428,400	0.268	33.4	15.3
Bhaghar jheel	1,508,000	1,570,800	228,000	0.120	14.6	15.1
Sangara	1,611,304	1,011,800	222,360	0.166	22.0	13.8
Ratanpur	1,491,176	844,560	152,160	0.142	18.0	10.2
Sonari	1,589,814	1,057,800	255,960	0.212	24.1	16.1
Kuthala	2,588,265	1,509,960	253,650	0.135	16.8	9.8
Bahausi	2,018,000	1,591,800	261,600	0.124	16.4	13.0
Aheerwan	1,350,000	987,400	199,680	0.150	20.2	14.8
Saman jheel	1,640,000	1,077,960	118,080	0.089	10.9	7.2
Average	**1,686,585**	**1,095,948**	**192,506**	**0.136**	**17.6**	**10.9**

Fig 1. Diel cycle of chemical parameters in two wetlands reflecting extreme magnitudes

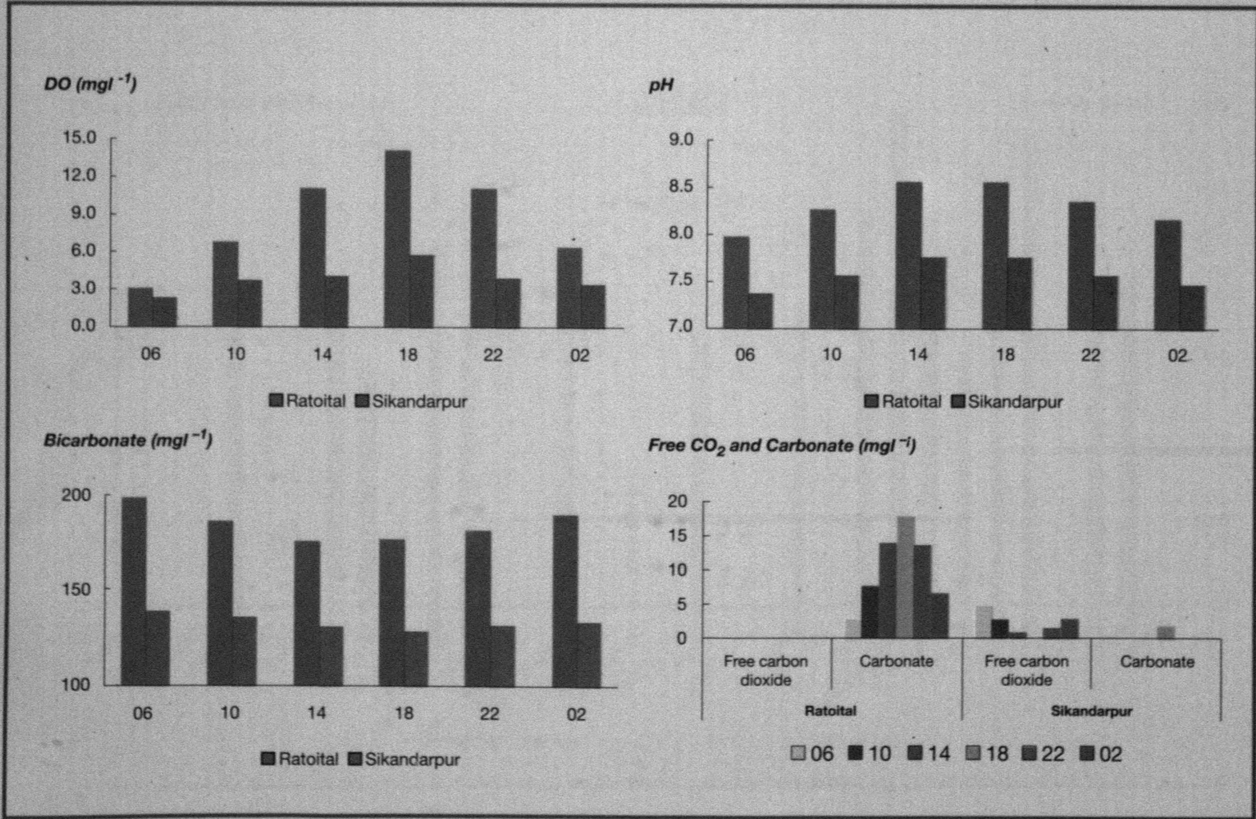


Fig3. Potential energy resource (K cal ha^{-1} y^{-1}) in wetlands of Uttar Pradesh

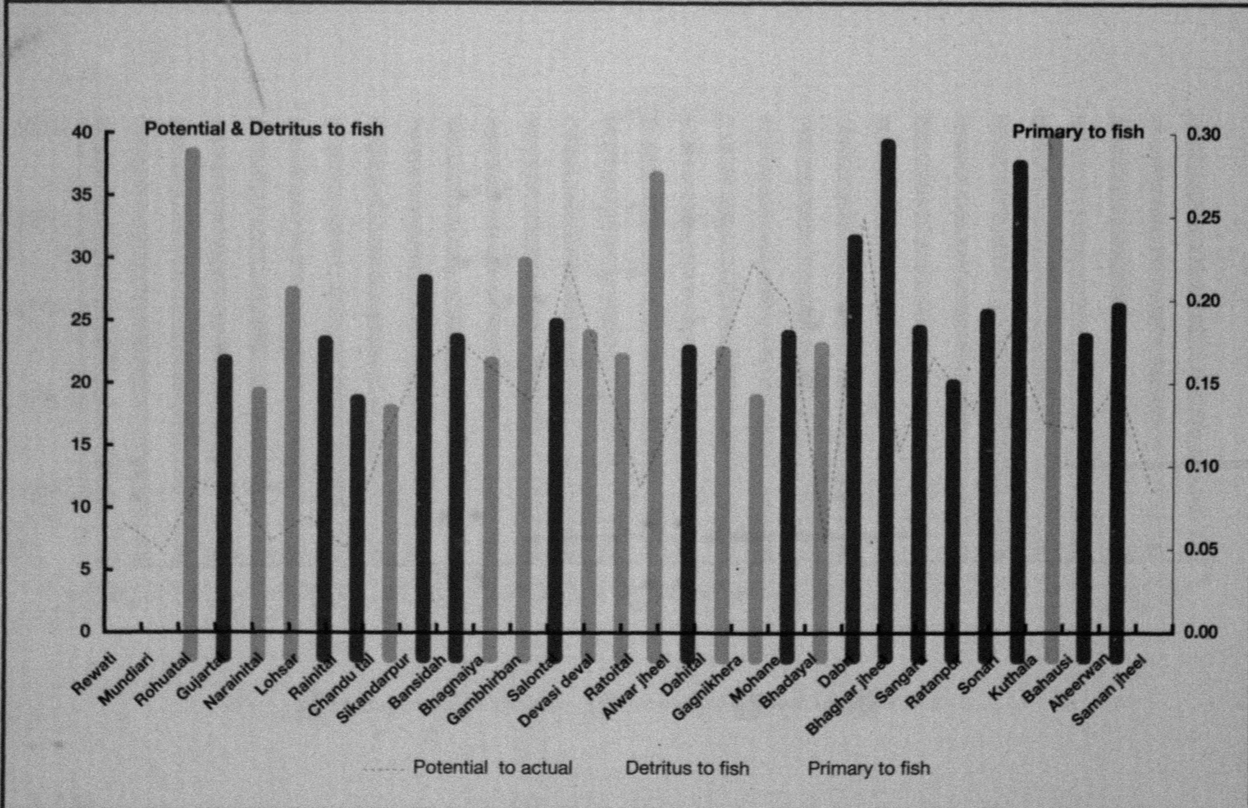


Fig 5. Utilization of potential energy resource in wetlands of Uttar Pradesh

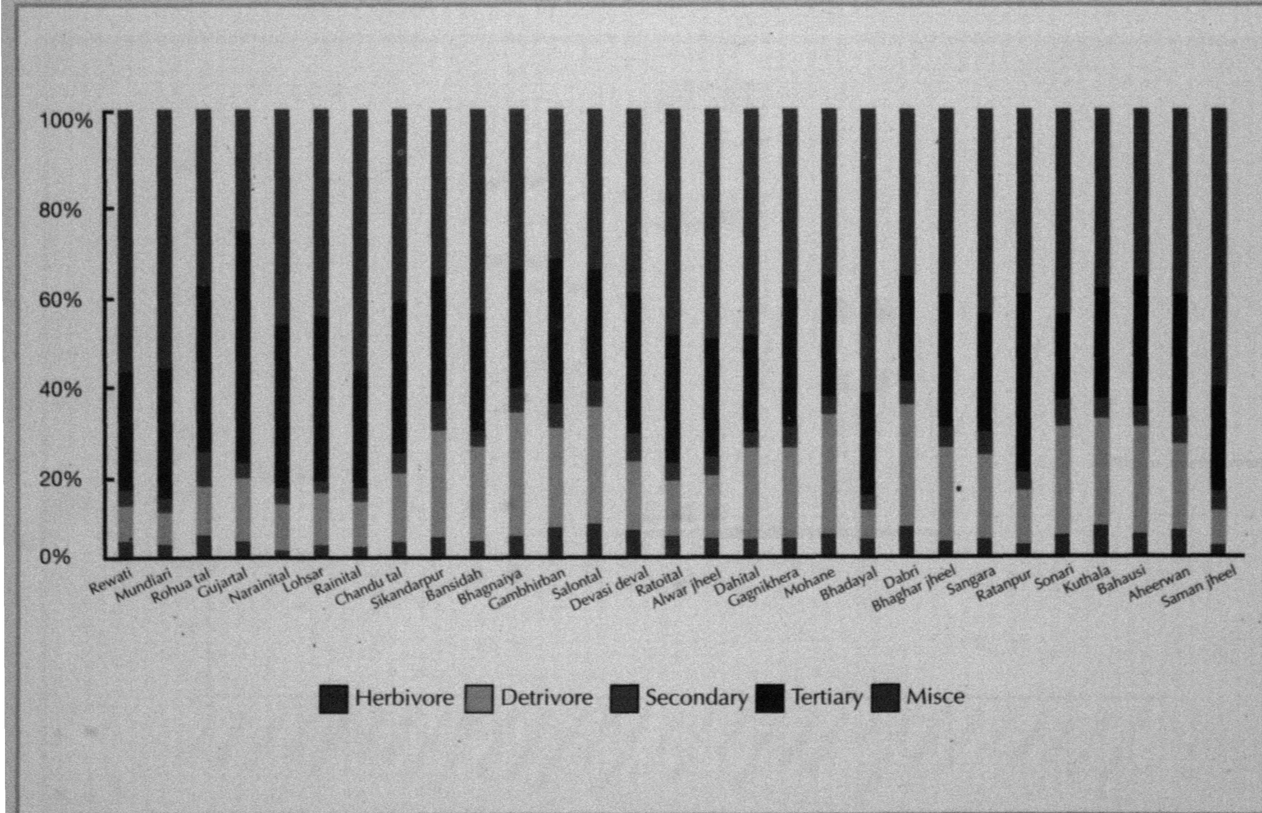
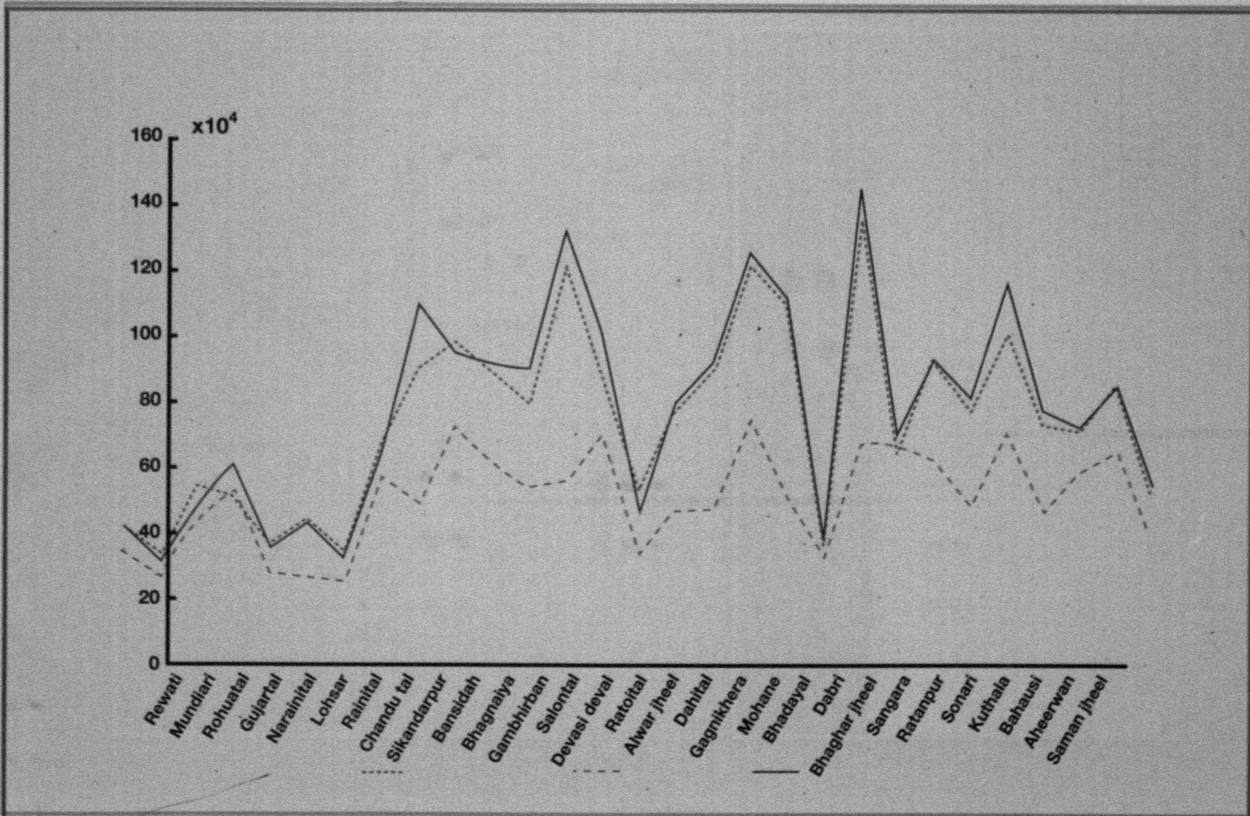


Fig 6. Energy conversion efficiencies (%) in wetlands of Uttar Pradesh



Ratanpur Jheel

Bahausi Jheel

Hydrobiological collection in a Tal

Fish catch from Dahital

Saman Jheel

Aheerwan Jheel

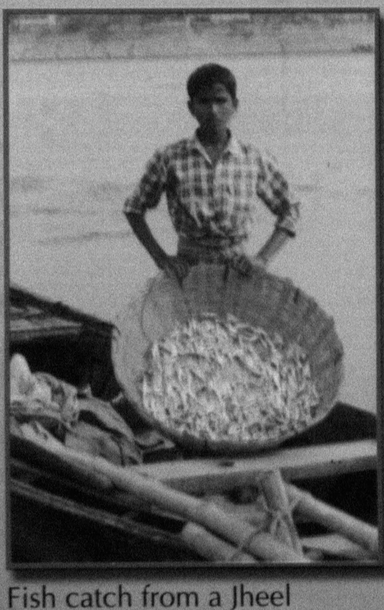
Eichornia infestation

Macrophyte infestation in a Jheel

Hydrobiological sampling in Dahital

Trapa harvesting in a Jheel


Trapa Cultivation in a Jheel


Fish catch from a Jheel