TROPHIC STRUCTURE AND FISHERY POTENTIAL OF SELECTED FLOODPLAIN WETLANDS (BEELS) OF BRAHMAPUTRA VALLEY

Thesis Submitted
In Partial Fulfillment of the Requirements
for the Degree of

Ph. D. In Fish & Fishery Science
(Fishery Resources Management)

BY

B. K. BHATTACHARJYA, M. F. Sc.
(Ph. D. -77)

Central Institute of Fisheries Education
(Deemed University)
Indian Council of Agricultural Research
Versova, Mumbai-400 061

FEBRUARY 2002

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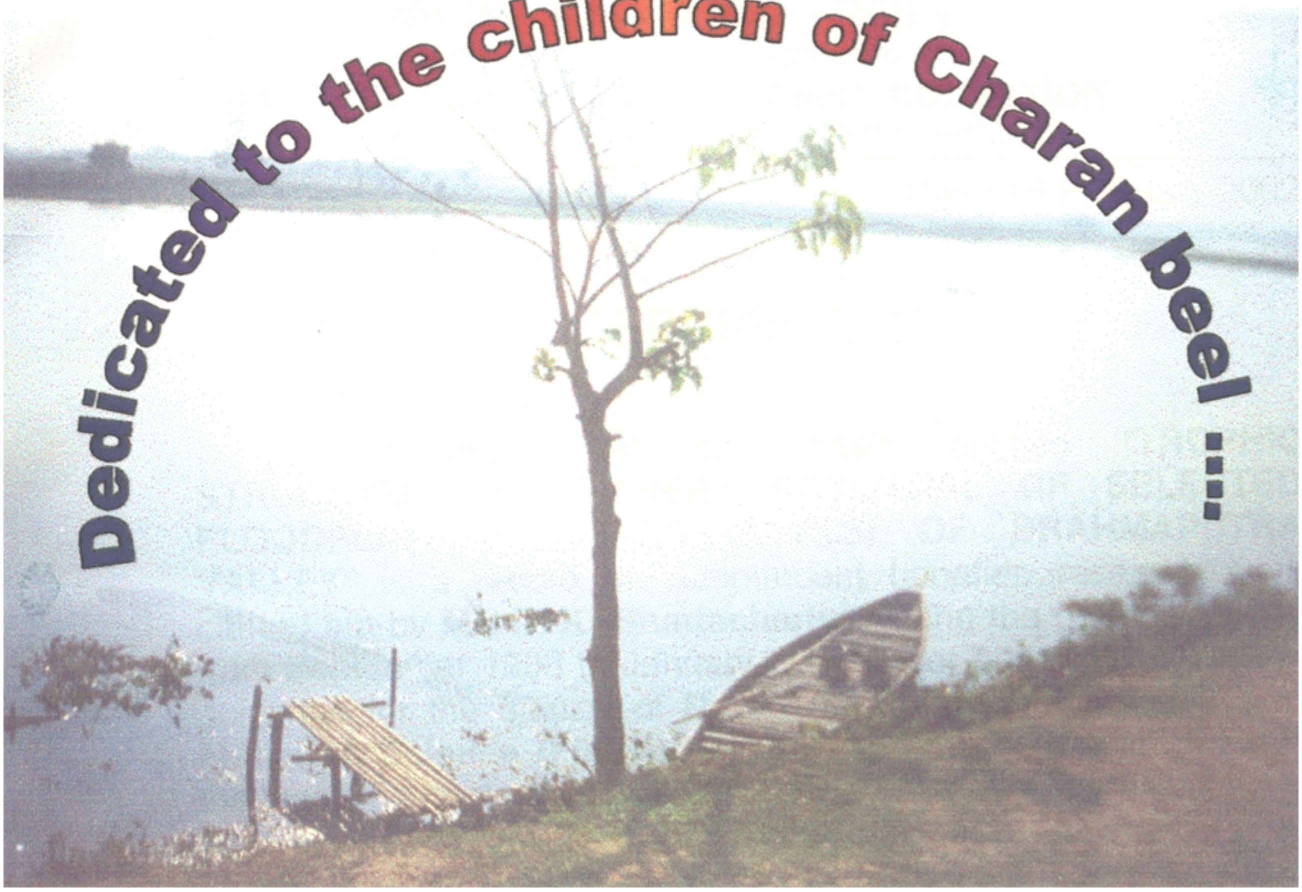
Dedicated to the children of Charan beel ....


...Their lives depend on the lifeline

केन्द्रीय मत्स्य शिक्षा संस्थान
(समतुल्य विश्वविद्यालय) भारतीय कृषि अनुसंधान परिषद
CENTRAL INSTITUTE OF FISHERIES EDUCATION
(Deemed University) Indian Council of Agricultural Research

Date: 16 February 2002

CERTIFICATE

Certified that the thesis entitled **"TROPHIC STRUCTURE AND FISHERY POTENTIAL OF SELECTED FLOODPLAIN WETLANDS (*BEELS*) OF BRAHMAPUTRA VALLEY"** is a record of independent bonafide research work carried out by **Mr. B. K. Bhattacharjya** during the period of study from September 1998 to January 2002 under our supervision and guidance for the degree of **Doctor of Philosophy in Fish and Fisheries Science (Fishery Resources Management)** and that the thesis has not previously formed the basis for the award of any degree, diploma, associateship, fellowship or any other similar title.

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DECLARATION

I hereby declare that the thesis entitled "**TROPHIC STRUCTURE AND FISHERY POTENTIAL OF SELECTED FLOODPLAIN WETLANDS (*BEELS*) OF BRAHMAPUTRA VALLEY**" is an authentic record of the work done by me and that no part thereof has been presented for the award of any degree, diploma, associateship, fellowship or any other similar title.

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16 February 2002
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Mumbai
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(B. K. Bhattacharjya)

सारांश

वर्तमान शोध कार्य मछली की उत्पादन क्षमता एवं पोषक संरचना को मध्य ब्रम्हपुत्र धारी आंचल, आसाम (भारत) के दो बाढ़कृत मैदानी क्षेत्र (बील) में निर्धारित करने के लिए की गई । इसमें चरन बील कोलोग नदी के संबंध को धारण करके एक खुली बील का प्रतिनिधित्व करती है, जबकि जालुगुटी बील नदीय संबंध टूटने से बंद बील श्रेणी में आती है । शोध क्षेत्र एक उप-कटिबंधीय जलवायु एवं उच्च वर्षापात (2308.4 एम.एम.) क्षेत्र से संबंधित है जहां कि चार अलग-अलग मौसम जैसे पूर्व-बरसात (मार्च से मई), बरसाती (जून से सितम्बर) पाश्च बरसाती (अक्तूबर से नवम्बर) एवं सर्दी (दिसम्बर से फरवरी) है । मृदा संरचना की विभिन्नता रेतीली मिट्टी से चिकनी रेतीली मिट्टी तक है । दोनों बीलों की मृदा के लक्षण अम्लीय पी.एच. (4.5-6.2) मध्यम से उच्च जैव कार्बन (1.06-8.27%) मध्यम स्तरों की उपलब्ध - नाईट्रोजन (9.58-36.65 ग्रा./100 ग्रा.) एवं उपलब्ध फास्फोरस (0.26-1.44 एम.जी./100 ग्रा.) है । जलगुटी बील पी.एच. मे हल्की कमी के साथ अपेक्षाकृत स्तरीय जैव कार्बन, उपलब्ध नाइट्रोजन एवं फास्फोरस चारण बील की अपेक्षा अंकित करके जैव पदार्थ एवं पोषक तत्वों का धीरे-धीरे बंद बील में सालों में इकठ्ठा होने को इंगित है । बीलों के जल का मध्यम तापमान (4.5-34.0 से.) बदलती सॅची डिस्क पारदर्शता (0.23-1.45 मी.) लगभग उदासीन पी. एच. (6.3-7.6), कुल क्षारकता (21.45-81.60 एम.जी./ली.) एवं कुल कठोरता (4.8-78.1 एम.जी./ली) बदलने घुली आक्सीजन के स्तर (4.77-12-14 एम.जी./ली) एवं भुक्त कार्बन डाइआक्साइऊ (18.59 एम.जी./ली तक) तथा कुल निम्न लोह (0.05-0.85 एम.जी./ली) एवं कुल क्लोरीन (12.8-29.4 एम.जी./ली)। विशिष्ट धारकता (48.2-158.5 माइक्रोमाहो/सी.एम.) एवं कुल घुले ठोस (28.5-84.7 एम.जी./ली)। सभी मृदा में जैव-कार्बन एवं उपलब्ध फास्फोरस से सीधे संबंध एवं मृदा की उत्पादकता के सूचक है । घुली जैव पदार्थ की पानी के (0.94-4.14एम.जी.का./ली) संध्रता दूसरी ब्रम्हपुत्र-घाटी की बीलों से तुलनीय है । नाईट्रेट स्तर (0.01-1.14एम.जी./ली) मत्स्य उत्पादन के लाभदायी हैं । फास्फोरस स्तर (नगण्य से 0.035एम.जी./ली) बील की उत्पादक प्रकृति को सूचित करता है । सिलिकेट का स्तर (2.4-7.8 एम.जी./ली) वर्षापात से सीधे संबंधित है । मृदा में मौसमी बदलाव जल गुणवत्ता मूल रुप से तापमान और वर्षा प्रेणित सतहीय जल/बाढ जल से प्रेरित थे । बील के जल के विशाल दैनिक बादलाव रसायनिक प्राचल में विशेषकर घुलीय आक्सीजन में (7.04एम.जी./ली) तक में उच्च उत्पादक स्तर की प्रकट करता है । चरन बील जलीय महापादक (मुख्यतम जलमग्न) से प्रकोपित (38%) है । जबकि जलगुटी बील मुख्यतः जलकुंभी से घनी प्रकोपित (69%) है । औसत जैविक भार चारण बील (1.40 कि.ग्रा. शुष्क भार/मी^{2}) में जलगुटी बील (1.62 शुष्क भार/मी^{2}) से कम है । घने महापादक बील में प्रचुरता (औसत 863 एवं 623 इकाई) चारन बिल एवं जालुगुटी बील क्रमशः को रोकते हैं । महत्वपूर्ण सार्थक उपस्थित नील-हरे शैवाल जैसे *Anabaena* (ऐनबीमा), *Microcystis* (माइक्रोसिसटिस) और डेसमिड जनसंख्या (10% और कम) बील की अति पोषित प्रकृति को दर्शाते हैं । तलीय-प्राणीजात (41.9 से 837.5 ग्राम गीले भार/मी^{2}) खड़ी फसल मुख्यतः गेस्ट्रीपोड (35.7-38.0%) जबकि कीटों में मुख्यतः

(40.2-42.1%) जैव-भार से जुडे महापादक-प्राणिजति का (56.1 से 9.01.3 ग्रा. गील भार/मी^{2}) दोनों बील में थी । महापादक से जुड़े प्राणीजाति उच्च बंधुता गर्म तापमान से महातलीय प्राणीयों के विपरित दर्शायी । तापमान, वर्षापात, मृदा एवं जल गुणवत्ता के साथ-साथ जातियों में आदान-प्रदान विभिन्न जैविक प्रजातियों में प्रेरित करता है । औसत कुल उत्पादन 2994.96मि.ग्रा.का./मी^{2}/दिन^{1} चारन बील में थी जिसमें प्लवकों का योगदान 52.9% था । जलगुटी बीले में सार्थक उच्चतर (पी < 0.5) औसत कुल उत्पादकता (3639.31मि.ग्रा.का./मी^{2}/दिन^{1}) चारन बील में दर्शाई । कुल उत्पादकता में प्लवक का योगदान बस 31% इस महापादकों से भरी झील में कुल प्राथमिक उत्पादकता बील की उच्च उत्पादक क्षमता के बील में (2-3%) चारन बील (1.9%) से ज्यादा थी । मत्स्य उत्पादन चरन बील में (228 कि.ग्रा./हें./वर्ष) जलगुटी बील (60 कि.ग्रा./हें./वर्ष) में अनुपूरक संचयन अनदेखा करने के कारण बहुत अधिक थी । छोटी मछलियां (<15 सेमी आकार) चारन बील की मात्स्यिकी में मुख्य थी । जबकि कटला के अनुपूरक संचयन से जलगुटी बील मेंभारी मात्रा में मुख्य मछली मिली । झुरमुट मत्स्यन (कटाल एवं पिट) सबसे महत्वपूर्ण वाणिज्यिक मत्स्य आखेट प्रणाली थी । रोक मात्स्यिकी (भेटा/बाना) एवं द्विप्रागामी पठन (थैला जाल) ने बील में इसका अनुगमन किया । जलगुटी बील (29) की तुलना में चारण बील में अधिक संख्या में मत्स्य प्रजातियाँ अंकित की गई । अधिकतम वाणिज्यिक पकड़ कुछ प्रजातियाँ से प्रभावित थी जैसे (वालेगी ऑटू) (ले.गोनियस) एवं (ले. रोहिता) । प्राथमिक उत्पादन क्षमता पर आधारित प्राक्कलित मत्स्य उत्पादन समर्थता चरन बील (874 कि.ग्रा./हे./वर्ष) में जलगुटी बील (1063 कि.ग्रा./हे./वर्ष) से कम आकलित की गई । जबकि कुल प्राथमिक मत्स्य उत्पादन क्षमता की संपरिवर्तन क्षमता चारण बील (0.26%) में जलगुटी बील से कई गुना अधिक आंकी गई । मत्स्य फसल की समर्थता की दर चारन बील में मध्यम (0.26%) एवं जलगुटी बील में निम्न थी, जो विशाल अनुपयोगी समर्थता को इन बीलों में प्रतिबिम्बित करती है । ऊर्जा बहाव मुख्यतया प्रस्तावित ऊर्जा बहाव प्रतिरुप चार पोषी स्तर से बना और दोनों बीलों में समान था । मुख्य ऊर्जा बहाव चारक बील में चराव श्रृंखला के द्वारा और जबकि जलगुटी बील में 43 से ज्यादा ऊर्जा बहाव मलवा खाद्य श्रृंखला के द्वारा था । दोनों कड़ी अंतरासंबंध थी, जो कि एक जटिल खाद्य जाल को परिनामित करती है । सर्वाहारियों की उपस्थिति और जटिलता बढ़ाती है । सच्चा जैव भार का पिरामिड दोनों बीलों की पोषी-संचरना को दर्शाती है । पिरामिड का बड़ा आधार, बडी प्राथमिक जैव भार की उपस्थिति में दर्शाती है । विशेषकर जलगुटी बील पोषी संरचनाएं चरन बील में मत्स्य फसल को कतला एवं रोहिता को घोंघाहारी पी.पंगेशियस एवं देशी घासभक्षी जैसे *Puntius pulchellus* (पुंटिअस पुलचेलस) और (पी.डोबसोनी) के अनुपूरक संचयन के द्वारा बढ़ाया जा सकता है ।

ABSTRACT

The present investigation was undertaken to assess the fish production potential and trophic structure of two floodplain wetlands (*beels*) of the Central Brahmaputra Valley Zone, Assam (India). Of these, Charan *Beel* retained connection with River Kolong and represented an open *beel*, while Jaluguti *Beel* lost riverine connection (closed *beel*). The study region experiences sub-tropical climate with high rainfall (2308.4 mm) and has four distinct seasons, *viz*., pre-monsoon (March to May), monsoon (June to September), post-monsoon (October to November) and winter (December to February). Charan *Beel* experienced three major floods during the monsoon season, while Jaluguti *Beel* received spilled over water from the river during the highest flood. Soil texture of the *beels* varied from sandy-loam, loam, silty-loam to sandy-clay-loam. Soils of the two *beels* were characterized by acidic pH (4.5-6.2), moderate to high organic carbon (1.06-8.67%), moderate levels of available nitrogen (9.58-36.67 mg 100 g^{-1}) and available phosphorus (0.26-1.44 mg 100 g^{-1}). Jaluguti *Beel* recorded slightly lower pH as well as considerably higher levels of organic carbon, available nitrogen and phosphorus than Charan *Beel* suggesting gradual accumulation of organic matter and nutrients in the closed *beel* over the years. Water of the *beels* was characterized by moderate temperature (21.5-34.0°C), fluctuating Secchi disc depth (0.23-1.45 m), near-neutral pH (6.3-7.6), favourable total alkalinity (21.45-81.60 mg l^{-1}) and total hardness (21.8-78.1 mg l^{-1}), fluctuating levels of dissolved oxygen (4.77-12.14 mg l^{-1}) and free carbon dioxide (undetectable to 18.59 mg l^{-1}) as well as low total iron (0.05-0.82 mg l^{-1}) and total chloride (12.8-29.4 mg l^{-1}). Specific conductivity (48.2-158.5 μmho cm^{-1}) and total dissolved solids (28.5-84.7 mg l^{-1}) were directly related to organic carbon and available phosphorus in soils indicating that both these parameters are directly influenced by soil fertility. Dissolved organic matter concentrations in water (0.90-4.14 mg C l^{-1}) were comparable to that of other Brahmaputra Valley *beels*. Nitrate-nitrogen levels (0.01-1.14 mg l^{-1}) were within the desirable limits for fish production, while the observed phosphate-phosphorus levels (traces to 0.035 mg l^{-1}) indicated productive nature of the *beels*. Silicate-silica levels (2.4-7.8 mg l^{-1}) were directly related to rainfall. Seasonal variation in soil quality and physico-chemical characteristics of water was influenced by temperature, rainfall and biotic communities. Wide diurnal

fluctuations observed in chemical parameters of water, especially in dissolved oxygen (up to 7.04 mg l^{-1}), revealed high productive status of the *beels*. Charan *Beel* was moderately infested (average 38% area) by aquatic macrophytes (mainly submerged), while Jaluguti *Beel* was heavily infested (69%), mainly by water hyacinth. The average biomass of macrophytes was lower in Charan *Beel* (1.40 kg dry wt m^{-2}) than that of Jaluguti *Beel* (1.62 kg dry wt m^{-2}). Dense macrophytes resricted plankton abundance (average 863 and 623 units l^{-1} in Charan and Jaluguti *beel*s, respectively). The significant presence of blue-green algae like *Anabaena* spp. and *Microcystis* spp. as well as low desmid population (10% or lower) suggested the eutrophic tendency of the *beel*s. The standing crop of benthic fauna (41.9 to 837.5 g wet wt m^{-2}) was dominated by gastropods (35.7-38.0%), while insects dominated (40.2-42.1%) the biomass of macrophyte-associated fauna (56.1 to 971.3 g wet wt m^{-2}) in both the *beel*s. Macrophyte-associated fauna showed high affinity to warmer temperature unlike macrobenthos. Temperature, rainfall, soil and water quality as well as the interaction among the communities influenced spatio-temporal variations in biotic communities. The average gross primary productivity was 2994.96 mg C $m^{-2}d^{-1}$ in Charan *Beel*, out of which contribution of phytoplankton was 52.4%. Jaluguti *Beel* recorded significantly higher ($P<0.05$) average gross primary productivity (3639.31 mg C $m^{-2}d^{-1}$) than Charan *Beel*. Phytoplankton contributed only 31.8% of the total gross primary productivity in this macrophyte-choked *beel*. The gross primary productivity indicated the high productive nature of the *beels*. The photosynthetic efficiency was higher in Jaluguti *Beel* (2.3%) than in Charan *Beel* (1.9%). Fish yield was much higher in Charan *Beel* (228 kg $ha^{-1}yr^{-1}$) than that of Jaluguti *Beel* (60 kg $ha^{-1}yr^{-1}$) due to negligible autostocking in the latter. Minor fishes (<15 cm size) dominated the landings in Charan *Beel* (52.9%), while supplementary stocking with *Catla catla* resulted in overwhelming dominance of major fishes in Jaluguti *Beel* (86.2%). 'Brush fishing' (*katal* and *pit*) was the most important commercial fishing method, followed by shore seining (*mosori jal),* gill netting (*langi jal*), encircling net (*dub jal*), barrier fishing (*bheta/banas*) and skimming (*thela jal*) in the *beels*. Charan *Beel* recorded higher number of fish species (38) than Jaluguti *Beel* (29). Most of the commercial catches were dominated by a few species like *Wallago attu, Labeo gonius, C. catla* and *L. rohita*. The estimated fish production potential based on primary productivity was lower in Charan *Beel* (874 kg $ha^{-1}yr^{-1}$) than that in Jaluguti *Beel* (1063 kg $ha^{-1}yr^{-1}$). However, the conversion efficiency of total primary production to fish yield was much higher in Charan *Beel* (0.26%)

than that in Jaluguti *Beel* (0.06%). The rate of utilization of potential to fish yield was moderate (26.1%) in Charan *Beel* and low (5.7%) in Jaluguti *Beel* reflecting a huge waste of available potential in these *beel*s. The proposed energy flow models comprised four trophic levels and were similar in both the *beel*s. Most of the energy flow was routed through the grazing chain in Charan *Beel*, while over two-thirds of the energy flow was routed through the detritus food chain in Jaluguti *Beel*. Both the chains were interconnected resulting in complex food webs. The presence of omnivores further added to complexity. True upright pyramids of biomass represented the trophic structure of both the *beel*s. The large base of the pyramids suggested that the existing large primary producer biomass could support much bigger biomass of primary consumers in the *beel*s, particularly in Jaluguti *Beel*. The trophic structures indicated that the fish yield of Charan *Beel* could be enhanced by supplementary stocking with *C. catla* and *L. rohita*, together with the introduction of molluscivorous *Pangasius pangasius* and indigenous herbivores like *Puntius pulchellus* and *P. dobsonii*. In Jaluguti *Beel*, supplementary stocking of detritivores like *L. gonius, L. rohita, Cirrhinus mrigala, L. calbasu* and *C. reba* coupled with the introduction of *P. pangasius* and *Ctenopharyngodon idella* is expected to augment fish yield. Clearance of water hyacinth in Jaluguti *Beel* is likely to change its trophic structure to a plankton-based system, making it potentially more productive.

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1. INTRODUCTION

Wetland is a broad term, which encompasses a wide range of inland, coastal and marine habitats sharing the common feature of temporary or permanent freshwater or shallow coastal waters. The Ramsar Convention (1971) defined wetlands as "areas of marsh, fen, peat land or water, whether natural or artificial, permanent or temporary, with water that is static or flowing, fresh, brackish or salt, including areas of marine water, the depth of which at low tide does not exceed six metres". Maltby (1991) gave a more precise definition according to which "wetlands occupy the transitional zone between permanently wet and generally dry environments. They share characteristics of both environments, yet cannot be classified exclusively as either aquatic or terrestrial".

Since the wetlands of India are mostly situated on floodplains of major rivers, which form a rich and varied inland fishery resource, they are better designated as floodplain wetlands or floodplain lakes (Sugunan, 1997). The lands along both sides of a river channel formed by layers of river alluvium, containing the meanders or braided reaches of a river and periodically inundated at times of high river discharge, constitute its floodplain (ICLARM, 1999). According to Maltby (1991), "floodplains are the flat land bordering rivers that is subject to periodic flooding, which tend to be most expansive along the lower reaches of rivers". In many areas, floodplains are associated with coastal lowlands often ending in estuaries and deltas. These may also spread out into large deltas at a considerable distance from the coast. The floodplains are either permanent or temporary water bodies associated with rivers that constantly shift their beds, especially in the potamon regimes. The frequency with which a river changes its course depends on a number of variables like flow velocity, sediment transportation rate, slope, channel pattern, water and sediment yield, amount and duration of precipitation over the catchments, texture and lithology of soil, tectonic status and so on.

According to Leopold *et al.* (1964), a typical floodplain includes: the river channel, oxbows or oxbow lakes (cut-off portion of river meander bends), point bars, meander scrolls (depressions and rises on the convex side of bends), sloughs (dead water areas), natural levees (raised crests above floodplain surface adjacent to the river channel), back swamp deposits and sand splays (deposits of flood debris).

Floodplains can be classified in several ways, *e.g.*, into permanently or seasonally flooded ones (ICLARM, 1999). Based on the flow of water, these can be divided into two broad groups: the plains and the standing waters (Welcomme, 1979). The plain (lotic component) includes the river channel, the levee region (more or less follows the river channel course) and the flats (extending from the levees to the terrace or plateau delimiting the plain). The standing waters are the lentic components of floodplains. Receding floods leave permanent or semi-permanent standing waters in the form of sloughs, meander scroll depressions, back swamps and residual channels (oxbow lakes). These water bodies expand or contract in area according to annual flood cycle and tend to merge into a continuous sheet of water covering the whole plain during the highest floods.

Floodplain wetlands (locally known as *beel*s in India) usually represent the lentic component of floodplains and exclude the lotic component. These vary widely in area, shape, depth, extent of riverine connection, etc. and have tremendous potential for development of capture, culture and culture-based fisheries in them. The characteristic ecological features binding these wetlands together are their periodic inundation by floodwaters (or by surface run-off from the catchments, if separated from the adjacent rivers by flood control embankments), and infestation with aquatic macrophytes.

Since time immemorial, the floodplains and their associated wetlands have been utilized for sustenance and well being of human societies. Nowhere is this truer than in Asia, where high population densities are exerting huge pressures on all natural resources in general and floodplain wetlands in particular. In many areas wetlands are the critical resource for the survival of both rural and urban communities. They are a source of protein and other nutrients required for human health (fish, birds, edible plants, reptiles, etc.), water (for drinking and irrigation), building materials (reeds and timber), transport and communication routes, effective sewerage treatment systems, fertile soils for agriculture, and buffers against flooding, erosion and nutrient loss (Howes, 1995). In addition, floodplain wetlands present diverse aquatic habitats from deep lakes to shallow marshes and from lotic (open *beels* retaining riverine connection)) tc lentic (closed *beels* that have lost riverine connection) environments, which support rich faunistic biodiversity including fishes and waterfowl. Thus, conservation of these diverse habitats is necessary for *in situ* conservation of aquatic biodiversity. China has several major river systems. The Ganga watershed covers over one million square kilometres (covering parts of India and Bangladesh), 18% of which are wetlands (locally known as *beels* or *baors/haors* in Bangladesh). The Mekong watershed encompasses an area of approximately 800,000 km^2, involving four countries, 9% of which are wetlands. In Africa, major watersheds are the Congo, Niger, Lake Shad, Nile, Okavango Swamp and Zambesi (ICLARM, 1999). The Murray-Darling River system in south Australia has numerous *billabongs* (oxbow lakes), many of which have been alienated from the main river channel due to river regulation (Shiel, 1980). The floodplain fisheries (*varzea*) have been one of the major resources of the Amazon economy (South America) since the beginning of European colonization of the region over 400 years ago (McGrawth *et al.*, 1998).

India has extensive areas covered by floodplain wetlands, which are an integral component of the Brahmaputra and Ganga river systems. These wetlands together cover an area of 0.2 million hectares and constitute important fishery resources in the states of Assam, West Bengal, Bihar, Manipur, Arunachal Pradesh, Tripura and Meghalaya (Sugunan *et al.*, 2000). These water bodies are locally known as *beels* (in most states), *mauns*, *chaurs* and *dhars* (Bihar), *pats* (Manipur), *charhas*, *baors/haors* and *anoas* (parts of West Bengal and Assam bordering Bangladesh). *Beels* constitute an important fishery resource contributing significantly to the fish production of these states apart from providing livelihood to thousands of poor fishers.

Among the Indian states, Assam has the maximum number and the largest water area under floodplain wetlands (*beels*), mainly associated with the Brahmaputra and Barak river systems (Sugunan and Bhattacharjya, 2000). This northeastern state has 1392 *beels* covering 100,000 ha, which is 49.5% of the total area under floodplain wetlands in India. *Beels* constitute 28.9% of the total fishery resources (347,000 ha) and as much as 70.4% of lentic water bodies of Assam (142,000 ha, excluding 205,000 ha of rivers). Thus, they are the second largest and the most potential fishery resource of the state. Though precise data on fish yield from *beels* are not available, they reportedly contribute *c* 12.5% of the total fish production from Assam (Goswami, 1997). These wetlands generally possess high potential for *in situ* fish production and where the topography allows, provide a 'collection sink' for the fish produced in the flooded catchment areas. Further, most of the riverine fishes are harvested from the adjoining *beels*, since operation of most fishing gear is difficult in the main river. The open *beels* act as breeding and nursery grounds for a number of riverine fishes including Indian major carps. The registered *beels* (numbering 423) that are under the administrative control of the Revenue Department and the Assam Fisheries Development Corporation (AFDC) generate considerable revenue for these government establishments. However, a combination of the natural processes of river-bed evolution and anthropogenic changes (*e.g.,* extensive flood control/irrigation works and overexploitation) have reduced fish production of many *beels* through reduced autostocking from rivers, depletion of fish stocks, siltation, habitat destruction and heavy macrophyte infestation.

The average yield of Assam *beels* is 173 kg $ha^{-1}yr^{-1}$ (Sugunan and Bhattacharjya, 2000), which - although higher than that from other open waters of India like rivers, reservoirs and lakes - can be increased significantly through scientific management including fisheries enhancements. For example, studies conducted by the Central Inland Capture Fisheries Research Institute (CIFRI), Barrackpore, for the past 15 years have shown that fish yield from West Bengal *beels* can be raised to 1,000-1,500 kg $ha^{-1}yr^{-1}$ (Sugunan *et al.*, 2000). Thus, there is an urgent need to formulate sound management norms for sustainable development and optimal utilization of the *beels* of Assam to increase their fish production. Such a step is urgently required considering the facts that the state produced only 159,768 t of fish during 1999-2000, which could meet only 60.6% of the requirement (263,720 t) resulting in draining out about Rs. 300 million from the state every year (Anon, 2000) and that the *beel*s are the most potential resource of the state, which will have to account for most of the additional fish production.

Information on the ecology and fisheries of *beel*s is an essential pre-requisite for planned development and management of these productive aquatic ecosystems. The physico-chemical characteristics of soil and water as well as biomass and composition of biotic communities strongly influence the fish production potential of a *beel* ecosystem. Aquatic macrophytes play a very important role in the biological productivity contributing to the vast load of detritus in most *beel*s, thereby altering their trophic structure significantly. A proper understanding of the complex relationship of food chain and patterns of energy flow in *beel*s will help in formulating policies for their stock manipulation (Jhingran, 1991). Though some investigators have made stray attempts to study aspects of limnology and fisheries of selected *beel*s of Assam, systematic and synoptic studies on the pathways of energy flow from the primary producers to terminal consumers and a reasonably good estimate of fish production potential based on primary productivity (of both macrophytes and phytoplankton) in open and closed *beel*s are lacking. Studies conducted by CIFRI have shown that the ecology and fisheries of open *beel*s differ significantly from those of closed ones, necessitating formulation of separate sets of management guidelines for these two types of *beel*s (Sugunan *et al.*, 2000). Hence, in the present study, an attempt was made to assess and compare the fish production potential as well as trophic structure in open and closed *beel*s of the Brahmaputra valley, Assam, with the following objectives:

1. To assess and compare the spatio-temporal variations in hydrobiology of open and closed *beel*s created by the same river.
2. To evaluate and compare the fish and fisheries of open and closed *beel*s located within the same agro-climatic sub-zone.
3. To assess and compare the pathways of energy flow resulting in clearly defined trophic structures in open and closed *beel*s.
4. To estimate and compare the fish production potential of open and closed *beel*s based on primary productivity.

2. REVIEW OF LITERATURE

The floodplain wetlands (*beels*) spread over the eastern and northeastern regions of India represent extensive and rich areas for fisheries. The growing interest in these wetlands stems from the fact that they are one of the most productive environments of the world. Floodplain wetlands can produce benefits eight times more than those of a paddy field of an equivalent area (Jhingran, 1989). They are resilient and highly dynamic ecosystems, and are important habitats for a large number of plant and animal species, many of which have commercial importance. These wetlands play an extremely important role in fish production and livelihood security, and have a number of other (direct/indirect) values.

Wetlands have high component and system level values (E. P. Odum, 1978) and therefore, have caught the attention of researchers as well as international organizations like the International Biological Programme, International Union for Conservation of Nature and Natural Resources, The United Nations Educational, Scientific and Cultural Organisation (UNESCO), and so on. The importance of wetlands has initially been highlighted mainly on account of their recognition as important waterfowl habitats and a wetland convention was adopted in 1971 at the Ramsar Conference (Iran). In recent years, there has been a great surge of interest in wetland ecosystems on account of the realization and demonstration of their significant role in recharge of aquifers (Carter *et al.*, 1979), regulation of water quality (Larsons, 1982), treatment of waste waters (Kadlec, 1978), secondary production and wild life (Turner, 1982), erosion control (Dean, 1979), conserving biodiversity (Denny, 1995) and recycling organic wastes (Bhattacharyya, 1995). Maltby (1991) categorized the enormous variety of wetlands into marshes, swamps, peat lands, floodplain wetlands, mangroves, lakes, estuaries and lagoons as well as artificial wetlands (paddy fields, fish ponds, reservoirs, waterways and salt pans). Some of the largest floodplain regions of the world are found in South America (Maltby, 1991) and Asia (Scott, 1991). In many of Asia's rivers and floodplain wetlands, notably the lower Mekong Basin and the Ganga-Brahmaputra Basin, fisheries production is extremely high (Scott, 1991).

Investigations on various aspects of hydrobiology and fisheries of floodplain wetlands were mostly conducted during the past three decades following the Ramsar Convention. However, a large volume of documented scientific literature is available on these aspects in other types of wetlands like lakes, estuaries and reservoirs both in India and abroad. In view of the above, it is rather difficult to discuss all of them in detail. Hence, an attempt is made to review the recent works among them, which are relevant to the present investigation. Kar (1984), Acharjee (1997) and Deka (1999) have reviewed the earlier literature on various aspects of limnology and fisheries of Indian lakes, reservoirs and *beels*.

2.1 Biological productivity of wetlands

Biological productivity of inland water bodies has attracted the attention of limnologists for many years. Terms such as 'eutrophy', 'oligotrophy' and others appeared 70 years ago as general denominations of the status of lakes. Such concepts became better defined during the last five decades. Major thrust was given in India and abroad on various aspects of limnology and productivity of lakes and reservoirs in order to formulate effective and suitable management measures for optimizing fish production from them. Rawson (1951, 1952, 1955, 1956) based on studies on a number of lakes concluded that the productivity of lakes depends to a large extent on their morphometric features. He established an inverse relationship between mean depth and fish production. Other workers like Northcote and Larkin (1956), Hutchinson (1957) and Larkin (1964) discussed the importance of edaphic features in evaluating the productivity of lakes and established direct relation between edaphic features and fish production. Workers like Steeman-Nielson (1946), Moore (1950), Edmondson (1956), Varduin (1956), Waldichuk (1956), Teal (1957), Rodhe (1958), Ivlev (1961), Wright (1961), Goldman (1963), Talling (1965a, 1965b, 1966a, 1966b, 1966c) Beedle (1966), Phillipson (1966), Gerkin (1967) and many others studied different aspects of limnology and productivity of natural lakes and reservoirs in different countries.

The basic relationship between organisms and their environment is the maintenance of life through various kinds of energy exchanges. Lindemann (1942) was the first to propose the community energetics approach (also called trophic dynamic concept) to ecology, which enables an investigator to compare the relative rates at which different kinds of ecosystems convert solar energy to chemical form. Workers like Zuday (1940), Ohle (1956), Reiley (1956), E. P. Odum (1959, 1962, 1969, 1975), Teal (1962), Wilson (1963) and Mann (1965, 1969) studied the trophic dynamic model, pathways and extent of utilization of energy at various trophic levels in different aquatic ecosystems. H. T. Odum (1957) and Teal (1957) based on studies on trophic structure and productivity of temperate springs have emphasized the importance of detritus derived from wetlands in the aquatic food chain. Wilson (1962) studied the energetic principles in investigation of trophic relation and productivity of an ecological system.

In India, Pruthy (1933) initiated studies on the physico-chemical parameters of fresh waters, which can be considered as one of the earliest limnological works. Pioneering work in respect of fisheries of impounded waters was carried out by Raj (1941) in Mettur Dam. This was followed by studies on the hydrology of Stanley Reservoir at Mettur Dam (Ganapati, 1955) and limnological studies in Bhavanisagar Reservoir (Dorairajah, 1956; Sreenivasan, 1964b and Natarajan, 1976). Workers like Ganapati (1955, 1956, 1957, 1959) and Sreenivasan (1964a, 1964c, 1964d, 1965, 1966a, 1966b, 1968a, 1968b, 1970, 1971, 1972, 1977) studied the limnology and productivity of a number of reservoirs in Tamil Nadu. Pankajan (1956), Raj (1958), David *et al.* (1959), Govind (1963, 1969), Krishnamurty (1966), Vasisht (1968), Ganapati and Pathak (1969), Natarajan (1972, 1977, 1979), Mathew (1975), Kohli (1981), Pathak (1990), Pandey *et al.* (1993) and many others studied the ecology and productivity of a number of reservoirs located in different parts of the country. However, only a few Indian workers like

Ganapati and Sreenivasan (1972) and Natarajan and Pathak (1983, 1985) studied the flow of energy in different aquatic ecosystems.

2.2 Energy dynamics and trophic structure

The ecosystem plays its key role as an energy sink where solar energy is entrapped and passed on through different trophic levels. Ultimately, all biochemical energy is converted to heat via respiration. When passage and conversion of energy flow is postponed, and energy is stored in the form of biodeposits, as coal and oil (Dickinson and Murphy, 1998). One of the important components of community organization is "who eats-whom" (Krebs, 1994). "Trophic" literally means feeding, so trophic levels are the levels or positions at which species feed. The trophic structure can be defined as the structure of energy transfer and loss between different populations in the community (Kundu, 1999).

Elton (1927) was the pioneer worker to apply his idea of energy dynamics in ecology through critical analysis and has drawn the ultimate inference. Moved by Elton's (1927) idea, Lindemann (1942) proposed the energy-flow diagram, showing energy flow through different trophic levels and developed the concept of energy dynamics, which is called trophic dynamics. The modified model of Lindemann (1942) is recognised as predator or grazing food chain (E. P. Odum, 1959). A number of eminent ecologists like Golley (1960), H. T. Odum, (1956), E. P. Odum, (1959, 1971), Slobodkin (1959, 1960, 1962), Teal (1962), Greenwood (1987), Stiling (1992), Chapman and Reiss (1995), Castro and Huber (1997) and Dickinson and Murphy (1998) have worked on trophic dynamics in different ecosystems. Kundu (1999) reviewed the conventional food chain models with necessary modifications.

Every population belongs to a particular trophic level. It has been found that different trophic levels are linked with one another to form food chains, which in turn are linked together to form food web. According to E. P. Odum (1971), the transfer of food energy from the source in plants, through a series of organisms with repeated eating and being eaten, is referred to as the food chain. The ecological classification should not be confused with the taxonomic one, as the former is based on functions (Whittaker, 1957). Likewise, trophic classification is based upon functional similarity rather than systematic position. The ecologists have not gathered much data on the length of food chains. Pimm (1982) and Pimm *et al.* (1991) dwelt on the length of the food chain and opined that a tenth-level carnivore was not possibly found in a food chain as such a lengthy, hypothetical food chain was most unstable due to environmental fluctuations. Kundu (1999) stated that a food chain usually comprised more or less five trophic levels.

In order to understand the trophic structure of any community it is necessary to trace the pathways that energy flows through the food chain (Vass, 1992). Based on overall observations, food chains have been broadly categorized into two groups (E. P. Odum, 1959), *viz.*, the predator or grazing food chain and the saprophytic or detritus food chain. E. P. Odum (1983) has given a generalized model of Y-shaped or 2-channel energy flow concept, which presents a lucid relationship between grazing and detritus food chain. In many cases, 90% of energy is transmitted through detritus food chain whereas 50% of energy is transmitted through grazing food chain (Ananthakrishnan, 1982). The presence of omnivorous organisms receiving energy from two or more trophic levels make the one way energy flow to some extent complex (Stiling, 1992).

The interaction of the food chains i.e., the loss of up to 80 or 90% of enrgy at each transfer (Slobodkin, 1959, 1962) and the size-metabolism relationship results in communities having a definite trophic structure, which often characterizes a particular type of ecosystem (E. P. Odum, 1983). Trophic structure and trophic function can be shown graphically by ecological pyramids. Ecological pyramids may be of three general types: the pyramid of numbers, biomass and energy. In the aquatic environment, a pyramid of biomass based on specific studies in Weber Lake, Wisconsin was constructed by Juday (1942). H. T. Odum (1957) constructed a pyramid of energy based on studies in Silver Springs, Florida. According to E. P. Odum

(1983), the pyramids of numbers and biomass can be inverted (or partly so), whereas the energy pyramid must always have a true upright pyramid shape.

DeVries (1990) stated that the introduction of the shad (*Dorosoma* spp.) enhanced predator growth and negatively affected presumed competitors in reservoir community dynamics in the USA. Recently, Currie *et al.* (1999) have shown that the trophic structure of aquatic ecosystems can potentially be controlled by two sets of factors *viz.*, resource availability and predation. Dettmers and Wahl (1999) demonstrated that the omnivorous gizzard shad *(Dorosoma cepedianum)* regulated reservoir food webs from an intermediate trophic position through a complex series of predation and competition interactions.

2.3 Role of macrophytes in wetland productivity

Aquatic plants are an important component of floodplain wetlands, lands, ponds and floodplain rivers throughout the world. The rapid proliferation of the vascular plants can present impediments to navigation and pose a threat to the balance of biota in the aquatic system. However, in spite of their nuisance characteristics, the ecological and environmental significance of these plants, including their capability to improve water quality, has created substantial interest in their photosynthetic and physiological activities, and their potential use for beneficial purposes (Jamil, 1990).

Significant contributions on the aquatic macrophytes from the fresh waters of India are not many. Besides, most of the works were aimed at their ecology and distribution (*e.g.*, Ganapati, 1941; Sen and Chatterjee, 1960; Sahai and Srivastava, 1976; Puri and Mahajan, 1958; Jha, 1965; Jha *et al.*, 1978; Unni, 1967, 1971). Many others like Hussainy (1967), Michael (1968), Khan and Siddique (1970), Nassar and Dattamunshi (1971), Nassar (1975), Vivekanandan and Pandian (1976), Haniffa and Pandian (1978) and Haniffa (1978) concentrated on the ecology of ponds with special reference to macrophytes and their utilization. Jamil (1993) reviewed the role of macrophytes in aquatic ecosystems.

In tropical environments, studies on population dynamics and primary production of aquatic macrophytes are rare. And the papers that stand out are those of Piedade *et al.* (1991), and Junk and Piedade (1993, 1997). A special mention may also be made about the work of Camargo and Florentino (2000) who have analysed the productivity of macrophytes with floating leaves (rooted emergent). In India, only a few reports are available on the productivity of macrophytes in wetlands (Rai, 1980; Laal, 1981).

Most of the floodplain wetlands in India are infested by aquatic macrophytes (commonly referred to as aquatic weeds by aquaculturists), which frequently interfere with human activities and decrease the efficiency with which the aquatic resources can be utilized. As a result, many earlier workers in India focused on the menacing role of the aquatic macrophytes, especially that of *Eichhornia crassipes* (Ahmed, 1954; Saha and Muthuri, 1958) and on various control techniques (Mitra, 1992) based on the use of chemical, biological and mechanical agents. However, many overseas workers like Wilson (1939), Low and Bellrose (1944), Varduin (1951), Penfound (1956), Swindle and Curtis (1957), Westlake (1963), Sculthrope (1967), Boyd (1969, 1970a, 1970b, 1971), Stake (1968), Linda and Cottam (1969), and Boyd and Hessa (1970) have studied the limnological significance of macrophytes and their role in fish production in lakes, reservoirs and other shallow waters. E. P. Odum (1959) suggested that although macrophytes may not be used directly by the consumers, they form very rich detritus load at the bottom and in fact the best way to utilize such water bodies where aquatic weeds are in plenty is through detritus pool. According to Camargo and Florentino (2000), the aquatic macrophytes stand out as one of the main primary producers of shallow aquatic ecosystems. They play a fundamental role in the cycling of matter and energy flow (Camargo and Esteves, 1995a).

2.4 Limnology and fisheries of floodplain wetlands

The studies made by the above workers have given us some tools for evaluating the productivity of wetlands, both man-made and natural based on hydrobiological studies. But, these deductions cannot be applied *in* *toto* to the floodplain wetlands (*beels*) as they differentiate themselves from lakes in many respects. The shallow nature, penetration of light up to bottom, rich nutrient status of the soil and rich growth of macrophytes leading to high detritus load at the bottom are some of the characters that make *beels* a separate identity. Ecological investigations specific to these unique wetlands are, therefore, needed to formulate and adopt suitable management measures for optimizing the fish production from them. As elucidated earlier, the importance of the floodplain wetlands as an important ecotone/fishery resource has been recognized all over the world in recent years. As a result, many aspects of the hydrobiology and fisheries of these unique wetlands have been investigated in different parts of the globe.

The dynamics of every floodplain river ecosystem rely upon the interactions between the river and its floodplain habitats (Gooselink and Turner, 1978; Welcomme, 1979). During floods, these links are reinforced when the aquatic habitats are replenished with water, allowing exchange of nutrients and biota (Brinson *et al.*, 1983). As a result, tropical floodplain lakes show wide seasonal variations in their physical and chemical characteristics (Furch, 1984; Payne, 1986). This seasonality is determined principally by the "flood pulse" (proposed by Junk *et al.*, 1989), which causes enrichment of the water through diverse ecological factors (Camargo and Esteves, 1995b). Variation in frequency and duration of river inputs or "connectivity" is a major distinguishing factor among floodplain water bodies (Hamilton and Lewis, 1990; Amoros, 1991; Ward and Stanford, 1995). Several authors (Melack, 1984; Forsberg, 1984) verified the occurrence of seasonal variations in the physical and chemical characteristics (pH, electrical conductivity, concentration and distribution of oxygen, nutrient availability) in *varzea* (floodplain) lakes of Amazonia. In Central Amazonia, high water levels fertilize oxbow lakes, but the intensity and period of fertilization vary from year to year and between environments (Day and Davies, 1986). In contrast, fertilization occurred during low water in an oxbow lake of the Rio Parana, Argentina (Bonetto *et al.*, 1984), and the same pattern was observed in Lago Tineo, Venezuela, by Hamilton and Lewis (1987). Knowlton and Jones (1997) evaluated the trophic status of Missouri River floodplain lakes in relation to basin type and connectivity.

However, in many floodplain habitats, the annual replenishment with floodwater is adversely affected by human activities. For example, in River Murray, South Australia, regulation has altered the normal flooding regime, alienating *billabong*s (oxbow lakes) from the main channel (Shiel, 1980) and leading to the decline of several riverine species (Walker, 1986). A number of workers have studied various aspects of ecology in both natural (Boulton and Lloyd, 1991; Olsen, 1997) and artificial *billabong*s of River Murray in South Australia (Nielsen and Chick, 1997). Outridge (1988) studied macroinvertebrate communities in *billabong*s of Magela Creek, Northern Territory, Australia. Nearer home, Hossain *et al.* (1997) studied the physico-chemical characteristics of a completely closed floodplain lake (BSKB *beel*) in Bangladesh.

Many aspects of limnology of temperate ox-bow lakes have received the attention of researchers. These include macroinvertebrate community structure in some oxbow lakes of River Innerste (Lower Saxony), Germany (Rehfeldt and Soechting, 1990; Soechting, 1992; Foechler *et al.*, 1995) and that of River Waal, the Netherlands (Brock and Van der Velde, 1996); zooplankton structure in an eutrophic oxbow of Po River, Italy (Primicerio *et al.*, 1984) and diel dynamics of certain ecological factors in some oxbow ponds of northern Italy (Sconfietti and Airo, 1994). Airo and Sconfietti (1995) assessed the productivity of six dominant submerged macrophytes in an oxbow lake near Pavia, Italy. A number of workers concentrated on the theoretical habitat templets, species traits and species richness in many taxonomic groups of aquatic plants and animals occurring in the floodplain habitats of the Upper Rhone River, France (Resh *et al.*, 1994; Richoux, 1994; Tachet *et al.*, 1994; Usseglio-Polatera, 1994; Usseglio-Polatera and Tachet, 1994).

Ecological studies related to tropical aquatic macrophytes in areas subject to flood pulses are few (Junk, 1970, 1986; Howard-Williams and

Junk, 1976, 1997; Junk and Howard-Williams, 1984). Wolf (1990) studied floating and littoral vegetation of some shallow lakes near the mouth of Rio Ypane, Paraguay. Camargo and Esteves (1996) showed that the overflowing water of the parent river fertilized the water column of an oxbow lake that - along with other factors - determined a typical seasonal variation of its aquatic macrophytes.

Ali (1989) described the importance of the floodplain lakes (*beel/haor*) during the monsoon season in the continuation and sustenance of the stocks of a large variety of fish species in Bangladesh. Studies on the ichthyofauna of the main river and its oxbows underlined the importance of oxbow lakes as spawning and nursery grounds, refuges for endangered species and resting places for fish during the winter or dry periods (Beckedorf and Blohm, 1994; Smith and Bakowa, 1994). Middendrop *et al.* (1996) described a method of community fisheries management introduced in selected *baors* of western Bangladesh. Hohausova and Jurajda (1996, 1997) investigated the fish assemblages of Upper River Morava (Danube Basin, Chzeck Republic) and its oxbow lakes.

In India, Chaudhuri and Banerjea (1965) carried out pioneering studies in Takmu *beel* area in Manipur. Subsequently, many workers have studied the hydrodynamics (Vass, 1992b), limnology and fisheries (*e.g.*, Pathak *et al.*, 1986; De and Mukherjee, 1992; Paul, 1992; Srivastava 1992; Vass, 1992a; Rana *et al.*, 1996) of Indian *beel*s. Kumar (1985) initiated studies on the hydrobiology of a *beel* of Bihar, which was followed by studies on their ecology and fisheries of some oxbow lakes (*beels*/*mauns*) of the state (Chitranshi, 1992; Jaiswal and Singh, 1994; Jha, 1995, 1997; Singh and Singh, 1997; Sinha and Jha, 1997). An overview of the productivity status of Indian *beel*s was given by Vass (1989), while Jha (1989) gave an overview of the *beel* fishery resources of Bihar. Vass and Langer (1990) assessed the changes in primary production and trophic status of a Kashmir oxbow lake, consequent to man-made modifications in the environment. Singh (1990, 2000) studied phyto and zooplankton in an ox-bow lake of Uttar Pradesh. Some generalized account of the community structure and seasonality of aquatic macrophytes and associated fauna in *beels* is available (Mitra, 1989, 1992; Mitra and Ghosh, 1992). The removal of macrophytes in a West Bengal *beel* resulted in over three folds increase in its fish yield (Saha *et al.*, 1990). Choudhury (1989, 1992a, 1992b) gave an account of the various fishing methods employed in floodplain lakes together with their fish landings and catch composition. Parameswaran and Vass (1995) gave an overview of *beels* in West Bengal. Sugunan and Mukhopadhyaya (1995), based on the case studies in two open and closed *beels* of West Bengal, showed for the first time that soil and water quality as well as biotic communities varied considerably in these two types of *beels*. This notion was further strengthened with the synthesis and compilation of the results of studies conducted by the Central Inland Fisheries Research Institute (CIFRI) in selected *beels* located in all the agro-climatic sub-regions of West Bengal (Sugunan *et al.*, 2000).

In Assam, which is endowed with the largest number (and area) of *beels* among the Indian states, very few systematic studies have been made. Dey (1977, 1980, 1981) made pioneering observations on the limnology of some commercially important *beels* of Kamrup District in lower Assam and their bearing on fish production. Following this, workers like Lahon (1979, 1980, 1983), Lahon and Dey (1979, 1980), Goswami and Dey (1980), Lahon *et al.* (1982a, 1982b), Yadava *et al.* (1983, 1984, 1986), Kolekar *et al.* (1983), Yadava and Choudhury (1984), Goswami (1985), Singh *et al.* (1985), Bhuyan (1987), Choudhury (1987a, 1987b), Dewri and Lahon (1987), Jhingran and Pathak (1987), Yadava (1987a, 1987b, 1988), Sarma *et al.* (1993) and Acharjee *et al.* (1995, 1999) studied various aspects of limnology and fisheries of selected *beels* of the Brahmaputra Valley. Various indigenous fishing methods employed in Assam *beels* have been well documented (Yadava *et al.*, 1981; Yadava and Choudhury, 1986; Bhagowati and Kalita, 1987; Choudhury, 1987b; Goswami *et al.*, 1994; Ali, 1997). Goswami and Devaraj (1993) estimated the potential yield of *Labeo rohita* from Dhir *Beel* in lower Assam.

A few workers have concentrated on the limnology and productivity of selected *beels* of lower Brahmaputra Basin (Yadava, 1987a;

Yadava *et al.*, 1987; Acharjee, 1997; Acharjee *et al.*, 1998). Goswami (1987) and Acharjee *et al.* (1997) gave an account of aquatic macrophytes present in Assam *beel*s. Agarwala (1996) concentrated on the productivity indicators in *beel*s. Deka (1999) assessed the status of selected *beel* fisheries of Assam and their impact on the fishermen community. Most of these studies were concentrated in lower Assam with the *beel*s of Kamrup District receiving far greater scientific attention than those of the other districts. Only a few reports are available on the limnology and fisheries of Sone *Beel* of the Barak Valley (Kar, 1984; Kar and Dey, 1986, 1993). Fish species occurring in selected *beel*s of the state have been documented (Chandra *et al.*, 1990; Kar and Dey, 1986, 1993, Deka *et al.*, 2001). Yadava *et al.* (1989) reported the occurrence of juveniles and adults of prized hilsa in certain open *beel*s like Dhir, Dora and Sone *beel*s of the state. Sugunan and Bhattacharjya (2000) gave a comprehensive overview of the ecology and fisheries of *beel*s of the state based on extensive field surveys conducted by CIFRI in both the Brahmaputra and Barak Vallies. Deka *et al.* (2001) observed that fish diversity of selected *beel*s of the state has declined over the past few years due to some extrinsic and intrinsic factors with associated impact on the income of the fishermen community.

Investigations conducted so far in Indian *beel*s mainly concentrated on their soil and water quality, and the abundance and quality composition of biotic communities as well as their fisheries. Published literature on aspects related to the trophic structure of *beel* ecosystems in India is rare. Pathak *et al.* (1985) showed the importance of detritus food chain in *beel* ecosystem. Pathak (1990) gave a comparative account of energy dynamics of open and closed *beels* in the Ganga and Brahmaputra basin. It is apt to mention the brief account of energy flow pathways generally found in open and closed *beels* of West Bengal (Sugunan *et al.,* 2000). Further, no literature is available on the comparative fish production potential of open and closed *beels* located in the same agro-climatic sub-region of Assam. Thus, the present investigation is an attempt to assess and compare the trophic structure and fish production potential of selected open and closed *beel*s located in the Central Brahmaputra sub-zone of Assam.

3. MATERIAL AND METHODS

The present study was conducted during 2000-01 in two open and closed *beels* located within the agro-climatic sub-region of the Central Brahmaputra Valley Zone of Assam (India). The study consisted of two parts: field and laboratory work. The field work involved the collection of soil, water and biota (including aquatic macrophytes and associated fauna) samples, assessment of meteorological (*e.g.*, air temperature) and limnological parameters (*e.g.,* Secchi disc visibility, water temperature, etc.). Observations on aspects of limnology (*e.g.*, per cent area covered by aquatic macrophytes) and fisheries (*e.g.*, fish catch composition, exploitation means, etc.) also formed part of the field work. The other part of the study involved the analysis of soil, water and biota samples in the laboratory. The location of the study sites and the research methods followed for the study are briefly described here.

3.1 Location of the study

The northeastern state of Assam was selected for the study since it has nearly one half of the total area under *beels* in India. Among the three geographical zones of Assam, the Brahmaputra Valley houses the overwhelming majority of *beel*s accounting for 92% of the state's *beel* area. For the purpose of agro-climatic regional planning for development of agriculture and allied activities, Assam has been divided into six proximate homogenous sub-zones (Table 1). The various agro-climatic parameters used for sub-regionalization of the Eastern Himalayan Region (Zone II) are topography, rainfall and temperature, soil type, crop system and geographical continuity/proximity (Bhattacharyya *et al.*, 2001). The Brahmaputra Valley has been sub-divided into four agro-climatic sub-regions. Among these, the Central Brahmaputra Valley (CBV) Zone is located in the middle of the Brahmaputra Valley on the southern bank of River Brahmaputra and consists of the districts of Nagaon and Morigaon (Fig. 1). The CBV Zone is centrally located and, therefore, presents agro-climatic conditions that are more or less

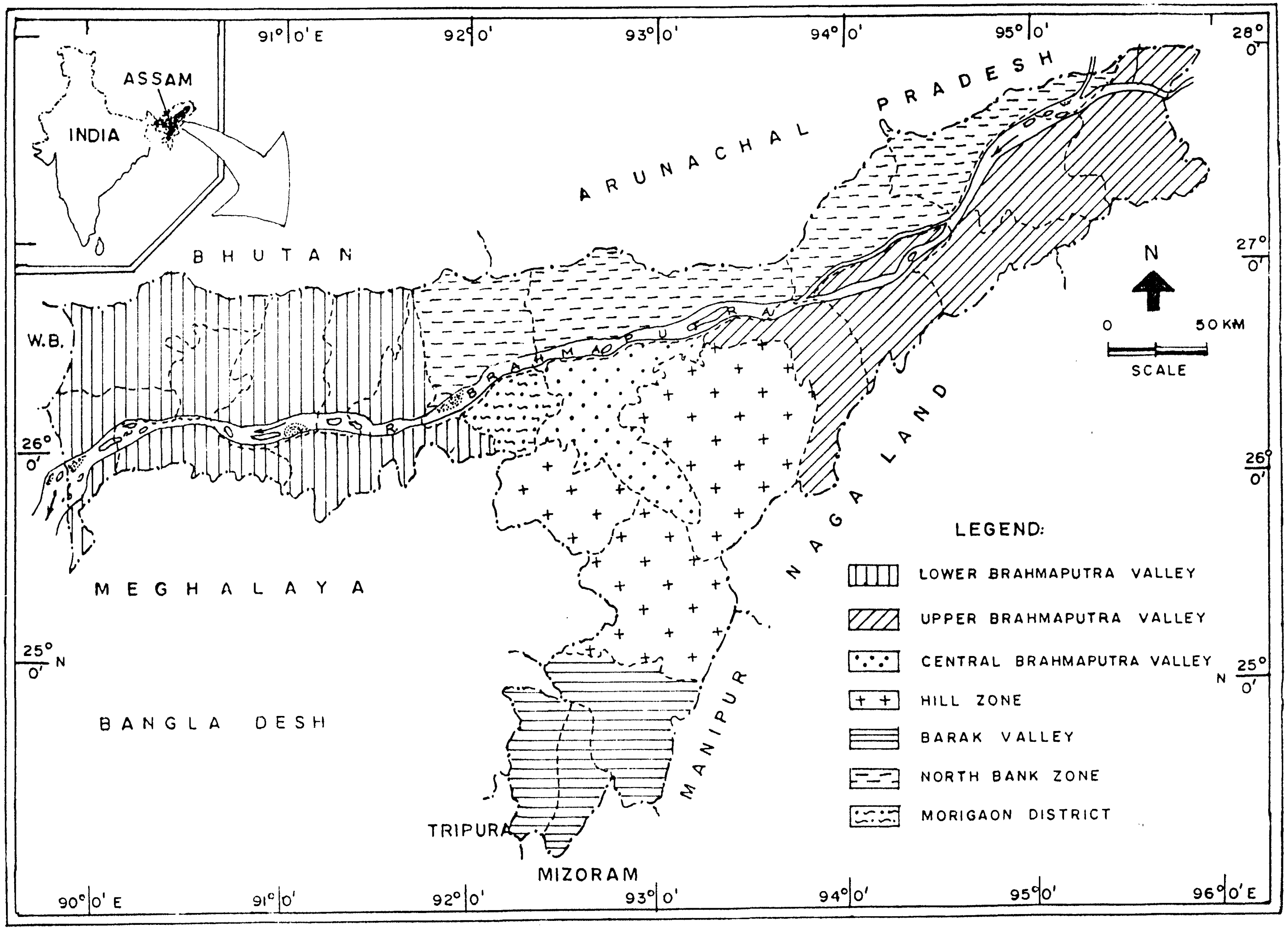


FIG. I. LOCATION OF THE STUDY AREA

representative of the entire Brahmaputra Valley. Within this sub-zone, two nearly identical and contiguous oxbow lakes representing open (Charan *Beel*) and closed types (Jaluguti *Beel*) located in the southern parts of Morigaon district (Fig. 2) were selected for the study based on a reconnaissance survey undertaken during February, 2000. Both the oxbows were created by Kolong River, which is one of the largest rivers flowing through this sub-zone and joining Brahmaputra River at Chandrapur near Guwahati. While Charan *Beel* still retains connection with River Kolong through a connecting channel (Khanda *Jan*), Jaluguti *Beel* has become isolated from its parent river due to the construction of flood control embankments. The selected *beels* share similar soil type (old alluvium), climatic conditions, catchments, etc. and therefore, riverine connection appears to be the only major factor differentiating them. Another factor favouring their selection is their easy accessibility (by road). Further, both are registered *beels* under the administrative control of the Assam Fisheries Development Corporation (AFDC), Guwahati, whose *Beel* Managers maintain reasonably reliable fish landing records.

Table 1. Agro-climatic sub-zones of Assam

Geographical region	Agro-climatic sub-zone	Districts included
I. Brahmaputra Valley	1. North Bank Plains	Dhemaji, Lakhimpur, Sonitpur & Darrang
	2. Upper Brahmaputra Valley	Golaghat, Jorhat, Sibsagar, Dibrugarh & Tinsukia
	3. Central Brahmaputra Valley	Nagaon & Morigaon
	4. Lower Brahmaputra Valley	Nalbari, Kamrup, Barpeta, Bongaigaon, Kokrajhar, Goalpara & Dhubri
II. Barak Valley	5. Barak Valley	Karimganj, Cachar & Hailakandi
III. Hills	6. Hills	Karbi Anglong & North Cachar Hills

Source: Bhattacharyya *et al.*, 2001.

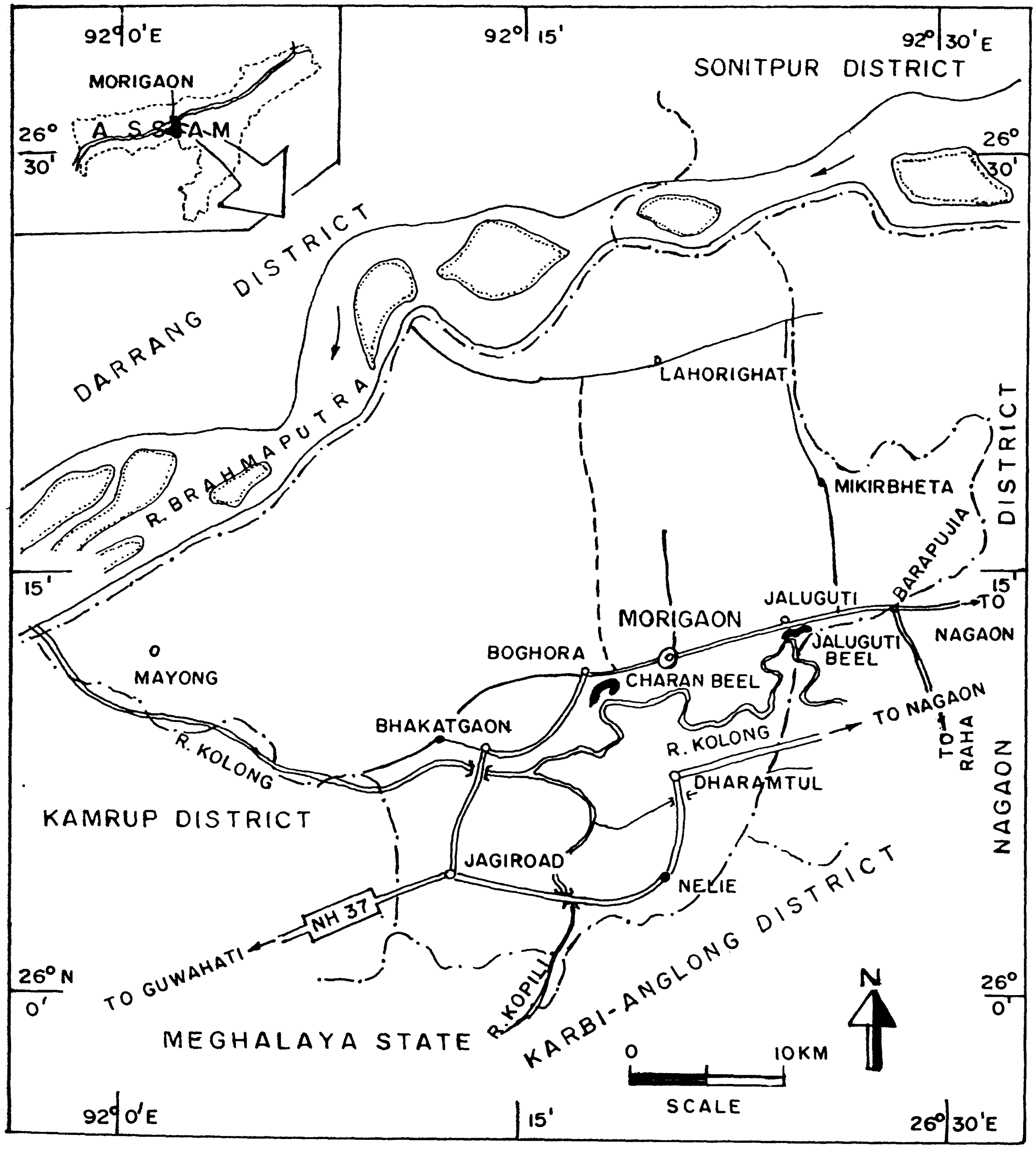


FIG. 2. LOCATION OF SELECTED BEELS IN MORIGAON DISTRICT, ASSAM

3.2 Description of the study area

Assam is one of the seven states constituting the northeastern region of India. It is situated in the Eastern Himalayan Region (Lat. 24°0' and 28°18' N; Long. 89°50' and 97°40' E) and covers an area of 78,438 km^2. The state is divided into three geographical zones, *viz.*, the Brahmaputra Valley (northern and the largest zone covering an area of 56,335 km^2), the Hill Zone (middle zone covering 15,141 km^2) and the Barak Valley (southern and the smallest zone covering 6,962 km^2) (Bhagowati, 2001). Soils of the two river valley zones are dominated by old alluvium type. However, soil is of recent alluvium type in areas along the bank of River Brahmaputra, particularly in the lower reaches. Areas of the Hills Zone are characterized by either red loam or laterite soil. Assam experiences sub-tropical climate climate with high rainfall. Four distinct seasons are recognized in the state, *viz.*, pre-monsoon (March to May), monsoon (June to September), post-monsoon (October and November) and winter (December to February) (Bhattacharyya *et al.*, 2001). As much as 65% of the average annual rainfall (2197.7 mm) in the state occurs during the monsoon season, followed by the pre-monsoon (25%) and the post-monsoon (7%) seasons. The winter is a virtually dry period, receiving only 3% of the average annual rainfall. The mean annual maximum temperature lies between 23.6° and 31.7°C and the minimum temperature varies from 10 to 25.2°C. The average solar radiation indicates that the radiation interception is only 36 to 38% of the astronomically possible sunshine hours during June to August owing to continuously overcast sky. Though the sunshine hours are much longer during November to February (70-74%), the radiation is not up to the desired extent due to foggy weather (Bhattacharyya *et al.*, 2001). The state has fairly humid climate with relative humidity ranging from 55 to 65% during the dry season and from 75 to 100% during the rainy season (mean: 76.6±12.5%) (Dey and Bhattacharjee, 1995).

The 2900 km long Brahmaputra River enters Assam from Arunachal Pradesh through the northeastern district of Tinsukia at an elevation of more than 600 m above mean sea level (MSL) (Sugunan and

Bhattacharjya, 2000). It flows through the northern plains of the state (average elevation 106 m MSL) longitudinally in an east-west direction before entering Bangladesh through Dhubri District. It bisects the valley into north and south banks. The Brahmaputra Valley is bordered by the sub-Himalayan mountain ranges of Bhutan and Arunachal Pradesh in the north and northeast, Nagaland hills in the east and southeast, the Hill Zone of Assam and Meghalaya hills in the south and the plains of West Bengal and Bangladesh in the west. These mountains/hills give rise to many fast flowing streams/rivers flowing down the gradient and ultimately joining River Brahmaputra. The Brahmaputra flows through Assam for about 730 km from the east to west before entering Bangladesh. It has 42 tributaries in the state – 27 on the north and 15 on the south banks (Bhagowati, 2001). These numerous rivers criss-cross the valley and irrigate the rich alluvial plain round the year; they also wreak havoc and destruction by way of recurring floods during the rainy season.

The Brahmaputra floodplain is narrow and elongated with a length of about 550 km and an average width of 70 km, and the gradient is as low as 13 cm per kilometre (Dey and Bhattacharjee, 1995). The northern margin is very steep with the Himalayas falling sharply from a height of 500 to 200 m. The tributaries of River Brahmaputra extend the floodplain in Arunachal Pradesh up to Dambuk, Nizamghat and Roing, and in the east up to Brahmakunda. The Brahmaputra floodplain is quite irregular along the south bank, extending near the confluence of Buhridihing, Disang, Dhansiri, Kolong-Kapili and Kulshi. The Assamese floodplains are subjected to as many as five flood events every year (Dey and Bhattacharjee, 1995). The floodplains of north and south banks together form an extensive physiographic unit containing a large number of *chars* and *chaporis* (riverine sand areas subjected to annual flood), temporary/semi-permanent shoals and islands (Taher, 1986).

The Brahmaputra Valley, constituting 72% of Assam's geographical area, houses most of its *beel*s (numbering 1070) and 92% of its total *beel* area. The predominance of *beels* in this valley is attributed to the often-changing course of rivers and their tributaries caused by heavy rainfall and associated discharge/floods during the southwest monsoon season. This, coupled with frequent earthquakes due to crustal instability of the northeastern region, triggers the process of meander cut-offs leading to the formation of oxbow lakes (Sugunan and Bhattacharjya, 2000). In addition, tectonic depressions are also formed due to earthquakes.

Morigaon District, which houses the two *beels* under investigation, is the second smallest district of the state (after Hailakandi). Most parts of the district lie close to River Brahmaputra and have numerous *beels*. Most of the areas of the district consist of alluvial plains; only a few hilly areas are found along the northwestern and southern borders.

3.3 Environment and sampling stations

The Charan and Jaluguti *Beels* are oxbow lakes created by River Kolong. Both lie parallel to the Jagiroad-Morigaon-Nagaon Road in Morigaon District. These are registered *beels* under the administrative control of the AFDC, Guwahati and are leased to local fishers' cooperative societies for five-year terms.

Charan *Beel* (Lat. 26°11' N; Long. 92°18' E) is an open *beel* situated at Oujari Village, which is about 17 km northeast of Jagiroad Town and 6 km west of Morigaon Town (district headquarters). The *beel* is connected to River Kolong through a narrow connecting channel (Khanda *Jan)* and Morikolong *Beel* (another open *beel*) through which ingress of floodwaters and riverine fish fauna takes place into the *beel* during the southwest monsoon season. It is infested with moderate growth of aquatic macrophytes, mainly of submerged type. The northern and northwestern sides of the *beel* are bordered by the Jagiroad-Morigaon Road and Oujari Village; northeastern side by the Khanda *Jan*, the southwestern side by a village road and the eastern side gradually merges with paddy fields. The water depth of the *beel* during March-April is in the range of 1.0 to 2.2 m, which increases by another 3 m during high floods (July-August). The *beel* is crescent-shaped, medium-sized (water spread area 60 ha) and has a total length of about 3.4 km. It has an average width of 274 m in the northeastern end, which gradually becomes wider towards the southwestern part (389 m). For the present study, three sampling stations were selected in the *beel* (Fig. 3). Station 1 is located south of the AFDC's Field Office near the first silk cotton tree along the southwestern arm of the *beel*. Station 2 is located in front of the AFDC's Field Office and represents the middle sector of the *beel*. Station 3 is located near the Oujari *Tiniali* (bus stoppage) along the northern arm of the *beel*.

Jaluguti *Beel* (Lat. 26°14' N; Long. 92°23' E) is a closed *beel* situated near Jaluguti *Bazar* (weekly market), which is about 12 km east of Morigaon Town and 7 km west of Barapujia. It is serpentine in shape and roughly lies along the east-west direction, parallel to the road linking Morigaon and Nagaon towns. The *beel* receives surface run-off from the catchments as well as occasional floodwaters from River Kolong through Veloupara *Jan* located towards the southeastern side. It is 80 to 149 m wide and most parts are choked with water hyacinth. The eastern side of the *beel* is comparatively shallower than the western side. The average depth of water ranges from 2.1 m (March-April) to 5.6 m (July-August). The *beel* is bordered by the Morigaon-Nagaon Road and Jaluguti and Tukunabori villages on the northern side, Kashodhora Village on the east, Nabhanga-Barapujia Village on the south and Bonpara-Danduwa Village on the west. The *beel* is medium in size (water spread area 35 ha) and is 3.02 km long. Two stations were selected in this *beel* for the present study (Fig. 4). Station 1 is located near the Jaluguti State Dispensary where infestation of water hyacinth was moderate. The other station (No. 2) was located behind the Jaluguti *Anchalik* College; this station represented the macrophyte-choked segment of the *beel*.

3.4 Field work and sampling procedure

Monthly samples were collected for a period of one year, from May 2000 to April 2001, from the five selected stations of the two *beels*. Soil, water and biota samples were collected using wooden plank-built boats (5.5 m

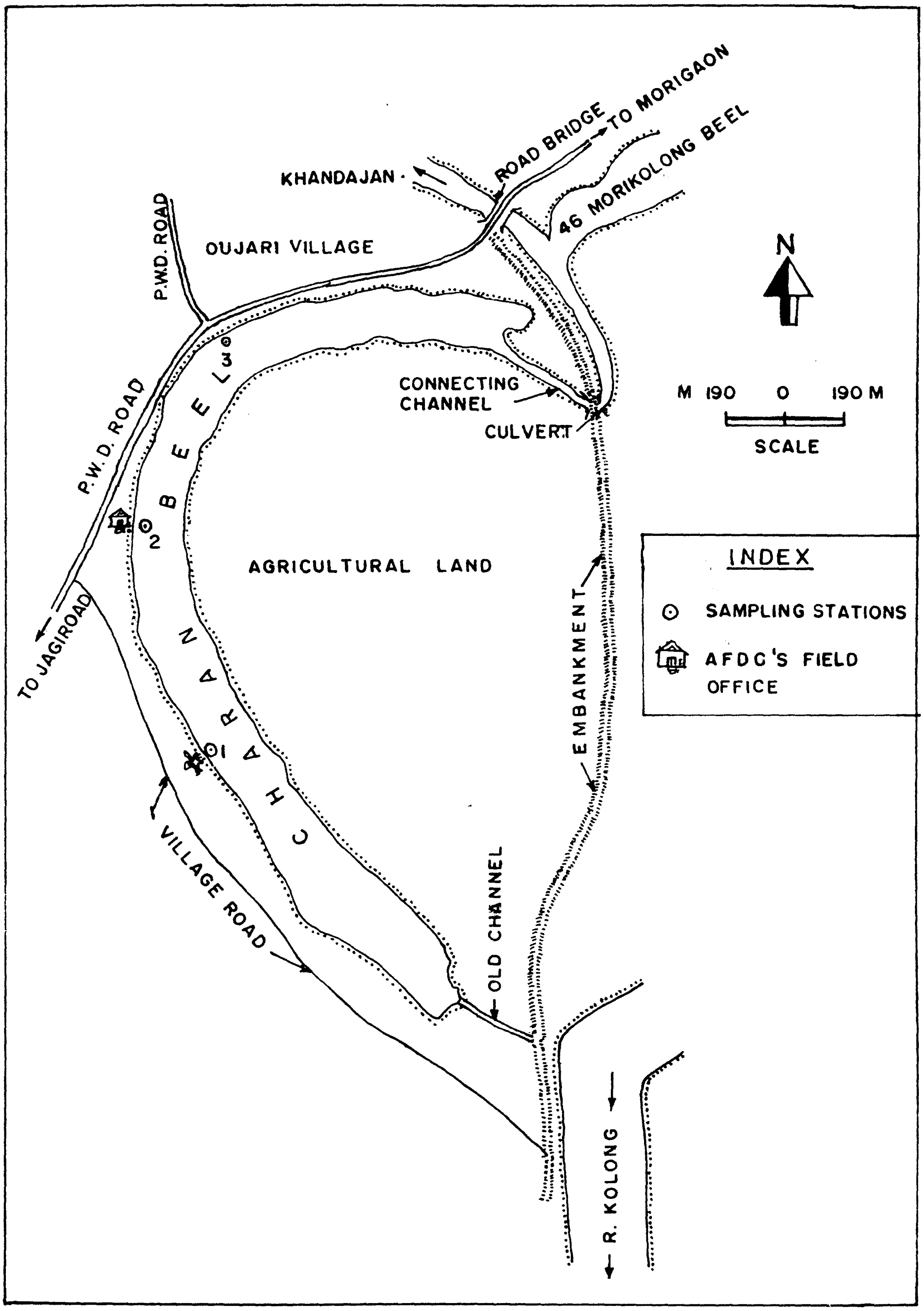


FIG. 3. LOCATION OF SAMPLING STATIONS IN CHARAN BEEL

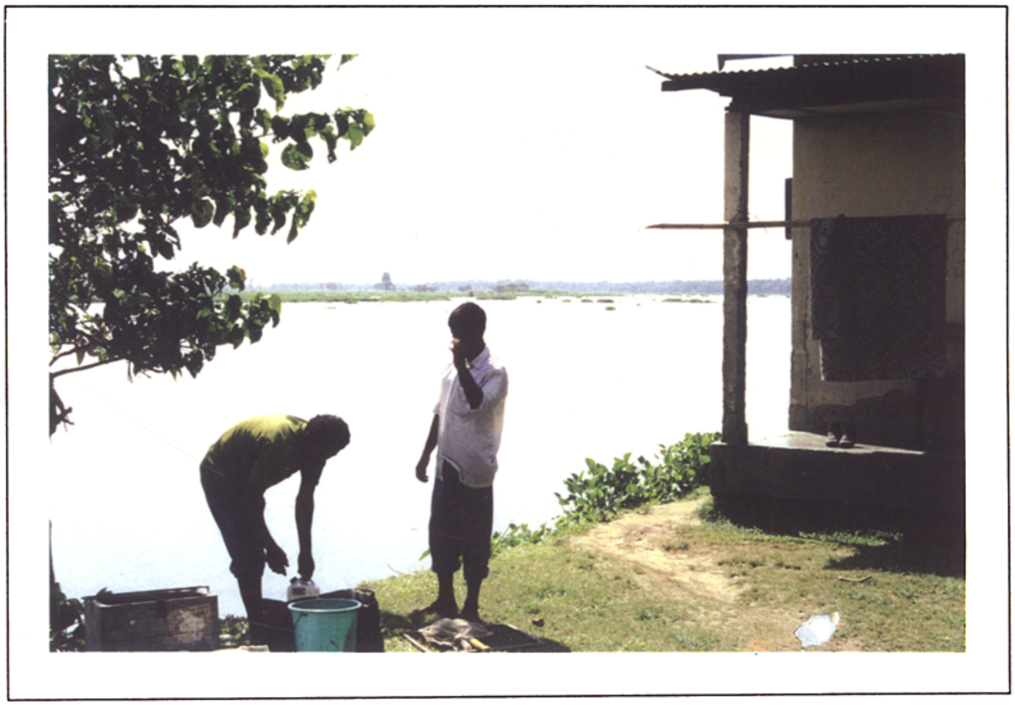


Plate 1. Photographs showing station 1 (top) and station 2 (bottom) of Charan *Beel*

Plate 2. Photograph showing station 3 of Charan *Beel*

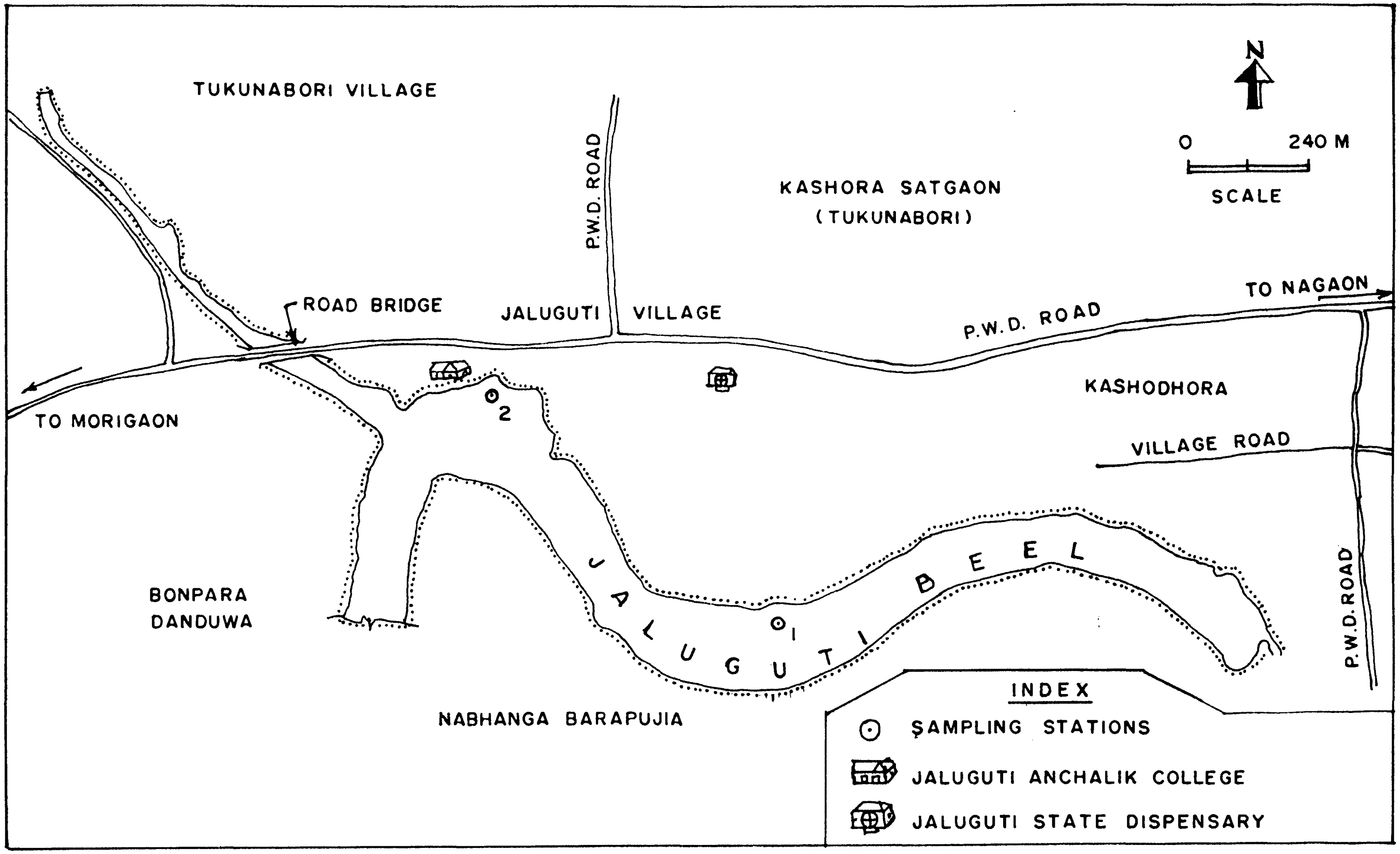


FIG. 4. LOCATION OF SAMPLING STATIONS IN JALUGUTI BEEL

Plate 3. Photographs showing station 1 (top) and station 2 (bottom) of Jaluguti *Beel*

overall length) or canoes (4.3 m OAL). Generally, samples were collected in the forenoon. In addition to the monthly samplings, water samples were also collected at 4 hours' interval starting at 6 A.M. from the two *beels* (at station 2) for assessing diurnal variations in selected physico-chemcial parameters during the months of May (pre-monsoon season), July (monsoon), November (post-monsoon) and January (winter).

3.4.1 Soil

Soil samples from the *beel* were collected using an Ekman dredge. From each station, five samples were collected, gross plant and animal parts removed and mixed thoroughly to get uniform composite samples of about 5 kg in weight. The samples were collected in black plastic bags and brought to the laboratory.

3.4.2 Water

Water samples for determination of various physico-chemical parameters were collected using a clean plastic bucket. The air and water temperatures (^{o}C) were recorded at each station using a standard mercury-in-glass thermometer. The depth of light penetration was measured at each station using a Secchi disc and was expressed in metres.

The pH of water was estimated in the field by a Lovibond comparator using the required discs and cross-checked in the laboratory with a WTW pH meter. The specific conductivity (µmho cm^{-1}) and total dissolved solids (mg l^{-1}) were estimated with the help of a portable Century kit/ WTW multiline. Free carbon dioxide and total alkalinity of water were estimated in the field following standard methods (APHA, 1998). For the estimation of dissolved oxygen, water samples were fixed in the field following Winkler's method.

3.4.3 Primary productivity

Primary productivity of phytoplankton was estimated by the light and dark bottle oxygen method using short-term *in situ* exposure of 4-6 hours

(Vollenweider, 1969). The rate of primary productivity of macrophytes was estimated using the diel oxygen curve, after deducting the amount fixed by phytoplankton from the total (Pathak, 1990). The oxygen values were converted to carbon by multiplying these with the factor 0.375, after Qasim *et al.* (1968).

3.4.4 Biota

3.4.4.1 Plankton

The phyto and zooplankton in the surface water were collected by filtering 50 litres of water through plankton nets having 60 μm and 150 μm mesh size, respectively. The nets used were of truncated cone shape having net mouth diameter of 20 cm and filtering cone length of 54 cm. Samples were immediately preserved in 4% buffered formalin.

3.4.4.2 Aquatic macrophytes

The larger aquatic plants were collected using a square-shaped wooden quadrat sampler (Jhingran *et al.*, 1988) having 0.25 m^2 area. The collected plants were segregated group-wise, excessive water drained out and weighed with the help of a portable top pan/spring balance. The collected plants were then brought to the laboratory in polyethylene bags to identify them and also to estimate their dry weight.

3.4.4.3 Macrophyte-associated fauna

Fauna associated with aquatic macrophytes were collected using a conical net (mouth area 0.09 m^2 and filtering cone length 84 cm) having 0.5 mm mesh size. The collected samples were immediately preserved in 5% formalin.

3.4.4.4 Macrobenthos

Sediment samples were collected using an Ekman dredge (area 0.025 m^2) and were sieved through 0.5 mm mesh size. The collected macrobenthos samples were preserved in 5% formalin.

3.4.4.4 Fisheries

Ichthyofaunistic composition of the two *beels* was examined through observation of fish catch at the auctioning centres as well as at the fishing spots. In addition, information on fish species dominating the landings, common and rare species, etc. were extracted from fishers, fish traders, AFDC's field staff (*Beel* Managers, watchmen), lessees and their employees. As far as possible, fish species were identified at the site itself. The species that could not be identified in the field were preserved in 5% formalin and brought to the laboratory for identification using standard manuals (*e.g.,* Day, 1978; Sen, 1985; Talwar and Jhingran, 1991).

To determine the composition of fish catch, the field-tested size criterion followed by AFDC's *Beel* Managers for recording catch was made use of. In this method, the landed fish are divided into two broad categories based on the size. The major fishes (A group) comprise those having a total length of 15 cm or more, which generally include the Indian major carps and large carnivores. The minor fishes (B group) include all fishes that are less than 15 cm in total length. Such segregation of fish catch into two broad size-groups is conveniently practised by fishers, while selling their catch by auction at the lessee's office/landing site.

3.5 Laboratory work

3.5.1 Soil quality

The soil samples collected from *beels* were air-dried in shade, ground to fine powder by gently pounding them with a wooden hammer, strained through sieves having 2 mm mesh size and again air-dried. Laboratory analyses to determine soil quality was done with these air-dried and powdered samples following the procedures described by Jhingran *et al.* (1988) and the results are expressed on dry weight basis.

Soil texture was determined by mechanical analysis using a Bouyocos hydrometer (graduated in g l^{-1}) and the results are expressed as percentage of sand, silt and clay particles in the soil sample. Soil pH was estimated in the suspension by glass electrode method after shaking the soils with distilled water (soil to water ratio 1.0:2.5) for half an hour using a WTH pH meter.

Organic carbon was determined by wet oxidation method of Walkley and Black (1934) and results expressed as percentage. Available nitrogen was estimated following the alkaline permanganate distillation method as described by Subbiah and Asija (1956). Available phosphorus was extracted following Bray's (P-1) method for acidic soils (Bray and Kurtz, 1945). Phosphorus in the extract was determined colorimetrically by chlorostannous reduced molybdophosphoric blue colour method (Jackson, 1967). Available nitrogen and available phosphorus levels are expressed as mg 100 g^{-1} soil.

3.5.2 Limnochemistry

The water samples were analyzed in the laboratory following standard methods and the values expressed as mg l^{-1} unless otherwise stated. Water samples fixed for dissolved oxygen in the field were analyzed in the laboratory following Winkler's method. Total hardness was estimated using the EDTA titrimetric method (APHA, 1998). Dissolved organic matter was estimated using the permanganate oxidation method (Jhingran *et al.*, 1988) and the values are expressed as mg C l^{-1}.

Phosphate-phosphorus and silicate–silica contents of water were estimated spectrophotometrically (APHA, 1998). Nitrate-nitrogen was estimated employing the phenol-disulphonic acid reduction method (Jhingran *et al.*, 1988). A Spectronic spectrophotometer (model UV 1) was used for measuring the absorbance for the above parameters.

3.5.3 Biotic communities

3.5.3.1 Plankton

In the laboratory, the phytoplankton samples were filtered through a 150 μm nylon cloth to separate the zooplankton. From the known volume, a sub-sample of 1 ml was drawn for estimating the numerical abundance of different genera of phytoplankton by the drop method and also using a Sedgwick-Rafter cell. The phytoplankton density is expressed as units per litre (u l^{-1}), the units being single cells, colonies or filament length in millimetres as the case may be. The specific weight of phytoplankton was considered to be unity, so that $10^6 \mu m^3 = 1 \mu g$ was used for conversion. The phytoplankton biomass is expressed as "algal fresh weight". This method was used by Goldman *et al.* (1968). The total phytoplankton biomass per square metre surface area within the entire trophogenic layer (0-4 m) was calculated by approximate integration (Vass *et al.*, 1988).

For estimating numerical abundance and quality composition of zooplankton, the macro-plankters were separated and counted under low magnification. From the known volume, a sub-sample of 1 ml was drawn. The number of different groups of micro-zooplankton present was counted under high magnification. The values are represented as numbers per litre (no. l^{-1}). Average zooplankton density and biomass were estimated following Edmondson and Winberg (1971). The biomass values were calculated by multiplying the unitary volume of each species with the number of animals present in each sample. The unitary volumes were calculated following Nauwerk (1963).

3.5.3.2 Aquatic macrophytes

In the laboratory, macrophytes were segregated and identified up to genus/species level using standard identification manuals (*e.g.*, Biswas and Calder, 1936; Fassett, 1940) and their dry weights were estimated using an electronic monopan balance. The values are expressed as kg dry wt m^{-2}.

3.5.3.3. Benthos and macrophyte-associated fauna

These were segregated in the laboratory and identified using standard manuals (*e.g.*, Ward and Whipple, 1959; Tonapi, 1980; Mitra and Kumar, 1988; ZSI, 1992). The individuals of each taxon were weighed and counted. Shell weight of molluscs was excluded while weighing. The values are expressed as g wet wt m^{-2}.

3.6 Secondary information

Data on meteorological parameters in respect of rainfall (mm), maximum and minimum air temperature (°C), and relative humidity (%) were collected from the Regional Agricultural Research Station (RARS), Assam Agricultural University, Shillongoni, Nagaon District. This RARS established under the National Agricultural Research Project in the CBV Zone makes daily meteorological observations for this agro-climatic sub-region of Assam. The visible solar radiation was calculated for the appropriate latitude from tables furnished by the US Weather Bureau (Kimball, 1935), and the values were cross checked with actual radiation data for Guwahati furnished by the India Meteorological Department, Pune. Monthly fish catch data for the selected *beels* were collected from the records of the headquarters and field offices of the AFDC, Guwahati. Fish catch composition was validated with field observations.

3.7 Computations and statistical analyses

The average primary production values were integrated to obtain values in g C $m^{-2}d^{-1}$, which were later converted to kcal $ha^{-2}yr^{-1}$. The following conversion factors were used for computing energy transformation and fish production potential of the selected *beels* based on primary productivity:

1 g of oxygen = 0.375 g carbon

1 g of O_2 produced during photosynthesis = 3.68 kcal

1 g of carbon = 2 g organic matter (Ryther, 1956)

1 g of dry weight of organic matter = 4.5 kcal

1 g of carbon = 10 g of wet weight of fish (Rodhe, 1958)

1 g carbon = 10 k cal (approx.)

Photosynthetic efficiency was calculated after Lindemann (1942) using the formula,

$$\text{Photosynthetic efficiency} = I_n/I_{n-1} \times 100,$$

where I_{n-1} is the solar radiation and I_n is the energy fixed by primary producers (expressed as kcal $ha^{-1}yr^{-1}$).

Assuming the average composition of freshwater fish to be 18% protein and 2% fat (the calorific value of protein and fat being 5600 and 9400 cal g^{-1} respectively), one gram wet weight of fish comes to be approximately 1200 cal (Natarajan and Pathak, 1983). Since the average dry matter content of fish is 20% (18% protein and 2% fat), out of which 50% can be taken as carbon, 10% of wet weight of fish can be reckoned as carbon (Vinogradov, 1953). These conversion factors have been used by many workers (*e.g.*, Natarajan and Pathak, 1983; Pathak *et al.*, 1985; Yadava *et al.*, 1987; Vass *et al.*, 1988; Acharjee *et al.*, 1998).

3.7.1 Student's t test

Average gross phytoplankton productivity and average gross macrophyte productivity were tested using Student's t test (Snedecor and Cochran, 1994) to find out significant differences, if any, between the *beels* at 5% level of significance.

3.7.2 Correlation

The data collected on various meteorological and hydrobiological parameters were subjected to correlation analysis using a statistical programme (SYSTAT, Version 8.0) in a personal computer. Significance of the observed simple correlation coefficient was tested at 5% level of significance.

3.8 Trophic structure

The energy flow models for the selected *beel*s were proposed based on the food web proposed for a small stream community in south Wales by Steele (1970) and the detritus food chain proposed for estuarine mangrove areas of south Florida, USA by W. E. Odum (1970). The 'compartment model' (E. P. Odum, 1983) was used for the purpose since it helped to compartmentalize a group of organisms into different trophic levels. The trophic levels (steps in the food chain/web) were determined on the basis of levels or positions at which a species or group of organisms feeds. The macrophytes and phytoplankton occupied the first trophic level (primary producers, denoted by P), the herbivores/omnivores (primary consumers or C_1) the second level, the secondary consumers (C_2) or primary carnivores the third level and the tertiary consumers (C_3) or piscivores the fourth and the last level. Food chains were initiated with producers at the bottom; successive trophic levels were connected by arrows, which led from the organism being eaten to the organism eating it (E. P. Odum, 1983; Kundu, 1999). Fish species contributing significantly to fish catch of the selected *beels* were divided into herbivores, omnivores and carnivores on the basis of their actual dietary habits, depending on the percentage of animal and vegetable food consumed by the fish (Das and Moitra, 1963). Information on the food and feeding habits of dominant fish species occurring in the selected *beels* was mainly extracted from literature (Verheust, 1998; Chondar, 1999). The biomass of organisms (dry weight m^{-2}) occupying the four trophic levels in the *beels* was estimated and plotted to obtain the ecological pyramid of biomass (Juday, 1942; Harvey, 1950; E. P. Odum, 1983).

4. RESULTS

4.1 Meteorology

During the study period, the region experienced a total annual rainfall of 2308.4 mm (Table 2). Over three-fourth of the total annual precipitation (1802.2 mm; 78.07%) occurred during the southwest monsoon season (June to September) (Fig. 5). The pre-monsoon season (March to May) contributed to 18.96% of annual rainfall (437.6 mm), followed by the post-monsoon months of October and November (54.6 mm, 2.37%). The winter season was an almost dry period receiving only 14 mm (0.6%) of rainfall and no precipitation occurred in the month of January. In total, it rained for 114 days, with an average daily rainfall of 16 mm.

The mean annual maximum temperature fluctuated between 25.3 and 33.3°C while the minimum temperature varied from 10.4 to 26°C. The ambient temperature started declining appreciably from November and attained the lowest levels during December-January. The region had a fairly humid climate with relative humidity ranging from 53 to 95% during the dry season and from 71.5 to 99.3% during the rainy season.

4.1.2 Air temperature

Air temperature ranged from 24.1 to 34.8°C in Charan *Beel* (Table 3). Jaluguti *Beel* recorded slightly higher ambient temperature (24.8 to 35.8°C) than that of Charan *Beel*. Air temperature recorded at Jaluguti *Beel* was marginally higher than that of Charan *Beel* throughout the study period except in April. Temporal variation of air temperature followed an identical bimodal pattern in both the *beels* (Fig. 6). Lowest air temperatures were recorded during December in both the *beels*. Air temperature was low during the period from November to February. It gradually increased during the premonsoon and monsoon months to reach peak levels in July. Only exception to this seasonal trend was observed in May when slightly lower

Table 2. Monthly variations in meteorological parameters in the study region

Months	No. of rainy days	Rainfall (mm)	Av. air temp. (°C)		Av. RH (%)	
			Max	Min	Max	Min
2000 May	16	227.6	31.8	23.1	92.4	73.0
Jun	22	443.6	32.5	25.0	94.3	77.5
Jul	25	289.8	33.3	26.0	92.4	71.5
Aug	23	527.0	31.9	25.4	94.3	76.9
Sep	20	541.8	30.8	24.7	95.1	80.0
Oct	10	38.0	31.2	22.6	95.5	71.5
Nov	4	16.6	27.2	17.4	99.3	69.2
Dec	2	9.4	25.3	11.1	ND	ND
2001 Jan	0	0	23.9	10.4	ND	ND
Feb	3	4.6	25.7	13.5	95.0	56.9
Mar	5	27.6	29.7	15.0	91.0	53.0
Apr	14	182.4	30.3	18.6	89.0	56.0
Annual av.	144	2308.4	-	-	-	-

Note: Av. = Average; RH = Relative humidity; ND = No data

Courtesy: Regional Agricultural Research Station (Assam Agricultural University), Shillongoni, Nagaon District, Assam.

Table 3. Variations in air temperature (°C) in the selected *beels*

Months	Charan *Beel*				Jaluguti *Beel*		
	Station 1	Station 2	Station 3	Monthly average	Station 1	Station 2	Monthly average
2000 May	29.3	29.0	29.8	29.4	30.5	30.7	30.6
Jun	34.2	34.0	34.6	34.3	35.3	35.1	35.2
Jul	34.8	34.7	35.0	34.8	35.8	35.6	35.7
Aug	34.3	34.0	34.7	34.3	35.6	35.5	35.6
Sep	32.6	32.6	32.8	32.7	33.2	33.2	33.2
Oct	33.3	34.1	34.3	33.9	34.7	34.5	34.6
Nov	26.4	26.0	26.5	26.3	27.1	27.1	27.1
Dec	24.2	24.1	24.4	24.2	24.8	24.8	24.8
2001 Jan	26.0	25.2	26.3	25.8	27.4	27.3	27.4
Feb	25.7	25.7	28.0	26.5	28.2	28.2	28.2
Mar	32.1	32.0	32.2	32.1	34.8	35.0	34.9
Apr	33.0	32.2	33.1	32.8	32.1	32.1	32.1
Annual av.	30.5	30.3	31.0	30.6	31.6	31.6	31.6

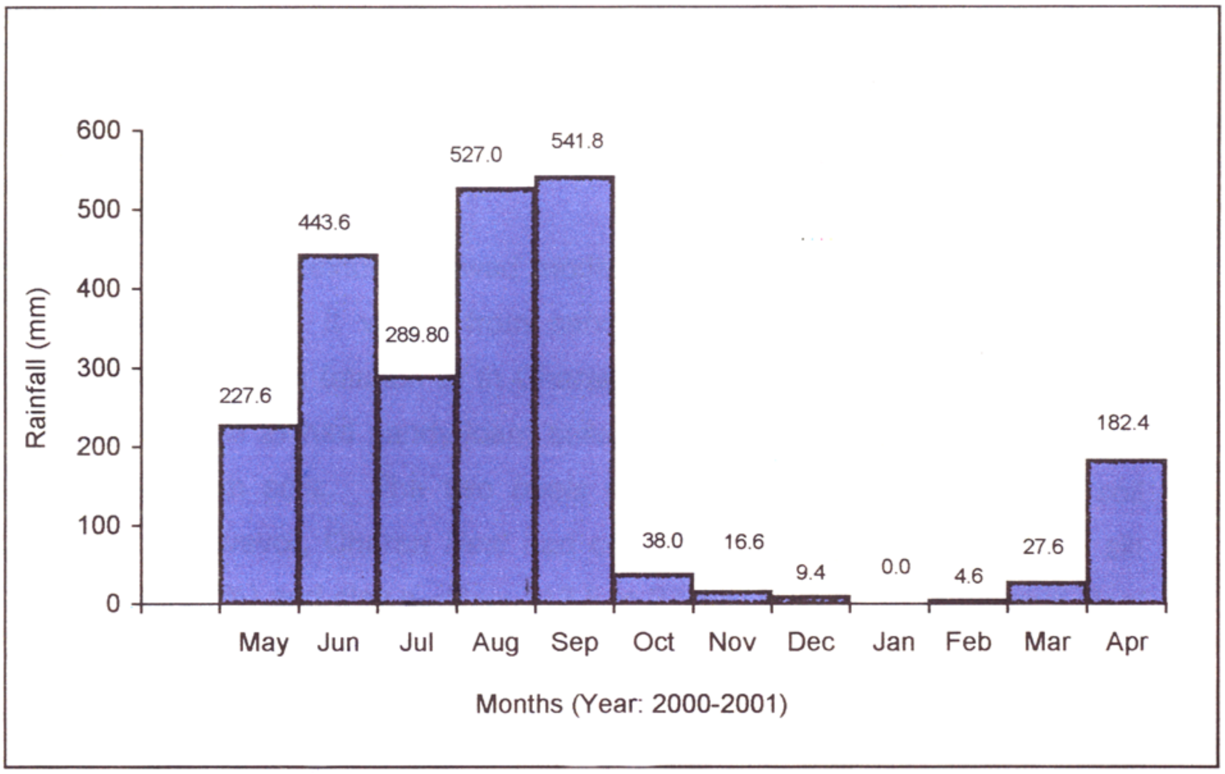


Fig. 5. Monthly variations in rainfall in the study region

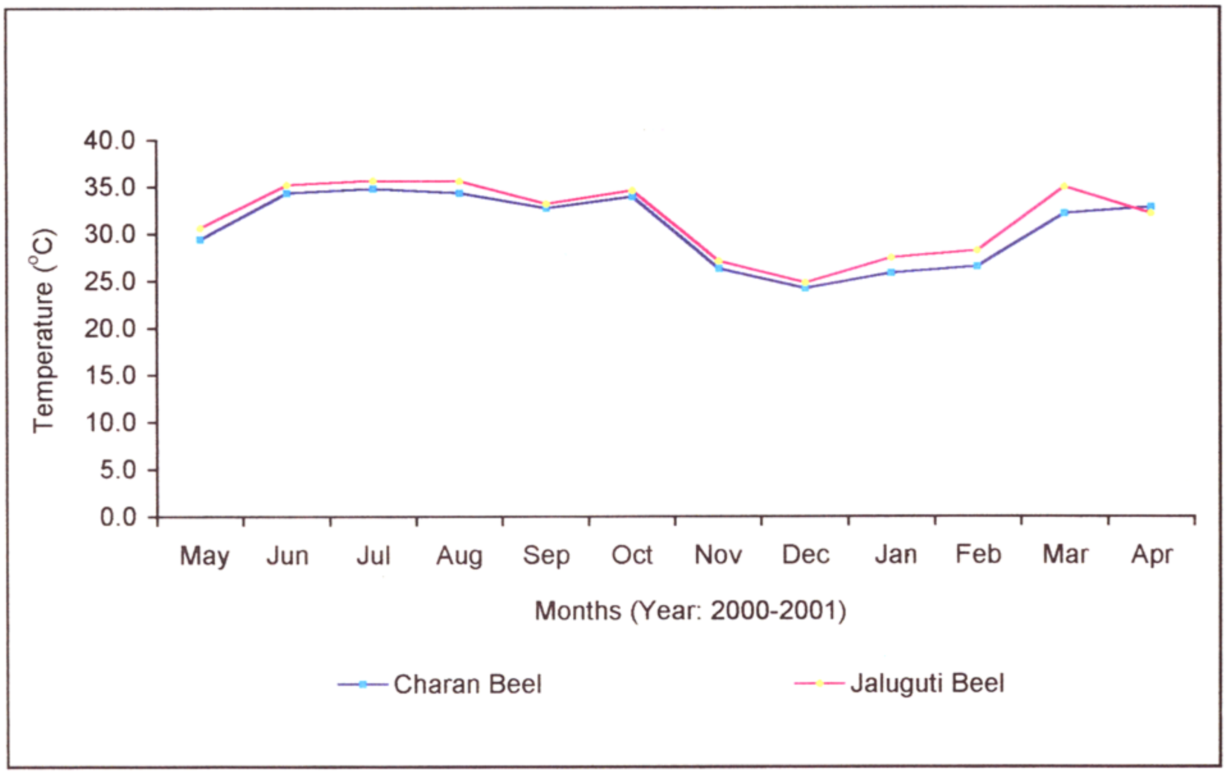


Fig. 6. Variations in mean air temperature in the selected beels

temperature was recorded at all the stations. Air temperature remained above 30°C up to October, after which it declined sharply to reach lowest levels during the winter months.

4.2 Soil quality

4.2.1 Soil texture

Soil texture showed moderate spatial variations in the selected *beels* (Table 4). It varied from sandy-loam (station 3), sandy-clay-loam (station 1) to loam (station 2) in Charan *Beel*. In Jaluguti *Beel*, the western sector (station 2) had sandy-loam soils, while the eastern sector (station 1) had silty-loam soils. The two *beels* did not show much variation in soil texture. However, Charan *Beel* had comparatively higher proportion of silt (31.1 to 46.7%) and clay particles (13.5 to 27.3%) than those of Jaluguti *Beel* (silt 21.2 to 44.3%, clay 9.3 to 12.3%), respectively.

4.2.2 Soil pH

Soil pH ranged from 4.6 to 6.2 in Charan *Beel* (Table 5). The range of variation between months and stations was comparatively lower (4.5 to 5.8) in Jaluguti *Beel*.

Soil pH exhibited distinct seasonal variation during the study period (Fig. 7). The trend of temporal variation was more or less similar in both the *beels*. The soils of the *beels* recorded minimal pH levels during the late pre-monsoon months (April-May). The pH levels increased sharply with the onset of monsoon season and reached peak levels either in June (Charan *Beel*) or in July (Jaluguti *Beel*). Soil pH showed a declining trend from July onwards. Smaller secondary peaks were observed in September (at station 2 of Charan *Beel* and station 1 of Jaluguti *Beel*), January (at station 1 of Charan *Beel* and station 2 of Jaluguti *Beel*) or in August (station 3 of Charan *Beel*). Generally, high soil pH was recorded during the period from June to November. Soil pH recorded during these periods was equal to or higher than the annual average values of the corresponding stations. Only station 2 of Jaluguti *Beel* had marginally lower soil pH than the annual average level in November.

Table 4. Soil texture in the selected *beels*

Name of *beel*	Station	Composition of soil particles (%)			Textural class
		Sand	Silt	Clay	
Charan	1	38.4	33.2	27.3	Sandy-clay-loam
	2	30.7	46.7	20.9	Loam
	3	53.0	32.1	13.5	Sandy-loam
Jaluguti	1	31.4	44.3	12.3	Silt-loam
	2	67.4	21.2	9.3	Sandy-loam

Table 5. Variations in soil pH in the selected *beels*

Months	Charan *Beel*			Jaluguti *Beel*	
	Station 1	Station 2	Station 3	Station 1	Station 2
2000 May	4.0	4.4	4.9	3.9	4.9
Jun	6.3	6.1	6.1	5.9	5.3
Jul	6.2	5.8	5.8	5.8	5.6
Aug	5.9	5.6	5.9	5.5	5.5
Sep	5.8	5.7	5.7	5.7	5.3
Oct	5.8	5.5	5.6	5.5	5.2
Nov	5.5	5.4	5.6	5.3	5.1
Dec	5.2	5.3	5.3	5.2	5.1
2001 Jan	5.4	5.3	5.4	5.2	5.2
Feb	5.3	5.4	5.2	5.1	5.2
Mar	5.3	5.4	5.3	5.2	5.0
Apr	5.1	4.5	4.6	5.0	3.8
Annual av.	5.5	5.4	5.5	5.3	5.1

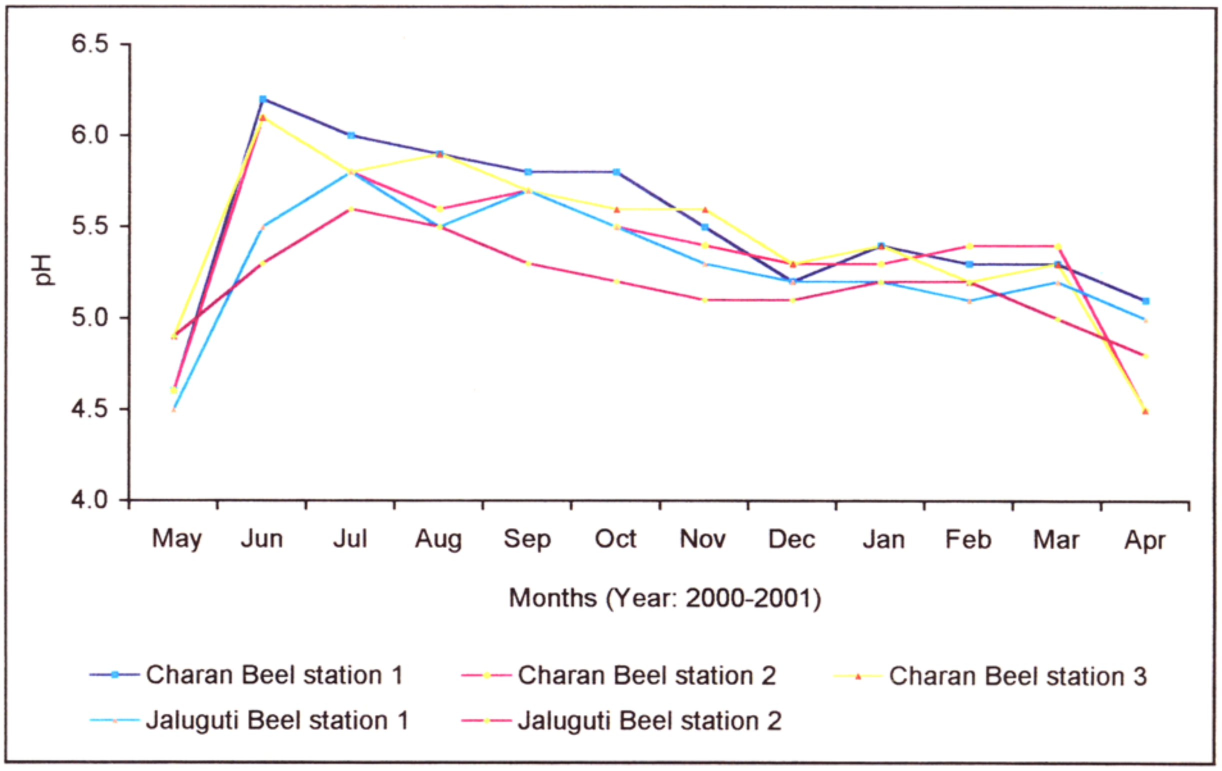


Fig. 7. Variations in soil pH in the selected beels

Soils of Charan *Beel* had comparatively higher pH levels (overall average 5.5) than that of Jaluguti *Beel* (5.4). Both the *beels* also showed slight variation between stations. In Charan *Beel*, the middle sector (station 2) had marginally lower soil pH (annual average pH 5.4) than the other two sectors. In Jaluguti *Beel*, soils of the western sector (station 2) had marginally lower pH (annual average 5.2) than the eastern sector (5.3). Further, the range of variation in soil pH was wider (4.5 to 5.8) at station 1 than at station 2 (4.8-5.6).

4.2.3 Organic carbon

Organic carbon in soil exhibited considerable spatio-temporal variations in the selected *beels* (Table 6). It ranged from 1.06 to 5.52% in Charan *Beel*. The range of variation was comparatively wider (1.39 to 8.67%) in Jaluguti *Beel*. Jaluguti *Beel* had comparatively higher organic carbon content in soil (average value 3.19%) than Charan *Beel* (2.49%). Jaluguti *Beel* also recorded the highest organic carbon levels (8.67%) at station 2 in April.

Organic carbon content of soil underwent irregular temporal variation during the study period (Fig. 8). Further, the individual stations differed considerably in their seasonal variation patterns. Generally, the period from June to August recorded low organic carbon concentrations (except at station 1 of Jaluguti *Beel*). Organic carbon content of soil gradually increased from September onwards to reach maximal levels in April at all the stations. The only exception to this trend was observed at stations 2 and 3 of Charan *Beel*, which recorded low levels of soil organic carbon during January-February. A secondary peak in organic carbon content was observed in December at most stations.

4.2.4 Available nitrogen

The concentration of available nitrogen in soils varied from 9.58 to 36.21 mg 100 g^{-1} in Charan *Beel* (Table 7). Jaluguti *Beel* recorded comparatively higher soil available nitrogen levels (range 12.58-38.67 mg 100 g^{-1}, average 24.78 mg 100 g^{-1}) compared to that of Charan *Beel* (average 18.20 mg 100 g^{-1}). Spatial variation within Charan *Beel* showed highest

Table 6. Variations in soil organic carbon (%) in the selected *beels*

Months	Charan *Beel*			Jaluguti *Beel*	
	Station 1	Station 2	Station 3	Station 1	Station 2
2000 May	2.66	2.15	1.46	2.60	1.48
Jun	1.96	1.71	1.39	1.39	1.52
Jul	1.48	1.52	1.65	2.66	1.39
Aug	1.58	1.06	1.77	1.52	1.65
Sep	1.77	2.56	2.15	3.18	2.60
Oct	2.15	1.84	1.90	2.60	2.28
Nov	2.60	2.28	2.66	3.18	2.03
Dec	3.18	2.15	3.93	3.30	4.44
2001 Jan	2.60	1.96	1.46	3.28	3.93
Feb	2.66	1.52	3.30	3.18	4.76
Mar	3.42	3.30	3.93	5.08	4.60
Apr	5.39	5.52	5.14	5.14	8.67
Annual av.	2.62	2.30	2.56	3.09	3.28

Table 7. Variations in soil available nitrogen (mg 100 g^{-1}) in the selected *beels*

Months	Charan *Beel*			Jaluguti *Beel*	
	Station 1	Station 2	Station 3	Station 1	Station 2
2000 May	23.96	23.16	20.23	32.22	34.68
Jun	18.10	22.90	18.10	26.70	27.62
Jul	20.23	26.89	22.90	21.79	27.01
Aug	19.97	23.69	19.97	29.77	30.98
Sep	15.71	25.29	12.78	21.79	27.62
Oct	18.10	18.10	10.92	20.87	26.39
Nov	10.92	12.78	9.58	21.18	20.26
Dec	9.58	10.92	9.58	15.96	23.32
2001 Jan	10.92	9.58	10.92	18.11	18.11
Feb	12.78	13.84	12.78	14.73	12.58
Mar	15.71	29.29	20.23	15.96	32.22
Apr	34.61	36.21	23.96	38.67	36.24
Annual av.	17.55	21.05	16.02	23.15	26.42

average soil available nitrogen levels at station 2 (21.05 mg 100 g^{-1}) followed by station 1 (17.55 mg 100 g^{-1}), whereas station 3 had the lowest levels (16.02 mg 100 g^{-1}). In Jaluguti *Beel*, station 2 had considerably higher available nitrogen levels (26.42 mg 100 g^{-1}) than that of station 1 (23.15 mg 100 g^{-1}).

Available nitrogen content of soils exhibited distinct temporal variation during the study period (Fig. 9). The trend of seasonal variation was more or less similar in both the *beels*. Maximal values were recorded in April at all the stations. Available nitrogen levels declined with the first monsoon showers and the declining trend continued up to November or January, when the lowest levels were recorded. However, both the stations of Jaluguti *Beel* recorded secondary peaks in August and recorded the lowest levels in February, which was at variance with the generalized trend observed in Charan *Beel*.

4.2.5 Available phosphorus

Available phosphorus content of soils fluctuated between 0.26 to 1.3 mg 100 g^{-1} in Charan *Beel* during the study period (Table 8). Jaluguti *Beel* recorded slightly higher levels of soil available phosphorus (range 0.36 to 1.44 mg 100 g^{-1}, average 0.85 mg 100 g^{-1}) compared to that of Charan *Beel* (average 0.66 mg 100 g^{-1}). In Charan *Beel,* soils of station 2 recorded the highest average phosphorus content (0.73 mg 100 g^{-1}) followed by station 1 (0.66 mg 100 g^{-1}) and station 3 (0.58 mg 100 g^{-1}). Spatial variation was negligible in Jaluguti *Beel*.

The temporal variation pattern showed considerable differences between the *beels* and among the stations (Fig 10). However, a distinct increasing trend was observed from December (Charan *Beel*) or January (Jaluguti *Beel*) onwards reaching maximal level in April at all the stations. The values declined sharply during May to reach low levels in June at most stations, after which there was a slight increase in available nitrogen levels to reach secondary peaks in August at most stations. The lowest levels of available phosphorus were recorded either during November-December or in January (Jaluguti *Beel*).

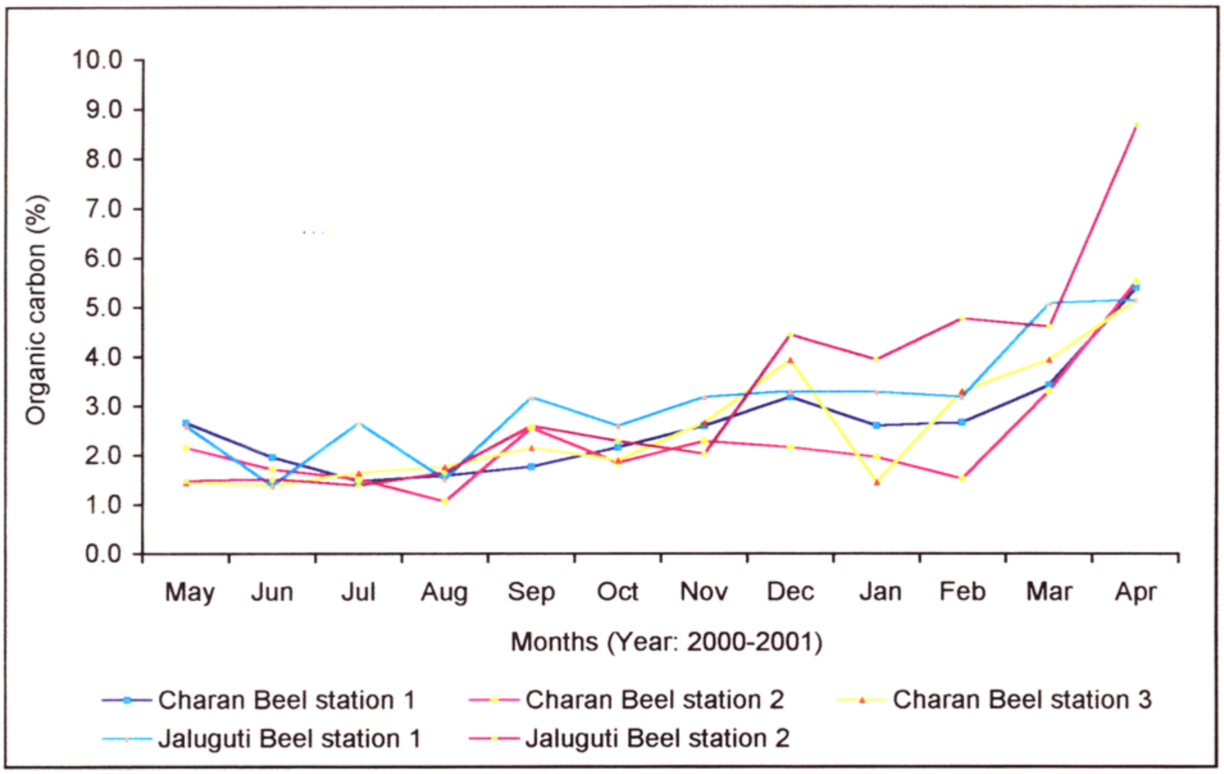


Fig. 8. Variations in soil organic carbon in the selected beels

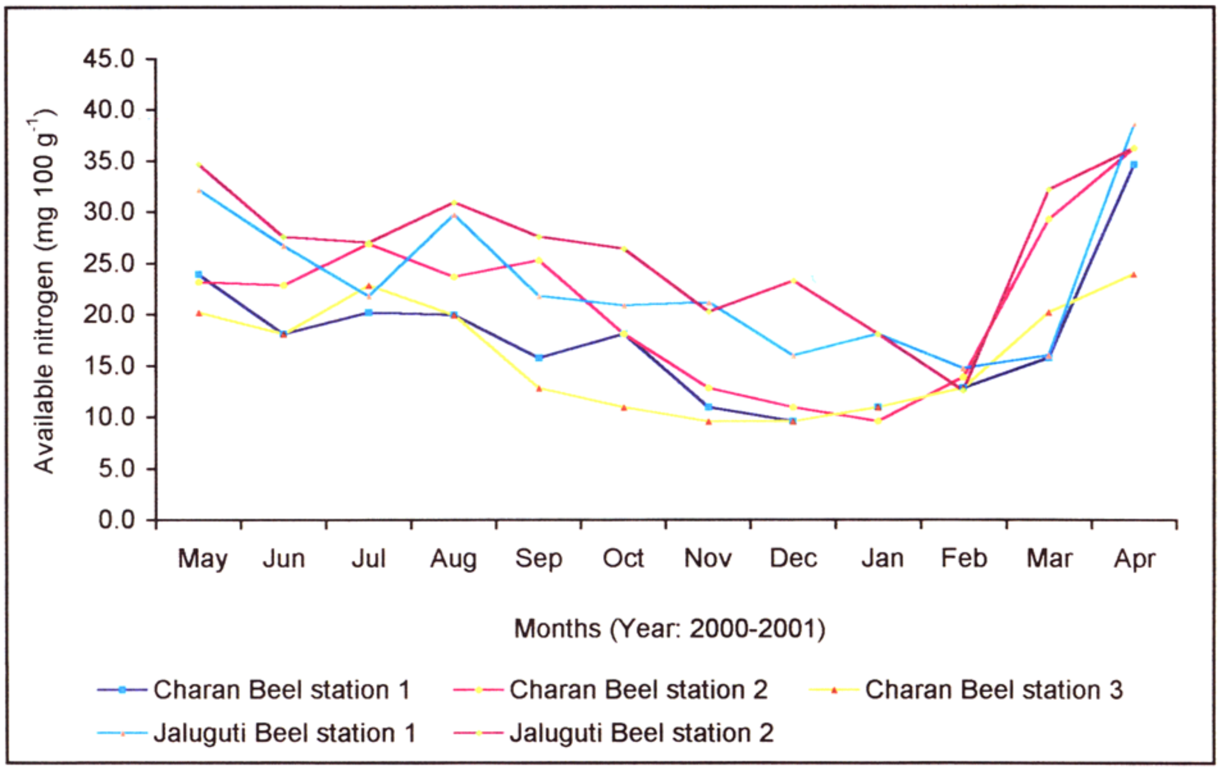


Fig. 9. Variations in soil available nitrogen in the selected beels

4.3 Physico-chemical characteristics of water

4.3.1 Water temperature

Water temperature varied from 21.5 to 33.4°C in Charan *Beel*, whereas it ranged from 21.8 to 34.0°C in Jaluguti *Beel* (Table 9) during the study period.

The pattern of temporal variation in respect of water temperature was similar in both the *beels* (Fig 11) with coolest water temperature recorded in January. Water gradually became warmer from February onwards to reach maximal temperature in August. The secondary peak was observed in October, after which water temperature declined sharply during the period from November-December. Charan *Beel* recorded slightly lower water temperature (average 28.7°C) compared to that of Jaluguti *Beel* (29.1°C). The variation among different stations of each *beel* was minimal during the study period.

4.3.2 Secchi disc depth

Secchi disc depth fluctuated between 0.39 and 1.35 m in Charan *Beel*, whereas in Jaluguti *Beel* it varied from 0.23 to 1.45 m (Table 10). The range of variation was higher in Jaluguti *Beel* than that of Charan *Beel*. On an average, Secchi disc depth was slightly lower (0.95 m) in Charan *Beel* compared to that of Jaluguti *Beel* (1.0 m). The average Secchi disc depth was lower at station 3 of Charan *Beel* (0.81 m) and at station 2 of Jaluguti *Beel* (0.94 m) than that of the other stations (1.01 to 1.05 m).

No definite seasonal variation pattern with respect to Secchi disc depth was discernible in the selected *beels* (Fig. 12). The lowest values were recorded either in June (Charan *Beel* station 3, Jaluguti *Beel* station 1), September (Jaluguti *Beel* station 2) or in April (stations 1 and 2 of Charan *Beel*). Similarly, maximal values were recorded either in May (Charan *Beel* station 1 and Jaluguti *Beel* station 2), August (Charan *Beel* station 2) or in February (Jaluguti *Beel* station 1). In general, lower Secchi disc depth was recorded in April, September or June in most of the stations of the two *beels*.

Table 8. Variations in soil available phophorus (mg 100 g^{-1}) in the selected *beels*

Months	Charan *Beel*			Jaluguti *Beel*	
	Station 1	Station 2	Station 3	Station 1	Station 2
2000 May	0.90	1.05	0.86	1.36	1.13
Jun	0.48	0.69	0.76	0.87	0.76
Jul	0.68	0.71	0.68	0.89	0.95
Aug	0.75	0.71	0.76	1.01	0.90
Sep	0.59	0.68	0.48	0.68	0.88
Oct	0.68	0.71	0.41	0.86	0.90
Nov	0.36	0.59	0.26	0.48	0.66
Dec	0.36	0.48	0.36	0.41	0.86
2001 Jan	0.41	0.52	0.41	0.36	0.41
Feb	0.59	0.52	0.36	0.52	0.59
Mar	0.76	0.87	0.76	0.95	1.01
Apr	1.30	1.26	0.90	1.44	1.44
Annual av.	0.66	0.73	0.58	0.82	0.87

Table 9. Variations in water temperature (°C) in the selected *beels*

Months	Charan *Beel*			Jaluguti *Beel*	
	Station 1	Station 2	Station 3	Station 1	Station 2
2000 May	28.0	27.5	28.3	28.5	28.6
Jun	30.5	31.0	32.2	31.5	31.0
Jul	32.0	31.9	32.3	32.6	32.5
Aug	33.3	33.1	33.4	34.0	33.7
Sep	31.1	31.0	31.4	31.5	32.0
Oct	32.0	31.9	32.1	32.3	32.2
Nov	25.1	25.5	25.2	26.1	26.0
Dec	23.6	23.5	23.7	23.9	23.8
2001 Jan	22.1	21.5	21.8	22.8	22.2
Feb	25.0	25.2	26.0	27.6	27.4
Mar	30.1	30.3	30.2	28.1	29.0
Apr	30.9	31.0	31.2	30.2	30.1
Annual av.	28.6	28.6	29.0	29.1	29.0

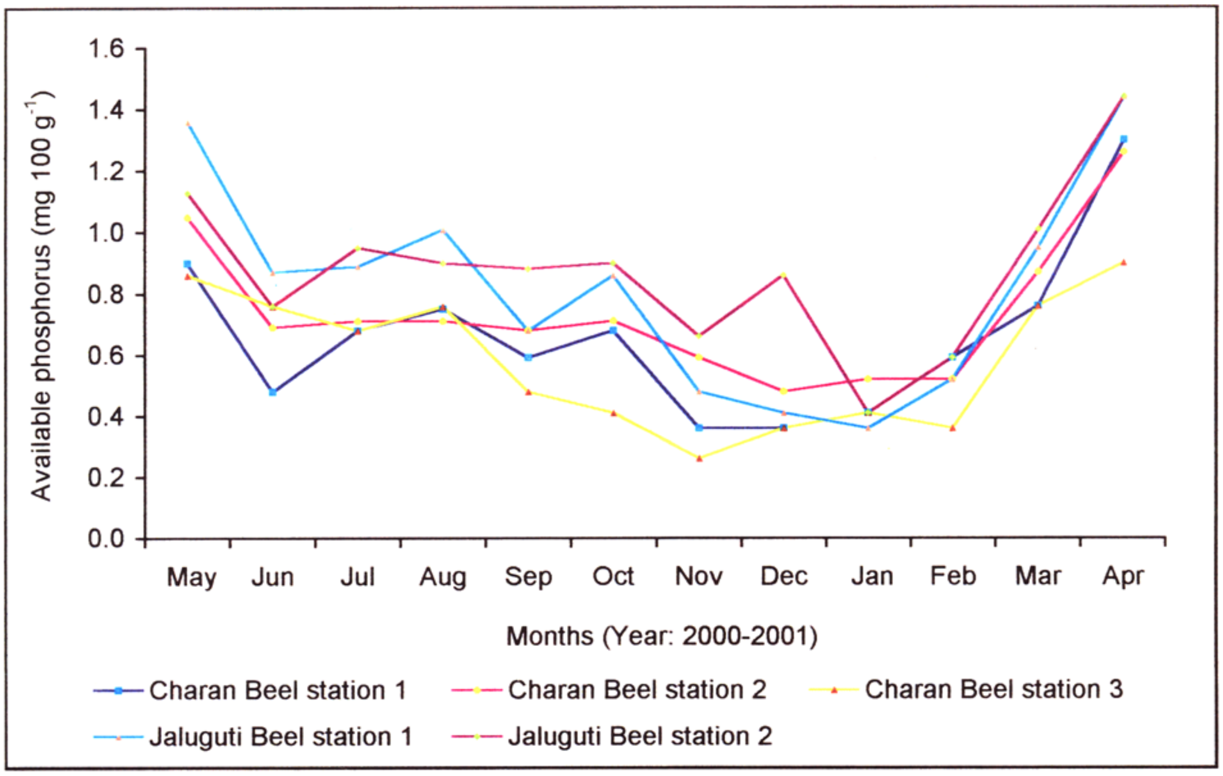


Fig. 10. Variations in soil available phosphorus in the selected beels

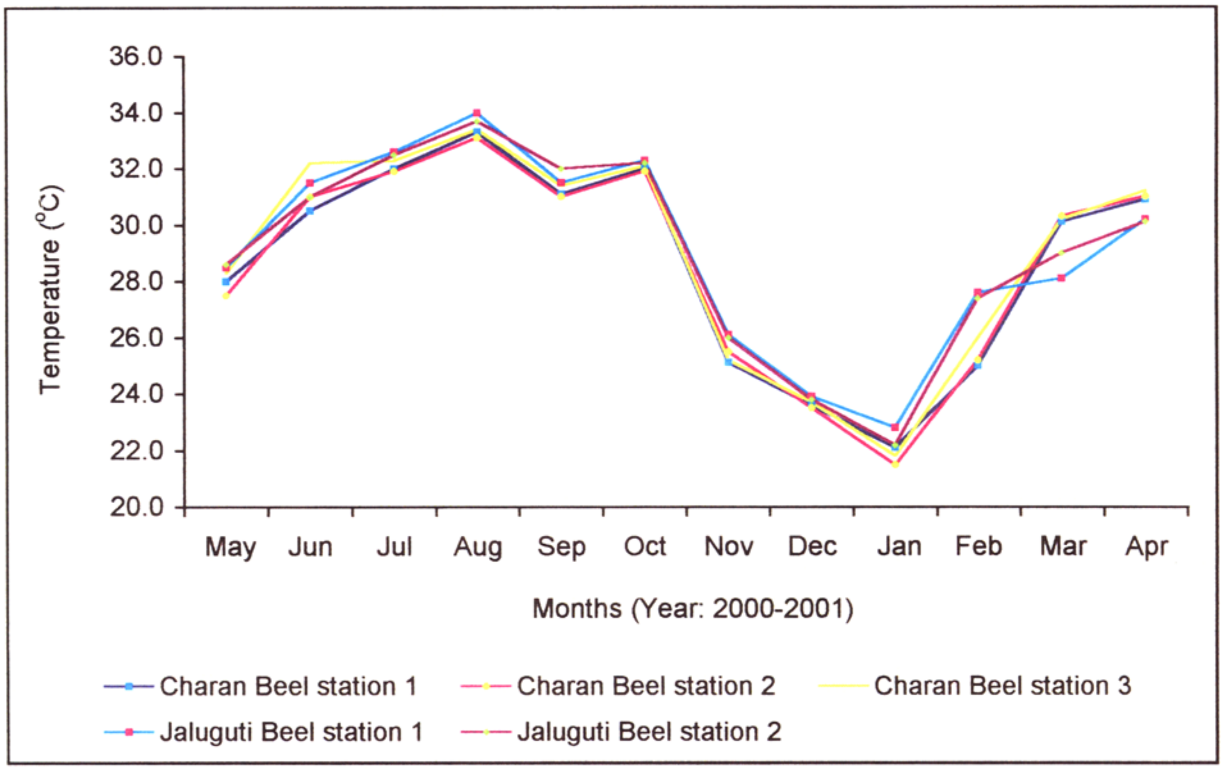


Fig. 11. Variations in water temperature in the selected beels

Similarly, the months of May, August and January recorded high Secchi disc depth. Staion 3 of Charan *Beel* and station 2 of Jaluguti *Beel* recorded considerably lower depth of visibility during September-October than the adjacent stations.

4.3.3 Hydrogen ion concentration

pH of water varied from 6.3 to 7.6 in Charan *Beel* and from 6.5 to 7.4 in Jaluguti *Beel* during the study period (Table 11). The range of variation was higher in Charan *Beel* than that of Jaluguti *Beel*. Charan *Beel* also recorded slightly higher pH of water (average 6.9) than that of Jaluguti *Beel* (6.8).

The temporal variation pattern in both the *beels* varied considerably among the stations (Fig. 13). Both the *beels* also showed irregular variations. Generally, the pH of water was lower during the period from June to October with a few exceptions. Water pH gradually increased from November onwards to reach maximal levels either in March or April at most instances. The lowest pH levels were recorded either in June (stations 1 and 2 of Charan *Beel*), July (Jaluguti *Beel* station 1) or in September (Charan *Beel* station 3 and Jaluguti *Beel* station 2).

4.3.4 Total alkalinity

Total alkalinity of water fluctuated considerably during the study period, ranging from 21.45 to 50.59 mg l^{-1} in Charan *Beel* (Table 12). The range of variation was much higher (29.42 to 81.60 mg l^{-1}) in Jaluguti *Beel*. The average total alkalinity was considerably higher (56.29 mg l^{-1}) in Jaluguti *Beel* than in Charan *Beel* (34.18 mg l^{-1}).

The pattern of seasonal variation showed some differences between the two *beels* (Fig. 14). However, both the *beels* recorded lowest alkalinity levels in August. Generally, water of both the *beels* was less alkaline during the monsoon season. Total alkalinity increased sharply during the post-monsoon season in Jaluguti *Beel* and the increasing trend continued to reach maximal levels either in March (station 1) or in April (station 2). In

Table 10. Variations in Secchi disc depth (m) in selected *beels*

Months	Charan *Beel*			Jaluguti *Beel*	
	Station 1	Station 2	Station 3	Station 1	Station 2
2000 May	1.27	1.14	0.96	1.22	1.34
Jun	1.20	0.93	0.39	0.67	0.78
Jul	1.13	1.07	0.85	0.90	1.22
Aug	1.10	1.35	1.17	1.13	1.20
Sep	0.83	0.95	0.58	0.78	0.23
Oct	0.92	1.13	0.65	1.08	0.64
Nov	1.05	1.19	0.88	1.20	0.75
Dec	0.87	1.08	1.02	1.08	1.12
2001 Jan	1.25	1.25	1.14	1.24	0.92
Feb	1.07	1.14	0.92	1.45	1.28
Mar	0.82	0.61	0.73	1.18	1.05
Apr	0.62	0.50	0.46	0.72	0.80
Annual av.	1.01	1.03	0.81	1.05	0.94

Table 11. Variations in pH of water in the selected *beels*

Months	Charan *Beel*			Jaluguti *Beel*	
	Station 1	Station 2	Station 3	Station 1	Station 2
2000 May	6.7	6.8	6.9	6.7	6.8
Jun	6.3	6.3	6.5	6.7	6.9
Jul	6.5	6.7	6.6	6.5	6.6
Aug	6.6	6.7	6.5	6.8	6.6
Sep	6.8	6.9	6.3	6.7	6.5
Oct	6.6	6.8	6.5	6.8	6.6
Nov	6.7	6.9	6.8	6.7	6.7
Dec	6.8	6.7	7.0	6.6	6.6
2001 Jan	7.2	7.3	7.1	7.0	6.8
Feb	7.1	7.0	7.2	6.9	6.9
Mar	7.4	7.5	7.6	7.1	6.9
Apr	7.3	7.5	7.5	7.4	7.2
Annual av.	6.8	6.9	6.9	6.8	6.8

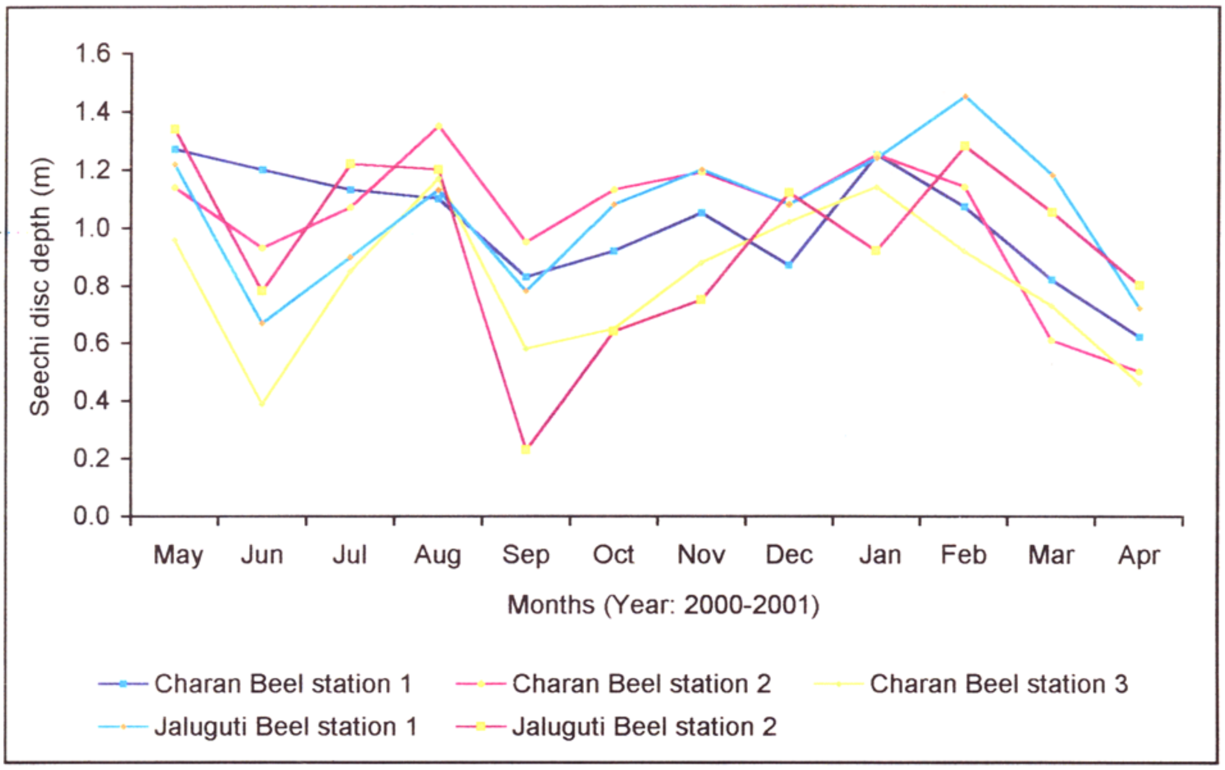


Fig. 12. Variations in Secchi disc depth in the selected beels

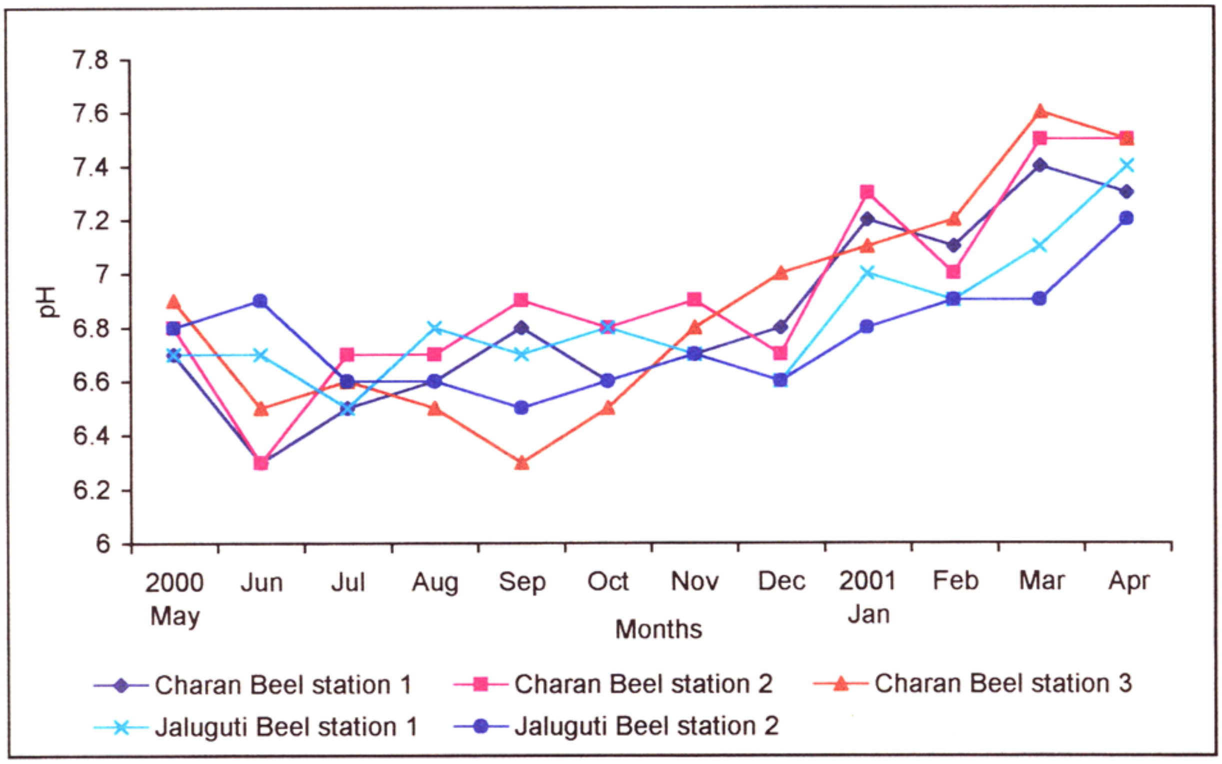


Fig. 13. Variations in pH of water in the selected beels

Charan *Beel*, total alkalinity increased sharply during September from the lowest levels recorded in August. Thereafter, alkalinity increased gradually to reach peak levels in March. The pattern of seasonal variation showed some differences between the stations of Jaluguti *Beel* during September-October and November. The seasonal variation trend also showed considerable variation among the stations of Charan *Beel*.

4.3.5 Total hardness

During the study period, total hardness varied from 21.8 to 54.5 mg l^{-1} in Charan *Beel* (Table 13). Jaluguti *Beel* recorded a wider range of total hardness (28.2 to 78.1 mg l^{-1}). On an average, water was much harder in Jaluguti *Beel* (average total hardness 54.5 mg l^{-1}) than Charan *Beel* (35.9 mg l^{-1}).

A distinct seasonal variation pattern in total hardness of water was observed in Jaluguti *Beel* (Fig. 15). Lowest hardness levels were recorded during July-August in this *beel*. Hardness of water gradually increased up to October followed by a steep increase during November, after which the increase was gradual, reaching maximal levels in April. Total hardness declined after April and the decline was sharp during June-July. In Charan *Beel*, hardness of water gradually declined from May to reach the lowest levels either in August or July at different stations, after which it increased gradually during September-October. It fluctuated during the period from November to April in this *beel*. However, maximal levels were recorded in March at all the stations.

4.3.6 Dissolved oxygen

Dissolved oxygen concentrations fluctuated between 5.34 and 12.14 mg l^{-1} in Charan *Beel* (Table 14). The range of variation was much lower (4.77 to 9.44 mg l^{-1}) in Jaluguti *Beel*. Dissolved oxygen content of Charan *Beel* water was comparatively higher (average 7.57 mg l^{-1}) than that of Jaluguti *Beel* (7.16 mg l^{-1}).

Table 12. Variations in total alkalinity (mg l^{-1}) of water in the selected *beels*

Months	Charan *Beel*			Jaluguti *Beel*	
	Station 1	Station 2	Station 3	Station 1	Station 2
2000 May	27.34	23.44	35.28	52.36	51.84
Jun	28.26	28.26	23.44	56.18	58.24
Jul	23.42	23.42	22.62	31.04	31.04
Aug	21.45	21.55	21.55	29.42	29.42
Sep	31.53	35.20	27.34	37.24	37.24
Oct	33.32	33.32	38.15	35.69	37.68
Nov	35.62	30.08	31.96	63.45	66.12
Dec	33.84	38.15	35.90	68.36	63.65
2001 Jan	41.64	43.18	40.23	73.44	72.26
Feb	37.54	41.64	43.63	71.45	75.72
Mar	48.96	45.70	50.59	76.70	76.44
Apr	43.18	44.06	45.42	74.32	81.60
Annual av.	33.84	34.00	34.68	54.14	56.77

Table 13. Variations in total hardness (mg l^{-1}) of water in the selected *beels*

Months	Charan *Beel*			Jaluguti *Beel*	
	Station 1	Station 2	Station 3	Station 1	Station 2
2000 May	28.9	28.9	30.2	44.6	48.5
Jun	28.2	29.6	28.2	48.1	52.4
Jul	26.4	26.4	22.8	28.2	28.8
Aug	29.6	24.6	20.9	26.3	26.3
Sep	28.1	28.1	30.2	34.6	34.6
Oct	34.8	35.6	39.4	43.6	46.2
Nov	40.6	37.8	36.7	60.2	66.7
Dec	33.8	32.7	34.6	67.2	68.3
2001 Jan	42.7	49.3	46.8	72.1	70.6
Feb	40.6	43.6	44.3	70.9	71.2
Mar	48.1	50.3	54.5	72.5	72.5
Apr	43.6	48.1	49.2	74.8	78.1
Annual av.	35.0	36.3	36.5	53.6	55.4

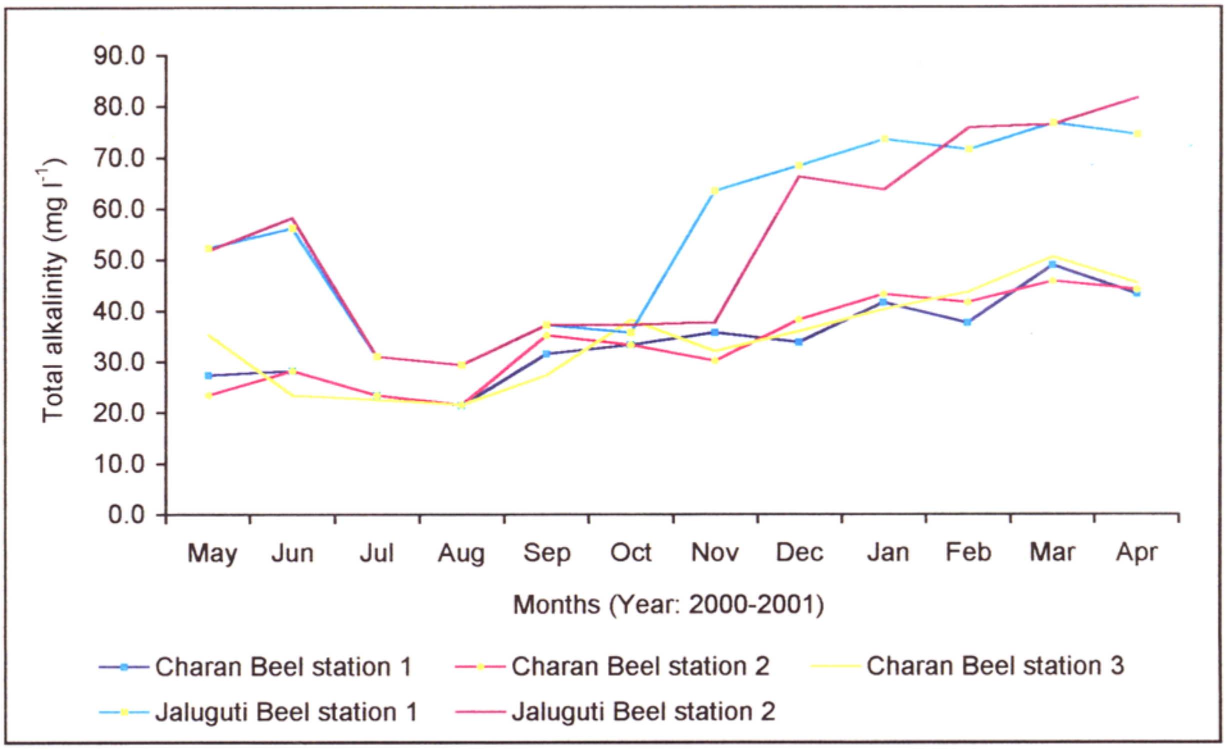


Fig. 14. Variations in total alkalinity of water in the selected beels

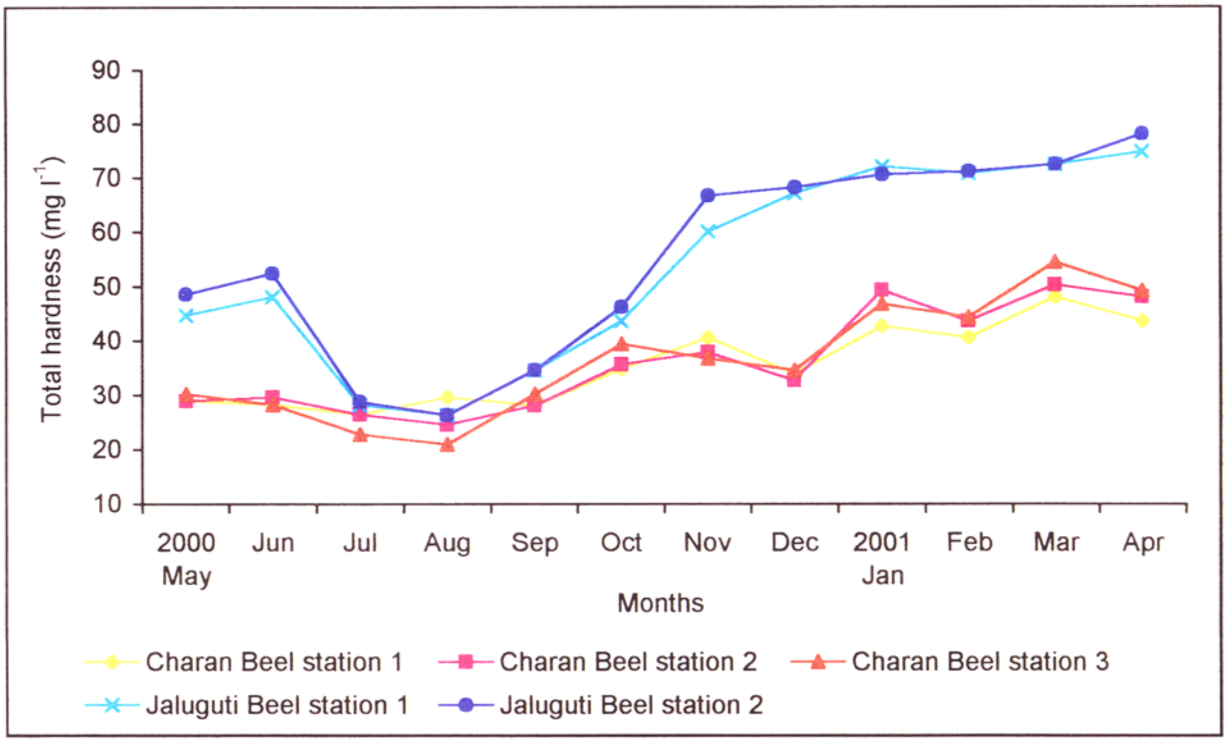


Fig. 15. Variations in total hardness of water in the selected beels

The pattern of temporal variation was more or less uniform in both the *beels*, even though minor deviations were observed at some stations/instances (Fig. 16). In general, higher dissolved oxygen levels were recorded during the winter months (December to February) in both the *beels*. The highest dissolved oxygen concentrations were recorded in January. Station 1 of Jaluguti *Beel* was the lone exception to this trend where the highest dissolved oxygen concentration was recorded in February. Two secondary and tertiary peaks were observed in the *beels* in June and August respectively. The lowest dissolved oxygen levels were recorded either in March, September or July at different stations. In general, water had lower dissolved oxygen content during the pre-monsoon season (March to May).

4.3.7 Free carbon dioxide

Dissolved free carbon dioxide content of water fluctuated widely in both Charan *Beel* (undetectable levels tc 13.77 mg l^{-1}) and Jaluguti *Beel* (2.45 to 18.59 mg l^{-1}) during the study period (Table 15). Jaluguti *Beel* recorded considerably higher concentrations of free carbon dioxide (average 9.3 mg l^{-1}) compared to Charan *Beel* (7.31 mg l^{-1}).

The pattern of seasonal variation showed considerable deviations at different stations in both the *beels* (Fig. 17). Maximal carbon dioxide concentrations were recorded at all the stations in May except at station 3 of Charan *Beel* (in September). A secondary peak was observed either in November (Charan *Beel* station 2), October (both the stations of Jaluguti *Beel*) or in May (Charan *Beel* station 3). Lowest concentrations of free carbon dioxide were recorded at all the stations either in March or April. Free carbon dioxide concentrations were very low (undetectable) in Charan *Beel* on many instances during March-April.

4.3.8 Total iron

The total iron content of water varied from 0.05 to 0.82 mg l^{-1} in Charan *Beel* (Table 16). The range of variation was marginally smaller in Jaluguti *Beel* (0.05 to 0.74 mg l^{-1}). The spatial variation among the 3 stations of Charan *Beel* was negligible, ranging from 0.23 to 0.26 mg l^{-1} (annual

Table 14. Variations in dissolved oxygen (mg l^{-1}) of water in the selected *beels*

Months	Charan *Beel*			Jaluguti *Beel*	
	Station 1	Station 2	Station 3	Station 1	Station 2
2000 May	6.86	6.28	5.93	6.62	6.34
Jun	7.28	8.12	8.44	8.10	8.42
Jul	5.34	6.18	5.34	5.92	6.37
Aug	6.86	7.43	7.12	7.78	7.78
Sep	6.15	5.68	6.43	6.05	5.17
Oct	7.20	7.12	6.27	7.84	6.06
Nov	7.43	6.86	7.65	7.78	6.92
Dec	7.68	7.09	10.51	9.20	8.50
2001 Jan	11.78	11.41	12.14	8.12	9.10
Feb	10.15	8.87	10.90	9.44	8.86
Mar	7.64	6.62	6.18	4.77	5.18
Apr	7.20	6.48	5.83	5.91	5.73
Annual av.	7.63	7.35	7.73	7.29	7.04

Table 15. Variations in free carbon dioxide (mg l^{-1}) of water in the selected *beels*

Months	Charan *Beel*			Jaluguti *Beel*	
	Station 1	Station 2	Station 3	Station 1	Station 2
2000 May	12.31	12.87	10.01	18.59	17.16
Jun	10.68	10.43	9.28	14.56	13.73
Jul	8.14	9.06	9.06	8.29	11.45
Aug	6.92	7.58	7.58	6.92	8.65
Sep	5.63	7.88	18.58	7.26	14.64
Oct	7.23	8.42	13.77	12.24	15.30
Nov	7.74	9.56	9.56	10.83	7.23
Dec	7.15	7.78	8.14	8.29	8.14
2001 Jan	6.84	6.31	3.88	6.48	8.74
Feb	7.58	6.92	2.16	6.14	6.31
Mar	ND	2.12	ND	3.07	3.42
Apr	1.88	ND	ND	3.26	2.45
Annual av.	6.84	7.39	7.67	8.83	9.77

Note: ND = Not detected

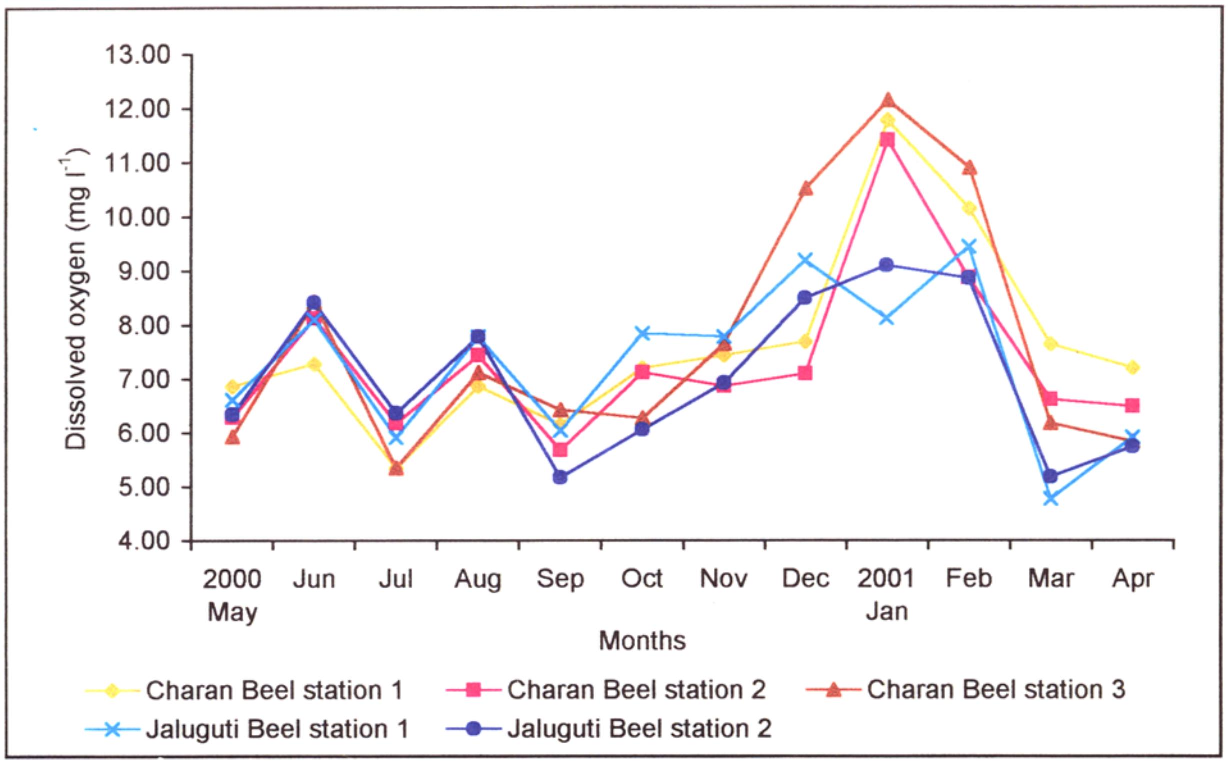


Fig. 16. Variations in dissolved oxygen of water in the selected beels

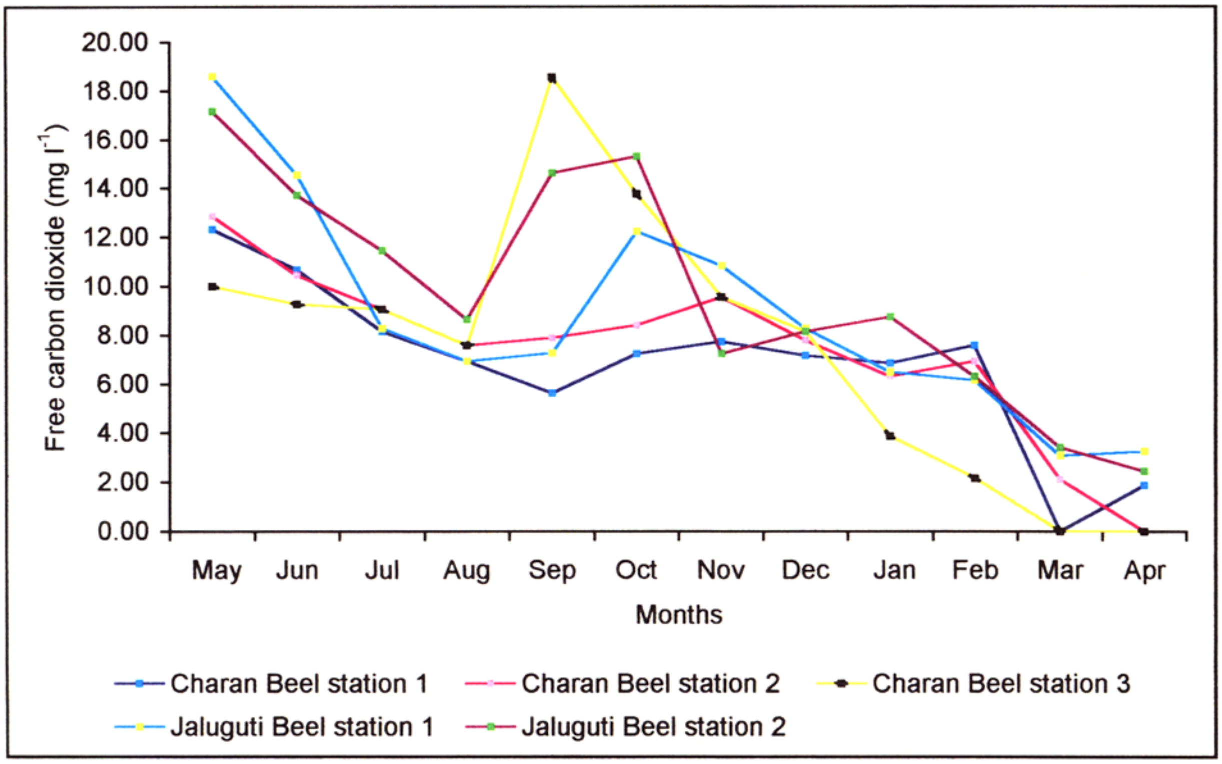


Fig. 17. Variations in free carbon dioxide of water in the selected beels

average values). The variation in average total iron content of water was also negligible between the stations of Jaluguti *Beel* (0.21 and 0.23 mg l^{-1}). Water of the two *beels* did not differ much in their average total iron content (0.24 mg l^{-1} in Charan *Beel* and 0.22 mg l^{-1} in Jaluguti *Beel*).

The total iron concentrations of water showed distinct temporal variation patterns during the study period (Fig. 18). The pattern of variation was identical in both the *beels* though minor deviations were observed among individual stations. Peak values were recorded uniformly in June at all the stations, which was followed by a sharp decline during July to record lowest total iron levels in August. The total iron content of water increased gradually during the period from September to May, after which the rate of increase was steeper to reach peak levels in June.

4.3.9 Total chloride

Total chloride content of water ranged from 14.7 tc 27.4 mg l^{-1} in Charan *Beel* (Table 17). In Jaluguti *Beel*, the concentration of total chloride was comparatively higher (range 12.8-29.4 mg l^{-1}, average 23.0 mg l^{-1}) compared to that of Charan *Beel* (average 20.5 mg l^{-1}). The spatial variation in total chloride content of water among the individual stations was negligible both in Charan *Beel* (20.2 to 20.6 mg l^{-1}).and in Jaluguti *Beel* (22.7 and 23.2 mg l^{-1}).

A clear-cut seasonal variation pattern was observed in the selected *beels* except for minor deviations observed during the period of November-December (Fig 19). The maximal concentrations of total chloride were recorded in May at all the stations. The values uniformly declined during the monsoon months (June to August) to reach lowest levels in September. Station 1 of Jaluguti *Beel* was the lone exception to this trend, where lowest values were recorded in October. Total chloride content of water gradually increased from November onwards to reach peak levels in May. A secondary peak was observed in November in Jaluguti *Beel* (at both the stations) and in December at station 1 of Charan *Beel*.

Table 16. Variations in total iron (mg l^{-1}) of water in the selected *beels*

Months	Charan *Beel*			Jaluguti *Beel*	
	Station 1	Station 2	Station 3	Station 1	Station 2
2000 May	0.56	0.52	0.60	0.45	0.38
Jun	0.82	0.70	0.74	0.74	0.62
Jul	0.08	0.14	0.11	0.11	0.18
Aug	0.05	0.05	0.05	0.08	0.05
Sep	0.06	0.06	0.08	0.10	0.10
Oct	0.12	0.12	0.16	0.08	0.08
Nov	0.10	0.10	0.12	0.12	0.14
Dec	0.12	0.12	0.14	0.14	0.18
2001 Jan	0.18	0.16	0.16	0.12	0.16
Feb	0.22	0.22	0.24	0.20	0.20
Mar	0.24	0.24	0.28	0.28	0.24
Apr	0.34	0.30	0.38	0.29	0.26
Annual av.	0.24	0.23	0.26	0.23	0.21

Table 17. Variations in total chloride (mg l^{-1}) of water in the selected *beels*

Months	Charan *Beel*			Jaluguti *Beel*	
	Station 1	Station 2	Station 3	Station 1	Station 2
2000 May	27.4	24.5	24.5	29.4	28.8
Jun	23.7	23.7	22.8	25.4	25.4
Jul	19.6	20.3	19.6	21.9	22.8
Aug	18.4	18.4	19.6	19.6	19.2
Sep	14.7	16.4	16.4	18.4	12.8
Oct	17.9	17.5	17.5	17.2	17.2
Nov	18.4	18.4	18.4	23.0	23.6
Dec	22.0	19.8	19.0	20.2	20.2
2001 Jan	18.4	18.4	18.4	23.0	23.6
Feb	22.0	21.6	20.9	25.4	26.0
Mar	22.4	22.4	21.6	26.7	26.7
Apr	24.1	23.7	23.7	27.6	27.6
Annual av.	20.6	20.4	20.2	23.2	22.7

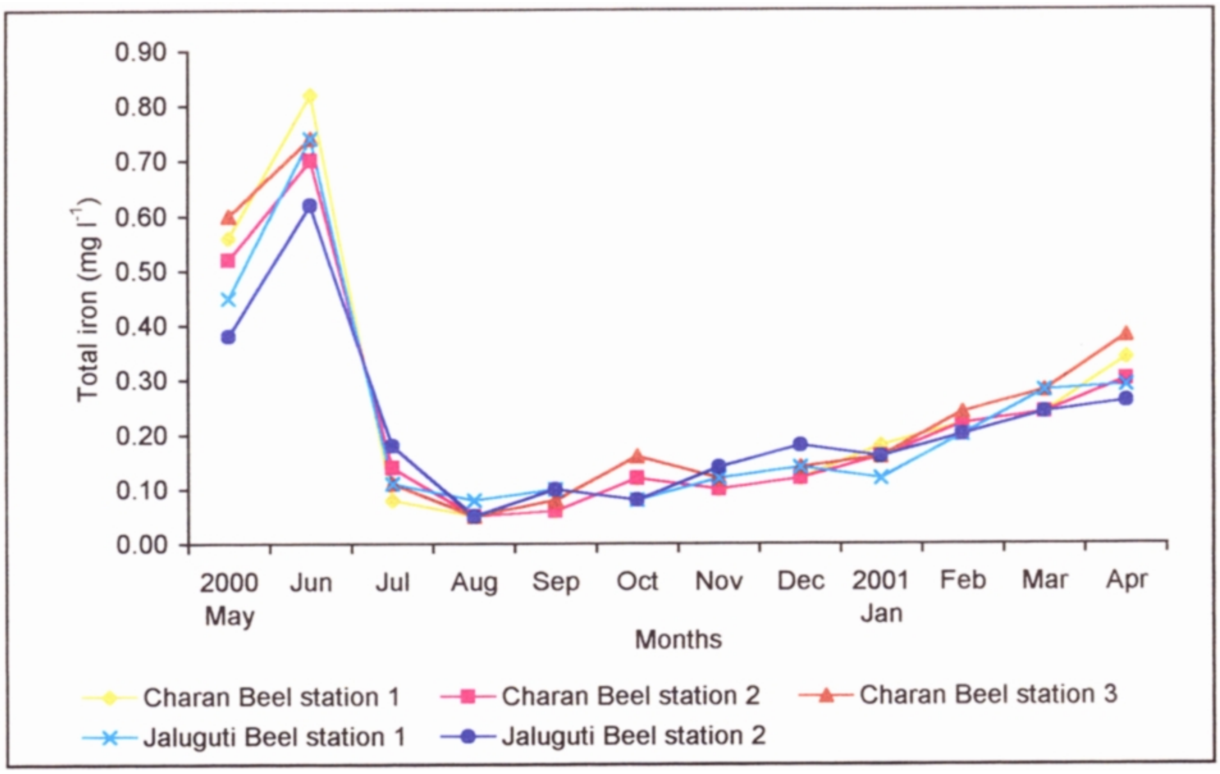


Fig. 18. Variations in total iron of water in the selected beels

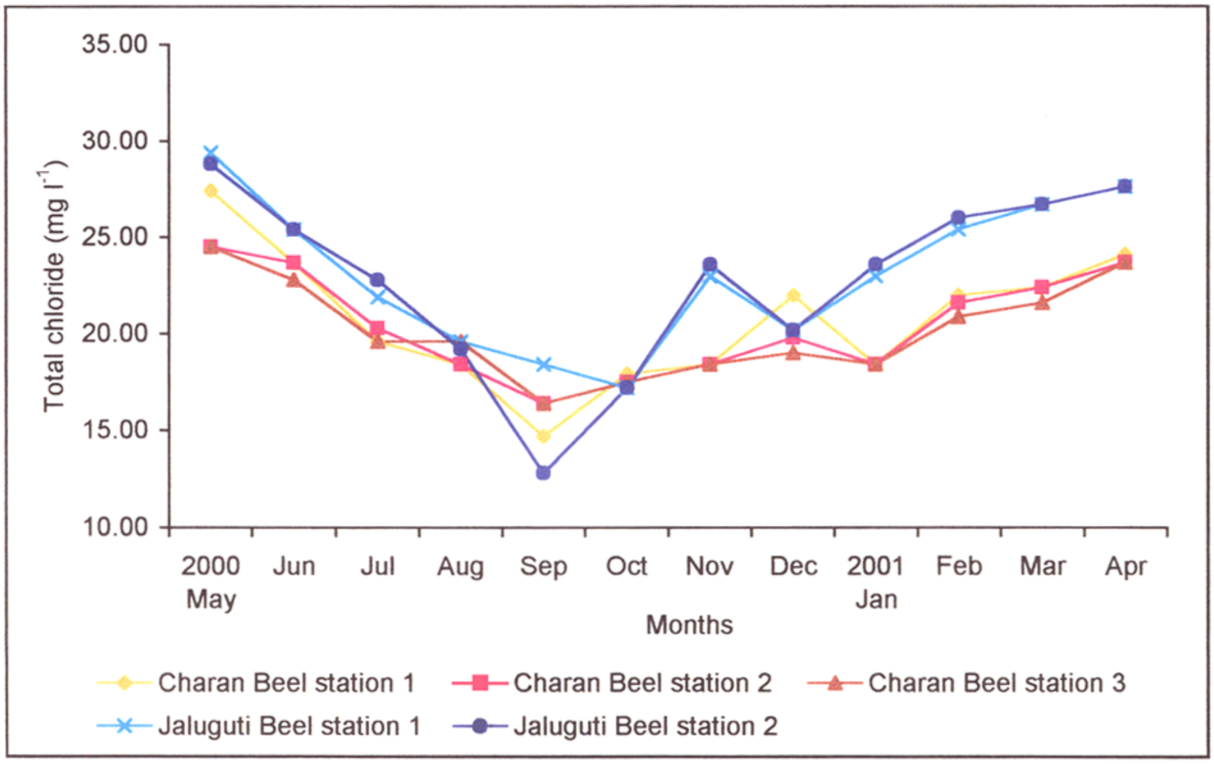


Fig. 19. Variations in total chloride of water in the selected beels

4.3.10 Specific conductivity

Specific conductivity of water varied from 58.2 to 126.9 µmho cm^{-2} in Charan *Beel* during the study period (Table 18). The range of variation was much higher (55.8-158.5 µmho cm^{-2}) in Jaluguti *Beel*. The average specific conductivity of water was significantly higher in Jaluguti *Beel* (112.1 µmho cm^{-2} compared to that of Charan *Beel* (77.8 µmho cm^{-2}). Spatial variation between the stations of Jaluguti *Beel* was negligible. However, the stations of Charan *Beel* showed appreciable variation in average specific conductivity of water varying from 76.0 (at station 3) to 79.7 µmho cm^{-2} (station 1).

A distinct seasonal variation pattern was observed in specific conductivity of water (Fig. 20). The period from August to October recorded low levels in both the *beels*. The month of September recorded the lowest levels at all the stations. Specific conductivity of water started increasing from November onwards to reach maximal levels either in April (Charan *Beel*) or May (Jaluguti *Beel*). The values declined after May to reach low levels during the period of August-September. The seasonal variation was very distinct in Jaluguti *Beel* showing a primary peak in May and a minor peak in January at station 2. In Charan *Beel,* some fluctuations in specific conductivity was observed during the period from May to July and from December to February showing two minor peaks in July and December. Further the increasing trend during the period from September to May and the declining trend during May to August was very distinct in Jaluguti *Beel* unlike those of Charan *Beel*, where it was more gradual/fluctuating. Though both the *beels* recorded almost equal (low) levels of specific conductivity during the period of August-September, the levels increased at an higher rate in Jaluguti *Beel* from October onwards and remained much higher (on an average 1.4 times) than those of Charan *Beel*.

4.3.11 Total dissolved solids

The concentration of total dissolved solids (TDS) ranged from 29.7 to 64.0 mg l^{-1} in Charan *Beel* during the study period (Table 19). The range of variation was considerably higher (28.5-84.7 mg l^{-1}) in Jaluguti *Beel*.

Table 18. Variations in specific conductivity (μmho cm^{-2}) of water in the selected *beels*

Months	Charan *Beel*			Jaluguti *Beel*	
	Station 1	Station 2	Station 3	Station 1	Station 2
2000 May	79.7	80.6	80.5	167.3	164.6
Jun	65.4	65.4	59.1	119.4	120.4
Jul	74.1	73.2	71.4	102.2	106.3
Aug	67.5	59.2	63.4	68.5	60.9
Sep	61.6	58.2	59.9	66.6	55.8
Oct	62.0	61.3	61.2	75.9	73.7
Nov	70.2	67.3	66.3	93.3	92.4
Dec	77.5	73.9	70.7	112.1	112.1
2001 Jan	75.5	75.0	68.4	125.7	132.5
Feb	87.5	86.9	86.1	130.9	131.9
Mar	108.5	109.5	107.1	141.1	140.2
Apr	126.9	121.2	117.4	157.0	158.5
Annual av.	79.7	77.6	76.0	111.7	112.4

Table 19. Variations in total dissolved solids (mg l^{-1}) of water in the selected *beels*

Months	Charan *Beel*			Jaluguti *Beel*	
	Station 1	Station 2	Station 3	Station 1	Station 2
2000 May	40.5	40.9	43.9	84.7	83.5
Jun	33.3	33.4	30.1	60.6	61.1
Jul	37.4	36.9	36.0	51.5	53.7
Aug	33.5	30.2	32.4	34.7	31.2
Sep	31.6	29.7	30.6	34.0	28.5
Oct	31.4	30.9	30.8	38.7	37.6
Nov	35.7	34.3	33.8	47.6	47.1
Dec	39.2	37.4	35.8	56.8	56.8
2001 Jan	38.4	37.9	34.5	63.4	62.2
Feb	44.6	44.3	43.9	66.7	67.2
Mar	55.3	55.8	54.6	71.9	71.4
Apr	64.0	61.2	59.5	79.5	80.3
Annual av.	40.4	39.4	38.6	57.5	56.7

This *beel* also recorded much higher concentrations of TDS (57.1 mg l^{-1}) than Charan *Beel* (39.5 mg l^{-1}). The spatial variation among the stations of Charan *Beel* was nominal with average concentrations ranging from 38.6 mg l^{-1} (station 3) to 40.4 mg l^{-1} (station 1). Station 1 of Jaluguti *Beel* recorded marginally higher total dissolved solids concentration (57.5 mg l^{-1}) than station 2 (56.7 mg l^{-1}).

The pattern of seasonal variation in total dissolved solids was identical to that of specific conductivity of water except for the fact that no secondary peak was observed in January at station 2 (Fig. 21). The lowest (nearly equal) total dissolved solid levels were recorded in September in both the *beels*. The values increased rapidly in Jaluguti *Beel* from October onwards to reach the maximal levels in May. In Charan *Beel*, the increase was more gradual and reached the peak levels in April.

4.3.12 Dissolved organic matter

Dissolved organic matter (DOM) showed considerable fluctuations during the study period, ranging from 1.20 to 4.14 mg l^{-1} in Charan *Beel* and from 0.90 to 2.92 mg l^{-1} in Jaluguti *Beel* (Table 20). The range of variation was much smaller in Jaluguti *Beel* than that of Charan *Beel*. However, Jaluguti *Beel* recorded marginally higher average DOM concentrations (2.05 mg l^{-1}) than Charan *Beel* (2.00 mg l^{-1}). The spatial variation from station to station was minimal in both the *beels*.

The pattern of temporal variation in dissolved organic matter was entirely different in both the *beels*. The maximal levels were recorded in July in Charan *Beel*, whereas the month of September recorded the peak levels in Jaluguti *Beel* (Fig. 22). Charan *Beel* exhibited an irregular trimodal pattern of seasonal variation with minor peaks observed in October and May. On the other hand, Jaluguti *Beel* showed a bimodal seasonal variation pattern with a secondary peak observed in May. The stations of Jaluguti *Beel* showed less variability in their seasonal variation pattern than those of Charan *Beel*.

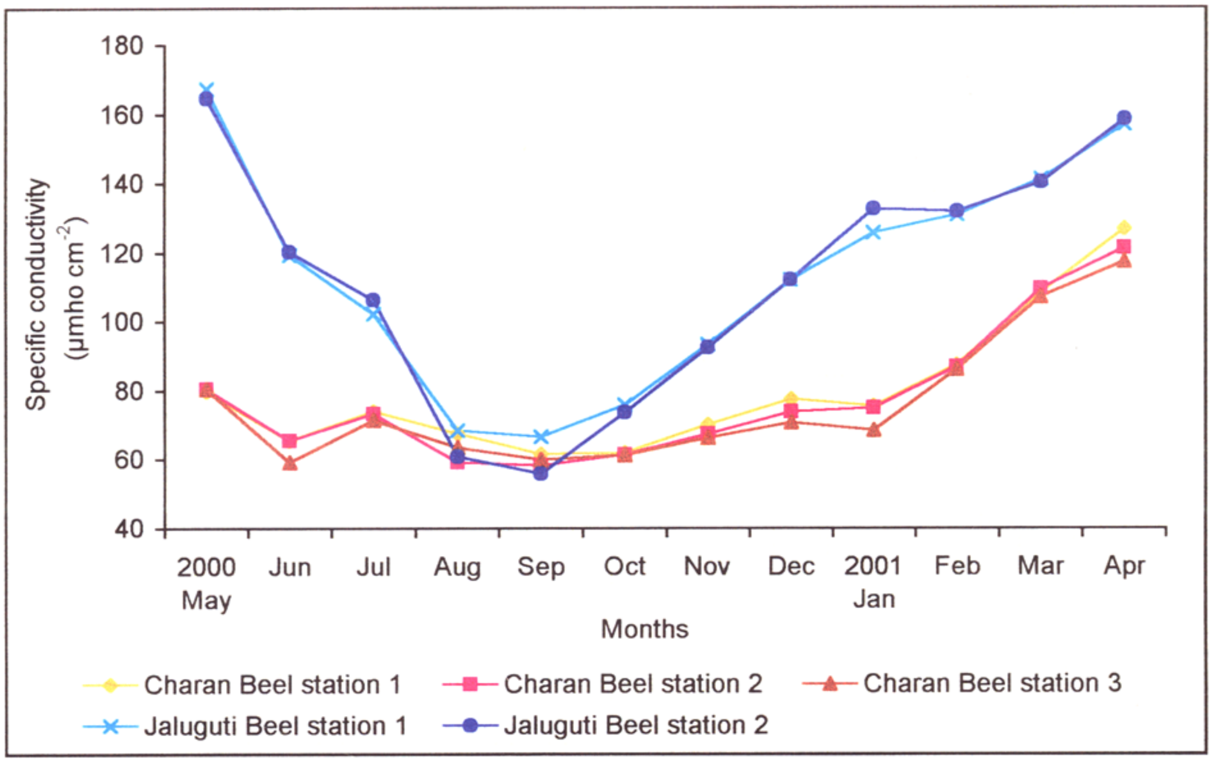


Fig. 20. Variations in specific conductivity of water in the selected beels

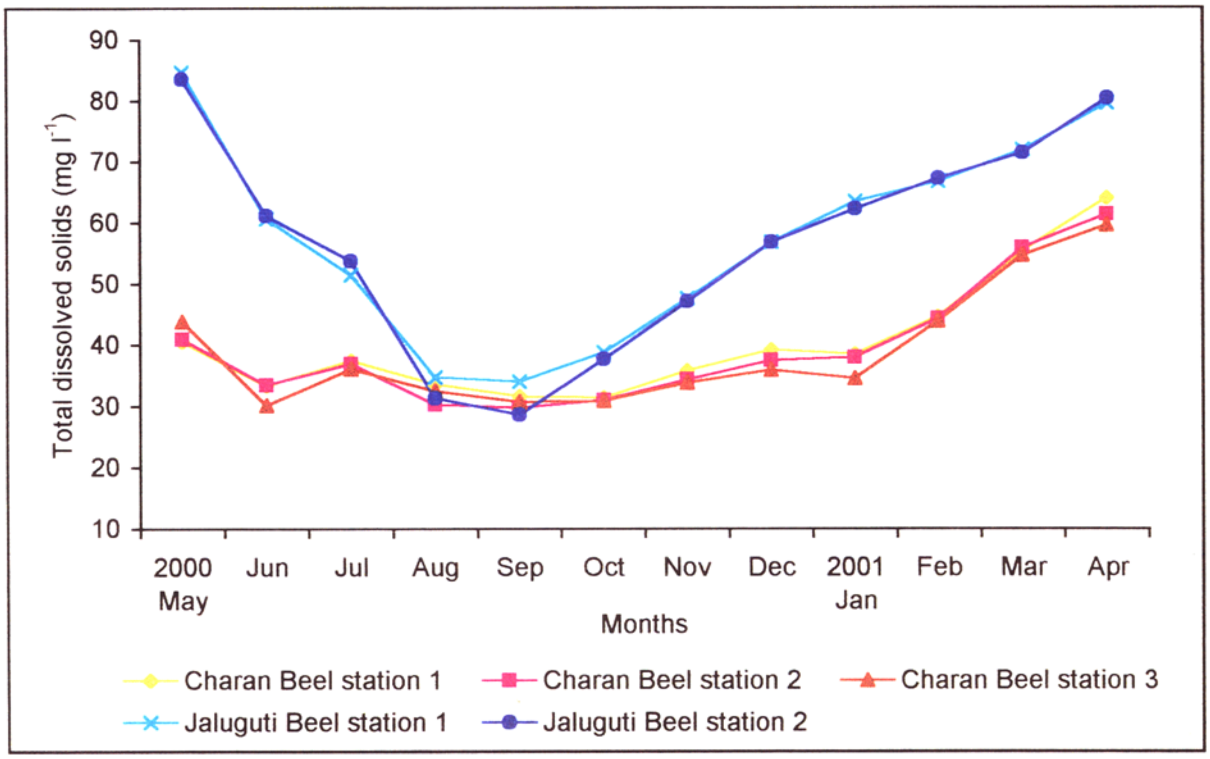


Fig. 21. Variations in total dissolved solids in the selected beels

4.3.13 Nitrate-nitrogen

The concentration of nitrate-nitrogen showed considerable fluctuations during the study period. It ranged from 0.01 to 0.80 mg l^{-1} in Charan *Beel* (Table 21). Jaluguti *Beel* recorded considerably higher levels of nitrate-nitrogen (range 0.02-0.14 mg l^{-1}, average 0.29 mg l^{-1}) than that of Charan *Beel* (average 0.20 mg l^{-1}). Station 1 of Charan *Beel* recorded comparatively higher average nitrate-nitrogen (0.24 mg l^{-1}) than that of the other two stations (0.19-0.20 mg l^{-1}). In Jaluguti *Beel*, station 2 recorded marginally higher average value (0.34 mg l^{-1}) than station 1.

Nitrate-nitrogen exhibited an irregular and oscillating pattern of seasonal variation with many peaks and troughs (Fig. 23). Further, the individual stations deviated from one another in their seasonal variation patterns. However, the maximal concentration of nitrate-nitrogen was recorded in June at all the stations. The months of April, September and November-December recorded minor peaks. The lowest levels of nitrate-nitrogen were recorded either in August or February.

Generally, the periods of July-August, December-March and May recorded low nitrogen levels, whereas the period from September to December recorded moderate levels.

4.3.14 Phosphate-phosphorous

The concentration of phosphate-phosphorous of water varied from 0.002 to 0.020 mg l^{-1} in Charan *Beel* (Table 22). In Jaluguti *Beel*, this nutrient parameter ranged from trace levels to 0.035 mg l^{-1}. The average phosphate-phosphorous level was comparatively higher in Jaluguti *Beel* (0.009 mg l^{-1}) than that of Charan *Beel* (0.007 mg l^{-1}). The range of variation was also comparatively higher in Jaluguti *Beel*. However, both the stations of Jaluguti *Beel* recorded equal average phosphate-phosphorus concentration (0.009 mg l^{-1}) during the study period. In Charan *Beel*, the average phosphate-phosphorous level marginally increased from station 1 (0.006 mg l^{-1}) to station 3 (0.008 mg l^{-1}).

Table 20. Variations in dissolved organic matter (mg C l^{-1}) of water in the selected *beels*

Months	Charan *Beel*			Jaluguti *Beel*	
	Station 1	Station 2	Station 3	Station 1	Station 2
2000 May	2.25	1.95	2.05	2.49	2.49
Jun	1.57	1.78	1.82	2.25	2.25
Jul	3.14	3.49	4.14	2.21	2.28
Aug	2.28	2.64	2.92	2.42	2.50
Sep	2.57	2.07	2.35	2.92	2.78
Oct	2.57	2.85	2.00	2.78	2.28
Nov	1.78	1.50	1.78	2.21	1.95
Dec	1.50	1.35	1.50	1.85	1.64
2001 Jan	1.57	1.50	1.65	0.90	1.05
Feb	1.28	1.20	1.20	1.35	1.35
Mar	1.57	1.50	1.50	1.78	1.65
Apr	1.65	1.65	1.78	1.95	1.88
Annual av.	1.98	1.96	2.06	2.09	2.00

Table 21. Variations in nitrate–nitrogen (mg l^{-1}) of water in the selected *beels*

Months	Charan *Beel*			Jaluguti *Beel*	
	Station 1	Station 2	Station 3	Station 1	Station 2
2000 May	0.12	0.08	0.12	0.18	0.21
Jun	0.80	0.70	0.80	1.00	1.24
Jul	0.05	0.03	0.03	0.05	0.04
Aug	0.04	0.01	0.02	0.02	0.05
Sep	0.46	0.50	0.30	0.60	0.50
Oct	0.30	0.30	0.24	0.10	0.10
Nov	0.50	0.30	0.30	0.14	0.21
Dec	0.04	0.02	0.03	0.46	0.30
2001 Jan	0.02	0.02	0.03	0.08	0.12
Feb	0.02	0.03	0.02	0.06	0.04
Mar	0.12	0.08	0.12	0.10	0.10
Apr	0.46	0.32	0.24	0.60	1.20
Annual av.	0.24	0.20	0.19	0.28	0.34

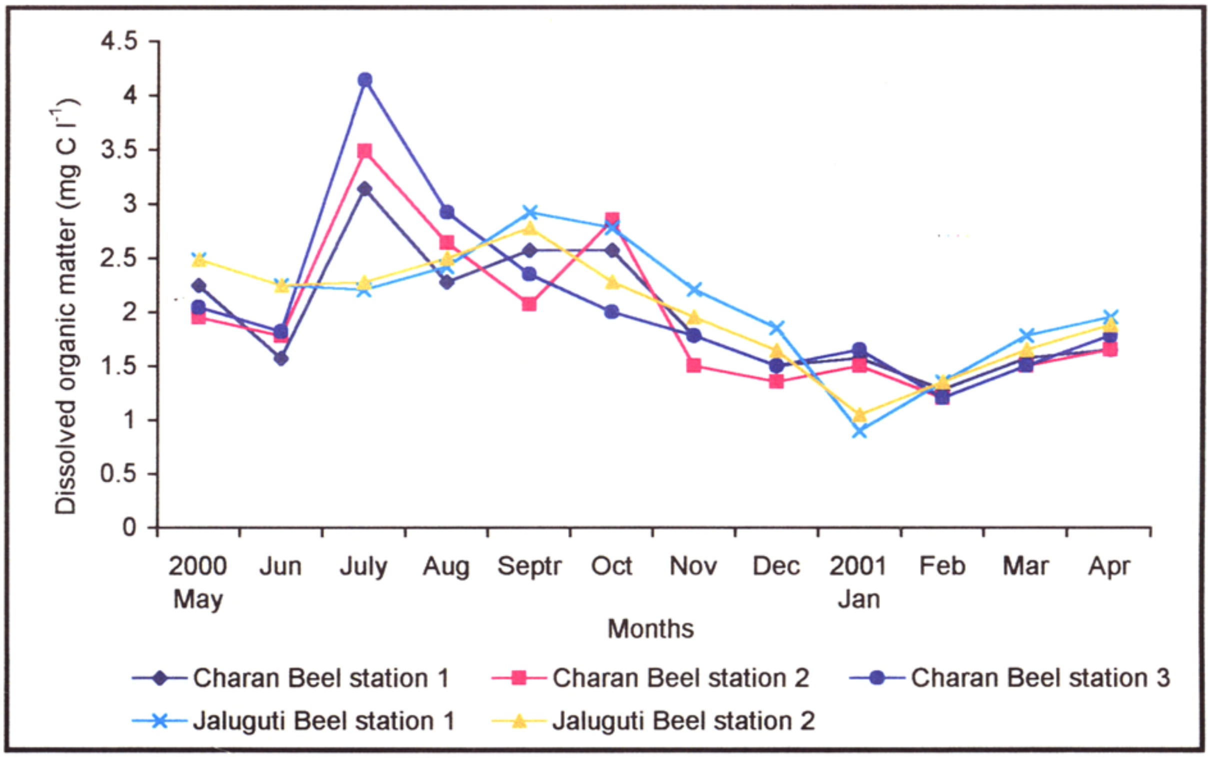


Fig. 22. Variations in dissolved organic matter in the selected *beels*

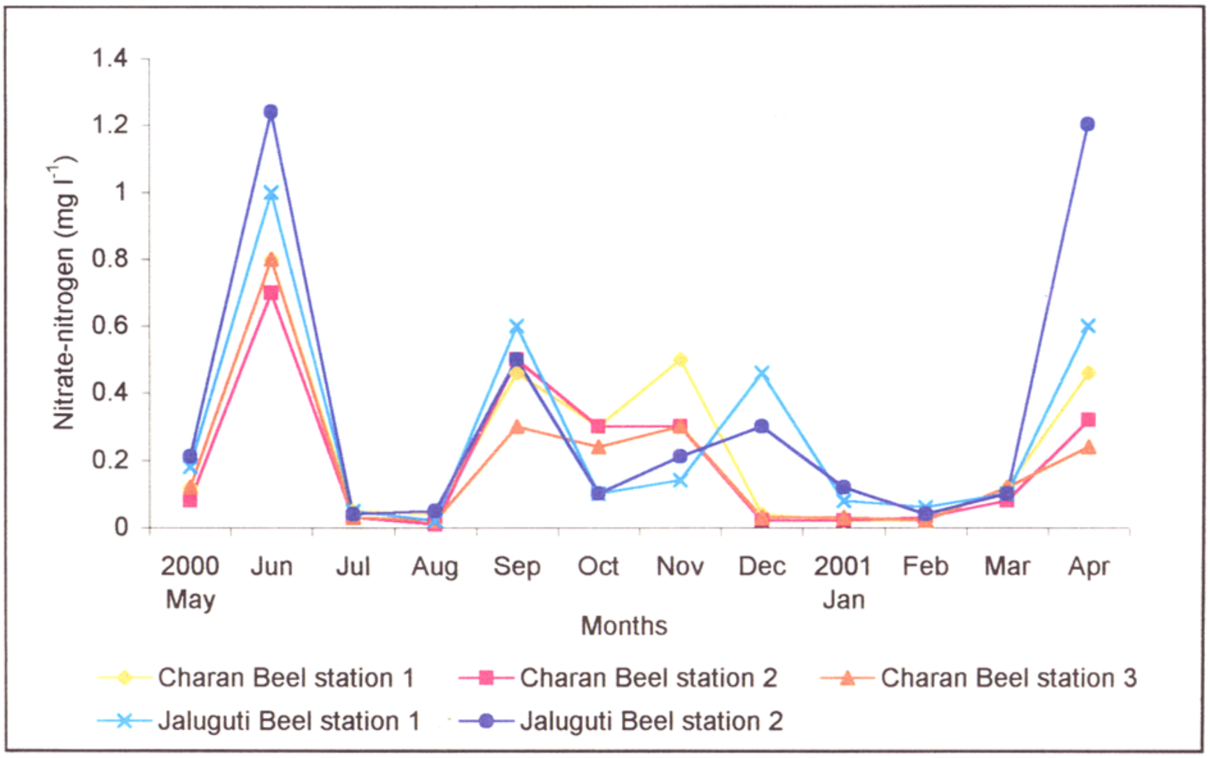


Fig. 23. Variations in nitrate-nitrogen of water in the selected *beels*

Phosphate-phosphorous of water exhibited irregular variation during the study period showing many peaks and troughs (Fig. 24). However, both the *beels* exhibited more and less similar trend of temporal variation even though minor deviations were observed at some stations. The primary peak was observed in July and the month of April recorded the lowest levels at all the stations. Minor peaks were observed during September and November-December. Generally, the period from January to May and October recorded low phosphate-phosphorous levels.

4.3.15 Silicate-silica

Silicate-silica concentrations varied from 3.0 to 7.8 mg l^{-1} in Charan *Beel* and from 2.4 to 7.2 mg l^{-1} in Jaluguti *Beel* (Table 23). The average concentration and the range of variations were found to be identical in both the *beels* (average 4.9 mg l^{-1}). The spatial variation between the stations was negligible in Charan *Beel*, whereas in Jaluguti *Beel*, station 2 recorded marginally higher levels of silicate-silica (4.9 mg l^{-1}) than station 1 (4.7 mg l^{-1}).

The distribution of silicate-silica of water showed distinct seasonal variation (Fig. 25). Both the *beels* exhibited more or less similar seasonal variation patterns. Maximal levels were recorded in July, after which the values gradually declined to reach the lowest levels in April. However, the minimal level was recorded in March at station 2 of Jaluguti *Beel* instead of April. Similarly, all the stations of Charan *Beel* showed a sudden drop in silicate-silica levels in October. The period from April to July showed a step increase in silicate-silica levels reaching maximal levels in July.

4.4 Diurnal variations in physico-chemical characteristics of water

The diurnal variations in selected water quality variables during different seasons in the selected *beels* have been presented in Tables 24 and 25.

Table 22. Variations in phosphate –phosphorus (mg l^{-1}) of water in the selected *beels*

Months	Charan *Beel*			Jaluguti *Beel*	
	Station 1	Station 2	Station 3	Station 1	Station 2
2000 May	0.005	0.004	0.005	0.004	0.005
Jun	0.008	0.010	0.006	0.005	0.002
Jul	0.012	0.014	0.020	0.020	0.035
Aug	0.005	0.004	0.004	0.016	0.010
Sep	0.010	0.012	0.020	0.018	0.014
Oct	0.006	0.007	0.004	0.003	0.004
Nov	0.008	0.008	0.008	0.015	0.010
Dec	0.005	0.007	0.015	0.010	0.010
2001 Jan	0.002	0.002	0.003	0.004	0.006
Feb	0.005	0.006	0.006	0.005	0.005
Mar	0.004	0.003	0.003	0.003	0.005
Apr	0.002	0.002	0.002	T	T
Annual av.	0.006	0.007	0.008	0.009	0.009

Note: T = Traces

Table 23. Variations in silicate-silica (mg l^{-1}) of water in the selected *beels*

Months	Charan *Beel*			Jaluguti *Beel*	
	Station 1	Station 2	Station 3	Station 1	Station 2
2000 May	3.6	3.6	4.0	4.0	4.4
Jun	5.6	6.0	5.6	6.0	6.2
Jul	7.2	7.2	7.8	7.2	6.8
Aug	6.4	6.6	6.6	6.2	6.2
Sep	6.8	6.0	6.2	6.0	6.0
Oct	4.4	4.0	4.0	5.6	5.4
Nov	5.0	5.2	5.0	5.0	5.2
Dec	4.6	4.6	4.6	3.8	4.2
2001 Jan	4.4	4.4	4.4	4.0	4.4
Feb	4.0	4.2	4.0	3.6	4.0
Mar	3.8	4.0	3.8	3.0	3.4
Apr	3.4	3.0	3.4	2.4	3.8
Annual av.	4.9	4.9	5.0	4.7	4.9

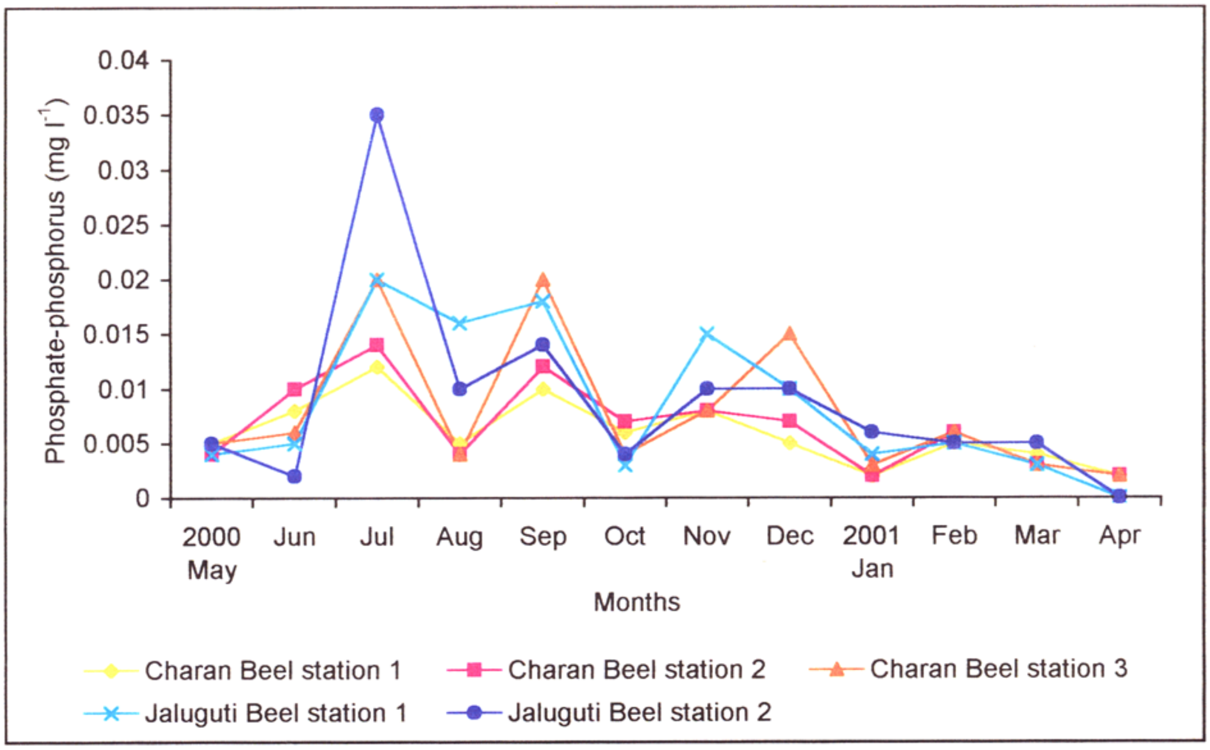


Fig. 24. Variations in phosphate-phosphorus of water in the selected *beels*

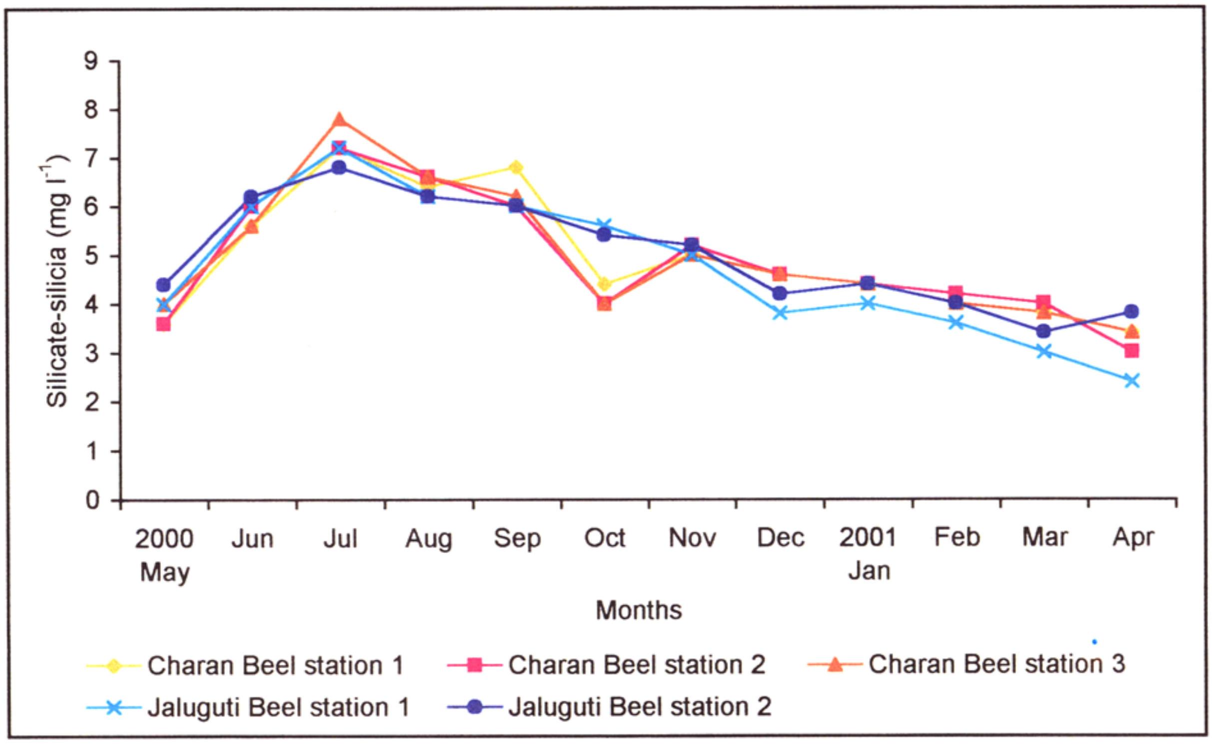


Fig. 25. Variations in silicate-silica of water in the selected *beels*

4.4.1 Water temperature

Considerable diurnal fluctuations in water temperature were observed in both the *beels* with varying magnitudes during different seasons (Fig. 26). Temperature of water exhibited an increasing trend from early morning (6.00 hrs) to afternoon hours (either 14.00 or 18.00 hrs), after which it declined to reach minimal levels during early morning hours (6.00 hrs). The diurnal fluctuations in water temperature was maximum during the pre-monsoon season, followed by the post-monsoon and the monsoon seasons, while the winter season recorded the smallest fluctuations. The maximum diurnal fluctuation of water temperature recorded during the pre-monsoon season in Charan *Beel* was 7.5°C (Table 24). In Jaluguti *Beel*, the maximum fluctuation observed during the pre-monsoon season was marginally lower (7.3°C, Table 25). In general, Charan *Beel* recorded slightly higher temperature throughout the day in all seasons except during the pre-monsoon season.

4.4.2 Dissolved oxygen

A sharp increase in the concentration of dissolved oxygen in water was discernible from early morning (6.00 hrs) to reach maximal levels soon after mid-day (14.00 hrs) in both the *beels* (Fig. 27). However, the increase was comparatively more gradual during the winter season. Dissolved oxygen content of water started declining during the afternoon and night hours to reach minimal level again during early morning (6.00 hrs) of the next day. The lone exception to this declining trend was observed during the monsoon season in Jaluguti *Beel*, when dissolved oxygen levels marginally increased at 22.00 hrs. The magnitude of diurnal fluctuations in oxygen content of water showed considerable differences among the seasons in both the *beels*. The maximum daily fluctuations in dissolved oxygen levels from early morning (6.00 hrs) to early afternoon hours (14.00 hrs) was recorded during the post-monsoon season followed by the pre-monsoon and the monsoon season in Charan *Beel* (Table 24). In contrast, Jaluguti *Beel* recorded the maximum diurnal fluctuation during the monsoon season followed by the post-monsoon and the pre-monsoon seasons (Table 25). The lowest diurnal fluctuation in dissolved oxygen levels was recorded during the

Table 24. Diurnal variations in selected physico-chemical parameters of water in Charan *Beel*

Parameters	Time of collection (hrs)						Total fluctuations
	06	10	14	18	22	02	
Pre-monsoon							
Water temperature (°C)	27.0	30.8	34.5	33.5	31.8	30.3	7.5
Dissolved oxygen (mg l^{-1})	3.33	6.28	8.75	7.23	6.67	5.75	5.42
pH	6.4	6.8	7.1	6.9	6.7	6.6	0.7
Free carbon dioxide (mg l^{-1})	16.27	12.87	10.20	10.84	12.92	14.50	6.07
Bicarbonates (mg l^{-1})	26.31	23.44	19.56	18.08	19.74	22.40	8.23
Monsoon							
Water temperature (°C)	31.1	32.9	35.3	35.8	34.5	33.5	4.7
Dissolved oxygen (mg l^{-1})	3.73	6.18	8.27	7.13	6.57	6.04	4.54
pH	6.5	6.7	6.9	6.7	6.6	6.4	0.5
Free carbon dioxide (mg l^{-1})	10.75	9.06	5.85	6.43	7.25	9.09	4.90
Bicarbonates (mg l^{-1})	27.30	23.26	21.15	22.50	23.86	25.64	6.15
Post-monsoon							
Water temperature (°C)	29.2	32.0	35.8	34.9	32.8	30.4	6.6
Dissolved oxygen (mg l^{-1})	3.80	7.24	10.60	8.86	5.62	4.73	6.80
pH	6.6	6.9	7.4	7.2	7.0	6.8	0.8
Free carbon dioxide (mg l^{-1})	14.70	9.56	6.84	8.76	8.92	10.20	7.86
Bicarbonates (mg l^{-1})	37.32	31.80	27.46	28.10	31.62	34.37	9.86
Winter							
Water temperature (°C)	20.4	21.5	23.6	22.7	21.9	20.7	3.2
Dissolved oxygen (mg l^{-1})	10.15	12.15	13.77	13.33	12.17	11.64	3.62
pH	7.2	7.3	7.5	7.3	7.2	7.1	0.4
Free carbon dioxide (mg l^{-1})	9.15	6.31	4.97	5.35	7.01	8.85	4.18
Bicarbonates (mg l^{-1})	46.94	43.40	41.89	42.64	44.00	45.28	5.05

Table 25. Diurnal variations in selected physico-chemical parameters of water in Jaluguti *Beel*

Parameters	Time of collection (hrs)						Total fluctuations
	06	10	14	18	22	02	
Pre-monsoon							
Water temperature (°C)	26.7	30.2	35.1	36.0	32.4	30.8	7.3
Dissolved oxygen (mg l^{-1})	3.59	5.73	8.52	7.17	6.25	4.80	4.93
pH	6.5	6.8	7.1	6.8	6.7	6.5	0.6
Free carbon dioxide (mg l^{-1})	19.70	17.16	14.64	15.80	17.14	18.32	5.06
Bicarbonates (mg l^{-1})	54.40	49.84	47.64	47.28	48.86	51.26	7.12
Monsoon							
Water temperature (°C)	28.4	31.7	32.5	32.8	31.3	29.8	4.4
Dissolved oxygen (mg l^{-1})	4.88	8.42	11.92	10.06	10.44	7.54	7.04
pH	6.2	6.4	6.6	6.3	6.1	5.7	0.9
Free carbon dioxide (mg l^{-1})	19.36	15.40	11.26	12.10	14.72	16.26	8.10
Bicarbonates (mg l^{-1})	43.94	36.42	32.54	34.68	36.52	41.79	11.40
Post-monsoon							
Water temperature (°C)	19.4	22.5	26.1	25.3	23.2	21.6	6.7
Dissolved oxygen (mg l^{-1})	1.84	4.96	7.72	6.40	5.48	3.92	5.88
pH	5.9	6.4	6.7	6.5	6.3	6.2	0.8
Free carbon dioxide (mg l^{-1})	13.54	11.30	7.23	7.70	9.95	11.88	6.31
Bicarbonates (mg l^{-1})	73.12	68.06	66.12	64.44	65.50	69.08	8.68
Winter							
Water temperature (°C)	19.4	20.1	22.3	21.9	20.3	19.1	3.1
Dissolved oxygen (mg l^{-1})	5.33	8.27	9.10	8.59	8.01	7.17	3.77
pH	6.5	6.7	6.8	6.7	6.5	6.3	0.5
Free carbon dioxide (mg l^{-1})	12.04	10.56	7.74	8.30	9.38	11.12	4.30
Bicarbonates (mg l^{-1})	77.66	75.92	72.26	73.12	74.56	75.94	5.40

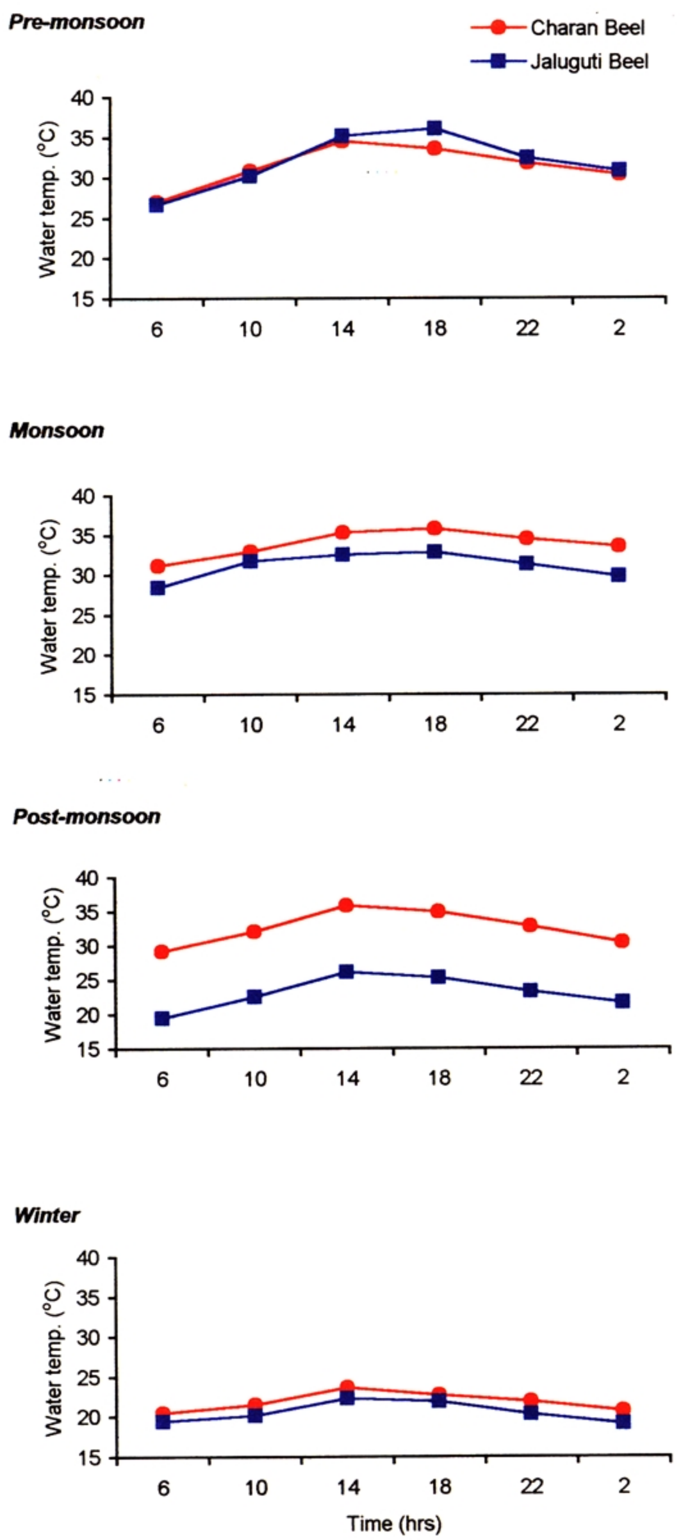


Fig. 26. Diurnal variations in water temperature in the selected *beels*

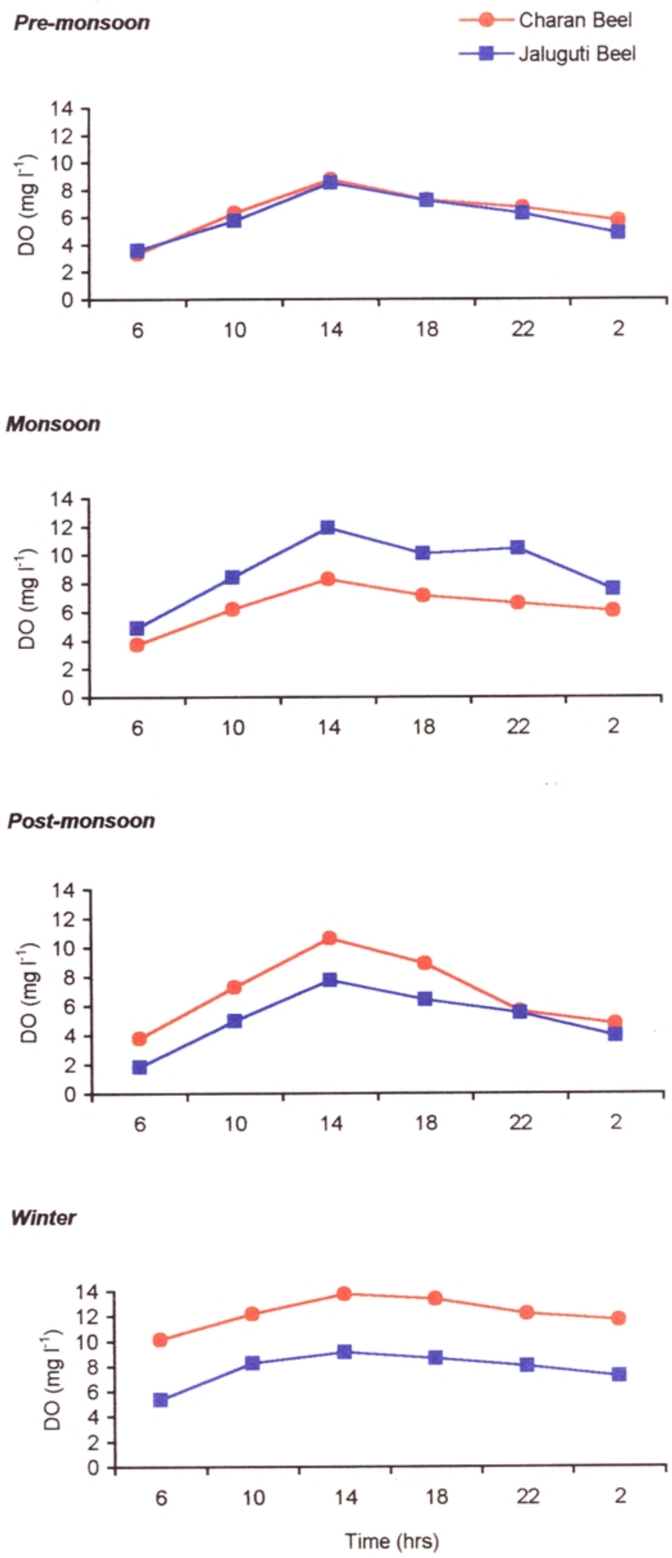


Fig. 27. Diurnal variations in dissolved oxygen of water in the selected beels

winter season in both the *beels*. The magnitude of diurnal variations in all the seasons was slightly higher in Jaluguti *Beel* compared to that of Charan *Beel*. The maximum daily fluctuations in dissolved oxygen content recorded in Charan *Beel* and Jaluguti *Beel* was 6.80 and 7.04 mg l^{-1} respectively. Similarly, the minimal fluctuations recorded during winter in these two *beels* were 3.62 (Charan) and 3.77 mg l^{-1} (Jaluguti *Beel*) respectively.

4.4.3 Hydrogen ion concentration

Hydrogen ion concentration of water showed a gradual increase from early morning (6.00 hrs) to reach maximal pH levels at 14.00 hrs in the selected *beels* in all the seasons, after which it declined gradually to reach minimal levels during early morning hours (either at 2 A.M. or at 6 A.M.) (Fig. 28). The decline was more pronounced during the post-monsoon season in both the *beels*. The magnitude of diel fluctuations in pH of water varied considerably from season to season. The seasonal variation in diel fluctuations in water pH followed a trend similar to that of dissolved oxygen. The maximal fluctuations were recorded either during the post-monsoon (Charan *Beel*) or the monsoon season (Jaluguti *Beel*) while the lowest fluctuations were observed during the winter season in both the *beels* (Tables 24 and 25). Generally, Charan *Beel* recorded comparatively higher diel variation of water pH than Jaluguti *Beel* in all seasons except during the pre-monsoon season, when no definite pattern was discernible.

4.4.4 Free carbon dioxide

A considerable decline in the dissolved free carbon dioxide content of water was observed from early morning (6.00 hrs) hours to reach the lowest levels during early afternoon hours (14.00 hrs) at all the instances (Fig. 29). The concentration of free carbon dioxide started building up gradually in the afternoon and night hours to reach maximal levels in early morning (6.00 hrs) hours of the next day. The magnitude of diel variations in free carbon dioxide levels showed a distinct seasonal pattern, which varied considerably in the two *beels*. The seasonal changes in the relative magnitude of diel fluctuations in free carbon dioxide content exhibited an identical trend with that of dissolved oxygen and pH of water, with the lowest

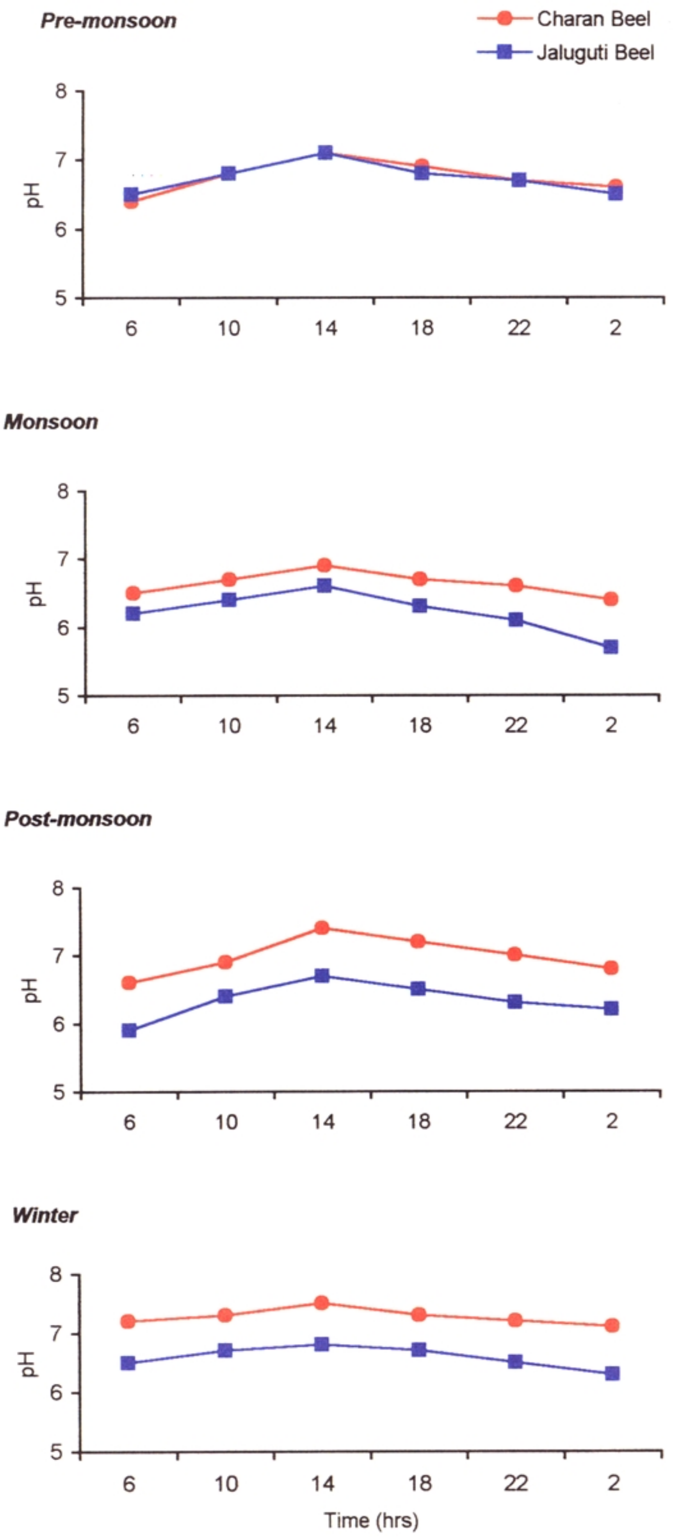


Fig. 28. Diurnal variations in pH of water in the selected *beels*

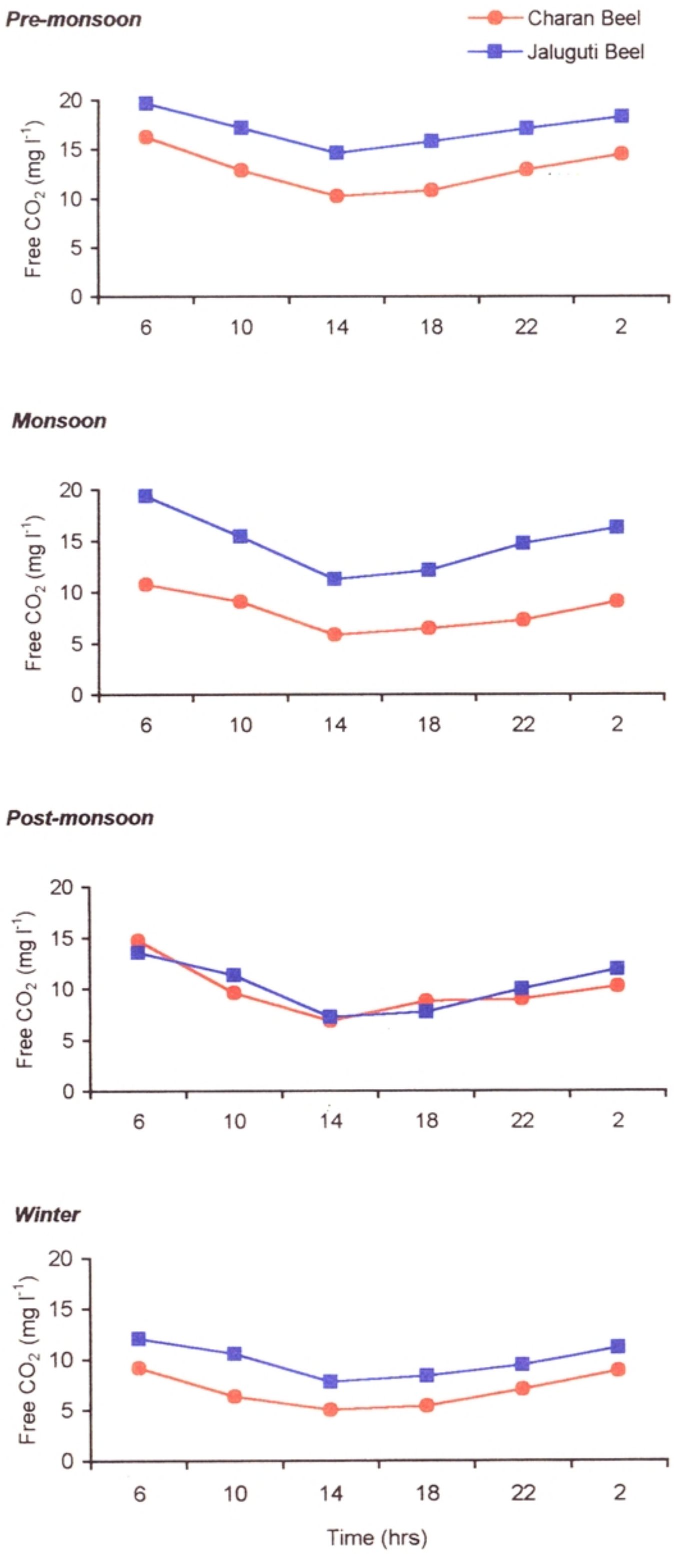


Fig. 29. Diurnal variations in free carbon dioxide of water in the selected beels

diel fluctuations recorded during the winter season in both the *beels* (Tables 24 and 25). Jaluguti *Beel* recorded comparatively higher free carbon dioxide concentrations than Charan *Beel* in all the seasons except during the post-monsoon season, when no definite pattern was observed.

4.4.5 Bicarbonates

The concentration of bicarbonates was found to be the maximum in the early morning hours (6.00 hrs) and subsequently showed a considerable decline to reach minimal levels in the afternoon hours (either at 14.00 or 16.00 hrs) in all the seasons (Fig. 30). After recording the lowest levels, the bicarbonate content of water started increasing gradually to reach the maximal levels again in the early morning hours (6.00 hrs). The magnitude of diurnal variations in the concentration of bicarbonates exhibited a distinct seasonal pattern, with considerable variation observed between the two *beels*. The seasonal alterations in the relative magnitude of diurnal fluctuations in bicarbonate content of water was similar to that observed in respect of dissolved oxygen, pH and free carbon dioxide. Thus, in Jaluguti *Beel* the maximum diurnal fluctuation of 11.40 mg l^{-1} in bicarbonates was recorded during the monsoon season, while the minimum daily variations recorded in the winter season was as low as 5.40 mg l^{-1}. Charan *Beel* water recorded comparatively lower daily fluctuations ranging from 5.05 (winter) to 9.86 mg l^{-1} (post-monsoon season).

4.5 Biotic Communities

4.5.1 Plankton

The average plankton population in Charan *Beel* and Jaluguti *Beel* was observed to be 863 and 623 units litre^{-1} (u l^{-1}) respectively. The maximum and minimum plankton population was recorded in November (1872 u l^{-1}) and June (278 u l^{-1}) in Charan *Beel* (Table 26). The monthly variation in plankton showed many peaks and troughs (Fig. 31) with the secondary and tertiary peaks observed in March and July. The order of month-wise abundance of plankton in this *beel* was November > October > March > February > January > April > December > May > July > September >

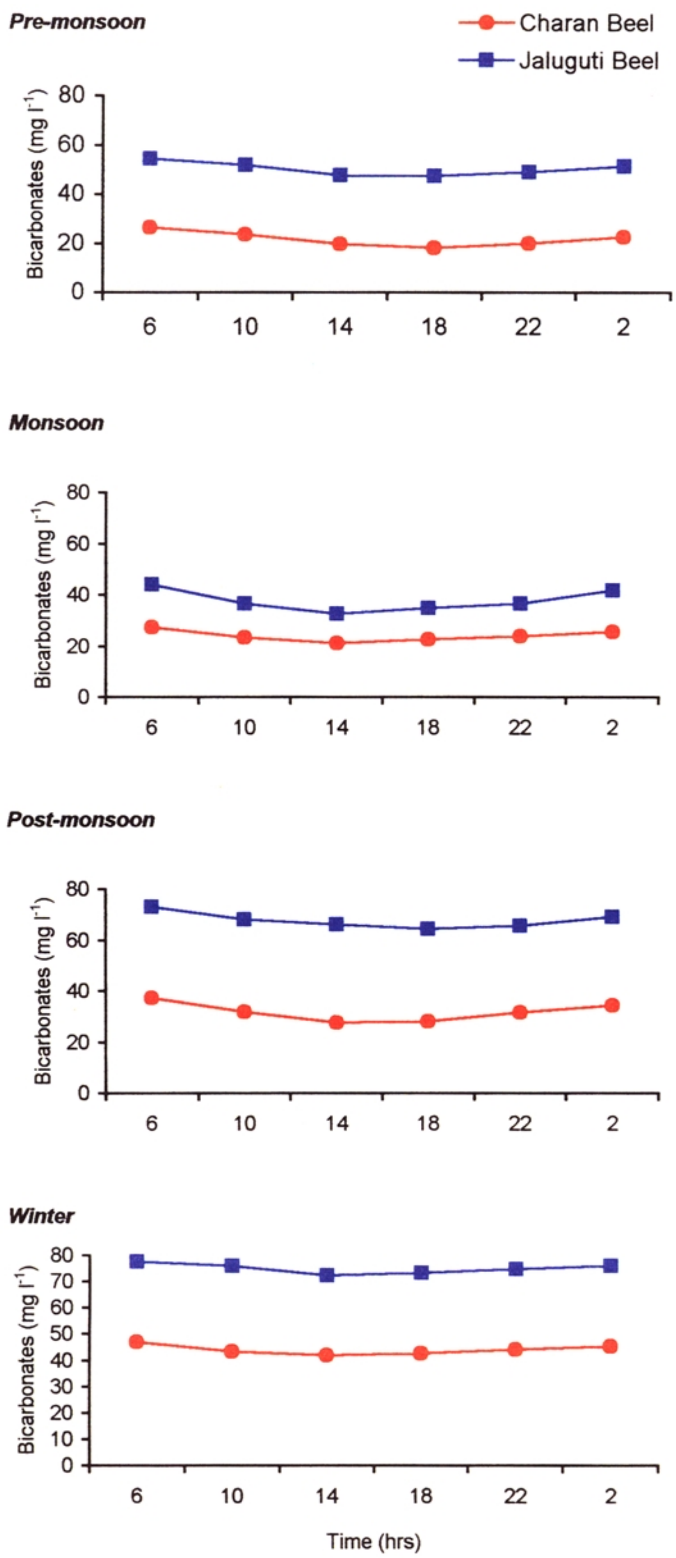


Fig. 30. Diurnal variations in bicarbonates in water of the selected *beels*

Table 26. Monthly variations in numerical abundance of plankton (u l^{-1})* in Charan *Beel*

Groups	Months												Annual average
	2000 May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	
Phytoplankton:													
Bacillariophyceae	176 (34.7)	81 (38.3)	179 (37.7)	103 (36.8)	150 (39.2)	398 (40.4)	522 (39.5)	209 (39.9)	269 (40.9)	284 (38.2)	326 (36.3)	199 (34.7)	241 (38.3)
Chlorophyceae	166 (32.7)	61 (28.8)	145 (30.5)	99 (35.4)	126 (33.1)	356 (36.1)	465 (35.2)	167 (31.9)	227 (34.6)	240 (32.3)	291 (32.4)	181 (31.6)	210 (33.3)
Myxophyceae	123 (24.3)	46 (21.8)	96 (20.2)	49 (17.5)	70 (18.3)	146 (14.8)	205 (15.5)	91 (17.4)	101 (15.4)	135 (18.2)	183 (20.4)	150 (26.2)	116 (18.4)
Desmidiaceae	48 (9.4)	24 (11.3)	55 (11.6)	29 (10.3)	36 (9.4)	86 (8.7)	130 (9.8)	57 (10.8)	60 (9.1)	84 (11.3)	98 (10.9)	44 (7.7)	63 (10.0)
Total phytoplankton	507 (79.2)	212 (76.4)	474 (82.4)	280 (81.4)	382 (78.5)	986 (68.5)	1322 (70.6)	525 (73.1)	657 (71.8)	743 (69.4)	897 (73.2)	574 (72.5)	630 (73.0)
Zooplankton:													
Copepoda	51 (38.4)	28 (42.4)	46 (45.5)	28 (43.8)	46 (44.0)	200 (44.1)	224 (40.8)	78 (40.3)	101 (39.1)	123 (38.0)	120 (36.5)	81 (37.0)	94 (40.3)
Rotifera	46 (34.6)	18 (27.3)	31 (30.6)	22 (34.4)	33 (32.0)	147 (32.5)	185 (33.6)	66 (34.1)	90 (34.9)	116 (35.8)	119 (36.2)	78 (35.6)	79 (33.9)
Protozoa	27 (20.6)	12 (17.7)	17 (16.4)	9 (14.6)	16 (15.4)	73 (16.0)	92 (16.8)	34 (17.6)	48 (18.7)	62 (19.2)	64 (19.4)	41 (18.8)	41 (17.6)
Cladocera	9 (6.4	8 (7.2)	7 (6.8)	5 (8.4)	9 (8.6)	34 (7.4)	48 (8.8)	15 (8.0)	19 (7.3)	23 (7.0)	26 (7.8)	19 (8.6)	19 (8.2)
Total zooplankton	133 (20.8)	66 (23.6)	101 (17.6)	64 (18.6)	104 (21.5)	454 (31.5)	550 (29.4)	193 (26.9)	258 (28.2)	323 (30.6)	329 (26.8)	218 (27.5)	233 (27.0)
Total plankton	640	278	575	344	486	1440	1872	718	915	1070	1226	792	863

Note: Figures in parenthesis indicate percentage composition of each group to total * Average of three stations

August > June. In Jaluguti *Beel*, plankton population ranged from 204 (June) to 1324 u l^{-1} (December) (Table 27). A trimodal pattern of seasonal variation was observed in this *beel* with secondary and tertiary peaks observed in August and April. The order of month-wise abundance in this *beel* was December > August > November > April > October > July > March > February > May > January > September > June. Phytoplankton contributed 73.0 and 61.8% to total plankton population in Charan and Jaluguti *Beel* respectively.

4.5.1.1 Phytoplankton

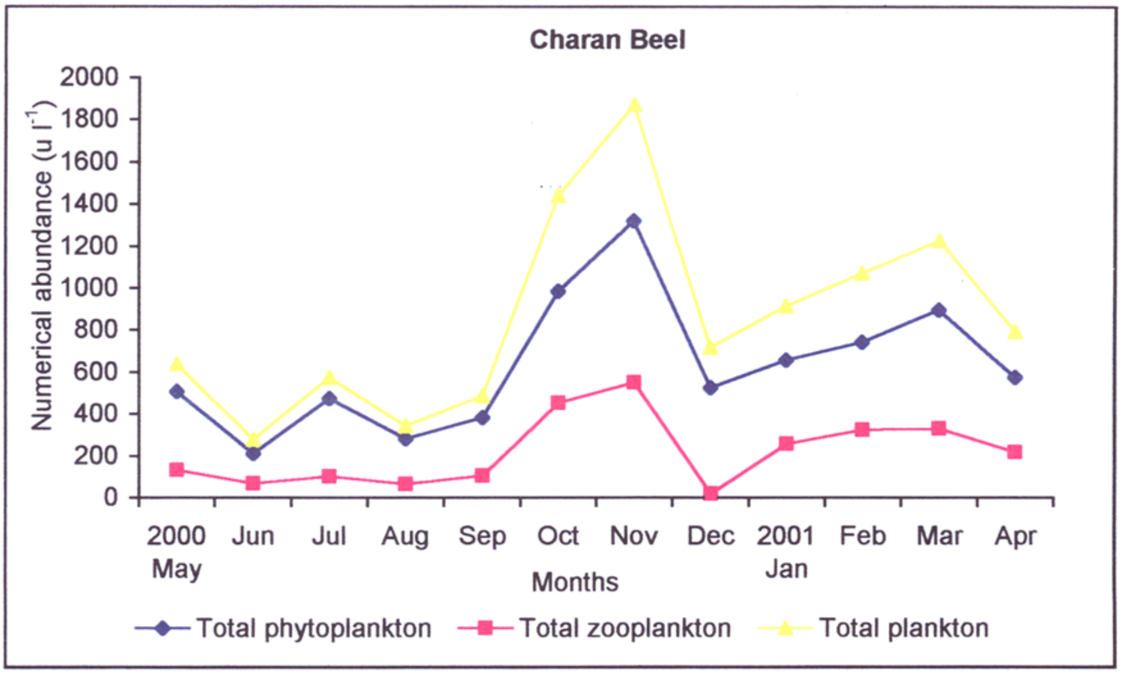
Phytoplankton population ranged from 212 (June) to 1322 u l^{-1} (November) with monthly average population of 630 u l^{-1} in Charan *Beel*, while in Jaluguti *Beel* it fluctuated between 127 (June) and 804 u l^{-1} (December), with an average monthly population of 385 u l^{-1}. The monthly variation of phytoplankton population exhibited four peaks with the primary and secondary peaks observed in November and March in Charan *Beel* (Fig. 31). Generally, the monsoon months (June to September) recorded low phytoplankton population, while the post-monsoon months (October-November) had high population in this *beel*. The seasonal variation showed a trimodal pattern in Jaluguti *Beel* with secondary and tertiary peaks observed in August and April. Phytoplankton abundance was low in June, September and January in this *beel*.

Among the various groups of phytoplankton, Bacillariophyceae remained the most dominant group (38.3% on an average) followed by Chlorophyceae (33.3%), Myxophyceae (18.4) and Desmidiaceae (10.0%) in Charan *Beel*. The contribution of Bacillariophyceae fluctuated between 34.7 (April-May) and 40.9% (January) in this *beel* (Fig. 32). Myxophyceae showed maximum contribution (26.2%) in April. In Jaluguti *Beel*, Chlorophyceae was the most dominant group (36.1%), followed by Bacillariophyceae (29.6%), Myxophyceae (15.3%), Euglenoida (10.4%) and Desmidiaceae (8.6%). The contribution of Euglenoida was maximum during the pre-monsoon season (12.2-12.7%), while it was minimum (8.2-8.9%) during the period from August to October.

Table 27. Monthly variations in numerical abundance of plankton (u l^{-1})* in Jaluguti *Beel*

Groups	Months												Annual average
	2000 May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	
Phytoplankton:													
Chlorophyceae	91 (35.0)	44 (34.4)	120 (34.0)	222 (34.6)	86 (35.8)	143 (37.3)	194 (38.2)	302 (37.6)	89 (37.0)	99 (36.4)	114 (36.0)	168 (35.7)	139 (36.1)
Bacillariophyceae	82 (31.4)	34 (26.9)	111 (31.4)	205 (31.9)	73 (30.4)	111 (28.9)	143 (28.2)	225 (28.0)	67 (27.8)	79 (29.0)	94 (29.8)	146 (30.9)	114 (29.6)
Myxophyceae	37 (14.2)	22 (17.2)	58 (16.4)	101 (15.8)	37 (15.4)	57 (14.8)	73 (14.3)	124 (15.4)	38 (15.8)	43 (15.8)	48 (15.1)	67 (14.2)	59 (15.3)
Euglenoida	32 (12.2	14 (11.3)	34 (9.6)	56 (8.8)	20 (8.2)	34 (8.9)	47 (9.3)	81 (10.1)	26 (10.7)	32 (11.6)	39 (12.3)	60 (12.7)	40 (10.4)
Desmidiaceae	18 (6.9)	10 (7.8)	30 (8.5)	58 (9.1)	24 (9.8)	39 (10.2)	50 (9.8)	72 (9.0)	21 (8.6)	20 (7.2)	22 (6.8)	30 (6.4)	33 (8.6)
Total phytoplankton	260 (63.1)	127 (62.3)	353 (64.1)	642 (63.3)	240 (63.7)	384 (60.5)	507 (59.6)	804 (60.7)	241)61.4	273 (62.0)	317 (62.4)	471 (61.8)	385 (61.8)
Zooplankton:													
Rotifera	57 (37,8)	28 (36.4)	70 (35.4)	133 (35.8)	47 (34.3)	86 (34.2)	120 (34.8)	185 (35.6)	55 (36.4)	62 (37.0)	73 (38.1)	113 (39.0)	86 (36.1)
Copepoda	53 (35.0)	26 (33.8)	71 (35.8)	135 (36.4)	48 (35.3)	84 (33.5)	110 (32.1)	165 (31.8)	49 (32.4)	55 (33.0)	65 (33.8)	101 (34.6)	80 (33.6)
Protozoa	28 (18.4)	15 (20.1)	36 (18.4)	65 (17.6)	30 (21.6)	62 (24.7)	90 (26.2)	131 (25.2)	36 (23.8)	36 (21.6)	37 (19.4)	50 (17.2)	52 (21.8)
Cladocera	14 (9.5)	7 (9.7)	20 (10.4)	38 (10.2)	12 (8.8)	19 (7.4)	24 (7.0)	39 (7.5)	11 (7.3)	14 (8.1)	16 (8.4)	27 (9.2)	20 (8.4)
Total zooplankton	152 (36.9)	77 (37.7)	197 (35.9)	372 (36.7)	137 (36.3)	251 (39.5)	344 (40.4)	520 (39.3)	151 (38.6)	167 (38.0)	191 (37.6)	291 (38.2)	238 (38.2)
Total plankton	412	204	550	1014	377	635	851	1324	392	440	508	762	623

Note: Figures in parenthesis indicate percentage composition of each group to total * Average of two stations.



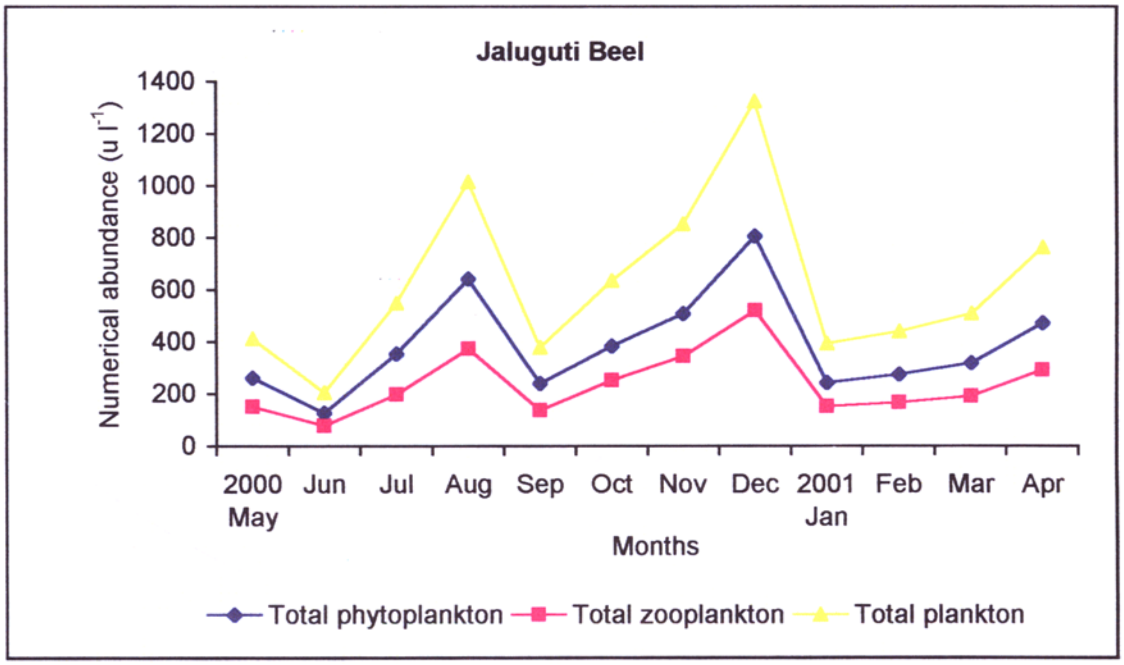
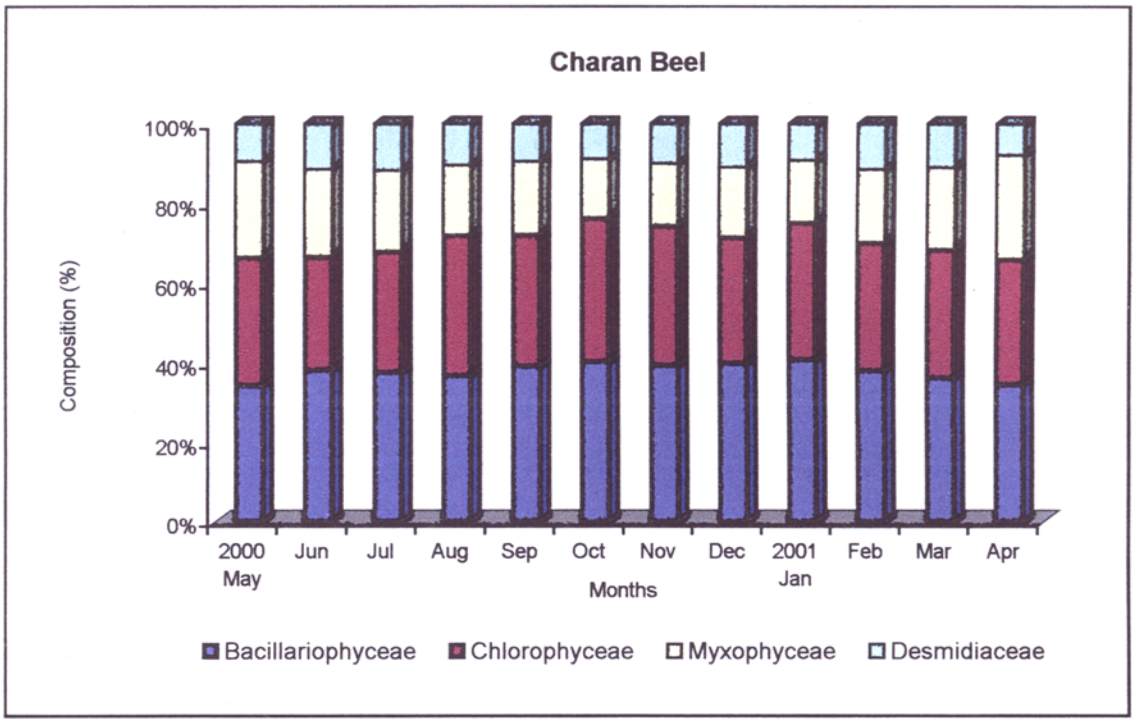


Fig. 31. **Monthly variations in numerical abundance of plankton in the selected beels**



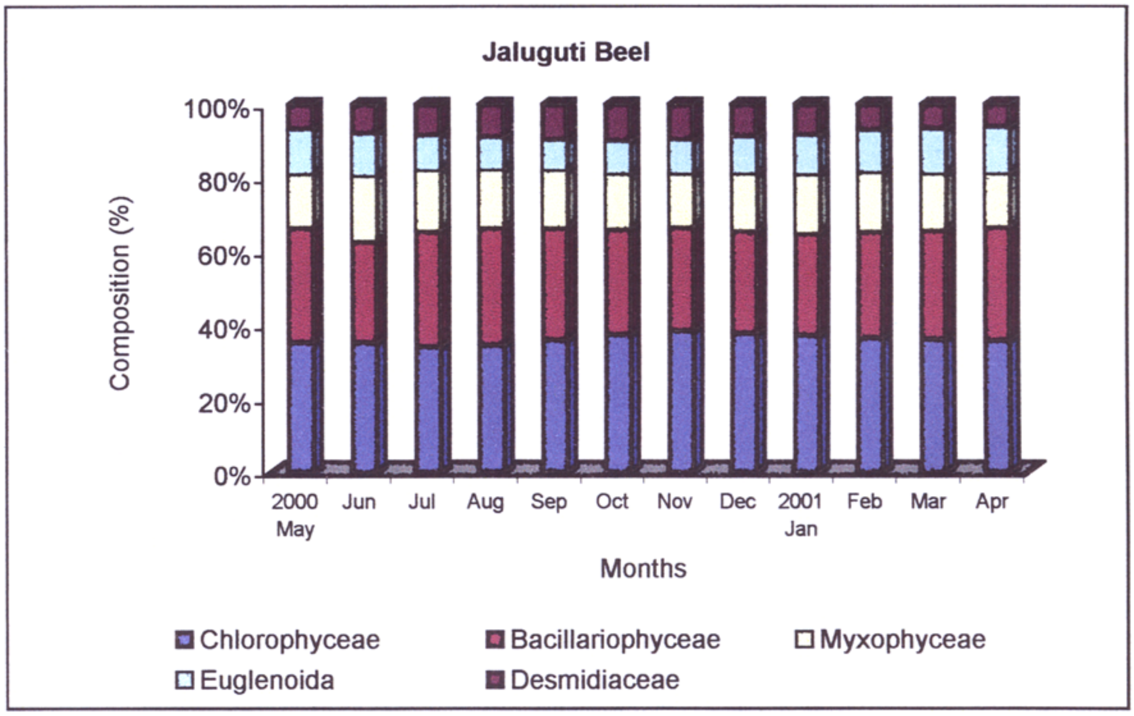


Fig. 32. Monthly variations in percentage composition of different phytoplankton groups in the selected beels

A total of 63 genera of phytoplankton were recorded in the *beels* (Table 28). The number of phytoplankton genera occurring in Charan *Beel* was higher (52) than that in Jaluguti *Beel* (45 genera). The group Bacillariophyceae was represented by 20 genera (19 in Charan *Beel* and 14 in Jaluguti *Beel*) out of which *Fragilaria* spp., *Melosira* spp. and *Navicula* spp. were the most dominant ones. Chlorophyceae was represented by 20 genera (14 in Charan *Beel* and 17 in Jaluguti *Beel*) of which *Spirogyra* spp., *Pediastrum* spp. and *Mougeotia* spp.were commonly encountered. Out of the 10 genera representing Myxophyceae (9 in Charan *Beel* and 6 in Jaluguti *Beel*), *Microcystis* spp., *Anabaena* spp. and *Oscillatoria* spp. were fairly common. Desmids were represented by 11 genera (10 in Charan *Beel* and 6 in Jaluguti *Beel*), of which *Cosmarium* spp. and *Staurastrum* spp. were the most dominant ones. The group Euglenoida, represented by *Euglena* spp. and *Phacus* spp., occurred only in Jaluguti *Beel*.

4.5.1.2 Zooplankton

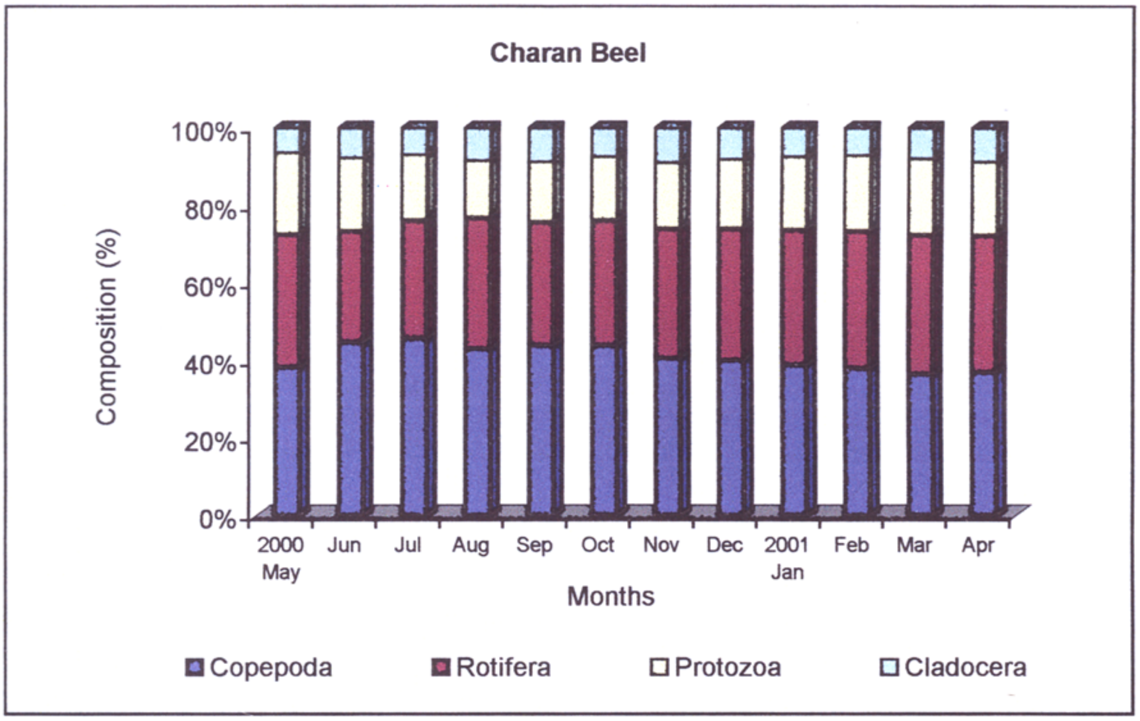
Numerical abundance of zooplankton varied from 64 (August) to 550 u l^{-1} (November) in Charan *Beel*. In Jaluguti *Beel,* zooplankton population fluctuated between 77 (June) and 520 u l^{-1} (December). The average zooplankton population was 233 and 238 u l^{-1} in Charan and Jaluguti *Beel* respectively and it did not show significant variation in the two *beels*.

The seasonal variation pattern of zooplankton population closely followed that of phytoplankton in both the *beels* (Fig. 31). In Charan *Beel*, zooplankton showed low abundance during the period from May to September and in May. The periods of October-November and January to April showed high and moderate abundance respectively. In Jaluguti *Beel*, the period from October to December, July-August and April-May recorded high zooplankton abundance.

The monthly variation in percentage composition of different groups of zooplankton has been presented in Tables 26 and 27 as well as in Fig. 33. In Charan *Beel*, the copepods remained the most dominant group,

Table 28. Common phytoplankton genera recorded in the selected *beels*

A. Myxophyceae	*Asterionella* (C,J)
Anabaena (C, J)	*Cocconeis* (C)
Aphanocapsa (C)	*Cyclotella* (C,J)
Coelosphaerium (C,J)	*Cymbella* (C,J)
Lyngbya (C)	*Diatoma* (C,J)
Microcystis (C,J)	*Epithemia* (J)
Nostoc (C,J)	*Fragilaria* (C,J)
Oscillatoria (C)	*Frustulia* (C)
Phormidium (C,J)	*Gomphonema* (C,J)
Rivularia (C)	*Gyrosygma* (C,J)
Spirulina (J)	*Melosira* (C,J)
B. Chlorophyceae	*Meridion* (C)
Ankistrodesmus (J)	*Navicula* (C,J)
Botryococcus (J)	*Nitzschia* (C,J)
Chlamydomonas (C,J)	*Pinularia* (C,J)
Closteriopsis (C)	*Stephanodiscus* (C)
Coelastrum (C, J)	*Surirella* (C)
Crucigenia (C)	*Synedra* (C,J)
Dictyosphaerium (J)	*Tabellaria* (C,J)
Dinobryon (C,J)	**D. Desmidiaceae**
Kirchneriella (J)	*Arthrodesmus* (C)
Microspora (C,J)	*Closterium* (C,J)
Mougeotia (C,J)	*Cosmarium* (C,J)
Oedogonium (C,J)	*Desmidium* (C,J)
Pachycladon (C)	*Euastrum* (C)
Pediastrum (C,J)	*Micrasterias* (C,J)
Scenedesmus (J)	*Netrium* (C)
Spirogyra (C,J)	*Penium* (C)
Synura (J)	*Staurastrum* (C,J)
Ulothrix (C,J)	*Tetradesmus* (J)
Volvox (C,J)	*Xanthidium* (C)
Zygnema (C,J)	**E. *Euglenoida***
C. Bacillariophyceae	*Euglena* (J)
Amphora (C)	*Phacus* (J)



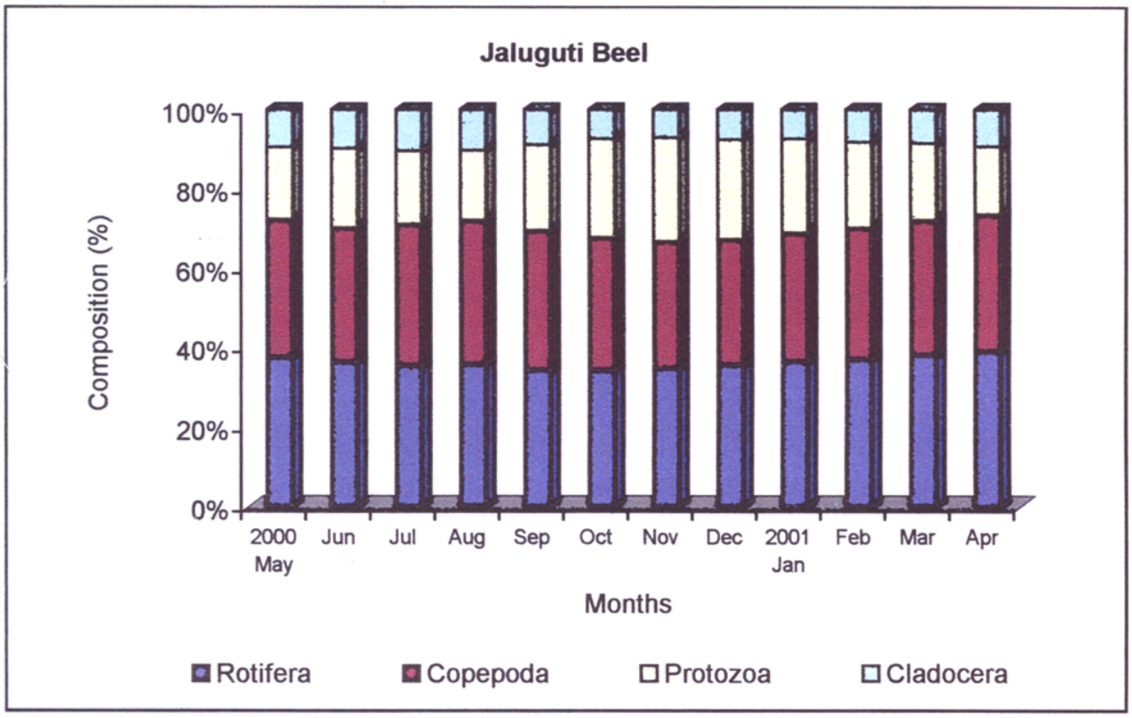


Fig. 33. **Monthly variations in percentage composition of different zooplankton groups in the selected beels**

contributing 37.0 to 45.5% (average 40.3%) to total zooplankton population, followed by rotifers (average contribution 33.9%), protozoans (17.6%) and cladocerans (8.2%) in this *beel*. On the other hand, rotifers were the most dominant group (36.1%) in Jaluguti *Beel*, followed by copepods (33.6%), protozoans (21.8%) and cladocerans (8.4%). Copepods dominated over rotifers during the period from July to September, after which rotifers dominated zooplankton population.

Out of 31 zooplankton genera recorded in the *beels*, 25 occurred in Charan *Beel* and 26 in Jaluguti *Beel* (Table 29). The group Copepoda was represented by 5 genera, of which *Cyclops* spp. and *Diaptomus* spp. were the most dominant ones. Out of the 12 genera of rotifers recorded, 9 occurred in Charan *Beel* and 10 in Jaluguti *Beel*. *Brachionus* spp., *Keratella* spp. and *Filinia* spp. were the most common rotifers. The protozoans were represented by 7 genera (5 in Charan *Beel* and 6 in Jaluguti *Beel*), out of which *Pandorina* spp. and *Eudorina* spp. were dominant ones. Out of the 7 cladoceran genera encountered (6 in each *beel*), *Moina* spp. and *Ceriodaphnia* spp. were fairly common.

4.5.2 Aquatic macrophytes

Extensive growth of floating (mainly free-floating), submerged, emergent and marginal aquatic macrophytes were observed in both the *beels* throughout the study period. Floating and submerged macrophytes dominated macrovegetation cover in both.

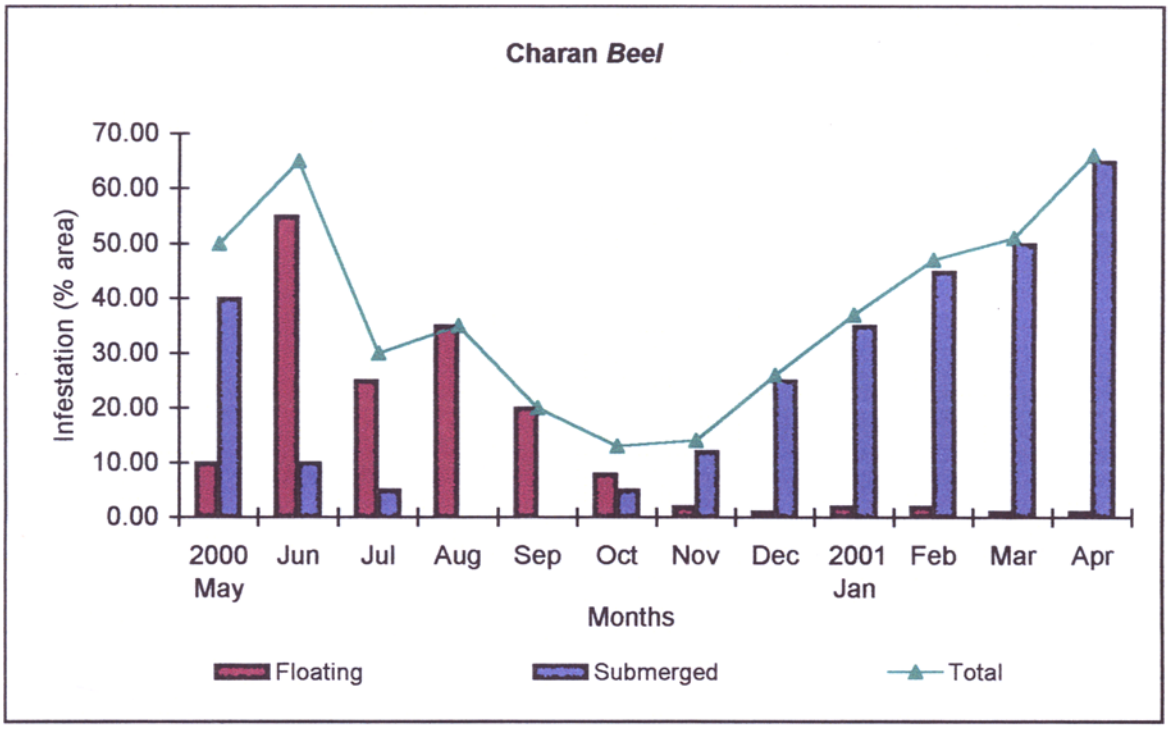
4.5.2.1 Infestation intensity

The intensity of macrophytic infestation (in terms of per cent area covered) varied from as low as 13% (in October) to 66% (April) in Charan *Beel* (Table 30). On an average, this *beel*, was moderately infested by macrophytes (38%). The period from March to June showed heavy infestation (over 50% of area), while the remaining months recorded moderate infestation (14 to 47%) in this *beel* (Fig. 34). Average infestation of submerged and floating macrophytes was 24 and 14% respectively. Infestation of submerged macrophytes was negligible (<1%) during August-

Table 29. Common zooplankton genera recorded in the selected *beels*

A. Protozoa	*Polyarthra* (C,J)
Centropyxis (C,J)	*Synchaeta* (C)
Difflugia (C)	*Trichocera* (C,J)
Eudorina (C,J)	**C. Copepoda**
Euglypha (J)	*Cyclops* (C,J)
Pandorina (C,J)	*Diaptomus* (C,J)
Pleodorina (C,J)	*Eucyclops* (C,J)
Vorticella (J)	*Mesocyclops* (C)
B. Rotatoria	*Neodiaptomus* (C,J)
Asplanchna (C,J)	**D. Cladocera**
Brachionus (C,J)	*Bosmina* (C,J)
Chromogaster (J)	*Ceriodaphnia* (C,J)
Euchlanis (C,J)	*Chydorus* (C,J)
Filinia (C,J)	*Daphnia* (J)
Hexarthra (C)	*Eurycerus* (C,J)
Keratella (C,J)	*Moina* (C,J)
Lecane (J)	*Sida* (C)
Monostyla (J)	

Note: C = Charan *Beel*; J = Jaluguti *Beel*



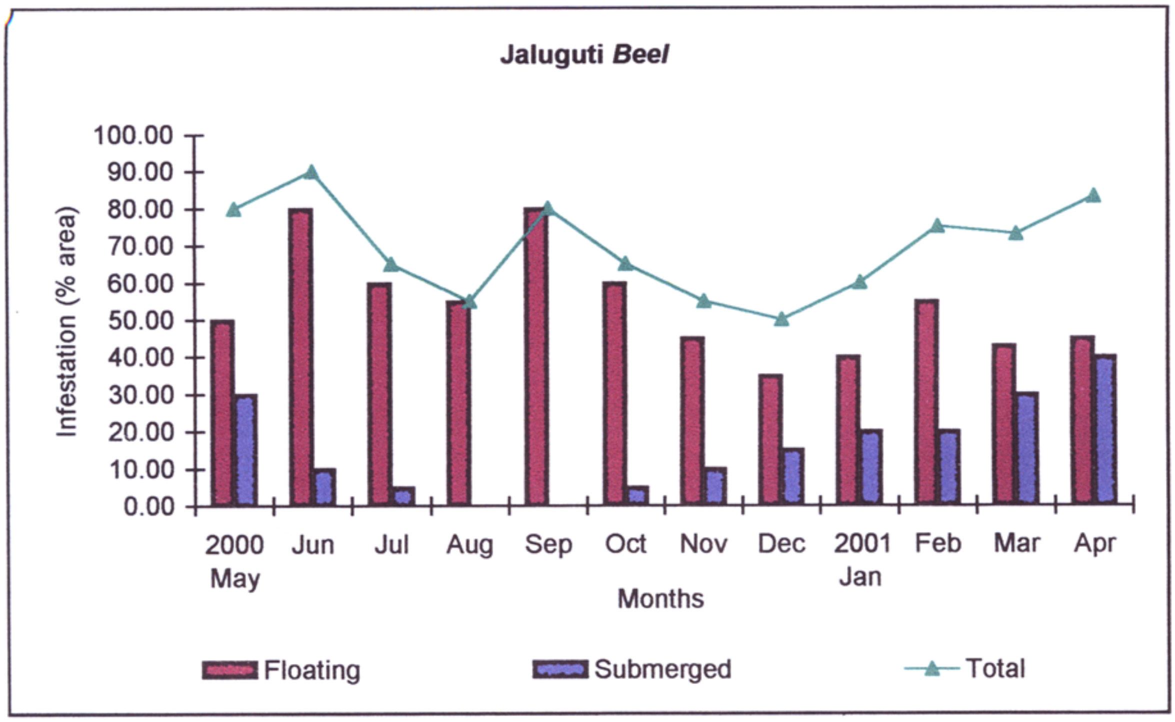


Fig. 34. Monthly variations in macrophyte infestation in the selected *beels*

September and low during June-July and October-November (5-12%). They started covering more areas from December onwards, showing maximum infestation in April. Their infestation declined sharply from May onwards reaching negligible levels in August. On the other hand, floating macrophytes had the maximum intensity in June (55%) followed by a steep decline in July. Their infestation was moderate during the period from May to September (10-35%) except in June. Infestation of floating macrophytes remained low (1-8%) in the remaining months. Jaluguti *Beel* was heavily infested throughout the study period, ranging from 50 (December) to 90% (June). Average macrophyte infestation was 69% in this *Beel*. Floating macrophytes had moderate (November to January, March-April) to heavy infestation in this *beel* (average 54%). Submerged macrophytes were negligible during August-September, low during June-July and October-November and moderate in the remaining months (average infestation 15%).

4.5.2.2 Biomass

The average standing crop of macrophytes was 1.40 kg dry wt m^{-2} in Charan *Beel* (Table 31). Jaluguti *Beel* had comparatively higher biomass (1.62 kg dry wt m^{-2}). In Charan *Beel*, the lowest biomass (0.75 kg dry wt m^{-2}) was recorded in December and the highest (2.77 kg dry wt m^{-2}) in June. Macrophyte biomass was low (<1 kg dry wt m^{-2}) during December–January, moderate (1.0-1.5 kg dry wt m^{-2}) during the period from February to April, August to November and high (1.80-2.77 kg dry wt m^{-2}) during May to July (Fig. 35). The seasonal variation in the biomass of floating macrophytes followed a similar trend as that of the total macrophytes in this *beel*. However, submerged macrophytes had low biomass during the period from July to September (0.03-0.08 kg dry wt m^{-2}). Their biomass gradually increased from October onwards, reaching maximum (0.64 kg dry wt m^{-2}) in February, after which biomass again declined to reach low levels in July. On an average, free-floating macrophytes contributed overwhelmingly (81.4%) to the total macrophyte biomass in this *beel*. In Jaluguti *Beel,* the lowest standing crop of macrophytes (0.80 kg dry wt m^{-2}) was recorded in January while the maximum biomass was in June (2.92 kg dry wt m^{-2}). The period from May to September recorded high macrophyte biomass, while that from October to April had

Table 30. Monthly variations in macrophyte infestation (% area covered) in the selected *beels*

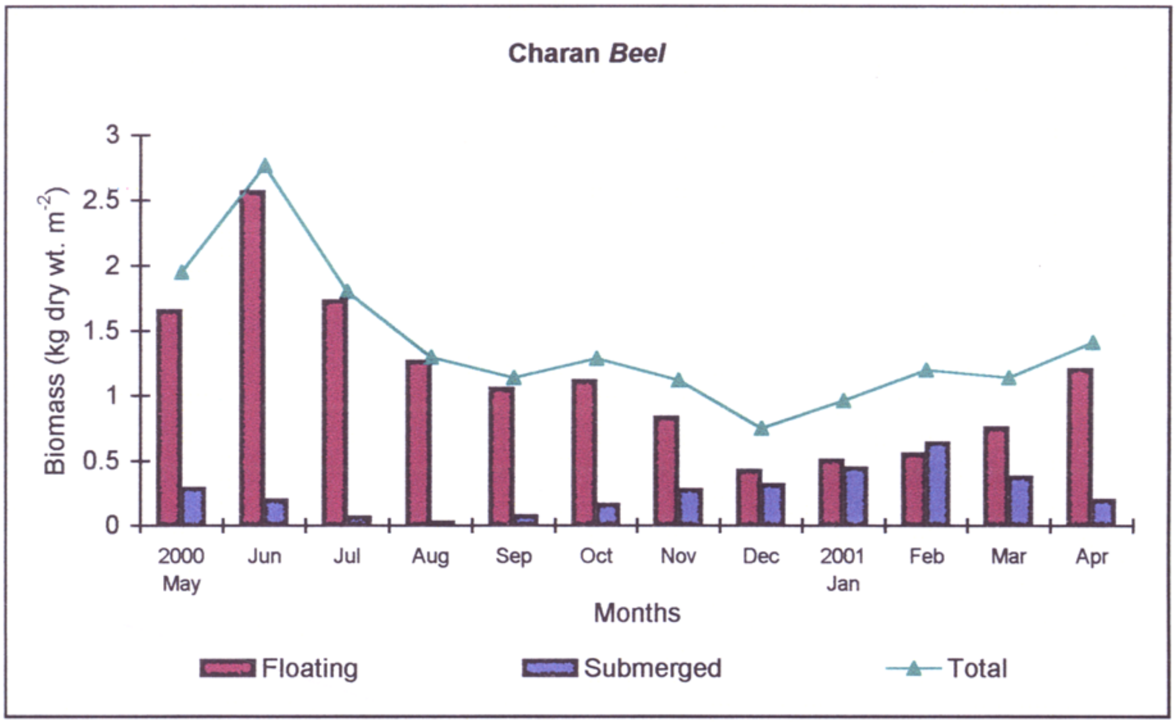
Months	Charan *Beel*			Jaluguti *Beel*		
	Floating	Submerged	Total	Floating	Submerged	Total
2000 May	10	40	50	50	30	80
Jun	55	10	65	80	10	90
Jul	25	5	30	60	5	65
Aug	35	-	35	55	-	55
Sep	20	-	20	80	-	80
Oct	8	5	13	60	5	65
Nov	2	12	14	45	10	55
Dec	1	25	26	35	15	50
2001 Jan	2	35	37	40	20	60
Feb	2	45	47	55	20	75
Mar	1	50	51	43	30	73
Apr	1	65	66	45	40	83
Annual av.	14	24	38	54	15	69

Note: - indicates negligible

Table 31. Monthly variations in macrophyte biomass (kg dry wt. m^{-2}) in the selected *beels*

Months	Charan *Beel*			Jaluguti *Beel*		
	Floating	Submerged	Total	Floating	Submerged	Total
2000 May	1.66	0.29	1.95	1.99	0.34	2.33
Jun	2.57	0.20	2.77	2.74	0.18	2.92
Jul	1.73	0.07	1.80	2.15	0.15	2.30
Aug	1.27	0.03	1.30	1.95	0.08	2.03
Sep	1.06	0.08	1.14	1.66	0.04	1.70
Oct	1.12	0.17	1.29	1.38	0.07	1.45
Nov	0.84	0.28	1.12	1.03	0.18	1.21
Dec	0.43	0.32	0.75	0.76	0.27	1.03
2001 Jan	0.51	0.45	0.96	0.47	0.33	0.80
Feb	0.56	0.64	1.20	0.67	0.39	1.06
Mar	0.76	0.38	1.14	0.64	0.49	1.13
Apr	1.21	0.20	1.41	1.23	0.28	1.51
Annual av.	1.14	0.26	1.40	1.39	0.23	1.62
	(81.43)	(18.57)	-	(85.80)	(14.20)	-

Note: Figures in parenthesis indicate average per cent contribution of each group



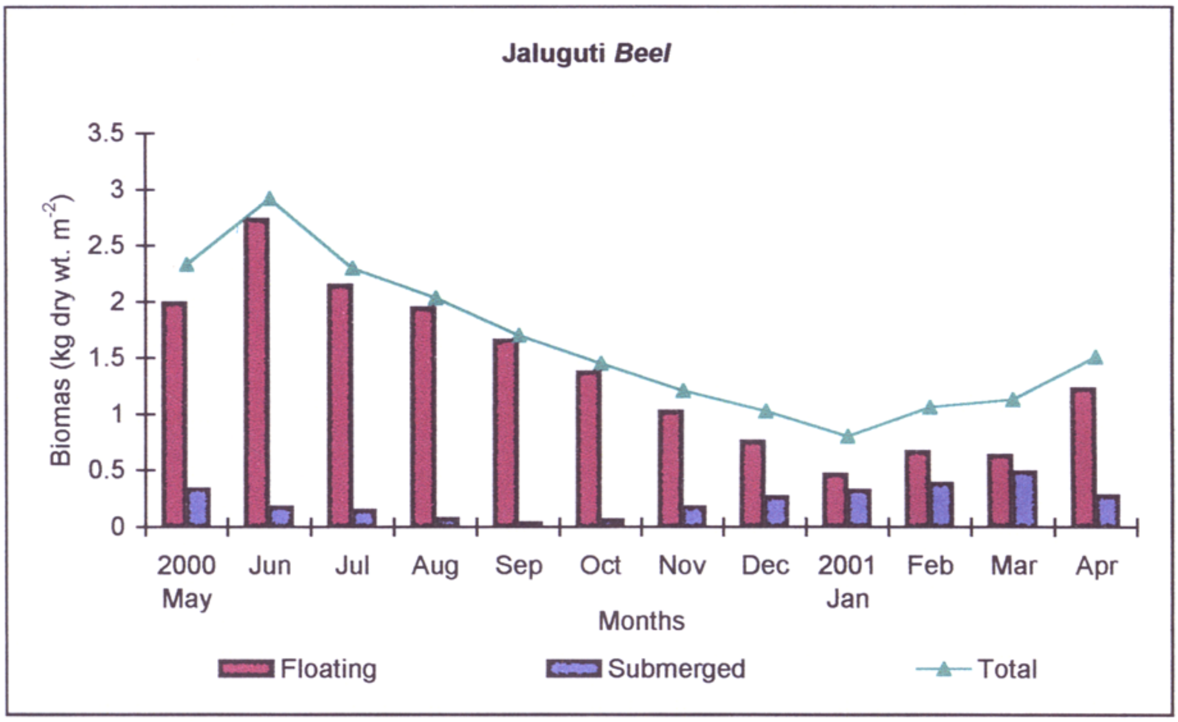


Fig. 35. Monthly variations in macrophyte biomass in the selected *beels*

moderate to low biomass. The trend of seasonal variation in the biomass of free-floating macrophytes was similar to that of the total biomass. Submerged macrophytes had low biomass (0.04-0.08 kg dry wt m^{-2}) during the period from August to October. Their standing crop gradually increased from November onwards reaching maximum (0.49 kg dry wt m^{-2}) in March. It declined sharply during May-June and became low in August. The floating macrophytes contributed overwhelmingly (85.8%) to the average total macrophyte biomass in this *beel*.

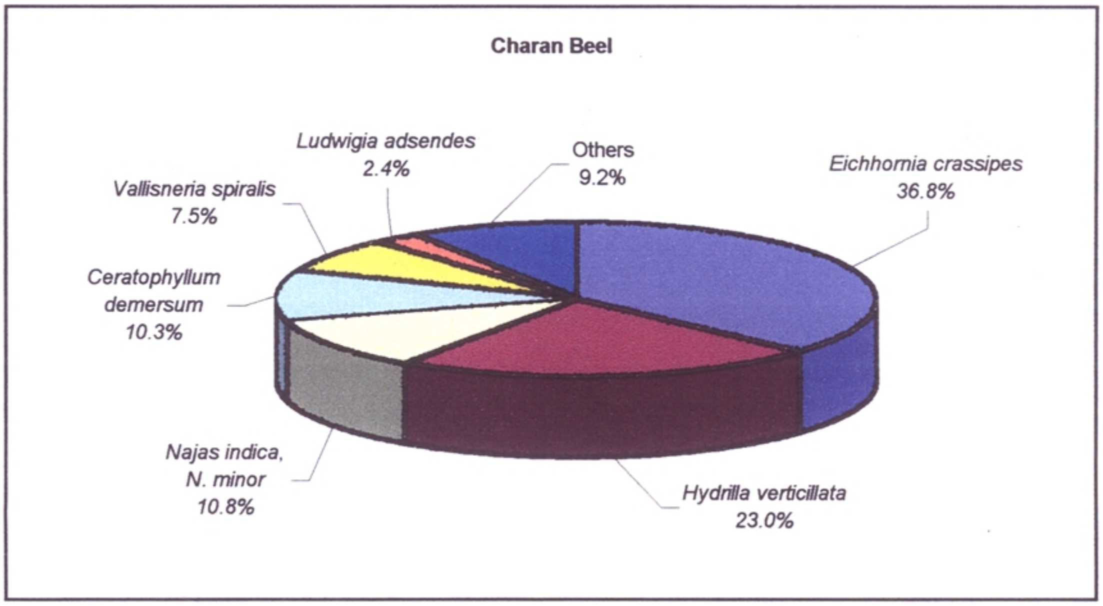
4.5.2.3 Species composition

Eichhornia crassipes (free-floating) was the most dominant species in both the *beels*; it contributed to 36.8 and 52.2% of the average total macrophyte standing crop in Charan *Beel* and Jaluguti *Beel* respectively (Table 32 and Fig. 36). In Charan *Beel*, water hyacinth was followed by the submerged macrophytes *Hydrilla verticillata* (23.0%), *Najas indica* and *N. minor* (10.8%), *Ceratophyllum demersum* (10.3%) and *Vallisneria spiralis* (7.5%) in order to their percentage contribution to the average total biomass. *Ludwigia adsendens*, an emergent species, contributed to 2.4% of the total biomass, while the remaining seven species, *viz., Salvinia cucullata, S. natans, Azolla pinnata* (free-floating), *Myriophyllum tuberculum* (floating-leaved), *Colocasia antiquorum* (marginal), *Potamogeton octondus* (submerged) and *Prosperpinaca palustris* (submerged) contributed to the remaining biomass (9.2%) in this *beel* (Table 32). In Jaluguti *Beel,* water hyacinth contributed to 52.2% of the total macrophyte standing crop, followed by the submerged macrophytes, *H. verticillata (12.8%), Najas* spp. (11.2%), *V. spiralis* (7.9%) and *C. demersum* (7.5%) in order of dominance (Fig. 36). The remaining six species occurring in this *beel viz., S. cucullata, S. natans, C. antiquorum, Ipomoea aquatica* (emergent), *Marsilia quadrifolia* (marginal) and *Pistia stratiotes* (free-floating) together contributed to 8.4%. A total of 17 macrophyte species (14 in Charan *Beel* and 13 in Jaluguti *Beel*) were recorded during the study period.

Table 32. Occurrence and percentage contribution of macrophyte species in the selected *beels*

Species recorded	Type of macrophyte	Charan *Beel*		Jaluguti *Beel*	
		Occurrence	% composition	Occurrence	% composition
1. *Eichhornia crassipes*	Free floating	Ubiquitous	36.8	Ubiquitous	52.2
2. *Hydrilla verticillata*	Submerged	Ubiquitous	23.0	Ubiquitous	12.8
3. *Najas indica, N. minor*	Submerged	Ubiquitous	10.8	Ubiquitous	11.2
4. *Ceratophyllum demersum*	Submerged	Ubiquitous	10.3	Ubiquitous	7.5
5. *Vallisneria spiralis*	Submerged	Ubiquitous	7.5	Ubiquitous	7.9
6. *Ludwigia adsendes*	Submerged	Ubiquitous	2.4	Fairly common	-
7. Others			9.2		8.4
Salvinia cucullata	Free floating	Common		Fairly common	
S. natans	Free floating	Common		Fairly common	
Colocasia antiquorum	Marginal	Occasional		Occasional	
Myriophyllum tuberculum	Floating leaved	Fairly common		NR	
Potamogeton octondus	Submerged	Occasional		NR	
Ipomoea aquatica	Emergent	NR		Occasional	
Marsilia quadrifolia	Marginal	NR		Occasional	
Azolla pinnata	Free floating	Occasional		NR	
Pistia stratiotes	Free floating	NR		Rare	
Prosperpinaca palustris	Submerged	Rare		NR	

Note: NR = Not recorded



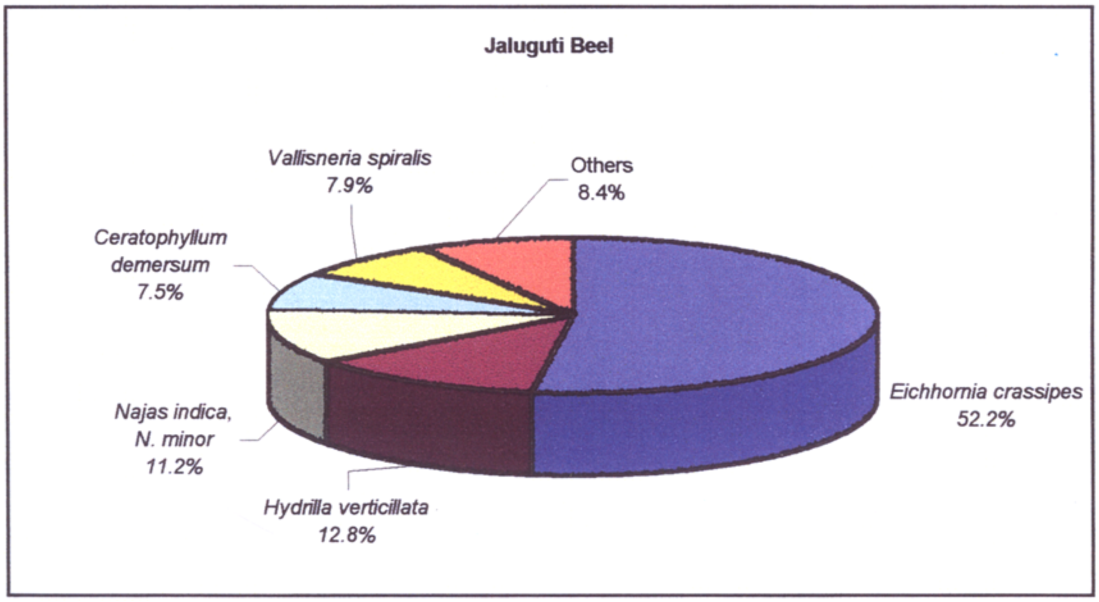


Fig. 36. Percentage contribution of dominant macrophyte species in the selected beels

4.5.3 Benthic macroinvertebrates

The biomass of benthic macroinvertebrates ranged from 55.3 to 837.5 g wet weight m^{-2} in Charan *Beel* and from 41.9 to 676.6 g wet wt m^{-2} in Jaluguti *Beel* (Table 33). Charan *Beel* supported comparatively higher average biomass (429.1 g wet wt m^{-2}) than Jaluguti *Beel* (354.2 g wet wt m^{-2}). The lowest and the highest standing crop was recorded in August and May respectively in both the *beels*. However, the pattern of seasonal variation in macrobenthos biomass was slightly different in the *beels*. In Charan *Beel,* the biomass declined sharply from the maximum in May to reach low levels during July-August, after which there was a marked increase to record a secondary peak in October (Fig. 37). Their biomass increased further during the subsequent months to reach maximum in May. The decline in biomass after May was gradual and reached low levels during the period from August to October, after which the biomass more or less increased from November onwards to reach maximum biomass in May. Gastropods dominated the average standing crop of macrobenthos in both Charan *Beel* (38.0%) and Jaluguti *Beel* (35.7%). It was followed by oligochaetes (31.7 and 31.1%), insects (21.8 and 21.7%) and bivalves (8.5 and 11.5%) in both the *beels* (Fig. 38). The percentage contribution of bivalves was comparatively higher in Jaluguti *Beel* compared to that of Charan *Beel.*

A total of 21 genera/species of benthic macroinvertebrates were recorded in the *beels* (Table 35). While all of the 21 taxa occurred in Charan *Beel*, four taxa, *viz.*, *Bellamya bengalensis*, *Amnicola* spp., *Bithynia stenothyroid* (gastropods) and *Piscidium* spp. (bivalve), were absent in Jaluguti *Beel*. The group Gastropoda was represented by 10 taxa of which *Gyraulus convexiusculus* and *Melania* spp. were the most dominant ones. Among the four oligochaete taxa recorded, *Aelosoma* spp. and *Chaetogaster* spp. were fairly common. Dragonfly nymphs and *Chironomus* spp. were the most common insects while *Corbicula striatella* and *Lamellidens marginalis* were fairly common among bivalves.

Table 33. Monthly variations in macrobenthos biomass (g wet wt m^{-2}) in the selected *beels*

Groups	Months												Annual average
	2000 May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	
Charan *Beel*													
Gastropoda	326.7	148.0	29.2	17.2	36.6	228.8	168.9	84.5	153.3	195.9	254.9	311.7	163.0 (38.0)
Oligochaeta	281.1	128.6	27.7	18.7	39.6	189.1	153.3	82.2	138.3	145.0	213.8	211.6	136.1 (31.7)
Insecta	158.5	76.3	25.4	15.7	26.9	112.1	98.7	62.8	74.0	116.6	166.0	185.4	93.4 (21.8)
Pelecypoda	71.0	26.9	5.2	3.7	7.5	42.6	36.6	18.7	42.6	50.8	66.5	70.3	36.6 (8.5)
Total	837.3	379.8	91.2	55.3	110.6	572.6	457.5	248.2	408.2	508.3	701.3	779.0	429.1
Jaluguti *Beel*													
Gastropoda	258.5	123.0	73.1	14.2	25.2	30.2	161.9	133.5	113.2	153.7	198.9	230.9	126.4 (35.7)
Oligochaeta	221.9	106.3	63.0	12.2	21.8	25.8	139.5	116.0	98.6	134.2	177.4	207.4	110.3 (31.1)
Insecta	108.2	82.0	55.8	11.9	24.2	31.1	143.3	100.1	74.6	92.3	103.0	95.1	76.8 (21.7)
Pelecypoda	88.0	36.1	19.4	3.6	6.2	7.2	42.9	39.7	36.9	52.8	71.6	84.0	40.7 (11.5)
Total	676.6	347.4	211.3	41.9	77.4	94.3	487.6	389.3	333.3	433.0	550.9	617.4	354.2

Note: Figures in parenthesis indicate percentage composition of each group.

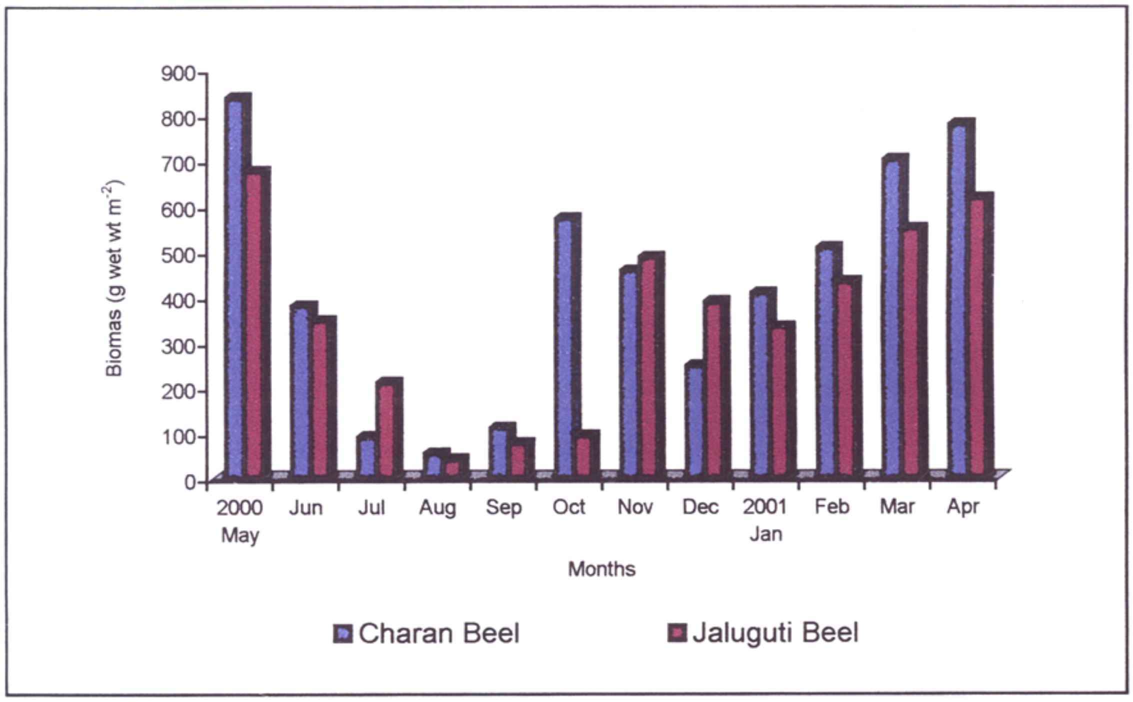
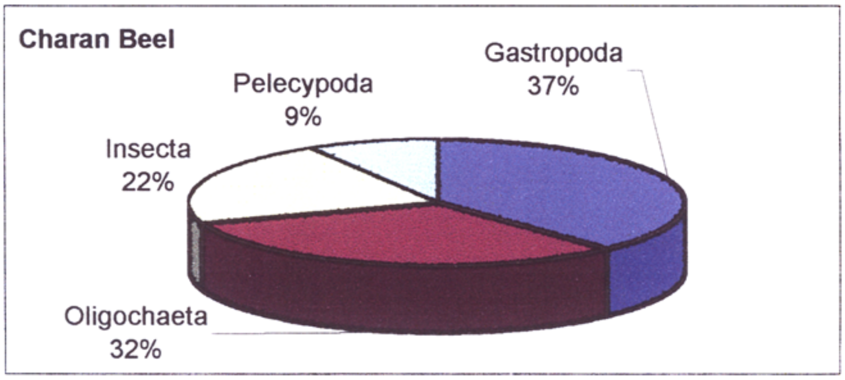


Fig. 37. Monthly variations in macrobenthos biomass in the selected beels



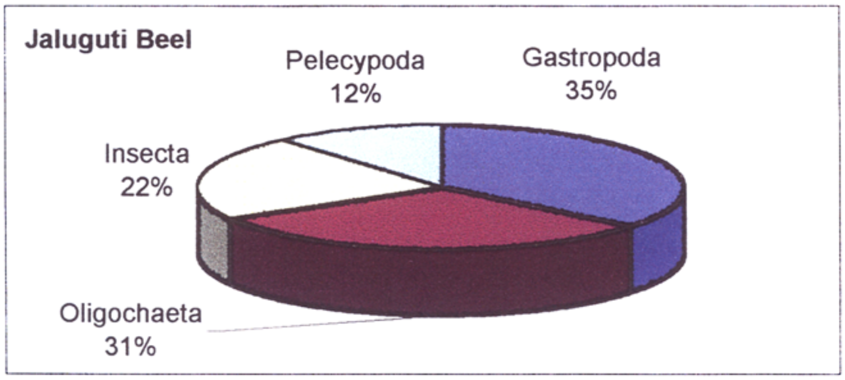


Fig. 38. Percentage contribution of various groups of macrobenthos in the selected beels

4.5.4 Macrophyte-associated fauna

The standing crop of macrophyte-associated fauna varied from 64.1 to 971.3 g wet wt m^{-2} in Charan *Beel* and from 56.1 to 906.4 g wet wt m^{-2} in Jaluguti *Beel* (Table 34). The average biomass was higher in Charan *Beel* (497.4 g wet wt m^{-2}) than that in Jaluguti *Beel* (474.4 g wet wt m^{-2}). Both the *beels* recorded the highest biomass of associated fauna in June. However, the period of the lowest biomass was December in Charan *Beel* and January in Jaluguti *Beel*. The periods of low biomass were from November to January in Charan *Beel* and from December to February in Jaluguti *Beel* (Fig. 39). The period from April to August supported high biomass in both the *beels*. The period from May to September showed a declining trend, while the pre-monsoon months (March to May) showed an increasing trend in both the *beels*. The average biomass of macrophyte-associated fauna was dominated by insects (40.2 and 42.1% of total biomass in Charan *Beel* and Jaluguti *Beel* respectively), followed by molluscs (29.5 and 33.3%), worms (20.3 and 18.9%) and other forms (9.9 and 5.6%). The percentage contribution of the most dominant groups, *viz.*, insects and mollusks, was comparatively higher in Jaluguti *Beel* than that of Charan *Beel* (Fig. 40).

The macrophyte-associated fauna recorded in the selected *beels* numbered 28 taxa, out of which 25 occurred in Charan *Beel* and 23 in Jaluguti *Beel* (Table 35). The most dominant group Insecta was represented by 8 taxa, of which *Chironemus* spp. and *Caenis* spp. were the most common. The group Mollusca was represented by 10 taxa, of which *Bellamya bengalensis*, *Amnicola* spp. and *Bithynia stenothyroid* occurred only in Charan *Beel*. *Lymnaea acuminata* and *Gyraulus convexiusculus* were the most common molluscan species recorded in the *beels*. The annelids comprised 5 genera, of which *Dero* spp. and *Hirudo* spp. occurred only in Jaluguti *Beel*. *Aelosoma* spp. and *Chaetogaster* spp. were the most commonly encountered annelids. In addition to the above three major groups, two fish species (*Badis badis* and *Colisa lalia*), small prawns (*Macrobrachium* spp.) and frog (*Rana* sp.) were part of the macrophyte-associated fauna in both the *beels*. The chameleon fish (*B. badis*) and small prawns were fairly common in macrophyte-infested areas.

Table 34. Monthly variations in biomass (g wet wt m^{-2}) of macrophyte-associated fauna in the selected *beels*

Groups	Months												Annual average
	2000 May	Jun	July	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	April	
Charan *Beel*													
Insecta	378.6	397.0	337.7	241.2	108.0	209.0	51.5	26.9	41.8	189.8	165.4	254.4	200.1 (40.2)
Mollusca	263.1	273.4	232.0	171.6	85.4	164.8	37	17.7	27.1	148.4	138.2	204.4	146.9 (29.5)
Annelida	169.4	206.5	156.5	109.9	68.8	107.5	28.2	14.2	24.5	79.9	100.8	147.1	101.1 (20.3)
Others*	92.5	94.4	87.2	67.0	25.7	49.5	11.7	5.3	8.1	55.4	36.2	58.4	49.3 (9.9)
Total	**903.7**	**971.3**	**813.5**	**589.7**	**287.9**	**530.8**	**128.4**	**64.1**	**101.5**	**473.5**	**440.6**	**664.3**	**497.4**
Jaluguti *Beel*													
Insecta	354.0	382.5	317.4	278.3	244.2	192.7	175.4	41.3	22.6	51.5	118.3	221.1	199.9 (42.1)
Mollusca	269.6	302.7	251.0	226.0	203.0	158.2	144.2	33.8	18.0	40.0	88.6	160.1	157.9 (33.3)
Annelida	168.8	179.5	132.8	115.0	100.4	86.6	84.9	21.3	11.6	25.5	54.0	97.5	89.8 (18.9)
Others*	34.7	41.7	36.9	34.0	32.5	27.9	28.6	7.3	3.9	9.3	22.1	42.8	26.8 (5.6)
Total	**827.1**	**906.4**	**738.1**	**653.3**	**580.1**	**465.4**	**433.1**	**103.7**	**56.1**	**126.3**	**283.0**	**521.5**	**474.4**

Note: Figures in parenthesis indicate percentage contribution of each group * Includes small fishes, prawns and frogs.

Table 35. Benthic macroinvertebrates and macrophyte-associated fauna of the selected *beels**

BENTHIC MACROINVERTEBRATES	MACROPHYTE-ASSOCIATED FAUNA
I. Gastropoda:	**I. Insecta:**
1. *Digoniostoma pulchella* (C,J)	1. *L. maculatus* (C,J)
2. *Melania striatella* (C,J)	2. *Chironemus* sp. (C,J)
3. *M. scabra* (C,J)	3. *Gerris* sp. (C,J)
4. *Gyraulus convexiusculus* (C,J)	4. *Ranatra sp.* (C,J)
5. *Faunus ater* (C,J)	5. *Lethocerus* sp. (C,J)
6. *Paludomus obesa* (C,J)	6. *Caenis sp.* (C,J)
7. *Lymnaea acuminata* (C,J)	7. Mosquito larvae (C,J)
8. *Bellamya bengalensis* (C)	8. *Anisops sp.* (C)
9. *Bithynia stenothyroid* (C)	**II. Mollusca:**
10. *Amnicola* sp. (C)	9. *D. pulchella* (C,J)
II. Oligochaeta:	10. *M. striatella* (C,J)
11. *Aelosoma* sp. (C,J)	11. *M. scabra* (C,J)
12. *Chaetogaster* sp. (C,J)	12. *L. acuminata* (C,J)
13. *Branchiura* sp. (C,J)	13. *Pila globosa* (C,J)
14. *Dero sp.* (C,J)	14. *G. convexiusculus* (C,J)
III. Insecta:	15. *P. obesa* (C,J)
15. *Chironomus* sp. (C,J)	16. *F. ater* (C,J)
16. Dragonfly nymph (C,J)	17. *B. bengalensis* (C)
17. *Laceotrephes maculatus* (C,J)	18. *Amnicola sp.* (C)
18. Mosquito larvae (C,J)	19. *B. stenothyroid* (C)
IV. Pelecypoda:	**III. Annelida:**
19. *Corbicula striatella* (C,J)	20. *Branchiura* sp. (C,J)
20. *Lamellidens marginalis* (C,J)	21. *Aelosoma sp.* (C,J)
21. *Piscidium* sp. (C)	22. *Chaetogaster sp.* (C,J)
	23. *Dero* sp. (J)
	24. *Hirudo* sp. (J)
	IV. Others:
	25. *Badis badis* (C,J)
	26. *Macrobrachium* sp. (C,J)
	27. *Rana* sp. (C,J)
	28. *Colisa lalia* (C)

Note: C = Charan *Beel*; J = Jaluguti *Beel*
* Arranged in order of dominance/occurrence.

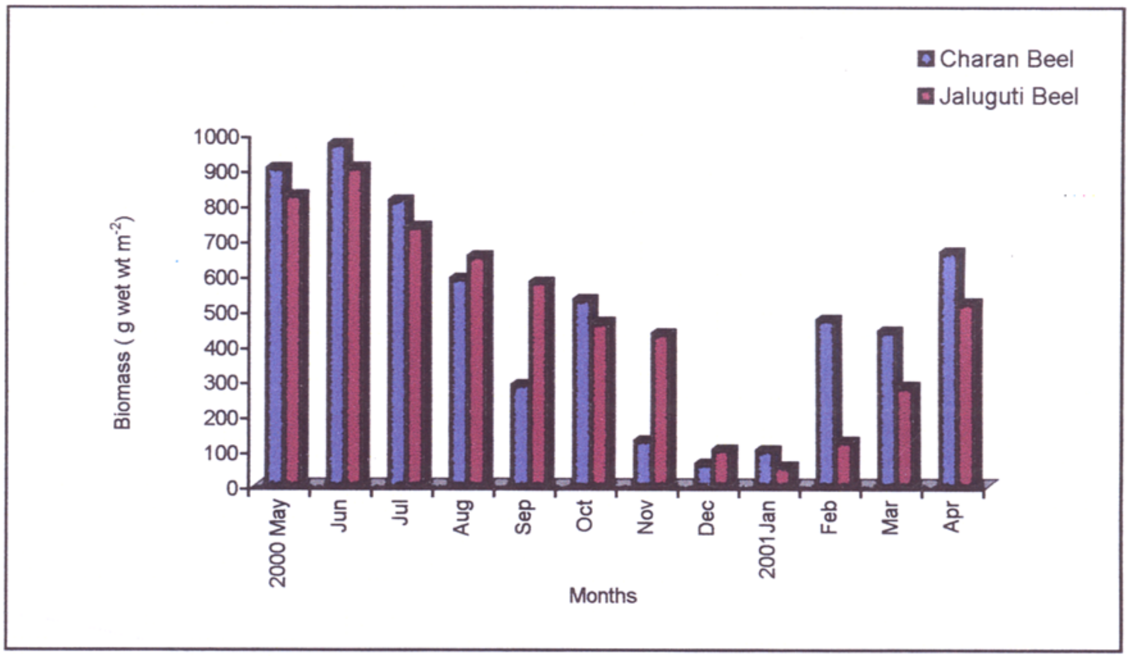


Fig. 39. Monthly variations in biomass of macrophyte associated fauna in the selected beels

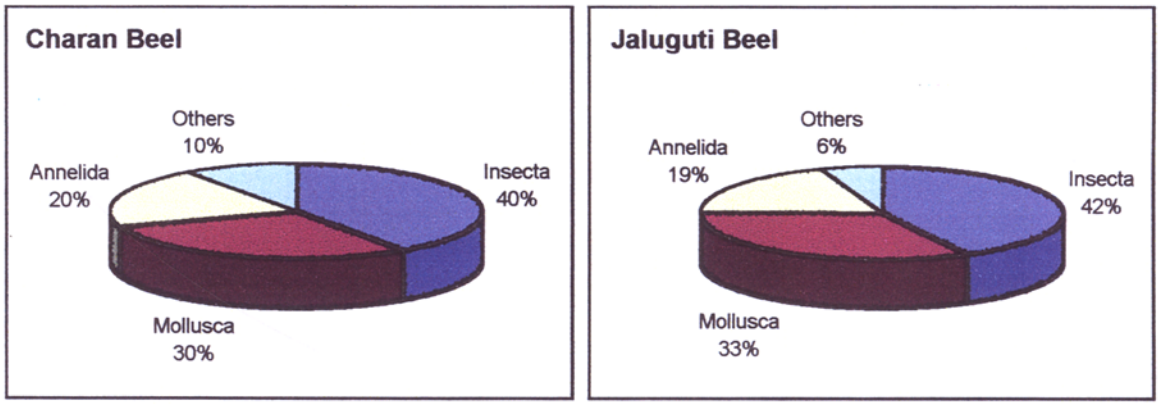


Fig. 40. Percentage contribution of different groups of macrophyte associated in the selected beels

4.6 Primary productivity

4.6.1 Phytoplankton primary productivity

Variations in the rate of carbon production by phytoplankton in the selected *beels* have *been* presented in Table 36 and Fig. 41.

The gross primary productivity (GPP) and net primary productivity (NPP) of phytoplankton ranged from 45.67 (August) to 267.71 mg C $m^{-2}hr^{-1}$ (November) and from 18.75 (July) to 134.38 mg C $m^{-2}hr^{-1}$ (November) in Charan *Beel* and Jaluguti *Beel* respectively. Generally, the period from May to September recorded lower GPP, except in July. The GPP showed a trimodal pattern of seasonal variation with secondary and tertiary peaks observed in March and July. The seasonal variation pattern of NPP followed that of GPP during the period from August to April. However, in case of the NPP, the primary, secondary and tertiary peaks were observed in March, November and May respectively. The average GPP in Charan *Beel* (130.84 mg C $m^{-2}hr^{-1}$) was considerably higher than that of Jaluguti *Beel* (96.37 mg C $m^{-2}hr^{-1}$). The average NPP in Charan *Beel* was comparatively higher (69.87 mg C $m^{-2}hr^{-1}$) than the respiration rate (60.97 mg C $m^{-2}hr^{-1}$). However, the respiration rate exceeded the NPP in June, October and November and was almost equal to the later in August and September.

In Jaluguti *Beel*, the GPP and NPP of phytoplankton ranged from 47.88 (September) to 276.56 mg C $m^{-2}hr^{-1}$ (November) and from 8.75 (January) to 92.19 mg C $m^{-2}hr^{-1}$ (November) respectively. The gross primary productivity showed a trimodal temporal variation pattern in this *beel*, which was slightly different from that in Charan *Beel*. Though both the *beels* recorded maximum gross phytoplankton production in November, the secondary and tertiary peaks were recorded in August and April in this *beel*. Further, the lowest gross phytoplankton production was recorded in September instead of August. The NPP of phytoplankton showed an irregular seasonal variation pattern with four peaks. However, the period of maximal NPP (November) was the same as that of GPP. The average net phytoplankton productivity in this *beel* (41.29 mg $Cm^{-2}hr^{-1}$) was considerably lower than that of the respiration rate (54.99 mg C$m^{-2}hr^{-1}$). Respiration rate exceeded NPP during five months of the year. In some months like January, July and April, the net phytoplankton productivity was very low (8.75-15.63 mg C $m^{-2}hr^{-1}$), while the respiration rates were considerable (45.0-77.4 mg C $m^{-2}hr^{-1}$).

4.6.2 Macrophyte primary productivity

The gross primary productivity of aquatic macrophytes ranged from 41.45 (December) to 242.95 mg C $m^{-2}hr^{-1}$) (June) in Charan *Beel* with an average of 118.74 mg C $m^{-2}hr^{-1}$ (Table 37). The average gross macrophyte productivity in Jaluguti *Beel* (206.91 mg C $m^{-2}hr^{-1}$) was 1.7 times higher than that in Charan *Beel*. It ranged from 102.79 (January) to 593.75 mg C $m^{-2}hr^{-1}$ (June).

The gross macrophyte productivity showed a distinct bimodal seasonal variation pattern in Jaluguti *Beel* with the primary and secondary peaks observed in June and September (Fig. 42). The values declined gradually from September to December after which they remained more or less at the same level up to March. It increased sharply during the period from March to June, reaching peak values in June. Gross macrophyte productivity in Charan *Beel* also recorded maximal values in June. However, it showed a trimodal pattern of seasonal variation with the secondary and tertiary peaks observed in October and February respectively. Net macrophyte productivity showed irregular seasonal variation patterns in both the *beels*, which were different from the gross macrophyte productivity. The maximum net productivity was recorded either in June (similar with gross productivity pattern) or in May in Jaluguti and Charan *Beel* respectively.

The average net macrophyte productivity in Charan *Beel* (63.41 mg C $m^{-2}hr^{-1}$) was comparatively higher than that of the average respiration rates (55.33 mg C $m^{-2}hr^{-1}$). However, the respiration rate exceeded that of the net macrophyte productivity during four months of the year. In October, the net macrophyte productivity was very low (17.02 mg C $m^{-2}hr^{-1}$) while the respiration rate was considerable (88.86 mg C $m^{-2}hr^{-1}$). In the months of

Table 36. Monthly variations in phytoplankton primary productivity (mg C $m^{-2}hr^{-1}$) in the selected *beels*

Months	Charan *Beel*			Jaluguti *Beel*		
	Gross production	Net production	Respiration	Gross production	Net production	Respiration
2000 May	95.83	81.43	14.40	54.65	28.05	26.00
Jun	79.69	34.38	45.31	53.98	32.95	21.03
Jul	116.67	18.75	97.92	89.90	12.50	77.40
Aug	45.67	23.08	22.60	148.44	73.44	75.00
Sep	74.38	37.50	36.88	47.88	31.25	15.63
Oct	185.94	92.19	93.75	109.30	56.14	53.06
Nov	267.71	114.58	153.13	276.56	92.19	184.38
Dec	110.63	73.75	36.88	93.08	54.37	38.72
2001 Jan	121.60	79.74	41.86	53.75	8.75	45.00
Feb	152.96	83.44	69.52	57.30	38.08	19.22
Mar	207.29	134.38	72.92	76.04	15.63	60.42
Apr	111.74	65.24	46.50	95.60	52.15	43.45
Annual av.	130.84	69.87	60.97	96.37	41.29	54.99

Table 37. Monthly variations in macrophyte primary productivity (mg C $m^{-2}hr^{-1}$) in the selected *beels*

Months	Charan *Beel*			Jaluguti *Beel*		
	Gross production	Net production	Respiration	Gross production	Net production	Respiration
2000 May	188.12	121.95	66.18	318.69	157.67	161.02
Jun	242.95	103.98	138.97	593.75	197.92	395.85
Jul	168.74	83.66	85.08	234.66	120.53	113.92
Aug	110.35	72.36	37.99	193.01	26.84	166.17
Sep	86.97	73.90	13.07	199.84	116.73	83.13
Oct	105.88	17.02	88.86	163.25	33.56	129.72
Nov	72.32	31.20	41.12	115.89	70.74	45.15
Dec	41.45	20.95	20.51	115.40	18.79	96.61
2001 Jan	67.50	34.03	33.47	102.79	67.09	33.56
Feb	101.40	59.21	42.19	117.33	60.22	57.11
Mar	100.40	66.93	33.47	123.02	81.75	41.26
Apr	138.80	75.72	63.09	205.25	111.96	93.28
Annual Av.	118.74	63.41	55.33	206.91	88.65	118.07

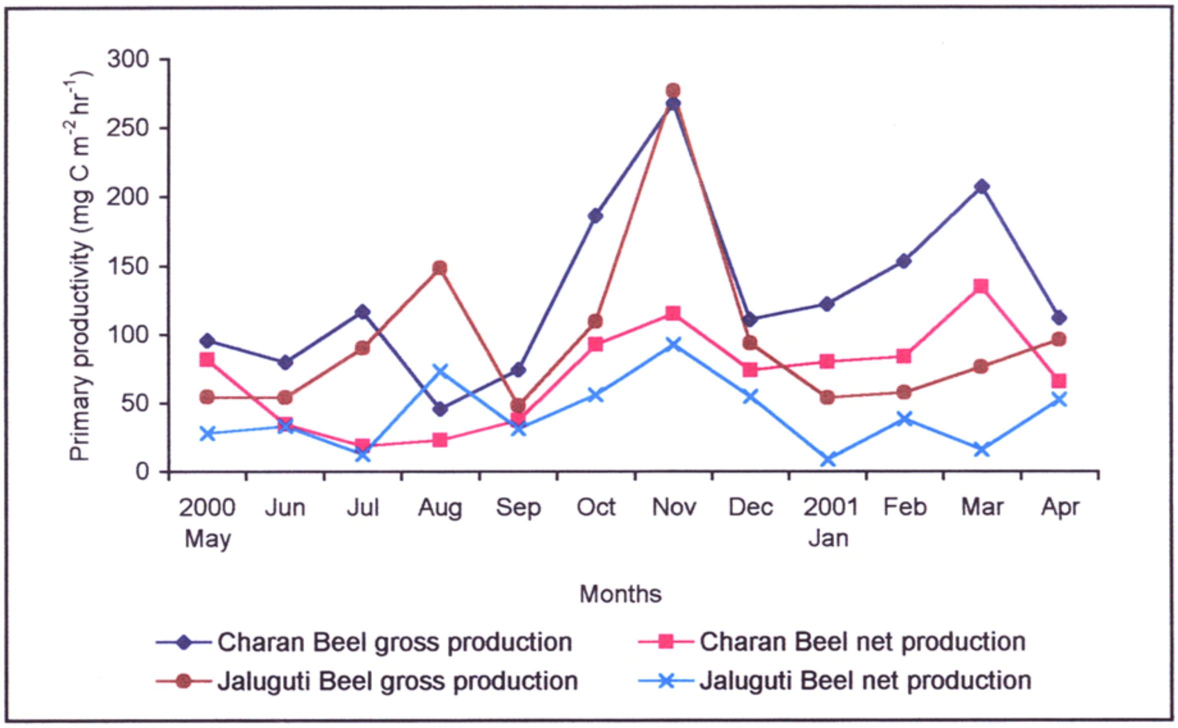


Fig. 41. Monthly variations in phytoplankton primary productivity in the selected beels

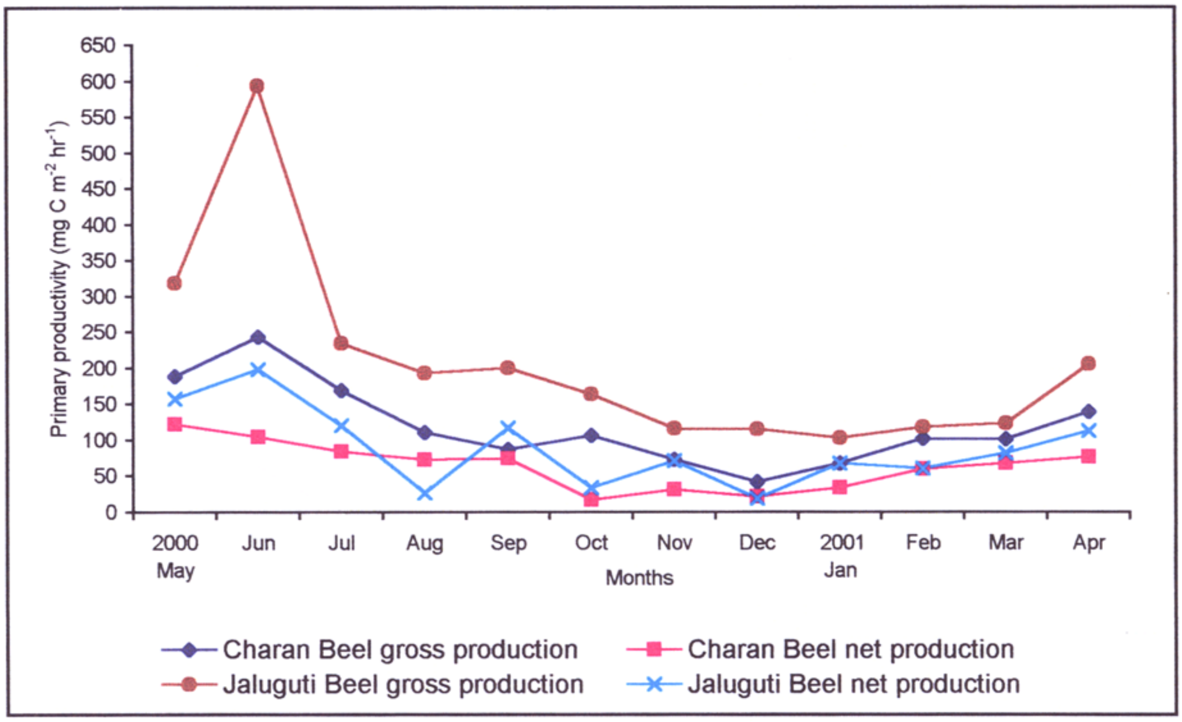


Fig. 42. Monthly variations in macrophyte primary productivity in the selected beels

December and August, net macrophyte productivity was very low (18.79-26.89 mg C $m^{-2}hr^{-1}$) while the respiration rates were considerable (96.61-166.17 mg C $m^{-2}hr^{-1}$). In fact, the average respiration rate (118.07 mg C m^{-2} hr^{-1}) was much higher in this *beel* than the average net macrophyte productivity (88.65 mg C $m^{-2}hr^{-1}$).

4.7 Statistical analyses

Student's t test showed that the gross phytoplankton productivity varied significantly between the two *beels* (t = 2.043, degrees of freedom = 11) at 5% level of significance. Significant differences also existed between the *beels* in respect of the gross macrophyte productivity (t = 3.418, d.f. = 11, $P<0.05$).

The simple correlation coefficients (r) between different meteorological and hydrobiological parameters have been presented in the form of a correlation matrix in Table 38. As many as 87 simple correlation coefficients were found to be significant at 5% level of significance (indicated by putting asterix marks in the table). Out of these, very high significant correlation coefficient were obtained between air and water temperature (r = 0.967), available nitrogen and available phosphorus of soil (0.950), total alkalinity and total hardness (0.964), specific conductivity and total dissolved solids (0.998), gross phytoplankton productivity and phytoplankton abundance (0.968), gross phytoplankton productivity and zooplankton abundance (0.936), gross macrophyte productivity and macrophyte biomass (0.979), gross macrophyte productivity and biomass of associated fauna (0.947) as well as between phytoplankton and zooplankton population.

4.8 Fisheries

4.8 .1 Fish yield

The annual commercial fish catch from Charan *Beel* during the study period was 13887 kg, out of which the contribution of major fishes was 47.1% (Table 39). These generated considerable gross revenue of Rs. 638449, out of which fisher's share was 40% as per the AFDC's guidelines

Table 38. Simple correlation coefficients (r) between different meteorological and hydrobiological parameters

X1 \ X2	Rainfall	Air temperature	Soil pH	Soil organic carbon	Soil avail-able N	Soil avail-able P	Water temp-erature	Secchi disc depth	Water pH	Total alka-linity	Diss. oxygen	Free Carbon dioxide	Total hard-ness	Specific conuct-ivity	Total diss. solids	Diss. organic matter	Total iron	Total chloride	Nitrate-nitrogen	Phosph ate-phosph orus	Silicate silicate	Phyto-plankton GPP	Macro-phyte GPP	Phyto-plankton abund-ance	Zoopla-nkton abund-ance	Macro-phyte biomass	Macro-benthos biomass
Air temperature	0.669*																										
Soil pH	0.402	0.375																									
Soil organic carbon	-0.357	-0.138	-0.589*																								
Soil available nitrogen	0.452	0.722*	-0.255	0.406																							
Soil available P	0.290	0.556	-0.505	0.495	0.950*																						
Water temperature	0.678*	0.967*	0.311	-0.083	0.721*	0.563																					
Secchi disc depth	-0.069	-0.431	0.084	-0.698*	-0.590*	-0.508	-0.442																				
Water pH	-0.558	-0.409	-0.480	0.548	-0.016	0.132	-0.500	-0.098																			
Total alkalinity	-0.783*	-0.431	-0.485	0.707*	-0.052	0.108	-0.462	-0.303	0.833*																		
Dissolved oxygen	-0.470	-0.675*	-0.007	-0.103	-0.641*	0.522	-0.778*	0.500	0.524	0.437																	
Carbon dioxide	0.386	0.050	0.290	-0.761*	0.321	-0.363	0.063	0.454	-0.761*	-0.807*	-0.167																
Total hardness	-0.723*	-0.373	-0.414	0.676*	-0.063	0.078	-0.418	-0.323	0.869*	0.964*	0.422	-0.799*															
Specific conductivity	-0.363	-0.032	-0.626*	0.875*	0.550	0.642*	-0.020	-0.579*	0.659*	0.762*	-0.062	-0.858*	0.707*														
Total dissolved solids	-0.360	-0.039	-0.645*	0.869*	0.551	0.648*	-0.025	-0.571	0.655*	0.757*	-0.066	-0.843*	0.701*	0.998*													
Diss. organic matter	0.517	0.661*	0.359	-0.481	0.357	0.179	0.639*	0.071	-0.520	-0.707*	-0.606*	0.408	-0.673*	-0.383	-0.390												
Total iron	0.153	0.152	-0.171	0.061	0.330	0.395	0.076	-0.200	-0.108	0.051	0.017	0.112	-0.038	0.181	0.201	-0.286											
Total chloride	-0.141	-0.137	-0.601*	0.452	0.330	0.520	-0.113	-0.183	0.215	0.426	0.106	-0.271	0.302	0.551	0.572	-0.597*	0.780*										
Nitrate-nitrogen	0.387	0.366	0.339	0.036	0.172	0.080	0.328	-0.486	-0.384	-0.230	-0.255	0.257	-0.146	-0.175	-0.173	-0.106	0.541	0.172									
Phosphate-P	0.028	-0.123	0.186	-0.409	-0.349	-0.419	-0.063	0.094	-0.686*	-0.464	-0.196	0.758*	-0.512	-0.530	-0.516	0.166	0.136	-0.166	0.277								
Silicate-silica	0.668*	0.417	0.763*	-0.636*	-0.007	-0.272	0.398	0.209	-0.586*	-0.802*	-0.307	0.453	-0.746*	-0.617*	-0.627*	0.711*	-0.291	-0.682*	0.084	0.231							
Phytoplankon GPP	-0.731*	-0.330	-0.099	0.221	-0.340	-0.291	-0.303	-0.103	0.250	0.499	0.038	-0.224	0.561	0.189	0.118	-0.286	-0.217	-0.077	-0.009	0.109	-0.360						
Macrophyte GPP	0.486	0.601*	0.103	-0.195	0.595*	0.523	0.520	-0.202	-0.405	-0.342	-0.341	0.257	-0.394	0.015	0.028	0.297	0.804*	0.417	0.489	0.187	0.165	-0.359					
Phytopl. abudnance	-0.752*	-0.392	-0.204	0.223	-0.380	-0.290	-0.350	-0.005	0.291	0.486	0.083	-0.194	0.564	0.154	0.152	-0.276	-0.333	-0.117	-0.106	0.066	-0.422	0.968*	-0.481				
Zoop. abundance	-0.766*	-0.402	-0.157	0.227	-0.435	-0.337	-0.364	-0.013	0.278	0.516	0.180	-0.196	0.594*	0.119	0.114	-0.360	-0.300	-0.087	-0.037	0.073	-0.477	0.936*	-0.490	0.978*			
Macrophyte biomass	0.496	0.547	0.231	-0.290	0.454	0.367	0.460	-0.142	-0.483	-0.402	-0.278	0.358	-0.455	-0.127	-0.114	0.255	0.851*	0.367	0.588*	0.273	0.231	-0.330	0.979*	-0.463	-0.458		
Macrobenth. biomass	-0.515	-0.147	-0.751*	0.563	0.275	0.500	-0.154	-0.310	0.450	0.661*	0.031	-0.360	0.623*	0.652*	0.668*	-0.493	0.501	0.747*	0.074	-0.157	-0.894*	0.403	0.186	0.413	0.418	0.192	
Assoc. fauna biomass	0.483	0.694*	0.006	-0.146	0.715*	0.655*	0.655*	-0.212	-0.409	-0.330	-0.453	0.174	-0.397	0.106	0.117	0.409	0.667*	0.097	0.296	0.116	0.131	-0.389	0.947*	-0.478	-0.492	0.878*	0.209

Note: *Indicates significant coefficients at 5% level of significance.

(60% going to the lessees). The average wholesale price of fishes at the *beel* site worked out to be Rs. 46.65 per kilogram. The rate of fish production was 228.12 kg ha^{-1} yr^{-1}. Most of the fish catch from this *beel* (94.2%) was obtained during the period from November to March (5 months). The maximum fish yield was recorded in December followed by November and February (Fig. 43). There was no commercial fishing during April-May, while 800 kg of fishes (5.8%) were landed from barrier fishing (*bheta mara*) in June. Commercial fishing was also negligible during the period from July to October due to floods/high water level, though subsistence fishing using gill netting, line fishing and skimming (*thela jal*) were observed. The peak fishing season lasted only for four months (November to February) and the catch declined many folds in March.

The total commercial fish catch from Jaluguti *Beel* was 2107 kg (Table 40), which was overwhelmingly dominated by major fishes (86.2%). The estimated yield rate was many folds lower in this *beel* (60.20 kg $ha^{-1}yr^{-1}$) than that of Charan *Beel*. The *beel* generated gross revenue of Rs.196285, of which 40% was shared by the fishers. The average wholesale fish price at the *beel* site (Rs. 93.16 kg^{-1}) was nearly two folds higher than that of Charan *Beel*. The commercial fishing lasted for five months (December to April) in this *beel*. Fish yield gradually increased after December to reach maximum in March, after which there was a sharp decline in catches in April (Fig. 43). Nearly half of the total landings (49.4%) occurred in March. There was no fishing during the period from May to August. Fishing was closed for another two months (September-October) on account of release of approximately 50000 catla fry. Commercial fishing could not be started in November due to high water levels. However, occasional subsistence fishing using gill netting, skimming and cast nets was observed during this period.

4.8.2 Fishing methods and catch composition

Nearly 100 fishers belonging to scheduled caste (*Biswas*) from Oujari Village carried out commercial fishing in Charan *Beel*. Among the commercial fishing methods, 'brush fishing' (*jeng/katal mara*) was the most important, followed by shore seining (*mosori jal*), gill netting (*langi jal*),

Table 39. Monthly fish yield (kg) and revenue (Rs.) generated in Charan *Beel* during 2000-01

Months	Fish yield (kg)			Revenue (Rs.)		
	Major/A[1] group	Minor/B[2] group	Total	Major/A group	Minor/B group	Total
2000 May	NF	-	-	-	-	-
Jun	800 (100.0)	-	800	80,000	-	80,000
Jul	NFF	-	-	-	-	-
Aug	NFF	-	-	-	-	-
Sep	NFF	-	-	-	-	-
Oct	NFF	-	-	-	-	-
Nov	1,183 (34.81)	2,215 (65.19)	3,398	83,310	58,300	141,610
Dec	2,131 (51.52)	2,005 (48.48)	4,136	141,510	29,445	170,955
2001 Jan	1,111 (68.96)	500 (31.04)	1,611	99,990	10,000	109,990
Feb	936 (34.68)	1,763 (65.32)	2,699	65,457	35,259	100,716
Mar	286 (27.42)	757 (72.58)	1,043	20,048	15,130	35,178
Apr	NF	-	-	-	-	-
Total	6,447 (47.10)	7,240 (52.90)	13,687	490,315	148,134	638,449

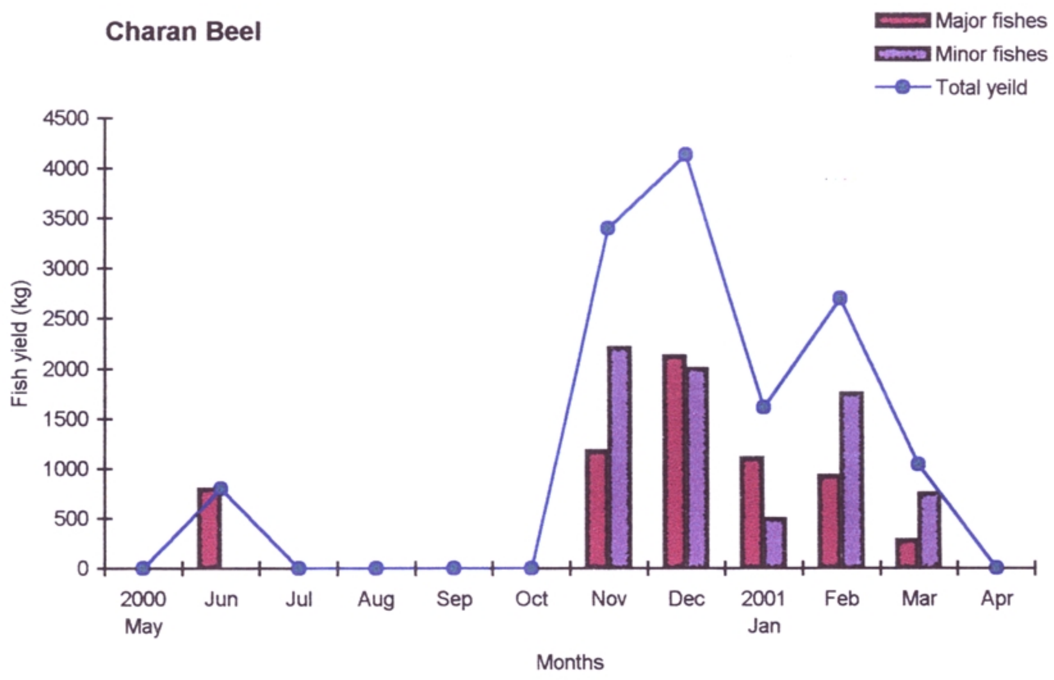
Note: [1] Fishes having total length of 15 cm and above [2] Fishes having total length of <15 cm.
Figures in parenthesis indicate percentage contribution of each group
NF = No fishing; NFF = No fishing due to flood; - indicates nil.
Source: Assam Fisheries Development Corporation (AFDC), Guwahati.

Table 40. Monthly fish yield (kg) and revenue (Rs.) generated in Jaluguti *Beel* during 2000-01

Months	Fish yield (kg)			Revenue (Rs.)		
	Major/A[1] group	Minor/B[2] group	Total	Major/A group	Minor/B group	Total
2000 May	NF	-	-	-	-	-
Jun	NF	-	-	-	-	-
Jul	NF	-	-	-	-	-
Aug	NF	-	-	-	-	-
Sep	NFSR	-	-	-	-	-
Oct	NF	-	-	-	-	-
Nov	NFHW	-	-	-	-	-
Dec	125 (60.98)	80 (39.02)	205	12,000	1,280	13,280
2001 Jan	220 (72.13)	85 (27.87)	305	14,300	1,955	16,255
Feb	370 (100.0)	-	370	40,700	-	40,700
Mar	1040 (100.0)	-	1,040	1,14,400	-	114,400
Apr	62 (33.16)	125 (60.98)	187	4,650	7,000	11,650
Total	1817 (86.24)	290 (13.76)	2,107	186,050	10,235	196,285

Note: [1] Fishes having total length of 15 cm and above [2] Fishes having total length of <15 cm.
Figures in parenthesis indicate percentage contribution of each group
NF = No fishing; NFSR = No fishing due to fish seed release; NFHW = No fishing due to high water levels;
- Indicates nil.

Source: Assam Fisheries Development Corporation (AFDC), Guwahati.



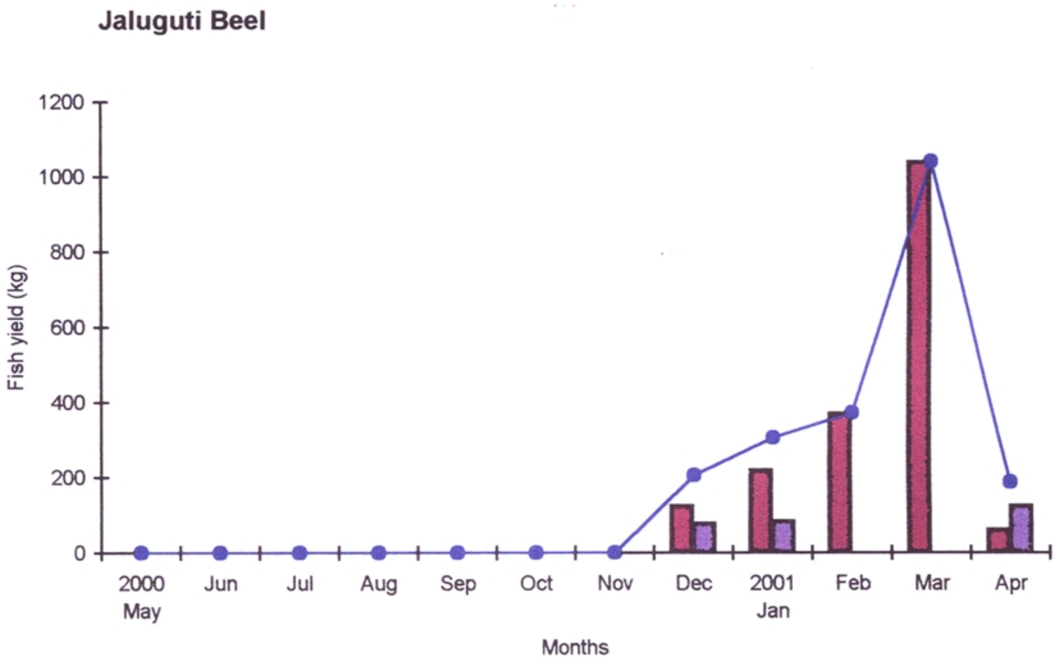


Fig. 43. Monthly fish yield in the selected *beels*

encircling net (*dub jal*) and set barriers (*bheta mara/banas*). In addition, line fishing and fishing with skimming gear (*thela jal* and *chaloni*) were practised by the local inhabitants for subsistence fishing in marginal areas. 'Brush fishing' was the single most important fishing method contributing 53.7% of total commercial catches in Charan *Beel* during the study period. A total of 15 'brush parks' (*jengs*) were installed during the period September-October, when the water level started receding, in deeper pockets of the *beel* (3-4 m) by dumping branches of trees and bamboos. The surface of this artificial shelter was fully covered by a dense circular patch of water hyacinth. The diameter of the *jengs* ranged from 20 to 25 metres. The patches of water hyacinth was secured with the help of split-bamboo tied on to bamboo poles driven into the *beel* bottom (14 no.) after every 5 m or so. Harvesting of the *jengs* started from November and continued up to January. For harvesting, first the *jeng* area was encircled by shore seine (*masori jal*) or surrounding net (*ber jal*) and the floating water hyacinth and submerged tree/bamboo branches were removed. The fish in the net enclosure were caught using surrounding nets (*dub jal*) and cast nets (*khewali jal*). A group of 10-15 fishers using 2-3 boats harvested one *jeng* in 10-12 hours' time. The yield per unit area of *jeng* was high (2.8-3.6 kg m^{-2}). The entire catch from *jengs* comprised exclusively large and medium-sized fishes (*Wallago attu, Labeo rohita, L. gonius, L. dero, Cirrhinus reba, L. bata, Notopterus notopterus*). Some of the *jengs* that were harvested at the beginning of the fishing season (November-December) were harvested for a second time. Such *jengs* are referred to as *chera jengs*. Subsequent harvesting of a *jeng* yielded only about 10-30% of the first harvest.

Operation of shore seine (*mosori jal*) started from November and continued till *Magh Bihu* (mid January) in areas which had moderate to low macrophyte infestation. This net was fabricated using fine-meshed polyethylene mosquito netting (hence the name *mosori jal*). The *mosori jal* used in Charan *Beel* was 100 m long and 5 m deep. Operation of the net required 8-10 persons and two boats. During operation, the net was paid out in a semi-circular fashion using boats covering a certain area, after which both the ends of the net were gradually pulled ashore, thereby reducing the

Plate 4. Photographs showing a *katal/jeng* installed in Charan *Beel* (top) and part of harvesting operation of a *katal* (bottom)

Plate 5. Photographs showing the operation of shore seine (*mosori jal*) (top) and minor fishes being sun-dried (bottom) in Charan *Beel*

encircled area. The fishes accumulated in the central bunt portion of the net were harvested. The catches were overwhelmingly (80-90%) dominated by small economic fishes (*Puntius* spp., *Colisa* spp., *Amblypharyngodon mola,* rasboras, etc.). Operation of gill nets required only one or two fishers and single boat. The catches from set gill net ranged from 1-3 kg per net. *Puthi langi jal* was most commonly used to catch *C. reba*, *Puntius* spp., *Colisa* spp., etc. in this *beel.* This gill net was prepared by joining 3 pieces of monofilament nylon netting having a mesh size of 2.5 cm (No. 35). The net was usually 1.5 m deep and used hollow earthen pipes as sinkers. It was set in shallower areas using bamboo poles driven into the bottom and hauled after 4-6 hours. *Dub jal* is an encircling net, which was very effective to catch major fishes in areas infested by submerged macrophytes. Its operation required 4-10 persons and 1-2 boats depending on the size of the net. The net was paid from boat(s) to encircle a certain area. The area was gradually reduced by hauling the two ends into the boat(s). Thereafter, the head rope was pulled together to close the top of the net. The fishers then went on stepping over the net. The fishes entrapped in flaps of the net were caught by diving (hence the name *dub jal).* Catches from *dub jal* mostly comprised large and medium fishes like *L. gonius, W. attu, L. rohita, L. dero* and *N. notopterus.* Barrier fishing to catch migratory fishes was practiced in June when floodwaters started entering the *beel* through the connecting channel. V-shaped, gradually tapering barriers (*bheta*) were erected in the connecting channel using split-bamboo screens (*bana*) with the help of bamboo stakes, leaving a gap of 2-3 m at the central, tapering end. A second *bana* was erected encircling the tapering end of the V-shaped barrier. Fishes were caught mainly by hauling a Chinese dip net at frequent intervals behind the tapering end. A second broad net secured with bamboo poles was set flatly to reach bottom in the encircled area between the barriers. This net was also lifted at regular intervals to catch fishes accumulated in the enclosure. In addition, fishes that attempted to jump over the net were caught in aerial net traps (*dolonga*) along the sides of the *banas.* Both major and minor fishes were caught in barrier fishing including carps, murrels, barbs and knife-fishes. Long lines were operated during the monsoon season in marginal areas. Their catch comprised carnivorous fishes like *W. attu, Channa* spp. and

Plate 6. Photographs showing a set barrier (banas/bheta) installed in Charan *Beel* (top) and a plank-built boat and gill nets kept fordrying in the same *beel* (bottom)

Mystus spp. Among the skimming gear, the triangular skimming net locally known as *thela jal* (meaning push net) was operated throughout the year by individuals (men/women) for subsistence fishing in moderately macrophyte-infested areas to catch miscellaneous fishes including small prawns. Scoop baskets (*chaloni* - a large circular paddy sieve made from bamboo strips) were used specifically to scoop out fishes taking shelter among the roots of water hyacinth during the winter months. These baskets were operated by two persons (men/women) in areas covered by dense water hyacinth and their catch included *Anabas testudineus*, *Heteropneustes fossilis*, *Channa* spp., *Macrognathus* spp. and *Colisa* spp.

The period from December to March was the peak fishing season in Jaluguti *Beel.* The principal fishing methods used in this *beel* included 'brush fishing' (*pit mara*), shore seining (*mosori jal*), gill netting (*puthi langi jal*) skimming (*thela jal*) and fishing with falling gear (cast net). About 90 fishers belonging to scheduled caste (*Biswas*) from nearby Satgaon Village, caught fish in this *beel.* 'Brush fishing' (*pit/chek mara*) was the single most important commercial fishing method in this heavily macrophyte-infested (mainly water hyacinth) *beel*, contributing as much as 67% of total commercial catches. Considerable variations were noted in the installation, extent of area covered, catch composition, yield rate and gear used in *pit* fishing with that of *jeng/katal* fishing. Erection of *pits* was simple and cheaper than that of *jengs.* An extensive area (up to 0.67 ha) covered by water hyacinth was simply barricaded at both the ends with split-bamboo tied to closely-spaced (every 3 m) bamboo poles driven into the bottom from shore to shore during October-November so as to prevent chunks of water hyacinth from drifting/spreading to clearer areas. Here no branches of trees/bamboo were used unlike *jengs.* Harvesting of the *pits* started from January and continued up to March. Harvesting a large *pit* took up to 15 days at a stretch for 10-12 persons using 2 boats. For harvesting, both the boundaries of the *pit* were secured with seine nets (*ber* or *mosori jal).* The floating macrophytes were pulled out of the enclosure from one side and the area gradually reduced by dragging another net *(mosori jal)* inside the outer boundary net. This inner net was finally brought to one shore so as to encircle a sub-area of the *pit.* Fishing operation

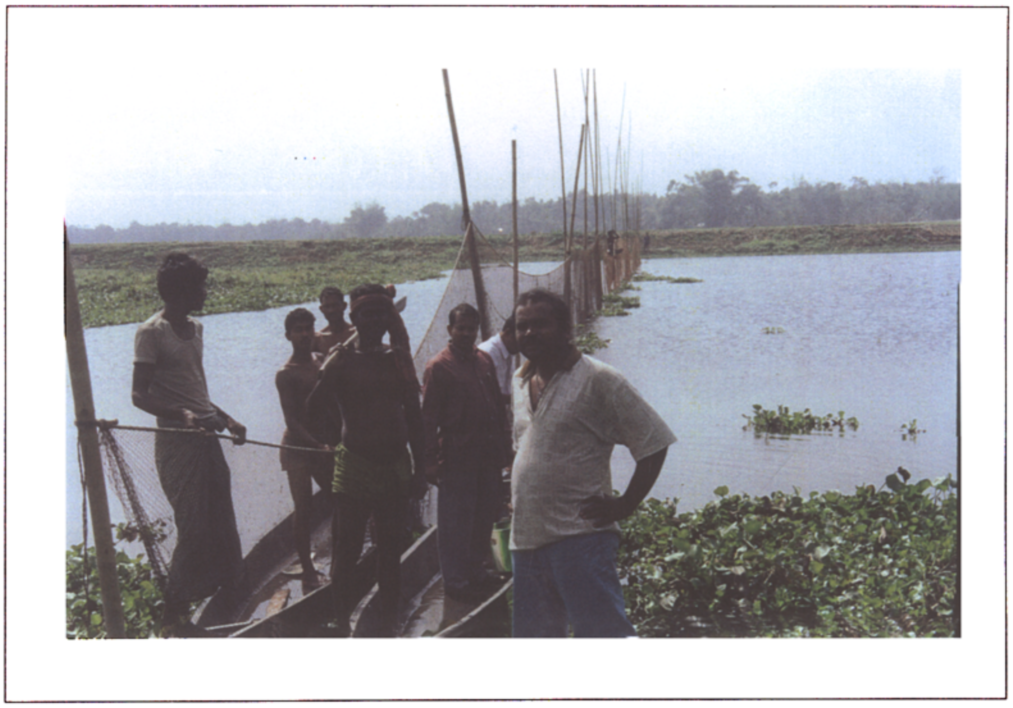


Plate 7. Photographs showing the lessees and the fishers party preparing to encircle a pit prior to its harvesting (top) and fishing operation in progress (bottom) in Jaluguti *Beel*

thereafter was similar to that of the shore seine. Fishing of a sub-area usually took 2-3 days and the total duration of harvesting was 12-15 days. The yield per unit area of 'brush parks' was many folds lower in *pits* (0.1-0.3 kg m^{-2}) than that of *jengs* obtained from Charan *Beel* (2.8-3.6 kg m^{-2}). However, *pit* fishing was less selective than *jeng* and yielded considerable proportion of minor fishes (average 31%) in addition to major fishes (*Catla catla, W. attu, L. gonius, L. rohita, C. mrigala, L. bata and C. reba).* Operation of the shore-seine (*mosori jal*) started from February, when water level reduced considerably and continued up to March. Most of the shore seining was carried out in the relatively macrophyte-free areas between station 1 and 2. Operation of a 250 m long (5 m deep) shore seine required 8-12 persons and 2 boats. It was operated 3-4 times at a time, after which the operation was suspended for 15-20 days until the area was replenished with fishes from nearly macrophyte-infested areas. Its catch comprised miscellaneous fishes, similar to that of Charan *Beel.* Drift gill nets (*puthi langi jal*), which used corks as floats and hollow earthen pipes as sinkers, yielded small economic fishes like *Puntius* spp. and *Colisa* spp. In this beel, the skimming net (*thela jal*) was employed for commercial fishing. The net was operated by 2-3 persons using small (1.5 m diameter) rafts made of floating macrophyte mass (locally known as *bhur*) in areas choked with water hyacinth during the winter months (December to February). Catches from commercial *thela jal* operation during this period comprised *Channa* spp., *N. notopterus, Macrognathus* spp., *Glossogobius giuris,* loach (*Lepidocephalus guntea*) and small prawns (*Macrobrachium* spp.). Cast net was operated either from shores or from boats in relatively macrophyte-free areas. The catches of small-meshed (1 cm) *khewali jal* usually operated from shores composed of miscellaneous small fishes, while that of bigger and large-meshed (2 cm) cast nets operated from boats in deeper waters comprised major fishes.

4.8.3 Ichthyofaunistic composition

A total of 43 fish species belonging to 9 orders, 18 families and 30 genera were recorded from the selected *beels* (Table 41). Order Cypriniformes contributed the largest number of species (19) followed by

Plate 8. Photographs showing a fisher operating a *thela jal* in Jaluguti *Beel* (top) and his catch (bottom)

Plate 9. Commercial vs. subsistence fishing: a fisher from Jaluguti *Beel* showing his catch (top) and a *Tiwa* woman of Oujari Village with her meagre catch (bottom)

Table 41. Ichthyofauna* of the selected *beels*

Fish species		Charan	Jaluguti
Order I.	OSTEOGLOSSIFORMES		
Family (1)	Notopteridae		
1.	*Chitala chitala* (Hamilton)	✓	x
2.	*Notopterus notopterus* (Pallas)	✓	✓
Order II.	CLUPEIFORMES		
Family (2)	Clupeidae		
3.	*Gudusia chapra* (Hamilton)	x	✓
Order III.	CYPRINIFORMES		
Family (3)	Cyprinidae		
4.	*Amblypharyngodon mola* (Hamilton)	✓	✓
5.	*Brachydanio rerio* (Hamilton)	x	✓
6.	*Danio devario* (Hamilton)	✓	x
7.	*Esomus danricus* (Hamilton)	✓	x
8.	*Rasbora daniconius* (Hamilton)	✓	x
9.	*R. rasbora* (Hamilton)	✓	✓
10.	*Catla catla* (Hamilton)	✓	✓
11.	*Cirrhinus mrigala* (Hamilton)	✓	✓
12.	*C. reba* (Hamilton)	✓	✓
13.	*Labeo bata* (Hamilton)	✓	x
14.	*L. calbasu* (Hamilton)	✓	x
15.	*L. dero* (Hamilton)	✓	x
16.	*L. gonius* (Hamilton)	✓	✓
17.	*L. rohita* (Hamilton)	✓	✓
18.	*Puntinus chola* (Hamilton)	✓	✓
19.	*P. conchonius* (Hamilton)	✓	✓
20.	*P. ticto* (Hamilton)	✓	✓
Family (4)	Cobitidae		
21.	*Lepidocephalus guntea* (Hamilton)	✓	✓
22.	*Botia dario* (Hamilton)	✓	x
Order IV.	SILURIFORMES		
Family (5)	Bagridae		
23.	*Mystus cavasius* (Hamilton)	✓	✓
24.	*M. vittatus* (Bloch)	✓	✓
Family (6)	Siluridae		
25.	*Wallago attu* (Schneider)	✓	✓

(Contd..)

Table 41 (Contd.)

Fish species		Charan	Jaluguti
Family (7)	Claridae		
26.	*Clarias batrachus* (Linnaeus)	✓	x
Family (8)	Heteropneustidae		
27.	*Heteropneustes fossilis* (Bloch)	✓	x
Order V.	BELONIFORMES		
Family (9)	Belonidae		
28.	*Xenentodon cancila* (Hamilton)	✓	x
Order VI.	CYPRINIDONTIFORMES		
Family (10)	Aplocheilidae		
29.	*Aplocheilus panchax* (Hamilton)	✓	✓
Order VII.	PERCIFORMES		
Family (11)	Ambassidae		
30.	*Chanda nama* (Hamilton)	✓	✓
31.	*Pseudambassis ranga* (Hamilton)	✓	✓
Family (12)	Nandidae		
32.	*Badis badis* (Hamilton)	✓	✓
Family (13)	Gobiidae		
33.	*Glossogobius giuris* (Hamilton)	x	✓
Family (14)	Anabantidae		
34.	*Anabas testudineus* (Bloch)	✓	x
Family (15)	Belontidae		
35.	*Colisa fasciatus* (Schneider)	✓	✓
36.	*C. latia* (Hamilton)	x	✓
37.	*Channa orientalis* Bloch and Schneider	✓	✓
38.	*C. punctatus* (Bloch)	✓	✓
39.	*C. striatus* (Bloch)	x	✓
Order VIII.	MASTACEMBELLIFORMES		
Family (17)	Mastacembellidae		
40.	*Macrognaths aral* (Bloch and Schneider)	✓	✓
41.	*M. pancalus* (Hamilton)	✓	✓
42.	*Mastacembellus armatus* (Lacepede)	✓	x
Order IX.	TETRAODONTIFORMES		
Family (18)	Tetraodontidae		
43.	*Tetraodon cutcutia* (Hamilton)	✓	x

Note: * Phylogenetically arranged; ✓ = Species recorded; x = Not recorded.

Perciformes (10), Siluriformes (5), Mastacembelliformes (3) and Osteoglossiformes (2 species). The remaining four orders, *viz.,* Clupeiformes, Beloniformes, Cyprinidontiformes and Tetraodontiformes, were represented by single species. Charan *Beel* recorded considerably higher number of fish species (38) compared to Jaluguti *Beel* (29).

Out of the fairly large number of ichthyospecies occurring in Charan *Beel*, 45.9% of the commercial catches were contributed by 5 major fish species (Table 42). The large catfish, *W. attu* was the most dominant species contributing to 15.8% of total fish landings (Fig. 44), followed by *L. gonius* (14.1%), *L. rohita* (9.2%), *L. dero* (4.3%) and *C. reba* (2.4%). Among the minor fishes, which contributed to the majority of landings (52.9%), *Puntius* spp., *Colisa* spp., *Amblypharyngodon mola*, *Mystus* spp., *Channa* spp., *Rasbora* spp., and *Chanda nama* predominated the landings. In Jaluguti *Beel,* among the 29 fish species recorded, as much as 79.4% of catches were contributed by 5 major species, *viz.*, *W. attu* (31.0%), *C. catla* (27.6%), *L. gonius* (10.4%), *L. rohita* (6.9%) and *C. mrigala* (3.5%). Minor fishes contributed only to 13.8% of the total landings in this *beel* (Table 39), among which *Puntius* spp., *Channa* spp., *Colisa* spp., *Mystus* spp., and *G. giuris* dominated the landings. Among the minor fishes, small herbivores dominated the landings, followed by omnivores and carnivores in both the *beels* (Table 42 and Fig. 44).

4.8.4 Estimated fish production potential and conversion efficiencies

The annual photosynthetic productivity and energy conversions in the selected *beels* are depicted in Table 43. About 54.71 x 10^8 kcal $ha^{-1}yr^{-1}$ of visible radiant energy falls on the *beels.* In Charan *Beel*, the rate of energy transformation by primary producers was 104.9 x 10^6 kcal $ha^{-1}yr^{-1}$, out of which 52.4% was fixed by phytoplankton. Thus, the photosynthetic efficiency was worked out to be 1.9%, out of which the contribution of phytoplankton to the fixation of total radiant energy was 1.0%. The total energy fixation rate was 102.5 x 10^6 kcal $ha^{-1}yr^{-1}$ in Jaluguti *Beel* (photosynthetic efficiency 2.3%).

Table 42. Contribution of important fish species/groups to total catch in the selected *beels*

Fish species/group	Feeding habits	Charan *Beel*		Jaluguti *Beel*	
		Total catch (kg)	Per cent contribution	Total catch (kg)	Per cent contribution
I. Major fishes					
A. Carps					
1. *Labeo gonius*	Herbivore	1,933	14.12	218	10.35
2. *L. rohita*	Herbivore	1,263	9.23	145	6.90
3. *Catla catla*	Omnivore	-	-	582	27.60
4. *L. dero*	Herbivore	594	4.34	-	-
5. *Cirrhinus mrigala*	Herbivore	-	-	73	3.45
6. *C. reba*	Herbivore	331	2.42	-	-
7. Others (including *L. calbasu* and *L. bata*)	Herbivore	166	1.21	109	5.17
Total carps		4287	31.32	1127	53.47
B. Large carnivores					
8. *Wallago attu*	Carnivore (P)	2160	15.78	654	31.05
9. *Channa striatus/ Chitala chitala*	Carnivore (P)	-	-	36	1.72
Total large carnivores		2160	15.78	690	32.77
Total major fishes		***6447***	***47.10***	***1817***	***86.24***
II. Minor fishes					
C. Small herbivores[1]	Herbivore	4021	29.38	110	5.23
D. Small omnivores[2]	Omnivore	2390	17.46	99	4.68
E. Small carnivores[3]	Carnivore (IWf)	829	6.06	81	3.85
Total minor fishes		***7240***	***52.90***	***290***	***13.76***
Total catch		***13687***	-	***2107***	-

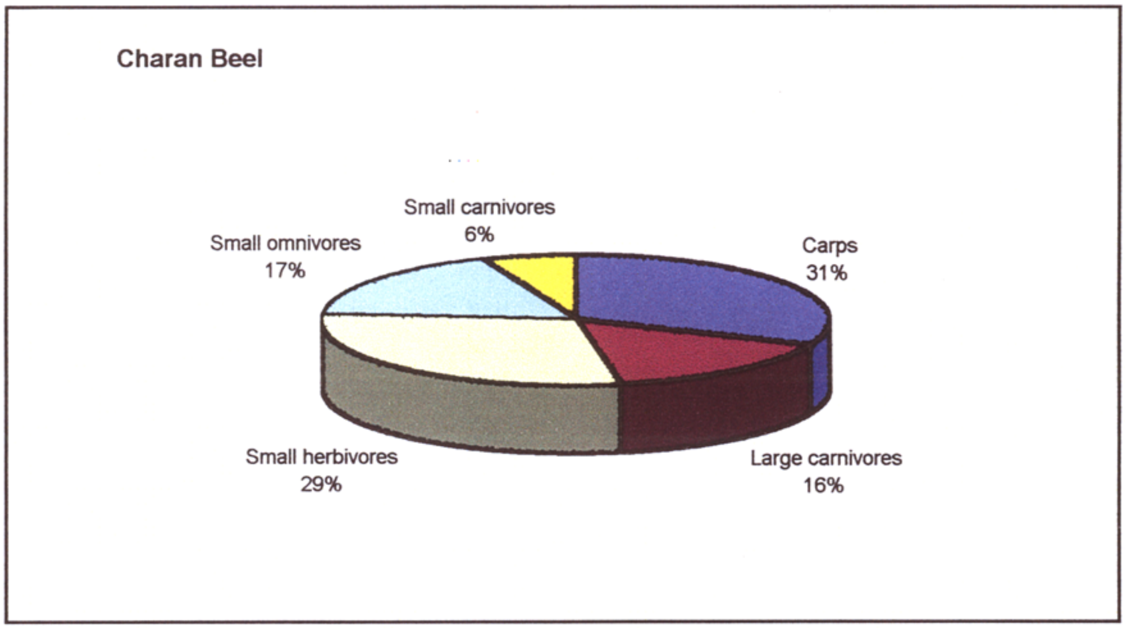
Note: * After Das and Moitra (1963) and Chondar (1999).

P = Piscivore; IWf = Insects, worms and small fishes.

[1] Includes *Amblypharyngodon mola, Rasbora* spp., *Badis badis*, etc.

[2] Includes *Puntius* spp., *Colisa* spp., *Gudusia chapra* and *Anabas testudineus*.

[3] Includes *Channa punctatus, C. orientalis, Mystus* spp., *Glossogobius giuris, Chanda nama* and *Pseudambasis ranga*



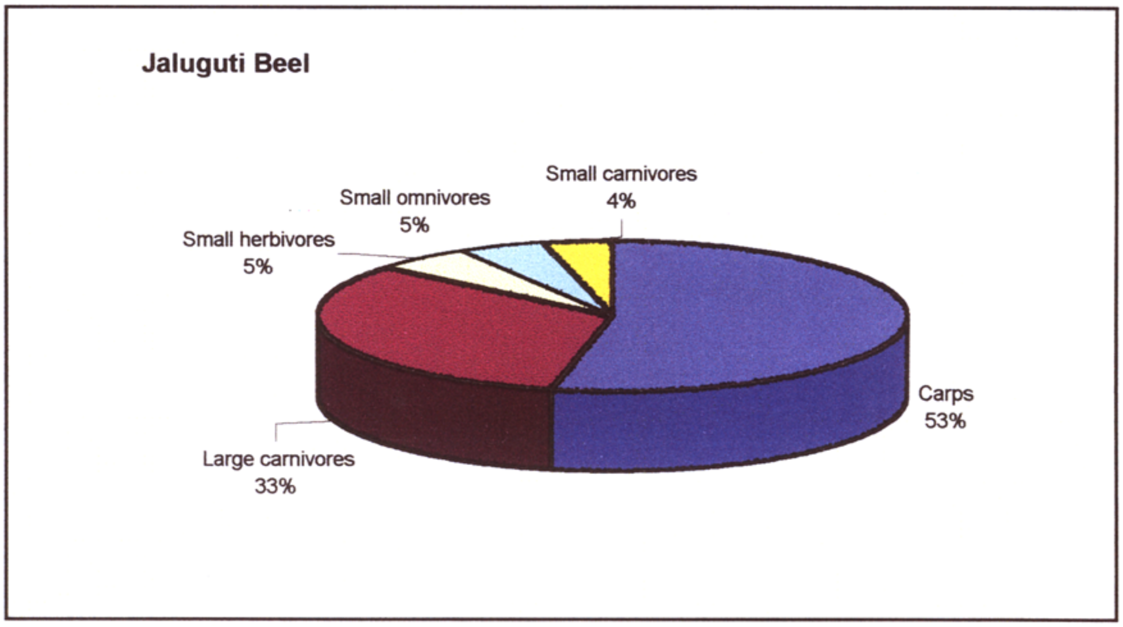


Fig. 44. **Percentage contribution of important fish groups to total catch in the selected beels**

Macrophytes contributed to over two-thirds (68.2%) of total energy transformation in this *beel*. Phytoplankton converted only 0.7% of total radiant energy in this heavily macrophyte-infested *beel*. The photosynthetic fixation of energy was considerably higher (1.2 times) in Jaluguti *Beel* than that of Charan *Beel*.

The energy output as fish from Charan *Beel* was estimated at 273740 kcal $ha^{-1}yr^{-1}$. In this *beel,* as much as 60.7% of energy output was contributed by herbivores (mainly *L. gonius*, *L. rohita*, *Cirrhinus* spp. and *A. mola*) and another 17.5% by small omnivores (*Puntius* spp., *Colisa* spp., etc.) (Table 42). The energy output from Jaluguti *Beel* was estimated at 72240 kcal $ha^{-1}yr^{-1}$, which was 3.8 times lower than that from Charan *Beel*. In this *beel*, detritivores contributed only to 31.1% and omnivores (mainly *C. catla*) 32.9%, while carnivores contributed the maximum (36.6%) to total energy output. The conversion efficiency of radiant energy to fish yield (0.0050%) and primary producers to fish yield (0.26%) was much higher in Charan *Beel* than those of Jaluguti *Beel* (0.0013 and 0.06% respectively).

The fish production potential of Charan *Beel* (assuming conversion of 1% energy fixed by producers) was estimated at 10.49 x 10^5 kcal $ha^{-1}yr^{-1}$ or 874.24 kg fish $ha^{-1}yr^{-1}$. The estimated production potential was considerably higher in Jaluguti *Beel* (12.75 x 10^5 kcal $ha^{-1}yr^{-1}$ or 1,062.81 kg $ha^{-1}yr^{-1}$). Thus, the conversion efficiency of potential to fish yield was 26.1 and 5.7% in Charan *Beel* and Jaluguti *Beel* respectively.

4.9 Trophic structure

Four trophic levels were recognized in the selected *beels*. The primary producers (macrophytes and phytoplankton) occupied the first trophic level (designated by P). Phytoplankton contributed to more than half (52.4%) of the total photosynthetic energy fixation in Charan *Beel*. On the other hand, phytoplankton contributed only to 31.8% of the total photosynthetic energy fixation in Jaluguti *Beel* (Table 43). In the absence of fishes directly feeding on macrovegetation (Tables 41 and 42), most of the vascular plants contributed to the detritus pool upon their death and decay. These decaying

Table 43. Energy transformation and estimated fish production potential in the selected *beels*

	Parameters	Charan *Beel*	Jaluguti *Beel*
1.	Location (latitude)	26°11'N	26°14'N
2.	i) Average visible radiation received at the water surface (cal cm^{-2} d^{-1})	149.88	149.88
	ii) Total radiant energy (kcal $ha^{-1}yr^{-1}$ x 10^8)	54.71	54.71
3.	Photosynthetic productions i) Macrophyte productivity (g C $ha^{-1}yr^{-1}$ x 10^6)	5.20	9.06
	ii) Phytoplankton productivity (g C $ha^{-1}yr^{-1}$ x 10^6)	5.73	4.22
	iii) Total primary productivity (g C $ha^{-1}yr^{-1}$ x 10^6)	10.93	13.28
	iv) Total energy fixed by producers (kcal $ha^{-1}yr^{-1}$ x 10^6)	10.49	12.75
4.	Fish yield (existing) a) Biomass (kg $ha^{-1}yr^{-1}$)	228.12	60.20
	b) Energy (kcal $ha^{-1}yr^{-1}$ x 10^3)	273.74	72.24
5.	Fish production potential (estimated) a) As energy (kcal $ha^{-1}yr^{-1}$ x 10^5)	10.49	12.75
	b) As biomass (kg $ha^{-1}yr^{-1}$)	874.24	1062.81
6.	Conversion efficiency (%) i) Photosynthetic efficiency	1.92	2.33
	ii) Radiant energy to fish yield	0.0050	0.0013
	iii) Primary producers to fish yield	0.26	0.06
	iv) Potential to fish yield	26.10	5.67

plant matter together with associated bacteria and fungi formed the organic detritus complex in the *beels*. The second trophic level (primary consumers or C_1) was a mixed one, which comprised both herbivores and omnivores that derived their energy from the producers either directly (*e.g.,* zooplankton) or through the organic detritus complex. The principal herbivorous groups in the *beels* were zooplankton, molluscs and annelids. The omnivores contributed 17.5 and 32.3% of total energy output as fish in Charan and Jaluguti *Beel* respectively (Table 42). *Puntius* spp., *Colisa* spp. (dominant), *Gudusia chapra* and *Anabas testudineus* (occasional) were the main omnivores in Charan *Beel*. In Jaluguti *Beel*, *Catla catla* was the most dominant omnivorous fish contributing to 27.6% of the total landings, while small omnivores like *Puntius* spp. and *Colisa* spp. contributed to another 4.7%. The secondary consumers (C_2) or primary carnivores occupied the third trophic level. Small carnivorous fishes, insects and frogs comprised the primary carnivores in both the *beels*. However, there were minor variations in the composition of primary carnivorous fishes between the two *beels*. *Channa* spp., *Mystus* spp., *Chanda nama*, *Pseudambassis ranga* and *Notopterus notopterus* were common to both the *beels*. However, *Xenentodon cancila, Mastacembellus armatus* and *Tetraodon cutcutia* occurred only in Charan *Beel*. Another small carnivore, *viz*., *Glossogobius giuris,* was recorded only in Jaluguti *Beel* (Table 41). The tertiary consumers (C_3) or secondary carnivores comprising piscivorous fishes like *W. attu* (in both the *beels*), *Chitala chitala* (Charan *Beel*) and *Channa striatus* (Jaluguti *Beel*) formed the fourth and last trophic level in both the *beels*.

The energy flow models proposed for the selected *beels* have been presented in Fig. 45 and 46. The food chains started with the producers (macrophytes and phytoplankton) at the bottom; successive trophic levels (C_1, C_2 and C_3) were connected by arrows, which led from organism being eaten to the organism eating it. The omnivores partly fed on zooplankton and worms in addition to organic detritus complex and phytoplankton, which is shown by an additional horizontal arrow to this group from herbivores. A part of the primary energy moved out of the *beel* ecosystem by way of energy output (fish yield) to humans as well as food for aquatic birds. Four species of

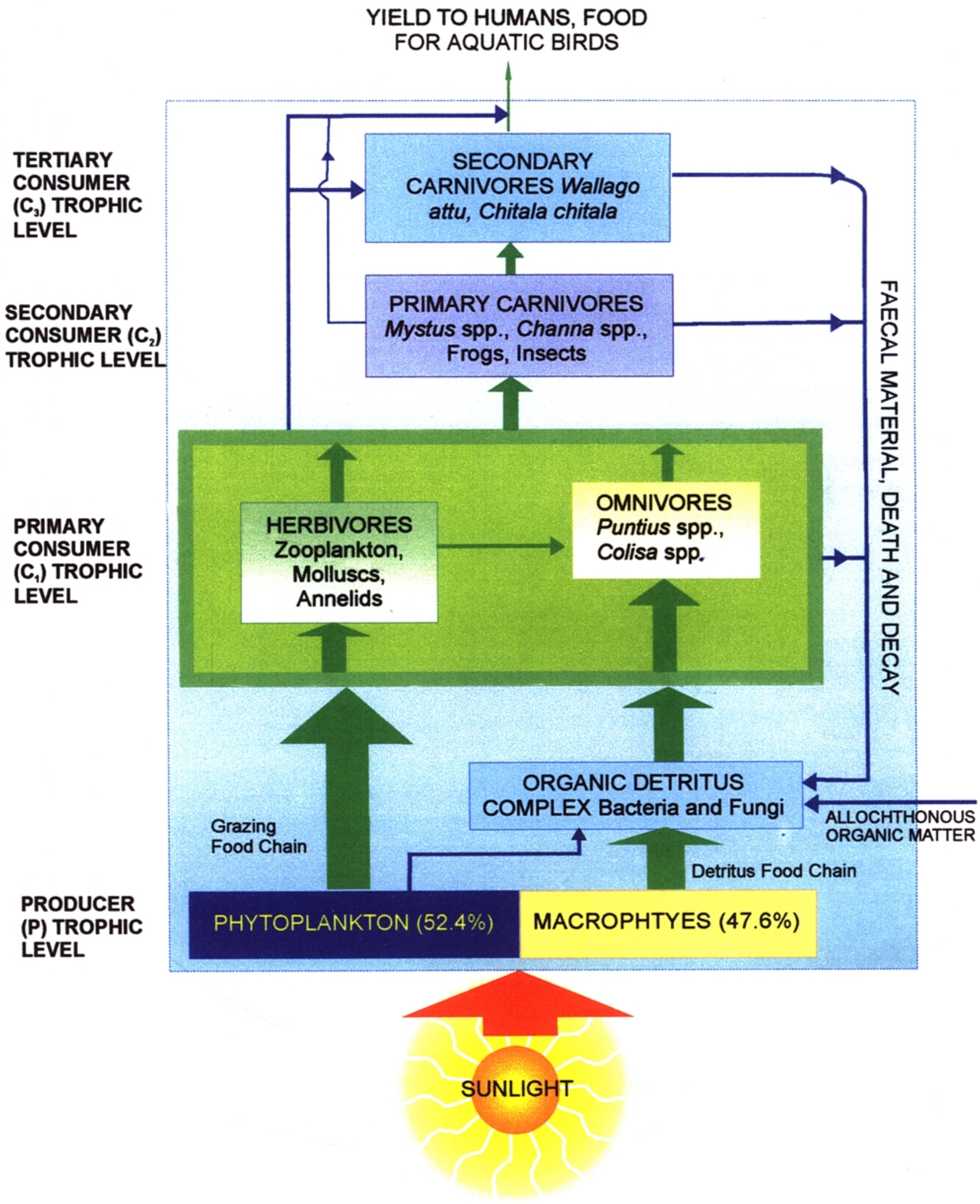


Fig. 45. Eenergy flow model proposed for Charan *Beel*
(based on Steele, 1970 and W. E. Odum, 1970)

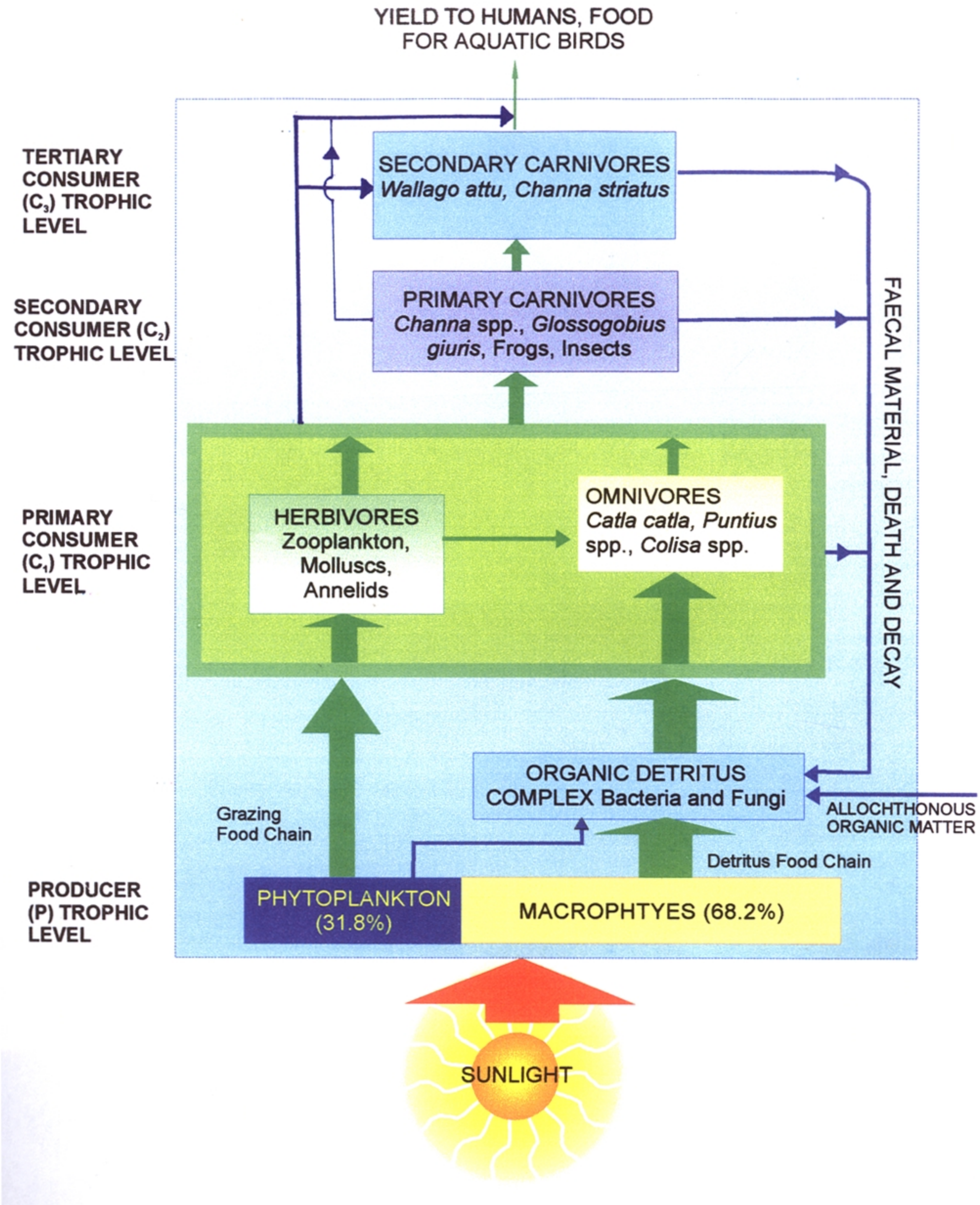


Fig. 46. Energy flow model proposed for Jaluguti *Beel* (based on Steele, 1970 and W. E. Odum, 1970)

aquatic birds, *viz.*, *Egretta intermedia* (medium egret), *E. garzetta* (little egret), *Alcedo athis* (common kingfisher) and *Phalacocorax niger* (little coromorant), were commonly sighted in the *beels* in addition to domestic ducks.

There were two main routes through which solar energy fixed by primary producers flew in the *beel* ecosystem, *viz.*, the grazing and the detritus food chains. The grazing chain started with the producers (P), moved on to the herbivores (C_1, which included zooplankton, herbivorous fishes, molluscs and annelids), the primary carnivores (C_2) and the secondary carnivores (C_3). The detritus food chain started with the producers (P), moved on to organic detritus complex, the detritivores (C_1), C_2 and C_3. Both the grazing and the detritus food chains were interconnected, since most of the consumers fed on more than a single group of organisms. These interconnections gave rise to complex food webs in the ecosystem. The proposed energy flow models were more or less similar in both the *beels*. However, in Charan *Beel* the proportion of energy flowing through the grazing food chain was slightly higher than that through the detritus chain (Fig. 45). In contrast, over two-thirds of the energy fixed by the producers flew through the detritus food chain in Jaluguti *Beel* (Fig. 46). The faecal materials as well as death and decay of organisms at the three consumer trophic levels contributed to the detritus energy on a continuous basis, thereby completing the cycling of materials/nutrients in the ecosystem. The energy output as fish yield (considerable in Charan *Beel*) as well as food for aquatic birds (yet to be quantified) was permanently lost to the ecosystem, which was compensated by the allochthonous organic matter brought in by surface run-off water into the *beels*. In addition, floodwaters (three 'flood pulses' occurred during the monsoon season) brought in additional (unspecified) quantities of organic matter from the upstream catchments every year to Charan *Beel* and occasionally (during high floods) to Jaluguti *Beel*.

The estimated biomass (g dry wt m^{-2}) of organisms at the four trophic levels (based on the results already described) has been presented in Table 44. The total biomass of producers (P) in Charan *Beel* (532.28 g dry wt m^{-2}) was less than half (47.6%) of that in Jaluguti *Beel* (1117.98 g dry wt m^{-2})

Table 44. Estimated biomass (g dry wt m^{-2}) at different trophic levels in the selected *beels*

Trophic level	Charan *Beel*	Jaluguti *Beel*
1. Producers (P):		
i) Aquatic macrophytes*	532.00	1,117.80
ii) Phytoplankton	0.28	0.18
Total P	532.28	1117.98
2. Primary consumers (C_1):		
i) Zooplankton	0.51	0.52
ii) Benthic herbivores	33.57	27.74
iii) Harbivores associated with macrophytes*	9.42	17.09
iv) Herbivorous and omnivorous fishes	1.78	0.33
Total C_1	45.28	45.68
3. Secondary consumers (C_2):		
i) Benthic carnivores	9.34	7.68
ii) Carnivores associated with macrophytes*	9.48	15.64
iii) Primary carnivorous fishes	0.13	0.02
Total C_2	18.95	23.34
4. Tertiary consumers (C_3):		
Secondary carnivorous fishes	0.36	0.17

Note: * Values adjusted considering the fact that on an average 38% of Charan *Beel* and 69% of Jaluguti *Beel* was covered by aquatic macrophytes.

even though the former supported a considerably higher phytoplankton biomass. The total biomass estimated at the second trophic level (C_1) was almost equal in both the *beels*. The total biomass at the third trophic level (C_2) was again considerably lower in Charan *Beel* (18.95 g dry wt m^{-2}) than that in Jaluguti *Beel* (23.34 g dry wt m^{-2}). However, the biomass at the fourth/apex trophic level (C_3) in Charan *Beel* (0.36 g dry wt m^{-2}) was more than double than that in Jaluguti *Beel* (0.17 g dry wt m^{-2}). The ecological pyramid of biomass for the *beels* was obtained by converting these biomass values into approximately proportional quadrangular boxes placed one above the other starting with the first trophic level. The trophic structures showed true upright pyramid shapes in both the *beels* (Fig. 47). In case of Charan *Beel*, the pyramid of biomass gradually tapered from the base to the top giving it a better shape. In case of Jaluguti *Beel*, the base was much large compared to the remaining three trophic levels.

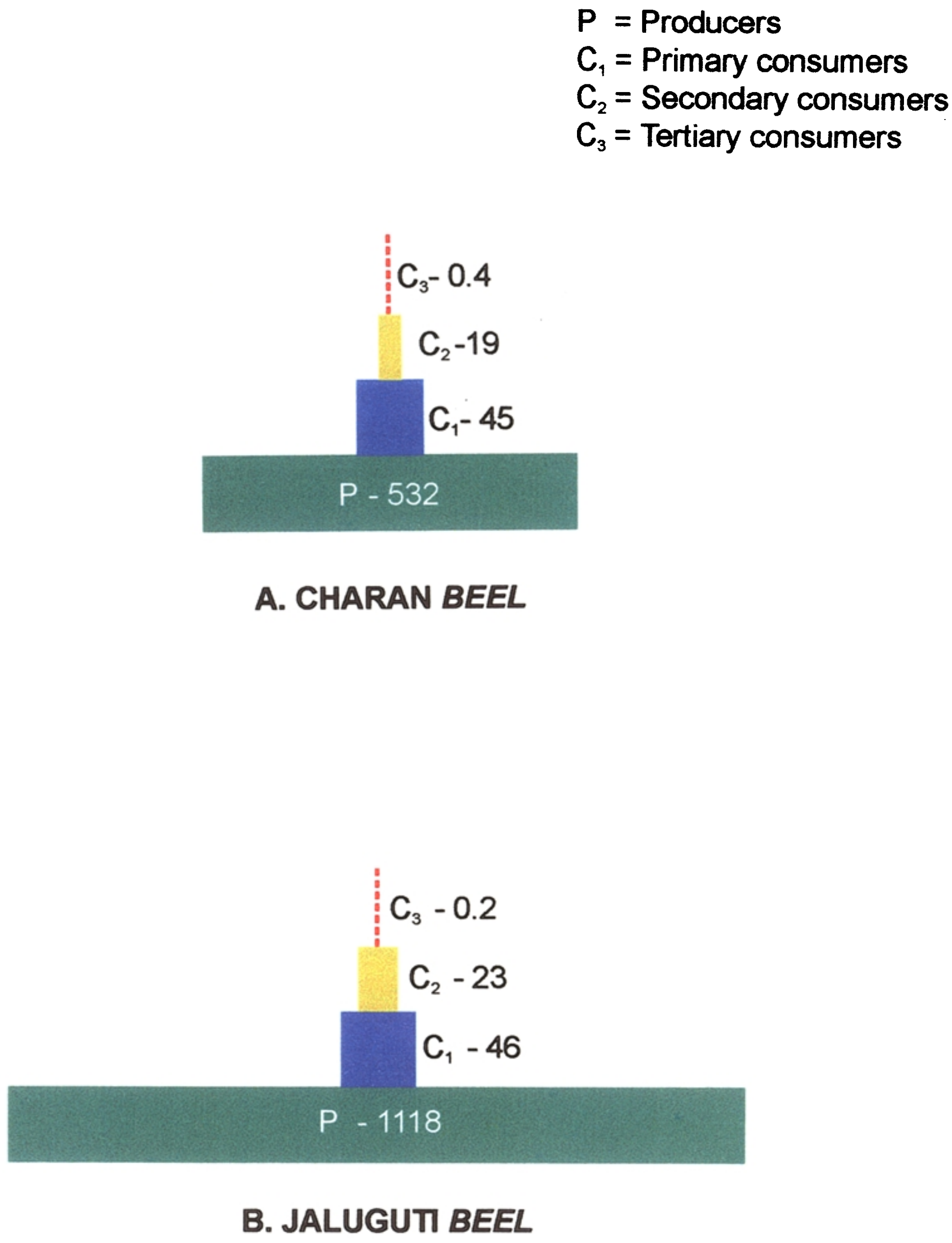


Fig. 47. Ecological pyramid of biomass (g dry wt m^{-2}) in the selected *beels* (based on Juday, 1942 and Harvey, 1950)

5. DISCUSSION

The biological productivity and trophic structure of an aquatic environment are influenced not only by the physico-chemical and biological features operating in the water body itself, but also by a host of other environmental conditions either in its vicinity or from far-flung areas. This assumes greater importance in the floodplain wetlands (*beels*), which are subjected to annual floods during the monsoon season. The dynamics of their ecology is governed to a large extent by the intensity, timing and magnitude of rainfall and river water incursion as well as the geo-chemical nature of the catchments. The hydrobiological characteristics of the *beel* ecosystem are greatly influenced by the meteorological conditions prevailing during different periods of the year in the given area and the neighbouring regions, which are reflected in their temporal variations. Annual floodwater discharge during the monsoon season further influence the hydrological conditions of these ecosystems altering their fish yield and biogenic capacity considerably. Thus, any investigation initiated for understanding the trophic structure and assessing the fish production potential in these dynamic environments should necessary take into account the above mentioned regulatory influences.

5.1 Meteorology

The agro-climatic conditions of northeastern India is unique and differ from the rest of India (Barthakur, 1986). The northeastern state of Assam experiences sub-tropical climate with high rainfall (Bhattacharjya *et al.*, 2001). During the study period, the CBV Zone received a total precipitation of 2308.4 mm, which was slightly higher than the long-term average for the state. As much as 78% of the total annual rainfall occurred during the monsoon season, followed by the pre-monsoon (19%) and the post-monsoon, while the winter season received negligible rainfall (0.6%). The seasonal pattern of rainfall is in broad agreement with that of the long–term average for the state (Bhattacharyya *et al.*, 2001). However, the contribution of monsoon season to the total annual rainfall was much higher during the present study than that of the long-term average (65%). During the study period, Charan *Beel* experienced three major periodic incursions of river water ('flood pulse' concept *sensu* Junk *et al.*, 1989) from Kolong river in close succession (June, July and August). Even Jaluguti *Beel* (closed) received spilled over water from the river during the highest flood (in August). According to Dey and Bhattacharjee (1995), the Assamese floodplains are subjected to as many as five flood events every year.

In general, air temperature starts declining from November and attains the lowest in January in the state (Bhattacharyya *et al.*, 2001). However, temperature declined from October onwards reaching the minimum during December in the present study. The highest air temperature recorded during July is apparently due to bright sunshine conditions, which prevailed after a heavy rainfall and larger sunshine hours (Bhat, 1979). The state of Assam has a fairly humid climate (Dey and Bhattacharjee, 1995). In the present study, high relative humidity ranging from 53 to 93% during the dry seasons and from 71.5 to 99.3% during the rainy season were recorded in the CBV Zone.

5.2 Soil quality

The quality of bottom soil plays a vital role in influencing the biological productivity of a water body. The overlying water remains in a state of dynamic equilibrium with the bottom soil. Usually, the quality of *beel* sediment differs from that of agricultural soil since the former is a mixture of different soil profiles and remains submerged for most parts of the year. In addition, the *beels* receive considerable amount of suspended and dissolved materials from their catchments through surface run-off and/or floodwater, most of which eventually settle down to the bottom and gradually alter the soil quality. Further, the autochthonous organic matter generated by the aquatic organisms (especially macrophytes) and the allochthonous organic debris brought in by surface run-off/floodwater also influence the soil quality of *beels* over the years.

Soil texture of the selected *beels* varied from sandy-loan, loamy, silty-loam to sandy-clay-loam. The *beels* did not show appreciable variations in soil texture. Minor variations observed at different stations may be related to varying composition of suspended materials brought in from surrounding catchments and their differential rates of deposition at these places depending on the local topography. According to Bhattacharyya *et al.* (2001), the texture of the soils of Assam varies considerably depending on the agro-climatic sub-zone and physiographic units. In the Central Brahmaputra Valley (CBV) Zone, the soil texture varies from sandy-clay-loam to silty-clay-loam to clayey.

Bottom soil of the selected *beels* were found to be acidic (pH 4.5-6.2) in nature, which is considered as a normal feature in Assam soil (Banerjea, 1967; Goswami, 1985). Major parts of the soils in the state are acidic having a pH range of 4.2 to 5.8 while the soils of the CBV Zone have marginally higher pH in the range of 4.9 to 5.5 (Bhattacharyya *et al.*, 2001). Higher detritus load generated by dense macrophytes may be responsible for the percolation of enhanced organic acid into the soil. This is corroborated by the significant negative correlation (r = -0.589) observed between soil pH and organic carbon. Organic carbon content of the selected *beels* fluctuated between 1.06 and 8.67% during the study period. It has been observed that soil with organic carbon content of 1.5 to 2.5% or above are productive in nature (Moyle, 1946; Banerjea, 1967). Borkakati *et al.* (2001) observed that the organic matter content of soil was generally high in Assam but in the CBV Zone, soil organic matter content was low to medium. The lower pH and higher organic carbon content of soil recorded during the monsoon season in the *beels* may be due to settlement of substantial quantities of organic matter generated by macrophytes and their decomposition during this period.

Soil of the selected *beels* recorded available nitrogen and available phosphorus in the range of 9.58 to 36.67 mg 100 g^{-1} and 0.26 to 1.44 mg 100 g^{-1} respectively. The available nitrogen content recorded during the present study were marginally lower than that of the Central Assam *beels* investigated by CIFRI (Sugunan and Bhattacharjya, 2000), while the available phosphorus levels were considerably lower in the selected *beels*. Borkakati *et al.* (2001) reported that the soils of the CBV zone contained low to medium levels of available nitrogen (271-330 kg ha^{-1}) and medium available phosphorus (26.5-28.4 kg ha^{-1}) levels. The concentrations of soil nutrients recorded during the present investigation were comparable to these levels. Moyle (1946) and Banerjea (1967) observed that lake and pond soils having available nitrogen and available phosphorus levels of 250-750 ppm or above and 30-60 ppm or above respectively were productive in nature. However, since the environmental conditions (especially soil acidity) differ substantially between the Brahmaputra Valley *beels* and the lakes/ponds located elsewhere, the same yardstick may not be applicable for both the ecosystems. Highest levels of available nitrogen and available phosphorus recorded during April may be due to the death and decay of submerged macrophytes coupled with the inflow of nutrient-laden allochthonous organic matter from the catchment areas. Both the nutrients had a very high positive correlation (r = 0.95) indicating that they undergo a similar biogeochemical cycle.

Charan *Beel* recorded marginally higher soil pH as well as considerably lower levels of organic carbon, available nitrogen and available phosphorus than Jaluguti *Beel*, which suggests gradual accumulation of organic matter and nutrients in the latter over the years. The prevailing hydrobiological regimes of Jaluguti *Beel* like heavy infestation by water hyacinth and reduced water exchange/mixing due to river regulation present favourable conditions for nutrient locking in bottom sediments.

5.3 Physico-chemical characteristics of water

Water quality includes all physical, chemical and biological factors that influence the beneficial use of water (Boyd, 1984). In the context of the present investigation, any characteristic of water that affects the fish production in a *beel* ecosystem in any way is a water quality variable. Obviously, there are many water quality variables in open water fisheries. Fortunately, only a few of these normally play an important role. The range and pattern of variations of selected physico-chemical characteristics of water are briefly described here. The biotic communities are being discussed separately for the sake of convenience.

According to Boyd (1984), all other things being equal, a pond with good water quality will produce more and healthier fish than a pond with poor water quality. The same can be said about open water fisheries including *beel* fisheries. However, no criteria has been set to define 'good' water quality in open water fisheries in respect of many parameters. Thus, one has to rely on the standards set for freshwater pond fish culture in such cases. Diana *et al.* (1997) have given a detailed account of the relationship between water quality and fish production.

Temperature of water is one of the most important water quality variables, since it has a pronounced effect on chemical and biological processes. In general, the rates of chemical and biological reactions are doubled with every 10°C increase in temperature. Warm water fish grow best at temperature between 25 and 32°C (Boyd, 1984). Water temperatures recorded in the *beels* (21.5-34.0°C) were lower than this optimal range only during December-January. Water temperature closely followed the changes in the atmospheric temperature in the *beels* as revealed by the very high positive correlation coefficient obtained between air and water temperature ($r = 0.967$). Yadava *et al.* (1987) noted a similar direct relationship between air and water temperature in Dighali *Beel*, lower Assam. The water was the coolest during January even though ambient temperature was the lowest during December. Similarly, *beel* water was the warmest in August instead of July, when highest air temperature was recorded.

The depth of Secchi disc visibility fluctuated widely (0.23 to 1.45 m) and showed irregular spatio-temporal variations in the selected *beels*. Even though the penetration of solar radiation in natural waters is a function of the angle of light falling on the water surface, the geographical position of the water body, presence of dissolved and particulate materials and other interfering factors will affect the rate of penetration during different times of the day and year (Bhat, 1979). In the selected *beels*, the inflow of surface run-off water, carrying a heavy load of inorganic and organic materials washed down from the catchments following pre-monsoon showers might have caused a sharp reduction in Secchi disc depth during March-April. Considerable lowering of Secchi disc depth in June and September may be attributed to the inflow of surface run-off/floodwater into the *beels* following heavy monsoon showers experienced during these periods. Marked lowering of the depth of visibility observed at station 3 of Charan *Beel* and at station 2 of Jaluguti *Beel* during the period of September-October was apparently due to the effects of jute retting at these places. These two stations had lower average Secchi disc depth compared to their adjacent stations. The depth of visibility recorded in the selected *beels* were considerably higher than that in other *beels* of the CBV Zone (Sugunan and Bhattacharjya, 2000), which indicated favourable conditions for primary production by way of penetration of solar radiation to deeper layers. However, it also indicated poor plankton populations throughout the year in these macrophyte-infested *beels*.

The pH of *beel* water showed considerable variations ranging from acidic to alkaline (6.3 to 7.6) with near-neutral average values (6.8-6.9). These levels were within the broad range of water pH of the Brahmaputra Valley *beels* but were more acidic compared to those of the CBV Zone (Sugunan and Bhattacharjya, 2000). Apparently, the fluctuations in pH of water was influenced by the acidic character of the basin soil and the dense aquatic vegetation (Yadava *et al.*, 1987) as well as by the inflowing surface run-off/floodwater. A sharp decline was observed in pH of *beel* water during May-June, which was probably due to the inflow of considerable organic matter from the catchments along with surface run-off/floodwater, coupled with mixing of bottom water rich in organic matter and their subsequent decomposition. The slight reduction in pH of water observed in September at station 3 of Charan *Beel* and at station 2 of Jaluguti *Beel* was apparently caused by jute-retting at these places. According to Swingle (1967), water having a pH range of 6.5 to 9.0 as recorded before daybreak is the most suitable for fish production. Banerjea (1967) observed a neutral condition of pH (6.5 to 7.5) to be the most favourable for productive ponds. The pH levels recorded in the selected *beels* more or less remained within these favourable ranges.

Total alkalinity varied moderately in Charan *Beel* (21.45-50.59 mg l^{-1}). The range of variation was much wider in Jaluguti *Beel* (29.42-81.60 mg l^{-1}). The present levels were slightly on the lower side than those recorded for the *beels* of the CBV Zone (Sugunan and Bhattacharjya, 2000). The selected *beels* may be considered medium alkaliphobic (Bhuyan, 1970; Dey, 1981; Lahon, 1983). The availability of carbon dioxide for primary production is related to alkalinity; water with total alkalinity levels of 20 to 150 mg l^{-1} contains suitable quantity of carbon dioxide (Boyd, 1984). Total alkalinity of both the *beels* were within this favourable range. According to Moyle (1946), water bodies having total alkalinity above 50 mg l^{-1} can be considered productive. The average total alkalinity recorded at Jaluguti *Beel* (56.29 mg l^{-1}) fell within the productive range, while Charan *Beel* had less alkaline (and hence less productive) water (34.18 mg l^{-1}). Total alkalinity was inversely related with rainfall ($r = -0.783$) and free carbon dioxide ($r = -0.807$). During the monsoon season, free carbon dioxide concentrations increased in the *beels* resulting in lowering of alkalinity levels, while the reverse trend was observed during the winter season. Total alkalinity had a directly relation ($r = 0.833$) with pH of water, which is in conformity with the observations made by Pahwa and Melhotra (1966).

Total hardness of water had an almost equal magnitude as that of total alkalinity (21.8-78.1 mg l^{-1}) and exhibited similar spatio-temporal variations. The total hardness levels of the *beels* were comparable with those of the *beels* of the CBV Zone (Sugunan and Bhattacharjya, 2000). Total hardness had a very high positive correlation ($r = 0.962$) with total alkalinity. The values of both these parameters are normally similar in magnitude because calcium, magnesium, bicarbonate and carbonate ions in water are derived in equivalent quantities from the solution of limestone in geological deposits of the catchments. Desirable levels of total hardness for fish culture generally fall within the range of 20 to 300 mg l^{-1} (Boyd, 1982). Swingle (1967) suggested that a total hardness of 50 mg l^{-1} calcium carbonate equivalent is the dividing line between soft and hard waters and according to him pond waters having a total hardness of 15 mg l^{-1} or above are satisfactory for growth of fish. Based on the average hardness levels, Charan *Beel* and Jaluguti *Beel* can be considered as soft and hard water *beel* respectively. According to V. G. Jhingran (1991), soft water lakes are generally poorer in regard to their aquatic fauna and flora and usually contain less living matter per unit area than hard water lakes. However, although the total mass of organisms is greater in hard water lakes, medium lakes hold a greater variety of living organisms.

Dissolved oxygen is one of the most critical water quality variables governing fish production, since it regulates the metabolic processes of aquatic plants and animals. Dissolved oxygen content of water fluctuated widely in Charan *Beel* (5.34-12.14 mg l^{-1}) and Jaluguti *Beel* (4.77-9.44 mg l^{-1}). According to Boyd (1982), fish do not feed or grow well when dissolved oxygen concentrations remain continuously below 4 or 5 mg l^{-1}. The oxygen levels recorded during the present investigation were above this critical level in both the *beels*. Comparatively lower dissolved oxygen levels recorded in Jaluguti *Beel* may be attributed to the extensive growth of water hyacinth covering the surface and thereby reducing free surface area for diffusion/wind action. Wide fluctuations in dissolved oxygen content of water in the *beels* might be due to dense aquatic vegetation, shallow water depth and intense fishing activities at times (Yadava *et al.*, 1987). Dissolved oxygen was inversely related to water temperature ($r = -0.778$). The solubility of oxygen in water is increased by lowering the temperature (Reid, 1961). Thus, the high dissolved oxygen concentrations were recorded during winter months. Low level of dissolved oxygen recorded during the pre-monsoon season, as well as in July and September is primarily governed by high temperature and through the decomposition process of macrophytes and other organic matter (Welch, 1935; Goswami, 1985) of the *beels*.

Fishes can tolerate high concentration of free carbon dioxide, although they avoid levels as low as 5 mg l^{-1}. Most fish species will survive in waters containing up to 60 mg l^{-1} (Hart, 1944). In the selected *beels* dissolved free carbon dioxide concentrations fluctuated widely (undetectable to 18.59 mg l^{-1}) but remained well within the tolerable range. The carbon dioxide levels recorded in the present *beels* were comparable to that of Brahmaputra valley *beels* but were much higher than that of other *beels* of the CBV Zone (Sugunan and Bhattacharjya, 2000). The highest concentrations of free carbon dioxide recorded in May at most stations indicates its influx through rain water in the form of carbonic acid (Chakravarty *et al.*, 1959) as well as decomposition of organic matter brought in by surface run-off. Considerably higher concentrations of free carbon dioxide recorded at station 3 of Charan *Beel* and station 2 of Jaluguti *Beel* during the period of September-October were apparently due to effect of jute retting at these places. Free carbon dioxide had significant inverse relation with pH of water (r = -0.761). Similar inverse relationship between these parameters was observed by many workers in lakes (Gonzalves and Joshi; 1946; Varduin, 1956) and *beels* (Goswami, 1985; Acharjee, 1997).

The concentrations of total iron recorded in the *beels* (0.05 to 0.82 mg l^{-1}) were higher than that in other *beels* of the CBV Zone but were much lower than that of the Brahmaputra Valley *beels* (Sugunan and Bhattacharjya, 2000). Banerjea and Ghosh (1970) opined that the presence of more than 2 mg l^{-1} of iron usually points to conditions unfavourable to fishes. The total iron levels recorded in the beels were well within the tolerable limit. Total iron concentrations showed a sudden increase during May-June, which may be due to land washings from the catchments and floods. David *et al.* (1969) and Pathak (1979) observed a similar increase in iron levels during the flood period in Tungabhadra and Nagarjunasagar reservoirs in south India.

Total chloride concentrations of the selected *beels* (12.8-29.4 mg l^{-1}) were slightly lower than those of other *beels* of the CBV zone (Sugunan and Bhattacharjya, 2000). Levels of chlorides in the range of 31-50 mg l^{-1} are considered ideal for freshwater fish culture (Saharan *et al.*, 2001). Total chloride exhibited distinct seasonal variations and recorded comparatively higher levels in Jaluguti *Beel*. The highest chloride content recorded in May was probably due to land washings brought into the *beels* by surface run-off following pre-monsoon showers. The chloride content gradually declined during the monsoon season ostensibly due to dilution with surface run off and floodwater culminating in minimal levels recorded in September.

Specific conductivity indicates the total concentration of the ionized constituents of natural waters. It ranged from 58.2 to 126.9 µmho cm^{-2} in Charan Beel and from 55.8 to 158.5 µmho cm^{-2} in Jaluguti *Beel*. It had significant positive correlation with total alkalinity (r = 0.762) and total hardness (0.707), which is natural since all these three parameters are related to the sum of the total ions, cations and anions respectively. Specific conductivity also had a very high positive correlation (0.998) with total dissolved solids (TDS). TDS ranged from 29.7 to 64.0 mg l^{-1} and from 28.5 to 84.7 mg l^{-1} in Charan *Beel* and Jaluguti *Beel* respectively. Slightly higher levels of specific conductivity and TDS have been recorded in other *beels* of the CBV zone surveyed by CIFRI (Sugunan and Bhattacharjya, 2000). Both of these parameters followed a similar pattern of seasonal variation, with maximal values recorded during April-May. Their levels sharply declined during the monsoon season, reaching lowest levels in September. Acharjee (1997) observed a similar decrease in specific conductance with an increase in the water level during the monsoon season. Northcote and Larkin (1956) observed better correlation of productivity with solids than with any other single factor. Both specific conductivity and TDS had significant direct correlation with organic carbon (0.875 and 0.869) and available phosphorus in soils (0.642 and 0.869), suggesting that both these water quality variables were directly influenced by the soil fertility.

The concentration of dissolved organic matter (DOM) in the selected *beels* (0.90-4.14 mg C l^{-1}) was slightly higher than that recorded in other *beels* of the CBV Zone, but were comparable to the range of values recorded in the Brahmaputra Valley *beels* surveyed by CIFRI (Sugunan and Bhattacharjya, 2000). The pattern of seasonal variation in DOM differed considerably between the *beels*. The highest DOM levels recorded during July in Charan *Beel* indicates a strong influence of floodwater either directly by bringing in high loads of dissolved and particulate organic matter into the *beel* or indirectly by inducing mixing of bottom water rich in accumulated organic matter. The fact that dissolved organic matter was inversely related to dissolved oxygen ($r = -0.606$) strengthens the latter surmise. The same factors may be contributing to the peak DOM concentration recorded during September in Jaluguti *Beel,* although the increase is less marked in this *beel.*

The role of nitrate-nitrogen and phosphate-phosphorus in biological productivity of aquatic ecosystems is well recognized. In the aquatic environment, nitrogen is present in the combined forms of ammonia, nitrite, nitrate, urea and dissolved organic compounds. The quantity of nitrogen accumulated by each animal or plant varies from 1 to 10 per cent of dry weight and to some extent reflects the availability of nitrogen in the adjacent environment (Goldman and Horne, 1983). Nitrate is the most oxidized form of nitrogen and is usually the most abundant from of combined inorganic nitrogen in water bodies. Nitrate levels remain almost constant in oligotrophic lakes, fall to zero in eutrophic lakes and does not become limiting in mesotrophic lakes. Accorcing to V. G. Jhingran (1991), the values of dissolved organic nitrogen below 0.1 mg l^{-1} may be considered as indicative of poor productivity, those in the range of 0.1 to 0.2 mg l^{-1} of average productivity, and those above 0.2 mg l^{-1} as favourable for productive ponds. Goldman and Horne (1983) noted that the nitrate level usually found in natural water bodies is up to 1 mg l^{-1} and is not toxic. Nitrate-nitrogen concentrations ranged from 0.01 to 0.80 mg l^{-1} (average 0.20 mg l^{-1}) in Charan *Beel* and from 0.02 to 1.14 mg l^{-1} (average 0.29 mg l^{-1}) in Jaluguti *Beel*, which were within the desirable limits for fish production. The nitrate-nitrogen levels recorded in the selected *beels* were much higher than that recorded in other *beels* of the CBV Zone and were within the broad range obtained in Brahmaputra Valley *beels* surveyed by CIFRI (Sugunan and Bhattacharjya, 2000). The marked increase in nitrate-nitrogen levels observed during April and June was probably due to rain washings from catchment areas (Acharjee, 1997) while the minor peak observed in September may be attributed to floodwater inflow. Comparatively higher average nitrate-nitrogen levels recorded in Jaluguti *Beel* indicate that it is more productive.

Phosphorus is an essential nutrient for primary producers and hence acts as one of the factors limiting growth of aquatic plants. Phosphorus occurs in nature in very small quantities, but is not the critical single factor in maintenance of pond fertility (V. G. Jhingran, 1991). Phytoplankters are able to use phosphorus only in the phosphate form for their growth. The main supply of phosphorus in natural waters is from the withering of phosphorus-bearing rocks and from the leaching of soils of the catchment area by rain. Lack of phosphorus is often the chief cause of poor productivity of waters. Natural waters having a phosphorus content of more than 0.20 mg l^{-1} phosphate are likely to be quite productive (V. G. Jhingran, 1991). Moyle (1946) reported that the optimum concentration of total phosphorus in fish ponds is between 0.10 and 0.20 mg l^{-1} and also found that with ample nitrogen, phosphorus in excess of 0.20 mg l^{-1} does not increase the yield. Based on the phosphate-phosphorus levels recorded, Charan *Beel* (0.002-0.020 mg l^{-1}) and Jaluguti *Beel* (traces to 0.035 mg l^{-1}) can be considered as productive. The average phosphate-phosphorus levels recorded in the two *beels* suggest that Jaluguti *Beel* is comparatively more productive (0.009 mg l^{-1}) than Charan *Beel* (0.007 mg l^{-1}). The present levels were much higher than those recorded in other *beels* of the CBV Zone and were similar to those in the Brahmaputra Valley *beels* (Sugunan and Bhattacharjya, 2000). Phosphate-phosphorus exhibited an irregular fluctuating pattern of seasonal variation in the present study, which may be related to the cycle of utilization of this important nutrient element by the primary producers. The peak phosphate levels recorded in July may be partly due to the leaching of soils of the catchment areas by rain and/or floodwater, which is one of the main sources of phosphorus in natural waters. Such high levels of nutrients recorded during the period of first flood/high water level (including high nitrate-nitrogen levels recorded in June) may also be attributed to the death and decomposition of submerged macrophytes and their subsequent mineralization.

The importance of silicate-silica in production of diatoms is well recognized. However, in the present investigation a significant direct relationship between the two parameters could not be established. Both the *beels* recorded similar levels of silicate-silica (range 2.4-7.8 mg l^{-1}, average 4.9 mg l^{-1}), which was comparable to that recorded in other *beels* of the CBV Zone (Sugunan and Bhattacharjya, 2000). Silicate-silica had a significant direct relation (r = 0.668) with rainfall, indicating rain-induced surface run-off/floodwater to be the primary source of this nutrient in the *beels.* This is corroborated by the sharp increase in silicate-silica levels from April onwards reaching maximal levels in July. Acharjee (1997) recorded the maximum concentration of silicate during the monsoon and immediately after in Dighali, Dora and Ghorajan *beels* in lower Assam.

In a natural setting, the characteristics of floodplain lakes are dominated by the annual cycle of flooding and the resulting periodic incursions of river water (Junk *et al.*, 1989). Variation in frequency and duration of river inputs or 'connectivity' is a major distinguishing factor among water bodies (Hamilton and Lewis, 1990; Amoros, 1991; Ward and Stanford, 1995). In case of Charan *Beel,* the construction of flood control embankments and the siltation of the connecting channel (Khanda *Jan*) have reduced its connectivity considerably, as a result of which river inputs were received only during the monsoon season. Jaluguti *Beel* is practically disconnected from its parent river; inputs from the river are received only during overflowing floods such as the one in August, 2000. Removing direct river influence means that floods can have only indirect effects caused by elevated water tables or accumulation of local run-off that would otherwise drain to the river (Knowlton and Jones, 1997). Such accumulation of local surface run-off along with that of the accompanying organic matter and nutrients was apparently responsible for the higher levels of organic carbon, available nitrogen and available phosphorus in soils as also higher nitrate and phosphate concentration of water recorded in Jaluguti *Beel.*

Melack and Fisher (1990) observed that during low water, nutrient concentrations increased due to sediment resuspension in a floodplain lake of Central Amazonia. Schmidt (1973) reported the enrichment of a floodplain lake in the same region with orthophosphates at the beginning of the flood, which was attributed to sediment resuspension. Hamilton and Lewis (1987) attributed the nutrient enrichment observed during low water to turbulence from wind action and sediment re-suspension, while Boneto *et al.* (1984) attributed it to hypolimnetic anoxic conditions and release of nutrients from the sediment. In the *beels* under the present study, nutrient enrichment occurred either during the first flood (Charan *Beel)* or during the first high surface run-off, which was apparently caused by sediment resuspension. Further, with the sudden rise in water level and turbidity, the submerged macrophytes like *Hydrilla verticillata,* which grow abundantly in the *beels*, decay and release nutrients to the water. A similar phenomenon was observed by Junk (1984) and Furch (1984) in Amazonian 'varzea' (floodplain) lakes as well as by Camargo and Esteves (1995b) in a floodplain lake of Sao Paulo, Brazil.

5.4 Diurnal variations in physico-chemical characteristics of water

There is a marked fluctuation in dissolved oxygen concentration of water during a 24 hour period; concentrations are lowest in the early morning just after sunrise, increase during daylight hours to reach the maximum in late afternoon and decrease again during the night (Boyd, 1984). The diurnal variation of dissolved oxygen followed a similar trend in the present study. During daylight hours, aquatic macrophytes and phytoplankton utilize carbon dioxide from bicarbonates resulting in decrease in bicarbonates and increase in carbonates and pH. Oxygen is liberated in the photosynthetic process, resulting in a gradual increase in dissolved oxygen concentration during daytime. The pH of natural waters is greatly influenced by the concentration of carbon dioxide, an acidic substance. Aquatic plants remove carbon dioxide from water during photosynthesis, so the pH of a water body rises during the day and decreases during the night (Boyd, 1984). During dark hours (night), the respiratory consumption of oxygen and liberation of carbon dioxide result in gradual decrease in oxygen, carbonates is converted into bicarbonates and pH decreases. The rate of these two opposing chemical processes during the two phases of the day regulates the diel cycle of chemical parameters in water. Productive waters show high rate of the above processes and, therefore, the relative productivity of any water body can be evaluated from the diel fluctuations in these chemical parameters of water. Natarajan (1979) showed that in productive reservoirs, the intensity of diurnal changes in chemical parameters is of high order. Hussainy (1967), Nassar and Dattamunshi (1971), Nassar (1975), Haniffa and Pandian (1978), Laal (1981) and many others showed that the water bodies infested with aquatic macrophytes reflected wide range of diurnal variations due to metabolic activities of both phytoplankton and macrophytes. Diurnal fluctuations in Dhir *Beel* in lower Assam (Jhingran and Pathak, 1987) also showed wide variations in these chemical parameters. In the present study, considerable diurnal variations were observed in dissolved oxygen, pH, free carbon dioxide and bicarbonates, which is agreeable with the above observations.

One of the basic differences between the *beels* under the present study and Dhir *Beel* (Jhingran and Pathak, 1987) or Kulia *Beel* in West Bengal (Saha *et al.*, 1990) is the complete absence of carbonates in the former. The *beels* studied by the above workers reflected sharp decrease in free carbon dioxide from high levels in the early morning and carbonates appeared at 14.00 hours in fairly high concentrations with complete absence of carbon dioxide. In the *beels* under the present study, free carbon dioxide was always present and the magnitude of diurnal changes in these chemical parameters was comparatively lower than that in Dhir *Beel* and Kulia *Beel*. The present findings are comparable with those of Acharjee (1997) in Dighali, Dora and Ghorajan *beels* in Kamrup District of Assam.

Among the chemical parameters whose diurnal variation was studied, dissolved oxygen is the most important indicator of aquatic productivity since it is directly linked with the metabolic processes of the aquatic organisms. Due to the photosynthetic production of oxygen by the aquatic macrophytes and phytoplankton, dissolved oxygen concentration of water register a sharp increase from early morning to peak light hours followed by a gradual decline during dark hours. The diel oxygen curve can, therefore, be used to evaluate the biological productivity of *beels*, especially those having substantial macrophyte infestations. Jhingran and Pathak

(1987) observed an increase in dissolved oxygen levels by 13.0 mg l^{-1} during photosynthetic hours in Dhir *Beel*. Pathak (1990) recorded maximum fluctuations of 11.8 mg l^{-1} in dissolved oxygen from morning to noon in Kulia *Beel* (West Bengal). Eco-energetic studies showed that these two *beels* had very high production potential in the range of 1300 to 2150 kg fish $ha^{-1}yr^{-1}$ (Pathak, 1990). Acharjee (1997) recorded the maximum daily increase of 8.8, 5.4 and 6.0 mg l^{-1} in dissolved oxygen content in Dighali, Dora and Ghorajan *beels*, the fish production potential of which was estimated at 865, 631 and 728 kg $ha^{-1}yr^{-1}$ respectively (Acharjee *et al*., 1998). The magnitude of maximum diurnal fluctuations recorded in Charan *Beel* (6.80 mg l^{-1}) and Jaluguti *Beel* (7.04 mg l^{-1}) in the present study was comparatively lower than that in Dhir and Kulia *beels* and comparable with that of Dighali and Ghorajan *beels*. The wide diurnal variations in chemical parameters in the *beels* under the present investigation revealed their high productive status. Further, the relative magnitude of diurnal fluctuations indicated comparatively higher productivity of Jaluguti *Beel* than Charan *Beel*. Similarly, the seasonal variation in the intensity of diurnal fluctuations suggested that the biological productivity was maximal during the monsoon and the post-monsoon seasons in Charan *Beel* and Jaluguti *Beel* respectively whereas it was the lowest during the winter season in both the *beels*.

5.5 Biotic communities

The biotic communities are the living component of the aquatic ecosystem. The living organisms and their abiotic environment are inseparably interrelated and interact upon each other (E. P. Odum, 1983). The abundance and quality composition of biotic communities of the *beel* ecosystem are governed by the physico-chemical characteristics of soil and water as well as the interaction among the communities. The biotic communities can be broadly grouped into autotrophs (primary producers) and heterotrophs. In the *beel* ecosystem, aquatic macrophytes and phytoplankton constitute primary producers, while heterotrophs include consumer and decomposer organisms. *Beels* are generally considered as highly eutrophicated systems with high rate of primary productivity (Sugunan and Bhattacharjya, 2000). However, the potential and actual fish yield of individual *beels* depends largely on the relative abundance of various biotic communities and the trophic interaction among them.

Aquatic plants are important components of lakes, ponds, rivers and stream ecosystems throughout the world (Jamil, 1993). Rich growth of macrovegetation due to allochthonous and autochthonous nutrient loading is a unique feature of the floodplain wetlands of the Brahmaputra basin (Sugunan and Bhattacharjya, 2000). However, significant contributions on the biomass, species composition and productivity of aquatic macrophytes in the *beels* of Assam are not many. A few workers like Lahon (1983), Goswami (1985), Yadava (1987) and Acharjee (1997) carried out pioneering studies on these aspects.

In the present study, Charan *Beel* was moderately infested by macrophytes; submerged macrophytes covered more areas than free-floating ones (mainly *Eichhornia crassipes)* even though the latter contributed more to the total macrophyte biomass. Yadava (1987a) observed that the forms of many large and small *beels* favoured extensive development of marginal and submerged vegetation. With optimum light quality and quantity (Peltier and Welch, 1970), temperature and total alkalinity (Yadava, 1987a), the submerged macrophytes play a major role in governing the plankton density and primary productivity. Jaluguti *Beel* was heavily infested by macrophytes throughout the study period and it supported higher macrophyte biomass than Charan *Beel*. The water hyacinth (*E. crassipes*) covered most of the area contributing to most of the total macrophyte biomass in Jaluguti *Beel*. *E. crassipes* showed high adaptive nature to the seasonal changes in environmental conditions in the *beels* as revealed by their substantial presence throughout the year. However, their biomass showed wide seasonal variations and the peak biomass (recorded in June) was nearly six times higher than the lowest biomass (January-February). Camargo and Florentino (2000) observed the largest biomass of *Nymphaea* sp. (floating-leaved) to be about three times greater than the values for other months in a Brazilian floodplain. The extensive growth of *E. crassipes* covering larger parts of the *beel* surface apparently hindered the growth of submerged macrophytes in Jaluguti *Beel.* The comparatively lower infestation and biomass of macrophytes observed in Charan *Beel* was partly due to its connectivity with the parent river and partly because of management intervention. Large patches of water hyacinth brought in by the first flood covered more than half of the area of *Charan Beel* in June. However, most of these floating macrophytes were pushed out of the *beel* during the receding flood. Some quantities of water hyacinth were required for the installation of 'brush parks' and, therefore, retained in this *beel.* Apart from *E. crassipes, Hydrilla verticillata, Najas* spp., *Ceratophyllum demersum* and *Vallisneria spiralis* were the other dominant species occurring in the *beels.* Infestation by *E. crassipes, Hydrilla* sp., *Najas* spp. and *Vallisneria* spp. is common in the *beels* of Assam (Gowami, 1985; Yadava, 1987a; Acharjee, 1997; Sugunan and Bhattacharjya, 2000).

The results obtained show a broad seasonal variation in the biomass of both free-floating and submerged macrophytes. Several authors, cited in Camargo and Florentino (2000), verified wide seasonal variation in the biomass of aquatic macrophytes in tropical water bodies. The variations in the biomass of submerged macrophytes observed in the present study are mainly due to the seasonal variation of the water level in the *beels.* This is in conformity with the observations of Junk (1986), Junk and Piedade (1993), Da Silva and Esteves (1993) and Camargo and Esteves (1996). However, the seasonal variation of the biomass of free-floating macrophytes cannot be attributed to water level fluctuations. In temperate regions, the seasonal variation of the biomass presented by aquatic macrophytes occurs mainly because of the seasonal variation of temperature (Esteres, 1988). The peak biomass of water hyacinth recorded in June in both the *beels* can be partially attributed to high temperature regimes in this sub-tropical region. However, the highest nutrient levels (particularly nitrate-nitrogen) recorded in June appears to have a more favourable influence than temperature on the biomass of water hyacinth. Goswami (1985) recorded higher macrophyte biomass during the post-monsoon season in a *beel* in lower Assam, which could not be attributed to temperature.

Studies made by Saha *et al.* (1990) in Kulia *Beel* in West Bengal revealed a considerable difference in water quality parameters during the planktonic and macrophyte phases. They found very high Secchi disc visibility (up to the bottom) during the macrophytic phase. However, no such definite relation between macrophyte dominance and transparency could be established in the present study. Water of the *beels* showed an increase in pH during the period from January to April, which were periods of dense growth of submerged macrophytes. This is agreeable with the observations of Munawar (1970), who stated that dense macrophyte population would mean increased photosynthetic activity and hence increased pH.

A direct relation was observed between the total macrophyte biomass and nitrate-nitrogen concentration of water ($r = 0.588$). The period of peak macrophyte biomass was recorded during June (first high water level) when the nitrate-nitrogen levels were the highest in the *beels* following sediment resuspension as well as death and decay of submerged macrophytes. Yount (1964), Sheffield (1967), Boyd (1970a), Steward (1970), Woofen and Dodd (1976) and Cornwell *et al.* (1977) were the pioneers to demonstrate nutrient removal by aquatic macrophytes. Vascular aquatic macrophytes are involved in the biogeochemical cycles of both nutrients and non-essential elements in many aquatic ecosystems (Jamil, 1993). The correlation between macrophyte biomass and phosphate-phosphorus was not significant ($r = 0.273$). This indicates that nitrate was a more limiting nutrient than phosphate for macrophytes growth in the *beels*. Apparently, phosphorus is kept in solution because of reducing conditions prevailing in the soil-water interface of the *beels*, whereas a part of nitrogen is lost through the denitrification process from sediment surface (Acharjee, 1997).

Plankton comprises microscopic aquatic organisms (both plant and animal) with limited or no power of locomotion. The phytoplankton, which bear photosynthetic pigments, make use of the rich inorganic nutrients available in the *beel* ecosystem and synthesize organic matter. They form the base of the ecological pyramid together with aquatic macrophytes. On the other hand, zooplankton feed on the phytoplankton as well as on the huge reserve of organic matter (organic detritus). Thus, zooplankton is the secondary producer or primary consumer, linking phytoplankton and detritus with biotic communities occupying higher trophic levels. Zooplankton play a vital role in making efficient use of dead and living organic matter in *beels* (Sugunan and Bhattacharjya, 2000). Both phyto and zooplankton form direct food for a number of planktivorous fish species and thereby sustain a considerable portion of fish yield from the *beels.* Smith and Swingle (1939) and Melack (1976) reported a direct relationship between plankton production and fish yield. Thus, plankton productivity hence, can be used as a dynamic biological correlate for the assessment of fish yield (Almazan and Boyd, 1978).

The *beels* under the present study recorded poor population of plankton, with average total plankton population being 863 and 623 u l^{-1} in Charan *Beel* and Jaluguti *Beel* respectively. *Beels* in Assam are generally characterized by poor concentration of plankton but consist of a diverse assemblage of nearly all major taxonomic groups (Lahon, 1983; Goswami, 1985; Yadava, 1987a; Acharjee, 1997; Sugunan and Bhattacharjya, 2000), despite the fact that different plankton have different environmental requirements. The utilization of nutrients by profuse growth of macrovegetation resulted in poor phytoplankton population in the *beels* (Yadava *et al.*, 1987). Acharjee (1997) observed a bimodal seasonal variation in total plankton population in three *beels* of lower Assam. In the present study, seasonal variation of total plankton population showed three to four peaks. Davis (1955) stated that while studying the fluctuations of plankton population, a number of physico-chemical, biological and environmental circumstances acting simultaneously should be taken into consideration. The biological processes are so complex that no single ecological factor can be identified to be responsible for the growth and production of plankton community.

Lahon (1983), Goswami (1985), Yadava (1987a) and Acharjee (1997) reported the dominance of phytoplankton in *beels* of the Brahmaputra Valley. Phytoplankton dominated total plankton population in both Charan

Beel (73.0%) and Jaluguti *Beel* (61.8%). In general, phytoplankton density is poor in all the *beels* of Assam; although low pH, transparency and conductivity are attributable to low phytoplankton population, the predominant factor is the competition with macrophytes in garnering sunlight and nutrients (Sugunan and Bhattacharjya, 2000). Macrophytes make the best use of a rich environment and grow rapidly, thereby adversely affecting the growth of phytoplankton (Moss, 1983). According to Boyd (1971), macrophytes rapidly absorb nutrients for their growth and retain them for a longer period, while nutrients used by phytoplankton are recycled rapidly as their life span is short, usually two weeks or less. Yadava (1987a) observed that an increase of 37% in the annual standing crop of macrophytes in Dhir *Beel* (lower Assam) resulted in a decrease of 64% in the phytoplankton population in a span of one year. Heavy infestation of macrophytes, mainly water hyacinth, in Jaluguti *Beel* resulted in low phytoplankton population in this *beel*.

Byars (1960) stated that temperature was the determining factor in seasonal distribution of aquatic organisms. In the present study, peak population of phytoplankton was recorded in November, suggesting that temperature was not responsible for seasonal variation of phytoplankton in the *beels*. Imevore (1967) could not correlate seasonal variation in plankton with temperature. Subramanyam (1959) observed an increase in plankton production during monsoon and immediately after, while Acharjee (1997) recorded peak plankton production in October. The peak plankton population was recorded during the period of November-December in the present study and a secondary peak was observed during August in Jaluguti *Beel*, which are agreeable with the above observations.

Increased production of phytoplankton is generally associated with higher values of dissolved oxygen (Alikunhi *et al.*, 1955; Das and Srivastava, 1956; Moitra and Bhattacharyya, 1965; Saha *et al.*, 1971). Since phytoplankton population fluctuated considerably during the present study, no such relationship could be observed. However, dissolved oxygen content of water was comparatively higher in December and August, which were periods of primary and secondary peaks in phytoplankton abundance.

The importance of nutrients in growth and abundance of phytoplankton is well recognized. Yadava *et al.* (1987) established a regulatory (negative) role of phosphate in the growth and abundance of plankton besides the penetration of sunlight, which had a direct bearing. However, no significant relation was obtained between phosphate and phytoplankton population in the present study. According to Atkins (1923), silicate is correlated with phytoplankton activity. However, Sverdrup *et al.* (1942) found that the reduction in silicon does not become a limiting factor in plankton concentration, which is supported by the present finding. In the present case, phytoplankton abundance was inversely related to rainfall ($r = -0.752$), which is logical considering the fact that periods of higher rainfall were associated with higher allochthonous turbidity and relatively unstable hydrographical conditions hindering the colonization of phytoplankton.

A total of 196 phytoplankton species have been recorded and reported form the *beels* of Assam (Bordoloi, 1973; Devi, 1981; Lahon, 1983), out of which 63 genera have been recorded in the present study. Charan *Beel* supported higher number of phytoplankton taxa than Jaluguti *Beel* probably because of lesser macrophyte growth and diverse ecological conditions (both lotic and lentic) prevailing in this open *beel.* The phytoplankton community structure observed in Charan *Beel* (Bacillariophyceae> Chlorophyceae> Myxophyceae> Desmidiaceae) in respect of relative abundance showed the dominance of Bacillariophyceae, which is in concurrence with the trend reported by Yadava (1987a) and Acharjee (1997) in open *beels* of the Brahmaputra Valley. On the other hand, the dominance of Chlorophyceae observed in Jaluguti *Beel* (Chlorophyceae> Bacillariophyceae> Myxophyceae> Euglenoida> Desmidiaceae) is in conformity with the observations made in other closed *beels* of the valley (Lahon, 1983; Goswami, 1985; Acharjee, 1997). The group Chlorophyceae, which is the most successful competitor in waters well exposed to penetration of sunlight, was commonly represented by *Spirogyra* spp., *Pediastrum* spp. and *Mougeotia* spp. Hutchinson (1967) observed that *Pediastrum* spp. and *Scenedesmus* spp. were abundant in eutrophic waters. Chlorophyceae dominance may be due to the reduction in old vegetation strands after annual decomposition bearing higher exposed areas for light penetration (Acharjee, 1997). Bacillariophyceae, which was the most dominant group in Charan *Beel* was dominated by *Fragilaria* spp., *Melosira* spp. and *Navicula* spp. In the present study, Bacillariophyceae occurred in all months with bimodal peaks observed during the post-monsoon and the winter months (Shetty *et al.*, 1961; Yadava, 1987a; Acharjee, 1997). Myxophyceae was the third most dominant group in the *beels* and was commonly represented by *Microcystis* spp., *Anabaena* spp. and *Oscillatoria* spp.

Acharjee (1997) observed positive correlation between diatom abundance and silicate concentration. The above finding is in agreement with that of Dhir *Beel* (Yadava, 1987a), which indicate utilization of silicon in the water body due to fast depletion of desmid biomass. In the present study, no significant correlation was observed between these parameters. Since the maximal abundance of diatoms was recorded during November-December, temperature did not seem to have played an important role in their seasonal variation. Whitford and Schumacher (1968) correlated abundance of blue-green algae with hot summer months. Acharjee (1997) observed the favourable temperature range for blue-green algae to be 26 to 30°C. Jackson (1961) reported the optimum alkalinity range for blue-green algae to be 50 to 110 ppm. In the present study, the peak biomass of Myxophyceae corresponded to a lower range of temperature (23.5-26.1°C) and total alkalinity (30.08-68.36 mg l^{-1}).

Investigations conducted by a number of ecologists have shown that the trophic status of a water body is reflected in the phytoplankton assemblages harboured by it. Preseott (1939), Rawson (1956) and Kutkuhn (1958) reported higher population of desmids in oligotrophic lakes. Similarly, an increase in the abundance of Cyanophyceae has been related to eutrophication. The presence of blue-green algal species like *Anabaena* spp. and *Microcystis* spp. in the *beels* indicated their eutrophic nature (Swayer, 1966). Kutkhuhn (1958) stated that Myxophyceae, Chlorococcales, Euglenoida and Centrales of Bacillariophyceae possess what is known as eutrophic tendency. According to Rawson (1956), desmids were characteristic of oligotrophy. The desmids contributed only to 10% and 8.6% of total phytoplankton abundance in Charan *Beel* and Jaluguti *Beel* respectively, which suggests that both the *beels* are gradually advancing towards eutrophy.

The zooplankton community, which is a vital link in the aquatic food chain, is influenced by a number of physico-chemical and biological factors. Temperature is considered as one of the determining factors in the seasonal distribution of zooplankton population (Byars, 1960). But in the present study, no such relationship was observed. Similar observations were made from the floodplain lakes of India (Acharjee, 1997; Singh, 2000). The seasonal variation of zooplankton population closely followed that of phytoplankton. According to Davis (1955) and Wright (1965), the abundance of zooplankton is chiefly dependent on the abundance of phytoplankton. Zooplankton population had a very high direct correlation with phytoplankton abundance ($r = 0.978$) in the present study, which further corroborates the above surmise. Apart from temperature and food availability, the zooplankton density is also related with chemical properties of water (Unni, 1981; Jana, 1973). The present study revealed poor population of zooplankton in Charan *Beel* although phytoplankton was rich in this *beel.* Similar observations were made by Lahon (1983), Goswami (1985), Yadava *et al.*, (1987) and Acharjee (1997). However, Jaluguti *Beel* supported considerably higher zooplankton population, contributing to 38.2% of the total plankton population in spite of having poor phytoplankton population. The zooplankton population apparently derived a part of their food from the organic detritus in addition to phytoplankton in this heavily macrophyte infested *beel.* Hamuska (1949), Pennak (1955) and Dornett (1961) opined that the food of zooplankton mainly consisted of nannoplankton including bacteria and suspended organic matter rich in bacteria rather than phytoplankton.

The zooplankton community structure in Charan *Beel* showed the dominance of copepods (Copepoda> Rotifera> Protozoa> Cladocera), which is a common feature in the *beels* of the Brahmaputra Valley (Sugunan and Bhattacharjya, 2000). On the other hand, the dominance of rotifers observed in Jaluguti *Beel* (Rotifera> Copepoda> Protozoa> Cladocera) was agreeable with the trend reported from Ghorajan *Beel,* a closed *beel* of the lower Brahmaputra Valley (Acharjee, 1997). A gradual decline was observed in the percentage contribution of copepods to the total plankton population from October onwards in Jaluguti *Beel,* which may be related to the predation pressure from the sizeable number of catla (*Catla catla*) fry stocked in this *beel* during September. According to Mookerjee and Das (1945) and Misra (1953), food of juvenile catla (2-10 cm) overwhelmingly comprised crustaceans (80%) and in adults also they were the most dominant food group (45%). Copepods, though present throughout the year, did not show any regular periodicity. Chen (1965) and Yadava (1987a) reported the affinity of copepod populations towards warm water. Ganapati and Rao (1954) observed temperature to be the controlling factor in the seasonal variation of copepods. The irregular periodicity observed in the present study indicated no definite relationship with water temperature. Mathew (1972) and Singh (2000) observed that the copepod production depended on the availability of food supply.

Rotifers have versatile capacity to survive in different environments as some of them feed on various phytoplankton, some feed on detritus and bacteria, while some others have been described as raptorial predators (Singh, 2000). Such high adaptive nature of this group apparently favoured its dominance of zooplankton community in Jaluguti *Beel.* Predominance of rotifers is a common feature of Indian freshwaters (George, 1961; Michael, 1969; Lahon, 1983). The relative abundance of rotifers in the *beels* under the present study may be attributed to the infestation of macrophytes and high accumulation of organic nutrients due to their annual decomposition (Edmondson, 1944, 1945, 1946). Peak rotifer abundance occurred during November-December in the present study. Maximum production of rotifers during the winter season has been reported by Shetty *et al.* (1961), while George (1966) and Singh (2000) recorded their peak during the summer season. Among the rotifers, the loricate forms like *Brachionus* spp. and *Keratella* spp. were predominant. Michael (1966) and Singh (2000) have made similar observations. The peak biomass of protozoans was recorded during November-December in the present study. Thus, a temperature range of 23.5 to 26.1°C seemed to favour their growth, which falls within the optimum temperature range for the growth of protozoans (Pennak, 1953). Various workers (Wright, 1965; Michael, 1966) have suggested that the density of cladocerans is primarily determined by the food supply. In the present study, their peak population coincided with periods of rich phytoplankton, which is in conformity with the above observation.

Several workers (Alms, 1922; Grimas, 1965) stressed the importance of benthic organisms as a link in the energy flow from primary producers to fish. In the *beel* ecosystem, decaying macrophytes are the main source of organic detritus at the bottom, which normally support a good bottom macrofauna (Sugunan and Bhattacharjya, 2000). Charan *Beel* and Jaluguti *Beel* supported average macrobenthos populations of 778 and 574 no. m^{-2} with corresponding biomass of 429.1 and 354.2 g wet wt m^{-2} respectively. Wide variations in the population of benthic macroinvertibrates, ranging from 0 to 1763 no. m^{-2}, have been reported (Yadava *et al.*, 1987, Acharjee, 1997; Sugunan and Bhattacharjya, 2000). According to Thienemann (1925), water bodies having benthos population less than 1000 no. m^{-2} is poor. On the basis of his classification, the *beels* under the present study can be regarded as poor in benthos production. The poor growth of macrobenthos biomass in these *beels* may be attributed to wide fluctuations in their water levels. The water level fluctuated as much as 3.2 and 3.5 m in Charan *Beel* and Jaluguti *Beel* respectively between the peak flood level (August) and the lowest pre-monsoon level (March). The *beels* were filled to the brim with water during the highest flood. However, in a matter of 2-3 months, the water level declined sharply by 2 m, thereby leaving extensive areas exposed rapidly. This might have caused death to the benthic fauna living in the littoral regions, especially to less mobile forms like insect larvae and oligochaetes. In Charan *Beel,* sudden incursion of river water during floods might have dislodged the benthic fauna near the connecting channel besides smothering them. Lower biomass of macrobenthos recorded in Jaluguti *Beel* may be attributed to its greater water depth (2.1 to 5.6 m). In addition, excessive deposition of organic matter might have caused anaerobic conditions in this macrophyte-choked *beel.*

Macrobenthos biomass exhibited wide seasonal variation in the *beels*. Yadava *et al.* (1984) and Acharjee (1997) observed similar marked seasonal variation in macrobenthos population. The increase in benthic biomass during the period from February to June may be related to the decomposed and settled organic matter and hydrophytes as a result of higher temperature (Gupta, 1976), which create a conducive environment for their growth and multiplication (Yadava *et al.*, 1987). The biomass of macrobenthos was dominated by Gastropoda, followed by Oligochaeta, Insecta and Pelecypoda in the *beels*. Lahon (1983), Goswami (1985) and Acharjee (1997) observed a similar composition of macrobenthic population in the *beels* of lower Assam. Gastropods dominated macrobenthos population in the *beels* of Assam (Sugunan and Bhattacharjya, 2000). The abundance of macrophytes providing both food and shelter (Dey, 1981) was thought to be the cause of high molluscan density recorded in the bottom fauna of Dighali *Beel* in lower Assam (Yadava *et al.,* 1987). Molluscs and Oligochaetes dominated macrobenthos population in freshwaters of Uttar Pradesh (Srivastava, 1959) and West Bengal (Michael, 1969). Molluscs, which dominate macrobenthic fauna, often account for 60-90% of the total biomass in *beels* (Mitra and Ghosh, 1992). The biomass of macrobenthos was directly related to total hardness of water (r = 0.623) in the present study. Gastropods and bivalves, which together constituted the bulk of the macrobenthos biomass (46.5-47.2%) in the *beels*, required calcium to secrete their shells and hence tended to grow well in hard water. Oligochaeta, which was the second most dominant group of macrobenthos, were usually associated with the roots of submerged weeds and organic debris.

The smaller number of benthos appearing in the dredge samples, particularly during the monsoon season, may be attributed to the fact that macrophytes typically harbour the majority of the invertebrate community (Kumar, 1985). According to Peter (1968), in the weed-choked shallow-basined eutrophic waters the benthic fauna usually leave the bottom due to hypoxic or anoxic conditions prevailing therein and mingle with the macrophytes. A similar situation prevails in most of the *beels,* particularly in macrophyte-choked *beels.* As a result, *beels* support a considerable proportion of macrophyte-associated fauna. Macrophyte-associated fauna has been studied as a separate biotic community of the *beel* ecosystem in recent years (Mitra and Ghosh, 1992; Sugunan and Mukhopadhyaya (1995). In the present study, the average standing crop of macrophyte associated fauna was 497.4 and 474.4 g wet wt m^{-2} in Charan *Beel* and Jaluguti *Beel* respectively, which was higher than that of macrobenthos in these *beels.* Sugunan and Mukhopadhyaya (1995) found that the abundance of weed-associated fauna was 47% of macrobenthos abundance in Bandardaha *Beel,* West Bengal. Thus, the macroinvertebrates associated with macrophytes play an equally important role in the trophic structure of a *beel* ecosystem as macrobenthos do. Sugunan and Bhattacharjya (2000) and Sugunan *et al.* (2000) treated weed-associated fauna as a separate group of organisms while proposing generalized pathways of energy flow in open and closed *beels.*

The biomass of macrophyte-associated fauna showed wide seasonal variation in the *beels.* The maximum and minimum biomass were recorded during June and December-January, suggesting that temperature is one of the factors determining their seasonal variation (Byars, 1960). Biomass of associated fauna was directly related to water temperature ($r = 0.655$) indicating that this group has affinity towards warmer temperature unlike macrobenthos. Further, their biomass had a high direct relationship with macrophyte biomass (0.878), which is expected since macrophytes provide food and shelter to the associated fauna.

Mitra and Ghosh (1992) stated that the bulk of the associated fauna is formed by ubiquitous mollusks, followed by nymphs, larvae and adults of insects and annelids. In the present study, the group Insecta dominated the biomass of macrophytes-associated fauna, followed by Mollusca, Annelida and others. The molluscs were mainly represented by gastropods and a few bivalves. Most of the species comprising insects, molluscs and annelids were common to both benthos and macrophyte-associated fauna. However, the leech (*Hirudo* spp.) belonging to Annelida and the organisms grouped as others (small fishes, prawns and frogs) occurred only in the macrophyte-associated fauna samples.

The factors, which determine the colonizing preference of macroinvertebrates (both benthos and macrophyte-associated fauna) are poorly understood and vary from species to species. Apparently, the interplay of a number of edaphic and hydrobiological factors is responsible for their growth and abundance. The choice of oviposition sites by adults and the availability of food may also be responsible for population growth (Mitra and Ghosh, 1992).

5.6 Primary productivity

Primary productivity is the rate at which radiant energy is stored by producer organisms in the form of organic substances usable as food materials. This rate depends on the efficiency with which the photosynthetic organisms transform incident light energy into chemical food energy. In the *beels* of Assam, carbon fixation takes place predominantly through the macrophytes (Sugunan and Bhattacharjya, 2000). In Charan *Beel,* the average gross primary productivity was estimated at 2994.96 mg C $m^{-2}d^{-1}$, out of which the contribution of phytoplankton was 52.4%. Jaluguti *Beel* recorded much higher average gross primary productivity (3639.31 mg C $m^{-2}d^{-1}$) than Charan *Beel.* However, the contribution of phytoplankton to the total gross primary productivity was only 31.8% and the major portion was contributed by macrophytes in this *beel.* Both gross phytoplankton productivity and gross macrophyte productivity was significantly higher ($P<0.05$) in Jaluguti Beel, indicating that this beel had higher biogenic capacity than Charan *Beel.*

It has been recognized in recent years that aquatic macrophytes stand out as one of the main producers of shallow aquatic ecosystems, both in lentic environments and in low turbulence areas of lotic environments (Camargo and Florentino, 2000). Their high production rate contributes to a large storage of nutrients in the biomass, playing a fundamental role in the cycling of matter and energy flow (Camargo and Esteves, 1995a). In the present study, primary production was mainly controlled by macrophytes in Jaluguti *Beel*. Growth of aquatic macrophytes in some way inhibits phytoplankton production (Hasler and Jones, 1949). The mechanism of this inhibition may be limiting either nutrient materials in water or condition for light (Hasler and Jones, 1949). The extensive growth of free-floating water hyacinth in Jaluguti *Beel* apparently repressed phytoplankton growth in underlying waters by hindering light penetration. Even in Charan *Beel*, which was moderately infested by macrophytes (38% area), macrophytes contributed 47.6% of the average gross primary productivity. Lahon (1983), Goswami (1985), Yadava *et al.* (1987a) and Acharjee (1997) observed poor phytoplankton production in Assam *beels* when compared with other lentic water of India (Sreenivasan, 1964b, 1965; Mathew, 1975; Singh and Desai, 1980).

The average gross primary productivity values estimated in the *beels* under the present study fall within the range of 1377.5 to 3762.5 mg C $m^{-2}d^{-1}$ obtained for selected *beels* of Central Assam (Sugunan and Bhattacharjya, 2000). The present values were also comparable with the average gross primary productivity levels obtained for Dora and Ghorajan *Beel* in lower Assam (Acharjee, 1997) and Kanti (ox-bow) Lake in Bihar (Vass, 1989). The present values were slightly lower than the average gross primary productivity estimated in Dighali *Beel*, lower Assam but were much higher than those observed in Manika Lake, Bihar (Vass, 1989), Nagarjunasagar Reservoir (Pathak, 1979) and that in some high altitude lakes of Kashmir (Vass *et al.*, 1988; Vass and Langer, 1990), which indicate their high productive nature. According to Wetzel (1964), the littoral regions of the aquatic ecosystems are among the most productive zones of the world and the shallow waters of the selected *beels* with large littoral zones depict an ideal situation for optimal productivity. The present gross primary productivity levels were lower than 5 mg C $m^{-2}d^{-1}$, which is characteristic of a eutrophic water body (Brylinsky and Mann, 1973). In Jaluguti *Beel,* the estimated average respiration rate (173.06 mg C $m^{-2}d^{-1}$) was much higher than the average net primary productivity (129.94 mg C $m^{-2}d^{-1}$) although net production values always remained positive. Such a situation can occur due to various reasons like sinking and grazing of plankton, oxygen consumption by the particulate and dissolved organic matter (Edberg and Hofsten, 1973), nutrient exhaustion, the so-called 'glass-effect' in the method (Olah, 1971) or microbial activity (Stewart *et al.*, 1977).

Considerable seasonal variation in gross primary productivity was discernible in the selected *beels*. The highest productivity was recorded either in November (Charan *Beel*) or in June (Jaluguti *Beel*), which was apparently related to the combined biomass of macrophytes and phytoplankton. Similarly, the lowest values recorded in December corresponded to low biomass of primary producers. This is corroborated by the very high direct correlation obtained between gross phytoplankton productivity and phytoplankton abundance (0.968) as well as that between macrophyte biomass and gross macrophyte productivity (0.979). Acharjee (1997) observed the highest and the lowest primary production during winter and monsoon seasons respectively. In Charan *Beel*, the maximum gross primary productivity was more than double of than the minimum level while in Jaluguti *Beel* the highest value was more than four times the lowest value. Laal (1989) observed the maximum values to be four to six times higher than the minimum values.

The photosynthetic efficiency was estimated at 1.9% in Charan *Beel*, out of which phytoplankton converted 1.0% of the total radiant energy. The photosynthetic efficiency was higher in Jaluguti *Beel* (2.3%), but phytoplankton converted only 0.7% of radiant energy in this *beel*. Acharjee (1997) reported photosynthetic efficiencies in the range of 2.11 to 2.58% in Ghorajan, Dora and Dighali *beels* in lower Assam, which are comparable with the present findings. Pathak (1992) obtained comparatively higher photosynthetic efficiencies in the range of 2.75 to 3.74% in Dhir *Beel* (lower Assam), Kulia *Beel* (West Bengal) and in Media *Beel* (West Bengal). Nassar (1975), Haniffa and Pandian (1978) and Natarajan and Pathak (1985) studied the efficiencies of energy transformation in different aquatic ecosystems of India and observed that primary production in weed infested water bodies was mainly contributed by macrophytes. Pathak (1990) reported that in *beels* infested with aquatic macrophytes, the contribution of phytoplankton as energy converter was only 5 to 21%. In the present study, the contribution of phytoplankton to the total energy fixation was considerably higher (31.8% in Charan and 52.4% in Jaluguti *Beel*).

5.7 Fisheries

The *beels* of Assam generally possess high potential for fish production. A number of them also provide a 'collection sink' for fish produced in the surrounding flooded catchments (Sugunan and Bhattacharjya, 2000). In the present study, the rate of fish production in Charan *Beel* and Jaluguti *Beel* was estimated at 228 and 60 kg $ha^{-1}yr^{-1}$ respectively. The fish yield of Jaluguti *Beel* was much lower than that of Charan *Beel*, which may be attributed mainly to negligible autostocking from River Kolong due to the construction of flood control embankments. Though the *beel* received floodwater during the peak flood in August, recruitment from the river was low owing to extensive barrier fishing (*banas/bheta mara*) practiced in the connecting channel (Nakhanda *Jan*). Low fish yield recorded in this *beel* despite supplementary stocking with catla fry may be due to inadequate stocking and possible low survival of stocked fry in presence of a large predatory fish (*Wallago attu*) population (31% of total catch). In addition, over-fishing and heavy infestation by water hyacinth also might have contributed to low fish yield from this *beel*. The knowledge of the natural stock from where new recruits come to a fishery is important (Gulland, 1955). According to Sugunan and Bhattacharjya (2000), even though the fish stocks are continuously exploited in open *beels*, they are replenished through fresh recruitment from the adjoining river. The average fish yield of Assam *beels* is 173 kg $ha^{-1}yr^{-1}$ (Sugunan and Bhattacharjya, 2000) which is much higher than that reported from the open water lakes and reservoirs of India (*c* 5 to 75 kg $ha^{-1}yr^{-1}$) (Sreenivasan, 1964d; Chaudhuri and Banarjea, 1965; V. G. Jhingran and Tripathi, 1969). Fish yield estimated from the selected *beels* were within the broad yield range of 14 to 418 kg $ha^{-1}yr^{-1}$ estimated in 17 *beels* of the Brahmaputra Valley (Sugunan and Bhattacharjya, 2000). The rate of fish production in Charan *Beel* was higher than that reported by Lahon (1983) in Salsala *Beel* (116 kg $ha^{-1}yr^{-1}$), Kar (1984) in Sone *Beel*, Barak Valley (90 kg $ha^{-1}yr^{-1}$), Yadava *et al.* (1987) in Dighali *Beel* (39 kg $ha^{-1}yr^{-1}$) and Acharjee *et al.* (1998) in Ghorajan *Beel* (14 kg $ha^{-1}yr^{-1}$) and Dora *Beel* (145 kg $ha^{-1}yr^{-1}$). However, it was lower than the average fish yield of Dhir *Beel* (377 kg $ha^{-1}yr^{-1}$) reported by Yadava (1987a). Though the fish yield was reasonably high in Charan *Beel*, the constant deposition of silt is likely to cause shortage of living space to fishes (Welcomme, 1979) and have fewer deep pockets of water that can act as refusia for fishes. This might result in the reduction of fish yield from this *beel* in the long run.

The seasonal variation in fish catch from the selected *beels* was found to be inversely related to the water level. During the period from November to April, the water level declined substantially in both the *beels* and intense harvesting ensued. Sustained fishing ostensibly resulted in sharp decline in catches during March-April and commercial fishing came to a halt in May. Commercial fish catches were negligible during the period from June to October because fishes got widely dispersed in the expanded area. Only exception to this trend was observed during June in Charan *Beel*, when barrier fishing yielded good catch for a few days. Acharjee (1997) reported low catch from three *beels* in lower Assam during the monsoon season and observed that the post-monsoon and winter seasons facilitated the operation of almost all types of gear.

A wide variety of fishing methods including 'brush fishing'/fish aggregating devices and dewatering is employed in the *beels* of Assam (Sugunan and Bhattacharjya, 2000). Exploitation of resources in *beels* is very traditional and includes certain methods not reported from other water bodies (Choudhury, 1992a). Some such methods have been reported by Yadava *et al.* (1981), Yadava and Choudhury (1986), Choudhury (1987b, 1992a), Bhagowati and Kalita (1987), Goswami *et al.* (1994) and Ali (1997). 'Brush fishing' was the most important commercial fishing method contributing as much as 54 and 67% of total fish catch in Charan *Beel* and Jaluguti *Beel* respectively. Two different types of 'brush fishing' were observed in this study: *jeng/katal* in Charan *Beel* and *pit/chek* in Jaluguti *beel.* While Yadava *et al.* (1981) have described all aspects of *katal/jeng* fishing in detail, *pit/chek* fishing has not been documented so far. Deeper pockets of Charan *Beel* in areas that were relatively free from water hyacinth infestation were found to be suitable for the erection of *jengs.* In contrast, shallower areas of Jaluguti *Beel*, which were heavily infested with water hyacinth, offered the scope for installing *pits.* Erection of *jeng* was costlier than that of *pit* in terms of per unit area of 'brush park'. However, the average yield per unit area of 'brush park' was many folds higher in *jeng* (3.2 kg m^{-2}) than that from *pit* (0.2 kg m^{-2}). *Jeng* acted as a better fish aggregating device than *pit* since branches of trees/bamboos were used in the former in addition to water hyacinth used in the latter. Almost the entire fish catch from *jeng* comprised major fishes (total length 15 cm or more), which is in conformity with the observation made by Yadava *et al.* (1981). On the other hand, 31% of the fish yield from *pit* fishing comprised minor fishes. This indicates that although *jeng* is more remunerative than *pit* fishing, there is an inherent risk of selective overexploitation of major fishes in the former. This is significant in Charan *Beel*, where the contribution of major fishes to the total fish catch was already low (47.1%). Repeated harvesting of a *jeng* observed in the present study is in conformity with the findings of Goswami *et al.* (1994) in *beels* of Dhubri District, lower Assam. Yadava and Choudhury (1986) observed that *banas/bheta* (set barrier) fishing was employed during the waning monsoon periods, to catch fishes undertaking return migration to the river. In Charan *Beel*, barrier fishing was employed during the first flood to catch fishes migrating from the river to the *beel.* The percentage contribution of barrier fishing to the total annual fish landings was much lower in Charan *Beel* (5.8%) than that observed in Dhir *Beel* (Yadava and Choudhury, 1986). Barrier fishing during June killed a large number of brood fishes (both major and minor) in Charan *Beel*, which is likely to adversely affect recruitment in the *beel* as well as that in the parent river. Fishing with *mosori jal* having very small mesh size (1 mm) was common in many *beels* of lower Assam (Goswami *et al.*, 1994). This net was non-selective and highly destructive, capable of catching even fish spawn. However, this net was found to be very efficient in bulk catching of small economic fishes. Availability of lesser macrophyte-free areas to operate this net may be one of the contributory factors for the overwhelming dominance of major fishes (86%) in fish catches of Jaluguti *Beel.* The encircling net (*dub jal*) employed Charan *Beel* was found to be similar in its mode of catching (by diving) to *chak jal* (a fixed conical falling net with bamboo frame) used in many shallow *beels* of West-Bengal and also in Assam's Jorhat District. Both these nets were very efficient in catching major fishes in shallow areas infested with submerged macrophytes. This net was not used in Jaluguti *Beel* apparently because most of the shallower areas of this *beel* were covered with water hyacinth. Thus, apart from the physiography of the water body and the nature of fish stocks (Choudhury, 1992a) the type and extent of macrophyte infestation also influenced the type of fishing method employed in the selected *beels.*

A total of 218 ichthyospecies have been recorded and reported from Assam (Bhattacharjya *et al.*, 2001) out of which 43 species belonging to 30 genera under 18 families have been recorded in the present study. The fish diversity in some *beels* of lower Assam, *viz.,* Chanddubi (57 species), Dora (62), Deepor (41) and Salsala (44) has been reported by previous workers (Lahon, 1979; Dey, 1981; Goswami, 1985). Rich ichthyofaunistic diversity in the *beels* of Assam was also reported by Chandra *et al.* (1990) in Dighali *Beel* (54 species), Kar and Dey (1986, 1993) in Sone *Beel*, Barak Valley (70), Agarwala (1996) in Tamranga *Beel* (63), Acharjee (1997) in three *beels* of Kamrup District (56) and Deka *et al.* (2001) in 54 *beels* of the state (67 species). The comparatively fewer fish species recorded in Jaluguti *Beel* and the absence of species like *Chitala chitala*, *Labeo calbasu, L. bata, L. dero* and *Botia dario* in this *beel* can be attributed to its loss of connectivity with the parent river. The surrounding physiographic conditions of open *beels* with vast shallow areas having submerged and emergent macrovegetation create a suitable environment for the riverine fish species for breeding (Deka *et al.*, 2001) and nursery rearing. According to Weller (1978), fishes find shelter and food in the littoral plants of lake or in emergent marshes; several fish species move into marshes from adjacent lakes to breed and some species also use marshes as a nursery ground. The presence of Indian major carp species like *L. gonius, L. rohita, L. calbasu,* and *Cirhinus mrigala* in

Charan *Beel* apparently indicated favourable breeding environment in this *beel* (Dey, 1981). The overwhelming dominance of major fishes in Jaluguti *Beel* (86.2%) can be attributed to supplementary stocking with catla fry, which accounted for 27.6% of landings, apart from less favourable conditions to operate *mosori jal* in this *beel.* The predominance of highly predatory *Wallago attu* in both the *beels* indicates the presence of large forage fish population in them in the absence of species management. Out of the fairly large number of ichthyospecies present in both the *beels,* only five major fish species contributed to the bulk of the catches in both the *beels.* According to Welcomme (1979) the diverse fish population of the floodplains offers a multispecies fishery, but as their abundance is lognormally distributed, only a few species predominate.

5.8 Fish production potential

Evaluation of fish production potential *beels* involves the quantitative assessment of primary production, the path of energy transformation leading to the desired end product (fish) and the extent of energy utilization at different trophic levels (Pathak, 1992). Workers like H. T. Odum (1957), E. P. Odum (1962), Teal (1962), Mann (1965, 1969), Natarajan and Pathak (1983, 1985), Yadava, *et al.* (1987), Vass *et al.* (1988), Pathak (1990) and Acharjee *et al.* (1998) have applied the energy flow approach for calculating the fish production potential of different aquatic ecosystems including *beels.* Slobodkin (1959, 1962) opined that in natural ecosystems, the gross ecological efficiency (ι_n/ι_m x 100) is almost a constant quantity and is of the order of 10% i.e., almost 90% of energy is lost in the process of energy transformation from one trophic level to the next higher level. Primary productivity is considered as an indicator of fish production. According to E. P. Odum (1962), a harvest of 1.2% of gross primary productivity (GPP) as fish in natural water would be excellent. In the present study, the fish production potential was estimated at 874. 24 and 1062.81 kg $ha^{-1}yr^{-1}$ in Charan *Beel* and Jaluguti *Beel* respectively, which remained within the broad range of 476 to 2324 kg $ha^{-1}yr^{-1}$ estimated for Brahmaputra Valley *beels* (Sugunan and Bhattacharjya, 2000). Pathak (1990, 1992) reported comparatively higher fish production potential in the rage of 1300 to 2150 kg $ha^{-1}yr^{-1}$ in Dhir *Beel* (Assam), Muktapur Lake (Bihar), Media *Beel* and Kulia *Beel* (West Bengal). However, the estimated fish production potential of Dora (631 kg $ha^{-1}yr^{-1}$), Ghorajan (728 kg $ha^{-1}yr^{-1}$) and Dighali *beels* (865 kg $ha^{-1}yr^{-1}$) in lower Assam (Acharjee *et al.*, 1998) was slightly lower than the *beels* under the present study.

Fish production in a water body is dependent on the food supply, which in turn is directly or indirectly related to the primary sources of organic matter (Vass, 1992a). Thus, fish yield worked out in terms of energy equivalent can be related to the energy fixed by primary producers during photosynthesis. In the present study, the conversion efficiency of total primary production to fish yield was estimated at 0.26% and 0.06% in Charan *Beel* and Jaluguti *Beel* respectively. The corresponding conversion efficiency of radiant energy to fish yield was 0.0050% and 0.0013% in these *beels.* Since 10% of wet weight of fish can be reckoned as carbon (Vinogradov, 1953), the estimated fish yield in Charan and Jaluguti *Beel* represented 22.81 and 6.02 kg C $ha^{-1}yr^{-1}$ respectively. The rate of organic matter production as estimated from GPP in the *beels* was 10930 and 13280 kg C $ha^{-1}yr^{-1}$ respectively. The conversion efficiency of GPP to fish (as carbon) was 0.209% and 0.045% in Charan *Beel* and Jaluguti *Beel* respectively. The conversion efficiency of photosynthetic carbon and its incorporation in fish varies in different aquatic ecosystems (Vass, 1992a). Ohle (1958) reported an efficiency of 0.09% in some West German lakes. Vass (1982) and Vass *et al.* (1988) estimated the conversion efficiency of phytoplankton photosynthesis to fish production in the range of 0.019 to 0.082% in some Kashmir Valley lakes.

The conversion efficiency of primary production to fish was 0.02% for Nagarjunasagar Reservoir (Pathak, 1979) and 0.07% for Govindgarh Lake (Mathew, 1975). Comparatively higher efficiencies of 0.10% for Stanley Reservoir (Sreenivasan, 1966b), 0.11% for Ooty Lake and 0.44% for Kodai Lake have been reported (Ganapati and Sreenivasan, 1970). Padma, Mogra and Garapota *beels* in West Bengal registered comparatively better energy transfer efficiencies (0.156 to 0.390%) due to stocking of suitable fish species (Vass, 1992a). In Assam, Yadava *et al.* (1987) estimated this efficiency at 0.219% in Dighali *Beel* while Acharjee *et al.* (1998) obtained comparatively lower values of 0.001 to 0.020% for three *beels* of Kamrup District. The higher energy transfer efficiencies observed in some open water bodies were presumably because of more favourable climate and efficient use of different food niches (Vass *et al*, 1988). Due to differences in their morphometry, nutrients regime and biotic communities, the *beels* do not show uniform energy conversion efficiency (Vass, 1992a). Since the climate, morphometry and nutrients regime was more or less comparable in the *beels* under the present study, much lower energy transfer efficiency observed in Jaluguti *Beel* indicated inefficient utilization of available food niches due to negligible autostocking in this closed *beel.*

Pathak (1990) reported moderate rates of utilization of fish production potential to fish yield (18 to 37%) in Dhir *Beel* (Assam), Media and Kulia *beels* (West Bengal). Acharjee *et al.* (1998) noted low utilization rates of 1.62 and 1.92% in Dighali *Beel* and Ghorajan *Beel* respectively while a moderate rate of utilization (22.98%) was obtained in Dora *Beel.* This rate was moderate (26.1%) in Charan *Beel* and low (5.7%) in Jaluguti *Beel*, which were comparable to the above observations. These findings reflect a huge waste of available potential in the *beels* under the present study particularly in Jaluguti *Beel*, where the potential remains grossly underutilized. There is scope for utilizing at least 50% of the potential yield by adopting suitable scientific management measures in both the *beels.*

5.9 Trophic structure

The floodplain wetlands are complex aquatic ecosystem presenting diverse ecological conditions ranging from lotic to lentic, permanently wet to seasonally dry and moderate to heavy macrophyte infestation. Thus, we have to look for ways of simplifying this complex ecosystem in order to make them easier to comprehend and manage. The most useful technique to analyze such a complex ecosystem is to divide it into functionally identifiable parts (trophic levels) and study the functioning of each compartment as well as the interactions among the individual compartments (Pathak, 1992). Such interactions lead us to the flow of energy through various trophic levels from producers to the final end product (fish). In the *beels* under the present investigation, four trophic levels were recognized. Usually, there are more or less five trophic levels in a food chain (Kundu, 1999). Pimm (1982) and Pimm *et al.* (1991) argued that the tenth-level carnivore is not possibly found in a food chain as such lengthy, hypothetical food chain is most unstable due to environmental fluctuations; a tenth-level carnivore has to have a huge home range area to stay and get enough food to eat, which is not feasible. However, ecologists have not gathered much data on the length of food chains (Kundu, 1999).

There were two main routes through which solar energy fixed by primary producers flew in the *beels* under the present study, *viz.*, the grazing and the detritus food chains. According to V. G. Jhingran (1991), the energy of producers can be utilized either directly by consumers through the grazing food chain or the unused energy can get deposited as organic detritus and utilized through the detritus chain. In the absence of organisms directly consuming aquatic macrophytes in the selected *beels*, most of the macrophyte biomass contributed to the organic detritus complex upon their death and decay. The proposed energy flow models were more or less similar for both the *beels*. However, in case of Charan *Beel*, the proportion of energy flowing through the grazing food chain was slightly higher than that through the detritus chain. In contrast, over two-thirds of the energy fixed by producers flew through the detritus food chain in Jaluguti *Beel*. Pathak *et al.* (1985) showed the importance of detritus food chain in *beel* ecosystems. Studies conducted in a number of *beels* in Assam (Sugunan and Bhattacharjya, 2000) have shown that energy flows mainly through the grazing and the detritus food chains in open and closed *beels* respectively. Both the grazing and detritus food chains were interconnected since most of the consumers fed on more than a single group of organisms. These interconnections gave rise to complex food webs in the ecosystem. E. P. Odum (1983) has proposed a generalized model of Y-shaped or 2-channel energy flow concept, which presents a lucid relationship between grazing and detritus food chains. It has been experimentally proved that transmission of energy through different trophic levels is quite slow in detritus food chain than in grazing food chain. Hence, loss of energy in trophic dynamic is considerably less in detritus food chain than in grazing food chain. In many cases, 90% of energy is transmitted through the detritus food chain whereas 50% of energy is transmitted through the grazing food chain (Ananthakrishnan, 1982).

Previously, grazing and detritus food chains were presented in a simplified way, representing the linear way of energy trafficking from one trophic level to the next one. However, recent review of trophic dynamics show that omnivorous organisms receive energy from two or more trophic levels (Stiling, 1992), thereby making the one way energy trafficking to some extent complex. In the present study, omnivores contributed significantly to the total energy output as fish (17.5% and 32.3% in Charan *Beel* and Jaluguti *Beel* respectively). W. E. Odum (1970) introduced a 'mixed trophic level' including herbivores and omnivores in his proposed 'compartment model' of food chain for coastal mangroves in order to make the model less complex.

The pattern of energy flow in the *beels* under the present investigation differed from that of the other inland open waters like lakes, reservoirs and rivers because of the strong presence of macrophytes and associated fauna. It was found to be closer to that of the coastal mangrove ecosystem of south Florida, where most of the energy flow is through the detritus food chain like the one proposed by W. E. Odum (1970). Sugunan and Bhattacharjya (2000) and Sugunan *et al.* (2000) included weed-associated fauna as an important group of organisms acting as a link between macrophytes and detritivorous/predatory fishes while proposing generalized pathways of energy flow in open and closed *beels*. This can be considered as an important step towards the fuller understanding of the trophic structure of the *beel* ecosystem having implications on their sustainable utilization. However, they presented only a 'picture model' (E. P. Odum, 1983) of the food webs and did not compartmentalize the group into different trophic levels. In the present study, the macrophyte-associated fauna was found to be a community comprising heterogeneous groups of organisms. It included diverse groups like gastropods, which have a key role in the aquatic food chain of freshwaters (Ahmed and Singh, 1989; Singh, 1993) as primary consumers (Dutta and Nath, 2001) and frogs, which were primary carnivores. The 'compartment model' (E. P. Odum, 1983) of the food chain/web used in the present treatise facilitated further compartmentalization of macrophyte-associated fauna into different trophic levels.

The interaction of the food chain phenomenon i.e., energy loss up to 90 percent at each transfer (Slobodkin, 1959, 1962) and the size-metabolism relationship results in communities having a definite trophic structure, which often characterizes a particular type of ecosystem, *viz.*, lake, coral reef and so on (E. P. Odum, 1983). Trophic structure may be measured and described either in terms of the standing crop per unit area as was done in the present study, or in terms of the energy fixed per unit area per unit time at successive trophic levels. Recent research has shown that the trophic structure of aquatic ecosystems can potentially be controlled by two sets of factors, *viz.*, resource availability and predation (Currie *et al.*, 1999). Predation and competition act to structure trophic interactions in natural north temperate lakes (USA) in relatively linear top-down or bottom-up interactions. For example, omnivorous gizzard shad (*Dorosoma cepedianum*) regulated reservoir food webs from an intermediate trophic position through a complex series of predation and competition interactions (Dettmers and Wahl, 1999). In Jaluguti *Beel*, supplementary stocking with catla (*Catla catla*) fry apparently modified the quality composition of zooplankton by reducing the relative abundance of copepods. However, the present data were inadequate to draw concrete conclusions on trophic interaction of introduced catla stocks with zooplankton. There appears to be no published correlative evidence that variation in plankton abundance among lakes is related to variation in fish assemblages, even though the link is mechanically plausible (Currie *et al.*, 1999). A review of shad (*Dorosoma* spp.) in regulating reservoir community dynamics in the USA (DeVries, 1990) revealed that shad introductions can enhance predator growth and negatively affect presumed competitors. However, responses were inconsistent within a species.

Trophic structure and trophic function may be shown graphically by ecological pyramids in which the first or the producer level forms the base, and successive levels form the tiers that make up the apex (E. P. Odum, 1983). Ecological pyramids may be of three general types: the pyramid of numbers, biomass and energy. In the aquatic environment, pyramids of biomass based on specific studies in Weber Lake, Wisconsin (Juday, 1942) and that of energy based on studies in Silver Springs, Florida (H. T. Odum, 1957) have been constructed. The numbers and biomass pyramids can be inverted (or partly so), whereas the energy pyramid must always have a true upright pyramid shape, provided all sources of food energy in the system are considered (E. P. Odum, 1983). In the present study, the trophic structures showed true upright pyramid shapes in both the *beels.*

The shape of the pyramids gives a qualitative idea of probable management interventions required to augment fish yield in both the *beels.* Apparently, the large base of the pyramids (large producer biomass) can support a much bigger biomass of primary consumers in both the *beels.* This calls for enhancement of species/stocks in these *beels* to augment their fish yield particularly in Jaluguti *Beel,* where the present rate of utilization of fish production potential is only 5.7%. Charan *Beel* already had a sizeable detritivorous fish population consisting of *Labeo gonius, L. rohita, L. dero, Cirrhinus reba, L. calbasu* and *L. bata*, which comprised 31% of the total landings. Stocking of omnivorous *C. catla* (primarily zooplanktophagous) together with limited supplementary stocking of *L. rohita* is expected to enhance fish production considerably in this *beel.* Since this *beel* is dominated by submerged macrophytes and gets connected to River Kolong during the rainy season, the introduction of indigenous herbivorous barbs from Peninsular India like *Puntius pulchellus* and *P. dobsonii* needs serious consideration. *P. pulchellus* is preferable since it grows to more than 5 kg (David *et al.*, 1970). Its introduction in this *beel* would help in effective utilization of submerged macrophytes for increasing fish yield. Yadava *et al.*

(1987) made a similar recommendation for enhancing fish production from Dighali *Beel*, which is an open *beel* in lower Assam.

The present investigation has shown that Jaluguti *Beel* is a detritus-based production system where detritus acts as a food store or larder for the fishes (Kumar, 1985). Since this *beel* has a low population of detritivorous fishes (25.7%) due to low autostocking from the river, this most important ecological niche remains grossly underutilized at present. This calls for supplementary stocking of detritivorous fishes like *L. gonius, L. rohita, C. mrigala, L. calbasu* and *C. reba.* Among these, the seed of *L. rohita* and *C. mrigala* are locally available. However, the *lessees do* not prefer *C. mrigala* because of its low demand and price, as observed in Jaluguti *Beel.* Though the minor carps, *L. bata* and *C. reba*, command high demand and price, their seed is not available in the locality. Supplementary stocking of catla fry is already being practiced in Jaluguti *Beel* and good growth of up to 500 g in six months was observed. Jaluguti being a closed *beel*, the exotic grass carp (*Ctenopharyngodon idella*) can also be introduced here on an experimental basis to convert the rich biomass of sumberged macrophyte into fish flesh. Even grass carp fry of 30 mm size are phytophagous and consume submerged macrophytes (Ghittino, 1972). Vass *et al.* (1988) suggested stocking of the grass carp to control submerged macrophytes in Lake Naranbagh in Kashmir.

Introduction of *Pangasius pangasius* to feed on the abundant molluscan fauna in both the *beels* (Yadava *et al.,* 1987) is also required. Since fingerlings of the Indian major carps are not available locally and the *beels* (particularly Jaluguti) have very high populations of predatory *Wallago attu,* rearing of carp fry to fingerling size in pens constructed in marginal areas of the *beels* before stocking them into the *beel* proper is required to achieve higher survival and production of stocked seed. Field trials on pen culture of Indian major carps in selected *beels* of Assam being undertaken by CIFRI have shown encouraging results (Saha, personal communication). In addition, encouraging selective fishing to control *W. attu* population in both the *beels* should also form part of the strategy for species/stock enhancement.

Seed of rohu and mrigal mixed with catla reportedly showed poor growth (approximately 200 and 100 g respectively) in Jaluguti *Beel*, suggesting probable unfavourable environmental conditions especially in bottom layers, which need further detailed studies. Habitat enhancement mainly comprising clearance of water hyacinth is necessary in this macrophyte-choked *beel*, though this is a costly proposition requiring government intervention. This, coupled with biological control of submerged macrophytes, is expected to alter the existing trophic structure from detritus-based to a plankton-based system, which is likely to result in higher energy conversion efficiency. Studies conducted in Kulia *Beel*, a closed *beel* choked with submerged macrophytes in West Bengal revealed that macrophyte clearance resulted in 100 times increase in the phytoplankton standing crop and 30-35 folds increase in the primary production leading to increase in fish production from 320 to 1077 kg $ha^{-1}yr^{-1}$ (Saha *et al.*, 1990).

The twin strategies of enhancement of species/stocks and macrophyte control would certainly increase the trophic efficiency and fish yield from these *beels.* However, all these strategies should be tried on an experimental basis and the results should be monitored continuously including the possible environmental impact of introducing herbivorous *Puntius* spp. into an open *beel.* The results of this limited exercise can serve as models for enhancement of fisheries in open and closed *beels* of the entire Brahmaputra Valley.

6. SUMMARY

The present study was carried out during 2000-01 to assess the fish production potential as well as to understand the trophic structure of two floodplain wetlands (*beels*) located within the agro-climatic sub-region of the Central Brahmaputra Valley (CBV) Zone of Assam (India). Out of the two *beels* selected for the study, Charan *Beel* (water spread area 60 ha) is an oxbow lake that gets connected to River Kolong during the rainy season and hence represents an open *beel*. Jaluguti *Beel* (35 ha), which is also an oxbow lake created by the same river, has lost riverine connection due to the construction of flood control embankments and hence represents a closed *beel*. The study region experiences sub-tropical climate with high rainfall and have four distinct seasons, *viz*., pre-monsoon (March to May), monsoon (June to September), post-monsoon (October to November) and winter (December to February).

Soil texture varied from sandy-loam, loam, silty-loam to sandy-clay-loam and did not differ appreciably between the *beels*/stations. Bottom soil of the *beels* was acidic (pH 4.5 to 6.2) and had moderate to high organic carbon (1.06 to 8.67%). Soil pH was inversely related with organic carbon, suggesting that the higher detritus load generated by dense aquatic macrophytes may be responsible for the percolation of enhanced organic acid into the soil. The available nitrogen and available phosphorus ranged from 9.58 to 36.67 mg 100 g^{-1} and from 0.26 to 1.44 mg 100 g^{-1} respectively.

Jaluguti *Beel* recorded comparatively higher levels of organic carbon, available nitrogen and available phosphorus in soil, suggesting gradual accumulation of organic matter and nutrients in this *beel*. Heavy macrophyte infestation and low water exchange/mixing due to river regulation present favourable conditions for nutrient accumulation in this closed *Beel*.

Water of the selected *beels* recorded moderate temperature (21.5 to 34.0°C). The Secchi disc depth fluctuated widely between 0.23 to

1.45 m and showed irregular spatio-temporal variations. The pH of *beel* water showed considerable variations ranging from acidic to alkaline (6.3 to 7.3) with near-neutral average values, which more or less remained within the favourable range for fish production. The *beels* recorded medium total alkalinity (21.45 to 81.60 mg l^{-1}) and total hardness (21.8-78.1 mg l^{-1}), which were within the favourable ranges. Jaluguti *Beel* had higher average total alkalinity (56.29 mg l^{-1}) than Charan *Beel* (34.18 mg l^{-1}), indicating that the former was more productive. Total alkalinity was inversely related with rainfall and free carbon dioxide and directly related with pH of water. The values of total alkalinity and total hardness were similar in magnitude and both these parameters had a very high positive correlation. Based on the average total hardness levels, Charan *Beel* (35.9 mg l^{-1}) and Jaluguti *Beel* (54.5 mg l^{-1}) can be considered as soft and hard water *beel* respectively.

Dissolved oxygen concentration of water fluctuated widely in the range of 4.77 to 12.14 mg l^{-1}. Dissolved oxygen was inversely related to water temperature. Free carbon dioxide concentrations varied widely (undetectable to 18.59 mg l^{-1}) but remained within the tolerable range. Free carbon dioxide was inversely related with pH of water.

The concentrations of total iron (0.05 to 0.82 mg l^{-1}) and total chloride (12.8 to 29.4 mg l^{-1}) were low in the *beels*. Total iron levels were well within the tolerable limits of fishes, while total chloride was lower than the desirable range for freshwater fish culture.

Specific conductivity (range 55.8 to 158.5 µmho cm^{-2}) and total dissolved solids of water (28.5 to 84.7 mg l^{-1}) followed a similar pattern of seasonal variation with maximal values recorded during April-May. Specific conductivity had significant positive correlation with total dissolved solids, total alkalinity and total hardness, which is natural since all these parameters reflected the ionic concentrations in water. Both specific conductivity and total dissolved solids had significant positive correlation with organic carbon and available phosphorus in soils, suggesting that both these parameters were directly influenced by the soil fertility.

The concentrations of dissolved organic matter (DOM) (0.90 to 4.14 mg C l^{-1}) were slightly higher in the selected *beels* than that recorded in other *beels* of the CBV Zone. DOM was inversely related to dissolved oxygen.

Nitrate-nitrogen concentrations ranged from 0.01 to 1.14 mg l^{-1} in the *beels*, which were within the desirable limits for fish production. Similarly, the levels of phosphate-phosphorus recorded in the *beels* (traces to 0.035 mg l^{-1}) indicated that they were productive in spite of having acidic soils. Higher average concentrations of nitrate and phosphate recorded in Jaluguti *Beel* showed that it was more productive than Charan *Beel.* The concentration of silicate-silica in the *beels* (2.4 to 7.4 mg l^{-1}) was directly related to rainfall.

The seasonal variation physico-chemical characteristics of water were influenced by temperature, rainfall and biotic communities. Nutrient enrichment occurred during the first surface run-off/flood in the *beels*, which may be due to sediment re-suspension and death and decay of submerged macrophytes.

Wide diurnal fluctuations were observed in dissolved oxygen (up to 7.04 mg l^{-1}), pH, free carbon dioxide and bicarbonate content of water in the *beels*, indicating their high productive status. The relative magnitude of diurnal fluctuations suggested comparatively higher productivity of Jaluguti *Beel.* Similarly, seasonal variation in the intensity of diel fluctuations indicated that the biological productivity was maximal during the monsoon and the post-monsoon seasons in Charan *Beel* and Jaluguti *Beel* respectively, while it was the lowest during the winter season in both the *beels.* Contrary to *beels* studied by many other workers, free carbon dioxide was always present in these beels.

Charan *Beel* was moderately infested by aquatic macrophytes, covering 38% of *beel* area; submerged macrophytes infested more areas (average 24%) than free-floating ones (mainly *Eichhornia crassipes*), even though the latter contributed more to the total macrophyte biomass. Jaluguti *Beel* was heavily infested by macrophytes (average 69% area), out of which *E. crassipes* covered most of the area (54%) and contributed to most of the total macrophyte biomass. Apart from *E. crassipes, Hydrilla verticillata, Najas* spp., *Ceratophyllum demersum* and *Vallisneria spiralis* were the other dominant species occurring in the *beels.* The average biomass of macrophytes was lower in Charan *Beel* (1.40 kg dry wt m^{-2}). Seasonal variation in the biomass of submerged macrophytes was mainly related to the water level variations, while that of water hyacinth may be attributed to temperature and nutrient levels. A direct relation was observed between the total macrophyte biomass and nitrate-nitrogen concentration of water, indicating that nitrate was more limiting than phosphate for macrophyte growth in the *beels.*

The *beels* recorded poor plankton, with average total plankton population being 863 and 623 u l^{-1} in Charan *Beel* and Jaluguti *Beel* respectively. Phytoplankton dominated the total plankton population in both the *beels.* The utilization of nutrients by profuse growth of macrophytes resulted in poor phytoplankton population in the *beels.* Phytoplankton population was inversely related to rainfall, indicating that the rainy season presented relatively unstable environmental conditions hindering the colonization of phytoplankton. A total of 63 genera of phytoplankton were recorded in the *beels*, with Charan *Beel* recording higher number of phytoplankton taxa. The phytoplankton community structure showed the dominance of Bacillariophyceae and Chlorophyceae in Charan *Beel* and Jaluguti *Beel* respectively. The group Bacillariophyceae was dominated by *Fragilaria* spp., *Melosira* spp. and *Navicula* spp., while Chlorophyceae was commonly represented by *Spirogyra* spp., *Pediastrum* spp. and *Mougeotia* spp. The group Myxophyceae was dominated by *Microcystis* spp., *Anabaena* spp. and *Oscillatoria* spp., while Desmidiaceae were commonly represented by *Cosmarium* spp. and *Staurastrum* spp. The group Euglenoida represented by *Euglena* spp. and *Phacus* spp. occurred only in Jaluguti *Beel.* The significant presence of blue-green algal species like *Anabaena* spp. and *Microcystis* spp. as well as low desmid population (10% or less) indicated the eutrophic nature of the *beels.*

Charan *Beel* had poor population of zooplankton (average 233 no. l^{-1}) although phytoplankton was rich in this *beel.* Jaluguti *Beel* supported slightly higher zooplankton population (average 238 no. l^{-1}) contributing to 38.2% of the total plankton population, suggesting that zooplankton derived a part of their food from the detritus pool apart from phytoplankton in this macrophyte-choked *beel.* The zooplankton community structure showed the dominance of Copepoda in Charan *Beel* and Rotifera in Jaluguti *Beel.* The group Copepoda was dominated by *Cyclops* spp. and *Diaptomus* spp., while Rotifera were commonly represented by *Brachionus* spp., *Keratella* spp. and *Filinia* spp. *Pandorina* spp. and *Eudorina* spp. dominated protozoa, while the group Cladocera was commonly represented by *Moina* spp. and *Ceriodaphnia* spp. Zooplankton population was directly related to phytoplankton population, indicating that the former was chiefly dependent on the latter.

The poor average standing crop of macrobenthos recorded in Charan *Beel* (429.1 g wet wt m^{-2}) and Jaluguti *Beel* (354.2 g wet wt m^{-2}) may be attributed to the wide fluctuations in their water levels. The biomass of macrobenthos was dominated by Gastropoda, followed by Oligochaeta, Insecta and Pelecypoda in the *beels.* A total of 21 genera/species of macrobenthos were recorded, out of which four taxa were absent in Jaluguti *Beel.* Gastropoda was commonly represented by *Gyraulus convexiusculus* and *Melania* spp. Among the Oligochaetes, *Aelosoma* spp. and *Chaetogaster* spp. were fairly common. Dragonfly mymphs and *Chironemus* spp. were the most common insects, while *Corbicula striatella* and *Lamellidens marginalis* were fairly common bivalves. The biomass of macrobenthos was directly related to total hardness of water, suggesting that the gastropods and bivalves, which constituted the bulk of the macrobenthos biomass, tended to grow well in hard water.

The average standing crop of macrophyte-associated fauna was higher in Charan *Beel* (497.4 g wet wt m^{-2}) than that in Jaluguti *Beel* (474.4 g wet wt m^{-2}), which was higher than that of macrobenthos in these *beels.* This indicates that the macrophyte-associated fauna play an equally important role in the trophic structure of a *beel* ecosystem as macrobenthos do. The biomass of macrophyte-associated fauna was directly related to water temperature, indicating that this group had affinity towards warmer temperature unlike macrobenthos. Further, their biomass was directly related to macrophyte biomass, suggesting that the macrophytes provide food and shelter to the associated fauna. The bulk of the macrophyte-associated fauna was formed by Insecta, followed by Mollusca, Annelida and others. The molluscs were mainly represented by gastropods and a few bivalves. Most of the species comprising insects, molluscs and annelids were common to both benthos and macrophyte-associated fauna. However, the leech (*Hirudo* spp.), small fishes (*Badis badis, Colisa lalia),* small prawns (*Macrobrachium* spp.) and frogs (*Rana* spp.) occurred only in associated fauna samples. The total number of taxa recorded in macrophyte-associated fauna (28) was higher than that in macrobenthos samples. Charan *Beel* supported higher number of taxa (25) than Jaluguti *Beel* (23).

The spatio-temporal variations in the biotic communities was influenced by temperature, rainfall, soil quality, physico-chemical characteristics of water and the interaction among the communities.

The average gross primary productivity was 2994.96 mg C $m^{-2}d^{-1}$ in Charan *Beel,* out of which the contribution of phytoplankton was 52.4%. On the other hand, phytoplankton contributed only 31.8% of average gross primary productivity of Jaluguti *Beel* (3639.31 mg C $m^{-2}d^{-1}$). The high rate of primary productivity recorded in the *beels* indicated their high productive status. Both the gross phytoplankton productivity and gross macrophyte productivity was significantly higher ($P < 0.05$) in Jaluguti *Beel,* suggesting that this *beel* had higher biogenic capacity than Charan *Beel.* Seasonal variation in the gross primary productivity was related to the combined biomass of macrophytes and phytoplankton. Very high positive correlation was obtained between gross phytoplankton productivity and phytoplankton abundance as well as between gross macrophyte productivity and macrophyte biomass.

The photosynthetic efficiency was estimated at 1.9% in Charan *Beel,* out of which phytoplankton converted 1% of the total radiant energy. The photosynthetic efficiency was higher in Jaluguti *Beel* (2.3%), but phytoplankton converted only 0.7% of total radiant energy in this *beel.*

The fish yield was estimated at 228 kg $ha^{-1}yr^{-1}$ in Charan *Beel*; minor fishes (<15 cm size) contributed 52.9% of total catch in this *beel.* The fish yield was much lower in Jaluguti *Beel* due to negligible autostocking from River Kolong. Supplementary stocking with *Catla catla* resulted in overwhelming dominance of major fishes in Jaluguti *Beel* (86.2%). Commercial fishing lasted for five months during the period from November to April, when the water level declined substantially in the *beels.* The addition, barrier fishing (*bheta mara/banas)* yielded good catch during June in Charan *Beel.*

'Brush fishing' (*katal/jing* and *pit)* was the most important commercial fishing method practised in the *beels*, followed by shore seining (*mosori jal*), gill netting (*langi jal*), encircling (*dub jal)*, barrier fishing, skimming (*thela jal)* and cast netting (*Khewali jal*). 'Brush fishing' contributed to as much as 54 and 67% of total fish catch in Charan *Beel* and Jaluguti *Beel* respectively. While *katal* has been described in detail by earlier workers, *pit* fishing has not been previously documented. A total of 43 ichthyospecies belonging to 30 genera has been recorded in the *beels.* Charan *Beel* recorded higher number of fish species (38) compared to Jaluguti *Beel* (29 species). Commercial fish catches of Charan *Beel* was dominated by *Wallago* *attu,* followed by *Labeo gonius, L. rohita, L. dero* and *Cirrhinus reba.* Among the minor fishes, which contributed to 52.9% of landings in this *beel*, *Puntius* spp., *Colisa* spp., *Amblypharyngodon mola*, *Mystus* spp., *Channa* spp., *Rasbora* spp. and *Chanda nama* predominated the landings. In Jaluguti *Beel*, as much as 79.4% of catches were contributed by 5 major fish species *viz.*, *W. attu, C. catla, L. gonius, L. rohita* and *C. mrigala.* Minor fishes contributed only to 13.8% of the total landings in this *beel*, among which *Puntius* spp., *Channa* spp., *Colisa* spp. and *Mystus* spp. dominated the landings.

The fish production potential, estimated based on primary productivity, was lower in Charan *Beel* (874 kg $ha^{-1}yr^{-1}$) than that in Jaluguti *Beel* (1063 kg $ha^{-1}yr^{-1}$). However, the conversion efficiency of total primary production to fish yield was much higher in Charan *Beel* (0.26%) than that in Jaluguti *Beel* (0.06%). The rate of utilization of production potential to fish yield was moderate in Charan *Beel* (26.1%) and low in Jaluguti *Beel* (5.7%), reflecting a huge waste of the available potential in these *beels* particularly in Jaluguti *Beel.*

Four trophic levels were recognized in the selected *beels* starting with the primary producers (both macrophytes and phytoplankton). Energy fixed by the primary producers was passed on to the higher trophic levels through both the grazing and the detritus food chains, representing a 2-channel flow of energy. The proposed energy flow models were similar in both the *beels*. However, most of the energy flow (52.4%) was routed through the grazing food chain in Charan *Beel*, while over two thirds (68.2%) of the energy flow was routed through the detritus food chain in Jaluguti *Beel.* Both the food chains were interconnected to form complex food webs in the *beels.* The presence of omnivores further added to the complexity.

The trophic structures were represented by the pyramid of biomass; true upright pyramid shapes were obtained in both the *beels*. The shape of the pyramids indicated that the large base of the pyramids (large producer biomass) can support a much bigger biomass of primary consumers in both the *beels*, particularly in Jaluguti *Beel.* The fish yield of Charan *Beel* can be increased considerably by supplementary stocking *C. catla* (primarily zooplanktophagus) and *L. rohita*. The introduction of indigenous herbivorous fishes like *Puntius pulchellus* and *P. dobsonii* and molluscivorous *Pangasius pangasius* to utilize the rich submerged macrophytes and molluscan fauna would increase the fish yield further in this open *beel.* Jaluguti *Beel* is a detritus-based system, where supplementary stocking of detritivorous fishes like *L. gonius, L. rohita, L. mrigala, C. reba* and *L. calbasu* is likely to increase fish yield considerably. The introduction of *P. pangasius* and the exotic herbivore, *Ctenopharyngodon idella* would enhance its fish yield further. Clearance of water hyacinth in Jaluguti *Beel* is expected to alter its trophic structure to a plankton-based system, thereby increasing its energy conversion efficiency.

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