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Modelling of Impact of Detritus on Detritivorous Food Chain of Sundarban Mangrove Ecosystem, India

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Abstract

Decomposition and subsequent remineralization of mangrove detritus is important in nutrient dynamics within the forest as well as in offshore system. In order to study the impact of detritivorous fish on the mangrove estuarine detritus food web, a five compartment model of detritus food web dynamics has been developed for mangrove estuarine creeks of Hooghly- Matla Estuarine complex, Sundarban. The model simulates concentration of nutrient, biomass of phytoplankton, zooplankton, detritus and detritivorous fishes. Almost 70% of the detritus formed in the soil was being washed in the estuarine water to act as source or sink of nutrient for the primary producers of aquatic food chain. A significant amount of detritus in the estuarine water is readily consumed by a group of detritivorous fishes before it is being rematerialized completely in to inorganic nutrient form. The model has been calibrated and validated using field data accordingly. Increased detrital nitrogen values in the late monsoon and post monsoon months, assists the growth and high yield of detritivorous fishes as found in simulated and field observations. Comparison of simulated and observed results demonstrates the dependence of phytoplankton growth is a function of nutrient concentration and zooplankton grazing. Model results also show the dependence of detritivorous fishes on detritus which is a function of detritus biomass. In turn, detritus biomass is dependent upon several factors like mortality of phytoplankton, zooplankton, and detritivorous fishes; and chiefly on litter biomass and litter decomposition.

Key words: Calibration; Detritivorous fish; Mangrove estuary; food web; Simulation; Phytoplankton; Nutrient; sensitivity analysis

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1. Introduction

Substantial light has been gained in recent time regarding the important role of tidal marsh vegetation (mangrove) in the detrital input and nutrient dynamics of coastal ecosystem. Mangroves play an

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imperative functional role in offshore nutrient cycles as exporters of significant amounts of plant detritus. Decomposition and subsequent remineralization of mangrove detritus is important in nutrient dynamics within the forest as well as in adjacent estuarine system. The present work focuses on a generalized detritus dynamic model of Sundarban mangrove ecosystem i.e. Hooghly-Matla estuary. Mangrove Ecosystem in India is one of the largest detritus based ecosystem of the world [1] and supplies detritus and nutrient through leaching and break down of leaf litter into the adjacent estuary and thus regulates the productivity of the adjacent Hooghly-Matla Estuarine complex [2]. Litter in Sundarban mangrove ecosystem is mainly produced from large mangroves such as *Avicennia* sp., *Exocaria* sp., *Heritiera* sp., *Bruguiera* sp., *Sonneratia* sp. etc. [2]. Litterfall undergoes the following processes: (1) consumed and physically broken down by ground macro fauna (Mainly crabs), (2) decomposed by microorganism (Bacteria, Fungi, (3) exported to the estuary with a very slight level of degradation [3] or (4) retained as refractory material and incorporated into the soil sediment [4-6]. Detritus and inorganic nutrients are washed out by tidal flows into the adjacent estuary and control the overall productivity of the mangrove ecosystem. The plankton productivity is mainly dependent on the nutrients produced from mangrove litters [7]. Sundarban estuarine region acts as a nursery ground for many commercially important fishes [8] [9].The system is inhabited by many carnivorous fishes which are zooplanktonivorous and pisciphagous. Several species of grey mullets belonging to the family Mugiladae are distributed throughout the mangrove swamps of sundarban. The juvenile mullets enter into the estuary in massive scale along with tide water for food and shelter. A very important group of fishes belonging to genus *Mugil*, is totally detritivorous in nature whose production is mainly controlled by detritus available in the system [2]. Other mullets are also mainly detritivorous in nature. In respect of fisheries science and for economic point of view, the detritivorous fish and pisciphagus fishes are very much of importance [1].

Present study is pertinent for the fact that detritus based models do not explicitly contain a detritivorous fish (DF) compartment [10-14]. The prime interest of this model is to incorporate detritivorous fish compartment in addition to a simple NPZD model. Subsequent addition of extra compartments increases the complexity of the model and simultaneously can profoundly change the dynamics of the model as well. In that case, conclusion concerning simple NPZD model is no longer applicable [15]. The objective of the present work is to estimate the possible impact of detritivorous fish on the overall production of mangrove estuarine system of sundarban. The present study investigates the impact of detritivorous fish which consume solely detritus on the overall detritus pool and also on nutrient coming from detritus through remineralisation, on production of phytoplankton, zooplankton and carnivorous fishes. Is has also been tried to investigate the relative abundance of detritus, zooplankton, phytoplankton and other fishes, primary production and overall fish production as well. Whether occupying a particular niche enables them to coexist with other fish species a five compartment simulation model has been proposed which introduces nutrient, detritus, phytoplankton, zooplankton, detritivorous fishes. Nitrogen has been identified as a nutrient, limiting the productivity of phytoplankton in shallow coastal water. Total work has been divided into two parts 1) field survey and experiments for getting the litterfall data and estimations of the detrital nitrogen of the mangrove intertidal forest floor. 2) construction of a five compartment model of detritus food web and its successive calibration, validation and sensitivity analysis.

2. Materials and methods

2.1. Study site and field experiment

Main study site, Sagar Island, the largest delta in the Sundarban mangrove ecosystem lies between $21^o56^/$ N to $21^o88^/$ N and meridians $88^o08^/$ E to $88^o16^/$ E which is about 144.9 km^2 in area and surrounded by river Hooghly in the north and north-western side and river Mooriganga in the eastern side (Fig.1.). This island is criss–crossed by small and large creeks with mangrove vegetation and all are connected to the principle estuarine water. The seasons of this region are categorized as premonsoon (March - June), monsoon (July - October) and postmonsoon (November - February). The premonsoon is characterized by high air temperature ranging from 28°C to 40°C and occasional rains. The monsoon encounters high rainfall (average 185cms.), when the south west monsoon-wind enters the Indian subcontinent. The postmonsoon is characterized by cold weather (average 22°C) and insignificant rainfall.

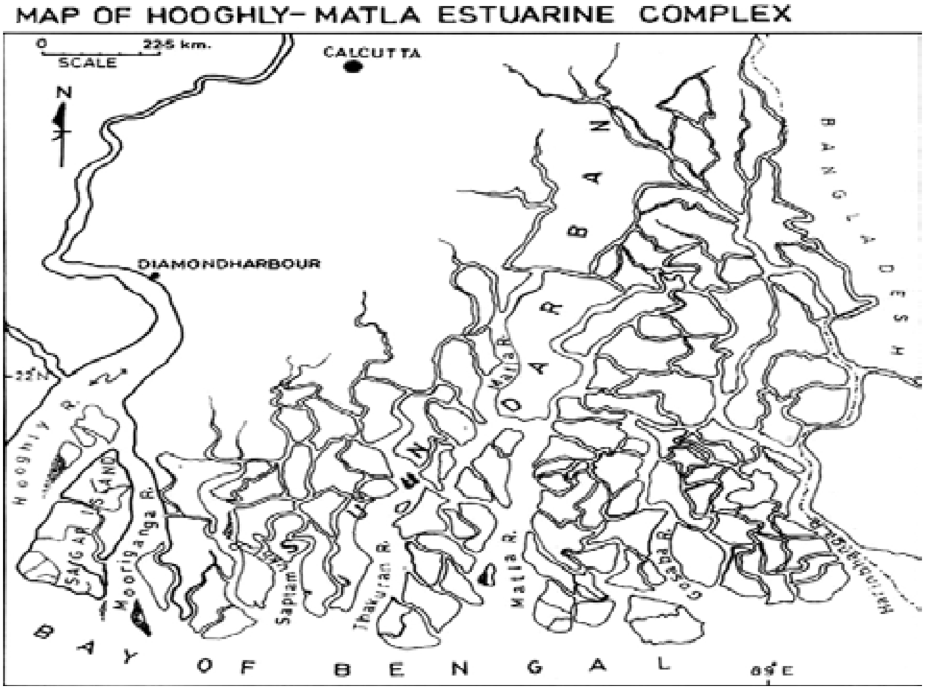

Fig.1. Map of Sundarban Mangrove ecosystem (Hooghly-Matla estuarine complex)

The litter collection is performed in the mangrove forest patch Chemagari in Sagar Island, Sundarban. The mangrove forest consists of mixed stands of B. gymnorhiza. Avicenia sp., Exocaria sp. Among these tree species, Avicenna sp. is predominating. Litter is collected monthly during two years (Jan 2005- Dec 2007) study period using standard litter trapping procedure, regardless of the probable mass loss resulting from leaching of labile components. Similar collection procedure has been followed worldwide by several authors enabling us to perform comparisons with this study [16-21]. All eight traps are emptied in near-monthly intervals for a period of two years and the collected litters are dried at 800C for 72-120 hrs for dry weight.

Inorganic nitrogen from in the estuarine water has been measured, particulate and dissolved organic nitrogen in water represents detritus; phytoplankton and zooplankton biomass are collected from field study and nitrogen content has been measured, In case of detritivorous fish biomass, the data for monthly fish production is collected from Central Inland Fisheries Research Institute (CIFRI), India, and also to some extent through survey from local fishermen and local fish markets). Biomass of fish per cubic metre is recorded following the method of Mukherjee et al. [22]. All the data in terms of nitrogen from adjacent estuarine water are collected at monthly intervals for over two years. These values are used to run the model and their subsequent calibration and validation. Nitrogen content from fish biomass is calculated using the method described in Ramseyer [23].

3. The model

3.1. Model description and equations

As an illustration of the importance of the integrative framework for detritus food web, a simple five compartment model is presented (conceptual model is shown in Fig. 2.) to know the dynamic behaviour of nutrient (N) coming from detritus, phytoplankton (P), zooplankton (Z), detritus (D), and detritivorous fish (DF). The model possesses several pathways of energy flow in and out of the each pool.

Table1. Symbols and their description used in the model.

Symbol	Description
I_n	Nutrient input from outside
o_N	Output of nutrient outside the system
r_D	Remineralization of D into N
p_U	Uptake of nutrient by P
r_P	Respiratory loss by P
gr_Z	Grazing of Z on P
r_P	Mortality of P
L_E	Light effect
I	Surface solar irradiance effect
$z1$	Light attenuation
grz_D	Grazing of Z on D
m_Z	Loss due to mortality of Z
r_Z	Respiratory loss of Z
o_{CF}	Predatory loss of Z by other fishes
i_D	Input of D form outside
m_P	P mortality fraction contributing to D
m_Z	Mortality fraction of Z contributing to D
m_{DF}	DF mortality fraction contributing to D
o_D	Output of D
r_D	Remineralization of D
i_D	Input of D from outside
m_P	Mortality of contributing D
m_Z	Mortality of Z contributing D
m_{DF}	Mortality of DF contributing D

o_D	Output of detritus outside the system
r_D	Remineralization of D
gz_D	Maximum grazing of DF on D
u_{CF}	Uptake of DF by CF
r_{DF}	Respiratory loss by DF
m_{DF}	Loss due to mortality of DF
E_{xt}	Self shading effect of P

The biomass of each state variable is expressed in units of nitrogen concentration. Symbols and their descriptions used in the model are given in Table.1. The nutrient (N) compartment represents all forms of dissolved inorganic nitrogen in the ecosystem mainly coming from detritus remineralization (Eq.1.). Inorganic nitrogen is the limiting factor for photosynthesis by phytoplankton (P) and uptake of nutrient by phytoplankton is concentration dependent (Eq.6.). Similarly uptake of phytoplankton (P) by zooplankton (Z) is also dependent on concentration (Eq.13.). The detritus (D) compartment receives contribution from phytoplankton, zooplankton, detritivorous fishes (Eq.18.) and other sources due to mortality, zooplankton grazing on phytoplankton, and also from self predation by zooplankton. Remineralization of detritus is actually mediated by bacteria and fungi whose effect incorporated as remineralization rate in the system. The detritivorous fish compartment is controlled by grazing upon detritus and death of detritivorous fishes and predation by other predatory fishes (Eq.23.).

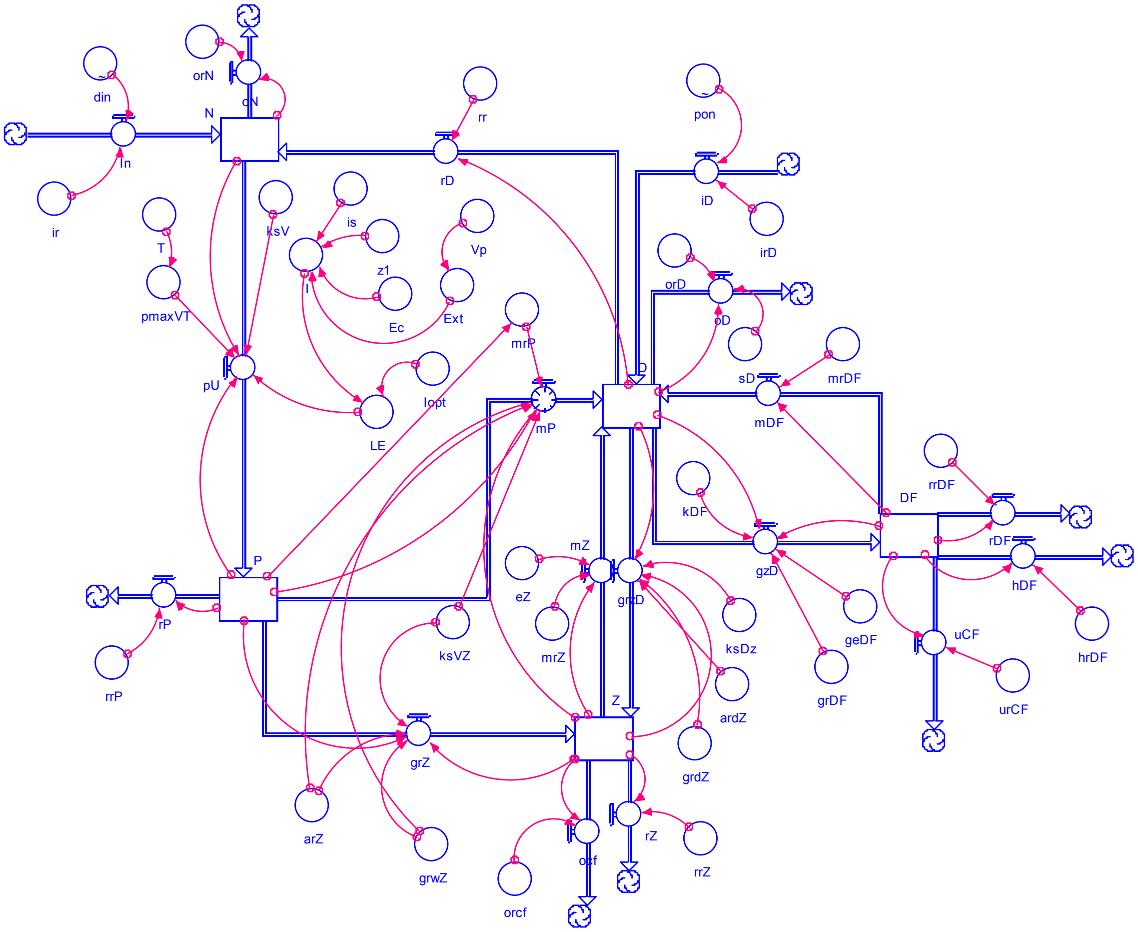

Fig.2. Conceptual model (drawn with Stella software) of Detritus food web dynamics. Rectangle boxes represent the state variables. Bold arrows indicate flow in between the compartments, from outside to the compartments and from inside of the compartment to the outside. Circles with arrows show all forcing functions. The model equations with their flows and their descriptions are as follows:

3.2. Model equations

$$\frac{dN}{dt} = I_n + r_D - o_N - p_U \tag{1}$$

Where,

$$I_n = ir \times din(Graphtime) \tag{2}$$

$$r_D = rr \times D \tag{3}$$

$$oN = or_N \times N \tag{4}$$

$$where,$$

$$p_U = \frac{(p\max_{VT} \times L_E \times N \times P)}{(N + ks_V)} \tag{5}$$

The main source (about 70-80%) of nutrient (N) in the mangrove estuarine water is from tidal washout of detrital inorganic nitrogen from mangrove forest floor. Which is controlled by input rate or leaching rate (Eq.2.) of inorganic nutrient. Monthly inorganic nutrient input is given in the present model as graph-time function. Nutrient uptake by phytoplankton (Eq.5.) is mediated by photosynthesis following the equation of Steele [24]. A small fraction of nutrient is not utilized by the system components represented by output (Eq.4.), regulated by the rate parameter or_N. Detritus compartment adds some nutrient through the process of remineralization (r_D) governed by the rate parameter *rr (*Eq.3.).

$$\frac{dP}{dt} = p_U - r_P - gr_Z - m_P \tag{6}$$

Where,

$$r_P = rr_P \times P \tag{7}$$

$$gr_Z = \frac{(ar_Z \times grw_Z \times P \times Z)}{(P + ksvz)} \tag{8}$$

$$m_P = mr_P + \left[\frac{(mr_P \times grw_Z \times Z \times P)}{(P + ks_{VZ})}\right] \tag{9}$$

$$p_U = \frac{(p\max_{VT} \times T \times L_E \times N \times P)}{(N + ks_V)}$$

and

$$L_E = \left(\frac{I}{I_{opt}}\right) \times ((2.7182818)^{\wedge}\left[1 - \left(\frac{I}{I_{opt}}\right)\right]) \qquad (10)$$

$$I = is \times \left[2.71881^{\wedge}(-Ec - Ext) \times d1\right] \qquad (11)$$

$$E_{xt} = 0.12 \times V_p^{-0.33} \qquad (12)$$

The phytoplankton dynamics is regulated by concentration dependent uptake of nutrient by P (Eq.5.). A little loss is due to respiration by P (Eq.7). Zooplankton grazing on phytoplankton represents a significant loss of phytoplankton biomass from compartment P (Eq.8). Mortality of phytoplankton also is an out flow of biomass in terms of nitrogen (Eq.9.) from P compartment. p_U in the mangrove estuarine system is mainly regulated by phytoplankton biomass (P), which follows Michaelis-Menten kinetics, P depends on photosynthesis ($pmax_{VT} \times L_E$), ks_V , P and N, (Eq. 5.). Photosynthesis is function of temperature (T), maximum growth rate of phytoplankton ($pmax_{VT}$) and light effect on photosynthesis (L_E) [24], (Eq. 10.). L_E depends on surface solar irradiance effect (I) and maximum light intensity (I_{opt}), (Eq. 11). I is function of is, Ec , d_1 and self shading of phytoplankton due to its own body size (E_{xt}), (Eq. 11.). Self shading is calculated by using the equation of Radtke and Straskraba [25], (Eq. 12.). The equation is based on the physical laws of particle sizes where, V_p is the average body volume of phytoplankton.

$$\frac{dZ}{dt} = gr_Z + grz_D - m_Z - r_Z - o_{CF} \qquad (13)$$

Where,

$$grz_D = Z \times grd_Z \qquad (14)$$

$$m_Z = Z \times \left[mr_Z + e_Z\right] \qquad (15)$$

$$r_Z = Z \times rr_Z \qquad (16)$$

$$o_{CF} = or_{CF} \times Z \qquad (17)$$

Maximum grazing of Z (Eq.14.) on P is dependent on maximum growth rate of Z (grw_Z), assimilation rate of Z (ar_Z) for P and half saturation constant (kz_{VZ}) of Z grazing (Eq.8). This phenomenon follows Michaelis-Menten kinetics. Another important factor which adds biomass to Z is grazing of Z on D (Eq.14.) which is governed by the rate parameter grd_Z. Zooplankton *biomass* is also dependent on loss due to mortality and excretion of Z regulated by the rate parameters mr_Z and e_Z respectively of Z (Eq.15.). Respiratory loss of Z (Eq.16.) and predatory loss of Z by other fishes (Eq.17.), which in turn is regulated by the rate parameters mr_Z, rr_Z and or_{CF} respectively.

$$\frac{dD}{dt} = i_D + m_P + m_Z + m_{DF} - o_D - r_D \qquad (18)$$

Where,

$$i_D = ir_D \times pon(graphtime) \tag{19}$$

$$m_Z = mr_Z \times Z \tag{20}$$

$$m_{DF} = mr_{DF} \tag{21}$$

$$o_D = (or_D + s_D) \times D \tag{22}$$

Input of detritus *(i_D)* chiefly comes from mangrove litter degradation as particulate organic nitrogen *(PON)* governing by the rate parameter ir_D (Eq. 19). Input of PON into the system has been shown as graph-time function. Mortality of P, Z and DF also contribute to the D compartment and are governed by the rate parameters mr_P, mr_Z and mr_{DF} (Eq.9., 20. and 21.). A fraction of P mortality is due to grazing of Z on P which is regulated by grw_Z, ks_{VZ} (Eq.8.). Fraction of detritus which goes out from the system are due to tidal effect represented by o_D governing by the rate parameter or_D and settling *(s_D)* of D also denotes a fractional outflow governing by the rate parameter s_D (Eq.22).

$$\frac{dDF}{dt} = gz_D - u_{CF} - r_{DF} - m_{DF} - e_{DF} \tag{23}$$

$$where,$$

$$gz_D = \frac{(gr_{DF} \times ge_{DF} \times DF \times D)}{(D + k_{DF})} \tag{24}$$

$$u_{CF} = ur_{CF} \times DF \tag{25}$$

$$r_{DF} = rr_{DF} \times DF \tag{26}$$

$$m_{DF} = mr_{DF} \times DF \tag{27}$$

$$h_{DF} = hr_{DF} \times DF \tag{28}$$

In Sundarban mangrove ecosystem, *DF* dynamics depends upon availability of *PON* coming from mangrove litter decomposition and its utilization or maximum grazing of DF on D (*gz_D)* governed by the rate parameters gr_{DF}, ge^{DF} and k_{DF} (Eq.24.), the population size is controlled by predation of *DF* by *CF*, (Eq.25.)*,* mortality of DF (m_{DF}), respiration (r_{DF}), excretion (e^{DF}) and harvest (h_{DF}). r_{DF}, m_{DF} and h_{DF} are regulated by rr_{DF} , mr_{DF} and hr_{DF} respectively (Eq. 26., 27. and 28).

3.3. Parameterization, calibration and validation of the model

Realistic parameters are obtained from current field study and also from the previous works by different authors [7-9] [26]. Due to unavailability of some parameter values in real field, secondary data source is used to calibrate the parameters. They have been calibrated from the works of similar type of system throughout the world by different authors [27-34]. During calibration, each parameter is modified and best fit is selected after analyzing the results of each run. First year data set is used for calibration followed by validation using second year data set. Parameters along with their descriptions and values which have been used for the standard run of the model are given in Table 2. The monthly average values of all the state variables of first year and second year are being used for calibration and validation of the model respectively. Calibration is done by adjusting selected parameters in the model to obtain a best fit between the model calculations and the field data collected during first year (March 2005 to February 2006). Validation of the model is performed using data collected during second year (March 2006 to February 2007). The model was run on STELLA 6.0 computer software (High Performance Systems Inc.) and simulated for the period of 365 days to observe the dynamic behaviour of all the state variables of detritus food web.

Table 2. Parameter symbols, their description and values used in the model run

Parameters	Description	Value	Unit
ir	Nutrient input rate	0.02	day-^{1}
or_N	Output rate of nutrient	0.10	day-^{1}
$Iopt$	Optimum surface radiation for Photosynthesis	680	cal cm^{-2} day^{-1}
d_1	Depth of water	4	m
is	surface solar radiation	0.41	cal. cm $^{-2}$d^{-1}
$Pmax$	Maximum phytoplankton growth activity	2.10	day-^{1}
mr_P	Phytoplankton specific mortality rate	0.08	day-^{1}
mr_Z	Zooplankton specific mortality rate	0.01	day-^{1}
ar_Z	Zooplankton specific assimilation rate	0.75	dimension less
grw_Z	Grazing rate of zooplankton on phytoplankton	2.5	day-^{1}
grd_Z	Grazing rate of zooplankton on Detritus	0.02	day-^{1}
rr_Z	Zooplankton specific respiration rate	0.001	day-^{1}
ks_{vZ}	Half saturation constant of zooplankton grazing	0.80	day-^{1}
ks_V	Half saturation constant of phytoplankton for nutrient uptake	3.2	dimentionless
k_{DF}	Half saturation constant for detritus Uptake by DF	0.05	day^{-1}
s_D	Detrital settling rate	0.05	day-^{1}
mr_{DF}	DF specific mortality rate	0.005	day-^{1}
rr_{DF}	DF specific respiration rate	0.02	day-^{1}
gr_{DF}	Detritus uptake rate of DF	3.0	day-^{1}
ge_{DF}	Detritus assimilation rate of DF	0.05	dimensionless
rr	Remineralization rate	0.50	day-^{1}
ir_D	Input rate of detritus	0.40	day-^{1}
or_D	Output rate of detritus	0.05	day-^{1}
V_p	Average body volume of phytoplankton	1.60	log($10^{1.6}$) µm^{3}
E_c	Extinction coefficient of water	0.2	m^{-1}
u_{CF}	Uptake rate of DF by other fishes	0.04	day^{-1}

3.4. Sensitivity analysis

Sensitivity analysis attempts to provide a measure of the sensitivity of either parameter, forcing functions etc. of greatest interest in the model. It is usually carried out by changing the parameter values within some limits and observing the corresponding response on the important state variable. Sensitivity analyses of these input parameters are conducted by varying one parameter at a time while keeping the other parameters constant. The relative change in parameter is chosen on basis of existing knowledge of the certainty of the parameters. Here in this model, each parameter is chosen to change at ± 10% the corresponding changes in the state variables are recorded (x). Thus, the sensitivity, S, of a parameter, P, is defined as follows [35]:

$$S = [\partial x / x] / [\partial P / P] \qquad (29)$$

where, S = Sensitivity, x = state variable (here N, P, Z, D and DF), p= parameter, ∂x and ∂p are change of initial values of state variables, parameters or forcing functions respectively at $\pm 10\%$ level.

4. Results

Simulation result shows that all living compartments contribute significant amount of detritus to the detritus compartment besides detritus input from outside. Comparing the ratio of biomass and its contribution to detritus, phytoplankton add maximum followed by zooplankton and detritivorous fish. Similarly contribution to the detritus pool is recorded significant in case of zooplankton and detritivorous fish. This result is consistent with the previous study by Ray et al. [23].

In Hooghly-Matla estuarine system high value of dissolved inorganic nitrogen (N) is observed in monsoon and lower in premonsoon and moderate value is found in postmonsoon which is consistent with field observations (fig.2.). rr and T governs the mineralization process of detritus (D) which adds to the N compartment and Up determines the availability of DIN in the estuary acting as an outflow of N. Higher values of D are observed during postmonsoon, significantly highest in February, whereas, lower values during monsoon and premonsoon, lowest in the month of May (fig.3.). The phytoplankton biomass in the estuarine system is balanced by uptake of nutrients, grazing by zooplankton and other processes mentioned earlier. Higher values of P are observed during postmonsoon lower values during premonsoon and moderate values are noted during monsoon (Fig.4.).

Zooplankton population shows a distinct seasonal variation in their abundance throughout the study period. Higher values are observed during premonsoon and lower values noticed during monsoon and moderate values are found in postmonsoon months. The simulated and observed values are shown in (Fig.5.). The production of *DF* in Hooghly-Matla estuarine system are estimated by the model (Fig.6.). The corresponding values of fish weight (in tons) for every month are represented in Fig. 12. The maximum biomass of *DF* is observed during late monsoon lower values are noted during premonsoon and moderate values are observed during postmonsoon.

Sensitivity analysis has been performed on different parameters (Table 3.). Detritus and nutrient input rates (ir_D and ir respectively) are found to be two most important sensitive parameters for controlling the overall productivity of the system. Detritus input rate (ir_D) shows sensitiveness to detritivorous fish growth. Results of model simulation are shown below graphically.

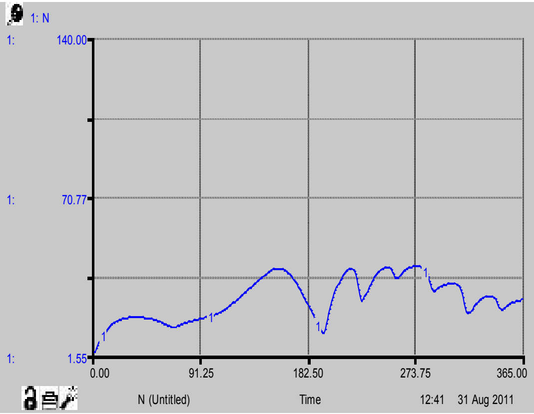

Fig.3. Model simulation result of N.

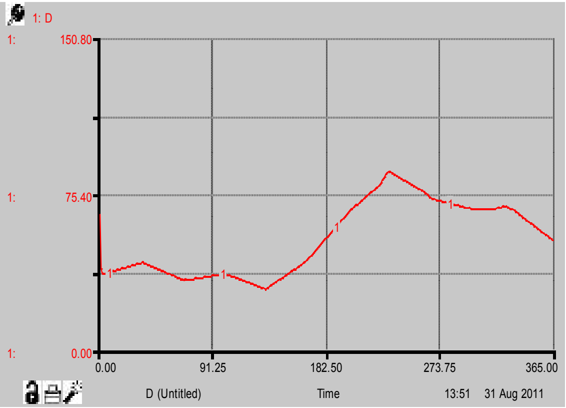

Fig. 4. Model simulation result of and D

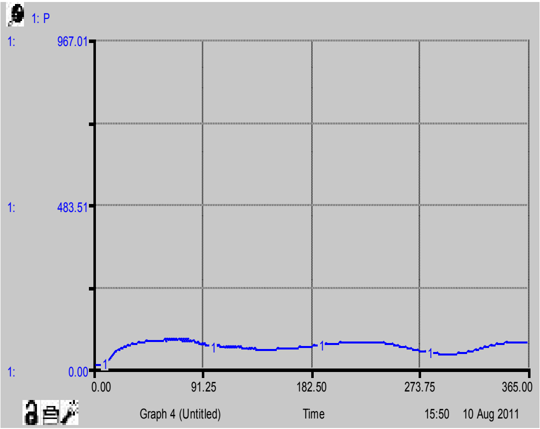

Fig.5. Model simulation result of P.

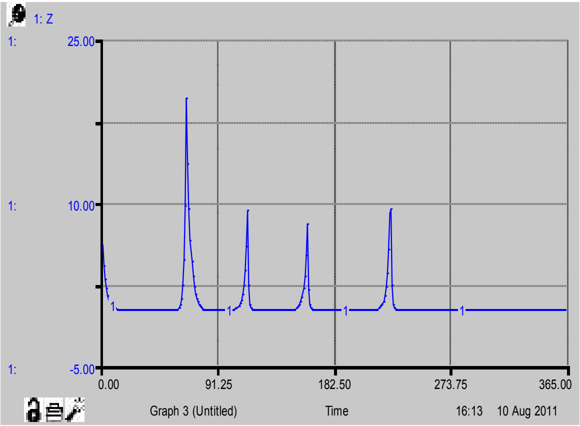

Fig.6. Model simulation result of Z

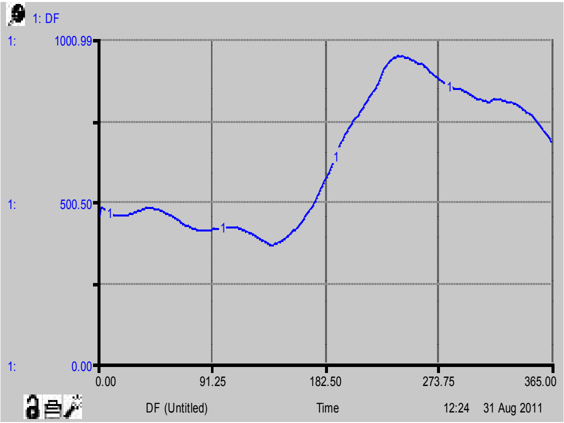

Fig.7. Model simulation result of DF.

5. Discussion

Examination of the behaviour of this NPZDDF model helps to understand the influencing factors for the dynamics of this system. This work is an attempt to simulate the earlier theoretical work of Ray et al. 2001 applying realistic field data [2]. A detritivorous fish compartment has been added to simulate the detritus compartment more realistically.

This model shows detritivorous fish compete with phytoplankton for available resource indirectly but overall steady state of the system is dependent upon the predation of detritivorous fishes by carnivorous fishes. Detritivorous fishes are even known to enhance the growth of other carnivorous fishes in the mangrove estuarine system [2]. Sundarban mangrove ecosystem is well known for its high fish production which seems to be possible due to the coexistence of detritivorous and other predatory fishes. Detritivorous fishes in turn are supported by high input of detritus and nutrients from mangrove ecosystem to the adjacent estuary.

During monsoon high nutrient availability, both organic and inorganic, brings about dynamic change of food chains [36] by inducing utilization of benthic organic detritus by detritivorous fish and then releasing a portion of the consumed detritus as excretory material which may provide an important source of nutrients to stimulate phytoplankton growth. Rich growth of phytoplankton during postmonsoon due to organic load and washed out materials which are rich in nutrients, leads to subsequent rise in zooplankton population. Assemblage of Z and N in this region induces crowding of carnivorous fishes and other fishes to this region from other parts of estuary. The above findings are in agreement with Ray and Straskraba [23]. They concluded that this group of fish had no impact on primary production but played a major role in total fish production.

Model results show a common parameter (for both DF and CF) u_{CF}, predation rate of carnivorous fish feeding on detritivorous fish is highly sensitive to DF and Z. Slight increase in the value of this parameter causes carnivorous fish biomass to increase as a result zooplankton population is almost become extinct from the system. Similarly, decrease in u_{CF} value causes detritivorous fish biomass to increase significantly. Therefore, it can be said that, u_{CF} plays a critical role in determining the balance not only between two groups of fishes but also population size of P and Z

According to Kang and Xiang [36], detritus plays a role of nutrients reservoir, affects the trophic structure and dynamics of communities, and supports a greater diversity of species and longer food chains. Mandal et al. [37] described the *PON* content of Hooghly-Matla estuarine system during monsoon is the organic nitrogen content of the sediment soil is about more than 90%. During monsoon period, the mangroves are more prone to tidal influence, which promotes the removal of both organic and inorganic nutrient to the adjacent estuarine water. The model results illustrate that higher biomass of *DF* are observed during late monsoon period probably due to availability of high food resource. Detritivorous fish are quite efficient in separating organic particles from sediments. D'Avanzo and Valiela [38] commented that nitrogen content is key feature of detrital diets. They found that detritivorous fishes that select detritus with high amino acid content in the form of *DON,* grows rapidly in contrast to those that do not. Observations of Mandal et al. [37] showed higher *DON* content during monsoon; these conditions promote rapid fish growth. Yossa and Lima [39] advocated that higher protein content in the detritus during monsoon is caused by allocthonous input. The present finding is consistent with the above statement

Detritivorous fish population declines in very little even when the harvest rates are changed significantly. This indicates that detritus based food chain is more stable and important in comparison to the grazing food in the mangrove estuary and to some extent resistant to anthropogenic perturbations. Fishes of *Liza* group among the grey mullets are the most suitable for culture in brackish water fisheries because of their intimate association with the mangroves [1]. The other tropical mullets species belonging to the genera *Liza*, *Mugil* and *Rhinomugil* are also suitable for culture in the mangrove associated areas of Sundarban. The present account deals with impact of mangroves and formation of detritus in the estuarine system.

6. Conclusions

The basic conclusions from this research are consistent with well established ecological principles. From this model, it can be concluded that the litter biomass of the mangrove forest played a major role in maintaining detritus food chain as well as grazing food chain. Higher production may lead to higher nutrient availability to the phytoplankton and zooplankton. Detritus fish population thrives due to ample food resource in Hooghly-Matla estuarine system which can affect other fish population significantly [23]. This modelling study will contribute significantly to an understanding of mangrove ecosystem in general. It will also help to understand the importance of mangrove detritus food web dynamics for sustaining the whole ecosystem as well. The present work also has emphasized controlling role of detritus in the biomass production of other compartments and in turn the effects on the detritus as well as grazing food chains of the adjacent estuarine region. For mathematical complexity all parameters, which govern the detritus dynamics are not incorporated in the present model. Therefore, it cannot be claimed to have presented an absolute realistic picture of the role of detritivorous fishes on mangrove soil organic nitrogen dynamics of sundarban mangrove forest ecosystem. In future, the present model will help to develop a complete and more realistic model of detritus and detritivorous fish by incorporating all important parameters which requires further experimental works. All survey works and experimental studies are carried out in reclaimed part of Sundarban, if these works are extended to pristine part of Sundarban, a comparative account of the role of detritus and detritivorous fish could be obtained.

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