A Model of Ecosystem Stability and Development of Ekperiama, Niger Delta

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Abstract: An Ecopath model was applied to analyse the stability and development of the aquatic ecosystem in Ekperiama in the Niger Delta. A total of 23 functional groups were used to determine the key features of the aquatic system. Indicators of ecosystem stability and development analysed were: Ominivory index 0.17**,** connectance index 0.23, path length 2.6**,** relatively low biomass to throughput ratio 0.0013, acendency 56%, Finn's cycling index 3.68, low primary production to biomass ratio 23.1 and ratio of total primary production to total respiration 0.46. These indicators are consistent with a system where moderate (or tolerable) exploitation generally drives back development to earlier stages suggesting a system in its developmental stage.

Keywords: Development, Ecosystem, Indicators, Stability

1. INTRODUCTION

Niger Delta is one of the most important deltas and third largest drainage basin in Africa. The region is unarguably the largest geomorphic wetland in West Africa [1], well-endowed with the highest concentrations of biodiversity in the world [2], abundant in crude oil, gas, water, useful vegetation and human resources. Richness of the delta has encouraged uncontrolled drainage of natural resources in the environment directly or indirectly through various human activities.

These human activities on the environment are due to unabated pollution which radiates directly from the different oil, petrochemical industries and sand drilling in the region. Crude oil exploitation activities causes widespread ecological disturbances including pollution of farmlands by gas flaring and refinery effluent, destruction of natural terrains for construction (industries, infrastructures, and other related physical installations) and explosions from seismic surveys. There are other serious environmental challenges which relate to massive waste generation by different industries, coastal erosion and river siltation. Aggravated coastal degradation caused by careless mining of useful sands and river dredging for the purpose of infrastructural construction leads to direct extermination of abundant wildlife of fauna and flora [3].

Understanding how ecosystems react and recover from perturbations is a fundamental goal of ecology [4] which could be predicted by using ecosystem modelling approach. The importance of ecological forecasting via models in the development of regulatory policy is well recognized [5] in assisting resource managers and scientists to determine the effects of anthropogenic changes on ecosystems. Odum's theory of ecosystem structure and function defined characteristics that explain the maturity, stability, and resilience of an ecosystem [6].

Stability is the ability of a system to return to an equilibrium state after a temporary disturbance [7] which is viewed as one property of matured ecosystem that tends to increase in size and diversity over time within the constraints of available resources [6]. This paper aims to describe some indicators of ecosystem stability and development of Ekperiama using the Ecopath software pertaining to some characteristics that indicates system resistance and resilience to stress.

2. METHODS

2.1. Study area

Ekperiama (formally known as Ekperikiri) is a passage from Okoroama in Nembe Local Government Area, to Ogbia town in Ogbia Local Government Area. The study area (Figure 1) is located on latitude 4^0 38’ 19”N and longitude $6^0$17’46” E of the equator. The creek is tidal and it is characterized by both estuarine and freshwater macrophytes that includes; *Rhizophoraracemosa* (Red mangrove) and *Raphiahookeri*, *Eicchornia crassipes* (water hyacinth), *Nymphae lotus* (water lily) and Pistia *stratiotes* (water lettuce).

Figure 1: map of Study area

2.2. Modelling approach

Ecopath with Ecosim (EwE) is a food-web modeling facility that could be used to build trophic static mass-balanced snapshots (Ecopath) and to create temporal dynamics (Ecosim) of an ecosystem. The model was derived from the original master equation proposed by [8] further developed and extended by [9] and [10]. It estimates biomass and consumption of various elements of an aquatic ecosystem based on the theory for analysis of flows among elements of an ecosystem [11].

A basic requirement in these models is that input to each group is equal to output (equilibrium conditions). Series of biomass budget equations are then determined for each group as:

Production– all predation on each grouping – non-predatory mortality – all exports = 0 (1)

The resulting equations are transformed into simultaneous equations following the formula:

$$B_i * (P/B)_i * EE_i - \sum B_j * (Q/B)_j * DC_{ji} - Y_i - E_i - BA_i = 0 \quad (2)$$

where: B_i is the biomass of (i), P/B_i is the production/biomass ratio of (i) that is equal to total mortality rate (Z_i), EE_i –ecotrophic efficiency, i.e. fraction of production of (i) that is consumed, B_j is the biomass of predators, Q/B_j is food consumption per unit of biomass for consumer j and DC_{ji} is the fraction of i in the diet of j, Y_i is the yield of (i) or its catch in weight, E_i the net migration rate (emigration – immigration) and BA_i is the biomass accumulation rate for (i).

Fish samples randomly collected from landings of artisanal fishers were analysed for biomass, P/B and Q/B. Biomass (B; metric tons/km^2) was estimated from single-species stock assessments, by dividing observed catches by estimated fishing mortality (B = C/F). The production rate (P/B) or instantaneous total mortality (Z) was calculated by using empirical equations for mortality ([12]; [13]). Estimates of consumption (Q) were derived empirically using equations that incorporate data on morphometrics, ambient water temperature, and diet ([14]; [15]). Primary production was estimated from the light and dark bottle method [16]. Zooplankton biomass was estimated from data collected during this investigation [17] and Q/B for zooplankton was estimated based on assumed gross food conversion efficiency (P/Q) of 0.2 [18]. Biomass and production estimates for the phytoplankton were obtained from samples collected and converted to the appropriate units by applying the conversion 1mgC phytoplankton [19]. Detritus biomass (D) was estimated by using empirical expressions of the Ecopath model [20].

A diet matrix was assembled using preferentially local literature on stomach content analyses, completed with information obtained from FishBase. Diets were adjusted until the Ecopath-generated ecotrophic efficiency of each group was between 0 and 1, where 0 indicates that the group is not being consumed and 1 indicates the group is being heavily preyed upon [21]. Credibility in the balanced model was rechecked [22] using the PREBAL approach [23]. Model pedigree which describes the origin and quality calculated was used to analyse the hypothesis that there is sufficient data to construct an ecosystem model of the study area and compared with reported range by [24].

2.3. Network analysis

The ecosystem stability and degree of system maturity were analyzed by various system metrics and network flow indices [6] after a preliminary run of the model. Total system throughput (TST) was calculated as the sum of all four energy flow such as total consumption (TC), total exports (TEX), total flows into detritus (TDET) and total respiration (TR) flows. Total production (TP) was the sum of the primary and secondary production within the ecosystem. Total net primary production (NPP) reflects the ecosystem bioenergetics and is the sum of net production by all the producers in the ecosystem. Total primary production/total respiration ratio (TPP/TR) is an indicator of the maturity of the ecosystem. A TPP/TR close to 1 suggests the ecosystem has reached a mature stage and a value greater than 1 indicates an early stage of development, while value less than 1 suggest a case of organic pollution [6]. Total respiration to total biomass ratio (TPP/TB), predatory index, Finn's mean path length (FML) and Finn's cycling index (FCI) indicated the degree of recycling in the ecosystem ([9]; [10]; [25]). Ascendency describes the growth and development of a system and is higher in mature and complex ecosystems. Transfer efficiency (TE) indicates efficiency of an ecosystem at tranferring energy. System Omnivory index close to 1 indicates a mature and stable system.

3. RESULTS AND DISCUSSION

Parameters for the balanced Ecopath model of Ekperiama are presented in Table1. Pedigree index was estimated to be 0.51. Ecotrophic efficiency of all groups was above 0.5 except for the plankton and detritus suggesting poor utilization of lower trophic levels by the whole ecosystem. Low EE value zooplankton might be due to wrong estimation of the biomass. Catfish had the highest trophic level of 3.878 as shown in figure 2.

Transfer efficiency obtained in this study (Table 2) shows that the system is poor at transferring energy up the food chain, since it is much lower than the value of 10% often assumed to exist in ecosystems [26] and has been shown to be a good estimate of the average transfer efficiency in aquatic ecosystems [27]. Hence, 7.3% transfer efficiency suggests instability in the ecosystem.

Table 1: Basic parameter for the groups considered in the Ecopath model of Ogbia creek in Niger Delta what is computed by the model is in italics

Group name	**TL**	**B (t/km^2)**	**P/B (yr^{-1})**	**Q/ B (yr^{-1})**	**EE**	**P/Q**
Red snapper	*3.762*	0.310	1.312	3.400	*0.957*	*0.386*
Hair tail	*3.677*	0.124	2.180	5.700	*0.939*	*0.382*
Shinny nose	*3.747*	0.193	1.190	6.800	*0.807*	*0.175*
Catfish	*3.878*	0.322	1.870	25.70	*0.879*	*0.073*
Snout fish	*3.318*	0.366	1.120	15.60	*0.633*	*0.072*
Citharinid	*2.830*	0.732	0.820	9.00	*0.599*	*0.091*
Mud catfish	*3.391*	0.562	0.783	1.161	*0.996*	*0.486*
Heterotis	*2.820*	0.133	0.933	5.20	*0.900*	*0.179*
Tilapias	*2.952*	0.137	1.680	13.20	*0.863*	*0.127*
Bonga	*2.880*	0.256	1.640	18.90	*0.767*	*0.087*
Sardines	*3.100*	0.267	1.500	9.80	*0.778*	*0.153*
Shad	*3.244*	0.168	3.160	11.20	*0.833*	*0.282*
Sungu	*3.436*	0.113	2.750	25.70	*0.932*	*0.107*
Alestes	*2.500*	0.223	2.060	6.44	*0.778*	*0.320*
Mullet	*2.500*	0.152	3.750	18.40	*0.848*	*0.204*
Ray	*3.124*	0.263	1.180	9.00	*0787*	*0.131*
Crabs	*3.068*	0.079	5.460	13.00	*0.921*	*0.420*
Big Shrimps	*2.400*	0.064	8.230	30.00	*0.984*	*0.274*
Small Shrimps	*2.400*	0.035	2.50	18.00	*0.577*	*0.139*
Clams	*2.500*	0.075	3.740	20.00	*0.924*	*0.187*
Perwinkles	*2.500*	0.078	5.24	20.00	*0.946*	*0.262*
Zoo-Plankton	*2.000*	15.00	-	377.00	*0.290*	*0.111*
Phy-to-plankton	*1.000*	29.40	384.86	400.00	*0.400*	*0.344*
Detritus	*1.000*	80.70	-	-	*0.272*	-

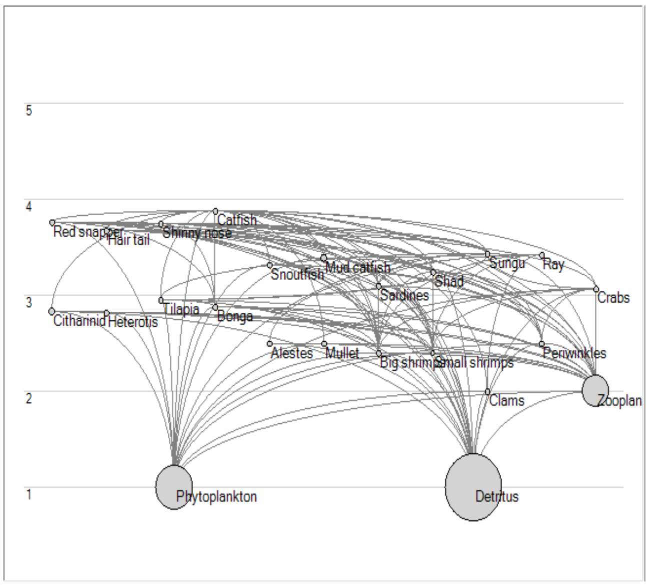

Figure 2. Flow diagram of Ekperiama in 2014

The system characteristics and degree of ecosystem maturity shown in Table 2 includes: consumption, production, flows to detritus, system throughput, export and respiratory flows. TPP/TR was 0.46 t/km^2/year, TB/TST was 0.0013. and TPP/TB was estimated as 23.1. Connectance Index (CI) was 0.23 and System Omnivory Index (SOI) was 0.17 both reflects the complexity of the relationships among internal systems.

Table 2. Summary statistics and network flow in dices for Ekperiama, Ogbia creek (flows in t per km^2 per year)

Parameters	Values	Unit
Sum of all consumption (TC)	17467.53	t/km^2/year
Sum of all exports (TEX)	7599.786	t/km^2/year
Sum of all respiratory flows (TR)	2438.833	t/km^2/year
Sum of all flows into detritus (TFD)	10427.57	t/km^2/year
Total system throughput (TST)	37933.72	t/km^2/year
Sum of all production (TP)	11535.19	t/km^2/year
Total biomass/total throughput (TB/TST)	0.0013	
Net system production (NSP)	2438.833	
Calculated total primary production (TPP)	1135.00	
Total primary production/total respiration(TPP/TR)	0.46	
Total biomass (excluding detritus)	49.052	
Total primary production/Total Biomass (TPP/TB)	23.1	
Total biomass/ Total primary production (TB/TPP)	0.043	
Gross efficiency catch/pp	0.004	Year^{-1}
Mean trophic level of the catch	2.56	
Connectance Index	0.23	
System Omnivory Index	0.17	
Finn' cycling index (%)	3.68	
Predatory index (%)	0.02	
Mean path length	2.61	
System transfer efficiency (%)	7.3	
Ascendency (%)	56	
Overhead (%)	44	

Another system descriptor is the path length; which is the average number of groups that a flow passes through [28], and which is also expected to increase with system maturity and stress [29]. As suggested by [29] greater amount of material is cycled through longer path lengths (>2) leading to stress on the system. The estimated path length of 2.61, suggest a system that is stressed. [30] compared 6 marine ecosystems worldwide using the results from net- work analysis. One of their conclusions is contrary to current view. The aggregate amount of cycling is not necessarily an indication of maturity but rather of stress because proportion of cycling increases in more stressed systems [31]. Low Finn's and predatory indices indicates the system is poor at cycling nutrients which could lead to a reduction in biodiversity.

Estimate of the average mutual information in the system is the ascendency ([31]; [32]). It is a measure of the network's potential for competitive advantage over other network configurations [31]. The upper limit for the ascendancy is the development capacity and the difference between them is the system overhead, which reflects the system's strength in reserve to meet unexpected perturbations [31].The relatively high system ascendency(56%) and overhead (44%) suggest that this system has a fair level of development, is resilient and has strength in reserve [31].

High Gross efficiency (GE) of 0.004 as compared to the global average 0.0002 as suggest by [21] indicates a developing system. Low Ominivory index indicates simplification of the food web and consequently a system that is not fully mature and stable. The low value of the omnivory index indicates that most functional groups exhibit a certain degree of diet specialisation. Other derived parameters indicative of an ecosystem under stress or in developmental stage and therefore inconsistent with steady-state (mature) conditions [33] include a relatively low biomass to throughput ratio (0.0013) and high respiration to biomass ratio (>1). Low TPP/TR (< 1) shows that the system is experiencing a certain degree of organic pollution [6] which might be due to oil exploitation and exploration activities in the Niger Delta [34]. These indicators are consistent with a system where moderate (or tolerable) exploitation generally drives back development to earlier stages of development [33].

5. CONCLUSION

Network analysis of system development and stability derived parameters indicates an ecosystem under stress, and therefore inconsistent with steady-state (mature) conditions. These indicators are as follows; a path length of 2.61, relatively low biomass to throughput ratio value of 0.0013, high respiration to biomass ratio (>1) and TPP/TR (< 1).

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