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Ecopath Model of Food Web Complexity and Energy Flow in Ekperiama (Ekperikiri) Niger Delta

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Abstract: An Ecopath model was constructed using the Ecopath with Ecosim (EwE) version 6.0 software with the aim of modelling trophic interaction and energy flow in Ekperiama, Niger Delta. Data was collected from artisanal fishers operating around the area between January 2014 and December 2014. Twenty-three functional groups used in the study to determine the key features of this aquatic system were selected based on most landed species. The Four estimated trophic levels of the groups varied from 1 for detritus and phytoplankton to 3.878 for omnivorous fishes (level IV) and the remaining groups were mainly at trophic levels II and III. Results indicate all groups had ecotrophic efficiency (EE) close to 1 with mean trophic level of 2.56 and transfer efficiency 7.4. Food web structure and interaction showed dominance of the grazing pathway (phytoplankton) over the detrital pathway. The proportion of total energy flow originating from detritus was 27% while the other 73% came from primary producers indicating superiority of phytoplankton in the web. Ominivory index was 0.17 and connectance index was 0.23. The simulated results obtained from the mass-balance model can provide some useful information for understanding the aquatic population that could be helpful for biodiversity preservation and monitoring.
Keywords: Ecopath, Food Web, Energy Flow, Ekperiama (Ekperikiri) Niger Delta.

INTRODUCTION

The flow of energy upwards through the food -web is the paramount structure of any ecosystem. Apart from light and nutrients, composition of the food-web regulates the productivity of the ecosystem [1] and resilience of the food web depending on how energy flows through the system in ecosystem dominated by variation [2].

Food webs and the pathways of energy flow within the food web are temporally variable in estuaries due to changes in river flow, water temperature, water column stratification, salinity gradients, seasonal variation in biota, and ontogenetic changes in feeding strategies of constituent species.

Species richness and abundance have been observed to have considerable effects on trophic structure [3] and system productivity [4]. In the same vein, species extinction due to exposure to stress may affect system functioning and lowering its resistance against environmental stress [5, 6]. Productivity and cycling of nutrient depend on the diversity of functional traits of biota in the system; hence it is important to understand how interaction strength patterns influence both structure and dynamics in food webs as it is crucial in elucidating several obstacles to production [7].

In order to describe the complexity and flow of energy through the food web of a relatively productive exploited ecosystem from the Niger Delta, an Ecopath mass-balanced model [8, 9] was constructed on trophic interraction and energy flow of Ekperiama. Ecopath can serve as a base for examining the ecological potential for biological productivity and consumption [10, 11]. Application of the model can reveal the food web structure based on food consumption relationships, the pathway of energy flows between the interdependent biotic and abiotic components and biomass evaluation [9].

MATERIALS AND METHODS

Study area

Ekperiama is a passage from Okoroama in Nembe Local Government Area, to Ogbia town in Ogbia Local Government Area. The study area (Fig 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). The creek is also subjected to pollutants from petroleum exploration and exploitation activities in the Niger Delta. This may have impacts on the ecosystem [12].

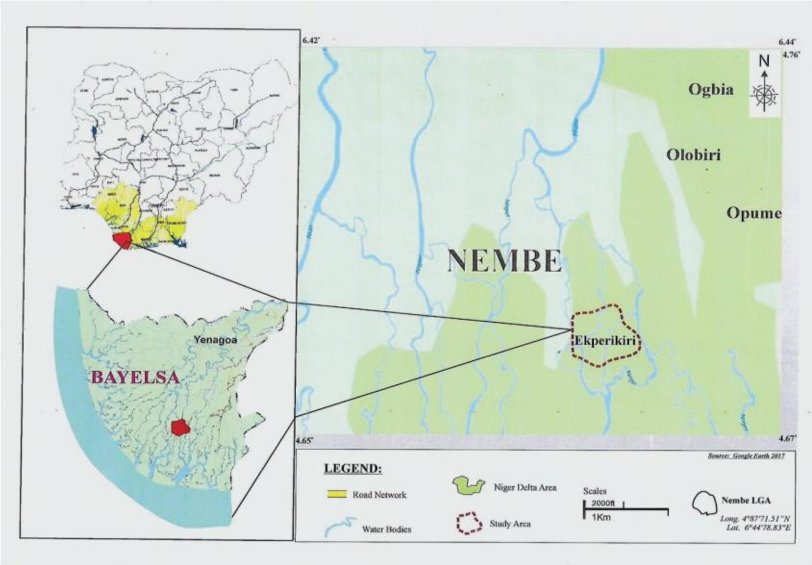

Fig-1: Map of study area

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 Polovina [13] further developed and extended by Christensen,*et al.* [14] and Pauly, *et al*. [8]. 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 [15].

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 (equation 1)

The resulting equation is transformed into simultaneous equations following the formula:

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

Where: Bi 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 [16, 17]. Estimates of consumption (Q) were derived empirically using equations that incorporate data on morphometrics, ambient water temperature, and diet [18]. Primary production was estimated from the light and dark bottle method [19]. Zooplankton biomass was estimated from data collected during this investigation [20] and Q/B for zooplankton was estimated based on assumed gross food conversion efficiency (P/Q) of 0.2 [21]. Biomass and production estimates for the phytoplankton were obtained from samples collected and converted to the appropriate units by applying the conversion 1mgC phytoplankton [22]. Detritus biomass (D) was estimated by using empirical expressions of the Ecopath model [9].

A diet matrix was assembled using preferentially local literature on stomach content analyses, completed with information obtained from FishBase database. 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 [24]. The balanced model was rechecked for credibility Heymans *et al*. [24] 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 Colléter, *et al*. [25]. After a preliminary run of the model, the food web interaction, complexity and energy flow were analysed from the parameterized ecopath model.

The mixed trophic impact (MTI) routine, developed by Ulanowicz and Puccia [26], was applied to evaluate the impact of direct and indirect interactions on the static food web model. The routine was used to assess the theoretical impacts of increased biomass of a particular group on the biomass of the other groups, assuming that the trophic structure remains the same. Connectance index and system omnivory index decribes the complexity of the food web. Connectance index is defined as the ratio of the number of actual links to the number of possible links. Feeding on detritus (by detritivores) is included in the count, but the opposite links (i.e. detritus 'feeding' on other groups) are disregarded. The system omnivory index is a measure of how the feeding interactions are distributed between trophic levels. Omnivory index is calculated for each consumer group where it measures the variance of the trophic level estimate for the group[9].

Twenty-three ecological groups were defined based on the most abundant families captured during the study period, economic importance, and abundance in the fish diets. The fish groups (Table 1) were red snapper, Hairtail, shine nose, catfishes, snout fishes, cithinirid, mud catfishes, Tilapias, Bonga, sardine, shad, sungu, alestes, mullet and rays. Invertebrate groups included are: crabs, big shrimps, small shrimps, clams, periwinkles and zooplankton. The other groups are phytoplankton and detritus.

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

Group name	Trophic Level	Biomass (t/km2)	Production/ Biomass(yr^{-1})	Consumption/ Biomass(yr^{-1})	Ecotrophic efficiency	Production/ consumption
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	1.61	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	0.787	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
Periwinkles	2.500	0.078	5.24	20.00	0.946	0.262
Zooplanktons	2.000	15	-	377.00	0.290	0.111
Phytoplankton	1.000	29.40	384.86	400.00	0.400	0.344
Detritus	1.000	80.70	-	-	0.272	-

RESULTS

The Rresults for 23 functional groups is shown in Table 1. All the estimated EE values were less than 1 and ranged from 0.272 to 0.996. The trophic level for each group was estimated according to the proportion of trophic levels utilized for all group members. As shown in figure 2, four trophic level are displayed for the different functional groups. The highest trophic level was 3.878 for omnivorous fishes. The remaining fish groups have TL ranging from 2.50 to 3.762. High-order secondary consumer groups (TL> 3.5) which are the top predators includes Catfish, Red snapper, shiny nose and

Hail tail. Low-order secondary consumers belonging to TL 3 to 3.5 are Sungu, Mud catfish, Snout fish, Shad, Ray, Sardine and Crab. High-order primary consumer groups (2.5 - TL <3) were dominated by Tilapias Citharinid, Heterotis, Bonga, Alestes, Mullet, Clams and Periwinkles. The Big shrimps, Small shrimps and Zooplankton were characterised as low-order primary consumers with 2 - TL < 2.5.

The trophic structure analysis showed that the ecological system can be divided into four main trophic levels and biomass decreased with an increase of trophic level. Most of the biomass and flows were confined to trophic levels II and III. The balanced network flow diagram (Fig 2) shows the correlation between biomass, energy flow, consumption and the range of biomass flows between functional groups and tropic levels. Some trophic energy was utilized in the respiration at each trophic level. Two primary energy pathways were identified. One was the grazing food chain, including phytoplankton, zooplankton and piscivorous fishes. The other one was the detritus food chain, including the trophic interactions between recycling organic matter and predators on detritus. Flows from phytoplanktons were comparable in magnitude to those from detritus and amounted to 73% of total flow.

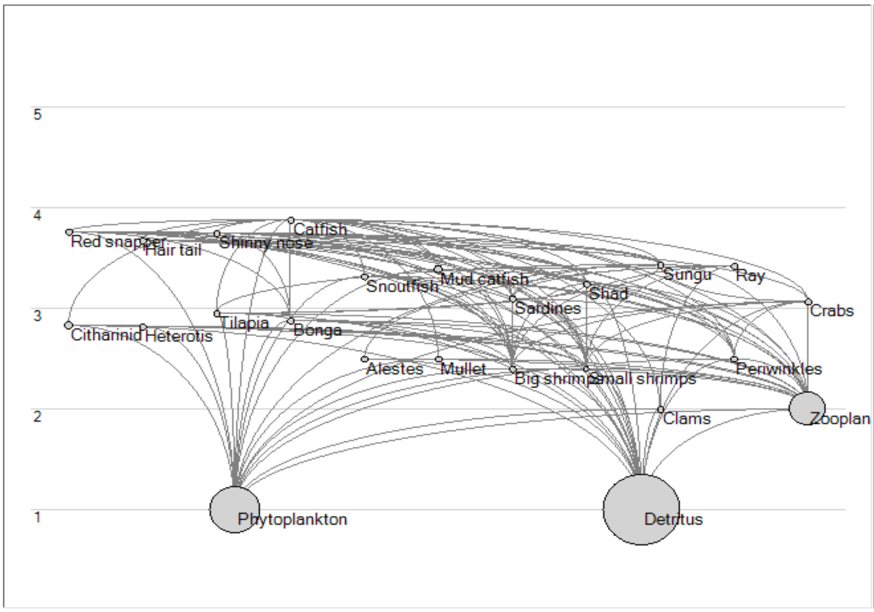

Fig-2: Mixed trophic impact for Ekperiama in 2014

The transfer efficiency was lowest at trophic level II, for primary consumers. It was found that 27% of total energy flow originated from detritus and the rest was from primary producers. The average transfer efficiencies between different trophic levels were 7.4% from primary producers and 7.3% from detritus. Total transfer effciency was also 7.4% (Table 2).

Table-2: Transfer efficiency

Transfer efficiency				
Source/ Trophic	II	III	IV	V
Producer				
Detritus	0.4	43.8	21.9	24.3
All flows	0.4	43.8	21.9	24.3
Proportion of total flow originating from detritus; 1.00				
Tranfer efficiency (calculated as geometric mean for TL II-IV)				
Tranfer efficiency (calculated as geometric mean for TL II-IV)				
From detritus: 7.4%				
Total: 7.4%				

Mixed Trophic Impact (MTI) analysis (Figure3) revealed the direct and indirect impact of an increase/decrease in biomass of an impacting group catch on an impacted group. The MTI indices ranged from 0.315, representing positive effect of big shrimps on Hairtail, to −0.377, indicating a strong negative effect of Clams zooplankton. The analyses showed Big shrimp having the stronger and positive influence in the ecosystem. All other groups have negative impacts on themselves.

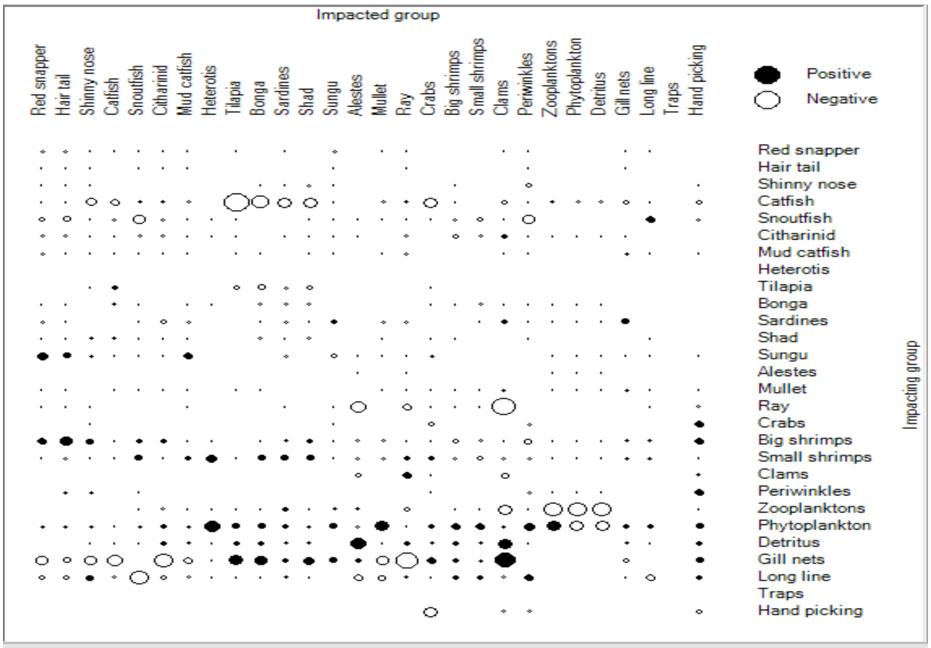

Fig-3: Mix Trophic Impact of Ekperiama

Connectance Index (CI) was 0.23 and System Omnivory Index (SOI) was 0.17. Both reflect the complexity of the relationships among internal systems.

DISCUSSION

The Model highlighted information about the system with pedigree of 0.51, indicate that there is sufficient data to construct an ecosystem model when compared with the mean 0.47 by Colléter, *et al.* [25] and is reliable as it meets Heymans *et al.* [24] guidelines for creating and using the Ecopath with Ecosim model. Hence, the model was built with source data of an overall reasonable quality**.** Biomass decreased with an increase in TL. This conforms to the rules of biomass distribution pyramid. All consumers have EE closer to 1 indicating full utilization of the animals except the planktons, which could be due to wrong estimation of the biomass (Table 1). The low EE of detritus, phytoplankton and zooplankton indicates a poor use of the lower trophic levels by the whole ecosystem, with the rest going toward detritus or exported out of the system.

The modelled ecosystem indicates four trophic levels with catfish having the highest TL 3.878. Typically, only top predators reach trophic level greater than 3.5 so this group was defined as high-order secondary consumer. At each trophic level, some of the energy is used in respiration and is lost from the ecosystem in the form of heat. This means that there will be less energy available at each successive level in the food chain and in most cases, so does biomass [27]. As shown in figure 2, the largest trophic value is 3.878. It is an advantage, as suggested by Odum [28] that the shorter the food chain the greater the available food energy. The food web and flow diagram shows the complex structure of the ecosystem (Figure 2). Mean trophic level for the total catch of the study area was estimated as 2.56. This is due to the relative importance of species belonging to intermediate trophic levels since typical chain reaction to fishing is generally well captured by TL-based indicators, which would decrease under fishing pressure.

Transfer efficiency obtained in this study (Table 2) shows that the system is poor at transferring energy up the food chain, and may indicate instability in the ecosystem since it is much lower than the value of 10% that is often assumed to exist in ecosystems [29], and which was shown to be a good estimate of the average transfer efficiency in aquatic ecosystems [28].

The study indicates the dominance of the grazing pathway (phytoplankton) over the detrital pathway. Only 27% of the total throughput originates from detritus, while the rest is derived primarily from phytoplankton production. This suggests that the system is essentially phytoplankton-based and immature (stress) because as a systems mature they become more dependent on detritivory than herbivory [28]. Ominivory index (0.17) 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. Another descriptor of system complexity such as the connectance index (0.23) is low indicating a system that is not mature.

Mixed Trophic Impact (MTI) assesses the impact that change in biomass of a group will have on the biomass of the other groups in an ecosystem trophically [8]. A prey group causes a positive impact on its predators, while a direct predator has negative impact on its prey. Big shrimp had the strongest and most positive impact in the system, suggesting the group is an important resource in the ecosystem. All the functional groups except detritus have a negative impact on themselves and this may show within group competition for resources [8].

CONCLUSION

The EwE analysis indicates the dominance of the grazing pathway (phytoplankton) over the detrital pathway. High catch of TL (2) may be due to highly exploited ecosystems, and they may later become important fishing resources which would decrease under fishing pressure. The mean TL is 2.56 with the catfish having the highest TL (3.878).Values of Ecotrophic Efficiency (EE) were >0.5 for all exploited groups, except phytoplankton and zooplankton. Connectance index was 0.23, while the system omnivory index was 0.17. Mixed trophic impact routine reflects what will happen in the future if certain interaction terms are changed in the ecosystem. Since scarcity or abundance of a particular prey could lead to a shift in diet composition and biodiversity in the aquatic environment.

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