Exploratory analysis of possible management strategies in Lake Victoria fisheries (Kenyan sector) using the recent Ecosim software

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Abstract

New developments in Ecosim, which is part of the well known Ecopath software have allowed the user to evaluate the effects of a range of possible fisheries management strategies for the Lake Victoria fisheries. The software is also used in this report to explore the fisheries and fish community of Lake Victoria. In particular, management strategies are explored aimed at achieving specified socio-economic objectives, including maximising the economic value of the ecosystem and maximising employment by altering the pattern of fishing effort by the fishing fleets comprising the Lake Victoria fishery. Further, the same approach was used to consider optimal management strategies from an ecological perspective.

Introduction

Lake Victoria, East Africa has undergone dramatic changes in the structure of its ecosystem since the introduction of Nile perch, *Lates niloticus* (L.) more than thirty years ago (Wandera & Wanink, 1995). The initial multispecies stock of the lake has been replaced by three commercially important species: two totally demersal exotics, the Nile perch and Nile tilapia, *Oreochromis niloticus* (L.), and the native sardinelike, zooplanktivorous, pelagic cyprinid dagaa, *Rastrineobola argentea* (Pellegrin) (Bundy & Pitcher, 1995; Wilson *et al.*, 1997). The vast expansion of fish production in the lake associated with this shift has been due to the increased population of Nile perch at the end of the 1970s, at the expense of heavy predation on endemic species, resulting in the decimation of many haplochromid species (Reynolds and Greboval, 1995; Wilson et al, 1997). The small cyprinid *R. argentea* is the only indigenous species of commercial economic importance remaining and became the major prey species of the Nile perch (Ogari & Dadzie, 1988).

This present paper is the follow-up of a previous contribution (Villanueva & Moreau 2000) in which ECOPATH was used in order to describe the trophic relationships occurring in the well documented and intensively exploited Kenyan sector of the lake since the middle of the eighties. In this updated work it was possible to estimate the biomass, food consumption, trophic level and other parameters of the ecosystem, as well as to simulate with Ecosim the variations of both the biomass and actual catch from 1985-86 to 1995-96. This study also confirmed most of the ecological trends observed in the field and reported by several authors (Pitcher & Bundy, 1995; Mkumbo *et al.*, 2000).

Methods

The Ecopath IV/Ecosim Software

To model the structure of trophic interactions occurring in the ecosystem, we used ECOPATH IV (Christensen and Pauly, 1992, 1993, and 1996 ; Walters *et al.*, 1997). The file which has been utilized is the one already documented in Villanueva and Moreau (2000). The current version of the software allows:

- the simulations of the variations in catch and biomass related to changes in fishing effort over time, a routine which is already known by several users of Ecopath and was used by Villanueva and Moreau (2000);
- the fitting of time series data of biomasses;
- the evaluation of the vulnerability coefficients of each group ;
- the fishing policy search options discussed Walters *et al.* (this volume).

Designing the present Ecopath/Ecosim database

The taxonimic groups considered here are those already identified in the previous contributions by Moreau *et al.* (1993) and Villanueva and Moreau (2000). The Nile perch *L. niloticus* was divided into separate adult and juvenile components to reflect differences in their specific P/B, Q/B and feeding habits. The necessary inputs for each group (P/B, Q/B, EE and the diet composition) have been documented in Villanueva and Moreau (2000).

The segregation of *Lates niloticus* group into juveniles and adults led to the division of the fish yield according to the fishing gears used, as documented by Wanink *et al.* (1999), Tweedle and Cowx (1999) and Njiru *et al.* (2000). In addition, reasonable economical data (personal communications from resident scientists in the riparian countries of the lake) have also been incorporated in the database: the selling prices of the exploited fish populations and the relative costs of the fishing operation with the fishing gears under utilization (see Table 1a and 1b).

Table 1. a) Landings from the Kenyan sector of Lake Victoria, East Africa (adapted from Mkumbo *et al.* 2000). Note that landings have been segregated among various current fishing gears for a proper utilization of Ecosim.

Group \ Catch	Lates long lines	Large mesh sizes	Small mesh sizes	Dagaa fisheries	Littoral lines	Total catch
Adult Lates n.	5	5				10
Juvenile Lates		1	2			3
Bagrus/Clarias					0.15	0.15
Protopterus					0.03	0.03
Morm./Synodont					0.03	0.03
Haplochr.Predat			0.01			0.01
Haplochr.Phytop			0.01			0.01
Haplochr.Bentho			0.02			0.02
R.argentea				6.4		6.4
O.niloticus		0.6	1			1.6
Other Tilapias			0.35			0.35
Total catch	5	6.6	3.39	6.4	0.21	21.6
Trophic level	3.61	3.42	2.8	2.83	3.19	3.19

b) The value, costs and profit by gear type for the Lake Victoria fishery in Kenya. The selling prices of the fish have been set as follows: 2 US$ kg for nile perch, 0.5 US$ for haplochromids and native tilapia, and 1 US$ per kilo for other groups including Nile tilapia.

Group \ Catch	Lates long lines	Large mesh sizes	Small mesh sizes	Dagaa fisheries	Littoral lines	Total catch
Adult Lates n.	10	10				20
Juvenile Lates		2	4			6
Bagrus/Clarias					0.15	0.15
Protopterus					0.03	0.03
Morm./Synodont					0.03	0.03
Haplochr.Predat			0.01			0.01
Haplochr.Phytop			0.01			0.01
Haplochr.Bentho			0.01			0.01
R.argentea				6.4		6.4
O.niloticus		0.6	1			1.6
Other Tilapias			0.18			0.18
Total value	10	12.6	5.2	6.4	0.21	34.41

Results

Table 2 shows the key features of the present Ecopath IV model and Table 3 summarizes the diet composition of the groups considered.

The search for an optimum strategy (the open loop strategy simulation)

This research involved the choice of relative weights reflecting the values attached to: the absolute financial value of the ecosystem ; the social value (as reflected by total employment across all fisheries) ; and the stability and sustainability of the ecosystem as defined by the user (see Cochrane, this volume). This paper differs from the others in that it did not explore the default strategies (maximising each of economic, social and ecosystem goals separately and the 'big compromise' in which equal weight was given to

Table 2. Key features of the Ecopath model of the Kenyan sector of Lake Victoria, Africa for 1985-86. The trophic levels, food consumption flow to detritus, and the biomass for all groups (except aquatic birds) have been computed by the model. The input (P/B, Q/B and EE) are documented in Villanueva and Moreau (2000).

Group name	Trophic level	Habitat area	Biomass in habitat area (t/km2)	Biomass (t/km2)	Prod./ biom. (year)	Cons./ biom. (/year)	Ecotrophic efficiency	Prod. / cons.
Fish eat. Birds	3.9	1	0.005	0.005	0.3	60	0	0.005
Adult Lates n.	3.6	1	10.526	10.526	1	5	0.95	0.2
Juvenile Lates	3.3	1	5.421	5.421	3.5	11.8	0.98	0.297
Bagrus/Clarias	3.2	1	1.637	1.637	0.9	6.5	0.95	0.138
Protopterus	3.2	1	1.532	1.532	0.3	4.3	0.95	0.07
Morm./Synodont	3.1	1	0.425	0.425	1	11.5	0.95	0.087
Haplochr.Predat	3.7	1	0.126	0.126	2.5	8.5	0.95	0.294
Haplochr.Phytop	2.1	1	0.214	0.214	3	41	0.95	0.073
Haplochr.Bentho	3	1	0.402	0.402	3	21	0.95	0.143
R.argentea	2.8	1	8.693	8.693	2.8	27	0.95	0.104
O.niloticus	2.1	1	12.019	12.019	0.95	24.6	0.95	0.039
Other Tilapias	2.1	1	1.146	1.146	1.2	32	0.95	0.038
Zooplankton	2	1	11.321	11.321	33.5	140	0.8	0.239
Lake prawn	2.3	1	5.562	5.562	16	64	0.95	0.25
Insects/Mollusc	2.1	1	24.879	24.879	5	25	0.8	0.2
Phytoplankton	1	1	5.327	5.327	365	-	0.95	-
Bent. Producers	1	1	13.99	13.99	25	-	0.95	-
Detritus	1	1	10	10	-	-	0.652	-

Table 3. Diet composition of the various groups for ECOPATH in Lake Victoria, Africa, as documented in Villanueva and Moreau (2000).

Prey \ Predator	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1 Fish eat. Birds															
2 Adult Lates n.															
3 Juvenile Lates		0.25	0.03	0.04	0.01	0.005									
4 Bagrus/Clarias		0.02		0.01	0.01	0.005									
5 Protopterus		0.005		0.005	0.01	0.005									
6 Morm./Synodont		0.005		0.005	0.005	0.005									
7 Haplochr.Predat	0.15	0.002	0.001	0.001	0.001	0.001	0.05								
8 Haplochr.Phytop	0.15	0.003	0.004	0.002	0.001	0.001	0.1								
9 Haplochr.Bentho	0.2	0.005	0.01	0.002	0.003	0.003	0.1								
10 R.argentea	0.5	0.15	0.1	0.1	0.05	0.05	0.6								
11 O.niloticus		0.1	0.05	0.04	0.025	0.04									
12 Other Tilapias		0.01	0.005	0.005	0.005	0.005									
13 Zooplankton			0.05	0.03	0.03	0.05	0.05	0.03	0.05	0.7	0.02	0.02	0.02	0.2	0.04
14 Lake prawn		0.4	0.5	0.2	0.15	0.05	0.05		0.15	0.05	0.03				0.01
15 Insects/Mollusc		0.05	0.25	0.5	0.65	0.7	0.05	0.02	0.7	0.05		0.03		0.05	0.05
16 Phytoplankton								0.5		0.2	0.7	0.45	0.95	0.1	0.05
17 Bent. Producers				0.01		0.02		0.25	0.05		0.1	0.3		0.2	0.35
18 Detritus				0.05	0.05	0.05		0.2	0.05		0.15	0.2	0.03	0.45	0.5
19 Import						0.01									

all three considerations) but instead considered five different scenarios which were all in general agreement with the current situation and concern of the Lake Victoria Fisheries Organization (M.Ntiba, pers. comm. to J.M.).

The settings for the two primary simulations are shown in Table 4 above. For the reasons discussed in the chapter by Cochrane (this volume), the weighting of 0.8 for ecological balance would probably have resulted in this consideration being largely over-ridden by the economic and social criteria. Therefore the primary differences in these two were the different weightings given to social value, and the values of jobs per unit of catch for each fishery. Running the open loop search routine with these two scenarios resulted in the following estimated fishing effort multipliers to achive the goals as specified by the weightings assigned to economic and social value and

Table 4: Summary of the specifications defining the fishing policies considered for the Kenyan sector of Lake Victoria. Time period for each simulation : 15 years

a) Weights assigned	Scenario 1	Scenario 2
Total economic value	1	1
Social value (job opportunities)	0.5	1
Ecosystem stability	0.8	0.8

(b) Relative no. of jobs per unit mass of catch.		
Lates long line	21.5	
Large mesh nets	21.5	
Small mesh nets	1	0.5
Dagaa fisheries	2	1.5
Littoral lines	0.5	0.5

(c) Relative weightings assigned to different species	
Default value	1
Nile perch, dagaa and Nile tilapias	1.2
Haplochromines	1.5

ecosystem stability. Results are expressed as multipliers of existing fishing mortality (e.g. to attain the goals reflected in Scenario 1, the effort in the Lates long line fishery would need to be increased to an estimated 2.8 times of the present effort level).

	Scenario 1	*Scenario 2*
Lates long lines	2.8	3.1
Large mesh sizes	2.4	2.3
Small mesh sizes	0.8	0.8
Dagaa fisheries	1.8	1.5
Littoral lines	1.2	1.4

These conclusions are consistent with what has been suggested and discussed with colleagues involved in Lake Victoria fisheries management (see various contributions in Cowx, 2001).

A third scenario was also examined, similar economic and social weightings as in Scenario 1 (Table 4), but with the additional goal of attempting to rebuild the populations of haplochromid species. The estimated pattern of fishing effort to achieve this goal was :

Lates longlines	0.09
Large meshsizes	1.83
Small mesh sizes	1.23
Dagaa fisheries	0.33
Littoral lines	0.61

This strategy would involve shutting down the fishery for Lates, and it is not clear how this would contribute to rebuild the haplochromid population. This requires further exploration.

In the fourth scenario we gave the same input as in Scenario 1 for economic and social value, but set a default target biomass of 0 for all species with the exception of economically important species (0.2) and haplochromids (0.5).

The estimated fishing effort multipliers to achieve this goal were :

Lates longlines	0.29
Large meshsizes	2.83
Small mesh sizes	9.98
Dagaa fisheries	0.004
Littoral lines	0.29

This represents a particularly large increase in the small mesh fishery which would increase fishing mortality on juveniles and Nile tilapias.

Finally, the fifth scenario maintained the Scenario 1 parameters but increased the social value to 1 instead of 0.5 and set the default target biomass as 1, with the exception of the haplochromids (2) and selected important species (1.5).

Lates longlines	1.06
Large meshsizes	1.60
Small mesh sizes	1.5
Dagaa fisheries	0.
Littoral lines	0.98

The closed loop strategy simulation

The closed loop strategy simulation examines the impact of observation and implementation uncertainty on the performance of the management strategy. In our example, a clear oscillation pattern is displayed for most of the groups situated at the highest trophic levels, meaning that the strong predator/prey relationship between adult and juvenile nile perch had indirect impacts on other components of the ecosystem.

Discussion

The open loop simulations suggested that a recovery of haplochromids could be stimulated by an appropriate fishing startegy.

The possible reasons for the oscillating and yet opposite behavior in the biomass trends and catch values of adult and the juvenile *Lates* under the closed loop simulations need to be investigated in detail. According to Walters *et al.* (1997) an increased density of adult *Lates* would first lead to a decrease of juvenile biomass simply by predation whereas, at a later stage, it would lead to a decrease in density of other predators and competitors. This would result in improving feeding conditions and a simultaneous decrease on the predation pressure for these juveniles. This could lead to the observed oscillatory behaviour.

Clearly the evolution of the ecosystem of Lake Victoria has been controlled by a top-down pattern during the early years of increasing importance of Nile Perch in the actual catch. The current situation may differ from the early period due to changes in the water quality (eutrophication, depletion of oxygen in the deep layers). An alternative hypothesis is the lower trophic levels are driven largely by bottom-up effects, whereas a top-down effect is controlling the dynamics of the higher trophic levels (D. Pauly, *pers.comm.*).

The scenarios for implementing an open loop search for the optimum fisheries strategy rely on specified values to be specified of the total economical value of the fishery, its value in terms of total employment, and of the ecological goals. The social value requires specification of the relative employment value of each fishing gear, while the ecological goals require an indication of the target biomass for each functional group in the ecosystem. It should be noted that when this study was done, little was known by the authors on these values or on the ecological targets that would be preferred by the different interest groups in the fishery. Hence the figures and choices shown here should be regarded as tentative only.

Conclusion

Although it provides very useful features for simulating the trajectory of catch and biomass over time, Ecosim has some limits in its predictive power. In particular, it would be useful to be able to include the impact of changes in water quality, especially in terms of variations in primary production. This could be explored further using the forcing functions of Ecosim, which opens up a large field for further investigation.

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