An Ecopath model of the Sine-Saloum Delta Biosphere Reserve (Senegal)

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— Note —

Modèle Ecopath pour une réserve de la biosphère : le delta du Siné-Saloum (Sénégal)

— Note —

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ABSTRACT

SINE-SALOUM (Senegal), an inverse hyper saline estuary, serves as an important resource of fish for local populations. In the last 20 years, annual catches have decreased (from 30,000 to 15,000 t) as has the diversity of species in the catch. Ethmalosa fimbriata, *a pelagic Clupeid, is increasingly dominating the estuary and, consequently, the fish landings. Ineffective fisheries management has contributed significantly to these declines while environmental degradation threatens the continued functioning of this ecosystem. The Ecopath with Ecosim programme has been used to characterise the current trophic state of the ecosystem and explore ecologically sustainable management.*

Key words

Ecopath — Trophic status — Sine-Saloum — Fisheries Management

RÉSUMÉ

LE DELTA du Sine-Saloum (Sénégal) présente un gradient de salinité inversé avec hyper-salinité à l'amont. Il offre une importante ressource piscicole aux populations locales. En vingt ans, les captures totales sont passées de trente mille à quinze mille tonnes et la diversité des captures a également baissé. *Ethmalosa fimbriata*, un Clupéidé pélagique, est devenu progressivement dominant. Des pratiques et un aménagement des pêches inadaptés ont amené ces déclins, également dus en partie à la dégradation de l'environnement qui fait courir à l'écosystème des risques écologiques réels. Le logiciel Ecopath avec Ecosim a été employé ici pour analyser les relations trophiques au sein de cet écosystème et pour explorer les possibilités d'un aménagement écologiquement durable de la ressource.

Mots clés

Sénégal — Siné-Saloum — Structure trophique — Ecopath
Aménagement

INTRODUCTION

WEST African estuaries, characterised by a high species diversity, are highly productive (ALBARET & DIOUF, 1994). Sine-Saloum (fig. 1) is located about 100 km south of Dakar (Senegal) and covers an area of 543 km². It is one of the country's most populated regions, with 10 per cent of this area inhabited by around 16 per cent of the country's total population many dependent on the natural resources of the area.

The inverse hyper salinity of the Sine-Saloum is an important factor affecting its biodiversity.

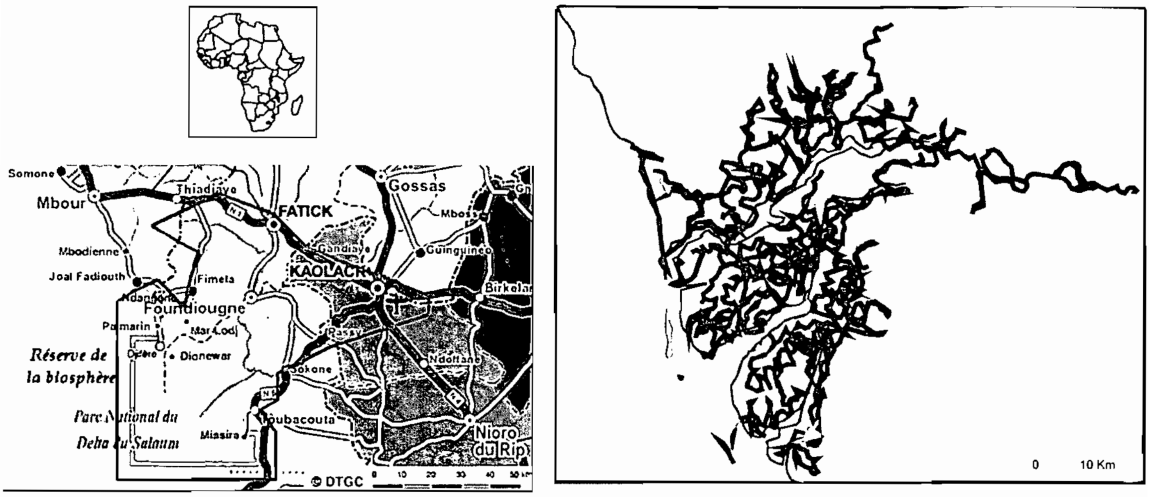

FIG. 1. — Map showing location of the studied area and the zone considered as Biosphere reserve of the Delta of Sine-Saloum. (Sources: http://www.au-senegal.com and Encarta).

Localisation du delta du Siné-Saloum, au sud de Dakar et du parc national du Delta (réserve de la biosphère).

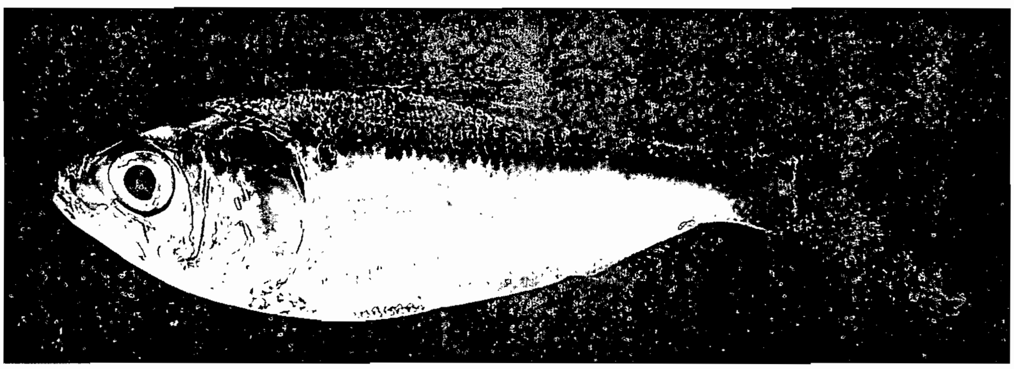

FIG. 2. — *Ethmalosa fimbriata*, a pelagic Clupeid, is the principle resource exploited in the Sine-Saloum estuary (photo by Guy Vidy).

Ethmalosa fimbriata *: Clupéidé pélagique et principale ressource exploitée au Siné-Saloum.*

This, notably, has affected the ecosystem and the catches of the fisheries (DIOUF *et al.*, 1998; BOUSSO, 1996; DIOUF, 1996). *Ethmalosa fimbriata* (fig. 2) now represents 80 per cent of the actual catch in 2000 (DEME *et al.*, 2000; 2001). Post-colonial fishing practices contributed significantly to the decline of catches both in numbers and diversity due to overexploitation, mostly by immigrating fishers (DIOUF *et al.*, 1998).

The aim of this contribution is to construct a preliminary food web model for the Sine-Saloum ecosystem, to describe its complex trophic structure and dynamics, and how their variations can affect the fisheries.

MATERIALS & METHODS

ECOPATH with Ecosim (EwE), described by CHRISTENSEN *et al.* (2000), and several contributors in this volume, was used to identify the trophic relationships and community structure in the Sine-Saloum estuary. Groups were mainly based on data by ALBARET and DIOUF (1994).

Existing data from field samples and various publications (UNESCO, 1982; 1985; BOUSSO, 1991; ALBARET & DIOUF, 1994; Bousso, 1994; DIOUF, 1996; DIOUF *et al.*, 1999; DEME *et al.*, 2001) on this ecosystem were utilised in order to build the model. A total of 38 groups were created (table I), based on species abundance and the structure of the trophic system (ALBARET & DIOUF, 1994; BOUSSO, 1996; DIOUF, 1996). Quantitative diet composition were not available, and thus qualitative information was used taken mainly from DIOUF (1996), Fishbase (FROESE & PAULY, 2000) and colleagues' personal communications. This preliminary Ecopath model was designed to investigate possible consequences to ecosystem health of further changes in fishing patterns and intensities.

The database used here, as well as the sources of any inputs, is available upon request from the first author (see also www.ecopath.org).

RESULTS & DISCUSSION

THE system's primary production/respiration ratio of 1.084 indicates that it is rich in organic materials from demineralisation and other active microbial processes (DIOUF, 1996).

The estimated biomass for each group (table I) seem to be reasonable but it should be emphasised that further studies are needed to improve the model. Estimated total annual biomass of fish groups considered is 37.7 $t.km^{-2}$ (table I).

The low system omnivory index of 0.146, with a connectance index of 0.184, is due to feeding specialisation by various fish groups. The fish assemblages are dominated by groups preying mainly on zooplankton, especially during the juvenile stages. Generally, estuarine food webs are driven by phytoplankton or detrital production (BLABER, 2000). For Sine-Saloum, the latter seems to be the case, due to the low primary production. The low primary productivity can be attributed to water turbidity, inefficient nutrient cycling and environmental degradation leading to reduced dissolved oxygen concentrations in the estuary (UNESCO, 1985; BLABER, 2000).

The trophic chain is short and flows mainly from detritus to higher trophic levels. The relatively high transfer efficiency (16 per cent) associated with these flows can be attributed to the low abundance of phytoplankton and of organisms grazing it.

The transfer efficiencies increase at higher trophic levels, which is related to the higher quality of the food being transferred.

TABLE I

Basic input and estimated parameters of the Ecopath model for Sine-Saloum. TL is the trophic level. Habitat area for each group is the fraction of the total area where biomass of species are concentrated. Biomass A pertains to biomass in this habitat area and B to biomass in total area. P/B is the production/biomass ratio, Q/B the consumption/biomass ratio Basic estimates calculated by the model are indicated in italics

Structure trophique du delta du Sine-Saloum telle qu'analysée par Ecopath : TL est le niveau trophique ; « Habitat area » désigne la fraction de la surface totale où le groupe considéré est concentré, la biomasse A est celle pour cet habitat et B celle comme une moyenne pour tout l'écosystème. P/B est le rapport Production/Biomasse, et Q/B est le rapport consommation/biomasse. Seules les valeurs en italiques ont été calculées par le logiciel

	Group name	TL	Habitat area	Biomass A ($t.km^{-2}$)	Biomass B ($t.km^{-2}$)	P/B (y^{-1})	Q/B (y^{-1})	EE	GE
1	*Scomberomorus tritor*	*3.4*	0.50	*0.009*	*0.004*	2.520	12.60	0.950	*0.200*
2	*Elops* spp.	*3.3*	0.50	*0.021*	*0.010*	1.990	9.95	0.950	*0.200*
3	*Sphyraena* spp.	*3.3*	0.25	8.688	2.172	1.700	8.50	*0.176*	*0.200*
4	*Arius* spp.	*3.2*	0.50	2.544	1.272	2.655	17.70	*0.312*	*0.150*
5	*Polydactylus quadrifilis*	*3.5*	1.00	1.272	1.272	1.540	7.70	*0.079*	*0.200*
6	*Pseudotolithus elongatus*	*3.3*	1.00	1.800	1.800	1.680	8.40	*0.026*	*0.200*
7	Other *Sciaenidae*	*3.3*	1.00	*0.089*	*0.089*	1.650	8.25	0.950	*0.200*
8	*Psettodes/Citharichthys*	*3.3*	0.50	*0.166*	*0.0166*	1.980	11.00	0.950	*0 .329*
9	*Galeoides decadactylus*	*3.2*	0.50	*2.150*	*2.150*	1.515	10.10	0.950	*0.150*
10	*Dasyatis* spp.	*3.1*	0.50	*0.075*	*0.037*	1.650	8.25	0.950	*0.100*
11	*Brachydeuterus auritus*	*2.7*	0.50	*0.019*	*0.010*	2.870	28.70	0.950	*0.150*
12	*Plectorhinchus/Pomadasys*	*3.2*	0.75	*1.558*	*1.168*	1.270	8.47	0.950	*0.150*
13	*Ilisha africana*	*2.9*	0.50	*2.444*	*1.222*	2.445	16.30	0.950	*0.150*
14	*Cynoglossus* spp.	*3.1*	0.50	*9.224*	*4.612*	1 .200	8.00	0.950	*0.180*
15	*Chloroscombrus/Hemicaranx*	*3.3*	0.25	0.066	0.016	3.312	17.40	*0.935*	*0.150*
16	*Carangidae* (bentho-pelagic)	*3.3*	0.50	*0.718*	*0.359*	1.335	8.90	0.950	*0.150*
17	*Gerreidae*	*2.9*	0.50	*0.128*	*0.064*	3.075	20.50	0.950	*0.180*
18	Other *Carangidae*	*3.2*	0.50	0.224	0.112	2.407	13.37	*0.440*	*0.150*
19	*Ephippidae*	*3.0*	0.75	*0.013*	*0.010*	2.130	14.20	0.950	*0.150*
20	*Ethmalosa fimbriata*	*2.7*	0.75	23.543	17.657	2.685	17.90	*0.543*	*0.100*
21	*Sardinella maderensis*	*2.8*	0.50	0.203	0.102	3.390	33.90	0.950	*0.050*
22	*Mugilidae*	*2.4*	0.50	2.750	1.375	1.386	27.72	*0.692*	*0.051*
23	*Sarotheradon melanotheron*	*2.3*	0.60	2.100	1.260	1.275	25.20	*0.856*	*0.050*
24	*Tilapia guineensis*	*2.3*	0.50	1.800	0.900	1.030	20.60	*0.613*	*0.250*
25	Pelagic Shrimps	*2.3*	0.75	*4.674*	*3.505*	4.500	18.00	0.950	*0.250*
26	Littoral shrimps	*2.3*	0.25	*26.853*	*6.713*	4.500	18.00	0.950	*0.312*
27	Pelagic crabs	*2.7*	0.75	*7.409*	*5.557*	2.500	8.00	0.950	*0.312*
28	Littoral crabs	*2.1*	0.25	*3.576*	*0.894*	2.500	8.00	0.950	*0.312*
29	Cephalopods	*3.0*	0.50	*29.892*	*14.946*	2.500	8.00	0.950	*0.333*
30	Bivalves and Gastropods	*2.0*	0.50	*21.320*	*10.600*	3.000	9.00	0.950	*0.320*
31	Annelids and Polychaets	*2.0*	0.25	*26.530*	*6.633*	8.000	25.00	0.950	*0.314*
32	Zoobenthos	*2.1*	0.25	*32.853*	*8.213*	22.000	70.00	0.950	*0.333*
33	Pelagic zooplankton	*2.1*	0.50	*7.221*	*3.611*	50.000	150.00	0.950	*0.333*
34	Littoral zooplankton	*2.1*	0.50	*4.104*	*2.052*	50.000	150.00	0.950	*0.333*
35	Benthic algae	*1.0*	0.25	*50.000*	*12.500*	36.798	-	0.950	-
36	Pelagic phytoplankton	*1.0*	0.50	*6.810*	*3.405*	200.000	-	0.950	-
37	Littoral phytoplankton	*1.0*	0.50	*1.968*	*0.984*	365.000	-	0.950	-
38	Detritus	*1.0*	1.000	1.000	-	-	-	*0.863*	-

TABLE II

Estimated catch (t.km^{-2}) per group for each gear. Total annual catch estimated was 32.34 (t.km^{-2}), operating at a trophic level of 2.63

Captures annuelles (t.km^{-2}) estimées par groupe pour chaque engin. Le total est estimé à 32,34 t.km^{-2}. Le niveau trophique moyen des captures est de 2.63

	GROUP \ CATCH	DUGOUT	BEACH SEINE	ENCIRCLING GILLNETS	CAST NETS	FIXED GILL NETS	DERIVED GILL NETS	TRAWL LINES	SHRIMP NETS	TRAPS	OTHER GEARS	TOTAL CATCH
1	*Scomberomorous tritor*			0.005			0.005					0.01
2	*Elops* spp.										0.010	0.01
3	*Sphyraena* spp.		0.200	0.100		0.070	0.260					0.63
4	*Arius* spp.	0.110	0.120	0.010		0.140	0.140	0.040				0.56
5	*Polydactylus quadrifilis*		0.060	0.015		0.010	0.050		0.005			0.14
6	*Pseudotolithus elongatus*		0.010			0.010	0.050					0.07
7	Other *Sciaenidae* spp.		0.030			0.025	0.070		0.005			0.13
8	*Psettodes/Citharichthys*										0.010	0.01
9	*Galeoides decadactylus*					0.009			0.001			0.01
10	*Dasyatis* spp.										0.010	0.01
11	*Brachydeuterus auritus*										0.010	0.01
12	*Plectorhinchus/Pomadasys*				0.005	0.003			0.002			0.01
13	*Ilisha africana*								0.010			0.01
14	*Cynoglossus* spp.		0,005			0.003			0.001	0.001		0.01
15	*Chloroscombrus/Hemicaranx* spp.			0.020								0.02
16	*Carangidae (bentho-pelagic)*			0.010			0.060					0.07
17	*Gerreidae* spp.		0.010									0.01
18	Other *Carangidae* spp.		0.015	0.005								0.02
19	*Ephippidae* spp.		0.010									0.01
20	*Ethmalosa fimbriata*		0.560	22.250	0.015	0.300	0.050		0.005	0.010		23.19
21	*Sardinella maderensis*		0.006	0.002	0.002							0.01
22	*Mugilidae* spp.		0.375	0.010	0.150		0.040		0.005	0.010		0.59
23	*Sarotheradon melanotheron*		0.180		0.030	0.030	0.010			0.090		0.34
24	*Tilapia guineensis*		0,070		0.020	0.030	0.005		0.005	0.010		0.14
25	Pelagic Shrimps								1.050			1.05
26	Littoral shrimps								0.350			0.35
27	Pelagic crabs										0.010	0.01
28	Littoral crabs									0.100		0.10
29	Cephalopods										0.010	0.01
30	Bivalves and Gastropods									4.800		4.80
31	TOTAL CATCH	0.110	1.651	22.427	0.222	0.630	0.740	0.040	1.439	5.021	0.060	32.340
32	TROPHIC LEVEL	3.18	2.74	2.75	2.40	2.92	3.20	3.18	2.28	2.01	3.02	2.63

Various fishing gears, though mostly non-specific, are used to exploit faunal resources in the estuary, *Sphyraena* spp., *Arius* spp., *Ethmalosa fimbriata*, *Sardinella maderensis*, *Sarotherodon melanotheron*, shrimps and crabs (table II). As a whole, the fishery is operating at a trophic level of about 2.63. Total annual catch is 32.34 t.km^{-2} (17,560 t) which is slightly higher than what has been observed (15,370 t) by DEME *et al.* (2001). This may be due to unreported captures of less economically important animals or discards of non-marketable species not included in annual catches, as well as unrecorded export of substantial amounts to neighbouring countries such as Gambia.

TABLE III

Evolution of biomass of affected groups when fishing effort is increased by a factor of two, all gears combined

Évolution de la biomasse des groupes dont l'abondance est affectée par un doublement généralisé (sur 10 ans) de l'activité de pêche, tous engins confondus

GROUP NAME	Biomass (Start)	Biomass (End)	Biomass (S/E)	Catch (Start)	Catch (End)	Catch (S/E)	Value (Start)	Value (End)	Value (S/E)
Scomberomorous tritor	0.004	0.000	0.00	0.011	0.000	0.00	0.006	0.000	0.00
Elops spp.	0.010	0.002	0.22	0.011	0.004	0.36	0.002	0.001	0.36
Sphyraena spp.	2.150	1.683	0.78	0.714	0.916	1.28	0.750	0.961	1.28
Arius spp.	1.256	1.131	0.90	0.633	0.934	1.47	0.253	0.373	1.47
Polydactylus quadrifilis	1.268	1.341	1.06	0.160	0.277	1.73	0.271	0.470	1.73
Pseudotolithus elongatus	1.797	1.681	0.94	0.080	0.123	1.53	0.015	0.023	1.53
Other *Sciaenidae*	0.085	0.001	0.01	0.142	0.002	0.02	0.027	0.000	0.02
Psettodes/Citarichthys	0.083	0.102	1.23	0.011	0.023	2.01	0.002	0.004	2.01
Galeoides decadactylus	1.076	1.584	1.47	0.011	0.028	2.41	0.002	0.005	2.41
Dasyatis spp.	0.037	0.022	0.60	0.011	0.011	0.99	0.002	0.002	0.99
Brachydeuterus auritus	0.009	0.021	2.22	0.011	0.041	3.63	0.002	0.008	3.63
Plectorhinchus/Pomadasys	1.167	1.010	0.87	0.011	0.016	1.42	0.002	0.003	1.42
Ilisha africana	1.222	1.356	1.11	0.011	0.021	1.82	0.002	0.004	1.82
Cynoglossus spp.	4.614	4.973	1.08	0.011	0.020	1.76	0.002	0.004	1.76
Chloroscombrus/Hemicaranx	0.016	0.012	0.73	0.022	0.026	1.19	0.004	0.005	1.19
Carangidae (bentho-pelagic)	0.357	0.531	1.49	0.080	0.194	2.24	0.015	0.037	2.44
Gerreidae	0.064	0.067	1.05	0.011	0.020	1.72	0.002	0.004	1.72
Other *Carangidae*	0.112	0.148	1.33	0.023	0.050	2.17	2.068	0.009	2.17
Ephippidae	0.010	0.011	1.12	0.011	0.020	1.84	0.002	0.004	1.84
Ethmalosa fimbriata	17.021	10.685	0.63	25.580	26.314	1.03	2.068	2.127	1.03
Sardinella maderensis	0.102	0.150	1.48	0.011	0.028	2.42	0.002	0.005	2.42
Mugilidae	1.356	0.740	0.55	0.666	0.595	0.89	0.173	0.155	0.89
Sarotherodon melanotheron	1.249	1.062	0.85	0.386	0.537	1.39	0.145	0.202	1.39
Tilapia guineensis	0.896	0.809	0.90	0.160	0.236	1.48	0.060	0.089	1.48
Pelagic shrimps	3.481	3.511	1.01	1.194	1.972	1.65	1.492	2.465	1.65
Littoral shrimps	6.710	6.984	1.04	0.401	0.683	1.70	0.501	0.854	1.70
Pelagic crabs	5.593	11.210	2.00	0.012	0.038	3.28	0.002	0.007	3.28
Littoral crabs	0.892	0.909	1.02	0.114	0.191	1.67	0.022	0.036	1.67
Cephalopods	15.047	23.919	1.59	0.012	0.030	2.60	0.002	0.006	2.60
Bivalves and Gastropods	10.528	8.532	0.81	5.427	7.205	1.33	1.031	1.369	1.33

In most simulation runs with Ecosim, increased fishing pressure using cast nets cause a marked decline of the *Mugilidae*. Increasing fishing activity using any gill or shrimp nets showed negative effects to the biomass of *Sciaenidae* except for *P. elongatus* (table III). Increasing fishing pressure by a factor of 2 led to a dramatic decrease in the biomass of *Pseudotolithus* spp., *Elops* spp. and *S. tritor*. Other groups such as *Sphyraena* spp., *Arius* spp., *Dasyatis* spp., *Chloroscombrus* and *Hemicaranx* spp. *E. fimbriata*, as well as the bivalve and gastropod group showed progressive decrease in their biomass. The biomasses of *Brachydeuterus auritus*, *Galeoides decadactylus*, *Sardinella maderensis*, *Psettodes* and *Citharychthys* spp., *Ilisha africana* as well as the cephalopods increased due to decrease of predation pressure and inter-specific competition among these groups.

Fish groups specialised in consuming molluscs, shrimp and other invertebrates showed negative responses in biomass only when the effort of gears capturing their preferred preys was increased.

Various scenarios were simulated using the fishing policy routine of Ecosim. Criteria considered were based on requirements outlined by DIOUF *et al.* (1998) regarding sustainable management strategies in agreement with the current fisheries legislation. The policy search routine, when set to favour ecosystem structure and net economic value suggested that fishing with gill nets heavily exploiting clupeid species, as well as targeting of shrimps and molluscs would lead to the best compromise.

CONCLUSION

THE trophic structure in the Sine-Saloum estuary is changing mainly from decline of fish stocks due to intensification of fishing activity and environmental degradation. Depletion of some groups due to increased catch and predation rates may allow consequential increase of biomass among other groups but will eventually lead to threats to ecosystem stability and resources sustainability.

Future management policies should consider resource conservation as such system serve as nursery grounds for many commercially exploited resources.

It should be noted that this is only a preliminary study, and that further investigations will be conducted in the near future. However comments will be greatly appreciated.

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