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## Rebuilding our marine ecosystems, protecting our future

Key findings of the International Symposium on Marine Fisheries,  
Ecosystems and Societies in West Africa – Half a century of change

### Dakar, Senegal, 24-28 June 2002

GENERAL INFORMATION



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## **Trends in Fish Biomass off Northwest Africa, 1960-2000**

— Article —

## **Tendances de la biomasse des poissons du Nord-Ouest africain, 1960-2000**

— Article —

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**ABSTRACT**

**W**E ESTIMATE biomass trends for demersal and large pelagic fishes, (i.e., excluding small pelagic and mesopelagic fishes) based on 17 Ecopath models from Mauritania, Cape Verde, Senegal, The Gambia, Guinea-Bissau, Guinea, Sierra Leone and the open waters of the central east Atlantic, made to represent various time periods during the second half of the twentieth century. We use a published method developed for estimating fish biomass in the North Atlantic, and modify it to account for the specificity of West African fisheries and ecosystems. We show that, overall, fish biomass as defined here (i.e., excluding low-trophic level and small fishes) has declined over the forty-year period from 1960 by a factor of 13. An implication of our results is that further increase in fishing mortality in the region will not lead to increased catches but will only drive biomasses further down.

**Key words**

*Biomass decline — Ecosystem models — Ecopath — Fishing intensity*

**RÉSUMÉ**

**N**OUS avons évalué les tendances de la biomasse des poissons démersaux et des grands pélagiques (c'est-à-dire après l'exclusion des petits pélagiques et des poissons mésopélagiques) sur la base de dix-sept modèles écosystémiques construits avec le logiciel Ecopath et représentant, pour différentes périodes de la deuxième partie du XX<sup>e</sup> siècle, les écosystèmes au large de la Mauritanie, du Cap-Vert, du Sénégal, de la Gambie, de la Guinée-Bissau, de la Guinée, de la Sierra Leone et du système océanique de l'Atlantique central. L'analyse de ces modèles a été effectuée à l'aide d'une méthode de spatialisation appliquée auparavant à l'Atlantique nord, et adaptée aux circonstances du Nord-Ouest africain. Notons que la biomasse de poissons définie ci-dessus n'a, en l'an 2000, qu'un treizième de sa valeur de 1960. Ceci implique qu'une augmentation de la mortalité par la pêche dans la sous-région ne pourra pas augmenter les prises et ne fera qu'accentuer le déclin de la biomasse.

**Mots clés**

*Déclin de biomasse — Modèles écosystémiques — Ecopath  
Intensité de pêche*

## INTRODUCTION

THIS contribution synthesises the results of the ‘Ecopath module’ of the Fias/Siap (Fisheries Information and Analysis System/Système d’information et d’analyse des pêches) project, devoted to the construction of ecosystem models for each of the major fishing areas in the countries of the sub-region covered by the Sub-Regional Fisheries Commission of West African States (SRFC), plus adjacent waters in Sierra Leone and off-shore.

In this synthesis, we concentrate on the change in biomass of demersal and large pelagic fishes, *i.e.*, we exclude small pelagic fishes (mainly sardinella and anchovies), whose environmentally-driven biomass fluctuations would tend to mask systematic, fishery-induced trends, and mesopelagic fishes, which occur only offshore in deeper waters

and are not exploitable by current fisheries (GJØSAETER & KAWAGUCHI, 1980). The methodological approach used here is similar to that developed for studying temporal trends in the biomass of high-trophic level fishes (CHRISTENSEN *et al.*, 2003), and hence this methodology will be presented only in summary form, with some emphasis on the modifications required to adapt it to the conditions of Northwest Africa.

We concentrate on biomass because this is usually proportional to the catch per effort of fishing vessels, and thus directly impacts on their profitability. Thus, we shall abstain from discussing here the implications on the biodiversity of West African fish that a massive reduction in their biomass is likely to have.

## MATERIALS & METHODS

### Materials

TABLE I summarises the major characteristics of the mass-balance food web (Ecopath) models used here as starting point for this analysis. Most of these models were constructed during the course of the Fias/Siap project, by members of that project (PAULY *et al.*, 2002). However, some additional models were contributed through the *Sea Around Us* Project to ensure a wide and consistent coverage both spatially and temporally (PALOMARES *et al.*, 2004). We refer to CHRISTENSEN & PAULY (1992), CHRISTENSEN *et al.* (2000) and PAULY *et al.* (2000) for details on construction and interpretation of Ecopath models in general (see also [www.ecopath.org](http://www.ecopath.org)). The spatially explicit primary production data used here originated as SeaWiFS data, as processed by the European Union’s Joint Research Centre, in Ispra, Italy (HOEPFFNER *et al.* unpublished data), based on a model that incorporates estimated chlorophyll, photosynthetically active radiation, and sea surface temperature patterns (BEHRENFELD & FALKOWSKI, 1997). The data used here are average values for 1998.

An upwelling index was derived based on latitude and basin-specific temperature anomalies by  $\frac{1}{2}$  by  $\frac{1}{2}$  degrees of latitude and longitude. Depth information by  $\frac{1}{2}$  by  $\frac{1}{2}$  degrees of latitude/longitude was obtained from the Etopo5 dataset available on the U.S. National Geophysical Data Center’s Global Relief Data CD [www.ngdc.noaa.gov/products/ngdc\\_products.html](http://www.ngdc.noaa.gov/products/ngdc_products.html). Spatialised fisheries catches by half-degree squares were obtained for the years 1950-1999 from the *Sea Around Us* Project database, and are based on the rule-based method developed by WATSON *et al.* (2001, 2004).

### Methods

The methodology we have used to predict the biomass of fish draws on a combination of ecosystem modelling, information from hydrographic databases, statistical analysis, and GIS modelling (CHRISTENSEN *et al.*, 2003). The mapping of biomass changes were performed using a series of steps, as follows:

- 1 The 17 models of Table 1 were re-expressed on a spatial basis using  $\frac{1}{2}$  by  $\frac{1}{2}$  degree cells

- (corresponding to 30 by 30 miles at the Equator) using the Ecospace program (WALTERS *et al.*, 1999). For each of the spatial models, the cells were distributed between habitats based on their mean depth. The following depth strata were used for all models: (1) <10 m; (2) 11-50 m; (3) 51-100 m, (4) 101-200 m; (5) 201-1000 m; and (6) >1000 m. These yielded estimates of biomass by Ecopath functional groups for each of the spatial cells covered by each model (tabl. I);
- 2 The biomass of different functional fish groups were re-expressed as a single value representing all fish with a trophic level of 3.0 or higher, excluding, however, the unexploited mesopelagics as well as the highly variable small pelagics (see above);
  - 3 Multiple linear regression analyses were performed using S-Plus 6 (INSIGHTFUL CORPORATION, 2001). We used additive and variance stabilising transformation, (Avas) to decide how individual variables are best transformed to obtain linearity (fig. 1);
  - 4 A multiple regression was identified which predicted fish biomass based on the year for which biomass was estimated, (log transformed) primary production in each half-degree cell, (log transformed) mean depth of each cell, distance from the coast (quadratic transformation), cell-specific average temperature at 10 meters depth in degrees Celsius, and catches of (i) medium demersals and (ii) large demersals. To prevent the records from models covering large areas from overwhelming those from other models, each of the records was weighted, in the regression analyses, by the inverse of the square root of the number of non-land cells in the model to which it belonged. From this, we extracted 5488 records based on the ½ by ½ degree spatial cells of the 17 ecosystem models in Table 1. Each of the records included estimates of fish biomass (trophic level ≥ 3.0), depth, primary production, and year of the model;
  - 5 Using the regression, the biomass for each cell represented was predicted and plotted for 1960 and 2000, representing the extremes for the period covered;
  - 6 As annual catches from 1960 and 2000 were available by ½ by ½ degree cells (see WATSON *et al.* 2001; 2004), a measure of fishing intensity was calculated for each cell as the ratio of its catch to its biomass. For a few areas (notably along coasts), the fishing intensity measure was smoothed by averaging over neighbouring cells.

TABLE I

Overview of the 17 ecosystem models used for estimating abundance trends in fishes of Northwest Africa. 'Spatial cells' indicate number of non-land ½ degree cells included in spatial model representations

*Caractéristiques des dix-sept modèles écosystémiques  
utilisés pour estimer les tendances de l'abondance des poissons du Nord-Ouest africain.  
« Spatial cells » indique le nombre de cellules d'un demi-degré incluses dans chaque modèle*

AREA COVERED	YEAR(S)	SPATIAL CELLS	FUNCTIONAL GROUPS	REFERENCE
Mauritania	1987, 1998	102	38	OULD TALEB OULD SIDI & GUÉNETTE (2004)
Cape Verde	1983	10	25	STOBBERUP <i>et al.</i> (2002)
Senegambia	1986	23	18	SAMB & MENDY (2002) DIOUF <i>et al.</i> (2002)
Gambia	1986, 1992, 1995	8	23	MENDY (2002)
Guinea-Bissau	1991	22	31	(AMORIM <i>et al.</i> , 2002)
Guinea	1985, 1998	18	32	DIALLO <i>et al.</i> (2002), GUÉNETTE & DIALLO (2004)
Sierra Leone	1964, 1978, 1990	12	44	HEYMANS & VAKILY (2002)
North Atlantic Ocean	1950, 1998	1100	38	VASCONCELLOS (2004)
Central Atlantic Ocean	1950, 1998	1460	38	VASCONCELLOS (2004)

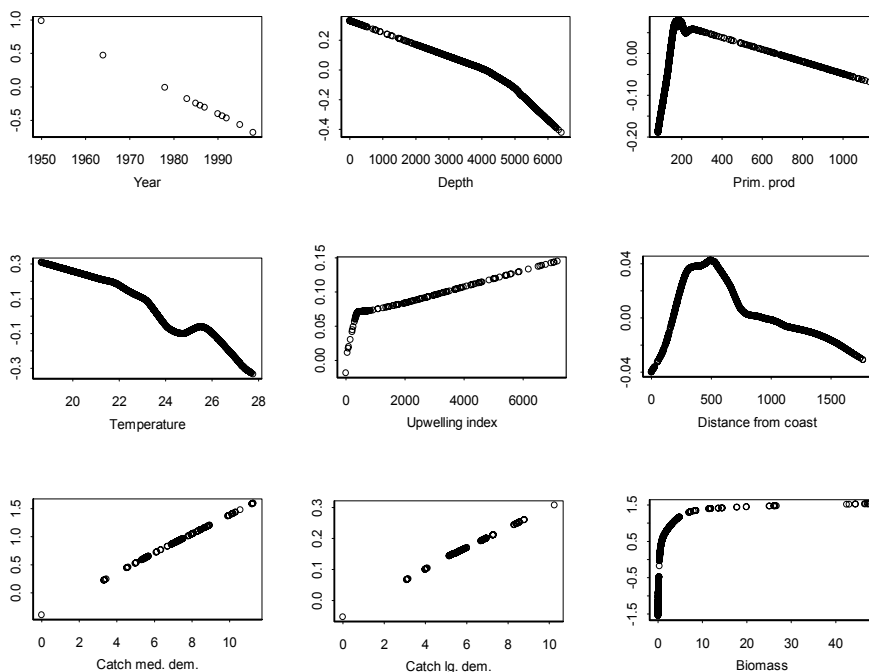


FIG. 1. — Avas transformations indicating how parameters (X-axis) should be transformed (Y-axis indicate biomass, linear scale) to linearise the individual parameters while considering their joint effects. These results indicate that logarithmic transformations are reasonable for depth (m), primary productivity ( $t \text{ km}^{-2} \text{ year}^{-1}$ ), upwelling index, and biomass ( $t \text{ km}^{-2}$ ), a quadratic transformation for distance from coast (km), while no transformations are required for temperature ( $^{\circ}\text{C}$ ), and for catch of medium and large demersals ( $t \text{ km}^{-2} \text{ year}^{-1}$ ).

The upwelling index was not used in the regression as its contribution was insignificant.

*Courbes indiquant comment les variables (en X) de la régression multiple linéaire doivent être transformées pour assurer la linéarité de la biomasse (en Y), en tenant compte des effets conjoints de toutes les variables. Ces courbes démontrent que des transformations logarithmiques suffisent pour linéariser la profondeur (en m), la production primaire ( $t \text{ km}^{-2} \text{ année}^{-1}$ ), l'index d'upwelling et la biomasse elle-même ( $t \cdot \text{km}^{-2}$ ), alors qu'une transformation quadratique suffit pour la distance de la côte (km). Aucune transformation ne paraît nécessaire pour la température (en degrés centigrades), et les prises de poissons de grande et moyenne tailles ( $t \text{ km}^{-2} \text{ année}^{-1}$ ). L'indice d'upwelling n'a pas été utilisé, son effet n'étant pas significatif.*

## RESULTS & DISCUSSION

TABLE II presents the parameter estimates for the multiple regression model used to predict biomasses off West Africa. For comparison, we present as figure 2 a plot of predicted versus observed biomasses. It is clear that there is a strong

relationship: the regression model explains 94 per cent of the variance, this high value reflecting the fact that many pairs of models cover different periods, and document strong declines in biomass over time.



TABLE II

Parameters estimates and associated test statistics for multiple linear regression to predict the (log) biomass for fishes (trophic level  $\geq 3.0$ ) during the period from 1960 to 2000. Logarithmic transformations are used for primary productivity and depth, and a quadratic transformation for distance from coast. The variables are arranged after their t-value (i.e., relative standard errors), which correspond to standardised partial slopes (BLALOCK, 1972)

All parameters are highly significant with  $\Pr(>|t|) < 0.0000005$  for all cases

*Paramètres et autres statistiques de la régression multiple linéaire utilisée pour prédire les (log) biomasses des poissons (niveau trophique  $\geq 3,0$ ) pour la période de 1960 à 2000*

*Des transformations logarithmiques sont utilisées pour la production primaire et la profondeur, et une transformation quadratique pour la distance à la côte.*

*Les variables sont ordonnées en fonction de leur valeur de t (c'est-à-dire en fonction de l'écart-type relatif), correspondant à des pentes partielles standardisées (BLALOCK, 1972)*

*Tous les paramètres sont significatifs, avec  $\Pr(>|t|) < 0.0000005$  dans tous les cas.*

VARIABLE (UNIT)	ESTIMATE	STD. ERROR	T-VALUE
Intercept	104.25	0.52704	197.8
Year	-0.052437	0.00026	-197.6
Temperature at 10 m ( $^{\circ}\text{C}$ )	-0.164374	0.00265	-61.9
Catch, med. demersals ( $\text{t} \cdot \text{km}^{-2} \cdot \text{year}^{-1}$ )	0.232355	0.00488	47.6
Catch, large demersals ( $\text{t} \cdot \text{km}^{-2} \cdot \text{year}^{-1}$ )	0.100082	0.00317	31.5
Primary production ( $\text{t} \cdot \text{km}^{-2} \cdot \text{year}^{-1}$ )	0.580376	0.02265	25.6
Depth (m)	-0.097444	0.00516	-18.9
Distance (km)	0.0004197	0.0000595	7.0
Distance <sup>2</sup> ( $\text{km}^2$ )	-0.0000003	0.0000000	-9.3

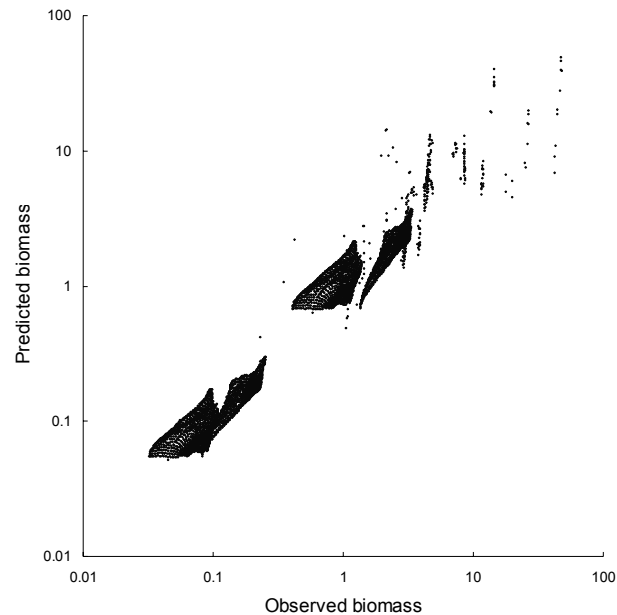


FIG. 2. — Plot of predicted versus observed biomass ( $\text{t} \cdot \text{km}^{-2}$ ). The 'observed' values are from the spatialisation of Ecopath models described in the Methods section, while the predicted values are from the multiple regression documented in Table II. Note close fit along the 1:1 line.

*Valeurs observées (modèles Ecopath spatialisés) et prédites (régression multiple du tableau II) obtenues d'après la méthode décrite plus haut. Notez la faible dispersion autour de la ligne du ratio 1 : 1.*

The predictions lead to the maps of biomass distributions presented in the two panels of figure 3 (plate VI), which jointly illustrate how the biomass of the larger fishes has declined in the last 40 years along the coast of West Africa. This figure thus both confirms and amplifies the impressions we may gather from assessments of individual stocks documented in other contributions included in this volume. Overall we find that fish biomass has declined by more than an order of magnitude over the forty years covered here.

Conversely, fishing intensity has increased dramatically (fig. 4, plate VI). Thus, by any standard models of fish population dynamics, the West African fisheries resources are overfished (*e.g.*, HILBORN & WALTERS, 1992). In such cases, the appropriate policy is to adjust (*i.e.*, reduce) fishing mortality such as to enable the resource to continue producing a flux of goods and benefits (fish for human consumption, income, foreign exchange, etc.). It is irrational, under such conditions, to add

to the fishing fleets of the region, whether that capacity is local, regional, or from other continents: it does not matter to the fish who it is that catches them. The present study is preliminary; it builds on an array of ecosystem models all of which have considerable uncertainty associated with them. We have not sought to quantify the uncertainty associated with our results, but we would be very surprised if the strong trends in biomass decline and increase in fishing intensity that we find are overestimated. We have sought throughout to err on the side of being too cautious, and think we are likely to have underestimated the actual trends.

We intend to develop the methodology we have used for the present study further. This will be done by reconstructing biomass trends by functional groups or species based on biological, ecological and fisheries information. Also, we plan to break the analyses down to finer spatial and temporal scales.

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