

TRENDS IN FISH BIOMASS OFF NORTHWEST AFRICA, 1960-2000^{1,2}

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ABSTRACT

We 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, and Guinea-Bissau, Sierra Leone and the open waters of the central east Atlantic, made to represent various time periods during the second half of the 20th 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. The economic and political consequences of our findings are briefly discussed.

RESUMÉ

Nous avons évalués 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 17 modèles des écosystèmes construits avec le logiciel Ecopath, et représentant, pour différentes périodes de la deuxième partie du 20^{ème} siècle, les écosystèmes au large de la Mauritanie, Le Cape Vert, le Sénégal, la Gambie, la Guinée, la Guinée-Bissau, le Sierra Leone, et le système océanique du l'Atlantique central, à différentes périodes de la deuxième partie du 20^{ème} siècle. L'analyse de ces modèles a été effectuée à l'aide d'une méthode de spatialisation appliquée auparavant à l'Atlantique nord, 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 en 1960. Ceci implique qu'une augmentation de la mortalité par pêche dans la sous-région ne pourra pas augmenter les prises et ne fera qu'accentuer le déclin de la biomasse. Nous discutons les conséquences économiques et politiques liées à ces résultats.

INTRODUCTION

This contribution synthesizes the results of the 'Ecopath module' of the FIAS/SIAP project, devoted to the construction of ecosystem models for each of the major fishing areas in the countries of the sub-region

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² An earlier version of this contribution is also included in: P. Chavance, M. Ba, D. Gascuel, M. Vakily and D. Pauly (eds.). 2004. *Pêcheries maritimes, écosystèmes et sociétés en Afrique de l'Ouest: un demi-siècle de changement*. Actes du symposium international, Dakar (Sénégal), 24-28 juin 2002, Bruxelles, Office des publications officielles des Communautés européennes, XXXVI-532-XIV p., 6 pl. h.-t. coul., ISBN 92-894-7480-7 (coll. Rapports de recherche halieutique ACP-UE n°15).

covered by the CRSP, 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 and Kawaguchi 1980). The methodological approach used here is similar to that developed for studying temporal trends in the biomass of high-trophic level fishes in the North Atlantic (Christensen *et al.*, 2003), and hence it 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 AND METHODS

Materials

Table 1 summarizes 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 (see Pauly *et al.*, 2002). However, additional models were contributed through the *Sea Around Us Project* to ensure a wide and consistent coverage both spatially and temporally (Palomares *et al.*, *in press*). We refer to Christensen and 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).

Some changes (most minor) were made to the models in Table 1 to make them mutually compatible, and in one case, to accommodate a publication with important information on biomass changes, not available when the model in question was constructed and balanced. This refers to the contribution of Myers and Worm (2002) on biomass change in tuna, which documents biomass declines stronger than estimated by Vasconcellos (this vol.). The Myers and Worm estimates have been contested by various tuna biologists, but the area of disagreement in the Central Pacific. There is, on the other hand, a broad consensus that tuna biomass declines have been extremely strong in the Central Atlantic. Thus, to align the abundance trends used here with those in Myers and Worm (2002), the 1950 tuna biomass estimates in Vasconcellos (this vol.) were increased, for the analysis presented here, by a factor of 5 for the North Atlantic, and 8 for the Central Atlantic.

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 and 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).

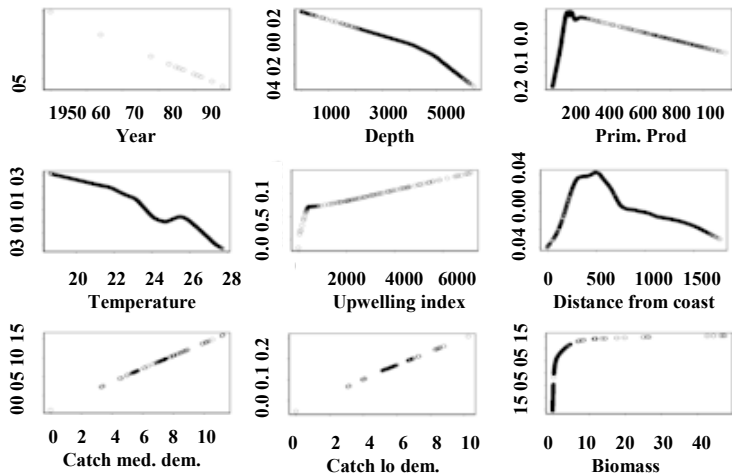
Spatialized fisheries catches by half-degree squares were obtained for the years 1950-1999 from the *Sea Around Us Project* database, and are based on the rule-based method developed by Watson *et al.* (2001, 2004).

Methods

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

- 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 (see Table 1);
- 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);

- Multiple linear regression analyses were performed using S-Plus 6 (Anon., 2001). We used additive and variance stabilizing transformation, (AVAS) to decide how individual variables are best transformed to obtain linearity (Figure 1);



- 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), and cell-specific average temperature at 10 m 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 $\frac{1}{2}$ by $\frac{1}{2}$ 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;

Figure 1. AVAS transformations indicating how parameters (X-axis) should be transformed (Y-axis indicate biomass, linear scale) to linearize 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.

- Using the regression the biomass for each cell represented was predicted and plotted for 1960 and 2000, representing the extremes for the period covered;
- As annual catches from 1960 and 2000 were available by $\frac{1}{2}$ by $\frac{1}{2}$ degree cells (see Watson *et al.* 2001; this vol.), 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 neighboring cells.

Table 1. Overview of the 17 ecosystem models used for estimating abundance trends in fishes of Northwest Africa. 'Spatial cells' indicate number of non-land $\frac{1}{2}$ degree cells included in spatial model representations.

Area covered	Year(s)	Spatial cells	Functional groups	Reference
Mauritania	1987, 1998	102	38	Ould Taleb Ould Sidi (this vol.)
Cape Verde	1983	10	25	Stobberup <i>et al.</i> (2002)
Senegambia	1986	23	18	Samb and 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 and Diallo (this vol.)
Sierra Leone	1964, 1978, 1990	12	44	Heymans and Vakily (2002)
North Atlantic Ocean	1950, 1998	1100	38	Vasconcellos (this vol.)
Central Atlantic Ocean	1950, 1998	1460	38	Vasconcellos (this vol.)

Table 2. Parameters estimates and associated test statistics for multiple linear regression to predict the (log) biomass for fishes (TL \geq 3.0 cm) during the period from 1960s to 2000. Logarithmic transformations are used for primary productivity and depth, and a quadratic transformation for distance from coast. The variable are arranged after their t-value (i.e., relative standard errors), which correspond to standardized partial slopes (Blalock, 1972). All parameters are highly significant with $\text{Pr}(> |t|) < 0.0000005$ for all cases.

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 ² (km^2)	-0.0000003	0.0000000	-9.3

RESULTS AND DISCUSSION

Table 2 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 % 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.

The predictions lead to the maps of biomass distributions presented in the two panels of Figure 3, 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 confirm 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 a factor of 13 over the forty year covered here.

Conversely, fishing intensity has increased dramatically (Figure 4). Thus, by any standard models of fish population dynamics, the West African fisheries resources

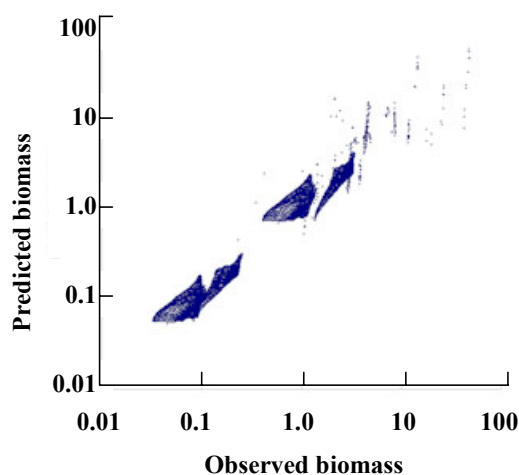


Figure 2. Plot of predicted versus observed biomass ($\text{t}\cdot\text{km}^{-2}$). The 'observed' values are from the spatialization of Ecopath models described in the Methods section, while the predicted values are from the multiple regression documented in Table 2. Note close fit along the 1:1 line.

are overfished (see, e.g., Hilborn and 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.). Conversely, 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. For the countries of the CSRP sub-region, this implies that they must begin to deal with the continued increased of fishing

effort along their coastline, whether in form of industrial fleets owned by nationals or in form of ever-growing 'small-scale' fisheries. For European countries, this implies that they should cease to present the export of surplus fishing capacity toward West Africa as a service to the countries of the sub-region. In

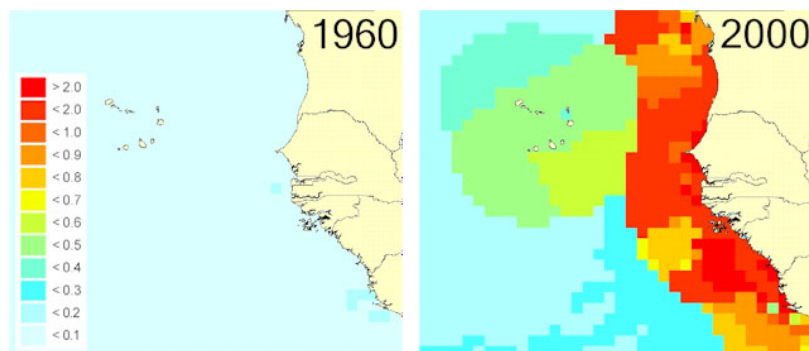


Figure 4. Fishing intensity (= catch/biomass ratio) for fishes (trophic level ≥ 3.0 , excluding small pelagics and mesopelagics) off West Africa in 1960, and 2000. (The units in the legend are year⁻¹).

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REFERENCES

- Amorim, P., G. Duarte, M. Guerra, T. Morato, and K.A. Stobberup. 2002. Preliminary Ecopath model of the Guinea-Bissau continental shelf ecosystem (NW-Africa), p. 73-90. In: Pauly, D., M.L.D. Palomares and J.M. Vakily (eds.) *Modèles trophiques des écosystèmes marins nord-ouest africains / Trophic models of northwest African marine ecosystems. Projet SIAP, Module Ecopath, Document Technique N° 3 (SIAP/EP/DT/03)*. SIAP Project Coordination Unit, Conakry, Guinea. [Available online as chapter in Palomares and Pauly (2004) at www.fisheries.ubc.ca].
- Behrenfeld, M. J. and Falkowski, P. G. 1997. Photosynthetic rates derived from satellite-based chlorophyll concentration. *Limnology and Oceanography*, 42, 1-20.
- Blalock, H. M. 1972. *Social Statistics*. McGraw-Hill, New York.

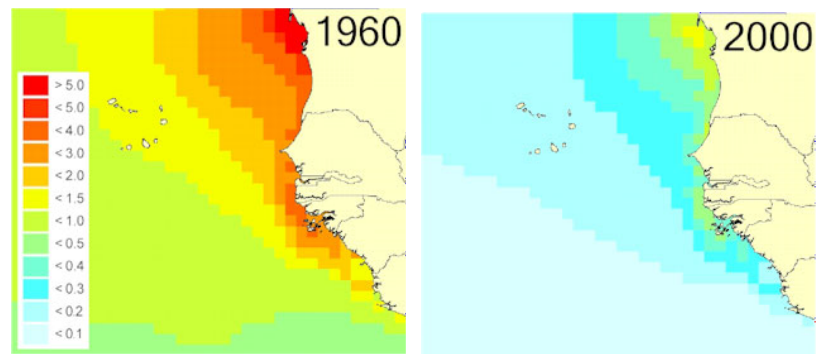


Figure 3. Biomass distributions for fishes (trophic level ≥ 3.0 , excluding small pelagics and mesopelagics) off West Africa in 1960 and 2000. (The units in the legend are t·km⁻²). The distributions are predicted from a multiple linear regression which considers on year, log-transforms of depth and primary production, distance from coast, temperature and the catch of medium and large demersal fishes. Note that the high coastal concentrations in the early period have nearly completely disappeared.

fact, as shown by Kaczynski and Fluharty (2002), the benefits of fisheries access agreements between the EU and the countries of the sub-region accrue overwhelmingly to the European countries, a situation which is only gradually becoming known to the wider public (see MacKenzie, 2002). This also largely applies to fleets from other parts of the world, which extract immense amounts of fish from West Africa (Bonfil *et al.*, 1998), without the coastal countries appearing to obtain fair compensation.

- Bonfil, R., Munro, G., Sumaila, U. R., Valtysson, H., Wright, M., Pitcher, T., Preikshot, D., Haggan, N. and Pauly, D. 1998. *Distant water fleets: An ecological, economic and social assessment*. Fisheries Centre Research Reports. 6(6), 111 p. [Available online at www.fisheries.ubc.ca]
- Christensen, V., Guénette, S., Heymans, J. J., Walters, C. J., Watson, R., Zeller, D. and Pauly, D. 2003. Hundred-year decline of North Atlantic predatory fishes. *Fish and Fisheries*, 4(1): 1467-2979.
- Christensen, V. and Pauly, D. 1992. Ecopath II - a software for balancing steady-state ecosystem models and calculating network characteristics. *Ecological Modelling*, 61, 169-185.
- Christensen, V., Walters, C. J. and Pauly, D. (2000) *Ecopath with Ecosim: a User's Guide, October 2000 Edition*. Fisheries Centre, University of British Columbia, Vancouver, Canada and ICLARM, Penang, Malaysia. [Available online at www.ecopath.org].
- Diallo, I., Cissé, I. and Bah, A. 2002. Modèle trophique du système côtier du plateau continental Guinéen, p. 91-103. In: Pauly, D., M.L.D. Palomares and J.M. Vakily (eds.) *Modèles trophiques des écosystèmes marins nord-ouest africains / Trophic models of northwest African marine ecosystems. Projet SIAP, Module Ecopath, Document Technique N° 3 (SIAP/EP/DT/03)*. SIAP Project Coordination Unit, Conakry, Guinea. [Available online as chapter in Palomares and Pauly (2004) at www.fisheries.ubc.ca].
- Diouf, T., Samb, B. and Mendy, A. 2002. Trophic modelling of the Senegal-Gambian upwelling system, p. 63. In: Christensen, V., Reck, G. and Maclean, J.L. (eds.) *Proceedings of the INCO-DC Conference Placing Fisheries in their Ecosystem Context. Galápagos Islands, Ecuador, 4-8 December 2000*. ACP-EU Fisheries Research Reports, (12): vii-79 p., Brussels.
- Gjøsaeter, J., and Kawaguchi, K. 1980. A review of the world resources of mesopelagic fish. Rome, FAO Fisheries Technical Paper, 193. 151 p.
- Guénette, S., and Diallo, I., 2003. Addendum: Modèles de la côte guinéenne, 1985 et 1998, p. 106-139. In: M.L.D. Palomares and D. Pauly (eds.) *West African marine ecosystems: models and fisheries impacts*. Fisheries Centre Research Report 12(7). UBC, Vancouver, BC.
- Heymans, J. J. and Vakily, J. M. 2002. Ecosystem structure and dynamics of the marine system of Sierra Leone for three time periods: 1964, 1978 and 1990, p. 109-120. In: Pauly, D., M.L.D. Palomares and J.M. Vakily (eds.) *Modèles trophiques des écosystèmes marins nord-ouest africains / Trophic models of northwest African marine ecosystems. Projet SIAP, Module Ecopath, Document Technique N° 3 (SIAP/EP/DT/03)*. SIAP Project Coordination Unit, Conakry, Guinea. [Available online as chapter in Palomares and Pauly (2003) at www.fisheries.ubc.ca].
- Hilborn, R. and Walters, C. J. (1992) *Quantitative Fisheries Stock Assessment: Choice, Dynamics and Uncertainty*. Chapman and Hall, New York.
- Kaczynski, V. M. and Fluharty, D. L. 2002. European policies in West Africa: who benefits from fisheries agreements? *Marine Policy*, 26, 75-93.
- MacKenzie, D. 2002. African fisheries on the brink of collapse. *New Scientist* 175 (2351): 5
- Mendy, A. 2002. A trophic model of the Gambian continental shelf system in 1986, p. 57-72. In: Pauly, D., M.L.D. Palomares and J.M. Vakily (eds.) *Modèles trophiques des écosystèmes marins nord-ouest africains / Trophic models of northwest African marine ecosystems. Projet SIAP, Module Ecopath, Document Technique N° 3 (SIAP/EP/DT/03)*. SIAP Project Coordination Unit, Conakry, Guinea. [Available online as chapter in Palomares and Pauly (2003) at www.fisheries.ubc.ca].
- Ould Taleb Ould Sidi, M. and D.M. Samba. 2003. Modèle écotrophique du Banc d'Arguin (Mauritanie) dans la période 1988 à 1998, p. 10-17. In: M.L.D. Palomares and D. Pauly (eds.) *West African marine ecosystems: models and fisheries impacts*. Fisheries Centre Research Report 12(7). UBC, Vancouver, BC.
- M.L.D. Palomares and D. Pauly (Editors). 2004. *West African marine ecosystems: models and fisheries impacts*. Fisheries Centre Research Report 12(7). UBC, Vancouver, BC. 204 p.
- Pauly, D., Christensen, V. and Walters, C. 2000. Ecopath, Ecosim, and Ecospace as tools for evaluating ecosystem impact of fisheries. *ICES Journal of Marine Science*, 57, 697-706.
- Pauly, D., M.L.D. Palomares and J.M. Vakily (Editors). 2002. Modèles trophiques des écosystèmes marins nord-ouest africains / Trophic models of northwest African marine ecosystems. Projet SIAP, Module Ecopath, Document Technique N° 3 (SIAP/EP/DT/03). SIAP Project Coordination Unit, Conakry, Guinea.
- Samb, B. and Mendy, A. 2002. Dynamique du réseau trophique de l'écosystème sénégalais en 1990, p. 35-51. In: Pauly, D., M.L.D. Palomares and J.M. Vakily (eds.) *Modèles trophiques des écosystèmes marins nord-ouest africains / Trophic models of northwest African marine ecosystems. Projet SIAP, Module Ecopath, Document Technique N° 3 (SIAP/EP/DT/03)*. SIAP Project Coordination Unit, Conakry, Guinea. [Available online as chapter in Palomares and Pauly (2004) at www.fisheries.ubc.ca].
- Stobberup, K. A., Ramos, V. D. M. and Coelho, M. L. 2002. Ecopath model of the Cape Verde coastal ecosystem, p. 17-33. In: Pauly, D., M.L.D. Palomares and J.M. Vakily (eds.) *Modèles trophiques des écosystèmes marins nord-ouest africains / Trophic models of northwest African marine ecosystems. Projet SIAP, Module Ecopath, Document Technique N° 3 (SIAP/EP/DT/03)*. SIAP Project Coordination Unit, Conakry, Guinea. [Available online as chapter in Palomares and Pauly (2004) at www.fisheries.ubc.ca].
- Vasconcellos, M. and R. Watson. 2004. Mass-balance of Atlantic oceanic ecosystems, p. 151-195. In: M.L.D. Palomares and D. Pauly (eds.) *West African marine ecosystems: models and fisheries impacts*. Fisheries Centre Research Report 12(7). UBC, Vancouver, BC.
- Walters, C., Pauly, D. and Christensen, V. 1999. Ecospace: Prediction of mesoscale spatial patterns in trophic relationships of exploited ecosystems, with emphasis on the impacts of marine protected areas. *Ecosystems*, 2, 539-554.
- Watson, R., Gelchu, A. and Pauly, D. 2001. Mapping fisheries landings with emphasis on the North Atlantic, p. 1-11. In: D. Zeller, R. Watson and D. Pauly (eds.) *Fisheries impact on North Atlantic marine ecosystems: catch, effort and national and regional data sets*. Fisheries Centre Research Reports, 9(3).