Census of Marine Life: Turning Concept into Reality
ICES CM 2002/L:19

Typology and characterization of European "Ecosystem Fisheries Units"

By Emmanuel Chassot, Didier Gascuel and Martial Laurans.

Abstract

Statistical analyses were carried out in order to define "Ecosystem Fisheries Units" (EFU) among ICES divisions. The main objective of EFU is to conciliate management areas at an ecosystem scale. In this view, Multiple Correspondence and Factor Analyses on 20 ICES areas for most of the fish stocks reported in the ICES Advisory Committee on Fishery Management (ACFM) were first performed to define potential ecosystem units. Factor analysis on catch data for the most harvested species was also conducted. Hierarchical classifications were then performed to gather areas presenting similar species and stocks compositions and productions. Regrouping ICES areas in a few EFU closer to an ecosystem view permitted to restrict the study to some fisheries units more easily comparable. Ecosystemic indicators are calculated to characterize the EFU: productivity, variability in catches, mean trophic levels of species landed, catches diversity and variability of the Primary Production Required to sustain fisheries. Multivariate analysis on a few indicators was conducted in order to compare the EFU and obtain their typology. Results show significant differences between the predefined units. Some of the EFU are highly productive, stable in the catches and seem to remain quite constant as time goes by. On the other hand, some EFU are showing trends of decrease in the production and in the mean trophic levels of the catches and increase in the diversity of targets. The interest of combining different ecosystem indicators through multivariate analysis and comparing fisheries units among Europe is discussed. Limits of reliability of the available data at this scale of study and pertinence in the choice of the indicators are questioned. Although fisheries history and species targeted can be very different, some EFU seem to show similar trends in regard to the studied indicators. This could be linked to a structure and/or function of the ecosystem that are close. Nevertheless, inference from the fishery to the ecosystem behaviour have to be done with great care.

Keywords : ecosystem management, trophic level, classification, indicator, variability, stability, diversity, productivity, multivariate analysis.

Emmanuel Chassot, Didier Gascuel, Martial Laurans : ENSAR, Laboratoire Halieutique, 65 rue de Saint Brieuc, CS 84215, 35042, Rennes cédex, France. Tel : +33 (0) 2 23 48 54 56, email : chassot@roazhon.inra.fr

Introduction

Fishing has an obvious impact on the structure and function of marine ecosystems by affecting all their components, (e.g. Jennings and Kaiser, 1998; Hall, 1999). In this view, an ecosystem approach is nowadays advocated to progressively replace or complete single-species management (Gislason et al., 2000, Caddy and Cochrane, 2001). Although ecosystem management is well defined (Christensen et al., 1996), the way of implementing it in fisheries science remains controversial because a holistic view tends to complicate greatly the system to understand and the management process (Caddy and Cochrane, 2001). As noted by Gislason et al. (2000), " this wider perspective in fish-stock assessment and management advice will be a great challenge for fisheries science at the turn of the millennium". In this context, a demand for the development of robust indices of ecosystem state to quantify the impact of fishing has been increasing (e.g. Caddy, 1999; Murawski, 2000). Many indicators have thus been developed (see for a review Rochet and Trenkel, 2002) and the SCOR/IOC Working Group 119 on 'Quantitative Ecosystem Indicators for Fisheries Management' has been created for the period 2001-2004. However, the ecosystem concept considers a specific spatial unit (O'Neill, 2001) and one of the main challenges to ecosystem management is "the mismatch between spatial and temporal scales of management and the scales at which ecosystem processes operate" (Christensen et al., 1996). Therefore, by a similar approach to the "Large Marine Ecosystem" (LME) defined as a regional unit for the management of living marine resources (Sherman, 1991; Birkett and Rapport, 1996), we specified "Ecosystem Fisheries Units" (EFU) in Europe. To define those EFU, we used the species and stocks compositions of the fish landed as well as the amounts of catches for each species. EFU have thus been determined from ICES areas because they correspond to the smallest scale at which data are available. Regrouping ICES areas in EFU closer to an ecosystem view permitted to restrict the study and to consider Europe as a few fisheries units more easily comparable.

In this paper, we applied some of the many existing indicators to the EFU in order to compare them or follow their evolution on a relatively long period. Indicators used are easy to estimate from catch data and species trophic levels and focus on production and its stability, diversity of the fishery targets, mean trophic levels' variability of the fish landed. Our aim was to characterize the European fisheries units by simple indices and to look for a certain typology of them. We thus wanted to answer the following questions : (1) Are there any EFU showing similar patterns according to the indices chosen? (2) Can we follow the evolution of the 'state' of an EFU for a time? (3) Are there significant correlations between the indicators employed? Finally, we discuss the possible use of the EFU as a management unit and the interest of using multivariate analysis as a way of combining different ecosystem indicators.

Data and methods

All data used in this study come from the ICES database using the FAO software Fishstat[1]. Caches by species from 1974 to 1998 for the ICES areas were used for a list of fishes and other organisms (molluscs and gastropods) given in table 1 (appendix). Correspondent trophic levels are also given in appendix and come from the internet site *http://www.fishbase.org*. Years 1999 and 2000 were not taken into account because of missing French data during this period.

In order to establish a few groups of “Ecosystem Fisheries Units (EFU)” within ICES areas, multivariate analysis under SPAD[2] software were used. Multiple Correspondence analysis (MCA) was first performed for the fish stocks defined by the Advisory Committee on Fishery Management. Twenty ICES sub-divisions were considered as statistical individuals (figure 1) and described by a presence/absence criterion for the ‘fish stocks’ variables. MCA objective is to realize a typology of the sub-divisions that relies on the notion of proximity. The more two individuals have modalities in common, the nearer they are (Escofier and Pagès, 1998). A hierarchical classification was then realized in order to obtain homogenous classes for the considered ICES areas. Factor Analysis (FA 1) for the same areas and variables was then carried out by replacing presence/absence criterion by amounts of fish catch for the given species (mean catch for the period 1989-1998). This relies on the assumption that for a given area, harvested species belong to a unique fish stock defined by ACFM. Hierarchical classification was also performed. Besides, Factor Analysis (FA 2) applied on an other set of variables characterizing the areas was driven. Considered variables were mean catches for the period 1989-1998 for 44 species of fish. Selected species represent at least 1% of total catches in at least one of the ICES sub-divisions and don’t include species not well defined (e.g. defined by the genus) or other species than fish. A classification was again realized to build groups of areas. Synthesis of the 3 classifications by taking into account a criterion of contiguity permitted to define the EFU.

In order to characterize each EFU, its “Catches Trophic Spectrum” (CTS; Gascuel, 2001), was estimated for a mean year representing the period 1989-98. CTS represents the amount of catches (expressed here in metric tonnes / km²) in relation to the trophic level of the species caught. The curve is smoothed 4 times with a mobile average on 3 points in order to take into account the range of diet of the catches. The spectrum was also calculated every 5 years (from 1973 to 1998) for some EFU in order to describe the evolution of these fisheries units.

Within each of these EFU, different indicators were also estimated for the period 1989-98 from catch data and fishbase trophic levels. Mean trophic level of fish landed may be used as an index of sustainability in multispecies fisheries (Pauly et al., 2001). Its CV enables to measure the stability in time of the trophic level. Mean production was another indicator to characterize the areas. As recommended by Caddy et al. (1995), one way to compare production in comparable units of measurement is to use the productivity per area of surface of continental shelf. Because our study includes a few deep-sea species as Orange roughy (*Hoplostethus atlanticus*) and some species harvested on the continental slope (e.g. *Micromesistius poutassou*), we decided to calculate the fishing areas within 1000 m depth. Areas were estimated from an ICES & NAFO map of the fisheries statistical areas that was digitised. A short programme written in PERL enabled to estimate the surfaces of each statistical area by counting their number of pixels. CV of the production was used as a index of stability of the catches. Mean Primary Production Required (PPR; Pauly and Christensen, 1995) were also estimated but appear to be highly correlated to mean catches. Simpson’s diversity index (Simpson, 1949) and its CV were employed in order to appreciate the catches diversity among the 60 species considered in the study.

In order to compare the ecosystem characteristics of the EFU, those indicators were used as active variables in a Principal Components Analysis (PCA; Hotelling, 1933). PPR was not conserved as an active variable because of too high correlation with mean catches but its CV was. Illustrative variables included thus mean PPR, and also means and CVs for

[2] Spad Version 4.01© CISTIA-CERESTA 1987-1999

Shannon-Weaver's index (Shannon and Weaver, 1963), Species Richness (RS), Evenness (E) and trends and determination's coefficients for all the variables cited. Those latter were calculated by fitting a linear curve to the variables plots for the period 1989-98. They were used for the interpretation of the main axes of the analysis. Multivariate analysis also permitted to follow the evolution of an EFU for different periods of time. Finally, a hierarchical classification was performed in order to regroup similar units.

We also investigated for any correlation between the indicators used. The joint distributions between those indicators were ignored therefore it seemed preferable to use Spearman rank correlation coefficients (Scherrer, 1984).

Results

Presentation of the EFU

For reasons of clarity, only one classification was exposed in the results. The hierarchical tree obtained from the factor analyses performed on ACFM stocks catches (FA 1) is shown in figure 1. This classification and the two others analyses lead us to associate area IV with IIIr.3015(r)2.80561(e)3.74(t)-2.1655860.1832(V)-8.43088(e)3I80561(i)-2.811.7424(t)-2.1655860.18

is cog90F-805(e)3.72659(e)260f..213(c)33.295585(.)-0.146573( )-60.1213(c)33.39556(F)5.640026(h)-S.3311

1976-80, when data were available. Except for the North Sea Unit, EFU have experienced a decrease in mean trophic level and an increase in diversity of the catches. Some of the EFU show an increase in the mean catches (South Celtic Sea, West Scotland) whereas North Sea and Irish Sea are characterized by a decreasing productivity.

EFU were then partitioned into 3 classes in order to compare them. According to the indices used, Irish Sea, Portugal, Bay of Biscay and North and South Celtic Sea units are characterized by a high diversity of catches, low productivity, low trophic level, stability of the diversity and instability in the catches. The second class composed of West Scotland, North Sea and Basque Country units is more productive, more stable and shows medium diversity and trophic levels for its catches. West Ireland represents the third class defined by low catches of high trophic level and very low diversity. Evolution of Irish Sea unit for the first class and North Sea unit for the second are shown in figure 5b. Since 1974, Irish Sea has experienced a big increase followed by a decline in the production associated with a decrease in the mean trophic levels, an increase in the diversity and the stability of the catches. On the other hand, North Sea production has decreased and become more variable. However, no trend in the diversity and trophic level of the catches has been stressed out for this area.

Correlations between the different indicators were examined. Figure 6 gives the plots for the variables that seemed well correlated according to the projection of the different variables on the first factorial plane. Correlation between the diversity index and the variability of the catches is significant according to the Spearman coefficient ($r=0.75$, $p<0.025$). Correlation between the diversity index and the coefficient of variation of this index is highly significant ($r=-0.97$, $p<0.001$). Mean trophic level and diversity of the catches are however not significatively correlated ($r=0.37$) and correlation between the coefficient of variation of the trophic level and the catches is just significant ($r=0.58$, $p<0.05$).

Discussion

Ecosystem Fisheries Units

The approach employed to form the "Ecosystem Fisheries Units" is clearly very simple and EFU generated are far from matching properly with a real marine ecosystem. Indeed, contrary to the Large Marine Ecosystems characterized by "distinct hydrographic regimes, submarine topography, productivity, and trophically dependent populations" (Sherman, 1991), EFU are only defined by taking into account the species composition of the catches harvested in the ICES areas and the share of common fish stocks. Therefore, the use of extra oceanographic and topographic data could permit to define more plausible marine ecosystems among Europe. However, that kind of data is often not available at the scale of interest. Moreover, our aim is not to define real marine ecosystems but to look for a new scale of study of the European fisheries, taking into account the similarity between fisheries and an ecosystem component (same species and stocks targeted). The EFU synthesis was mainly based on the Factor Analysis on the stocks defined by ACFM because we made the assumption that the more 2 areas have fish stocks in common (in the same order of magnitude), the nearer their ecosystem. A Factor Analysis on mean catches was also realized because ACFM stocks only include stocks of commercial interest and we wanted to take into account other harvested species. Moreover, some areas were only characterized by 1 or 2 stocks and couldn't be well separated by the analysis. Finally, EFU formed by the analysis seemed relatively coherent according to our knowledge of the fisheries. They correspond quite well with some of the divisions defined by Longhurst (1998). This approach has the advantage of studying average or integrated properties of a few fisheries units, each being located within a specified spatial area.

Catches Trophic Spectra

Trophic spectra are a picture of an ecological system or a fishery at a given time (Gascuel, 2002). It gives the biomasses present by trophic level or the harvested biomasses for the CTS. The use of a mobile average allows to take into account the range of potential food available for the species but limits the quantitative interpretation of the spectrum. Their interest is to characterize a fishery by emphasizing the trophic levels targeted and the importance of catches for each trophic level. It thus allows to compare different ecosystems or fisheries and to follow their evolution during a certain period of time. Figure 3 shows the history of the North Sea Unit from 1974 to 1998. The fishery mainly targets species of trophic levels within 3 and 3.8, especially Norway pout (*Trisopterus esmarkii*), Atlantic herring (*Clupea harengus*) and Sandeels (*Ammodytes spp.*). The short move forward higher trophic levels is mostly due to a decrease of Norway pout and European plaice (*Pleuronectes platessa*) catches in the nineties associated with an increase of the Sandeels production. Productivity for the low and high trophic levels seems to have decreased from the 70's to the 90's whereas intermediate trophic levels have experienced a relatively important increase. Thus, "Catches Trophic Spectra" seem to have an interest to globally describe the targets and productivity of a fishery and might be helpful in understanding its historic evolution. Their application to a real ecosystem would also permit to follow the shifts in abundance, diversity and composition among the species as time goes by and could be a way of comparison of different ecosystems. This approach is similar to the signatures of the ecosystem introduced by Froese et al. (2001) in order to compare the trophic structure of some LME. However, it requires an estimation of the abundances and trophic levels of all the species present, something almost impossible to obtain.

Ecosystem indicators

Indicators used in the study are easy to estimate from the catch data and the trophic levels of the species. However, limits about these indicators have to be mentioned. First, data

Diversity indices calculated were applied to the 62 species conserved in the study and not used to describe the marine ecosystems. Simpson's diversity index (D; Simpson, 1949) was chosen because Species Richness or Evenness (E) are considered too restrictive and the Shannon-Weaver index (SW) has no greater biological relevance (Hurlbert, 1971). Species richness was also certainly biased because of an improvement of the data collect since the seventies. PCA results showed however that E, SW and D were highly and positively correlated. The productivity for the EFU was calculated from a relatively rough estimation of the areas within 1000 meters deep. The Etopo5 database (US National Geophysical Data Center) of topography and bathymetry could permit to improve the estimation of the areas. Moreover, most of the pelagic fishes included in the study can be caught at the water surface, even beyond the continental shelf (Jacques Massé, *pers. com.*). Those catches remain nevertheless minor in comparison to the production realized on the continental shelf. Finally, by a similar approach as Pauly et al. (1995), we estimated the Primary Production Required to sustain the fisheries in each EFU. However, using Coastal Zone Colour Scanner (CZCS) data, available from 1978 to 1986, could allow to estimate mean PP in each of the areas and thus the percentage of PPR required for the fisheries. This would permit to compare the degree of utilization of PP between the areas and follow its evolution in time.

The correlation between diversity and stability in the catches is significant. This implies that diversification of the species targeted allows to buffer variability of the resource. This might be mainly due to an averaging statistical effect known when applied to the biomasses as the "portfolio effect" (Tilman, 1999). Interpretation as the ecosystem level is however difficult because of the too many factors involved. Relation between diversity and its variability is highly significant and negative. It means that the most diverse fisheries units remain diverse in time. Finally, variability of the trophic levels of species landed is correlated negatively with the production. This suggests that highly productive fisheries units target constantly the same trophic position whereas EFU with a low productivity modify the trophic levels sought. Shifts in the species abundances or diversification by changes in the targeted species might explain the relation observed.

Through a subset of selected species, indicators were used to describe the fisheries and not the ecosystems. As stated by Pauly and Froese (1998) about mean trophic levels as indicators, "using landing data as ecosystem indicators is not really a problem: landings of major resources species should generally reflect the relative magnitudes of their biomasses in the ecosystems from which the landings are extracted". Therefore, interpreting the EFU states, reflected by the PCA, as the states of the corresponding ecosystems might be a step forward in the reflection. This inference might however be seen very cautiously as the number of indicators is low, the fishing effort ignored and the number of species not exhaustive. Many other processes have to be taken into account to compare the different ecosystems: natural fluctuations of the environment, fisheries policies, economic demand, technological advances. Using abundance indices could permit to have a more direct relation with the ecosystem.

Conclusion

The main objective of the EFU is to find a scale of management that is closer to the ecosystem and for which data are available. Ecosystems are however seen today as "disequilibrial, open, hierarchical, spatially patterned and scaled" (O'Neill, 2001) and this questions our ability to match management with the ecosystem processes' scale, geographical boundaries of marine ecosystems being very difficult to define (Gislason et al., 2000). Otherwise, Ecosystem Fisheries Units might be an interesting approach in order to compare different areas around Europe. Some similar trends of the fisheries units can thus be emphasized and a relatively same structure or function of the correspondent ecosystems hypothesized. Inference from fisheries statistics to ecosystem behaviour have however to be done cautiously. Simple analyses realized seem to be quite interesting to evaluate the evolution of a fishery unit. Its situation in the factorial plane allows to define the state of an EFU and to qualify its trend with the time. Reasons of the evolution are however multiple and require a better knowledge of potential shifts met by the fishery and/or the ecosystem.

Combining different indicators in a synthetic index or by a multivariate analysis approach to estimate the state of an ecosystem could be interesting. This requires to carefully select the metrics used, to avoid their redundancy and to be able to estimate reference conditions (Hughes et al., 1998).

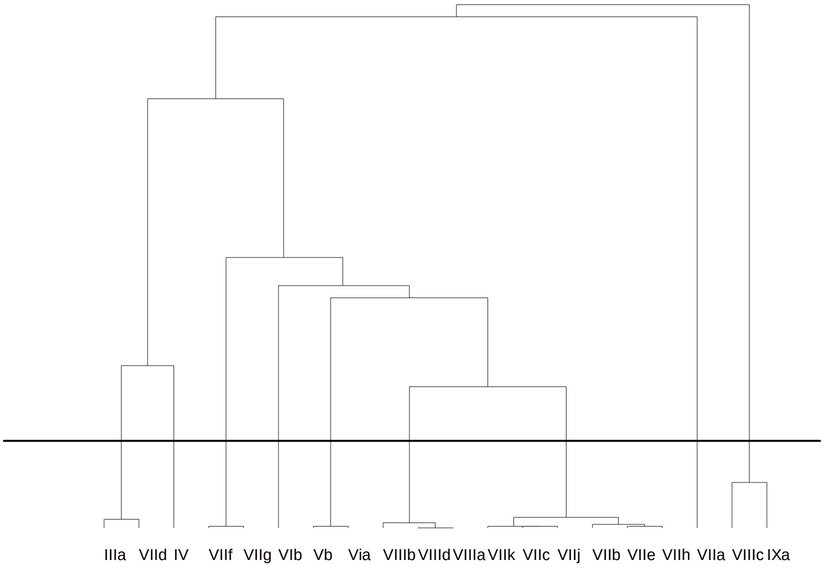


Figure 1. Hierarchical tree representing homogeneous classes of areas according to the amounts of ACFM fish stocks caught by the fisheries for a mean year representing the period 1989-1998. Horizontal line represents the level at which the classes were formed.

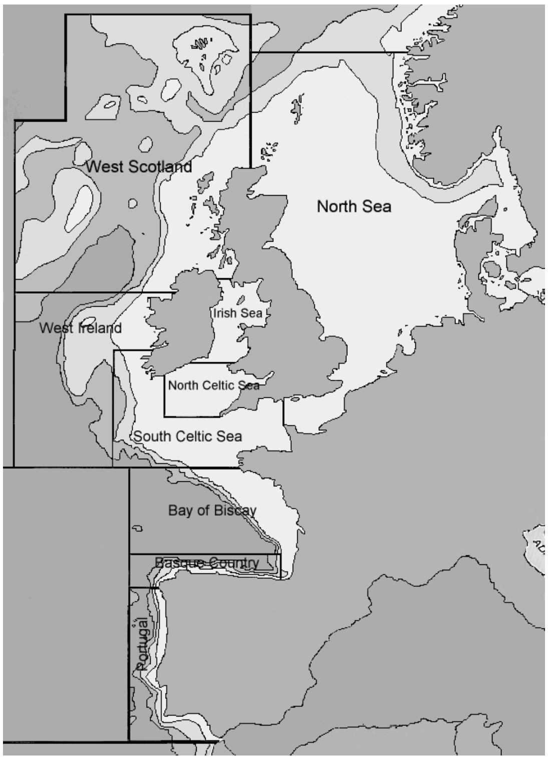


Figure 2. Map showing the “Ecosystem Fisheries Units “ defined from fish stocks/species harvested in Europe.

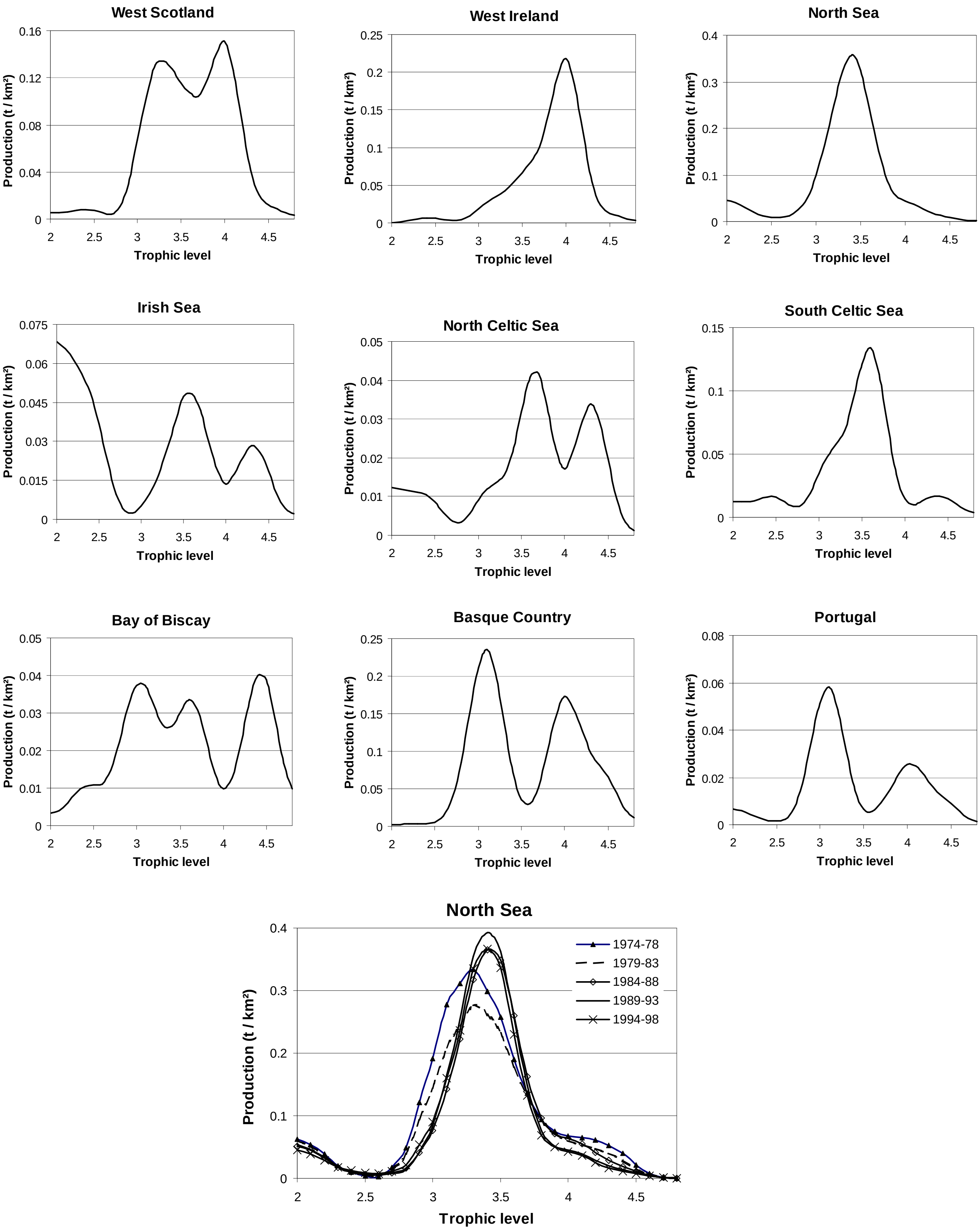


Figure 3. Catches trophic spectra for the 'Ecosystem Fisheries Units' for a mean year corresponding to the period 1989-1998. Scales of production are different according to the EFU considered. Last figure represents the evolution of the North Sea spectrum from 1974 to 1998, every five years.

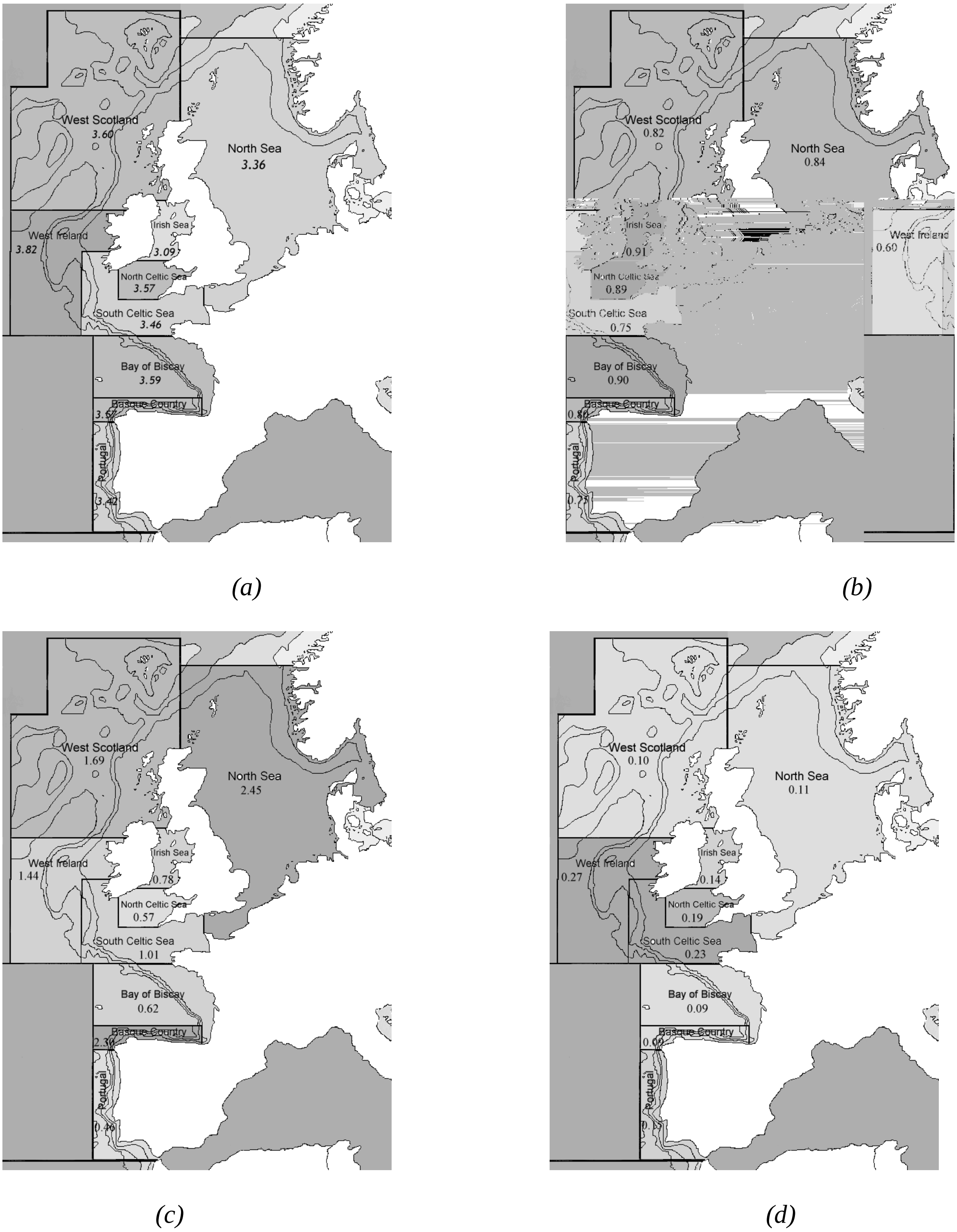
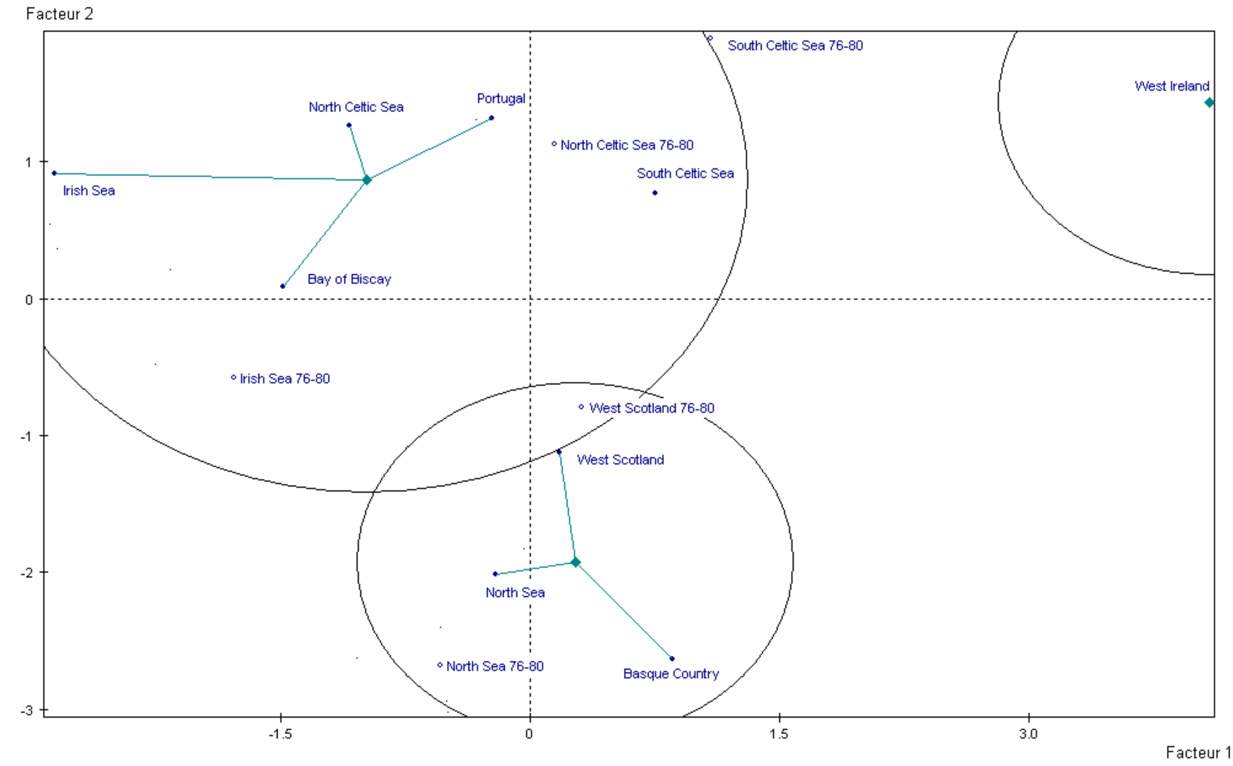
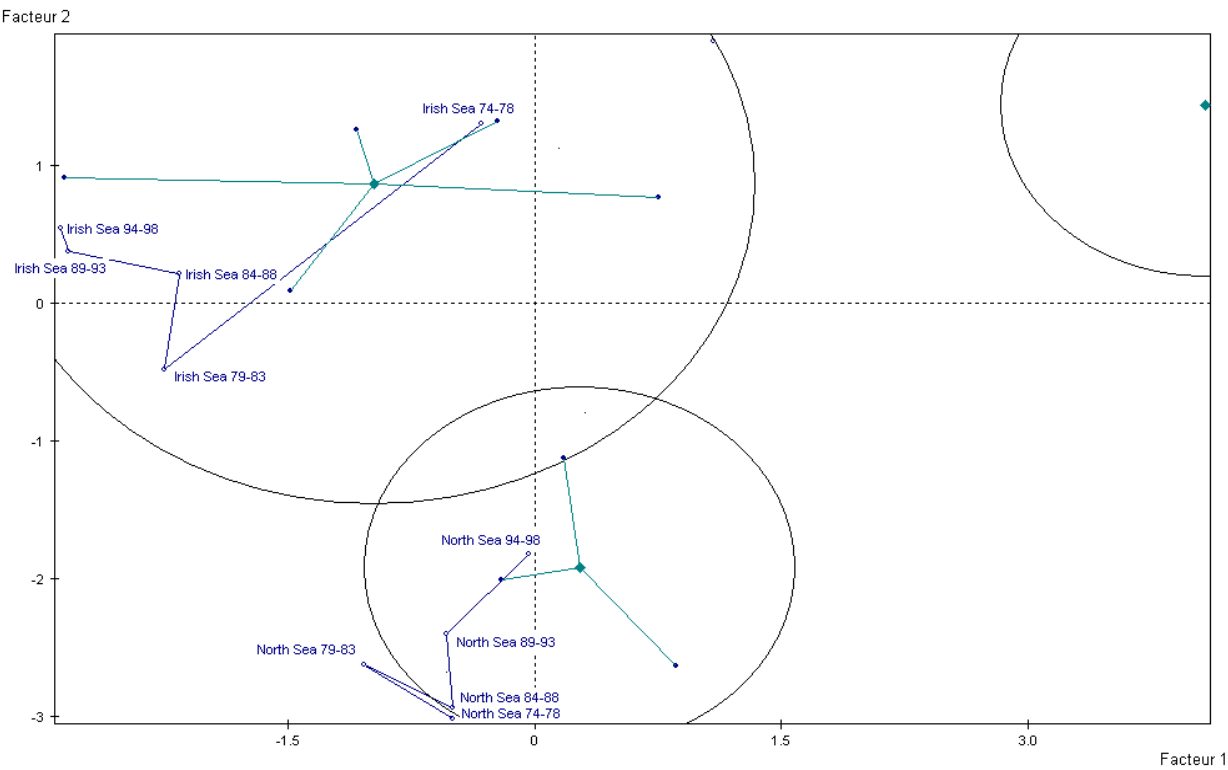


Figure 4. Maps showing different indicators values in the "Ecosystem Fisheries Units". (a) represents mean trophic level of all species landed, (b) gives Simpson's diversity index of the production, (c) gives productivity in tonnes per surface area within 1000 m depth and (d) represents the coefficient of variation of the productivity. All indicators are calculated for a mean year representing the period 1989-98.



5a



5b

Figure 5. First factorial plane defined by the first two axes of the PCA. Axis 1 represents a gradient of mean trophic level and instability of diversity of catches opposed to mean diversity and axis 2 mainly corresponds to instability in the catches opposed to high production. 5(a) represents the 9 EFU for the period 1989-98 and the 3 classes chosen. 5(b) shows the evolution of Irish Sea and North Sea units, every 5 years from 1974 to 1998.

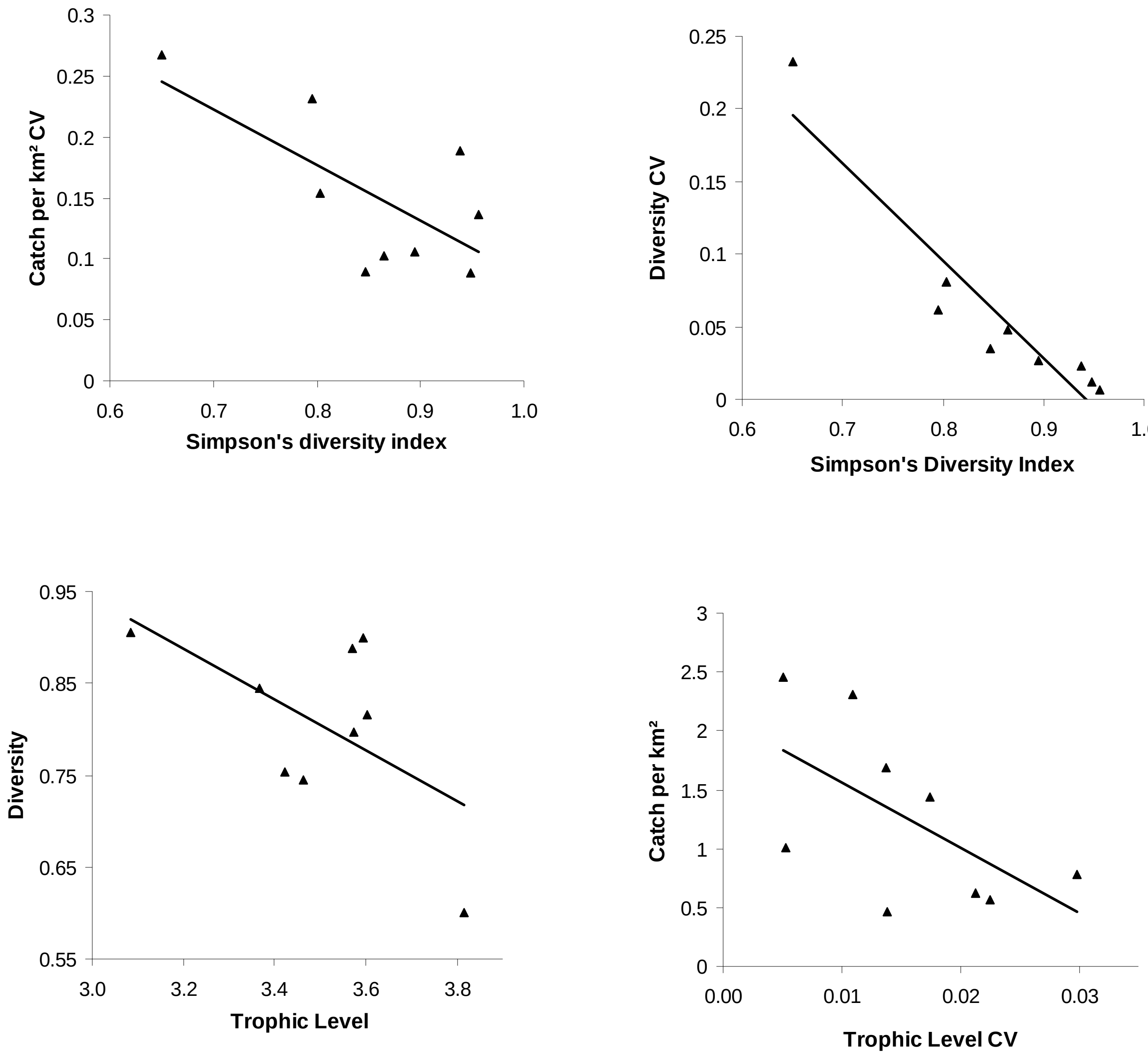


Figure 6. Correlations between some of the indicators estimated for each EFU

References

1. Birkett, S.H. and Rapport, D.J. 1996. Comparing the Health of Two Large Marine Ecosystems: The Gulf of Mexico and the Baltic Sea. *Ecosystem Health* **2 (2)**: 127-144.

2. Caddy, J.F. 1999. Fisheries management in the twenty-first century: will new paradigms apply? *Reviews in Fish Biology and Fisheries* **9**: 1-43.

3. Caddy, J.F. and Cochrane, K.L. 2001. A review of fisheries management past and present and some future perspectives for the third millenium. *Ocean and Coastal Management* **44**: 653-682.

4. Caddy, J.F., Csirke, J., Garcia, S.M., and Grainger, R.J.R. 1998. How Pervasive is "Fishing Down Marine Food Webs"? *Science* **282**: 1383a.

5. Caddy, J.F. and Garibaldi, L. 2000. Apparent changes in the trophic composition of world marine harvests: the perspective from the FAO capture database. *Ocean and Coastal Management* **43**: 615-655.

6. Caddy, J.F., Refk, R., and Do-Chi, T. 1995. Productivity estimates for the Mediterranean: evidence of accelerating ecological change. *Ocean and Coastal Management* **26 (1)**: 1-18.

7. Christensen, N.L., Bartuska, A.M., Brown, J.H., Carpenter, S., D'antonio, C., Francis, R., Franklin, J.F., MacMahon, J.A., Noss, R.F., Parsons, D.J., Peterson, C.H., Turner, M.G., and Woodmansee, R.G. 1996. The Report of the Ecological Society of America Committee on the Scientific Basis for Ecosystem Management. *Ecol. Applic.* **6 (3)**: 665-691.

8. Dufour, E. and Gerdeaux, D. 2001. Apport des isotopes stables ($^{13}C/^{12}C$ $^{15}N/^{14}N$ $^{18}O/^{16}O$ $^{36}S/^{34}S$ $^{87}Sr/^{86}Sr$) aux études écologiques sur les poissons. *Cybium* **25(4)**: 369-382.

9. Escofier, B. and Pagès, J. 1998. Analyses factorielles simples et multiples. DUNOD, Paris.

10. Froese, R., Piatkowski, U., Garthe, S., and Pauly, D. 2001. A preliminary comparison of the trophic structure of some large marine ecosystems. ICES conference. Theme session on Use and Information Content of Ecosystem Metrics and Reference Points **CM 2001/T:07**.

11. Gascuel, D. Un modèle structuré par niveau trophique : approche théorique de l'impact de la pêche sur la biomasse, la production halieutique et la dynamique des écosystèmes marins exploités. Halieutique : complexité et décision. 2002. Editions Ifremer. Actes de colloque. 26-28 juin 2001, Lorient, France.

12. Gislason, H. , Sinclair, M., Sainsbury, K., and O'Boyle, R. 2000. Symposium overview: incorporating ecosystem objectives within fisheries management. *ICES Journal of Marine Science* **57**: 468-475.

13. Hall, S.J. 1999. The effects of fishing on marine ecosystems and communities. Great Britain, 274 p.

14. Hotelling, H. 1933. Analysis of a complex of statistical variables into principal components. *Journal of Education and Psychology* **24**: 417-441, 489-520.

15. Hughes, R.M., Kaufmann, P.R., Herlihy, A.T., Kincaid, T.M., Reynolds, L., and Larsen, D.P. 1998. A process for developing and evaluating indices of fish assemblage integrity. *Can. J. Fish. Aquat. Sci.* **55**: 1618-1631.

16. Hurlbert, S.H. 1971. The non-concept of species diversity : a critique and alternative parameters. *Ecology* **52**: 577-586.

17. Jennings, S. and Kaiser, M.J. 1998. The effects of fishing on marine ecosystems. *Advances in marine biology* **34**: 203-302.

18. Kline, T. C. Jr. and Pauly, D. Cross-Validation of Trophic Level Estimates from a Mass-Balance Model of Prince William Sound Using $^{15}N/^{14}N$ Data. Ed. by T.J. Quinn II, F. Funk J. Heifetz J. N. Ianelli J. E. Powers J. F. Schweigert P. J. Sullivan and C. I. Zhang. *In* Fishery Stock Assessment Models, pp. 693-702. 98. Alaska Sea Grant, Fairbanks.

19. Longhurst, A. 1998. Ecological Geography of the Sea. Academic Press, San Diego. 398p.

20. Murawski, S.A. 2000. Definitions of overfishing from an ecosystem perspective. *ICES Journal of Marine Science* **57**: 649-658.

21. O'Neill, R.V. 2001. Is it Time to Bury the Ecosystem Concept? (with full military honors, of course!). *Ecology* **82 (12)**: 3275-3284.

22. Pauly, D. and Christensen, V. 1995. Primary production required to sustain global fisheries. *Nature* **374**: 255-257.

23. Pauly, D., Christensen, V., Froese, R., and Palomares, M.L. 2000. Fishing down aquatic food webs . American Scientist **88**: 46-51.

24. Pauly, D., Froese, R., and Christensen, V. 1998. How Pervasive is "Fishing Down Marine Food Webs"? *Science* **282**: 1383a.

25. Pauly, D., Palomares, M.L., Froese, R., Sa-a, P., Vakily, M., Preikshot, D., and Wallace, S. 2001. Fishing down Canadian aquatic food webs. *Can. J. Fish. Aquat. Sci.* **58**: 51-62.

26. Rochet, M.-J. and Trenkel, V. 2002. Which community indicators can measure the impact of fishing? A review and proposals. *Can. J. Fish. Aquat. Sci.*

27. Scherrer, B. 1984. Biostatistique. Gaëtan Morin éditeur, Chicoutimi, Québec. 850p.

28. Shannon, C.E. and Weaver, W. 1963. The mathematical theory of communication. Univ. Illinois Press, Urbana. 117p.

29. Sherman, K. 1991. The Large Marine Ecosystem Concept: Research and Management Strategy for Living Marine Resources. *Ecol. Applic.* **1 (4)**: 349-360.

30. Simpson, E.H. 1949. Measurement of Diversity. *Nature* **163**: 688.

31. Tilman, D. 1999. The Ecological Consequences of Changes in Biodiversity: a Search for general principles. *Ecology* **80 (5)**: 1455-1474.