Computational Techniques for Analysis of Spatial Time Series on Fish Species Catch Quantity in Greece

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ABSTRACT

This paper is based on a Multidimensional Fishery Time Series Database of Greece that stores spatial, biological, temporal, technical and economic data extracted from National Statistical Service of the country. Time series on fish species catch quantity are aggregated in order to form the spatial data on three levels: total, fish region and fish area. It provides consistent view of the spatial distribution of fish species catch quantities and allows a multi-scale analysis performance. Computational procedure and software techniques based on intersection of datasets are developed to extract specific features of catch by fish regions, areas and species, as well. Four case studies present analytical capabilities of computational techniques in order to find out significant differences and similarities on fish species catch by regions and by areas. This paper illustrates the use of public information sources on exploitation of natural resources for scientific analysis.

Keywords

fish species; intersection of sets; multi-scale analysis; spatial time series

1. INTRODUCTION

A key challenge in contemporary ecology and conservation is the accurate tracking of the spatial distribution of various human impacts, such as fishing [1]. The Greek coastal fishery is the largest one among all EU countries both in number of vessels and fishermen, causing difficulties in monitoring fishing activities and production. It has a multi-gear and multi-species character [2]. National Statistical Service of Greece (NSSG, ELSTAT) data is the best figures available with respect to length of time, spatial and temporal resolution, consistency, degree of subjectivity, and statistical design of data collection [3], [4], [5], [6]. Many scientific studies are focused on spatial and temporal distribution and analysis of fish production quantity in Greece by various species and areas, as well as, technical means and kind of fishery [7], [8], [9], [10]. The most significant biological parameters for various commercially fished populations are studied in [11], [12].

IMAS-Fish integrated system is considered as a solution which stores and homogenizes diverse datasets on Greek fisheries under a common relational database [13]. It offers a series of on-line fishery statistical analyses and visualizes spatial results. At the same time, software techniques based on data mining and mathematical logic have not been announced. We accept, and also enhance the view in [13] that uncertainties in human values, fisheries systems, and mathematical and computer science methodologies will always be there to be challenged to enrich our imperfect knowledge.

This work aims at aggregating time series on fish species catch quantity in order to form spatial data on three levels: total, fish region and fish area. It provides a consistent view of spatial distribution of fish species catch quantities and allows a multi-scale analysis. The paper presents a computational procedure and software techniques based on intersection of datasets to extract specific features of catch by fish regions, areas and species.

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2. MATERIALS AND METHODS

Multidimensional data on fishery in Greece: spatial, biological, temporal, technical and economical, are extracted from ELSTAT and stored in the hierarchically structured fishery time series (FTS) database [14]. Two processes caused changes in the list of statistically counted fish species of FTS database:

a) The decision to reduce the number of counted fish species from 72 to 65. Five of them are included to the nearest fish family. Two fish species are put into "Others" group considering that they are not very important economically.

b) The renewal of the Greek fish species list by adding new ones and changing the names of others in order to correspond to EU standards.

Both cases lead to discontinuation of the corresponding time series after year 2011 [15], but do not require modifications in FTS database model. Finally, all available data on fish species catch is stored in FTS database. There are stored time series "cut" in year 2011 and time series started in year 2014. As a whole, data on fish catch quantity of 81 fish species in 18 areas is stored in FTS database.

Computational techniques for spatial time series analysis are as follows:

a) Spatial time series on fish catch quantity in Greece by 18 areas and 81 fish species are extracted from the hierarchically structured multidimensional database. Then time series are aggregated on the base of three geographical fish regions of the country – Aegean sea, Ionian sea and Atlantic Ocean with eleven (11), five (5) and two (2) fishing areas, respectively. It gives the opportunity for multi-scale analysis of fish catch quantity time series on three levels: total – region – area.

b) Spatial time series on fish catch quantity are statistically analyzed. Descriptive statistics are calculated. The coefficient of variation c_v, defined as the ratio of standard deviation to average value, is proper in order to compare time series with a widely different means. This applies to the case of fish species catches by regions and areas. Polynomial and exponential models are tested during trend modeling application. If the linear trend model is adequate, the rate can be estimated.

c) A computational procedure is developed to analyze catch quantity by regions and fish species. It consists of the following steps:

- Sort the fish species according to the average of fish catch quantity;
- Extract certain fish species with the highest average value and store them in sets. Let's denote the sets gathering the list of extracted fish species as: A - Atlantic Ocean, B - Ionian sea and C – Aegean sea;
- Take the intersection of sets A, B and C in order to estimate the coincidence of fish species (figure 1).

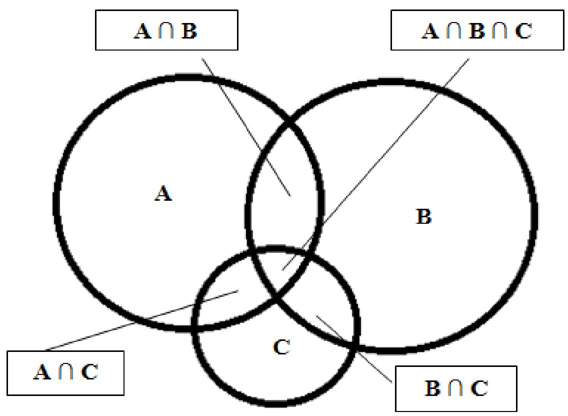

Figure 1 Intersection of ***A, B*** and ***C*** sets

The computing procedure, presented in technique c), can be applied on fish species catch quantity by areas through suitable definition of A, B and C sets. Therefore, the procedure gives the opportunity to find significant differences or similarities in fish species catch by regions and by areas. It is possible to define other criterion in the computational procedure, for example minimal catch by species.

The developed software modules are embedded in the database in order to give a better operability. The reuse of modules is essential related to multi-scale functions – view, data processing and analysis. The software gives the ability to process data for the chosen (different) time periods. This is an opportunity to analyze deeply the dynamic of fish catch quantity.

3. RESULTS AND DISCUSSION

Four case studies present analytical capabilities of the computational techniques regarding spatial time series on fish catch quantity in Greece.

3.1 Statistics by Regions

Table 1 shows the results of applying the software modules for computing descriptive statistics on aggregated time series – average ($\bar{X}$), standard deviation (σ) and coefficient of variation (c_v). Decreasing values of catch quantity from Atlantic Ocean is evident for the time period 2005-2015. Besides, the shares for this fish region decline from 2.8% for 2005 to 1.1% for 2015. The coefficient of variation (63.4%) also reveals the relatively big decline. In addition the catch quantity from Ionian and Aegean sea is decreasing according to the general tendency, but it is not so massive. The coefficient of variation values for these two regions and the total are similar (15-18 %). The largest share of fish catch quantity belongs to Aegean sea region, which is more than 90% for the year 2015.

3.2 Multi-Scale Analysis

This case study presents a multi-scale time series analysis of fish species catch quantity on the three levels: total – regions (3) – areas (18). The results are obtained after applying the software modules for statistical computing and sorting. Table 2 presents the biggest and smallest averages of fish catch quantity. European anchovy, European pilchard and European hake consist the largest catch quantity from Aegean sea, Ionian sea and total, as well. These fish species are from the group "Fishes". The interesting fact is that the big catch quantities from Atlantic Ocean are registered for Common octopus, Deep-water rose shrimp and Common cuttlefish from the group "Cephalopods" and Common spiny lobster from the group "Crustaceans". Great Atlantic scallop and European eel are in the list of fish species with minimal average values. Most probably these fish species are in risk and it has to be noticed that they contribute to the biodiversity of Greek fishery system. The detailed results of time series analysis can interest the fishery management specialists and marine biologists.

Table 1 Time series on fish catch quantity by regions and shares (%)

Year	2005	2006	2007	…	2014	2015	$\bar{X}$	σ	c_v/%/
Atlantic Ocean	2548.2	4183.0	3209.0		729.2	724.9	1766.7	1120.5	63.4
Share (%)	2.8	4.6	3.6		1.2	1.1			
Ionian sea	10864.8	8918.0	8502.0		6079.1	5407.4	7884.2	1420.4	18.0
Share (%)	12.0	9.7	9.6		10.1	8.4			
Aegean sea	76624.9	78037.0	76649.0		53510.1	58104.3	63660.4	10118.5	15.9
Share (%)	84.7	85.3	86.7		88.7	90.5			
Total	90471.6	91538.0	88360.0		60318.4	64236.6	73387.1	12289.5	16.7

Table 2 Average catch quantity $\bar{X}$ (m^3tons), time period 2005-2015

Total
Fish name ($\bar{X}$,m^3tons)
European anchovy (12125,276); European pilchard (=Sardine) (8368,591); Marine fishes nei (7050,946); European hake (4327,318); Bogue (3410,973); ……………………………………… Great Atlantic scallop (10,8288); European eel (8,806).

Region		
Atlantic Ocean	**Ionian sea**	**Aegean sea**
Fish name ($\bar{X}$,m^3tons)	**Fish name ($\bar{X}$,m^3tons)**	**Fish name ($\bar{X}$,m^3tons)**
Marine fishes nei (449,525); Common octopus (347,782); Deep-water rose shrimp (242,74); Common spiny lobster (198,03); Common cuttlefish (153,318); ……………………………… European hake (0,6); Greater amberjack (0,571).	European hake (912,355); European pilchard (=Sardine) (839,915); Bogue (753,621); Picarel (669,825); European anchovy (434,519); ………………………………… Great Atlantic scallop (0,036); Mediterranean mussel (0,032).	European anchovy (11690,76); European pilchard(=Sardine) (7528,68); Marine fishes nei (6215,376); European hake (3414,909); Bogue (2657,352); ……………………………………… Great Atlantic scallop (10,792); European eel (7,603).

Area		
Coasts of lpiros and Kerkyra	**…**	**Kriti**
Fish name ($\bar{X}$,m^3tons)		**Fish name ($\bar{X}$,m^3tons)**
European pilchard (=Sardine) (118,456); European anchovy (97,136); Bogue (91,094); Picarel (68,18); European hake (63,544); Red mullet (46,765); ……………………….. European eel (0,198); Marine crabs nei (0,191).	……	Marine fishes nei (305,704); Picarel (292,474); Bogue (216,924); Swordfish (148,452); European hake (129,030); Red mullet (96,396); ……………………………………… Garfish (0,145); Marine crabs nei (0,118).

Table 3 Time series and statistics on fish catch quantity in m^3 tons for fish species Bogue

Region name	2005	2006	…	2015	$\bar{X}$, m^3tons	σ	c_v/%/	Rate per year (m^3tons)	Rate per year (%)
Atlantic Ocean	_	_	_	_					
Ionean sea	1161.40	863.00	…	405.06	753.62	206.97	27.46	-55.98	-7.43
Aegean sea	3025.10	2986.00	…	2508.75	2657.35	276.55	10.41	-68.72	-2.59
Total	4186.50	3849.00	…	2913.82	3410.97	440.68	12.92	-124.71	-3.66

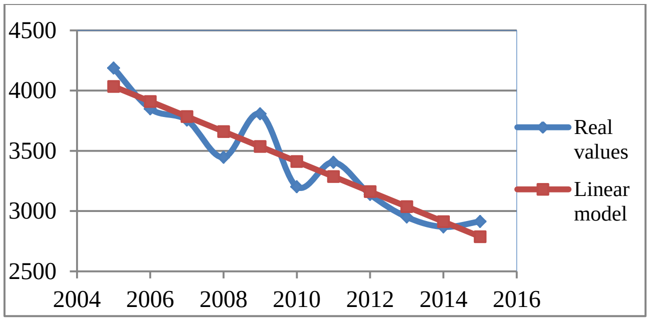

Figure 2 Real values and linear trend model for total catch quantity of Bogue

3.3 Spatial and Temporal Information Profile Of Each Fish Species Catch Quantity

This analysis aims at systematizing the information on the spatial and temporal catch quantity of the chosen one fish species. Table 3 shows time series and statistical estimations on the catch of fish species Bogue for the period 2005-2015. There are no catches from Atlantic Ocean. Computed coefficient of variation c_v shows higher stability of catch from Aegean sea comparing it with Ionian sea. Linear, second and third degree trend models and exponential one are studied. The adequacy of linear model is proven. The maximum declining rate per year is estimated for Ionian sea (-7.43%) while the minimum (-2.59%) is for Aegean sea (table 3). The real values of time series and linear model for total catch quantity are graphically presented in figure 2.

Catch quantity average values of areas, regions and total are sorted. Table 4 shows the position of fish species Bogue in the sorted lists.

Table 4 Position of fish species Bogue under the fish catch quantity average, period 2005-2015

Level	Position
Total	***4***
Region	
Atlantic Ocean	***-***
Ionian sea	***3***
Aegean sea	***5***
Area	
Coasts of Ipiros and Kerkyra	***3***
Amvrakikos Gulf and coasts of Lefkada island	***4***
……..	
Kriti	***3***

3.4 Intersection of Datasets

First of all, the computational procedure sorts the fish species according to the average catch quantity of fish species by regions for the chosen time period. Then, the 10 fish species with the highest average value are extracted and stored in sets, as follows: A - Atlantic Ocean, B - Ionian sea and C – Aegean sea. Intersection of the sets A, B and C is done in order to estimate the coincidence of fish species. Two examples are realized:

a) Long time period (1990-2013), when old list of fish species is used. It contains 72 species. Table 5 presents the results of the intersected datasets. The finding of fish species coincidence with the highest average value provides information on differences and similarities in fish catch among regions. It is evident that 9 from 10 fish species caught from Ionian and Aegean sea coincident. In the same time only Anchovy, Hake and Others are in the list of the coincident fish species of Atlantic Ocean. Therefore, the fish catch from Atlantic Ocean has a relevant contribution to the diversity of catch.

Table 5 Intersection, period 1990-2013, old list of fish species

A ∩ B		**A ∩ C**	
Fish Code	**Name**	**Fish Code**	**Name**
13	Anchovy	13	Anchovy
8	Hake	8	Hake
63	Others	63	Others
B ∩ C		**A ∩ B ∩ C**	
Fish Code	**Name**	**Fish Code**	**Name**
13	Anchovy	13	Anchovy
46	Pilchard	8	Hake
27	Picarel	63	Others
15	Bogue		
47	Horse mackerel		
22	Club mackerel		
8	Hake		
23	Goatfish		
63	Others		

b) Short time period (2014-2015) when the new list of fish species is applied. Statistically counted fish species are 81. The number of coincident fish species for Ionian and Aegean sea is 7 (table 6). An interesting result is seen regarding Atlantic Ocean:

- Anchovy and Hake are not in the list of coincident fish species;
- Common octopus and Caramote prawn appears in 10 fish species with the highest average value of Atlantic Ocean and Aegean sea.

Table 6 Intersection, period 2014-2015, new list of fish species

A ∩ B		**A ∩ C**	
Fish Code	**Name**	**Fish Code**	**Name**
63	Marine fishes nei	69	Common octopus
		63	Marine fishes nei
		72	Caramote prawn
B ∩ C		**A ∩ B ∩ C**	
Fish Code	**Name**	**Fish Code**	**Name**
13	European anchovy	63	Marine fishes nei
46	European pilchard (=Sardine)		
8	European hake		
15	Bogue		
63	Marine fishes nei		
27	Picarel		
23	Red mullet		

The obtained information from this time series analysis is interesting for marine biologists providing a precise view of the fish distribution in space. Besides, this information might be useful for fish management because fish species with the highest average catch quantity are usually economically the most important fish species.

4. CONCLUSION

The developed computational techniques and software provide multi-scale analysis of time series database on fishery in Greece and find out significant differences and similarities on fish species catch by regions and by areas. The quality of the achieved information proceeds with integrity and synergy between software and spatial time series stored in database. The software modules can be applied on other time series databases with spatial dimension.

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