HABITAT SELECTION OF FLATFISH IN RELATION TO SPATIAL, TEMPORAL AND ENVIRONMENTAL PARAMETERS IN THE AEGEAN SEA

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Abstract

Generalized additive models (GAMs) were applied to investigate the influence of spatial (subarea), temporal (season), and environmental variables (substrate characteristics, depth, temperature, and salinity) on the relative abundance of eight flatfish species (order: Pleuronectiformes) in the Aegean Sea. Most species exhibited a decreasing population density with depth, while all of them were encountered within the continental shelf or the upper continental slope. Sediment characteristics were included as important predictors in the best models of all species, which is a consequence of the close relation of flatfish to the substrate. Seasonal patterns in the relative abundance were observed in most species. During the period of water stratification (summer and autumn) the influence of temperature or salinity on abundance was always greater than during the period of vertical mixing (winter). The present results are discussed in the light of fostering current perception on factors influencing the spatiotemporal distribution of flatfish, which is a prerequisite for the sustainable exploitation of commercial stocks under the ecosystem approach to fisheries management.

Keywords: Pleuronectiformes, flatfish, depth, sediment, environment.

1. Introduction

Flatfish (order: Pleuronectiformes, Greek for "side-swimmers") are ray-finned fish typical examples of evolutionary adaptation to living on the seabed. Their unique morphological and behavioral characteristics enable them to feed on sedimentary prey and use the sediment as a refuge by temporarily burying themselves (Gibson and Robb, 2000). An average of 900 tons annually was officially landed in the Greek markets during the last decade, of which trawlers catches constituted almost 20 % (NSSG, 2006). To explore the underlying mechanisms by which the spatial, temporal and environmental variability affected their catches in the Aegean Sea bottom trawl fishery, non-parametric generalized additive models (GAMs; Hastie and Tibshirani, 1990) were developed. The models related the relative abundance of flatfish to spatial, temporal, and environmental predictor variables.

2. Materials and Methods

A number of 330 sampling hauls were performed on a seasonal basis in the Aegean Sea (eastern Mediterranean), between 1991 and 1996, by experimental trawl surveys. Eight flatfish species (*Arnoglossus laterna*, *Arnoglossus thori*, *Citharus linguatula*, *Lepidorhombus boscii*, *Microchirus variegatus*, *Symphurus ligulatus*, *Symphurus nigrescens*, and *Solea solea*) were studied in the current context. Catch per unit of effort (CPUE), defined as the number of individuals caught per hour of trawling was considered as the relative measure of population density. The relation of relative density and the following predictor variables was investigated: (1) *Bottom Depth*; (2) dry weight % of sand in the sediment (*Sand*); (3) dry weight % of carbonate content in the sediment (*Carbonates*); (4) *Season*, (1-winter, 2-spring, 3-summer, 4-autumn); (5) interaction of ambient temperature with season (*Temperature*:*Season*); (6) interaction of ambient salinity with season (*Salinity*:*Season*); and (7) *Area* (1-North Aegean, 2-central Aegean plateau). The dataset of the grain-size and the carbonate content of the surface sediments that was used in this study was based on the work of Karageorgis *et al*. (2005), which was extended and improved with new data.

Most commonly used analytical tools assume a linear relationship between fishery performance and environmental variables. However, when there is no straightforward functional relationship between the predictor and response variables, Generalized Additive Models (GAMs) have been suggested as a suitable solution (Maunder and Punt, 2004; Venables and Dichmont, 2004). Twenty-five different GAMs were fitted and selection among the set of candidate models was based on the GCV score criterion (Wood, 2006).

3. Results

Flatfish were present in 328 out of 330 hauls comprising 8.1% of the catch in numbers of fish caught. Detailed information about the models selected according to the GCV criterion and the significance of each parameter is given in Table 1. A variety of patterns of the bathymetric distribution of the studied species was found (Fig. 1). Most species (*A. laterna, A. thori, M. variegates, S. ligulatus, S. solea*) exhibited decreasing population density with *Depth*. The population density of the remaining species had peaks at intermediate depths (*C. linguatula, L. boscii*) or in a wide depth range both on the continental shelf and on the upper continental slope (*S. nigrescens*). Substrate type had a considerable relation to population density, since *Sand* % in the sediment was included in the best model of 7 out of 8 species and *Carbonates* content in 6 out of 8 (Table 1).

Table 1. *Summarized results for the "best" model selected for the 8 flatfish. (Pr(F) refers to the p-values from an ANOVA F-ratio test; edf are the estimated degrees of freedom).*

Species	best model	edf	Pr(F)							% of Deviance explained
			Depth	Area	Sand	Carbonates	Season	Temp: Season	Sal: Season	
Arnoglossus laterna	Depth+ Sand + Carbonates	8.9	0.000		0.000	0.004				54.3
Arnoglossus thori	Depth+ Sand + Carbonates + T:Season	8.0	0.000		0.000	0.008		0.044		41.5
Citharus linguatula	Depth+ Sand +Carbonates + T:Season	11.5	0.000		0.037	0.000		0.047		49.5
Lepidorhombus boscii	Depth+ Area + T:Season	7.9	0.000	0.000				0.041		88.0
Microchirus variegatus	Depth+ Sand +Carbonates + Season	12.4	0.000		0.000	0.000	0.003			58.1
Symphurus ligulatus	Depth+ Area + Sand + Sal:Season	6.9	0.001	0.000	0.006				0.032	27.7
Symphurus nigrescens	Depth+ Sand + Carbonates + T:Season + Sal:Season	19.4	0.000		0.000	0.000		0.000	0.003	52.0
Solea solea	Depth+ Sand +Carbonates + Season	14.5	0.000		0.000	0.002	0.000			73.6

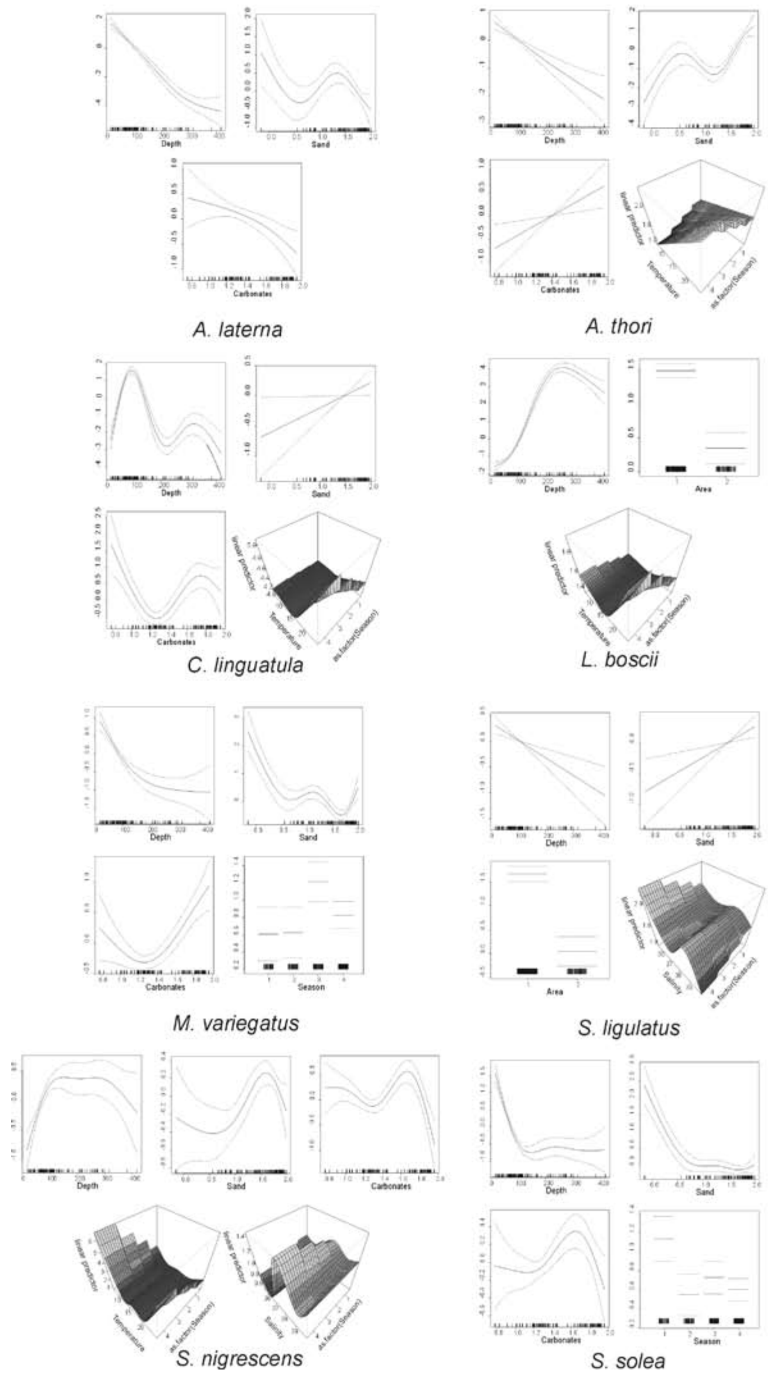

Fig. 1: *Estimated smooth terms and levels of the parameters in the selected best models of the relative abundance of flatfish, in the linear predictor scale. For Sand and Carbonates, x-axis scale is expressing* log_{10}*-transformed values of content in the sediment – in %.*

The smoothing curves of *Carbonates* with density displayed dissimilarities amongst species and their patterns were quite complex (Fig 1). *Area* differences were detected for no more than two species (*L. boscii, S. ligulatus*) with higher observed densities in the North Aegean (Fig. 1). Seasonal variation in distribution was apparent for *M. variegatus* (peak during summer) and *S. solea* (peak during winter) (Fig. 1). *Temperature*:*Season* interaction was included in the models of 4 species (Table 1). Two main patterns were observed: (1) population density increased with temperature (*A. thori, C. linguatula*); (2) population density was U-shaped (*L. boscii, S. nigrescens*) increasing at both higher and lower temperatures. The *Salinity:Season* interaction was significant for the model convergence of 2 species (Table 1). *S. ligulatus* plot was bimodal (max at <36 & 38.5 psu) while *S. nigrescens* demonstrated an obvious peak around 37.5 psu.

4. Discussion

The outcome of our analyses verified the magnitude of substrate type effect on the patterns of spatial distribution of flatfish (Table 2). Sediment characteristics were included in the best models of 7 out of 8 studied flatfish (except *L. boscii*). Flatfish are uniquely adapted for a benthic lifestyle and similar findings have been reported in other studies (Jager *et al.*, 1993; Abookire and Norcross, 1998; Gibson and Robb, 2000; Le Pape *et al.*, 2003). The juveniles of many flatfish appear to be concentrated in shallow and muddy habitats, especially in estuarine areas (Le Pape *et al.*, 2003). Juveniles of *S. solea* and *M. variegatus* were almost exclusively caught in large numbers in the north-western Thermaikos Gulf (North Aegean) in a shallow and muddy habitat close to the mouths of three rivers. The preference of juvenile flatfish for such areas can been attributed both to the abundance of prey in these highly productive grounds and to the enhanced capability of juveniles to burry themselves in finer sediments (Gibson and Robb, 2000; Le Pape *et al.*, 2003). However, opposing results have been reported for flatfish in certain areas. Jager *et al.* (1993) reported that 0-group plaice and flounder in Dollard (Waden Sea) are abundant in sandy areas and absent from muddy sites, and this distribution pattern was attributed to the distribution of the main prey species (Jager *et al.*, 1993). In the present study, Cynoglossidae (*S. ligulatus*, *S. nigrescens*) were absent from the estuarine grounds of north-western Thermaikos Gulf, and their population density was higher in sands or muddy sands (Fig. 1). Thus, the patterns of sediment preference of flatfish in the study area were found to be species-specific and no obvious general pattern was found. Neuman and Able (1998) have demonstrated that the sediment selectivity of a flatfish belonging to the Scophthalmidae family decreased in the absence of food. Therefore behavioural responses to prey distribution and abundance may be an important determinant of the observed patterns of relative abundance of flatfish. Distribution of prey probably indirectly affected sediment type preference.

The observed seasonal pattern in relative density of *S. solea* and *M. variegatus* (Table 2) is partly related to reproductive behaviour. When the new recruits enter the fishing grounds, relative abundance and catches increase. For example, recruitment of *M. variegatus* occurs in spring (Fischer *et al.*, 1987), probably causing the marked high density observed during summer in this paper (Fig. 1). The seasonally variable fishing effort (e.g., in Greece there is a closure of trawlers from beginning of June till end of September) may also affect relative density jointly with recruitment. Since recruitment occurs during the closure season, the increase of population density will be more pronounced than if it occurred during a period of intense fishing. Migration between the study area and adjacent areas (such as deeper bottoms or non-sampled spawning grounds) is also a potential reason for the observed seasonal variation in population density in the study area. The mature portion of *S. solea* population in the Bay of Biscay (east Atlantic Ocean) migrates offshore to participate in the reproduction process during early spring (Koutsikopoulos *et al.*, 1989). Additionally, the sea-land interaction in the Aegean Sea maximized during autumn and winter due to the increased river discharges (as a result of enhanced precipitation). Lloret *et al.* (2001) showed that enhanced hydroclimatic conditions in the NW Mediterranean were favorable for the productivity of the fish and invertebrate stocks, and suggested the presence of linkage between recruitment of Mediterranean species and river discharges. For species inhabiting areas close to river mouths during a part of their ontogeny or occasionally, such as *S. solea*, the seasonal variation of river discharges (winter peak) may also induce seasonal variation of their abundance in the surveyed area.

Table 2. *Synoptic table of the habitat-related trends in relative abundance of the studied flatfish species (n.s.: not significant).*

Species	Family	Abundance trends						
		Depth	***% Sand***	***% Carbonates***	***Area***	***Season***	***Temp: Season***	***Sal: Season***
A. laterna	Bothidae	↘	complex pattern	↘	n.s.	n.s.	n.s.	n.s.
A. thori	Bothidae	↘	↗	↗	n.s.	n.s.	↗	n.s.
C. linguatula	Citharidae	complex pattern	↗	U shaped	n.s.	n.s.	↗	n.s.
L. boscii	Scophthalmidae	peak at 250m	n.s	n.s.	N. Aegean	n.s.	U shaped	n.s.
M. variegatus	Soleidae	↘	↘	U shaped	n.s.	summer	n.s.	n.s.
S. ligulatus	Cynoglossidae	↘	↗	n.s.	N. Aegean	n.s.	n.s.	bimodal (max at <36 & 38.5 psu)
S. nigrescens	Cynoglossidae	unclear	peak at 40%	peak at 47% (1.67)	n.s.	n.s.	U shaped	peak at 37.5 psu
S. solea	Soleidae	↘	↘	peak at 45% (1.65)	n.s.	winter	n.s.	n.s.

Note: an upwards pointing arrow indicates that abundance increases as the predictor variable increases, *a downwards pointing arrow indicates that abundance decreases as the predictor variable increases.*

All flatfish were more abundant within the continental shelf or just the upper continental slope. Even though *Depth* was suggested as a highly influential factor (along with substrate type) it is unclear if its effect on flatfish distribution was direct or indirect because of the correlation that depth has with many crucial environmental parameters (light intensity, temperature, nutrient concentration, primary and secondary productivity).

The effects of environmental variables (*Temperature, Salinity*) interacted with time of year (*Season*) were very dissimilar (Table 2) indicating that there was no general pattern describing flatfish behaviour. A common pattern in all cases was that the effect of temperature and salinity was pronounced in summer and autumn, when there is a marked thermocline, while it was much less intense in winter, when the thermocline has broken down.

Understanding the patterns of spatial distribution of flatfish can assist fisheries managers with the identification of areas of high abundance and diversity, areas with species of conservation interest, and sites where particular life-history stages occur (such as spawning and nursery areas). The Greek demersal fisheries, similarly to most Mediterranean fisheries, are managed mainly through technical measures and effort control rules, which are often not based on sound scientific evidence. Trawlers landings of flatfish in Greece have been steadily plummeting since 1994 (NSSG, 2006), indicating the inadequacy of the current management regulations. Implementing plans and control schemes that would target flatfish assemblages, based on a good knowledge of the species spatial and temporal distribution, could serve as a novel approach to their management. GAMs would be a powerful tool to analyze such data and monitor the efficiency of management measures after their establishment.

5. References

Abookire, A.A., & Norcross, B.L., 1998. Depth and substrate as determinants of distribution of juvenile flathead sole (*Hippoglossoides elassodon*) and rock sole (*Pleuronectes bilineatus*) in Kachemak Bay, Alaska. *Journal of Sea Research* 39: 113–123.

Fischer, W., Bauchot, M.-L. & Schneider, M., 1987. *Fiches FAO d'identification des espèces pour les besoins de la pêche. (Révision 1). Méditerranée et mer Noire. Zone de pêche 37. Volume II. Vertébrés*. Publication préparée par la FAO, résultat d'un accord entre la FAO et la Commission des Communautés Européennes (Projet GCP/INT/422/EEC) financée conjointement par ces deux organisations. Rome, FAO, Vo1.2: 761- 1530pp.

Gibson, R.N., & Robb, L., 2000. Sediment selection in juvenile plaice and its behavioural basis. *Journal of Fish Biology* 56: 1258–1275.

Hastie T.J., & Tibshirani R.J., 1990. *Generalized additive models*. Chapman and Hall, London, 413pp.

Jager, Z., Kleef, H.L., & Tydeman, P., 1993. The distribution of 0-group flatfish in relation to abiotic factors on the tidal flats in the brackish Dollard (Ems estuary, Wadden Sea). *Journal of Fish Biology* 43 (Suppl. A): 31–43.

Karageorgis, A.P., Perissoratis, C., & Anagnostou, Ch., 2005. *Characteristics of surface sediments*. pp. 34–42. In:/ State of the Hellenic Marine Environment/, E. Papathanassiou and A. Zenetos (eds) Athens: HCMR Publ.

Koutsikopoulos, C., Desaunay, Y., Dorel, D., Marchand, J., 1989. The role of coastal areas in the life history of sole (*Solea solea* L.) in the Bay of Biscay. Topics in Marine Biology, Ros., J.D. (Ed.). *Scientia Marina* 53: 567-575.

Le Pape, O., Chauvet, F., Mahévas, S., Lazure, P., Guérault, D., & Désaunay, Y., 2003. Quantitative description of habitat suitability for the juvenile common sole (*Solea solea*, L.) in the Bay of Biscay (France) and the contribution of different habitats to the adult population. *Journal of Sea Research* 50: 139–149.

Lloret, J., Lleonart, J., Soleâ, I., & Fromentin, J.M., 2001. Fluctuations of landings and environmental conditions in the north-western Mediterranean Sea. *Fisheries Oceanography* 10: 33–50.

Maunder, M.N., & Punt., A.E., 2004. Standardizing catch and effort data: a review of recent approaches. *Fisheries Research* 70: 141-159.

Neuman, M.J., & Able, K.W., 1998. Experimental evidence of sediment preference by early life history stages of windowpane (*Scophthalmus aquosus*). *Journal of Sea Research* 40: 33–41.

NSSG, 2006. *Results of the Sea Fishery Survey by Motor Boats, Statistical Yearbooks for the years 1964–2006*. National Statistical Service of Greece (NSSG), Athens.

Venables, W.N., & Dichmont C.M., 2004. GLMs, GAMs and GLMMs: an overview of theory for applications in fisheries research. *Fisheries Research* 70: 319-337.

Wood, S.N., 2006. *Generalized Additive Models: An introduction with R*. Chapman and Hall/CRC, Florida, 553 pp.