HABITAT PREFERENCES AND SPATIOTEMPORAL DISTRIBUTION OF FOUR BENTHIC SKATES IN THE EASTERN MEDITERRANEAN 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 four benthic skates (family *Rajidae*) in the Aegean Sea. All species exhibited noticeable peaks within a restricted range of depths observed on the verge of the lower continental shelf or just within the upper continental slope. Due to their lifecycle (closely related to the substrate) all had an unmistakable preference for sandy bottoms, while high carbonate content had a significant impact on the frequent occurrence of *R. clavata* and *R. miraletus*. Seasonal patterns in the relative abundance of species were observed, related in most cases to recruitment and fishery closure during the summer months. Skates are extremely vulnerable to overfishing and reliable identification of the spatio-temporal distribution, habitat selection, fishing and discard mortality are of paramount importance in understanding the impact of fisheries on these poorly studied species in the Mediterranean Sea.

Keywords: Rajidae, GAMs, depth, substrate, environment.

1. Introduction

Cartilaginous fish of the family *Rajidae* (benthic skates – order: Rajiformes) are frequently caught in the Greek waters and at least 600 metric tons of them are annually landed and marketed in the local markets, mostly caught with bottom trawls (NSSG, 2006). Like the most elasmobranch fisheries worldwide they are actually unmonitored and completely unmanaged (Shotton, 1999). As a consequence of their low contribution to the market, because of their scarce economic value, they have remained in a very low priority for research and management and our knowledge on their biology, distribution and behavior is poor. On the other hand their special biological characteristics (slow growth, late maturation, low fecundity, low natural mortality, slow population increase) make them susceptible to population depletion as a result of anthropogenic activity, including unsustainable fisheries, by-catch, and habitat modification (Myers and Worm, 2003). The goal of the present work was to analyze the quantitative relationships between relative abundance of the four most common benthic skates caught by trawlers in the Aegean Sea, and spatial, temporal, and environmental variables (substrate characteristics, depth, temperature, and salinity) using generalized additive models (GAM; Hastie and Tibshirani, 1990).

2. Materials and Methods

The present study is based on a set of abundance indices calculated from 330 experimental bottom trawl survey samples collected in the Aegean Sea (Figure 1) from 1991 to 1996. Each sample was assigned the corresponding values from a series of investigated parameters: (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). *Temperature* and *Salinity* were not modeled separately, since such a formulation of a model might bias the results by masking the seasonal effect on their intra-annual cyclic variation.

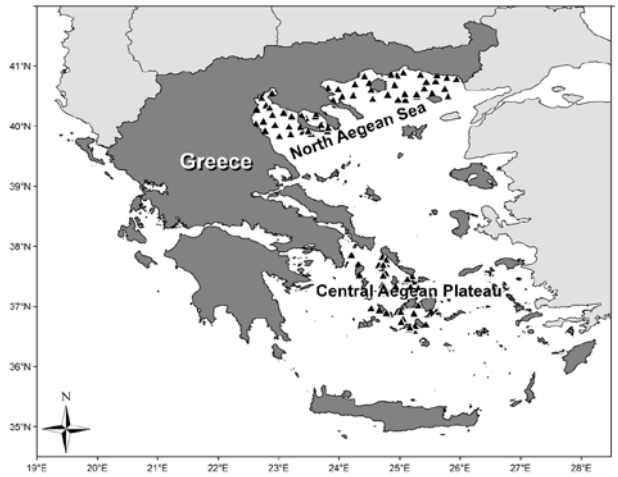

Fig. 1: *Map of the study area with the sampling stations indicated by black triangles*.

Assuming an inherent non-linearity between skates population density and environmental variables, we applied GAMs to identify variables influencing population density and to reveal the form of the relationships. A series of 25 candidate models were constructed including combinations of the seven parameters under investigation that plausibly influence species abundance. "Best" model selection was based on the generalized cross validation (GCV) method (Wood, 2006). GCV is a conceptually appealing approach, as models are not judged only by their ability to fit the data from which they were estimated, but are selected based on their ability to predict data to which the model was not fitted.

3. Results

Although the four species (*Raja clavata, Raja miraletus, Raja montagui,* and *Leucoraja naevus*) occurred in more than 60% of the hauls they comprised less than 1% of the total catch in number, *R. clavata* being the more abundant amongst them. GAM analyses based on the GCV criterion, suggested which model fitted best the data for each species under investigation. Detailed information about the models fitted and the significance of each parameter is given in Table 1. Depth stratum was the most influential factor in all species modelled. Three out of four species showed noticeable peaks within a restricted range of depths (Fig. 2). These peaks were observed on the verge of the lower continental shelf or just within the upper continental slope. Only *R. montagui* exhibited a negative association with bottom depth, being more abundant in the upper continental shelf (0-100 m). *L. naevus* and *R. montagui* prevailed in the North Aegean region, whereas *R. clavata* was observed in larger numbers in the Central Aegean area. Time of year (*Season*), unrelated to other environmental parameters, was significant for *R. miraletus* and *R. montagui*. Both displayed a minimum during winter while more proliferate catches were witnessed during spring and summer.

Table 1: *Summarized results for the "best" model selected for the 4 benthic skates. (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	T : Season	Sal : Season	
L.naevus	Depth+Area +Sand + T:Season + Sal:Season	12.3	0.00	0.01	<0.01			<0.01	<0.01	30.3
R.clavata	Depth+Sand+ Carbonates+T:Season	13.7	0.00		<0.01	<0.01		<0.01		47.3
R.miraletus	Depth+ Sand + Carbonates+Season	10.1	0.08		<0.01	<0.01	<0.01			44.1
R.montagui	Depth+Area+Sand+ Season	10.4	0.00	<0.01	<0.01		<0.01			32.5

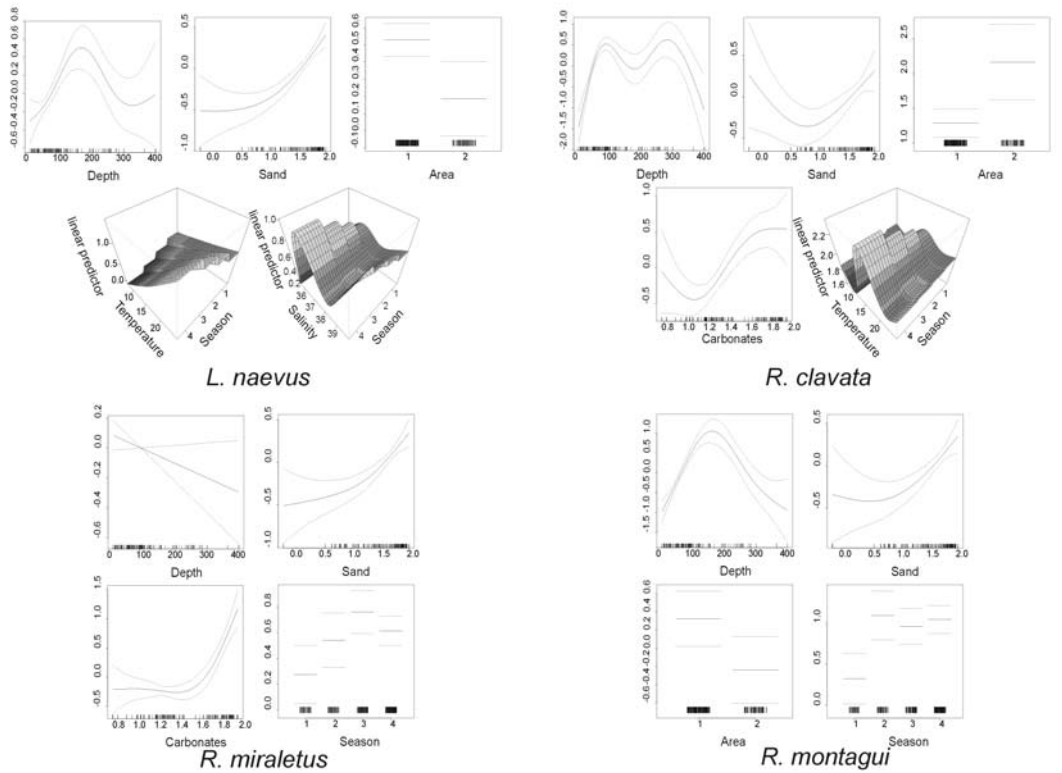

Fig. 2: *Estimated smooth terms and levels of the parameters in the selected best models of the relative abundance of benthic skates, in the linear predictor scale. (Area levels: 1-North Aegean; 2: Central Aegean plateau - Season levels: 1-winter; 2-spring; 3-summer; 4-autumn).*

Sediment type had a considerable effect in distribution and habitat selection. All species had an unmistakable preference for sandy bottoms, while high carbonate content had a significant impact on the frequent occurrence of *R. clavata* and *R. miraletus*. *L. naevus* catches were more or less unrelated to water temperature during winter, but showed a distinctive increasing trend favouring warmer waters (>20° C) in the rest of the year being more pronounced during summer and fall. On the other hand *R. clavata* was very sensitive to ambient water temperature showing a preference to very narrow temperature ranges (15° C), within which catches increased abruptly, especially during

summer and fall. Seasonal interaction of *Salinity* on catches was evident only for. *L .naevus*. The species seemed to have either selected areas where salinity values remained constant throughout the year (36.5 psu) or migrated towards waters with the desired salinity.

4. Discussion

Habitat selection by demersal fishes depends on a variety of biotic and abiotic factors. Depth and temperature are important abiotic factors, often accounting for much of the spatial variation in the species composition of demersal fish communities. Temperature is a key environmental variable for fishes, controlling the rates of physiological processes such as metabolism and growth. Prey abundance is a key biotic component of habitat quality (Swain and Benoit, 2006).

Although depth has been stated to be the main gradient along which fauna1 changes occur when analyzing shelf and upper slope assemblages (Bianchi, 1992; Fujita *et al.*, 1995; Moranta *et al*., 1998; Demestre *et al*., 2000; Kallianiotis *et al*., 2000), the direct effect of it on species abundance (through the increase of hydrostatic pressure) is less obvious and may be related to correlations with other important habitat variables like: productivity, prey and predator distributions, and sediment type. In the absence of such data in studies of fish spatial distribution, depth is concluded to be the main predictor variable of population density. On the other hand, a good knowledge of bathymetric distribution of marketed fish is essential for fisheries management even though depth is not always a causal predictor of fish abundance.

This study confirmed the importance of sediment characteristics in the patterns of skates spatial distribution (Table 2), as substrate type was included in the best models of all species (*Sand* in all cases and *Carbonates* in 2 out of 4). This preference has already been documented (Jardas, 1973; Skjæraasen and Bergstad, 2000) and it is partly attributed to the distribution of their preferred prey, as amphipods and sand shrimps (*Crangon vulgaris*) are the most frequently occurring food items in their stomachs (Holden and Tucker, 1974). Distribution of prey probably indirectly affected sediment type preference.

The observed seasonal pattern in relative density (Table 2) is partly related to recruitment. When the new recruits enter the fishing grounds, relative abundance and catches increase. Members of the *Rajidae* family are oviparous species laying their egg-cases mainly in winter and spring in the Mediterranean (Stehmann and Bürkel, 1984). Development of embryo takes about 5 months and as a result during summer and autumn young of the year specimens enter the fishery, reflecting in elevated trawlers catches. 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 of the studied species 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 of population density in the study area. Although skates have been considered for long as philopatric species, mostly remaining in a small area, recent studies revealed that even immature specimens are ranging further than previously reported, following a seasonal migration pattern (Chevolot *et al*., 2006). A more systematic examination of catches, incorporating supplementary aspects of the skates populations such as size, sex and maturity would elucidate the temporal effect

Regional variation of relative abundance (Table 2) is quite difficult to simplify. Sea-land interaction in the North Aegean Sea is much higher than the central Aegean plateau 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 species abundance and river discharges. *L. naevus* and *R. montagui* together, form less than half the population size of *R. clavata*. Swain and Benoit (2006) state that at low population sizes, only the habitats with the highest resource levels should be occupied (North Aegean in our case).

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

Species	Abundance trends						
	Depth	% Sand	% Carbonates	Area	Season	T:Season	Sal:Season
L.naevus	peak at 180m	↗	n.s.	N. Aegean	n.s.	↗ (more pronounced in autumn)	peak at 36.5 psu (all seasons)
R.clavata	high densities between 75 and 350m	↗	↗	C. Aegean	n.s.	peak at 15° C (all seasons)	n.s.
R.miraletus	↘	↗	↗	n.s.	summer	n.s.	n.s.
R.montagui	peak at 150m	↗	n.s.	N. Aegean	spring	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.

Elasmobranchii typically exhibit rapid declines in catch rates ('boom and bust' yields), with fisheries collapsing soon after initiation of heavy exploitation (Bonfil, 1994). Although there is some evidence that some elasmobranch species could be exploited sustainable at low fishing pressure, elasmobranchs taken as by-catch in fisheries targeting other species could be extirpated long before appropriate management policies could be implemented (Walker, 1998). Examples of skate overexploitation have already been observed in several areas of the world: common skate (*Raja batis*) is now locally extinct from the Irish Sea (Walker, 1998; Dulvy, 2000); thorny skate (*Amblyraja radiata*) in the southern Gulf of St. Lawrence is currently at the lowest biomass level ever observed (Swain and Benoît, 2006); white skate (*Rostroraja alba*) and longnose skate (*Dipturus oxyrhinchus*) are now locally extinct from the Irish Sea and Bristol Channel areas (Dulvy, 2000).

As a conclusion, identification of the spatio-temporal distribution, habitat selection and reliable estimations of fishing and discard mortality of skates are of paramount importance in understanding the impact of fisheries on these poorly studied in the Mediterranean Sea species.

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