

Habitat use by the pearly razorfish, *Xyrichtys novacula* (Pisces: Labridae)*

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SUMMARY: The population density of the pearly razorfish, *Xyrichtys novacula*, was estimated in eastern Mediterranean areas and was related to specific environmental variables, laying emphasis on the sediment granulometry. The density of *X. novacula* ranged from 0 to 20.0 individuals per 1000 m². No correlation between *X. novacula* density and season, depth or the presence of common prey species was found. The *X. novacula* density was significantly correlated to the granulometry of the sediment, specifically to the median grain diameter $Md\phi$ and the quartile deviation $QD\phi$, according to the model $Density^{1/4} = 1.626 - 0.354Md\phi - 0.491QD\phi$. The highest *X. novacula* densities occur in moderately or well sorted, coarse or very coarse sand. The density and distribution of *X. novacula* seem to largely depend on the sediment characteristics, due to the sand-diving behaviour of the species that necessitates the existence of appropriate substrate. Evidence is presented against the reported theory that during the cold season the species spends most of the time buried in the sand.

Keywords: behavioural ecology, Mediterranean, sand-diving, burying behaviour, sediment granulometry.

RESUMEN: USO DE HÁBITAT POR EL RAÓ, *XYRICHTYS NOVACULA*. – La densidad de población del raó, *Xyrichtys novacula*, se midió en áreas del Mediterráneo oriental y se relacionó con variables específicas de dicho ambiente, dando énfasis a la granulometría del sedimento. No se encontró ninguna relación entre la densidad de *X. novacula* y la estacionalidad, profundidad o presencia de especies de alimento. La densidad de *X. novacula* fue significativamente relacionada con la granulometría del sedimento, específicamente con el diámetro medio del grano $Md\phi$ y la desviación cuartil $QD\phi$, según el modelo $Density^{1/4} = 1.626 - 0.354Md\phi - 0.491QD\phi$. Las densidades más altas de *X. novacula* aparecieron en arenas moderadamente o bien clasificadas y bastas o muy bastas. La densidad y distribución de *X. novacula* parecen depender en gran medida de las características del sedimento, debido al comportamiento de esta especie de enterrarse en la arena, ya que necesita de la existencia de substratos apropiados. Se presentan evidencias contra la teoría de que en las temporadas de frío, esta especie pasa la mayor parte del tiempo enterrada en la arena.

Palabras clave: ecología del comportamiento, Mediterráneo, granulometría del sedimento.

INTRODUCTION

Patterns of habitat use are documented by relating the abundance of different components of a fish population to specific environmental variables (Kramer *et al.*, 1997). Each species is reliably found in some kinds of locality and not in others, depending on the habitat characteristics. Habitat character-

istics are fundamental to the ecology and evolution of a species and the understanding of habitat use and habitat selection is a prerequisite for the preservation of endangered species and the sustainable exploitation of commercial stocks.

The pearly razorfish, *Xyrichtys novacula* (L., 1758), is a labrid fish that inhabits clear shallow areas with sandy bottoms. It is a subtropical species, encountered in the Western Atlantic, from the North Carolina coast through the Caribbean to Brazil, and

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in the Eastern Atlantic, from the southern coast of Spain to south of Cape Lopez, including the Mediterranean and many Atlantic islands, at depths from 1 to 90 m (FishBase 2004: World Wide Web electronic database; available from the Internet URL <http://www.fishbase.org>). Its prey varies according to the geographical area. In the central Mediterranean it feeds mainly on bivalves, essentially *Acanthocardium tuberculatum*, and sea urchins, mostly *Echinocardium cordatum*, but also on gastropods and crustacea (Cardinale *et al.*, 1997), while in the Virgin Islands it feeds mainly on gastropods, bivalves and also on polychaetes, crustaceans and other molluscs (Randall, 1967). The pearly razorfish is a protogynous monandric hermaphrodite (Bentivegna and Rasotto, 1987) with sexual dimorphism apparent in head shape, length of pelvic fin and coloration (Gomon and Forsyth, 1990). *X. novacula* is polygynous and harem (Marconato *et al.*, 1995, Cardinale *et al.*, 1998). Females occupy small adjacent territories on extended flat sandy bottoms and males patrol and defend larger areas usually encompassing four to six female territories (Marconato *et al.*, 1995).

Unlike fish of coral reefs or rocky substrates that take advantage of physical structures (crevices, holes, etc) for shelter, fish on sand flats have to seek other ways to protect themselves from predators. Some of the adaptations for avoiding predators in sandy habitats include burrow construction, armour, toxicity, mimicry, cryptic coloration, group living and sand-diving (Nemtsov, 1994). The pearly razorfish dives, head first, into the sand with the approach of danger (Lieske and Myers, 1994 and personal observation) and may remain buried for long. The pearly razorfish constantly uses the same 'dive sites', which are distinguishable visually by a slight difference in the coloration than that of the surrounding sand; furthermore one can poke a finger into a dive site more easily than into a nondive site area just a few cm away (Clark, 1983 and personal observation). This burying defence strategy seems to be common among most species of the genus and it has been reported for many other wrasses as well, e.g. for *X. martinicensis* (Victor, 1987), *X. pentadactylus* (Clark, 1983), *X. niger* (Clark, 1983), *X. splendens* (Nemtsov, 1994). The unusual head shape of razorfish is an adaptation that enables sand-diving. Sand-diving apparently presupposes that the soft substrate is adequate for easy 'diving' at a sufficient depth that assures protection from predators. Furthermore, no impediments in respiration should

be caused by the sand when the razorfish remains buried for long. Thus, it seems that the distribution and abundance of the pearly razorfish on soft substrates may be restricted by the characteristics of the sediment. In this study the population density of the pearly razorfish was estimated in eastern Mediterranean areas and related to specific environmental variables, laying emphasis on the sediment granulometry.

MATERIALS AND METHODS

The population density of the pearly razorfish was estimated by visual census with SCUBA diving in Greek coastal waters (Eastern Mediterranean) and at depths from 3 to 25 m. The survey was conducted in randomly chosen areas with soft sediment. The *X. novacula* individuals were counted within strip transects, ranging between 1600 and 2080 m². The transects were outlined in a way similar to that described in Katsanevakis and Verriopoulos (2004). A total of 89 transects were outlined and measured in different sites in Eastern Mediterranean (Fig. 1). The survey lasted one calendar year, from July 2001 to June 2002.

A large percentage of pearly razorfishes were found hovering over their dive site. Those pearly razorfishes that were far from a dive site were usually made, by the presence of the diver, to move to the nearest dive site and hover over it. Razorfishes are territorial, do not move farther than a few meters from a dive site (Clark, 1983) and although the presence of the diver may force them to dive into the sand, this does not happen unless the diver approaches too close (less than \approx 1.0-1.5 m). Thus, in most cases the diver had the time to spot and record the fish before it dived into the sand. Consequently, underestimation of *X. novacula* density due to failure to record all individuals is considered to be small.

The depth range of each transect (maximum-minimum depth) was recorded with a dive computer, with an accuracy of 0.1 m, and in every case was less than 5 m. The mean value of the minimum and maximum depth of each transect was considered as the transect depth (*D*).

A 250 ml sample of the surface sediment (upper 5 cm) was taken from each transect. Particle size analysis of the sediment samples was conducted according to Buchanan (1984) and for each sample the median diameter *Md ϕ* and the quartile deviation *QD ϕ* were calculated as measures of the central ten-

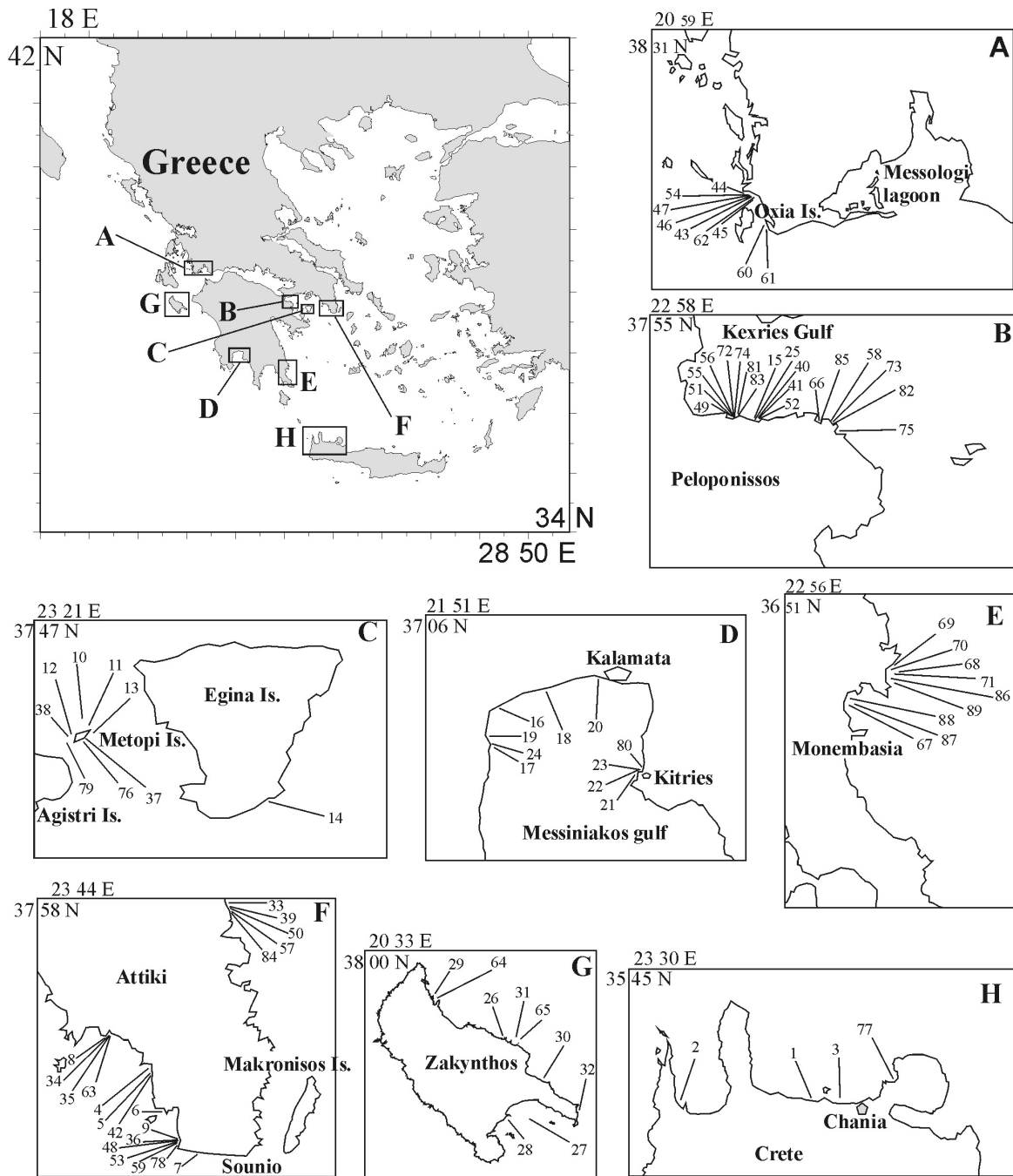


FIG. 1. – Map with the 89 transects of the study.

density and the degree of scatter of the granule size frequencies respectively.

The presence or absence of *Acanthocardia tuberculata* and irregular sea urchins in the surveyed transects was recorded. As these species are endobenthic, accurate estimation of their abundance is not feasible, thus only presence/absence data, based on empty shells was recorded.

General Linear Model (GLM) methods were used (Glantz and Slinker 2001) to identify the asso-

ciation between *X. novacula* density and the observed environmental or biotic variables, giving emphasis in sediment granulometry. Initially, a General Linear Model of the following form was calculated, with least squares method and assuming a normal error distribution:

$$\sqrt[4]{Density} = b_0 + b_1S_1 + b_2S_2 + b_3S_3 + b_4Md\phi + b_5QD\phi + b_6D + b_7P_A + b_8P_E \quad (1)$$

TABLE 1. – The raw data of the 89 density measurements of *Xyrichtys novacula* in this study, together with the values of the 6 predictive factors of Equation 1. d, density (ind/1000 m²); P_A and P_E are presence (1) – absence (-1) data; Sp, spring; S, summer; A, autumn; W, winter.

No	d	Mdφ	QDφ	D (m)	Season	P _A	P _E	No	d	Mdφ	QDφ	D (m)	Season	P _A	P _E
1	0.0	2.750	0.500	3.1	Sp	1	-1	46	0.0	4.050	0.375	9.7	A	-1	-1
2	0.0	1.300	0.425	4.7	Sp	-1	-1	47	0.0	3.450	0.325	2.5	A	1	-1
3	0.0	3.000	0.550	4.3	Sp	1	-1	48	0.0	0.650	0.425	9.7	A	-1	1
4	17.0	2.600	0.450	8.2	S	1	-1	49	0.0	2.850	0.775	8.5	A	-1	-1
5	0.7	3.200	0.500	5.0	S	1	-1	50	7.7	1.000	0.725	11.6	W	-1	-1
6	0.0	3.000	0.500	7.9	S	1	-1	51	0.0	2.450	1.350	13.0	W	-1	-1
7	0.0	2.400	0.350	7.8	S	-1	-1	52	0.0	2.500	1.050	16.8	W	-1	1
8	0.0	3.350	0.400	4.6	S	1	-1	53	0.0	1.050	0.525	6.0	W	-1	-1
9	0.0	4.200	0.525	6.0	S	-1	1	54	0.0	4.050	0.375	12.2	W	1	-1
10	12.9	0.800	0.825	14.0	S	-1	-1	55	0.0	1.800	1.125	12.1	W	-1	-1
11	7.4	0.650	0.200	7.8	S	-1	-1	56	0.0	2.600	0.800	14.3	W	-1	-1
12	4.2	-0.800	0.800	5.9	S	-1	-1	57	1.0	0.250	0.575	14.1	W	-1	-1
13	20.0	0.800	0.550	7.7	S	-1	-1	58	0.0	3.000	1.150	12.3	W	-1	-1
14	2.7	2.900	0.525	4.3	S	1	-1	59	0.0	0.850	0.500	8.7	W	-1	1
15	0.0	3.050	0.850	16.1	S	-1	1	60	3.8	2.500	0.300	3.7	W	1	1
16	0.0	3.400	0.450	5.9	S	1	-1	61	0.0	2.500	0.325	3.9	W	1	-1
17	0.0	3.300	0.500	6.1	S	1	1	62	0.0	3.300	0.425	6.1	W	1	-1
18	0.4	1.400	0.450	1.9	S	1	-1	63	0.0	3.650	0.450	5.6	W	1	1
19	0.0	3.450	0.375	8.3	S	1	-1	64	0.9	-0.500	0.400	8.3	Sp	-1	-1
20	0.0	3.250	0.475	6.5	S	1	-1	65	0.1	3.200	0.500	7.8	Sp	1	1
21	0.0	2.700	1.275	20.9	S	-1	1	66	0.0	3.300	0.950	17.6	Sp	-1	-1
22	0.0	3.750	1.625	12.5	S	-1	1	67	2.0	2.550	0.475	6.0	Sp	-1	1
23	0.0	2.500	1.625	15.2	S	-1	-1	68	5.3	1.650	0.675	12.3	Sp	-1	1
24	0.0	3.850	0.475	3.7	S	1	-1	69	7.1	0.100	0.650	7.4	Sp	-1	1
25	0.0	2.400	1.500	14.7	S	-1	1	70	1.9	0.100	0.650	7.5	Sp	-1	1
26	1.4	2.700	0.575	4.6	S	1	1	71	6.4	0.600	0.400	14.6	Sp	-1	1
27	0.0	3.450	0.300	14.3	S	1	1	72	0.0	1.500	1.300	17.4	Sp	-1	1
28	0.0	3.100	0.500	3.3	S	1	-1	73	0.0	3.000	1.050	17.4	Sp	-1	-1
29	1.7	-0.450	0.450	8.6	S	1	-1	74	0.0	3.250	0.900	20.9	Sp	-1	-1
30	0.0	2.850	0.500	4.7	S	1	1	75	0.0	2.700	0.950	20.5	Sp	-1	1
31	0.1	2.700	0.575	6.4	S	1	-1	76	11.3	-0.100	0.775	8.1	Sp	-1	1
32	0.0	2.850	0.500	3.4	S	-1	-1	77	5.4	2.600	0.325	9.8	Sp	1	1
33	2.8	0.000	1.025	21.5	A	-1	1	78	0.0	0.700	0.600	6.1	Sp	-1	1
34	0.0	3.350	0.400	3.4	A	1	-1	79	6.8	-1.000	0.900	7.2	Sp	-1	1
35	0.0	3.450	0.350	6.5	A	1	-1	80	2.9	0.350	0.675	3.4	Sp	-1	-1
36	0.0	0.950	0.525	6.3	A	-1	-1	81	0.0	2.700	0.950	12.8	Sp	-1	1
37	12.7	0.050	0.750	7.3	A	-1	1	82	3.3	1.000	1.000	12.6	S	-1	-1
38	6.4	-0.700	0.500	5.7	A	-1	1	83	0.0	0.800	1.525	24.3	S	-1	-1
39	10.0	1.000	0.725	15.0	A	-1	1	84	5.1	0.000	1.025	20.0	S	-1	1
40	0.0	2.800	1.175	21.9	A	-1	1	85	0.0	1.000	1.000	12.5	S	-1	1
41	0.0	1.200	1.300	14.7	A	-1	1	86	13.5	1.650	0.675	12.5	S	-1	1
42	3.6	2.700	0.500	9.8	A	1	-1	87	12.0	0.100	0.650	7.5	S	-1	1
43	0.0	3.500	0.375	10.0	A	1	-1	88	4.3	0.100	0.650	7.5	S	-1	1
44	0.0	3.450	0.325	3.1	A	1	-1	89	2.6	0.600	0.400	14.5	S	-1	1
45	0.0	4.600	0.375	16.8	A	-1	1								

Densities were fourth-root transformed in order to stabilize variance and produce fairly straight lines on the normal probability plots (Glantz and Slinker 2001); untransformed densities produced curves on the normal probability plot with one inflection, indicating that the distribution of the residuals was skewed. Variables S_1 , S_2 , S_3 are dummy variables, used to encode the effect of season, following the ‘effects coding’ approach, according to Glantz and Slinker (2001). Specifically, when the season is {autumn, summer, spring, winter} respectively then $S_1=\{1,0,0,-1\}$, $S_2=\{0,1,0,-1\}$ and $S_3=\{0,0,1,-1\}$. P_A and P_E are dummy variables (with ‘effects coding’) representing the presence/absence of *Acanthocardia tuberculata* and irregular sea urchins respectively. When the data are unbalanced, as in our case,

‘effects coding’ is essential for obtaining the correct sums of squares in the model (Glantz and Slinker 2001). The ‘StatGraphics Plus v.4.0’ (Statistical Graphics Corp.) software was used for the analysis. Marginal Sums of Squares (Type III) were used to test the significance of each regression coefficient. A residual analysis was conducted, according to Glantz and Slinker (2001), to check whether the results were consistent with the model assumptions.

To evaluate further the effect of sediment granulometry, $Md\phi$ and $QD\phi$ were classified according to the Wentworth scale (Wentworth 1922). The $Md\phi$ was classified to the following 6 classes: very coarse sand ($-1 < Md\phi \leq 0$), coarse sand ($0 < Md\phi \leq 1$), medium sand ($1 < Md\phi \leq 2$), fine sand ($2 < Md\phi \leq 3$), very fine sand ($3 < Md\phi \leq 4$), silt ($4 < Md\phi \leq 8$). The

classification of $QD\phi$ was: well sorted ($QD\phi < 0.50$), moderately sorted ($0.50 \leq QD\phi < 1.00$) and poorly sorted ($1.00 \leq QD\phi$). Multiple comparisons tests (Student-Newman-Keuls) were conducted to check the significance of differences between $Md\phi$ and $QD\phi$ classes, based on a multiple regression equivalent of analysis of variance (with effects coding and Marginal Sum of Squares) according to Glantz and Slinker (2001), as traditional ANOVA would require a balanced design.

RESULTS

The density of *Xyrichtys novacula* ranged from 0 to 20.0 individuals per 1000 m². $Md\phi$ varied from -1.0 to 4.6 and $QD\phi$ from 0.2 to 1.63. The raw data of all measurements are given in Table 1.

After the fourth-root transformation of densities, the residuals plotted against any independent variable or against the observed dependent variables showed no deviation from the constant variance assumption and the normal probability plots of the residuals were reasonably linear, indicating no substantial deviation from normality. The residuals showed no trend, curve or other systematic variation and in the scatterplots of the transformed densities against any of the independent variables there was no indication of nonlinearity; thus the linearity assumption, inherent in the GLM model, may be considered valid. There was no studentized-residual greater than 3.0 (maximum studentized-residual was 2.72). In every case, there was no leverage value greater than 3 times the average leverage and no data points with unusually large values of Cook's distance (no Cook's distance greater than 0.0085); thus there were no outliers or influential points. The variance inflation factor of all the regression coefficients was less than 2.4 in every case, thus there is no significant multicollinearity among the variables (Glantz and Slinker 2001).

The results of fitting the GLM described by Equation 1 are presented in Table 2. The induced model was:

$$\sqrt[4]{Density} = 1.569 - 0.056S_1 + 0.162S_2 + 0.024S_3 - 0.367Md\phi - 0.581QD\phi + 0.013D + 0.075P_A + 0.079P_E$$

where density is given in individuals per 1000 m².

Among the factors of the model, only $Md\phi$ and $QD\phi$ were significant (Table 2). If only these two

TABLE 2. – Summary of the results of fitting a general linear model relating the pearly razorfish densities to the 6 predictive factors of Equation 1. $Md\phi$: Median grain diameter, $QD\phi$: Quartile Deviation of grain distribution, D: Depth, P_A , P_E : presence/absence of *Acanthocardia tuberculata* and irregular sea urchins respectively (* p<0.05, ** p<0.01, *** p<0.001).

Source of variability	Sum of squares	Df	Mean square	F-ratio	p-value
Season	1.07	3	0.36	1.17	0.328
$Md\phi$	15.09	1	15.09	49.26	<0.001 ***
$QD\phi$	1.61	1	1.61	5.27	0.024 *
D	0.21	1	0.21	0.69	0.410
P_A	0.20	1	0.20	0.65	0.422
P_E	0.46	1	0.46	1.52	0.222
Model	23.96	8	2.99	9.78	<0.001 ***
Residual	24.50	80	0.31		
adj-R ² :	44.4%				
st.error:	0.553				

factors are kept in the model, it becomes (after recalculation of the new coefficients with least squares):

$$\sqrt[4]{Density} = 1.626 - 0.354Md\phi - 0.491QD\phi$$

The adjusted R² of the reduced model is 43.9% and the standard error of the estimate is 0.556, which are both quite close to the respective values of the full model (Table 2).

The coefficient of $Md\phi$ is significantly negative (p<0.001), indicating that the finer the sediments, the less abundant is *X. novacula*. The coefficient of $QD\phi$ is also significantly negative (p=0.008), indicating that the better sorted is the sediment the higher is the *X. novacula* density. This is enhanced by the Student-Newman-Keuls multiple comparisons tests (Table 3); it is obvious that the highest *X. novacula* densities occur in moderately or well sorted, coarse or very coarse sand.

TABLE 3. – The results of Student-Newman-Keuls multiple comparisons for $Density^{1/4}$ of *Xyrichtys novacula* among the 6 $Md\phi$ classes and the 3 $QD\phi$ classes, together with the mean value of each class. The homogenous groups are identified using columns of X's. Within each column, the levels containing X's form a group of means within which there are no statistically significant differences (95% confidence level).

	LS Mean ± stnd error	Homogenous groups			
<i>Md\phi</i> class					
silt	-0.17 ± 0.29	X			
very fine sand	-0.08 ± 0.13	X			
fine sand	0.36 ± 0.11	X	X		
medium sand	0.55 ± 0.20		X	X	
coarse sand	1.01 ± 0.13			X	X
very coarse sand	1.37 ± 0.20				X
<i>QD\phi</i> class					
poorly sorted	0.15 ± 0.15		X		
moderately sorted	0.67 ± 0.11			X	
well sorted	0.70 ± 0.10				X

DISCUSSION

The sediment characteristics represent a major factor in regard to the distributional patterns of the bottom fauna (Bacescu, 1972). The sediment characteristics, specifically the median diameter $Md\phi$ and the quartile deviation $QD\phi$, seem to be significant determinants for the distribution and abundance of *Xyrichtys novacula*. It might be argued that the significant association between the *X. novacula* density and the sediment characteristics does not imply a causal link, as this is an observational study and not a manipulative experiment (Glantz and Slinker, 2001). The abundance and composition of prey may depend on sediment characteristics, thus the *X. novacula* density dependence on sediment granulometry might be partly indirect and caused by a direct dependence on prey abundance. However, no solid conclusion may be made on whether the dependence of *X. novacula* density on sediment granulometry was direct (due to the sand-diving behaviour of the species) or partly indirect (due to the dependence of prey abundance on sediment characteristics). Nevertheless, the sand-diving behaviour of *X. novacula* necessitates the existence of appropriate substrate and indicates a strong link between *X. novacula* abundance and sediment characteristics.

We found that *X. novacula* density is not related to the presence or absence of *Acanthocardia tuberculatum* or of irregular sea-urchins, which made up 90% of the volume of prey of *X. novacula* in the Tyrrhenian Sea (Cardinale *et al.*, 1997). Many areas with no sign of *A. tuberculata* or irregular sea-urchins (measurements 10, 11, 12, 13, 50, 57, 64, 80, 82 in Table 1) were abundant with *X. novacula* and some areas with abundance of both *A. tuberculata* and irregular sea-urchins had zero *X. novacula* density (measurements 17, 27, 30, 63 in Table 1). Comparing the stomach content analyses of Randall (1967) and Cardinale *et al.* (1997), it is concluded that the prey of *X. novacula* may vary from site to site. Furthermore, Cardinale *et al.* (1997) found similar diversity of the ingested food of *X. novacula*, as compared to that of the environment, revealing the euryphagic nature of the species. Thus, it seems that the abundance of specific prey species does not affect the abundance of *X. novacula*, although the total prey abundance probably does so.

X. novacula density was not significantly correlated to depth, in the depth range of this study. However, sandy bottoms, as a rule, are limited to depths

down to the continental shelf in contrast to sediments with silt or clay that are found at all depths (Bacescu, 1972). Thus, the depth range of *X. novacula* (1-90 m) probably occurs mostly because of the corresponding depth range of sandy bottoms.

Cardinale *et al.* (1998) stated that no *X. novacula* was caught in winter either by their sampling gear (fishing lines) or by using traditional fishing methods and they support the theory that during the cold season the species spends most of the time buried in the sand. The present study, though, presents evidence against this hypothesis. No significant seasonal variation in *X. novacula* density was found and in many winter or early spring measurements many *X. novacula* individuals were counted. Specifically, from December 2001 till March 2002, *X. novacula* was found in 10 of the 22 areas measured (measurements 50, 57, 60, 64, 65, 67, 68, 69, 70, 71 in Table 1) with a highest density of 7.7 individuals per 1000 m² in measurement 50. The mean sea temperature during these 10 measurements varied from 11.9°C to 16.0°C. Although a reduced activity during winter might be possible, there is no indication that during the cold season *X. novacula* spends most of the time buried in the sand. The fact that pearly razorfishes do not get caught by fishing gear during winter might be due to a behavioural change in winter, or, in other words, the summer reproduction-related behaviour might render the species more vulnerable to fishing.

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