The age, growth and feeding habits of the European conger eel, Conger conger (L.) in the Adriatic Sea

SANJA MATIĆ-SKOKO1*, JOSIPA FERRI2, PERO TUTMAN1, DARIA SKARAMUCA3, DOMAGOJ DIKIĆ4, DUJE LISIČIĆ4, ZDENKO FRANIĆ5 & BOŠKO SKARAMUCA3

1Institute of Oceanography and Fisheries, Split, Croatia, 2University of Split, Center of Marine Studies, Split, Croatia, 3Faculty of Aquaculture, University of Dubrovnik, Dubrovnik, Croatia, 4Faculty of Natural Sciences and Mathematics, Department for Animal Physiology, University of Zagreb, Zagreb, Croatia, and 5Institute of Medical Research and Occupational Health, Zagreb, Croatia

Abstract
This study determined basic biological data for the European conger eel Conger conger (L.) population in the coastal waters of the eastern Adriatic Sea. Juveniles and immature females dominated the coastal population, whereas males were relatively uncommon. The population structure determined by the study suggested spatial separation of sexes and spawning grounds in deeper waters. Both edge-type and marginal increment analyses confirmed the formation of a single growth annulus per year on the ground otoliths. The observed maximum age of the coastal conger eels was 8 years, although most of the sampled fish were 5 years old. The estimated parameters of the von Bertalanffy growth model suggested that the growth of the conger eels was relatively slow. C. conger is an opportunistic predator. Its diet was composed primarily of fishes, followed by crustaceans and cephalopods. Due to the evident site fidelity of the species, the wide prey spectrum of the conger eels (33 taxa) reflected the local benthic community structure.

Key words: Age determination, growth, feeding, Conger conger, Adriatic Sea

Introduction
The European conger eel Conger conger (Linnaeus, 1758) is widely distributed throughout the northeastern Atlantic, extending from Norway in the north to Senegal in the south; it also occurs in the Canary Islands, Madeira and the Azores as well as in the Mediterranean and the western Black Sea (Bauchot & Saldanha 1986; Jardas 1996). Contrasting information from fishermen about both the declines and increases in C. conger stocks in the Mediterranean is available, but no comprehensive investigation of the population dynamics and ecology of this species have been performed. Local interest in the conger eel as a target species in both the commercial and recreational fisheries has increased (Relini & Piccinetti 1996) and there is a need for information facilitating improved management advice. However, although the total world catch reported for C. conger to the FAO for 2009 was approximately 17,229 tonnes and the annual landings of this species in the Mediterranean were approximately 4000 tonnes (www.fao.org), there are still no data indicating overexploitation.

The European conger eel is the largest species of the family Congridae. Although large specimens up to 3 m in total length are uncommon in catches, they have been observed by divers during the day in certain parts of the Mediterranean (Smith 1990). The males are usually smaller than the females (Cau & Manconi 1983; Jardas 1996) and the males and females become sexually mature at significantly different lengths of 70 cm and 200 cm, respectively (Jardas 1996) and ages (5 and 15 years, respectively) (Lythgoe & Lythgoe 1971). The conger eel is a large opportunistic predator. Although its diet is poorly studied, it is known to feed on both benthopelagic and strictly benthic prey (Cau & Manconi 1984; O’Sullivan et al. 2004; Xavier et al. 2010). In

*Correspondence: Sanja Matić-Skoko, Institute of Oceanography and Fisheries, Šetalište Ivana Mestrovića 63, 21000 Split, Croatia. E-mail: sanja@izor.hr

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general, the topics which have received the most attention are migration; the separation of the sexes by time, place and depth; the spawning period and place; and the distribution of the leptocephali as well as the early life history of *C. conger* premetamorphic and metamorphic larvae (Cau & Manconi 1983; Correia et al. 2002a, 2002b, 2003).

Data about the age and growth of this species have been reported for the coastal waters of southern Brittany (Sbaihi et al. 2001), the coastal waters of Ireland (O’Sullivan et al. 2003) and the Iberian Atlantic waters (Correia et al. 2009). This article presents the first detailed data on the age and growth of *C. conger* in the waters of the Adriatic and, therefore, for the waters of the Mediterranean. We also provide insights into the feeding and foraging strategies of this species and compare our results with those of previous diet studies conducted in Atlantic waters. Moreover, the data presented in this paper will certainly be useful in support of a future reliable assessment of the status of this commercially important species and its management in the study area. This consideration is especially important because Correia et al. (2011) clearly discriminated conger eel stocks in the northeastern Atlantic and the Mediterranean and stressed the necessity of treating these fisheries as different management units.

**Materials and methods**

Between July 2010 and August 2011 monthly samples of the European conger eel, *Conger conger*, were collected in the eastern Adriatic Sea by bottom longlines set at depths between 5 and 120 m. All specimens were measured for total length (TL) to the nearest 0.1 cm, total weight (W) to the nearest 0.1 g and the weight of the gonads (GW) to the nearest 0.01 g. The sex of the specimens was identified by the wrinkled or smooth gonad surface, which is a distinctive morphological feature for females and males, respectively. A routine histological analysis of the gonadal tissue was performed to validate the technique used for sex determination. Sagittal otoliths were removed from each fish, cleaned and stored dry in labelled envelopes for later examination.

**Fish condition indices**

The length–weight relationship, the condition index (CI) and the gonadosomatic index (GSI) were calculated (Ricker 1975). The difference between the estimated *b* value and the value expected from isometric growth was tested with a one-sample *t*-test. Significant seasonal differences in the CI and GSI values were evaluated with a one-way analysis of variance (ANOVA) followed by a Tukey test. All of the abovementioned indices of the condition of the fish were analysed for the combined data on both sexes.

**Age and growth determination**

One otolith from each pair was selected at random and ground along its medial face (sulcus) with wet abrasive paper. A stereo microscope coupled with a digital camera was then used to photograph the otolith under reflected light against a dark background (immersed in water) at a magnification of 1.2×. The otoliths displayed alternating opaque and translucent zones and ages were assigned to *Conger conger* specimens based on counts of these zones. The combination of one opaque zone and one translucent zone was interpreted as one year’s growth.

To investigate the periodicity of growth ring deposition, a marginal edge of the otolith was classified as opaque or translucent. The percentages of otoliths with defined margins were plotted by month of fish capture for the entire period of investigation. In addition, the marginal increment ratio (MIR) was calculated according to Araújo & Martins (2007). For each otolith, two readers independently counted the annual growth rings. A count was accepted only if the two readers reported the same value. The precision of the counts was estimated by the index of average percentage error (IAPE) (Beamish & Fournier 1981) and the coefficient of variation (CV) (Chang 1982). Length at age was described with the von Bertalanffy growth model (Beverton & Holt 1957).

**Diet analysis**

Immediately after the capture of the fish specimens, their stomachs were removed, weighed (to the nearest 0.01 g) and preserved in 4% formaldehyde for later analysis in the laboratory. The analysis of the stomach contents was performed under a binocular microscope. The prey items were identified to the lowest possible taxonomic level and then counted and weighed to the nearest 0.01 g. The rate of feeding activity was analysed by recording the numbers of empty stomachs and calculating the vacuity index (V) (Hyslop 1980). A *χ²* test was used to test for differences in the number of empty stomachs in relation to seasons. Food items identified as bait (primarily *Sardina pilchardus*) were not included in the diet analysis.

The diet of *Conger conger* was described using the frequency of occurrence (%F) and the percentages
by number (\%N) and by weight (\%W). The index of relative importance (IRI) was calculated according to Pinkas et al. (1971). Ontogenetic and seasonal changes in the diet of *C. conger* were assessed with a multivariate data analysis. The fish sample was split into four size groups: <50 cm TL, 50–75 cm TL, 75–100 cm TL and >100 cm TL. The statistical differences in the diet among fish sizes and seasons were tested with a one-way statistical analysis (ANOSIM routine, test R). This analysis was performed with the PRIMER 5 multivariate statistical package (v. 5.2.9; PRIMER-E Ltd).

**Results**

The length and weight of all sampled *C. conger* specimens (*n* = 317) ranged from 23.4 to 144.0 cm and 43.8 to 6180.0 g, respectively. Fish greater than 100 cm in total length were scarce and much less abundant in the entire sampled population, which was composed primarily of females (67.8\%) (online supplementary Figure 1S). Only 1.3\% of the conger eels collected were males. The sex of the remaining immature specimens (30.9\%) could not be identified macroscopically because they usually had thin or translucent gonads. Therefore, the results of this study will be presented for the entire sampled *C. conger* population, regardless of sex.

The slope (*b* = 3.28) of the length–weight relationship of the conger eels investigated differed significantly from 3.00 (*t*-test, *P* < 0.05), indicating positive allometric growth (Figure 1). The calculated condition index ranged from 0.02 to 0.59, and significant differences in the mean value were not found among the seasons (one-way ANOVA, *P* > 0.05). Moreover, the values of the GSI ranged from 0.002 to 6.782, with the highest values observed during the winter. This index varied significantly among the seasons (one-way ANOVA, *P* < 0.05), namely, between the winter and the summer (Tukey test, *P* < 0.05). Age and growth

The ground otoliths displayed a concentric pattern of alternating opaque and translucent zones (online supplementary Figure 2S). The opaque and translucent zones were deposited primarily from May to September and from October to February, respectively (Figure 2A). These results showed that the formation of growth rings on *Conger conger* otoliths followed a seasonal pattern. The same figure (Figure 2A) shows that the mean marginal increment ratio (MIR) was lowest during the winter (December) and highest during the summer (July). In conclusion, the results of both analyses indicated the formation of one (annual) ring per year.

The percentage agreement between the readers was relatively high (89.6\%), and the variability of the IAPE and CV indices was low (2.9\% and 4.2\%, respectively). Because only the age counts for which the readings agreed were considered reliable, we used the age-at-length data for 284 *C. conger* specimens in the subsequent analyses. Based on the annual growth ring counts, the conger eel ages ranged from 2 to 8 years. Most of the fish were 5 years old, whereas fish younger than 3 years and older than 6 years were poorly represented in the sample (Table I). The length interval-at-age data are also presented in Table I. The von Bertalanffy growth curve and the equation for the observed lengths-at-age of the *C. conger* specimens are shown in Figure 2B. Estimated parameters are *L*∞ = 187.23 cm (SE = 1.253), *K* = 0.11 year⁻¹ (SE = 0.067) and *t*₀ = −0.23 year (SE = 0.198) (*R*² = 0.84).

**Diet**

Of the total number of stomachs examined (*n* = 317), 67 were completely empty (21.1\%). The vacuity index varied significantly over the year (*χ*² = 110.73; *P* < 0.0001), with the highest value in the summer (41.2\%) and the lowest in the spring (8.3\%). In more than 90\% of the stomachs analysed, only one individual prey item was found.

Table I. Length range and the mean length (cm) (± SD) at each age group of the European conger eel, *Conger conger* sampled in the eastern Adriatic Sea (*N*, number of specimens).

| Age | *N* | Range (cm) | Mean length (cm) (± SD) |
|-----|-----|------------|------------------------|
| 2   | 13  | 33.2–44.9  | 40.04 ± 3.15           |
| 3   | 44  | 38.0–68.0  | 50.03 ± 7.84           |
| 4   | 75  | 40.0–84.3  | 63.83 ± 8.00           |
| 5   | 109 | 62.0–100.5 | 75.62 ± 7.98           |
| 6   | 34  | 67.5–125.0 | 89.34 ± 15.41          |
| 7   | 6   | 75.5–130.0 | 113.84 ± 19.98         |
| 8   | 3   | 123.0–144.0| 133.00 ± 10.54         |
Overall, 33 prey taxa belonging to four major groups (plants, cephalopods, crustaceans and fishes) were identified in the stomachs of *Conger conger* (Table II). In general, the conger eels investigated fed on a wide range of prey species. However, fishes were the most frequent prey items ingested, followed by crustaceans. The fish *Boops boops*, which occurred in 3.37% of the samples and represented 4.81% of the total mass, dominated the fish component. Except for *B. boops*, *Gobius* spp., *Phycis blennoides* and *Coris julis*, the fish species identified in the stomachs were found only once or twice. An interesting finding was that a *C. conger* individual of 49 cm TL occurred as a prey species in one of the stomachs. A few species of crustaceans, such as *Liocarcinus navigator*, *Munida rugosa*, *Galathea strigosa*, *Nephrops norvegicus* and *Palaemon* sp., represented the highest contribution of this group to the diet. Note also that the cephalopod *Octopus vulgaris* occurred in 2.59% of the samples and had the second-largest IRI value (Table II).

The dietary differences among the seasons and size groups did not differ statistically; all *R* values were near 0 (*P > 0.05*). However, regardless of these non-significant differences, it is evident that the mean prey weight was positively correlated with the size of the fish. In addition, the analysis of the food spectrum diversity per size class of *C. conger* showed that the highest diversity was concentrated in the smallest size class (< 50 cm TL), whereas all other classes showed a slightly lower level of diversity.

**Discussion**

The absence of males and ripe or spent females in the coastal waters confirms the observation that females are captured exclusively in the shallow coastal areas (Correia et al. 2009) and that sexual maturation in conger eels occurs somewhere in deeper spawning grounds. A few of the deep spawning grounds of *Conger conger* in the north and central Atlantic are already known (Lythgoe & Lythgoe 1971; Correia et al. 2002a, 2003). In the Mediterranean, Cau & Manconi (1983) and Matić-Skoko et al. (2011) suggested only the deep waters of the Sardinian Channel and of the South Adriatic Pit, respectively, are potential spawning grounds. In addition, the absence of *C. conger* males from shallow coastal waters suggests that females and males exhibit different migratory habits during their life cycles. This pattern of migratory behaviour is well known in freshwater eels (O’Sullivan et al. 2003).

Although the GSI was calculated primarily for females that were not yet fully mature, it was highest during the winter, which may indicate the preparation for maturation of *C. conger* in this area. The same has been reported for this species by other authors (O’Sullivan et al. 2003; Correia et al. 2009), and similar results were also found for *C. ocellatus* (Hood et al. 1988). According to Sébert et al. (2007), hydrostatic pressure plays a specific and positive role in the reproduction of the European eel (*Anguilla anguilla*), and this finding provides extra evidence of the important influence of depth on the conger eel’s life cycle.

Age estimation based on ground sagittal otoliths was conducted successfully for the specimens investigated in this study. The validity of the estimates is supported by the low values of the IAPE (2.9%) and CV (4.2%) indices. In agreement with the results for *C. conger* from the Iberian Atlantic waters (Correia et al. 2009), we observed that the otoliths exhibited a well-defined pattern. In addition, because the marginal increment analysis clearly showed that annual growth increments are formed once per year, we are convinced that interpreting annual growth rings in otoliths is a valid method of age determination in this conger eel.

![Figure 2.](image-url)
In this study, it was estimated that *C. conger* might live as long as 8 years in the coastal waters. However, based on the report by Bigelow & Schroeder (1953) that this species may grow as large as 3 m in total length and 73 kg in body weight and on the information that the largest fish in this study reached a length of only 1.4 m and a weight of 6.2 kg, we hypothesize that the maximum attainable age may

### Table II. Frequency of occurrence (F), percent frequency of occurrence (%F), numerical composition (N), percent of total number (%N), gravimetric composition (W), percent of total weight (%W), index of relative importance (IRI) and percent index of relative importance (%IRI) for food items of the European conger eel, *Conger conger* sampled in the north-central Mediterranean (*N* = 250). (+) indicates prey species with a contribution to the %IRI < 0.1%.

| Prey categories | F (%F) | N (%N) | W (%W) | IRI (%IRI) |
|-----------------|--------|--------|--------|------------|
| **SPERMATOPHYTA** |        |        |        |            |
| Posidonia oceanica | 4 (1.03) | 5 (1.26) | 4.70 (0.09) | 1.40 (+) |
| Total Spermatophyta | 4 (1.03) | 5 (1.26) | 4.70 (0.09) | 1.40 (+) |
| **MOLLUSCA – CEPHALOPODA** |        |        |        |            |
| Loligo vulgaris | 2 (0.52) | 2 (0.63) | 23.50 (0.44) | 0.56 (+) |
| Octopus vulgaris | 10 (2.59) | 10 (3.15) | 192.30 (3.64) | 17.60 (+) |
| Sepia officinalis | 1 (0.26) | 1 (0.32) | 17.60 (0.33) | 0.17 (+) |
| Total Mollusca – Cephalopoda | 13 (4.04) | 13 (4.10) | 233.40 (5.53) | 38.89 (+) |
| **ARTHROPODA – CRUSTACEA** |        |        |        |            |
| Eriphia verrucosa | 1 (0.26) | 1 (0.32) | 72.30 (1.37) | 0.44 (+) |
| Galathea strigosa | 4 (1.04) | 4 (1.26) | 24.70 (0.47) | 1.79 (+) |
| Liocarcinus navigator | 5 (1.30) | 5 (1.58) | 25.10 (0.48) | 2.66 (+) |
| Macroopus tuberculatus | 65 (17.35) | 53 (17.38) | 1082.10 (21.86) | 225.62 (8.57) |
| Maja squinado | 1 (0.26) | 1 (0.32) | 27.40 (0.52) | 0.22 (+) |
| Munida rugosa | 5 (1.30) | 7 (1.58) | 35.10 (0.66) | 2.90 (+) |
| Nephrops norvegicus | 4 (1.04) | 4 (1.26) | 13.70 (0.26) | 2.58 (+) |
| Palaemon spp. | 4 (1.04) | 4 (1.26) | 13.70 (0.26) | 2.58 (+) |
| Total Decapoda | 70 (22.51) | 72 (22.07) | 742.22 (17.98) | 1206.78 (15.58) |
| **STOMATOPODA** |        |        |        |            |
| Squilla mantis | 3 (0.78) | 3 (0.95) | 13.70 (0.26) | 0.94 (+) |
| Total Stomatopoda | 3 (0.78) | 3 (0.95) | 13.70 (0.26) | 0.94 (+) |
| **PISCES** |        |        |        |            |
| Scyliorhinus sp. | 13 (3.37) | 13 (4.10) | 254.14 (4.81) | 30.02 (1.05) |
| Callionymus sp. | 1 (0.26) | 1 (0.32) | 12.30 (0.23) | 1.79 (+) |
| Conger conger | 1 (0.26) | 1 (0.32) | 140.00 (2.65) | 0.77 (+) |
| Coris julis | 4 (1.04) | 4 (1.26) | 20.13 (0.32) | 2.88 (+) |
| Diplopterus annularis | 1 (0.26) | 1 (0.32) | 27.40 (0.52) | 1.58 (+) |
| Epinephelus costae | 1 (0.26) | 1 (0.32) | 27.40 (0.52) | 1.58 (+) |
| Gobius spp. | 5 (1.30) | 7 (1.58) | 35.10 (0.66) | 2.90 (+) |
| Helicolenus dactylopterus | 1 (0.26) | 1 (0.32) | 375.00 (7.10) | 1.92 (+) |
| Melichthys merluccius | 1 (0.26) | 1 (0.32) | 27.40 (0.52) | 0.22 (+) |
| Mulloides californicus | 1 (0.26) | 1 (0.32) | 17.30 (0.33) | 1.79 (+) |
| Pseudobalistes amblycephalus | 1 (0.26) | 1 (0.32) | 25.70 (0.48) | 1.79 (+) |
| Pomatomus saltatrix | 1 (0.26) | 1 (0.32) | 25.70 (0.48) | 1.79 (+) |
| Scorpaena sp. | 1 (0.26) | 1 (0.32) | 45.30 (0.86) | 0.30 (+) |
| Serranidae | 6 (1.59) | 6 (1.59) | 265.46 (5.03) | 10.75 (+) |
| Sphyraena japonica | 2 (0.52) | 2 (0.52) | 36.30 (0.69) | 3.66 (+) |
| Sphyraena maculata | 2 (0.52) | 2 (0.52) | 36.30 (0.69) | 3.66 (+) |
| Symphodus mandarinus | 1 (0.26) | 1 (0.32) | 3.74 (0.07) | 0.10 (+) |
| Thalassoma pavo | 1 (0.26) | 1 (0.32) | 22.36 (0.42) | 0.19 (+) |
| Osteichthyes unidentified | 97 (25.13) | 97 (30.60) | 1134.54 (21.48) | 1308.70 (45.93) |
| **Total Osteichthyes** | 147 (45.20) | 151 (46.37) | 2910.44 (69.67) | 5424.47 (69.23) |
| **Total Pisces** | 147 (45.65) | 151 (46.37) | 3058.14 (72.47) | 5425.28 (69.24) |
be over 20 years. The results of the few studies of age and growth in *C. conger* that are available across the geographical distribution of the species also support this hypothesis. The oldest conger eel specimens caught in the coastal waters of southern Brittany (Sbaihi et al. 2001), the Iberian Atlantic (Correia et al. 2009) and Ireland (Fannon et al., 1990; O’Sullivan et al. 2003) were 11, 12 and 21 years old, respectively. The difference between our data and these previous reports may reflect different sampling techniques, depths sampled and/or fishing pressures. Our largest individual was smaller than the largest individuals collected by the studies cited. However, the complete absence of the smallest individuals in the first year class is common to each of the studies cited and to this work. This result can be easily explained by the selectivity of the fishing gear used (in general, longlines; O’Sullivan et al. 2003). In conclusion, it is probable that the limited sampling of both small and large individuals by the present study as a result of gear selectivity and the previously mentioned separation of the sexes by depth resulted in the narrow age range observed (from 2 to 8 years).

The feeding of the *C. conger* population investigated was based primarily on benthopelagic and benthic species of Pisces, Crustacea and Cephalopoda. This finding indicates that the species forages actively in the water column and near rocky areas. Foraging near rocky areas is associated with a degree of site fidelity and allows the conger eel to use the rocks as a refuge (Xavier et al. 2010). This observation also confirms previous investigations in northeastern Atlantic waters (Morato et al. 1999; O’Sullivan et al. 2004; Xavier et al. 2010) and in deep Central Mediterranean waters (Cau & Manconi 1984). In general, fishes were the most numerous prey ingested, occurring in more than 45% of all the specimens analysed. However, previous studies have found very different species compositions in the diet, probably a reflection of geographical and bathymetrical variation in prey availability. Also, the almost complete absence of males in the shallow coastal area may suggest that significant differences in the composition of the diet between males and females according to depth are to be expected. The observation that no prey species was clearly dominant in numerical terms (> 19 fish species) suggests that *C. conger* is an opportunistic and also cannibalistic species, as previously reported by Xavier et al. (2010). In contrast, this species is considered a specialist feeder in Irish waters because only 2–3 fish species were found as prey (O’Sullivan et al. 2004). This finding shows the adaptability of this conger eel and might also partially explain the broad distribution of the species (Xavier et al. 2010). The high percentage (> 20%) of empty stomachs in the sample may be a consequence of the specificity of bottom longlines and the possible inadequacy of this passive gear as a sampling device for the purpose of diet analysis. However, Xavier et al. (2010) demonstrated that specimens caught on longlines contained numerous prey in very good condition. The longline samples allowed rapid and easy prey identification and thus provided good insights into the food items that had recently been consumed.

This study reports the values of the principal population parameters necessary for better conservation and a reliable stock assessment of *C. conger* in Adriatic and Mediterranean waters. However, several biological indices are still unclear, e.g. the spawning grounds, the separation of the sexes by depth, different migration habits, the nurseries and the mechanisms of retention and dispersion of the leptocephali of this species. In addition, it is important to determine trends in the total catch and to obtain reliable data on the fishing effort for this species. Only then would it be possible to determine a common strategy for the sustainable management of the conger eel fishery in the Mediterranean as a unique management unit distinct from the northeastern Atlantic unit previously described by Correia et al. (2011).

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Editorial responsibility: Kathrine Michalsen