

Size and age at onset of sexual maturity of female Norway lobster *Nephrops norvegicus* L. (Crustacea: Nephropidae) in the Strait of Sicily (Central Mediterranean Sea)*

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SUMMARY: The reproductive cycle of the Norway lobster (*Nephrops norvegicus*) female was investigated to determine the size and age at onset of sexual maturity (SOM), as a baseline to establish the minimum catchable size. Samples were gathered in four seasonal (Spring 1986 - Winter 1987) trawl surveys on the Italian side of the Strait of Sicily (Central Mediterranean Sea). The relative frequency of females in different stages of maturation and in berried conditions was observed. According to the ovary stages, gonadal maturation is attained during Spring and Summer; berried animals occur almost exclusively in Summer and Autumn, in about 40% of the sample. Length structure changes slightly by location and by season; recruitment to the gear occurs more or less continuously. Gaussian components appear to be highly overlapped; the resolution of the length frequency distribution values leads to the identification of multiple cohorts, five of which were well represented. The population attains 50% of maturity at 30-32 mm CL, corresponding to an age of 5 years. The mean size of the first Gaussian component from the catch (about 22 mm CL) is well below the estimated size at 50% maturity, suggesting a precocious recruitment to the fishery.

Key words: *Nephrops norvegicus*, Norway lobster, reproduction, Central Mediterranean.

INTRODUCTION

The Norway lobster, *Nephrops norvegicus*, is a benthic burrowing decapod crustacean that inhabits muddy bottoms on the continental shelves and slopes of the North-Eastern Atlantic and the Mediterranean. Highly regarded and prized as a delicacy, it is a sought-after species for the world trawl fisheries which land thousands of tons (Saila and

Marchessault, 1980), valued at several hundred million of dollars per year. Its scientific and economic importance has resulted in a large amount of studies with recurrent reviews (Figueiredo and Thomas, 1967; Farmer, 1975; Chapman, 1980; Sardà, 1993). For the Strait of Sicily, information on the spatial distribution and fishing yields is reported by Ragonese *et al.* (1993); at present, the fishery lands a few hundred tons per year, worth 15 US \$ per kg, and management is done by non-specific fishing bans and by limiting landing size (20 mm of carapace length, set empirically).

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In fact, size (or age) at maturity, defined as the size (or age) at which 50% of animals are in reproductive condition, may represent a more appropriate tool to assess the minimum catchable size compatible with sustained exploitation (Welch and Foucher, 1988).

Since only scanty information exists on maturity periodicity of Norway lobster in the Strait of Sicily (Azouz, 1972; Levi, 1991), the present study aims to assess in this area the size and the related age at sexual maturity of female Norway lobsters, based on ovarian development and presence of eggs on pleopods.

MATERIALS AND METHODS

Data came from four seasonal trawl surveys carried out from Spring 1986 to Winter 1987 (Levi, 1991). Norway lobsters were collected according to a stratified (by depth range) random design with proportional (by surface) allocation in the Strait of Sicily (Central Mediterranean Sea), an area characterized by irregular grounds, strong hydrodynamics and isothermal (12-14°C) waters below the thermocline (located at about 50 m deep).

Samples were taken using a chartered trawler of 1020 HP, with a commercial trawl net (net mouth of

TABLE 1. – Descriptive statistics for *Nephrops norvegicus* females by season, maturity stages and all data combined (measures in mm).

	1st white	2nd creamy	3rd pale green	4th dark green	5th mottled green	all stages combined	of which, berried
SPRING							
N	198	153	298	285	0	934	0
N(%)	21.2	16.4	31.9	30.5		100	
minimum CL	16	21	21	25		16	
maximum CL	42	47	47	51		51	
median CL	25	30	35	38		34	
mean CL	25.7	30.3	35.4	37.4		33.2	
s.e. of mean	0.31	0.37	0.26	0.25		0.21	
skewness	0.63	0.60	0.11	0.08		-0.18	
SUMMER							
N	275	44	40	64	28	451	180
N(%)	61.0	9.7	8.9	14.2	6.2	100	40.0
minimum CL	16	21	24	27	30	16	27
maximum CL	45	42	42	46	47	47	47
median CL	31	31	31	33	36	32	36
mean CL	31.1	31.8	31.7	33.4	36.6	31.9	36.3
s.e. of mean	0.41	0.72	0.64	0.43	0.87	0.29	0.31
skewness	-0.10	-0.19	1.36	1.18	0.51	-0.18	0.35
AUTUMN							
N	374	126	11	0	1	512	207
N(%)	73.0	24.6	2.2		0.2	100	40.4
minimum CL	13	20	21		31	13	22
maximum CL	46	48	37		31	48	48
median CL	30	34	31			31	34
mean CL	29.4	33.9	31.5		31.0	30.6	35.5
s.e. of mean	0.33	0.50	1.34			0.28	0.33
skewness	0.04	0.22	-1.02			0.00	0.24
WINTER							
N	646	308	112	72	0	1138	12
N(%)	56.8	27.1	9.8	6.3		100	1.0
minimum CL	11	21	24	27		11	29
maximum CL	46	48	47	47		48	42
median CL	30	34	35	33		33	34
mean CL	30.1	34.1	35.9	34.4		32.1	35.7
s.e. of mean	0.28	0.31	0.43	0.53		0.20	1.54
skewness	-0.20	-0.08	0.14	1.29		-0.38	0.09

0.9 m by 27 m; cod-end with 36 mm stretched mesh), fishing only in daylight. Each haul was about 5000 m long (1 hour at 2.8 knots), resulting in an estimated swept area of about 0.13-0.14 km². From a total of 244 hauls in the depth range 200-800 m (of which 189 positive for Norway lobster), 12807 specimens and 389 kg were retrieved. A subsample of 3035 female Norway lobsters was used for sexual maturity analysis.

The oblique length of the carapace (CL) of females was measured on board with a caliper rounding down the millimetre below. The ovaries, exposed after cutting the carapace, were examined on board in the fresh condition and classified into five stages of development, according to their morphology and colour following Farmer's (1975) maturity scale; berried specimens were also noted. Females with stage "3" (pale-green) and stage "4" (dark-green) ovaries, and berried females were combined and considered as "mature" females (Orsi Relini and Relini, 1989; Biagi *et al.*, 1990; Sardà, 1991).

The proportion of "mature" animals in each size class was computed and a logistic curve was fitted to each seasonal data set. The integral form of the curve that directly yields the length class at 50% of maturity was employed:

$$p_i = \frac{p_{\max}}{[1 + \exp^{-a(CL_i - b)}]}$$

where "p_i" is the proportion of mature animals in the ith class, "p_{max}" is the asymptote (usually assumed to be 1), "a" is a constant (the "steepness" parameter), "b" is the length corresponding to 50% of p_{max} (the "location" parameter), and CL_i is the ith carapace length class considered.

The parameters coefficients were estimated using the non-linear procedure ("NONLIN") of "SYSTAT for Windows" (1992). Given the binomial distribution of the events (mature/non mature), a maximum likelihood (ML) criterion (Welch and Foucher, 1988) was used in the loss function of the program. In particular, the negative of the log_e ML was minimized, i.e.:

$$\text{Loss} = -\{\text{Mat} * [\log_e(\text{estimate})] + (\text{Tot} - \text{Mat}) * [\log_e(1 - \text{estimate})]\}$$

where Tot and Mat represent the sample size and the number of mature females in the ith size class respectively. Only the last p_i = 0 and the first p_i = 1 value in each tail (of course, except those included between 0 < p_i < 1 proportions) were retained in the

computations. The estimated inflection point of the curve (size corresponding to half of the asymptotic proportion) was considered the size at onset of sexual maturity (SOM).

Length frequency distributions (LFDs) by season or seasons-combined were smoothed (three-point moving average) and analyzed by applying the Bhattacharya modal progression analysis method (MPA routine), as given in the "Compleat ELEFAN, v. 1.1" (Gayanilo *et al.*, 1989), for a discrimination of the Gaussian components.

In order to assign an age to the estimated SOMs, the evolution in time of the mean length estimated for "representative" components (as general rule, components with a frequency greater than 30 and a separation index greater than 2) was analyzed for the seasons-combined results after assignment of an age on the basis of literature growth data (Castro, 1992; Mytilineou and Sardà, 1995); then, absolute and instantaneous specific growth rates were computed according to Ricker (1979) and referred to an interval of 1 year.

RESULTS

Green and berried females were observed throughout the explored area and were caught in the whole depth range in which Norway lobster occurred (150-600 m), thus no specific spawning zone was evident. The number and percentage of females in different ovarian development stages, and the corresponding descriptive statistics, are reported in Table 1, together with the number and percentage of berried females.

"Green" females (stages "3" and "4") are predominant in Spring, when they constitute more than 60% of the sample and almost 100% in the larger sizes (CL > 36 mm), whereas "white-creamy" females (stages "1" and "2") are dominant in the other seasons. This prevalence of females with mature ovaries in Spring is in agreement with the general reproductive period (April-September) reported for Mediterranean and Atlantic populations (Vives and Suau, 1963; Orsi Relini and Relini, 1989; Sardà, 1991; 1993).

Females with green eggs on the pleopods are observed in Summer and Autumn in almost equal proportions, 40.0% and 40.4% respectively. No berried females were captured in Spring; a very low number (12; i.e. 1.05%) appears in the Winter catch, scattered in the size classes (from 29 mm to 42 mm CL). The smallest ovigerous specimen is 22 mm CL,

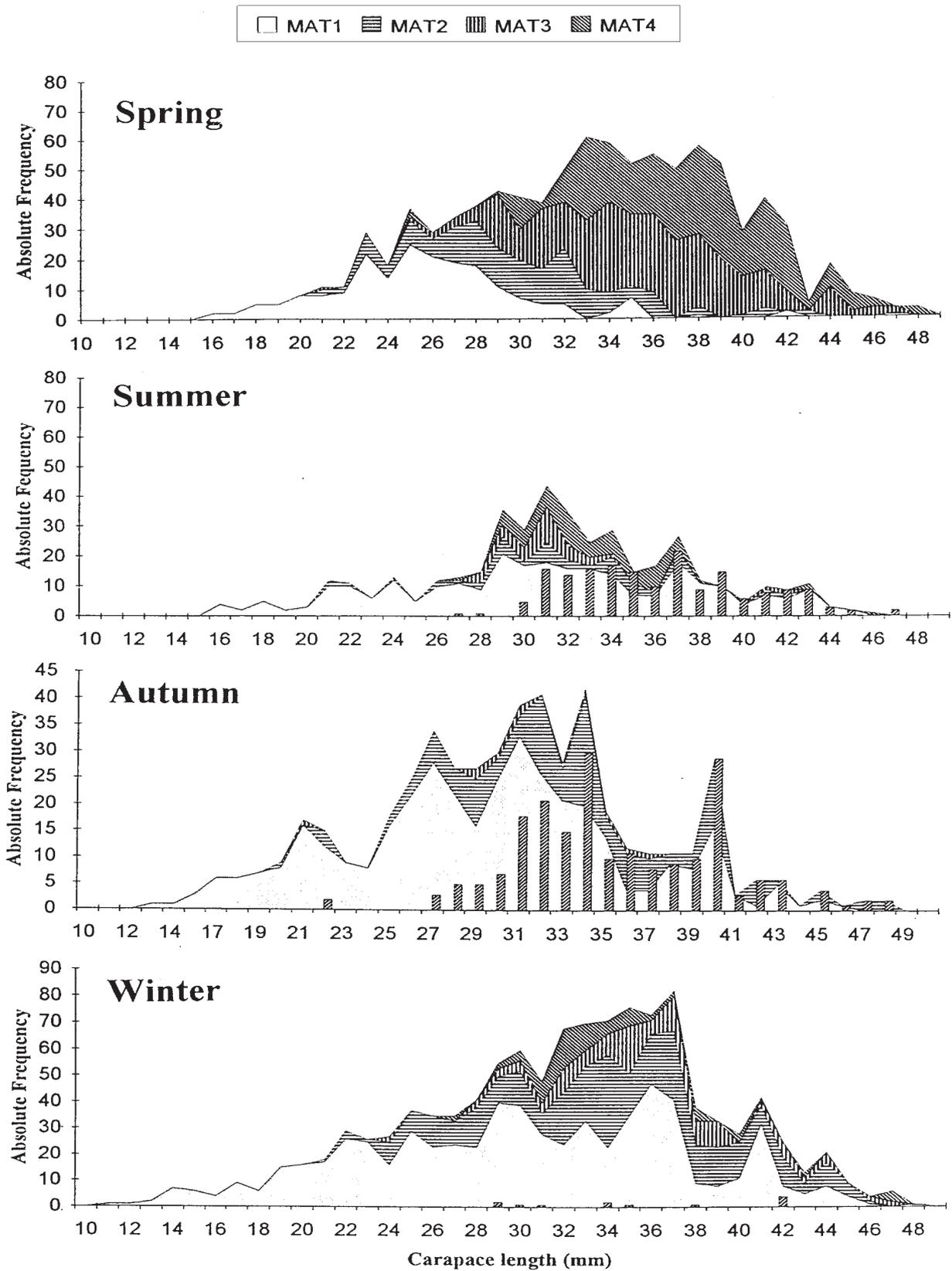


FIG. 1. – Length frequency distributions for *Nephrops norvegicus* females by season, showing also maturity stages. Legend: MAT1, white ovary; MAT2, creamy ovary; MAT3, pale-green ovary; MAT4, dark-green ovary. Berried females (OV) frequencies are superimposed as histograms.

but the presence of berried females is consistent only beyond the 27 mm (Autumn) and 30 mm (Summer) size classes; the mean length of berried females (35-36 mm) does not change with season.

The comparison of ovarian and ovigerous conditions (Fig. 1) shows the correspondence between the "green" ovarian components and the "berried" females of two successive seasons. It is worth noting that almost all berried females present the ovary in the first or second stages (a few also in a "spent" fifth stage).

The scarcity of berried females in Winter suggests that the incubation period takes only 4-6 months, close to the estimate of Orsi Relini and Relini (1989), but less than the 6-12 months generally reported for the species (Chapman, 1980; Sardà, 1993).

Since only green eggs, and never the more advanced orange-pink eggs, are observed in the berried females caught in the experimental surveys and since the green eggs in Autumn reveal, under microscopic observation, to contain embryos at the IV and V stages of development (according to Farmer, 1975), most of the berried females caught in Autumn should represent the females which have extruded their eggs in Summer.

All the female length frequency distributions (Fig. 1) present a similar shape: the modes are highly overlapped, the modal progression is not self-evident and recruits (below 20 mm CL) are always present, even though a stronger recruitment pulse occurs in Autumn. Generally, the LFDs are quite stationary, and the range, mean length and

related statistics do not change substantially (see the "combined" column in Table 1).

The results of the MPA are presented in Table 2; both seasonal and combined LFDs yield comparable results and the expected LFDs are always not significantly different from the observed LFDs (χ^2 test at $p=0.05$). A maximum of 7 components are detectable but only 4-5 are "representative" ($N_i > 30$, index of separation > 2); the number of representative components and the corresponding mean lengths are in agreement with Frogli and Gramitto (1988) and Mytilineou *et al.* (1990). The comparison of the results of the MPA analysis with the age estimates from Castro (1992), Sardà (1993) and Mytilineou and Sardà (1995) allow the assumption that each Gaussian component represents an individual annual cohort.

Based on the combined-seasons estimates, annual size increments are 4-5 mm/year, which is in agreement with the linear growth described for the Atlantic populations (Hillis, 1979; Castro, 1992; Sardà, 1993), and the specific growth rate decreases consistently (0.220, 0.141, 0.123 and 0.126).

The proportions of mature females by length class (Fig. 2) show a good approximation to a logistic curve (with an asymptote of 1) in each season but Winter; in the largest classes, "mature" females represent almost 100% of the specimens. The estimated sizes at 50% of maturity are 30.9, 29.9 and 32.1 mm for Spring, Summer and Autumn respectively; the "steepness" parameter is higher in Summer (0.45 vs. 0.38 and 0.39). The mean errors (loss/df) show that the seasonal curves fit quite well the observed data.

TABLE 2. – Bhattacharya's modal progression analysis (MPA) for *Nephrops norvegicus* females by season and data combined; combined estimates were derived after weighed pooling of the data. Legend: CL, carapace length in mm; sd, standard deviation of the mean length; N, number of specimens in each component; underlining denotes non-representative components ($N < 30$, or index of separation < 2); χ^2 : chi-square statistics (H_0 : exp = obs; never significantly different, $P > 0.05$); df: degrees of freedom

Group	Spring			Summer			Autumn			Winter			Combined		
	mean CL	sd	N	mean CL	sd	N	mean CL	sd	N	mean CL	sd	N	mean CL	sd	N
1	18.1	1.38	14	17.6	1.10	12	19.1	1.86	34	17.0	1.25	20	18.1	1.74	19
2	25.4	2.75	191	22.9	2.04	53	22.5	1.56	46	23.1	2.82	169	22.3	1.46	134
3	30.4	2.05	185	30.1	1.99	148	27.3	1.60	113	<u>27.6</u>	1.88	139	27.8	2.17	511
4	34.8	1.74	249	<u>33.6</u>	2.26	136	32.2	1.92	178	33.5	2.66	496	32.0	1.92	1441
5	38.8	1.10	185	38.0	1.57	63	<u>35.2</u>	1.62	61	37.9	1.62	168	36.4	1.88	976
6	42.3	1.71	93	42.6	1.59	40	40.2	1.47	64	42.2	1.12	101	41.3	1.76	193
7	<u>47.2</u>	1.21	18	<u>47.4</u>	0.87	3	<u>44.3</u>	1.17	9	45.3	1.57	31	<u>45.3</u>	0.81	9
	χ^2 8.9 (df 14)			χ^2 4.48 (df 13)			χ^2 2.78 (df 12)			χ^2 16.0 (df 16)			χ^2 13.4 (df 12)		

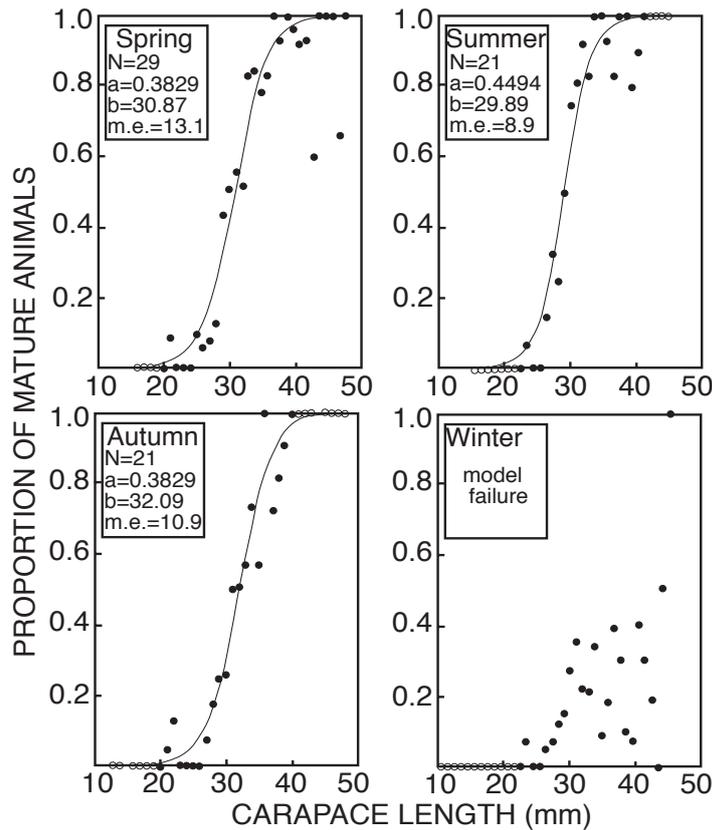


FIG. 2. – Percentage of mature females of *Nephrops norvegicus* as a function of carapace length, by season, fitted by a logistic curve. Legend: a, “steepness” parameter; b, size at 50% of maturity (SOM); m.e., mean error (loss/df). Solid symbols indicate the points included in the estimation, N their number, df the degrees of freedom ($df = N - 2$).

From the results of the modal progression analysis and assuming an absolute age of 3.5 year for the first representative mode (Castro, 1992), the present SOM estimates (30-32 mm) should correspond to an age of about 5.5 years, an age higher than that assigned to the SOM of the Atlantic populations (Morizur, 1983), but similar to that of the Western Mediterranean (Sardà, 1991).

As an ancillary result, it appears that the overall sex-ratio (fem/tot) was 0.48, and that all specimens above 51 mm CL are males, the largest size being 66 mm; females are slightly more abundant in the smallest classes (20-30 mm CL), then the ratio decreases linearly.

DISCUSSION

Norway lobster is generally considered as a slow-growing and long-living species (Conan, 1975; Hillis, 1979; Sardà, 1985, 1993; Castro, 1992), even though its life cycle is shorter than that of other Nephropidae (Saila and Marchessault, 1980).

The assessment of demographic parameters for this species is hampered by its territorial, foraging and burrowing behaviour, that changes with size, age and condition (Chapman, 1980), and by the difficulties of estimating age (Castro, 1992), making any generalization and comparison very difficult.

Norway lobster females are able to spawn very precociously (18-29 mm, CL), and the minimum spawning size seems linked to the geographical area; minimum spawning size is lower in the Atlantic (18-20 mm CL: Symonds, 1972), the Adriatic (18-22 mm: Figueiredo and Thomas, 1967; Frogliia and Gramitto, 1988) and central Mediterranean (22 mm: present study), than in the Northern Mediterranean Sea (29 mm: Orsi Relini and Relini, 1989; Campillo *et al.*, 1991).

A comparison of available data tends to point at the incubation requirements (temperature dependent), food availability and intraspecific competition, as the key factors in the dynamics of the different stocks (Briggs, 1987); in particular, populations (or “stocklets”) with different growth,

reproduction and mortality rates can be found close to each other (Froglia and Gramitto, 1988), even though the same basic life cycle (Sardà, 1991; 1993) is maintained. However, the principal discriminant among populations appears to be the incubation period which varies from 12-13 months around Iceland (Sterk and Redant, 1989) to 4-6 months in the Mediterranean. A consequence is the inverse correlation between percentage of berried females and size class of females in colder waters, which supports the Storrow's hypothesis (in Symonds, 1972) of the occurrence of a biennial spawning for largest females, unable to synchronize growth and maturity process with mating (Sardà, 1993). Biennial spawning has been reported also for the Mediterranean populations (Orsi Relini and Relini, 1989; Sardà, 1991), but the phenomenon should have a lower incidence, since 100% of maturity in the largest size classes has been observed for the Adriatic (Froglia and Gramitto, 1981), Ligurian (Orsi Relini and Relini, 1989) and Northern Tyrrhenian seas (Biagi *et al.*, 1990).

The presence of eggs is usually discouraged as a maturity criterion (Morizur, 1983), since berried females are supposed to be less available to the gear; in the present study, however, although the skewness toward the left of the distribution of the berried females in the Autumn sample suggests a gradual rarefaction at the end of incubation, a regular presence of berried females in the catch has been detected, and not only at the beginning of the spawning period. Moreover, the inclusion of berried, but with resting gonads, animals in the "mature" category offers a better approximation of the reproductive capacity of the population.

The observations indicate a rapid passage from "green" to berried females, a prolonged gonadic maturity (Spring and Summer) and spawning activity (Summer-Autumn) with a brief resting phase (Winter) which corresponds to the "fixed" moulting period for Norway lobster (Sardà, 1991; 1993); nevertheless, it is likely that moulting occurs continuously (Orsi Relini and Relini, 1989; Biagi *et al.*, 1990) also in the Strait of Sicily.

The occurrence of berried females with green eggs in Summer and Autumn, with a sharp decline in Winter, has already been reported for other Mediterranean populations (Vives and Suau, 1963; Orsi Relini and Relini, 1989; Sardà, 1991). A similar periodism, indeed with slight anticipation, is reported for the Atlantic populations (Symonds, 1972; Sterk and Redant; 1989; Sardà, 1993). Also,

the SOM estimates are similar to those available in the literature for the Mediterranean (31-32 mm: Orsi Relini and Relini, 1989; 30-32 mm: Biagi *et al.*, 1990; 30.5-31.5 mm: Sardà, 1991), with the exception of Greek waters (39 mm: Mytilineou *et al.*, 1990), and higher than those reported for the Atlantic (Morizur, 1983; Briggs, 1987; Sardà, 1993).

Speaking of the recruitment to the gear aspects, since incubation period in the Strait of Sicily is supposed to be almost constant, a wide but not continuous recruitment should be expected, but the samples show an opposite behaviour (i.e., recruitment occurs almost continuously). It might be that Norway lobster spends part of its larval period in the superficial layers, where the lower autumnal temperature will prolong the larval life, or that the Strait's grounds are colonized by recruits coming from neighboring populations (Hill and White, 1990) with slight different hatching schedules.

Unfortunately, even the basic information on Norway lobster growth is lacking; still, the MPA analysis supports a long life span (more than 8 years), absolute growth rates (of 4-5 mm/year) comparable to those estimated for the Atlantic populations, a piece-wise linear growth model. In fact, the absolute and specific growth rates from this study suggest, in agreement with Castro (1992), that the asymptotic model of von Bertalanffy is unsuited for the Norway lobster, notwithstanding its common use in the literature (Conan, 1975; Sardà, 1985; Froglia and Gramitto, 1988; Mytilineou *et al.*, 1990).

Stationarity in the LFDs has been generally reported for these stocks both in the Mediterranean (Sardà, 1985; Orsi Relini and Relini, 1989; Mytilineou *et al.*, 1990; Campillo *et al.*, 1991) and the Atlantic (Hillis, 1979; Briggs, 1987); still, some exceptions (i.e. LFDs showing well defined modes and modal progression) can be found in the literature (Morizur, 1983; Froglia and Gramitto, 1988).

Large differences exist in the degree of representativeness of the large-sized females: the largest carapace lengths, close to 70 mm, were observed in the Ligurian Sea, the Gulf of Lions and the Hellenic waters, whereas the 45-50 mm CL sizes represent the largest females in samples from the Catalan Sea and the Strait of Sicily; historical data to assess if this reduction in mean size might reflect a higher fishing pressure are not available. Finally, the scarcity of juveniles is not explained by gear selection, since the mesh sizes in use (16-18 mm side) prevent any escapement from the cod-end.

CONCLUSIONS

The present results indicate that the reproductive pattern of Norway lobster from the Strait of Sicily conforms to the general scheme reported for the species, with higher affinity to Western Mediterranean situations; Norway lobster females in this area undergo ovary ripening mainly in Spring and spawn in Summer and Autumn, averaging a size at onset of maturity around 31 mm CL (which should correspond to an age of 4-5 years from hatching). Periods of ripening (Spring) and recovery (Winter) are those when adult females withstand the highest fishing mortality; yet, data suggest that breeding females are commonly fished during the first period of incubation, too.

The prolonged maturity and spawning period, and the continuous recruitment, reduce the effectiveness of management tools such as the fishing ban presently enforced by the Italian government (Levi, 1991); the minimum legal landing size is also of small effect because of the coexistence of several cohorts in the same places (i.e., no "nursery area" is evident) and to the economic value of even juvenile Norway lobsters. Moreover, regulation of fishing mortality by enlarging the traditional diamond shaped mesh is not attractive due to the flat selectivity curves for the species (Sardà *et al.*, 1993).

As a consequence, technological improvements such as the introduction of safer bottom gear, in order to protect the integrity of the bottom, and the adoption of the square mesh or separator grids, aimed at improving the selectivity properties of the gear, should be sought to improve the Norway lobster fishery in the Strait of Sicily.

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