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Reproduction, age and growth in the grenadier *Nezumia aequalis* (Gunther, 1878) (Pisces: Macrouridae), a by-catch species of deep-water fisheries to the west of the British Isles.

by

R. A. Coggan[1], J. D. M. Gordon[1] & N. R. Merrett[2]

[1] Scottish Association for Marine Science, Dunstaffnage Marine Laboratory, PO Box 3, Oban, Argyll PA34 4AD, Scotland, UK. [tel: +44 1631 562244, fax: +44 1631 565518, e-mail: raco@ccms.ac.uk, jdmg @ccms.ac.uk]
[2] The Natural History Museum, Cromwell Road, London SW7 5BD, UK. [tel: +44 171 938 9430, fax: +44 171 938 9158, e-mail: n.merrett@nhm.ac.uk]

ABSTRACT

During bottom trawl research surveys of the NE Atlantic continental slope, the macrourid *Nezumia aequalis* was found to be common and widespread in the 750 - 1000 m depth zones. Although it has no commercial value, due to it's small adult size (total length ~30 cm), it is nevertheless large enough to be retained by commercial trawls targeting marketable species such as the roundnose grenadier *Coryphaenoides rupestris* and deep-water sharks (e.g. *Centroscymnus crepidater* and *C. coelolepis*). *Nezumia aequalis* is therefore seen to be an important component of the fish assemblage of the continental slope and a species which is impacted by commercial fishing operations, but little has been reported of its biology in this area. The breeding season extends over the first three quarters of the year, mature ovaries containing five size groups of eggs suggesting serial batch spawning. Total egg count ranged from 2109 to 26 847 and was strongly correlated with body size. Age, as determined from whole and sectioned otoliths, ranged from 1 to 10 years, the ageing methods being validated by a time-series study of the otolith edge. Growth was slow and maximum size small (von-Bertalanffy parameters: k = 0.175, L.inf = 676 cm head length), females attaining a larger adult size than males.

Key words: age, grenadier, growth, nezumia, reproduction.

INTRODUCTION

Macrourid fish dominate the ichthyofauna of the continental slope, both in terms of numbers and biomass (Marshall, 1965; Mauchline & Gordon, 1984). *Nezumia aequalis* is widely distributed throughout the Atlantic and Mediterranean, being benthopelagic by habit, occupying the continental slope at depths between 200 - 2 300 m (Geistdoerfer, 1986; Cohen *et al.*, 1990). It is one of the most common grenadier species caught in trawl surveys to the west of the British Isles (Merrett *et al.*, 1991*a,b*; Gordon & Bergstad, 1992; Gordon *et al.*, 1996;) and occurs as by-catch in commercial trawls (Connolly & Kelly, 1996; Newton & Blasdale, pers. comm.). Studies of the NE Atlantic population have mostly been restricted to its distribution and diet (e.g. Mauchline & Gordon, 1984), so the purpose of this paper is to present new data on aspects of its biology in this region.

MATERIALS AND METHODS

Nezumia aequalis were sampled using a variety of bottom trawls from two areas of deep-water to the west of the British Isles; the Rockall Trough (RT) between 1975-79 (Gordon & Duncan, 1985) and 1983-92 (Gordon & Bergstad, 1992; Gordon *et al.*, 1996) and the Porcupine Seabight (PSB) between 1979-83 (Merrett *et al.*, 1991*a,b*). In the RT sampling was carried out at approximately 250 m depth increments from 500 to 3000 m depth while in the PSB sampling extended from about 250 m to abyssal depths (4500 m+), specific depth zones only being sampled on some cruises. The most effective gear was a semi-balloon otter trawl fished on a single warp (denoted OTSB(S))

Morphometric measurements, sex and gonad maturity were recorded for most individuals. Head length (L_H in cm) was the preferred standard measurement as the elongated tails of many macrourid species are often foreshortened by predation or net damage. Total Length (L_T) was recorded for undamaged fish. Females were assigned to a maturity scale according to the gross appearance of their ovaries, where I = immature, II = virgin or resting, III/IV = maturing/mature, V = running, VI = spent, and temporal variations in gonad maturity investigated. Some specimens were frozen or preserved in 4% formaldehyde and returned to the laboratory for further examination. Total weight (W_T) and gonad weight (W_G) were measured to 0.1 g and a Gonadosomatic Index (GSI) calculated as $100*(W_G/ W_T - W_G)$. Fecundity and egg size were investigated in ovaries of maturity stages III/IV and V, as detailed previously (Coggan *et al.*, 1998). Several size groups of eggs were found, so fecundity was expressed as Absolute Individual Fecundity (AIF) being the total number of eggs in all size groups present. The size range of the various groups of eggs was determined by visual inspection of their size-frequency distribution and the proportion which each group contributed to the AIF calculated.

The growing edge of a selection of 208 otoliths was examined to determine whether hyaline or opaque material was being deposited at the time of capture, from which the annual pattern of deposition was assessed. Otoliths from smaller (juvenile) fish were preferred as these were easier to interpret and minimised the possibility of including hyaline spawning checks. Age was determined in a non-random sample of otoliths selected to represent the whole size range of fish, where possible having ≥ 10 specimens for each 0.5 cm L_H size range, and growth modelled using the Von Bertalanffy growth equation fitted to mean length-at-age data. Small otoliths (to length $\approx$ 5 mm) were examined whole while larger otoliths were mounted in resin and 0.5 mm thick transverse sections prepared. The birth date was taken to be 1 January and age classes were assigned according to whether or not the fish would complete the substantial part of its next slow growth phase (depositing hyaline material) before 31 December. Thus, an otolith showing 3 hyaline zones and a narrow opaque outer zone would be assigned to age class 4 if caught between January and June, but to age class 3 if caught between July and December. An otolith showing three hyaline zones, the last being at the outer, growing edge would always be assigned to age class 3.

RESULTS

In OTSB(S) trawls, *Nezumia aequalis* was ranked 5th by number (4.2%) of 105 species captured in RT and 2nd by number (7.4%) of 145 species in PSB. It dominated the fish fauna in the 750 m zone of the RT, comprising 29.4% of the catch. Summary data for specimens taken in OTSB(S) hauls are given in Table I. Sizes ranged from 0.8-6.0 cm Head Length (L_H), and the size distributions from both RT and PSB indicated that females attain a larger size than males. Sex ratio was stable, remaining at approximately 1:1 in all depth zones in both RT and PSB except where sample size was low (n<20). Neither the $L_H : L_T$ or the $L_H : W_T$ relationship differed significantly between sexes but fish of equivalent sizes were slightly heavier in RT than PSB (for L_H = 5.0 cm, W_T = 95.0

g in RT but 84.5 g in PSB).

Gonad maturity showed a moderate seasonal cycle, the proportion of spent and resting gonads increasing rapidly in the latter part of the year while that of the maturing and running gonads decreased (Fig. 1). Ripe (running) gonads were found from January to September indicating an extended spawning period but were notably absent from the February and March samples in the RT and the April sample in the PSB, suggesting at least two spawning epochs in any one breeding season. The seasonal variation in GSI, peaking in April in RT (Fig. 2) provides further evidence for peak breeding condition in the second quarter of the year (boreal spring). GSI data were only available for four months (February & May-July) in PSB but were consistent with the observations in RT. Size at first maturity (the size of the smallest fish showing mature gonads) was 3.5 cm L_H in RT and 3.4 cm L_H in PSB (approx. 4 years of age) with maturity ogives showing 50 % of fish reach maturity by 4.1 cm L_H in RT and 3.8 cm L_H in PSB.

In each specimen examined one ovary was far smaller than the other. It usually contained eggs but was occasionally empty. Ovaries which appeared to be mature contained eggs in various states of development from immature pre-vitellogenic oocytes to fully hydrated ripe ova (size range ~ 0.1 to 2.0 mm diameter). Five size groups were recognised (Fig. 3) and referred to by ascending sequential numerals (I = smallest, V = largest). The mean percentage which each size group contributed to the fecundity (AIF) was as follows (n = 3, range in parentheses): group I, 36.2 % (25.8 - 44.7); group II, 37.1 % (26.0 - 47.8); group III, 13.5 % (10.7 - 16.5); group IV, 9.5 % (7.2 - 11.3); group V, 3.8 % (2.6 - 4.7). Groups III, IV and V were vitelline and accounted for approximately 27% of the total egg count. Size-frequency distribution of egg diameters was compared between left and right ovaries in one specimen but no substantial differences were evident. Estimates of AIF ranged from 9109 to 26 847 (n=7, mean = 15 713, SD = 5982) and showed a strong positive correlation (r = 0.73) with body size (L_H).

Deposition of opaque and hyaline material at the growing edge of otoliths showed a seasonal periodicity with the proportion of otoliths depositing opaque material being greatest in February and least in September (Fig. 4). There appears to be a single annual cycle of deposition, with one opaque and one hyaline band per year, and otoliths were interpreted on this basis. The first hyaline zone, surrounding the opaque central area, was far more distinct and well defined than subsequent hyaline zones (Fig. 5) and was interpreted as a 'transitional zone', indicative of a change of habit from a pelagic post-larval phase to the benthopelagic juvenile phase. Transverse sections were best interpreted by counting annuli from the nucleus along the dorsal axis or in the sector between the dorsal axis and sulcus. Two distinct depositional patterns were apparent in most sectioned otoliths, with the first three to five annuli showing relatively broad opaque bands which progressively decreased in width but subsequent annuli having narrower and more regular sized opaque bands; this change was assumed to be coincident with the onset of sexual maturity. Age estimates ranged from 1 to 10 years. The Von Bertalanffy growth curve was fitted for mean L_H at age (Fig. 6, Table II) for age groups where $n \geq 5$.

DISCUSSION

Certain minor differences were found in the specific morphometric attributes examined but there is insufficient evidence to suggest geographical isolation between the populations in the RT and PSB. Size at first maturity and egg size are consistent with reports from the Mediterranean (Relini Orsi & Wurtz, 1979; Massutí *et al.*, 1995) and the five size groups of ova found in *Nezumia aequalis* equate to the five development stages recognised by Kelly *et al.* (1996) in macroscopic inspection of ova of another macrourid *Coryphaenoides rupestris*. The multi modal distribution of egg sizes and the seasonal cycle in GSI and gonad maturity shows *N. aequalis* is a multiple batch spawner in the NE Atlantic, in contrast to the Mediterranean where spawning occurs throughout the year, mainly in three episodes (January-February, April-May and October) (Carrasson & Matallanas, 1989; Massutí *et al.*, 1995).

It is not yet possible to derive a reliable estimate of annual fecundity *Nezumia aequalis* as the time taken for ova to mature is not known. If all ova mature and are shed in the current reproductive cycle then annual fecundity would be equivalent to the AIF, but if maturation takes longer only the vitelline eggs (groups III, IV & V) may be shed in the current cycle, giving an annual fecundity of approximately 27% of AIF. Carrasson and Matallanas (1989) recorded total egg counts of 4050 to 14 771 (with 86 to 640 fully mature eggs) in *Nezumia aequalis* from the Mediterranean. The available data are therefore in broad agreement, the order of magnitude for AIF being 10^3-10^4 with possibly only 10^2-10^3 of these shed per year. Carrasson and Matallanas (1989) also found a significant positive relationship between body size and the total number of eggs.

Time-series studies of the growing edge of the otoliths showed a pattern consistent with one hyaline and one opaque band being deposited each year. Transverse sections could be interpreted without major difficult but care was required to recognise the initial hyaline 'transition zone' and false hyaline checks which occurred after the first 3-5 years. Lombarte & Morales-Nin (1989) verified the annular periodicity of growth annuli in otoliths of *Nezumia aequalis* from the SE Atlantic (off Namibia) and estimated ages in the range 1-9 years. Relini Orsi & Wurtz (1979) recognised 'first-order' hyaline bands representing winter growth and 'second-order' bands representing false checks in material from the Mediterranean, but their interpretation gave a maximum age of only 5 years in specimens up to 43 mm L_H. A longevity of approximately 10 years is consistent with other *Nezumia* species, Savvatimsky (1989) interpreting otoliths from *N. bairdii* to show ages of 3 to 11 yrs, but is relatively short compared to some larger macrourids, the maximum age of *Coryphaenoides rupestris* varying in different reports between 25 to 72 years (see Gordon & Swan, 1996).

The population growth rate (i.e. the Von Bertalanffy growth parameter *k*) for *Nezumia aequalis* derived in this study is not directly comparable with those derived by Lombarte & Morales-Nin (1989) or Massutí *et al.* (1995), being based on a different measure of body size (head length rather than pre-anal length), but the latter authors found *Nezumia aequalis* to be one of the slower growing of five macrourid species studied in the Mediterranean. However, using comparable estimates from the Rockall Trough (Gordon & Swan, 1997) it is seen that *Nezumia aequalis* grows much faster than the longer lived *Coryphaenoides rupestris* and at a similar rate to *Trachyrinchus trachyrinchus* in the NE Atlantic (Table II).

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Table I. Size and sex of *Nezumia aequalis* caught by OTSB(S) gear in NE Atlantic.
L_H = head length, ♀ = female, ♂ = male, imm = immature, n.e. = sex not examined.

		Depth zones in RT						Depth zones in PSB					
		500	750	1000	1250	1500	1750	500	750	1000	1250	1500	1750
L_H (cm)	Min	3.8	1.1	1.2	2.9			1.4	0.8	1.5	2.3		3.3
	Max♀		6.0	5.6	5.0				5.7	5.9	5.0		4.4
	Max♂	3.8	5.1	5.0	4.4				5.2	5.2	4.3		4.5
n	♀		285	183	9				708	498	42		2
	♂	1	277	202	4				736	509	55		2
	imm		60	55	1			6	899	295	15		
	n.e.		50	1752				4	223	6	2		

Table II. Parameters of the Von-Bertalanffy growth equation (± standard error) fitted to mean head length (L_H in cm) at age for three species of macrourid from the Rockall Trough. (* data from Gordon & Swan, 1997)

	N. aequalis	*C. rupestris**	*T. trachyrinchus**
L_{inf}	6.76 (± 1.97)	21.88 (± 2.64)	10.63 (± 0.14)
t_0	-5.6×10^{-9} (± 0.59)	-3.08 (± 0.98)	-1.14 (± 0.46)
k	0.175 (± 0.107)	0.029 (±0.006)	0.154 (±0.014)
max. age	10	40	36

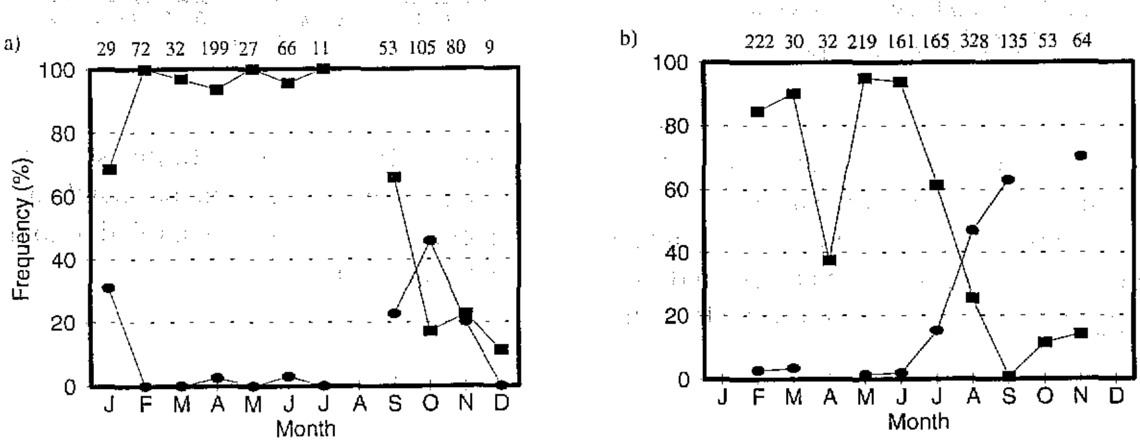

Figure 1. Percent frequency of mature & running gonads (stages III/IV + V) (■) and spent gonads (stage VI) (●) by month for *Nezumia aequalis* from a) the RT and b) the PSB. Figures show sample frequency.

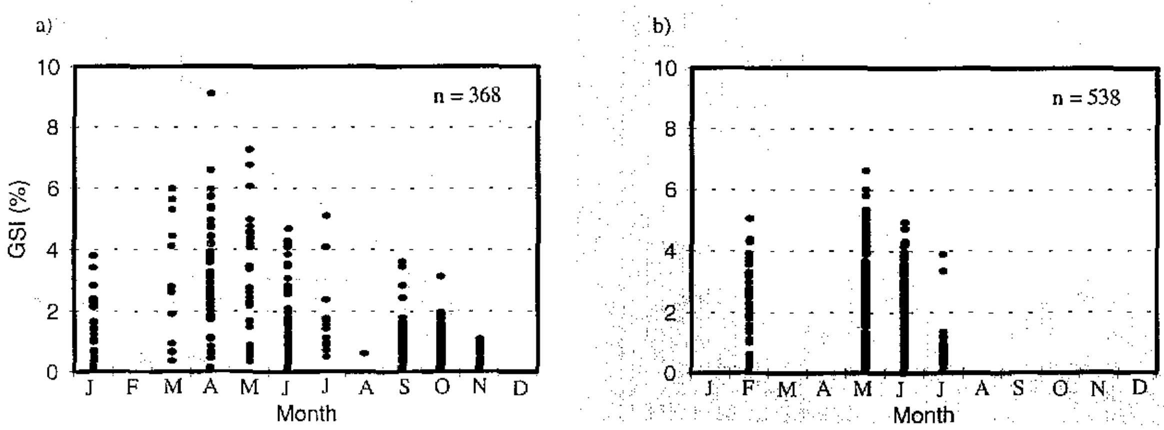

Figure 2. Gonado-somatic index (GSI) by month for *Nezumia aequalis* from the NE Atlantic. a) RT, b) PSB.

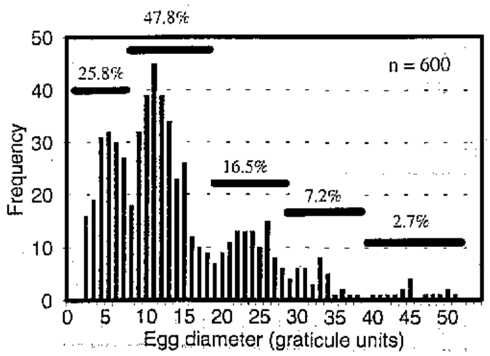

Figure 3. Size frequency distribution of ova from a 'mature' *Nezumia aequalis* caught in PSB, showing five size groups of eggs and the percentage which each group contributed to total egg count. 1 graticule unit = 0.1053 mm.

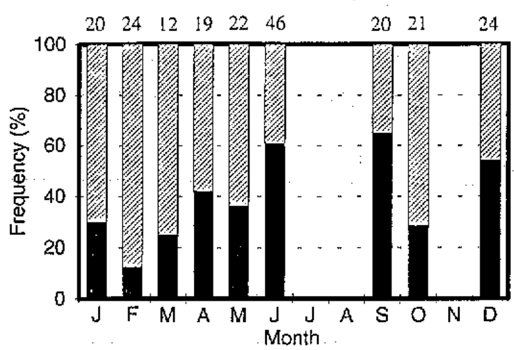

Figure 4. Proportion of otoliths showing hyaline (solid bar) or opaque (hatched bar) material at their outer edge relative to the month of capture.

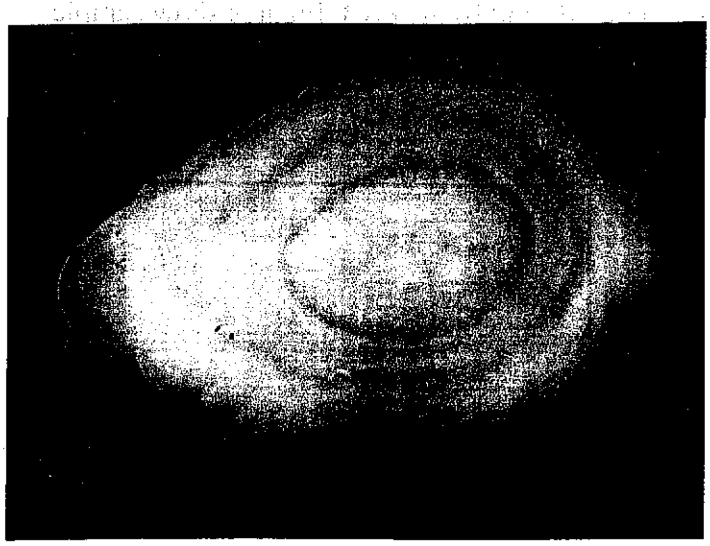

Figure 5. Otolith of *Nezumia aequalis* illustrating the 'transitional' first hyaline zone in comparison to subsequent annual hyalines.

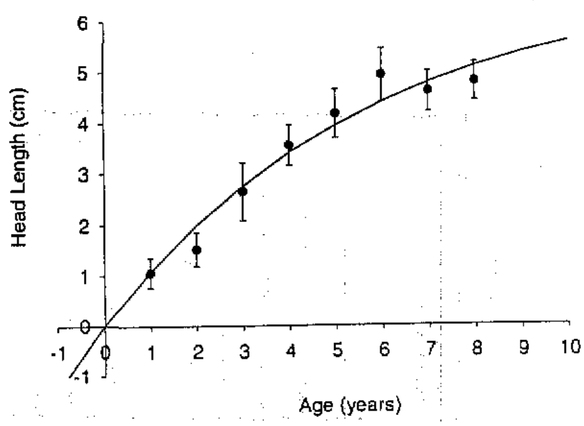

Figure 6. Von Bertalanffy growth curve fitted to mean head length (L_H in cm) at age. Error bars show standard error of mean.