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Gonad Development and Spawning of *Notoscopelus krøyeri* in the Northwest Atlantic, with Observations on Other Biological Characteristics

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Abstract

Maturation of male and female *Notoscopelus krøyeri*, one of the most common myctophids in the North Atlantic, was investigated from samples which were collected during autumn and winter months in the Grand Bank and Flemish Cap areas of the Northwest Atlantic. The specimens ranged in length from 45 to 150 mm and in age from 1 to 6 years. The data indicated that spawning occurs over the slopes of Grand Bank and Flemish Cap mainly during February and March. Maturation for first spawning occurs over the length range of 92–105 mm which appears to correspond to the size range of age 3 fish. The condition factor declined sharply from February to March, confirming that this is the time of peak spawning. The feeding intensity was quite low during the autumn and early winter period of gonad development but increased gradually during the spawning and postspawning season (February–April).

Introduction

Notoscopelus krøyeri is one of the most common species of myctophids in the North Atlantic, ranging from approximately 37°N to about 60°N in the Northwest Atlantic and to 65°N in the Northeast Atlantic (Bolin, 1959; Nafpaktitis, 1975). There are many reports of the occurrence of *Notoscopelus* in the Northwest Atlantic, including its presence in the stomachs of fish (e.g. Popova, 1962; Leim and Scott, 1966; Templeman, 1968; Halliday and Scott, 1969; Lear, 1972). In the Northeast Atlantic, some authors (Kashkin, 1974; Gjøsaeter, 1981) have related the spawning area of *N. krøyeri* to the Azores region, but the available literature contains no information on the spawning of this species in the Northwest Atlantic.

The frequent capture of *N. krøyeri* during midwater trawling over the continental shelf and slope off Newfoundland allowed investigation of the population which inhabits the Grand Bank and Flemish Cap areas from autumn to early spring. Data on length and age compositions and feeding, and observations on gonad development during the prespawning, spawning and postspawning periods are presented.

Materials and Methods

The samples for this study were collected from midwater trawl (codend with double 12 mm mesh netting) catches over the slopes of the Grand Bank and Flemish Cap at depths of 200–500 m. Samples were taken in February–April 1983, September–December 1984 and January 1985. Standard length (SL) measurements (tip of upper jaw to base of median rays of the caudal fin) were recorded in millimeters and body weights were taken in grams. Testes and ovaries (after weighing) were preserved in Bouin's fluid or 10% formalin, and otoliths for age determination were stored in glycerine. The degree of stomach fullness was estimated on the basis of a 5-point scale (0 = empty, 1 = up to 1/4 full, 2 = up to 1/2 full, 3 = up to 3/4 full, and 4 = full or nearly full).

In the laboratory, the gonads were dehydrated by immersion in gradually increasing strengths of alcohol, followed by xylene treatment and paraffin embedding. Microtome sections (5–6 μm thick) were mounted on glass microscope slides and stained with iron haemoxyline. The maturity coefficient was determined as the ratio of gonad weight to body weight (expressed as percent). The condition factor was calculated by Fulton's formula $K = (W \times 100)/L^3$, where W is body weight (g) and L is standard length (cm). Ages were determined from examination of otoliths under a binocular microscope against a dark background with reflected light. Each hyaline ring was assumed to represent one year of life, and the birthdate was taken to be 1 January.

Results

Length and age distributions

Notoscopelus krøyeri in the samples from the Grand Bank–Flemish Cap region ranged from 45 to 150 mm SL (Fig. 1). During September–December, the catches consisted mainly of 80–95 mm SL fish which were in their second year of growth but were still classified as age-group 1, because the birthdate was assumed to be 1 January for the purpose of designating ages. In January, the same modal length group (80–90 mm SL) remained dominant, but these fish

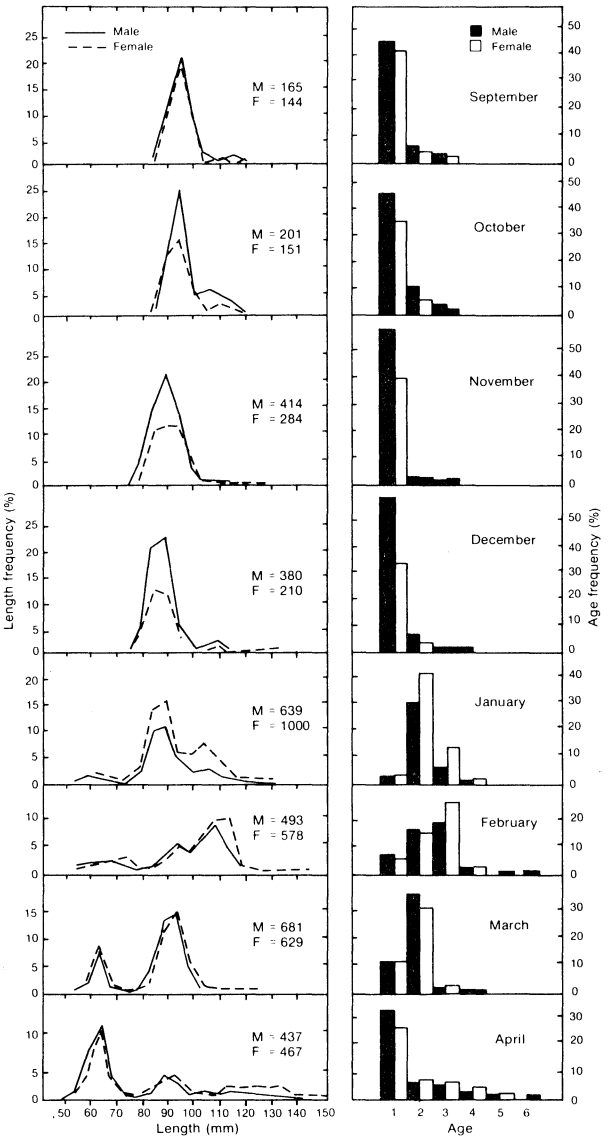

Fig. 1. Monthly length and age compositions of *N. krøyeri* samples by sex in the Grand Bank and Flemish Cap areas. (Numbers of males and females are designated by M and F respectively.)

were now designated as age-group 2. There was an increase in the proportion of older fish (mainly age 3 and a few age 4), and the modal group at 60 mm SL indicated the presence of age-group 1. In February, the catch was dominated by age-groups 2 and 3 (80-110 mm SL), with age-group 1 remaining in evidence. In March, the catch consisted almost entirely of age groups 1 and 2, with the latter being dominant. In April, on the other hand, the catch was dominated by age-group 1 (50-70 mm SL), with the larger fish being represented by age-groups 2-6. There was no sexual dimorphism or significant difference in growth of males and females during the sampled periods.

The existence of two or more modal groups in the January-April length distributions (Fig. 1) and the regularity in pattern enabled validation of at least the first three age-groups. The group with mode around 60 mm SL in these samples had completed the first full year of growth by January and could be classified as age-group 1. Although there were no samples to illustrate the growth pattern during May-August, this is perhaps the main growing period, because the age 1+ fish with modes around 90 mm SL in September-December and age 2 fish with the same mode in January imply that growth was about 30 mm in the second year of life. The modal groups of age 3 fish around 105-110 mm in the January-April samples imply that growth was about 15-20 mm at the completion of the third year of life. Thus, the growth increments during the first three complete years of growth appear to be about 60, 30 and 15-20 mm respectively.

Feeding intensity and condition factor

The feeding intensity of *N. krøyeri*, as measured by the average degree of stomach fullness, declined rapidly after September to minimal values in November-December and increased thereafter to almost double the minimal values by April (Table 1). The condition factors for both sexes in the autumn (September-December) were generally higher than in early spring (March-April).

Gonad development

The maturity stages which were used in assessing the development of gonads are listed in Table 2. The testes in small males (45-60 mm SL) were very similar in appearance to the ovaries of females. The transparent gonads were situated dorsally in the caudal region of the body cavity and covered with thin peritoneum. Sex cells were dispersed singly throughout the somatic tissue. The weights of testes ranged from 1.5 to 3.0 mg and ovaries from 2 to 15 mg.

The testes of immature males longer than 60 mm SL resembled flat bands. Sex cells evidently develop in the anterior two-thirds of the testes and the excretory ducts are located posteriorly. In addition to primary sex cells, the germinative tissue contained cysts with spermatogonia. The ovaries of immature females

TABLE 1. Average degree of stomach fullness and condition factor for *N. krøyeri* from the Grand Bank and Flemish Cap areas.

Month	No. of fish	Mean length (mm)	Average stomach fullness	Fulton's condition factor		
				Male	Female	Total
Sep	100	119	1.40	1.08	0.99	1.03
Oct	150	111	0.93	1.19	1.18	1.18
Nov	150	91	0.86	1.13	1.12	1.12
Dec	99	86	0.89	1.15	1.14	1.14
Jan	199	102	1.03	0.89	0.89	0.89
Feb	200	99	1.27	1.06	1.07	1.07
Mar	150	96	1.16	0.98	0.90	0.95
Apr	250	126	1.65	0.93	0.84	0.88

TABLE 2. Description of maturity stages for *N. krøyeri*.

Maturity stage	Physiological state of gonads
II	Immature; gonads generally like narrow translucent stings.
III	Ripening, with intensive yolk accumulation in ovaries and active spermatogenesis in testes.
IV	Prespawning condition; vitellogenesis in older eggs nearly complete; excretory ducts of testes filled with spermatozoa.
V	Functionally mature condition; hydrated eggs run freely from ovaries; seminal fluid flows from males under slight pressure of abdomen.
VI–III (VI–IV)	Maturation of next portion of sexual products after partial spawning.
VI	Spent condition of ovaries and testes, with traces of residual sexual products.
VI–II[a]	Recovering from spent condition, with some traces of past spawning in ovaries and testes.

[a] Stage VI–II is morphologically similar to stage II, and fish length should be considered during visual examination of ovaries and testes.

longer than 60 mm SL were like pale pink translucent bolsters. Groups of oocytes were seen microscopically, but the eggs were not visible through the ovarian membrane. The weights of testes ranged from 4 to 16 mg and ovaries from 10 to 150 mg.

In September–October, samples from the Grand Bank and Flemish Cap revealed that the gonads of nearly 80% of mature females and all of the mature males contained traces of past spawning. Microscopic examination revealed some residual follicular membrane and atretic bodies in the ovaries (Fig. 2) and fragments of residual sperm in the narrow ducts of the testes (stage VI–II). However, most of the female gonads were visually determined as stage II (immature) in September (Table 3), with some advancement to stage III in October. The stage II ovaries were pale pink in color with a translucent membrane. Although developing oocytes were present, the egg cells were not visible through the membrane. The ovaries of stage III females contained both developing egg cells and oocytes with vacuolized cytoplasm (i.e. start of vitellogenesis). The testes were milky white in color, but their excretory ducts were translucent and empty.

In November–December, samples from the Grand Bank and northwestern slope of Flemish Cap revealed that there was significant progression in maturation, with nearly 80% of the female gonads being visually

TABLE 3. Maturity coefficients (mean and range) and distribution of maturity stages (%) in female *N. krøyeri* from the Grand Bank–Flemish Cap region. (Samples contained no stage V females.)

Month	No. of fish	Maturity stage (%)					Coefficients	
		II(VI–I)	III	IV	VI–III	VI	Mean	Range
Sep	68	96.1	3.9	—	—	—	0.73	0.6–1.2
Oct	83	73.5	26.5	—	—	—	1.35	1.1–1.5
Nov	132	52.2	47.8	—	—	—	1.76	1.3–2.4
Dec	45	22.2	77.8	—	—	—	1.27	0.9–1.9
Jan	90	29.9	57.5	12.6	—	—	2.00	0.9–3.9
Feb	56	36.4	10.9	27.5	25.2	—	3.50	1.9–5.9
Mar	112	22.2	4.3	12.3	37.8	23.4	2.63	1.8–3.5
Apr	120	29.9	—	—	—	71.1	1.54	1.0–1.8

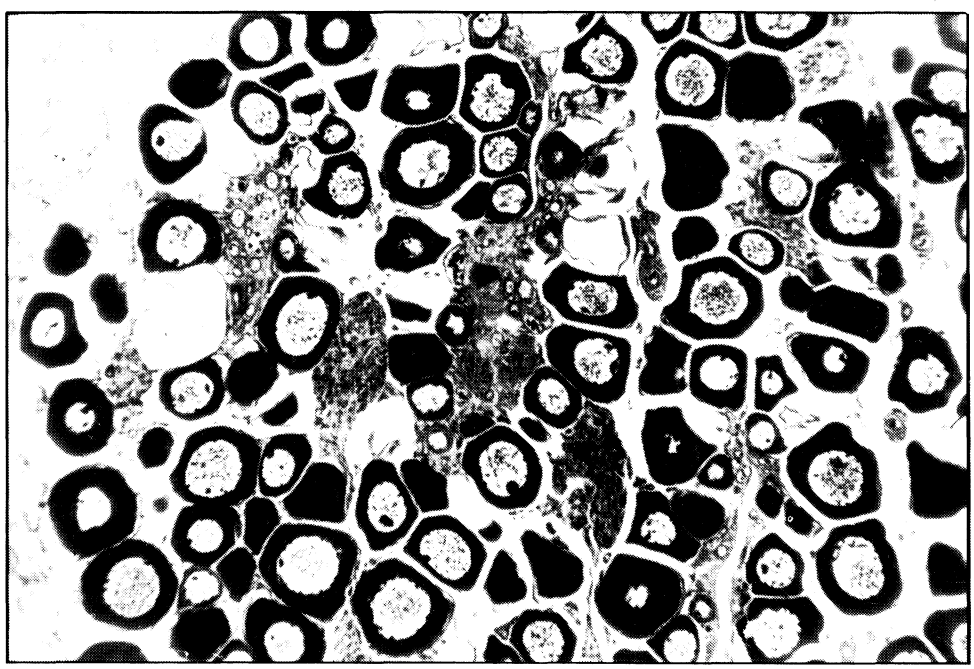

Fig. 2. Residual follicular membrane and atretic bodies in an ovary of *N. krøyeri*, September. (MBI-3, 8 × 10 magnification.)

classified as stage III (maturing or ripening) in December (Table 3). About two-thirds of the body cavity was occupied by the ovaries which looked like pale yellow, oblong bags with somewhat extended midsections. Grey-creamy eggs were visible through the membrane with the help of a magnifying glass. Egg cells with vacuolized cytoplasm were visible microscopically among the developing oocytes in such ovaries, and the yolk was present in the most advanced eggs (Fig. 3). Microscopic examination of testes indicated that a new wave of spermatogenesis had started in the germinative tissue by October, as confirmed by numerous spermatogonial mitoses (Fig. 4). By late December, spermatids accumulated in the testes and

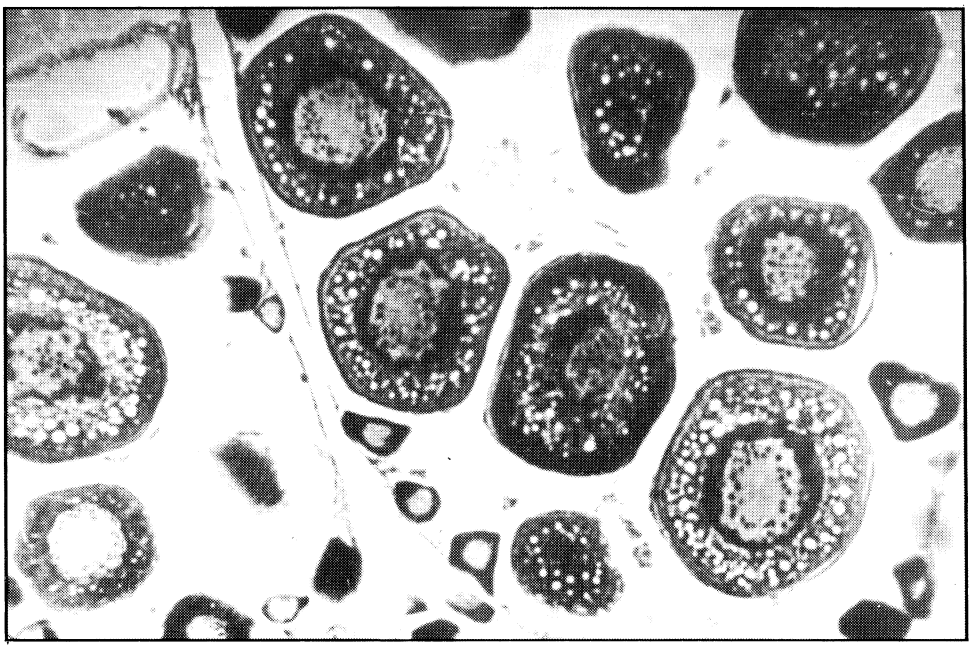

Fig. 3. Vacuolization of egg cell cytoplasm in a stage III ovary of *N. krøyeri*, December. (MBI-3, 8 × 10 magnification.)

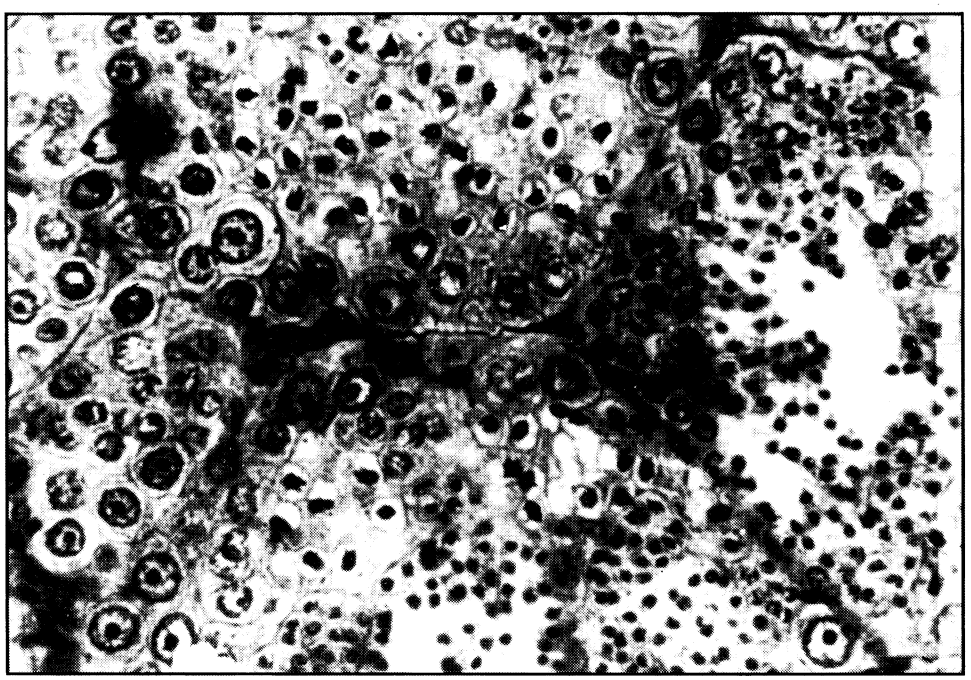

Fig. 4. Wave of spermatogenesis in a testis of *N. krøyeri*, October. (MBI-3, 10 × 60 magnification.)

started to transform into spermatozoa. During the November–December period, the weights of the ovaries varied from 150 to 300 mg and those of the testes from 15 to 25 mg. At this time, the average maturity coefficient for females was about 1.7 (Table 3) in contrast to about 0.7 in September.

In January, the majority of the female gonads (57.5%) were still at stage III but 12.6% had advanced to stage IV (Table 3). Light cream-colored ovaries occupied much of the abdominal cavity and varied in weight from 500 to 900 mg. The ovarian membrane was stretched and eggs of different sizes were visible. The eggs could be readily separated from each other with a dissecting needle. Some ovaries had eggs in the phase of intensive yolk accumulation (Fig. 5). Vitellogenesis was nearly complete in the ripest ovaries (Fig. 6). The band-like testes in mature males were white and thick

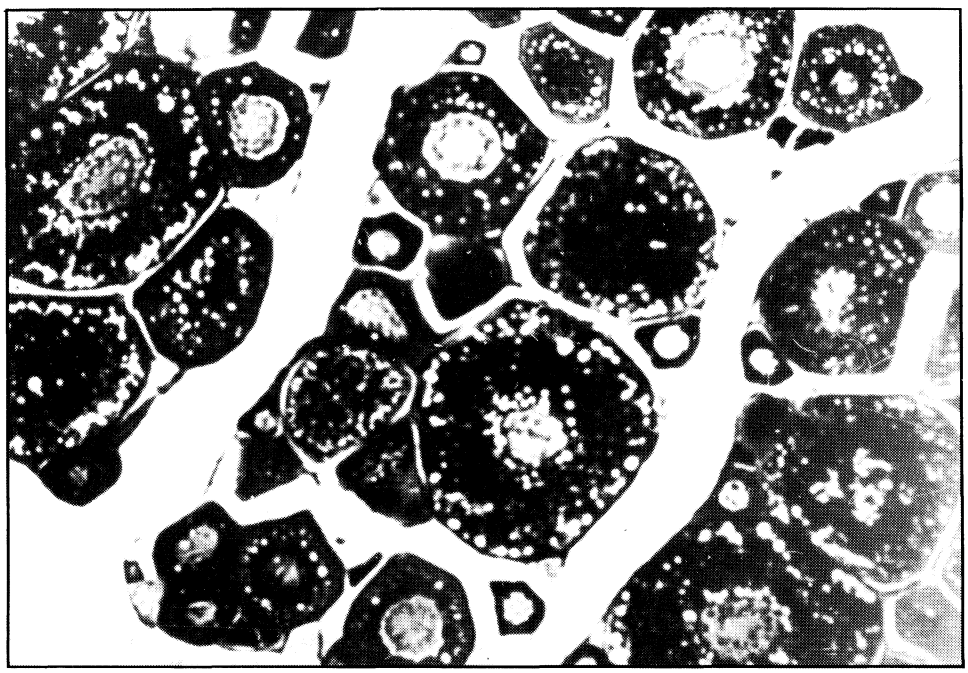

Fig. 5. Intensive yolk accumulation in a stage III ovary of *N. krøyeri*, January. (MBI-3, 7 × 8 magnification.)

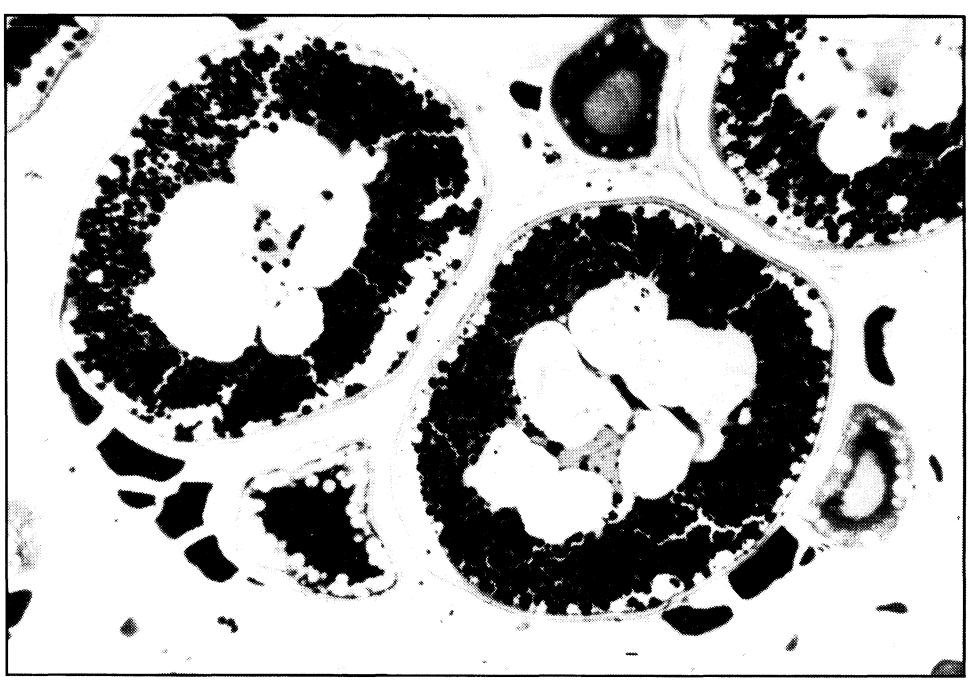

Fig. 6. Oldest generation of egg cells filled with yolk in a stage IV ovary of *N. krøyeri*, February. (MBI-3, 7 × 8 magnification.)

with rounded edges. The excretory ducts contained spermatozoa, and the uneven swollen surfaces of the ducts indicated that the testes were approaching or had reached the "ripe and running" stage.

In February, about 28% of the mature females were in prespawning condition (stage IV) and 25% were partly spent (stage VI-III) (Table 3). Maturity coefficients were 5.1-5.9 for prespawning and 2.6-3.5 for partly spent females, with the average for all fish being 3.5. The ovarian wall of the latter stage was generally flabby, but large ripening eggs were still visible through the membrane. In addition to numerous residual follicles, these ovaries contained many eggs in various phases of development, the largest number being in the phase of intensive yolk accumulation. The presence of near-wall gaps in the excretory ducts of testes indicated the partial extrusion of sperm. The ampullae which adjoin the excretory ducts were filled with sperm.

In March, the progression of maturity to the partly spent and spent condition in many females (Table 3) resulted in a substantial decrease in the average maturity coefficient from 3.5 in February to 2.6. However, spawning was evidently not complete at this time, because some of the females were still classified as stage IV and about 38% were partly spent (stage VI-III) with many eggs continuing to develop for later extrusion. Only 23% of the females were found to be in the spent condition (stage VI).

In April, the samples consisted of both males and females in the postspawning condition (stage VI). The ovaries of all females greater than 105 mm SL were at the stage of complete extrusion (Fig. 7), and the maturity coefficients were very low (1.0-1.8) (Table 3). The flat whitish ovaries with wrinkled membranes had a shrunken appearance, and residual eggs were occasionally visible through the ovarian walls. There was a significant decline in weight of testes from 27-60 mg in February to 16-36 mg by April. The excretory ducts with thickened walls were slack and contained residual sperm with features of phagocytosis (Fig. 8).

Spawning season and size at first spawning

Development of spawning products began in October and continued during November and December (Table 3). By January, some females were ripe, and partly-spawned individuals were caught in February and March. Some fish were spent in March and all mature fish were either spent or in the early stages of recovery by late April. Thus, the spawning season is quite short, being restricted mainly to February and March, although some spawning may occur in late January and early April.

The trend in percentage of mature females (i.e. stages III and IV) with length in January (Fig. 9) indicates that maturation probably occurs over the range of 92-105 mm SL, with 50% maturity at about 97 mm SL. A plot of the percentage of maturing females in the

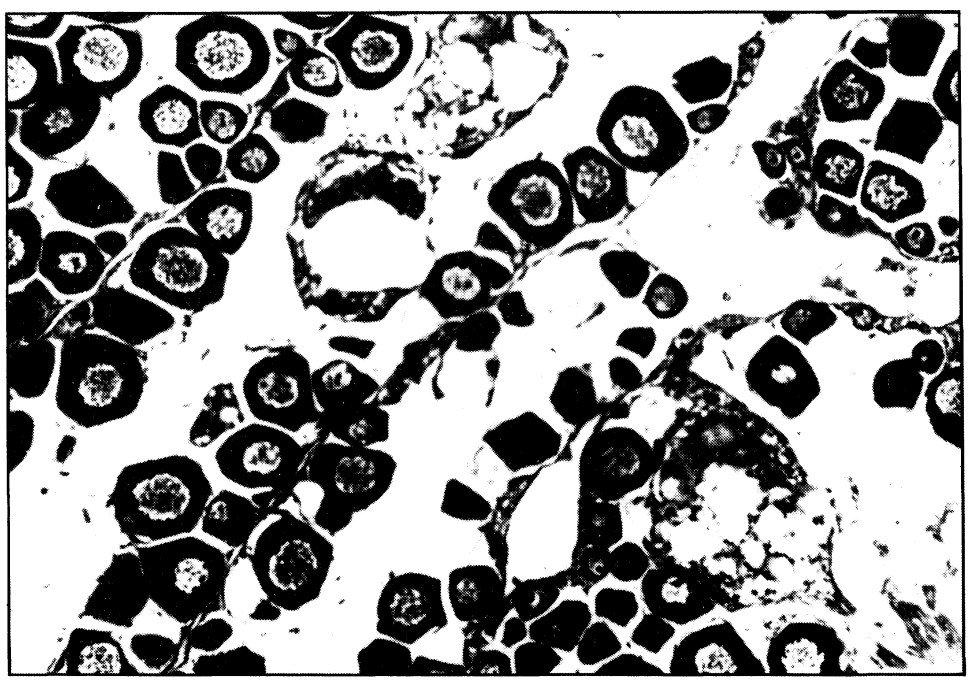

Fig. 7. State of complete extrusion in a stage VI ovary from *N. krøyeri*, April. (MBI-3, 8 × 10 magnification.)

Fig. 8. Phagocytosis of residual sperm by follicular epithelium in a stage VI testis of *N. krøyeri*, April. (MBI-3, 10 × 60 magnification.)

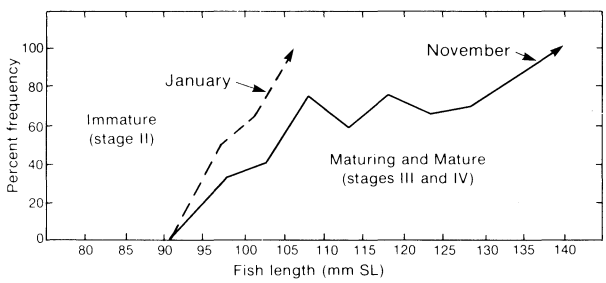

Fig. 9. Percentages of maturing and mature female *N. krøyeri* by 5-mm length group in November and January samples from the Flemish Cap area.

November samples by length-group (Fig. 9) indicated errors in visual classification of maturity at that time, whereby some of the large fish (>105 mm SL) were designated as stage II (immature), reflecting asynchronism in maturation of females with size. By January, it was assumed that all fish which showed evidence of spawning in the current season had reached stage III. From the age composition of the January sample (Fig. 1) and the apparent length range over which maturation occurs (92–105 mm), it seems that first spawning by most fish takes place after 3 years of growth (age-group 3).

Discussion

In the present study from January–April samples, the modal length of *N. krøyeri* which had completed the first, second and third year of growth (1 January birthdate) were found to be approximately 60, 90 and 105–110 mm SL, with inferred annual growth increments of 60, 30 and 15–20 mm respectively. Gjøsaeter (1981), in his study of the same species in the Northeast Atlantic showed a Bertalanffy growth curve from which the mean sizes of ages 1, 2 and 3 fish were estimated to be about 90, 105 and 113 mm SL, implying an unusual pattern of annual growth increments of 90, 15 and 8 mm respectively. It is unlikely that the growth of *N. krøyeri* during the first year of life is much faster in the Northeast Atlantic than in the Northwest Atlantic. Rather, Gjøsaeter (1981) may have interpreted the first ring in the otolith as a larval zone, with the result that his age readings were too low by 1 year. A key feature of the Northwest Atlantic data, not present in Gjøsaeter's (1981) samples, was the occurrence in January–March of age 1 fish with modal length about 60 mm SL. Additionally, the distinctness of modal length groups at about 90 and 115–120 mm, representing ages 2 and 3 fish, leads to a more typical pattern of annual growth increments for *N. krøyeri* than can be inferred from Gjøsaeter's (1981) growth curve.

It has been possible to describe the full cycle of maturation and spawning by *N. krøyeri* on the basis of samples from Grand Bank and Flemish Cap areas, indicating that spawning occurs in that region of the Northwest Atlantic. Maturation for first spawning evidently occurs mainly over a length range of 92–105 mm SL, and all fish larger than 105 mm SL are presumed to be adults. Thus, the spawning population is presumed to consist of many age 3 and all older fish. The five-fold

increase in average maturity coefficients of females from September to February indicated rapid gonad development during this period, and the subsequent decline in the coefficients during March and April was indicative of the extrusion of sexual products.

Condition factors did not change much during September-December but were substantially lower in March and April, when many of the fish had spawned. Conversely, feeding intensity, based on average degree of stomach fullness, was lowest during the period of gonad development (October-December) and increased gradually during the prespawning to postspawning periods (January-April).

Reproduction of *N. krøyeri* in the Flemish Cap area may be associated with the anticyclonic gyre which seems to persist there during most months of the year (Borovkov *et al.*, 1978; Kudlo *et al.*, 1984). This gyre results from merging of the Flemish Cap branches of the Labrador and North Atlantic Currents. Bioproductivity is usually high in such areas and all stages of the life cycle of some fish species may be found there (Amarov and Elizarov, 1982).

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