Dev. Reprod. Vol. 8, No. 1, 11~17 (2004)

The Larvae and Juvenile Development of Haddock, *Melanogrammus aeglefinus* Cultured in Atlantic Canada

Chi-Hong Kim†, Jae Hyun Im[1], Stewart C Johnson[2], Jun Wook Hur[3] and In-Seok Park[4]

Inland Fisheries Ecological Research Institute, National Fisheries Research and Development Institute, Chungpyung 477-810, Korea
[1]Department of Fisheries Science, Kunsan National University, Gunsan 573-701, Korea
[2]Institute for Marine Biosciences, National Research Council Canada, Halifax, Canada D3H 3Z1
[3]Research Institute of Marine Science and Technology, Korea Maritime University, Busan 606-791, Korea
[4]Division of Ocean Science, College of Ocean Science and Technology, Korea Maritime University, Busan 606-791, Korea

Atlantic Canada 해산어 Haddock, *Melanogrammus aeglefinus*의 자치어 발생 단계

김치홍† · 임재현[1] · Stewart C Johnson[2] · 허준욱[3] · 박인석[4]

국립수산과학원 내수면생태연구소, [1]군산대학교 수산과학과, [2]캐나다 국립연구위원회 해양생물과학연구소,
[3]한국해양대학교 해양과학기술연구소, [4]한국해양대학교 해양과학부

ABSTRACT : The larvae and juvenile development of haddock, *Melanogrammus aeglefinus* which is significant commercial fish living north Atlantic Ocean are described here. Larvae were reared in laboratory and sampled periodically for developmental study until 67 days after hatching. An increase in total length(TL) of fish indicated continuous growth, described by the growth expression $Y=4.07 e^{0.037}$(R^2=0.9978). The newly hatched pre-larvae was 4.9 mm in TL with ellipsoid yolk. In 16 days after hatching, larvae attained 6.8 mm in TL, and absorbed the yolk completely to become post-larval stage, but first heterotrophic food could be in 7 days after hatching already. Post-larval stage continued during 16~52 days after hatching with development of organs attachment. In 61 days after hatching with 41.3 mm in TL, the fries became a juvenile stage respectively having small teeth, lateral line, and a black blotch on the flank same as adults, but chin barbel was not developed yet. It was presumed that haddock changed food and ecological behavior after metamorphosis from this time.

Key words : Atlantic Canada, Haddock, *Melanogrammus aeglefinus*, Larvae and juvenile development.

요 약 : 북대서양에서 상업적으로 중요한 해산어류인 Haddock, *Melanogrammus aeglefinus*의 자치어 발생과정과 성장을 조사하였다. 자치어는 부화 후 67일까지 사육실 조건에서 사육되었고 주기적으로 표본한 재료를 실체현미경으로 관찰하였다. 발생단계별 크기 변화는 부화 후부터 지속적인 성장을 보여 $Y=4.07 e^{0.037}$(R^2=0.9978)의 성장식을 나타내었다. 부화 직후의 자어는 전장 4.9 mm 로 장방형의 난황을 가지고 있었다. 초기 먹이섭취는 부화 후 7일에 시작되었으나 부화 후 16일 째 전장 6.8 mm 때에 난황이 완전히 흡수되어 후기 자어 단계가 되었다. 부화 후 16~52일의 기간에 부속기관의 발달이 활발히 진행되었으며, 전장 41.3 mm인 부화 후 61일에 턱수염은 완전히 발달되지는 않았지만 치아, 측선, 체측의 검은 반점 등은 성어와 같은 모습의 치어 단계에 도달하여 본 종은 이 시기 이후로 먹이와 생태적 행동변화가 일어나는 것으로 추정된다.

INTRODUCTION

The haddock, a cold water gadiformes fish, *Melanogrammus aeglefinus* is found in Europe and the western Atlantic Ocean from the Strait of Belle Isle across to Gaspe and southward encompassing the Grand Bank to North Carolina and generally inhabit cool-temperate to subarctic waters from inshore regions the edge of the continental shelf(Coad, 1995). Haddock is one of the commercial important fish and are caught using otter trawls by Canadian and foreign ships. Catches in the northwest

* This work was supported by Korea Research Foundation Grant to I.-S. Park, Fishery Genetics and Breeding Laboratory, contribution number KRF-2002-005-F00004.

†Correspondence: Inland Fisheries Ecological Research Institute, National Fisheries Research and Development Institute, 114 Chungpyung-ri, Oeseo-meon, Gapyung-gun, Kyunggi-do 447-810, Korea. (Tel) 82-31-584-0332, (Fax) 82-31-584-4924, E-mail: chkim@nfrdi.re.kr

Atlantic Ocean have been reduced for overfishing and poor recruitment in 1970 but there has been some recovery in the early 1980s(Coad, 1995).

Haddock have attracted interest as candidate species for commercial aquaculture and restoration efforts in the Northeast U.S. and the Maritime Provinces of Canada(Buckley et al., 2000). There is considerable interest in developing haddock, for culture in Atlantic Canada because of rapid growing and rearing in salmon cages easily(Matthew, 1998). While some have been known about ecology, enhancement of growth, and morphology of haddock adults(Rechard & Carleton, 1986; Coad, 1995; Downing & Litvak, 1999; Roy & Lall, 2003; Trippel & Neil, 2003), little is known about their development series and early life history because of the difficulty in distinguishing them from other cod larvae.

So an understanding of the basic biology of this fish is essential. In this report, larval and juvenile development were described from a series of reared specimens to provide early developmental biology and more information on the identification of the larva and juvenile of this species.

MATERIALS AND METHODS

Haddock, *M. aeglefinus* larvae were hatched and reared at the National Research Counsil's Aquaculture Research Station, Sandy Cove, Nova Scotia. According to the method of Park & Johnson(2002) and Park et al.(2003a), filtered and UV-treated water(Salinity, 32‰) was supplied to each tank at a flow rate of 4 L min^{-1} in a flow through system with the water renewal rate of once every hour. Hatched larvae were held on a 12-h dark/12-h light photoperiod with the light intensity at the water surface between 40 and 60 Lx. Dissolved oxygen levels and water temperature were monitored each day and averaged 10±2 mg/L and 12±2℃, respectively.

Larvae and juveniles were removed from larvae rearing tank until 70 days after hatching periodically. Total length(TL), head length(HL) and eye diameter(ED) for 20 freshly sampled larvae at different stages were measured to the nearest 0.01 ㎝ with an 1/20 mm dial vernier caliper (Park et al., 1998); prior to measurement, the larvae were anaesthetized with 300 ppm lidocaine-HCl/$NaHCO_3$ at 18℃(Park et al., 2003b; Park et al., 2004). Growth in total length of fish was investigated by von Bertalanffy(1938) growth expression.

For subsequent morphological observation and measurements, the samples were fixed with 5% buffered formalin solution (diluted with sea water). Dissecting microscope with camera lucida was utilized for observation and drawing.

RESULTS

Table 1 showed the growth trends in total length(TL), head length(HL) and eye diameter(ED) of haddock, *M. aeglefinus* from hatching to the 67th day post-hatch. An increase in TL of fish indicated continuous growth, described the growth expression as $Y=4.07\ e^{0.037}(R^2=0.9978)$(Fig. 1). Growth in TL was accelerated until 67th day post-hatch.

The newly hatched larvae measured about averaging 4.9 mm in TL and contain a ellipsoid yolk(1.17 mm in longest diameter and 0.75 mm in shortest diameter as mean). Larvae were compressed and relatively slender. The HL was 15.1% of TL respectively. The eye diameter was 46.7% of HL. The mouth was formed and open already but anus was not. The pectoral fin contour was present posterior of the head(Table 1 and Fig. 2a).

Two days after hatching, the average was 5.1 mm in TL with yolk 1.05 mm in longest diameter and 0.70 mm in shortest. The HL was 15.5% of TL and ED was 45.5% of HL. Notochord was present on the center of body. Some melanophore pigments lie on the head side. Body elongated distinctively more than first day after hatching(Table 1 and Fig. 2b).

Three days after hatching, the average was 5.3 mm in TL with yolk 0.94 mm in longest diameter and 0.70 mm in shortest.

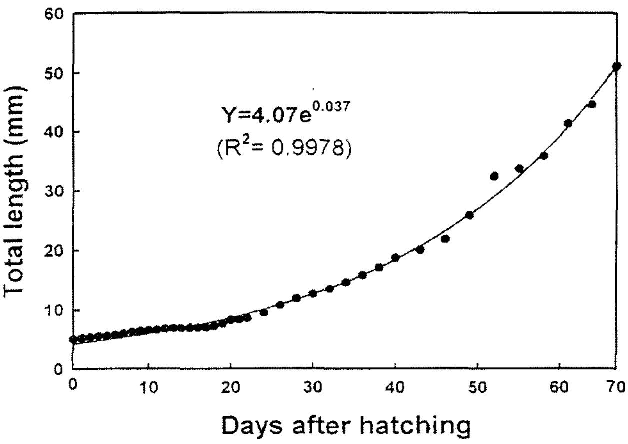

Fig. 1. The growth of total length of haddock, *Melanogrammus aeglefinus* from just hatching to 70 days.

Table 1. Measurement and counts of larvae and juvenile of haddock *Melanogrammus aeglefinus* reared in laboratory

Days after hatching	TL(mm) Mean	HL/TL Mean(%)	ED/HL Mean(%)	Number of fin rays				
				D1	D2	D3	A1	A2
Newly hatched	4.9	15.1	46.7					
2	5.1	15.5	45.5					
3	5.3	16.3	43.3					
4	5.4	16.7	43.3					
7	5.8	16.9	40.0					
10	6.4	17.1	39.8					
13	6.7	17.3	37.7					
16	6.8	18.6	35.8					
26	11.6	24.1	32.1					
28	11.8	24.5	32.0			6~ 7		6~ 7
30	12.6	25.5	31.7	8~ 9	8~ 9	10~11	7~ 8	9~10
32	13.5	26.5	31.7	9~10	14~15	16~17	12~13	14~15
34	14.6	27.7	31.3	10~11	15~16	18~19	16~17	18~19
36	16.4	29.3	31.0	10~11	16~17	19~20	18~19	20~21
40	18.7	31.6	30.7	12~13	16~17	19~20	18~19	21~22
43	20.0	31.8	31.0	12~13	16~17	20~21	18~19	21~22
46	21.8	31.5	31.0	13~14	19~20	20~21	21~22	22~23
52	32.4	30.0	31.0	14~15	19~20	20~21	21~22	22~23
61	41.3	28.4	31.6	14~15	19~20	20~21	22~23	22~23
67	51.2	27.0	31.7	14~15	19~20	20~21	22~23	22~23

* TL, total length; HL, head length; ED, eye diameter; D1-D3, number of first, second, and third dorsal fin rays; A1-A2, number of first and second fin rays

The HL was 16.3% of TL and ED was 43.3% of HL. Small melanophores are present on the snout, hindbrain and under the pectoral part of the body. The rudiment of anus canal was present obscurely(Table 1 and Fig. 2c).

Four days after hatching, 5.4 mm in TL was averaged with yolk 0.94 mm in longest diameter and 0.57 mm in shortest. The HL was 16.7% of TL and ED was 43.3% of HL. The alimentary canal was present first and was situated just to the rear of the yolk. Some melanophore pigments lie on the body upper of the yolk. Body elongated to the rounded caudal part(Table 1 and Fig. 2d).

Seven days after hatching, 5.8 mm in TL was averaged with yolk 0.55 mm in longest diameter and 0.40 mm in shortest. The HL was 16.9% of TL, and ED was 40.0% of HL. The snout was elongated and alimentary canal was developed some more clearly. Notochord was clear from behind of head to the caudal. The larvae possessed more than 20 myomeres. The rudiment of pectoral soft rays appeared. The distinctive xanthophores appeared on the head, on the dorsal surface of the visceral cavity, and along the dorsal and ventral sides of notochord(Table 1 and Fig. 2e).

Ten days after hatching, the average was 6.4 mm in TL with yolk 0.23 mm in longest diameter and 0.10 mm in shortest. The HL was 17.1% of TL, and ED was 37.7% of HL. The pelvic

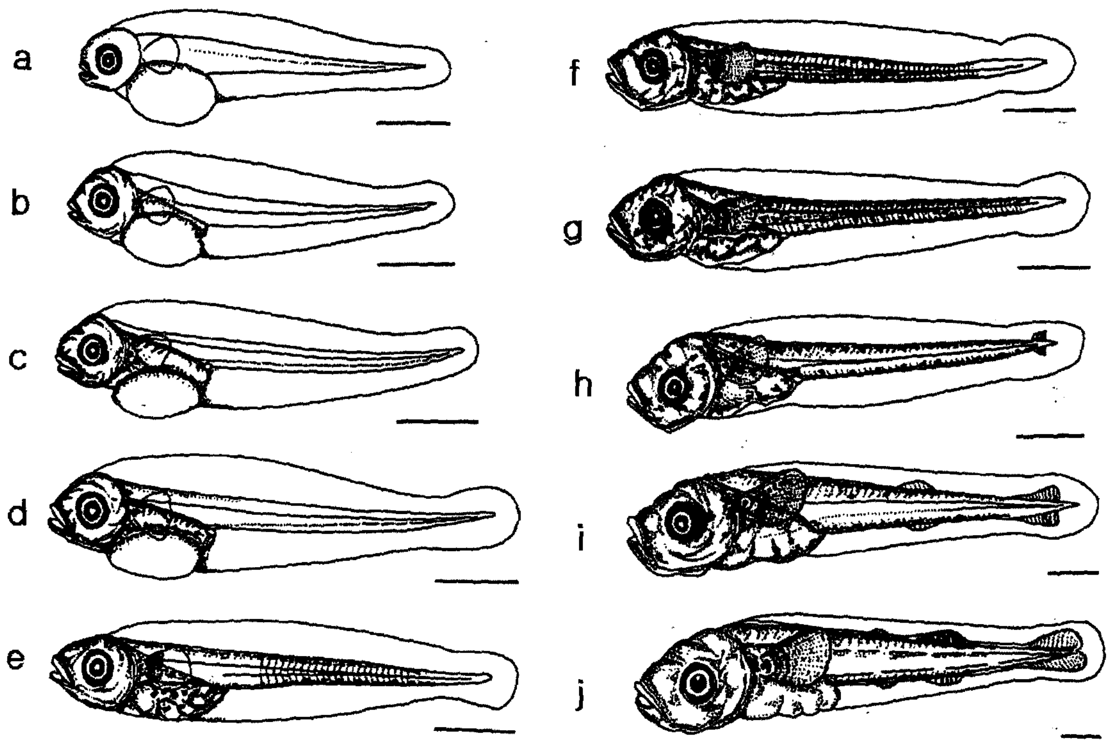

Fig. 2. Development of larvae and juveniles of haddock, *Melanogrammus aeglefinus* reared in the laboratory.
a: newly hatched larva; b: 2 days old; c: 3 days old; d: 4 days old; e: 7 days old; f: 10 days old; g: 13 days old; h: 16 days old; i: 26 days old; j: 28 days old. Bars indicate 1 mm.

buds and soft fin rays were clear. Caudal contour of tail was appeared with some more round. Xanthophores were located on about the same location as melanophores. Neither melanophores nor xanthophores were recognized on the tail(Table 1 and Fig. 2f).

Thirteen days after hatching, the average was 6.7 mm in TL. Absorption of yolk was about 90%. The HL was 17.3% of TL and ED was 37.7% of HL. The larvae was showed more than 40 myomeres on the body. External shape of head was angulated. The mandible and maxilla were ossified and developed remarkably. Xanthophores were heavily distributed along the myosepta of the body. Some melanophore patterns were located on the upper part of head, on the ventral surface of the jaw, beneath the eye, and the pectoral base respectively(Table 1 and Fig. 2g).

Sixteen days after hatching, 6.8 mm in TL was averaged and there were more than 45 myotomes. The yolk sac was barely retained. The HL was 18.6% of TL, and ED was 35.8% of HL average. Melanphores were present along the entire length of spinal chord. The rudiment of the caudal fin appeared ventrally at the posterior tip of the notochord(Table 1 and Fig. 2h).

Twenty six days after hatching, there was an average of 11.6 mm in TL. The HL was 24.1% of TL, and ED was 32.1% of HL average. The rudiment of third dorsal and second anal fin appeared. The segmentation of pectoral fin rays were observed. Numerous spotted melanophore pigments appeared at posterior part of the eye, dorsal and ventral part of body, and on the surface of digestive organ(Table 1 and Fig. 2i).

Twenty eight days after hatching, 11.8 mm in TL was averaged and there were more than 50 myotomes. The HL was 24.5% of TL, and ED was 32.0% of HL average. The rudiment of second dorsal and first anal fin appeared. Six or seven soft fin rays of third dorsal and 6∼7 of second anal were observed. Numerous spotted melanophore pigments spreaded to newly developed dorsal fin. The base of caudal fin began to ossify thickly(Table 1 and Fig. 2j).

Thirty days after hatching, 12.6 mm in TL was averaged. The HL were 24.3∼27.3% of TL, and ED was 31.7% of HL average. The first dorsal appeared having 8∼9 soft fin rays of third dorsal and 8∼9 of second were observed. Nine or ten soft fin rays of second anal and 7∼8 of first anal were observed.

The notochord started to flex toward the caudal fin(Table 1 and Fig. 3a).

Thirty two days after hatching, 13.5 mm in TL was averaged. The HL was 25.5% of TL, and ED was 31.7% of HL average. The first dorsal had 9~10 soft rays, second 14~15, and third 16~17. The first anal have 12~13 soft rays and the second 1 4~15. The dorsal and anal fins were still connected with caudal fin remnants of the fin fold at the caudal peduncle. Tip of notochord stretched out to caudal slightly crooked up. Pelvic buds were developed with soft rays. Rudiment of nostrils were appeared in front of the eye(Table 1 and Fig. 3b).

Thirty four days after hatching, 14.6 mm in TL was averaged. The HL was 27.7% of TL, and ED was 31.3% of HL average. The first dorsal 10~11 soft rays with some more high, second 15~16, and third 18~19 with smooth morphology. The first anal have 16~17 soft rays and the second 18~19. Though three dorsal fins were separated each other, third dorsal and anal fins were still connected with caudal fin. Flexion of the notochord was completed to the end of caudal fin(Table 1 and Fig. 3c).

Thirty six days after hatching, 16.4 mm in TL was averaged. The HL was 29.3% of TL, and ED was 31.0% of HL average. The first dorsal have 10~11 soft rays, second 16~17, and third 19~20. The first anal have 18~19 soft rays and the second 20~21. All of three dorsal fins were separated each other distinctly, and were not connected with caudal fin. Dorsal fins were well developed and segmentation of the caudal fin ray was started. There were distinct nostril which located at front of dorsal part of the head(Table 1 and Fig. 3d).

Forty days after hatching, averaging 18.7 mm in TL. The HL were 31.6% of TL, and ED was 30.7% of HL average. The first dorsal have 12~13 soft rays, second 16~17, and third 19~20. The first anal have 18~19 soft rays and the second 21~22. Segmentation of the dorsal and anal fin ray was started. The caudal fin was started to fork slightly. Dotted melanophores on the head increased in number, and those along the lateral median of the body spreaded upwards to the dorsal median(Table 1 and Fig. 3e).

Forty three days after hatching, averaging 20.0 mm in TL.

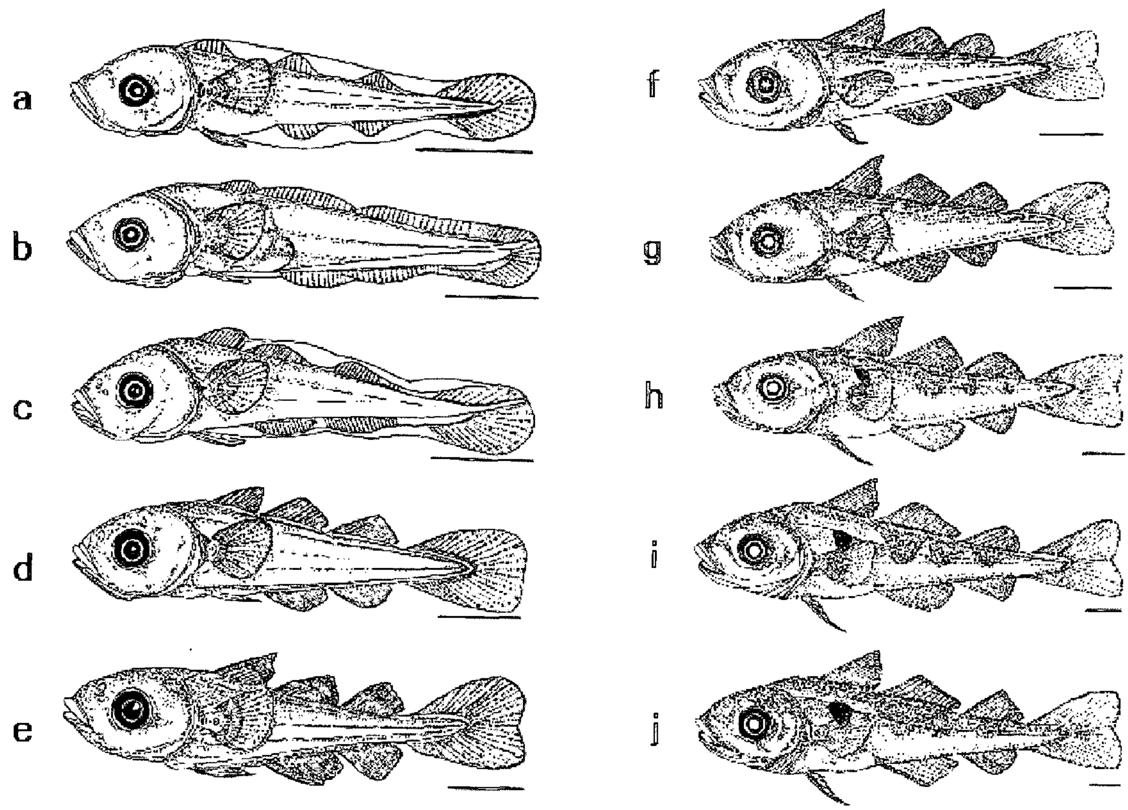

Fig. 3. Continued to Fig. 2.

a: 30 days old; b: 32 days old; c: 34 days old; d: 36 days old; e: 40 day sold; f: 43 days old; g: 46 days old; h: 52 days old; i: 61 days old; j: 67 days old. Bars indicate 3 mm.

The HL was 31.8% of TL, and ED was 31.0% of HL average. The first dorsal have 12~13 soft rays, second 16~17, and third 20~21. The first anal have 18~19 soft rays and the second 21~22. numberous melanophores appeared on the base of dorsal fins membrane. Color of the back was changed to dark and yellowish gray, and ventral part was changed to white and palely silver gray(Table 1 and Fig. 3f).

Forty six days after hatching, averaging 21.8 mm in TL. The HL was 31.5% of TL, and ED was 31.0% of HL average. The first dorsal have 13~14 soft rays, second 19~20, and third 20~21. The first anal have 21~22 soft rays and the second 22~23. First dorsal fin pointed slightly. Dorsal and ventral fins begin to change their color with dark gray. The second spinous ray of pelvics was prolonged slightly(Table 1 and Fig. 3g).

Fifty two days after hatching, averaging 32.4 mm in TL. The HL was 30.0% of TL, and ED was 31.6% of HL average. The first dorsal had 14~15 soft rays, second 19~20, and third 20~21. The first anal had 21~22 soft rays and the second 22~23. Aggregated numbers of all fin rays including the pelvic were completed. Melanophores were distributed on the ventral surface of the lower jaw, around the eye and the fins base except pelvic. There is a dim blotch on the frontal body side and about midway along the pectoral fin, which covers the lower portion of the blotch(Table 1 and Fig. 3h).

Sixty one days after hatching, averaging 41.3 mm in TL. The HL was 28.4% of TL, and ED was 31.6% of HL average. One or two rows of small teeth in lower jaw and two or three rows on upper jaw could be observed in dissecting microscope. Lateral line appeared discontinuously from under the mid of third dorsal fin to behind of the head with small holes, arched following dorsal contour of body. Three patches of melanophores were present, one was located under the third dorsal fin base along the lateral median of the body, and the other were located under the second dorsal fin base. The former is smaller than the others(Table 1 and Fig. 3i).

Sixty seven days after hatching, averaging 51.2 mm in TL. The HL was 27.0% of TL, first pre-dorsal length 24.6%, second 38.8%, third 59.7%, pre-ventral length 24.8%, first pre-anal 43.2%, second 63.3% and pre-anus 42.6% respectively. The eye diameter and snout length were 31.7% and 68.2% of HL, respectively. Lateral line was completed, arched following dorsal contour of body, distinctively black in color. The barbel could not be observed near tip of the low jaw yet(Table 1 and Fig. 3j).

DISCUSSION

Haddock, *M. aeglefiuns* have attracted interest as candidate species for commercial aquaculture and restoration efforts in the Northeast U.S. and the Maritime Provinces of Canada(Buckley, 2000; Ewart et al., 2000; Hamlin & Kling, 2001; Kim & Lall, 2001). One of the most critical determinants for successful aquaculture of finfish is the ability to obtain a consistent supply of larvae or juveniles(Buckley et al., 2000). One of the objectives of these experiments was to establish a successful culture technique for rearing larval haddock.

The larval and juvenile development of haddock is described here for the first time. Hatching of Atlantic cod occurs when embryos are 3.3~5.7 mm in TL(Scott & Scott, 1988), but this species occurs some more larger size 4.77~5.14 mm in TL. Pre-larval stage was maintained during 16 days from newly hatching times growing to 6.88 mm in TL, but it seems that first heterotrophic food could be in 7 days for the elongated snout and developed alimentary canal.

Post-larval stage continued during 16～52 days after hatching with growing of body and development of attachment organs. As post-larval stage ended, larvae attained full fin ray counts and reached the subjuvenile stage at 29.4~32.8(mean, 32.4) mm TL. We suggested developmental measurement and counts of larvae and early juveniles of haddock, *M. aeglefinus* reared in laboratory(Table 1). Haddock grows more rapidly than salmon in salmon cages(Matthew, 1998), and it reaches earlier to juvenile stage than chum salmon(Myoung & Kim, 1993) which is collected from Korea sea side.

In nature the larvae remain in or near surface water, living pelagically until they are over 25 mm long; then they transform to the adult form characterized by a subterminal mouth and natural diet consisting primarily of benthic invertebrates(Scott & Scott, 1988). Adults of haddock have 14~18 first dorsal fin rays, 20~26 second dorsal fin rays, 19~24 third dorsal fin rays, 21~28 first anal fin rays, 20~25 second anal fin rays, and very small chin barbel edge of the continental shelf. This species is separated from other Canadian Arctics-Atlantic cods by having 3 dorsal and 2 fins and having a large black blotch on the flank above the pectoral fin(Coad, 1995).

In this study morphology of cultured haddock resembles to adult at 52 days after hatching averaging 32.4 mm in TL with aggregated numbers of all fin rays except barbel appearance. It was presumed that haddock changed food and ecological behavior at 61 days after hatching as appearance of small teeth, lateral line, and a large black blotch on the flank above the pectoral fin which is a key character of the species(Rechard & Carleton, 1986).

For eventual commercialization of haddock aquaculture, techniques that result in consistently higher survival rates to metamorphosis need to be developed. Through the comparison of the similar species such as cod or salmons, future developmental study of haddock is needed for further understanding of the biology of this species.

ACKNOWLEDGEMENTS

The authors would like to express their gratitude to the technical staff of the Institute for Marine Biosciences, National Research Council Canada, Canada, for helpful supports, and the anonymous reviewers who critically reviewed this manuscript.

REFERENCES

Buckley LJ, Bradley TH, Allen-Guilmentte J (2000) Production, quality, and low temperature incubation of eggs of Atlantic cod *Gadus morhua* and haddock *Melanogrammus aeglefinus* in captivity. J World Aquacult Soc 31:22-29.

Coad BW (1995) Encyclopedia of Canadian fishes. Canadian catalogueing in publication data. Canadian Museum of Nature and Canadian Sportfishing Production. pp. 345-346.

Downing G, Litvak MK (1999) The influence of light intensity on growth of larval haddock. N Am J Aquacult 61:135-140.

Ewart KV, Blanchard B, Johnson SC, Bailey WL, Martin-Robichaud DJ, Buzeta MI (2000) Freeze susceptibility in haddock (*Melanogrammus aeglefinus*). Aquaculture 188:91-101.

Hamlin HJ, Kling LJ (2001) The culture and early weaning of larval haddock (*Melanogrammus aeglefinus*) using a microparticulate diet. Aquaculture 201:61-72.

Kim J-D, Lall SP (2001) Effects of dietary protein level on growth and utilization of protein and energy by juvenile haddock (*Melanogrammus aeglefinus*). Aquaculture 195:311-319.

Matthew KL (1998) The development of haddock culture in Atlantic Canada. Bull Aquacul Assoc Canada 98:30-33.

Myoung JG, Kim YU (1993) Morphological study of *Oncorhynchus* spp. (Pisces : Salmonidae) in Korea. Egg development and morphology of alevin, fry and smolt of chum salmon, *Oncorhynchus keta*. Korea J Ichthyol 5:53-67.

Park I-S, Johnson SC (2002) Determination of the temperature dependent index of mitotic interval (τ_0) for chromosome manipulation in winter flounder *Pseudopleuronectes americanus*. Aquaculture 213:95-100.

Park I-S, Kim J-H, Bang I-C, Kim DS (1998). Histological study of the early gonadal development and sexual differentiation in *Rhynchocypris oxycephalus*. Dev Reprod 2:69-74.

Park I-S, Kim J-H, Cho SH, Kim DS (2004). Sex differentiation and hormonal sex reversal in the bagrid catfish *Pseudobagrus fulvidraco* (Richardson). Aquaculture 232:183-193.

Park I-S, Nam YK, Douglas SE, Johnson SC, Kim DS (2003a). Genetic characterization, morphometrics and gonad development of induced interspecific hybrids between yellowtail flounder, *Pleuronectes ferrugineus* (Storer) and winter flounder, *Pleuronectes americanus* (Walbaum). Aquac Res 34: 389-396.

Park I-S, Oh HS, Koo J-G (2003b) Effect of oral tamoxifen on growth and survival in the bagrid catfish *Pseudobagrus fulvidraco*. Aquac Res 34:1471-1474.

Rechard RC, Carleton RG (1986) Atlantic coast fishes. Houghton Mifflin Company, Boston New York. pp 93.

Roy PK, Lall SP (2003) Dietary phosphorus requirement of juvenile haddock (*Melanogrammus aeglefinus* L.). Aquaculture 221:451-468.

Scott WB, Scott MG (1988) Atlantic fishes of Canada. Can Bull Fish Aquat Sci 219:274-276.

Trippel EA, Neil SRE (2003) Effects of photoperiod and light intensity on growth and activity of juvenile haddock (*Melanogrammus aeglefinus*). Aquaculture 217:633-645.

von Bertalanffy L (1938) A quantitative theory of organic growth (Inquiries on growth laws. II). Hum Biol 10:181-213.