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A Bibliography on Atlantic Halibut (*Hippoglossus hippoglossus*) and Pacific Halibut (*Hippoglossus stenolepis*) Culture, with Abstracts

compiled by

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FOREWORD

This bibliography includes publications on the culture of Atlantic halibut (*Hippoglossus hippoglossus*) and Pacific halibut (*H. stenolepis*). The literature was surveyed through early 1993, with concentration on the past decade when efforts to culture halibut began in earnest. For publications with abstracts, the abstracts (sometimes slightly modified to maintain continuity of style) are reproduced here. In the case of some of the publications where there were no abstracts, a brief summary is provided.

A Bibliography on Atlantic Halibut (*Hippoglossus hippoglossus*) and Pacific Halibut (*Hippoglossus stenolepis*) Culture,with Abstracts

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Andreasen, T. V., T. Haug, and E. Ringø. 1989. Food, condition, and the lipid and protein contents of young Atlantic halibut (*Hippoglossus hippoglossus* L.) captured in the autumn in north Norway. Int. Council Explor. Sea. C.M. 1989/F:3. 17 p.

The diet of young (2 - 4 years), immature Atlantic halibut (*Hippoglossus hippoglossus*) from nursery areas in north Norway was dominated by 0-group gadoids (cod (*Gadus morhua*) in particular) and sand eels (*Ammodytes* sp.). No variation was observed among the sexes in general condition (liver and body) or in the content of total lipids or proteins in red myotomal muscle, anal fin base and liver. In white myotomal muscle, however, significant intersexual heterogeneity was observed in lipid and protein contents. The muscle tissues showed a high content of polar lipids, reflecting the relatively low total lipid content, whereas the fin base notch and liver were totally dominated by the triglycerides of the neutral fraction. Analysis of the fatty acid composition revealed that the polyunsaturated fatty acid (PUFA) 22:6(w3) dominated the polar lipid fraction in all tissues examined, and white muscle in particular. Within the neutral lipid fraction, the monoene fatty acid 18:1, and the PUFAs 20:5(w3) and 22:6(w3) were the most abundant fatty acids in fin base and muscle tissue. However, in liver 18:1 dominated. The major constituent of the protein amino acids was glutamic acid, with lysine, aspartic acid, leucine and arginine also present in considerable amounts. The fraction of free amino acids and ninhydrine-positive substances was dominated by taurine. The data presented in this paper, taken from well-fed wild halibut at the end of an intensive feeding season, presents a good basis for comparison with captive halibut fed on man-made diets.

Anonymous. 1988. First glimmers of success with halibut. Fish Farmer 11(1): 16-18.

Details are given of activities conducted at the Seafish Marine Farming Unit regarding halibut (*Hippoglossus hippoglossus*) cultivation. The recirculation system used for halibut incubation/larval accommodation is described.

Avault, J. W. Jr. 1988. "New" species for aquaculture. Aquacult. Mag. 14(2): 53-55.

A brief account is given of various new species of commercial interest to the aquaculture industry. Amongst the species thought to show promise in the industry are *Penaeus penicillatus, P. marginatus, Mithrax spinosissimus, Cytopleura costata, Tridacna gigas, Siganus guttatus, Colossoma macropomum, Hippoglossus stenolepis* and *Epinephelus microdon.*

Berg, L., and V. Øiestad. 1986. Growth and survival studies of halibut (*Hippoglossus hippoglossus* L.) from hatching to beyond metamorphosis carried out in mesocosms. Int. Council Explor. Sea. C.M. 1986/f:16. 19 p.

To each of five floating plastic bags 1500 halibut larvae were transferred from the hatchery one day after hatching. The plastic bags had a volume of 11.5 m^3, a total depth of 5.5 m and they were moored to floating collars. The bags were made of polyethylene, coated with black PVC. Each bag was covered with a roof so the larvae were in a totally dark water column the first month. The general salinity was that of Atlantic water. Supplied water had a salinity of 30-32‰. The halibut larvae reached the functional stage 40 days after hatching and natural zooplankton was added. At this time opening gradually was made in the roof of three of the bags while in two bags light was supplied by underwater lamps. Survival to the first feeding stage was about 45%. Almost all functional larvae started to feed, and they reached a size of 20 mm at metamorphosis and bag termination 45 days after first feeding was observed. The dry weight had increased from 600 to 3500 µg in the period of active feeding. The mean overall survival was 3.3%.

Berg, L., K. Naas, and K. Pittman. 1987. Deepwater flowthrough as a temperature stabilizer in rearing of halibut (*Hippoglossus hippoglossus*) fry. Int. Council Explor. Sea. C.M. 1987/F:16. 7 p.

Through the period of yolk sac absorption, halibut (*Hippoglossus hippoglossus*) larvae were kept in plastic bags in plastic basins with flowthrough of deepwater. When maintaining sufficient flowthrough in this period, the temperature in the bags was consistently around 6°C, while the ambient temperature varied between 2°C and 11°C.

Berge, G. M., A. Krogdahl, Ø. Stroemsnes, A. Groenseth, P. Myhre, and E. Austreng. 1991. Digestibility determination in Atlantic halibut (*Hippoglossus hippoglossus*). Fisk. Dir. Skr., Ser Ernæring, 4: 117-125.

Experiments were carried out with Atlantic halibut (*Hippoglossus hippoglossus*) in order to adapt the digestibility assay with chromic oxide (Cr2O3) as an indigestible indicator for studies with the species. Macro anatomy of the digestive tract was studied, and two methods of collecting fecal samples were evaluated. Manual stripping proved to be the best method. An experiment was carried out to assess optimal time for stripping related to last feeding. Feces were obtained at all investigated points of time (24, 28, 32, and 36 hours), but most at 28 and 36 hours after feeding. The digestibility experiments showed successive digestion and absorption throughout the intestine, and digestibility coefficients ranged from 75 to 88 for protein, from 78 to 87 for fat, and from 0 to 23 for carbohydrate.

Bergh, Ø., and A. Jelmert. 1990. Antibacterial treatment procedures of eggs of halibut (*Hippoglossus hippoglossus* L.). Int. Council Explor. Sea. C.M. 1990/F:39. 6 p.

Halibut (*Hippoglossus hippoglossus*) eggs were surface disinfected with an iodophor one day before hatching, and mortality and larval development were recorded until the time of first feeding. The groups exposed to higher concentrations of disinfectant had lower mortalities and lower fraction of larvae with developmental deformities compared to groups exposed to lower concentrations and untreated control groups.

Bergh, Ø., G. H. Hansen, and A. Jelmert. 1990. Bacterial diseases of eggs and yolk sac larvae of halibut (*Hippoglossus hippoglossus* L.): characterization and experimental infection. Int. Council Explor. Sea. C.M. 1990/F:38. 7 p.

Scanning electron micrographs of halibut (*Hippoglossus hippoglossus*) eggs which were shown to have an epiflora dominated by a *Flexibacter* sp., revealed wounds colonized by large amounts of bacteria. The chorion was penetrated in most wounds, and the zona radiata was severely damaged. Infection experiments showed that exposure to these bacteria caused high mortality at hatching and early yolk sac stage. Eggs exposed to strains of *Vibrio anguillarum* and *Vibrio fisheri* showed a different mortality pattern, with low mortality at hatching, followed by a continuous high mortality throughout the yolk sac stage. Mortality in the uninfected control group was low throughout the experiment.

Bergh, Ø., I. Opstad, K. Pittman, A. B. Skiftesvik, L. Skjolddal, H. Strand, and V. Vanthuyne. 1989. Preliminary report on the effects of temperature on the development of eggs and larvae of halibut (*Hippoglossus hippoglossus*) and on the bacterial population in the incubators. Int. Council Explor. Sea. C.M. 1989/F:19. 19 p.

Eggs were stripped from one female of the halibut broodstock at Austevoll Aquaculture Station, and fertilized with sperm from two males immediately before incubation. Eggs were held in nine open-circulation 250 l incubators at either 3°, 6° or 9°C with three incubators at each temperature. When hatched, the larvae were transferred to fifteen similar incubators, with five incubators at each temperature. The timing of developmental events in the eggs and larvae was monitored, mortality in the egg and larval stages recorded, growth and yolk absorption measured in the larvae, RNA and DNA content and RNA/DNA ratios determined for each temperature group and samples taken for embryonal and larval histology. Total and viable count of free-living bacteria in the incubators was monitored from hatching until termination of the experiment. Flow rate, temperature, oxygen, and ammonia were recorded.

Differences in development rates were apparent from the first cell divisions. The mean number of Kuppfer's vesicles was most in the 9°C groups and least in the 6°C groups. At hatching, relative protein synthesis and yolk sac size was best at 3 C but there was no difference in standard length between the groups. At 9°C larvae grew faster, but developed abnormalities associated with sublethal stressors. A rise in mortalities occurred at the same stage of development at 6° and 9°C. An increase in larval mortalities lead to an increase in bacteria which preceded an increase in ammonia levels. There was no significant difference in bacterial numbers between groups. The experiment was terminated due to uncontrolled temperature fluctuations.

Bjørnsson, B. 1992. The effects of stocking density on the growth rate of young halibut (*Hippoglossus hippoglossus* L.) reared in large circular tanks for three years. Int. Council Explor. Sea. C.M. 1992/F:13. 14 p.

The aim of this study was to estimate the optimal stocking density during the ongrowing phase of halibut. Two size classes of young halibut of initial mean weight 1.8 and 3.2 kg were stocked at three different densities: 11, 22, and 33 kg/m^2 and reared in six large circular tanks (8 m) for three years at 7°C. The fish were fed to

satiation six days a week with frozen fish (capelin and herring). The stocking density increased as the fish grew but fish were removed four times to control it. The average stocking densities for the two size classes were: 18, 43, and 63 kg/m2 corresponding to 50%, 100%, and 160% coverage of the tank bottom by fish. The maximum observed stocking density, 95 kg/m^2, corresponded to 215% coverage. There was not a significant difference in growth rate (kg/year) between the two size classes. The mean weight at the end of the experiment was 5 to 7 kg for the males and 9 to 14 kg for the females. For the two size classes combined the growth rate was significantly lower at the highest as compared with the intermediate and low stocking densities, but no significant difference occurred between the groups at the intermediate and low densities. It is concluded that stocking density affects growth rate of halibut only above a certain threshold level, about 50 kg/m^2 for a 7 kg halibut. The results indicate that the optimal stocking density is somewhere between that which corresponds to one and two layers of fish. Thus, for 2 kg halibut the optimal stocking density is between 25 and 50 kg/m^2 and for 10 kg halibut between 50 and 100 kg/m^2.

Bjørnsson, B., G. Sigurthorsson, G-I. Hemre, and Ø. Lie. 1992. Growth rate and feed conversion factor of young halibut (*Hippoglossus hippoglossus* L.) fed six different diets. Fisk. Dir. Skr., Ser. Ernæring, 5: 25-35.

Six groups of halibut, initial weight 2.5 kg., were fed the following diets: I. lean capelin (*Mallotus villosus* M.), II. fat capelin, III. lean and fat capelin, IV. moist feed from capelin silage, V. dry salmon feed, and VI. moist feed from ground capelin, from 7 November 1988 to 31 May 1990. Most of the males became mature in the fall 1989, at a mean weight close to 4 kg. From 19 September 1989 to 31 May 1990 the mature males showed virtually no weight gain. For the first three months, the growth rates of the groups IV and V were substantially lower than for the other groups. These two groups showed a compensatory growth later on. Therefore, no significant differences in growth rate among the six groups were found during the experimental period. In the period prior to maturation of the males, the feed conversion factor was lowest, 1.0, for fish on diets I, II, and III and highest, 3.0, for fish on diet IV. In the period subsequent to maturation the feed conversion factor increased substantially. A protein-sparing effect by fat was demonstrated by increasing the fat/protein ratio of a diet from 1.0 to 1.5.

Bjørnsson, B., G. Sigurthorsson, Ø. Lie, and G-I. Hemre. 1991. Growth rate and food conversion of young halibut (*Hippoglossus hippoglossus* L.) fed six different diets. Int. Council Explor. Sea. C. P. 1991: 20 p.

Six groups of halibut, of initial weight 2.5 kg were fed the following diets: I. lean capelin (*Mallotus villosus*), II. fat capelin, III. lean and fat capelin (3:3 days per week), IV. moist feed from capelin silage, V. dry salmon feed (12 mm extruded feed), and VI. moist feed from ground capelin. The experiment lasted for 570 days, from 7 November 1988 to 31 May 1990, the fish being weighed every three months. Most of the males became mature in the fall 1989 at a mean weight close to 4 kg. In the period from 19 September 1989 to 31 May 1990 there was virtually no weight gain of the mature males. For the first three months of the experiment the growth rate of the groups on diets IV and V were substantially lower than those on the other diets. Later on those two groups were able to compensate to some extent for the initially slow growth.

Blaxter, J. H. S., D. Danielssen, E. Moksness, and V. Øiestad. 1983. Description of the early development of the halibut *Hippoglossus hippoglossus* and attempts to rear the larvae past first feeding. Mar. Biol. 73: 99-107.

Rearing experiments on the halibut *Hippoglossus hippoglossus* (L.) were carried out using gametes from parents caught at a depth of 600 to 700 m off the Norwegian coast in February 1980. After fertilization, the average egg diameter was 3.08 mm, average dry weight 1,038 µg and neutral buoyancy was 36.5‰ salinity. The eggs hatched after 20 days at 4.7°C, 18 days at 5°C, and 13 days at 7°C. Survival to hatching was better when antibiotics were used. At hatching the larvae were 6.4 mm long, there were no functional eyes or mouth, but prominent neuromast orginas were present. Resorption of yolk lasted 50 days at 5.3°C; the eyes and mouth were then functioning and the larva was about 11.5 mm long. The larvae were offered zooplankton as food, but with little success in initial feeding. A few larvae fed and grew in 2 500-liter plastic bags, one reaching length of 24 mm after 90 days.

Blaxter, J. H. S., J. C. Gamble, I-B. Falk-Petersen, S. Falk-Petersen, T. Haug, E. Kjøersvik, and J. Sargent. 1989. Lipids in Atlantic halibut (*Hippoglossus hippoglossus* L.) eggs from planktonic samples in northern Norway, p. 440. *In*: J. H. S. Blaxter, J. C. Gamble, and H. von Westernhagen (Eds.). The early life history of fish. The third ICES symposium, Bergen, Norway, October 3-5, 1988. Rapp. P. V. Réun. Ciem. 191.

Fertilized Atlantic halibut (*Hippoglossus hippoglossus*) eggs in different developmental stages (day 0 to day 18) were sampled from plankton in north Norway and analyzed for lipid classes and fatty acids. From levels of ca. 71% and 13% in unfertilized ovulated eggs, the percentage of polar and neutral lipids, respectively, decreased and increased to 67% and 16% in stage 3 (11-18 day old) fertilized eggs.

Bolinches, J., and E. Egidius. 1987. Heterotrophic bacterial communities associated with the rearing of halibut (*Hippoglossus hippoglossus*) with special reference to *Vibrio* spp. J. Appl. Ichthy. 3: 165-173.

The heterotrophic bacterial communities and their changes during the spring have been examined in the tanks of broodstock and larvae of halibut in an aquaculture station (SW Norway). The total viable counts in the fish tanks were higher than in the inlet water. The bacterial community associated with the healthy larvae was dominated by '*Actinomyces*-like' bacteria, which reached 7 x 1°6 CFU/ml when the larvae were in the sea-bags. The genus *Vibrio* was also present but in lower numbers. In this study, the *Vibrio* populations (known as potential fish pathogens) were characterized more accurately studying some aspects of their ecology, taxonomy and serology. The two main populations, *V. fischeri* and *V. anguillarum*, changed during the spring, apparently in response to temperature. Despite the high rate of *V. anguillarum* isolations, none of them belonged to the pathogenic 01 and 02 serotypes.

Bolla, S. 1989. Fatty acid composition of Atlantic halibut larvae fed on enriched *Brachionus*, *Artemia*, or collected plankton, p. 475. *In*: J. H. S. Blaxter, J. C. Gamble, and H. von Westernhagen (Eds.). The early life history of fish. The third ICES symposium, Bergen, Norway, October 3-5, 1988. Rapp. P. V. Réun. Ciem. 191.

The cultivated live feeds *Brachionus* and *Artemia* were compared to collected

plankton as first-feed for Atlantic halibut larvae (*Hippoglossus hippoglossus*). Proportions of the different fatty acids remained unchanged in larvae fed collected plankton, whereas larvae fed cultivated feeds showed marked differences, such as the depletion of the highly unsaturated fatty acids. This indicates that Atlantic halibut cannot synthesize HUFA from precursors. There was a good correspondence between the fatty acid profile of larvae and the respective diets. After 134 days of feeding, survival was similar for the three diets. The group fed on collected plankton had a better performance with regard to growth and percentage metamorphosing. Atlantic halibut larvae have high requirements for the HUFA and therefore fatty acid composition is an important factor in the evaluation of the nutritional value of a feed.

Bolla, S., and I. Holmefjord. 1988. Effect of temperature and light on development of Atlantic halibut larvae. Aquaculture 74: 355-358.

The influence of temperature and light intensity on the development of Atlantic halibut larvae (*Hippoglossus hippoglossus*) was studied during the resorption of the yolk sac. Holding at three different temperatures (2° C, 6° C, and 10°C) was investigated together with four light intensities (0, 3, 30, and 300 lux) at 6° C. The most common abnormality observed was a mouth deformity. The percent of normal larvae was significantly lower at 10° C than at 6° C and 2° C. Total darkness gave a significantly higher percent of normal larvae than any of the other three light regimes. There was no significant effect of light on survival during the resorption of the yolk sac.

Bolla, S., I. Holmefjord, and T. Refstie. 1987. Cryogenic preservation of Atlantic halibut sperm. Aquaculture 65: 371-374.

Sperm from three Atlantic halibut (*Hippoglossus hippoglossus*), diluted 1:3 in a saline extender, were cryopreserved as pellets or in straws and thawed in Ringer for marine fish. Controls were prepared with fresh sperm from the same males. There were no significant differences in fertilization ability between cryopreserved and fresh sperm nor between freezing procedures or thawing temperatures. There was a significant difference in fertilization rates between the three males.

Bolla, S., I. Holmefjord, and K. I. Reitan. 1989. Start-feeding of Atlantic halibut (*Hippoglossus hippoglossus* L.) on enriched rotifers and *Artemia* compared with collected plankton, p. 479. In: J. H. S. Blaxter, J. C. Gamble, and H. von Westernhagen (Eds.). The early life history of fish. The third ICES symposium, Bergen, Norway, October 3-5, 1988. Rapp. P. V. Réun. Ciem. 191.

Halibut larvae (*Hippoglossus hippoglossus*) were start-fed in 250 liter tanks and three different feeding regimes were tested: (a) *Artemia;* (b) rotifers for three weeks, then *Artemia;* (c) collected plankton. All groups started to feed and at metamorphosis all three regimes had a survival of about 1% from start of feeding. The weight of the halibut given collected plankton was twice that of groups given enriched rotifers or *Artemia.* Later, a pilot experiment was conducted, giving a succession of the three different feeds; first three weeks of rotifers, then *Artemia* and change to collected plankton before metamorphosis. This group had a survival of 4.8%.

Bowden, D. G., E. P. Groot, and J. O. T. Jensen. 1990. Tests on short-term storage of Pacific halibut (*Hippoglossus stenolepis*) sperm and salinity tolerance of Pacific halibut and sablefish *(Anoplopoma fimbria*) sperm. Can. Tech. Rep. Fish. Aquat. Sci. No. 1725. 23 p.

The effect of short term storage on the duration of forward motility (FM) of sperm from Pacific halibut (*Hippoglossus stenolepis*) as well as the salinity tolerance of halibut and sablefish (*Anoplopoma fimbria*) sperm were examined. Milt was collected from spermiating halibut and sablefish using routine techniques. Halibut milt was stored in sealed plastic bags at 3.3 plus or minus 0.35° C (plus or minus SD) and examined daily for duration of FM. Salinity tolerance was determined by mixing fresh milt in various sea water concentrations (5. 55‰ salinity for halibut sperm and 10.60‰ for sablefish sperm) and then examining the duration of FM of spermatozoa. Halibut sperm was successfully stored for up to 195.0 h.

Boxaspen, K., T. Harboe, and L. H. Skjolddal. 1990. A pilot study of halibut larvae (*Hippoglossus hippoglossus* L.) reared from start feeding to metamorphosis on diets of wild zooplankton and *Artemia.* Int. Council Explor. Sea. C. M. 1990/F:52. 20 p.

Halibut (*Hippoglossus hippoglossus*) larvae ready to start feed were placed in two outdoor tanks of 7 m3. The larvae in one tank were fed wild zooplankton throughout the whole period, and the larvae in the other tank were fed wild zooplankton from day one to day seven and *Artemia* thereafter. Measurements of growth, gut content and content of fatty acids were made of the larvae. Number and species of phytoplankton and zooplankton, as well as abiotic parameters were measured during the experiment. Larval myotome height and dry weight were significantly higher for the group supplied wild zooplankton and *Artemia* than for the group supplied only wild zooplankton, at day 22 after first feeding. For the larval group supplied only wild zooplankton, the myotome height and length, at day 43 (the end of the experiment), were significantly higher than the group supplied wild zooplankton and *Artemia.*

Crim, L. W., D. A. Methven, and B. Norberg. 1989. Seasonal profiles of the sex steroid hormones estradiol and testosterone in Atlantic halibut (*Hippoglossus hippoglossus*): implications for broodstock management. Bull. Aquacult. Assoc. Can. 89-3: 46.

Our results have two important implications for managing halibut broodstock. New prospective broodstock females may be accurately sexed several months prior to spawning (estradiol was undetectable in males). Secondly, by monitoring sex steroid concentrations prior to spawning, it might be possible to predict from elevated estradiol levels which females will be the best spawners (good quality eggs). There is considerable variation in egg quality and fertilization rates between females. An additional finding is that monthly blood samples may be collected from female broodstock apparently without disrupting spawning during the winter.

Davenport, J., E. Kjøsvik, and T. Haug. 1990. Appetite, gut transit, oxygen uptake and nitrogen excretion in captive Atlantic halibut, *Hippoglossus hippoglossus* L., and lemon sole, *Microstomus kitt* (Walbaum). Aquaculture 90: 267-277.

Atlantic halibut, *Hippoglossus hippoglossus* L., eat larger satiation meals (mean 11.7% body weight) than lemon sole, *Microstomus kitt* (Walbaum), (2.6% body

weight). Total gut clearance time was about 120 hours for halibut and 72 hours for lemon sole. There are marked differences in feeding behavior between the two species; halibut feed in midwater and require several body lengths of approach swimming before taking large items of food, while lemon sole eat only off the bottom. In shared tanks, no aggressive interaction was observed. A duoculture system holding small numbers of lemon sole with the more valuable halibut is recommended as a means of minimizing food waste and tank fouling. Oxygen uptakes of 0.07-0.11 ml O^2 per gram of fish weight per hour (depending on nutritional state) were recorded for the two species. Ammonia nitrogen outputs were also similar. Starved halibut excreted 2.32 µg N per gram per hour, fed animals 5.08 µg N per gram per hour. The corresponding values for lemon sole were 3.26 µg N per gram per hour and 6.37 µg N per gram per hour, respectively.

Falk-Petersen, S., I-B. Falk-Petersen, J. R. Sargent, and T. Haug. 1986. Lipid class and fatty acid composition of eggs from the Atlantic halibut (*Hippoglossus hippoglossus*). Aquaculture 52: 207-211.

Lipid class and fatty acid analyses were carried out on ripe roe of halibut caught in North Norway. The percentage of neutral lipids was ca. 30%, while the main polar lipids were phosphatidylcholine (62%) and phosphatidlethanolamine (7%). The phospholipids were very unsaturated, with high concentrations of (n-3) polyunsaturated fatty acids (PUFA), especially 20:5(n-3) and 22:6(n-3).

Falk-Petersen, S., J. R. Sargent, C. Fox, I-B. Falk-Petersen, T. Haug, and E. Kjøersvik. 1989. Lipids in Atlantic halibut (*Hippoglossus hippoglossus*) eggs from planktonic samples in northern Norway. Mar. Biol. 101: 553-556.

Fertilized Atlantic halibut (*Hippoglossus hippoglossus*) eggs in different developmental stages (days 0 to 18) were sampled from plankton in north Norway in February 1986 and analyzed for lipid classes and fatty acid content. In unfertilized ovulate eggs taken from ripe fish caught in 1983/1984, polar and neutral lipids comprised ca. 71 and 30% of the total lipids, respectively, decreasing and increasing to 67 and 33%, respectively, in Stage III (11 to 18 days old) fertilized eggs, while phosphatidylethanolamine increased from ca. 7 to 33%. Triacylglycerols, the major neutral lipids, increased from ca. 13% in unfertilized ovulated eggs to 16% in Stage III fertilized eggs. The total lipid in Stage I fertilized eggs had relatively low levels of polyunsaturated fatty acids (PUFA), with n-3 PUFA accounting for only ca. 25% of the total fatty acids. The n-3 PUFA increased to ca. 40% of the total fatty acids in Stage III, while the n-3:n-6 ratio increased from 4.1 to 7.0.

Finn, R. N., H. J. Fyhn, and M. S. Evjen. 1991. Respiration and nitrogen metabolism in halibut eggs (*Hippoglossus hippoglossus*). Mar. Biol. 108: 11-19.

Naturally spawned and fertilized eggs of Atlantic halibut, *Hippoglossus hippoglossus*, were analyzed for protein, free amino acids (FAA), ammonium ions and energy content. The chemical composition was found to be size-dependent but varied little during egg development. Ammonium ions did, however, accumulate during the late embryonic stage, and the trend in FAA content was downward during the same period. Rates of 0^2 uptake and NH^3 excretion followed exponential patterns. A total

of 1 µmole 0^2 was consumed and 120 nmol NH^3 excreted between the time intervals of fertilization and 1 day post hatch. Derived O:N ratios indicated that the dominant portion of the energy metabolism was lipid- or carbohydrate-based during the mid-development period but switched to FAA as hatch was approached.

Forrester, C. R., and D. F. Alderdice. 1973. Laboratory observations on early development of the Pacific halibut. Int. Pac. Halibut Comm. Tech. Report No. 9: 13 p.

Eggs of the Pacific halibut (*Hippoglossus stenolepis*) were artificially fertilized and incubated in water of 33‰ salinity at temperatures of 2 to 12°C. Hatching occurred at temperatures of 5, 6, 7, and 8°C. Time to 50% hatching ranged from 12.5 days (8°C) to 20 days (5°C). Mean larval size at hatching ranged from 6.03 to 7.24 mm; the largest larvae were hatched at 6°C. At hatching the length of yolk sac was approximately 50% of the total larval length. The observations complement information provided through earlier field studies by the International Pacific Halibut Commission.

Gillespie, M. J. S., R. Johnstone, R. J. Shields, J. E. Dye, and P. L. Smith. 1992. A progress report on the Sea Fish Industry Authority halibut rearing programme. Int. Council Explor. Sea. C.M. 1992/F:15. 4 p.

A summary is provided of the development and rearing procedures for Atlantic halibut (*Hippoglossus hippoglossus* L.) at the S.F.I.A. Marine Farming Unit, Ardtoe. The rearing procedures are discussed in relation to Norwegian systems, and the current emphasis of research activities at Ardtoe is described.

Glass, H. L., N. L. MacDonald, and J. R. Stark. 1987. Metabolism in marine flatfish. 4. Carbohydrate and protein digestion in Atlantic halibut (*Hippoglossus hippoglossus* L.). Comp. Biochem. Physiol. 86 : 281-289.

A survey of the digestive enzymes present in Atlantic halibut has been carried out. The endoproteases pepsin, chymotrypsin, trypsin and elastase and the exoproteases leucine aminopeptidase and carboxypeptidases a and b were identified together with activity toward casein at pH 4.5 to 5.3 The main carbohydrase activities were alpha-amylase and alpha-glucosidase. Although the activity toward p-nitrophenyl N-acetylglucosaminide was strong in all zones of the alimentary tract, there were only trace amounts of chitinase activity. With the exception of chymotrypsin and elastase, all hydrolytic enzymes were most active in extracts of pyloric caeca. A comparison has been made between the intestinal glycosidases of halibut and those of rat.

Glass, H. L., N. L. MacDonald, R. M. Moran, and J. R. Stark. 1989. Digestion of protein in different marine species. Comp. Biochem. Physiol. 94B: 607-611.

The digestive proteases in five marine species (Atlantic halibut, *Hippoglossus hippoglossus*; Dover sole, *Solea solea*; turbot, *Scophthalmus maximus*; European lobster, *Homarus gammarus*; and the giant prawn, *Penaeus monodon*) have been compared by biochemical methods. The pH profiles for the hydrolysis of casein by extracts from the digestive systems of each species showed different characteristics; extracts from adult halibut, turbot and sole exhibited strong pepsin-like activity; whereas that enzyme was absent in *P. monodon* and in sole larvae. Although lobster extracts, from either the hepatopancreas or the stomach, showed peaks in pH values of

5.8 and 2.5, the latter activity did not hydrolyze a specific substrate for pepsin. Halibut and turbot digestive extracts contained an activity optimal at pH values in the region of 5.0 resembling a cathepsin-like enzyme; an activity which was not evident in the other species under similar experimental conditions. Although all species possessed trypsin-like activity, the pH profiles of activity in the neutral to alkaline region were unique to each species. The significance of these results is considered with respect to the anatomical differences in the alimentary systems of these species.

Goff, G. P., and S. P. Lall. 1989. An initial examination of the nutrition and growth of Atlantic halibut (*Hippoglossus hippoglossus*) fed herring with a vitamin supplement. Bull. Aquacult. Assoc. Can. 89-3: 56-58.

The addition of a vitamin supplement to the whole frozen herring diet of juvenile Atlantic halibut (*Hippoglossus hippoglossus*) produced a beneficial effect on growth. The supplement improved the nutritional status of vitamins A, E and riboflavin.

Goff, G. P., D. A. Methven, and J. A. Brown. 1989. Low temperature tolerance of Atlantic halibut, *Hippoglossus hippoglossus*, at ambient ocean temperaures in Newfoundland. Bull. Aquacult. Assoc. Can. 89-3: 53-55.

Juvenile Atlantic halibut (*Hippoglossus hippoglossus*) survived extended periods of subzero winter seawater temperatures in good condition. Three of five halibut survived temperatures to -1.5°C in 1988 and five of six halibut survived temperatures to -1.1°C in 1989. These fish became inactive and ceased to feed at temperatures below 2.0°C.

Gulbrandsen, J. 1991. Function response of Atlantic halibut larvae related to prey density and distribution. Aquaculture 94: 89-98.

Two experiments were conducted in order to elucidate the relationship between prey density and feeding success of Atlantic halibut larvae (*Hippoglossus hippoglossus* L.) in terms of a functional response. One experiment was designed for the purpose of controlling zooplankton swarming, which otherwise would have complicated the interpretation of a response. Another experiment investigated the response in numbers of prey eaten by each larva. An inflection point referred to in the literature as an incipient limiting level, should indicate the optimal prey density to be offered. This work concludes that rotifers (*Brachionus plicatilis*) can be prevented from horizontal patching simply by providing diffused light; hunger motivation is seemingly without effect. Brine shrimp (*Artemia* sp.), on the other hand, appear to be less well controlled. Halibut seem to have an optimal feeding response at approximately 12 rotifers per milliliter, whereas the majority feed above a level of 2.5 ml.

Hansen, G. H., and J. A. Olafsen. 1989. Bacterial colonization of cod (*Gadus morhua* L.) and halibut (*Hippoglossus hippoglossus*) eggs in marine aquaculture. Appl. Envir. Micro. 55: 1435-1446.

Aquaculture has brought about increased interest in mass production of marine fish larvae. Problems such as poor egg quality and mass mortality of fish larvae have been prevalent. The intensive incubation techniques that often result in bacterial overgrowth on fish eggs could affect the commensal relationship between the

indigenous microflora and opportunistic pathogens and subsequently hamper egg development, hatching, larval health, and ongrowth. The adherent microflora on cod (*G. morhua* L.) and halibut (*Hippoglossus hippoglossus*) eggs during incubation was characterized and grouped by cluster analysis. Marked bacterial growth could be demonstrated two hours after fertilization, and at hatching eggs were heavily overgrown. Members of the genera *Pseudomonas, Alteromonas, Aeromonas*, and *Flavobacterium* were found to dominate on the surface of both cod and halibut eggs. The filamentous bacterium *Leucothrix mucor* was found on eggs from both species. While growth of *L. mucor* on halibut eggs was sparse, cod eggs with a hairy appearance due to overgrowth by this bacterium close to hatching were frequently observed. *Vibrio fisheri* could be detected on cod eggs only, and pathogenic vibrios were not detected.

Harboe, T., T. Nass, K. E. Næss, H. Rabben, and L. H. Skjolddal. 1990. Age of Atlantic halibut larvae (*Hippoglossus hippoglossus*) eggs at first feeding. Int. Council Explor. Sea. C.M. 1990/F:53. 7 p.

Halibut (*Hippoglossus hippoglossus*) larvae at different ages were transferred to outdoor start-feeding tanks. The larvae were fed wild zooplankton. One bag was sampled after 24 hours, and the other after nine days. Numbers of larvae with food in the gut, without food in the gut, and dead larvae were counted for each larval age tested. The results showed that some larvae captured prey at an age of 150 day-degrees. However, at this age few larvae were alive after nine days. The fraction of larvae with food in the gut increased during the period tested. Survival after 24 hours and after nine days was highest when first feeding took place at a larval age of approximately 230 day-degrees.

Haug, T. 1990. Biology of the Atlantic halibut, *Hippoglossus hippoglossus* (L. 1758), p. 1-70. *In*: J. H. S. Blaxter and A. J. Southward (Eds.). Advances in Marine Biology, Academic Press, London. 26.

This paper discusses, in detail, the taxonomy; distribution; reproduction; embryonic and larval development; migration, growth, and feeding of juveniles and adults; parasites and diseases; exploitation; and aquaculture of the Atlantic halibut.

Haug, T., and B. Gulliksen. 1988. Variations in liver and body composition during gonad development of Atlantic halibut, *Hippoglossus hippoglossus* (L.). Fiskeridir. Skr. (Havunders.) 18: 351-363.

Data were collected from Atlantic halibut (*Hippoglossus hippoglossus*) caught in gill nets and on long lines in northern Norway between September and March during 1981-1986. The liver is significantly depleted during the spawning season, indicating that it is an important energy source. The carcass seems less affected by the energy expenditures involved in the seasonal accumulation of reproductive tissues and in spawning, particularly in females where no significant sacrifice of body weight was observed.

Haug, T., and E. Kjøersvik. 1989. Comparative studies of Atlantic halibut (*Hippoglossus hippoglossus* L.) spawning in different areas, p. 440. *In*: J. H. S. Blaxter, J. C. Gamble, and H. von Westernhagen (Eds.). The early life history of fish. The third ICES symposium, Bergen, Norway, October 3-5, 1988. Rapp. P. V. Réun. Ciem. 191.

A comparison of reproductive parameters of *Hippoglossus hippoglossus* is made for various parts of North America, Iceland, the Faroes, and Norway. The males reach sexual maturity at a younger age and smaller size than the females. There are substantial variations in age at which sexual maturity is attained. Halibut maturity is probably more a function of size than of age, i.e. maturity is most probably attributable to observed variations in growth rate. Halibut spawning takes place near the bottom in deep water localities where temperatures and salinities range between 5 and 8°C and 34.5 and 35.1‰ salinity.

Haug, T., and J. Tjemsland. 1986. Changes in size- and age-distributions and age at sexual maturity in Atlantic halibut, *Hippoglossus hippoglossus*, caught in north Norwegian waters. Fish. Res. 4: 145-155.

There has been a decrease in the percentage of old, but not of large, fish in the catches of mature Atlantic halibut, *Hippoglossus hippoglossus*, taken in gill nets during the period 1981-85, compared with catches taken in northern Norway during the period 1945-60. This change is associated with increases in size at age and a substantial reduction in average age at first spawning between the two periods. The changes in these population parameters may point to a drop in halibut density due to exploitation.

Haug, T., E. Kjøsvik and P. Solemdal. 1984. Vertical distribution of Atlantic halibut (*Hippoglossus hippoglossus*) eggs. Can. J. Fish. Aquat. Sci. 41: 798-804.

It is suggested that the vertical distribution of Atlantic halibut (*Hippoglossus hippoglossus*) eggs is determined by their specific density and that it is closely correlated to seawater salinity. In two deep North Norwegian fjords, only one halibut egg was found near the bottom (approximately 5200 m^3 seawater filtered), while 278 eggs were found floating pelagically in intermediate water layers (approximately 190,000 m^3 seawater filtered). Eggs were most abundant in water masses where temperature and salinity ranged between 4.5 and 7°C and 33.8 and 35.0‰. Neutral buoyancy salinity measurements of living eggs corresponded approximately with the observed capture salinities. Mean capture salinity was 34.2±0.3‰ (Malangen) and 34.5±0.4‰ (Sørøysund). Egg diameters ranged from 3.06 to 3.49 mm.

Haug, T., E. Kjøersvik, and P. Solemdal. 1986. Influence of some physical and biological factors on the density and vertical distribution of Atlantic halibut *Hippoglossus hippoglossus* eggs. Mar. Ecol. (Prog. Ser.). 33: 207-216.

Atlantic halibut *Hippoglossus hippoglossus* (L.) eggs were sampled using a Tucker trawl and a MOCNESS-sampler at 3 selected localities in north Norway. The specific density of the eggs was determined in a density-gradient column. The eggs were found to achieve higher specific density with increasing age. In areas with a horizontally stable, clearly defined pycnocline (Andfjord and Sørøysund), the vertical distribution of eggs was characterized by a unimodal egg distribution. Furthermore, the older eggs were found at higher average capture salinities than younger eggs, i.e. they were distributed in relation to their neutral buoyancy. In an area with a horizontally more variable and less defined pycnocline (Malangen), the pattern of vertical distribution of eggs was less distinct, often with polymodal egg distributions. In this hydrographically variable system, no heterogeneity in the distribution of the various egg developmental stages could be discerned. In Malangen, thus, it is proposed that the vertical distribution of halibut eggs is most strongly influenced by physical factors.

Haug, T., I. Huse, E. Kjøsvik, and H. Rabben. 1989. Observations on the growth of juvenile Atlantic halibut (*Hippoglossus hippoglossus* L.) in captivity. Aquaculture 80: 79-86.

Growth of juvenile Atlantic halibut (*Hippoglossus hippoglossus*) kept in captivity in northern and western Norway was observed under satiation feeding conditions. Biomass gain was minimal during the winter months. It was evident that growth rate was maintained at a higher level in captivity than in nature. In general, the condition factor increased and was maintained at a higher level in captive fish than observed at the time of their capture.

Haug, T., E. Kjøsvik, and J. H. Sundet. 1982. A preliminary note on the ecology of eggs and larvae of the Atlantic halibut *Hippoglossus hippoglossus* (L.). Int. Council Explor. Sea. C.M. 1982/G:9.

Egg surveys were carried out in North Norway in the spawning season of the halibut *Hippoglossus hippoglossus* (L.) during January 1982. Eggs were looked for on the sea bed with Beyer's epibenthic closing net and at various depths in the water column with a Tucker trawl. Two spawning grounds were studied (Malangen and Sørøysund). No halibut eggs were found on the bottom, but 53 eggs were found floating bathypelagically at various depths. They were most abundant in and below a zone of rapidly changing sea water density. Temperatures between 4.5 and 7.0°C were observed; salinities ranged from 33.9 to 35.0‰. Neutral buoyancy salinities determined in the laboratory upon artificially fertilized eggs were significantly higher than the observed field salinities. Probably egg density varies from female to female, but the poor condition of the adult fish used for egg stripping may have contributed to the enhanced buoyancy.

Haug, T., E. Ringø and G. W. Petterson. 1988. Total lipid and fatty acid composition of polar and neutral lipids in different tissues of Atlantic halibut, *Hippoglossus hippoglossus* (L.). Sarsia 73: 163-168.

Analyses of total lipid, neutral and polar lipids, and their fatty acid compositions were carried out on different tissues of spawning Atlantic halibut, *Hippoglossus hippoglossus*, taken in January and February. Liver had the highest total lipid content, amounting to over 50% of the dry weight of the tissue. The lipid fractions of all tissues examined were dominated by neutral lipid which comprised approximately 75% of the lipid fraction. Triacylglycerols were the dominant neutral lipid. The neutral lipid fraction contained high concentrations of 18:1 fatty acid, whereas the polar lipid fraction had a high content of the w3 fatty acids 20:5 and 22:6.

Helvik, J. V., and K. Pittman. 1990. Light affects hatching, development and pigmentation of halibut (*Hippoglossus hippoglossus* L.) .Int. Council Explor. Sea. C.M. 1990/F:40. 19 p.

Artificially fertilized halibut eggs were exposed to various colors of light and their development, hatching and eye pigmentation was monitored. Hatching was delayed relative to development up to 19 days under white light although the enclosed larvae developed apace with the emerged larvae showing that anoxia is not a primary hatching stimulus. Extension of the period in the egg did not affect the normal rate of organogenesis but the belt of hatching gland cells degenerated. Time of hatching could be synchronized by exposing the eggs to light for a period and returning to

darkness, where hatching would take place within 90-120 minutes. Eye pigmentation was earliest and darkest under dim (0.2 lux) blue light whereas pigmentation was latest and lightest when larvae were held in darkness, suggesting that dark-rearing interrupts or delays normal eye development. Growth was not significantly different between these two groups. Two areas in the eye, a bar posterodorsal to the lens and spot ventral to the lens, were the last to develop pigment under all treatments. An ecological model is proposed where light is a primary mechanism regulating the larval distribution in the water.

Helvik, J. V., D. O. Oppen-Berntsen, and B. T. Walther. 1991. The hatching mechanism in Atlantic halibut (*Hippoglossus hippoglossus*). Int. J. Dev. Biol. 35: 9-16.
In general, fish larvae emerge from the protective egg after secreting a hatching enzyme (HE) from diffusely located hatching gland cells (HGCs). This proteolytic enzyme is distributed over the entire inner part of the eggshell (zona radiata). In a marine flatfish, halibut, (*Hippoglossus hippoglossus*), we have found a more specialized hatching process. A strategic location of the HGCs in a narrow belt on the anterior part of the yolk sac leads to restricted degradation of the eggshell resulting in cleavage of the eggshell into two distinct rigid parts.

Hemre, G. I., B. Bjørnsson, and Ø. Lie. 1992. Haematological values and chemical composition of halibut (*Hippoglossus hippoglossus* L.) fed six different diets. Fisk. Dir. Skr. Ser. Ernæring 5: 89-98.

Results from an experiment with reared wild caught halibut are reported using six different dietary treatments. Hematocrit and red blood cell counts were within normal ranges from 24-30% and 1.95-2.11 x 10^{12} L^{-1} respectively. Glucose levels were low and ranged within normal levels from 1.1 to 2.8 mmol/L. Low and stable fillet glycogen were found with no variation between dietary treatments. Also liver glycogen levels were low and ranged from 13 to 99 g/Kg. The results indicate no negative effects of feeding formulated feeds with approximately 10% starch on a dry matter basis to Atlantic halibut. Muscle protein levels were stable, while quite large variations were found in muscle dry matter and lipid contents. The variations of dry matter and lipid contents depended on dietary regime and on where the muscle samples were taken. The fatty acid compositions of the fillet lipids reflected those of the feeds, and only minor variations were observed between the groups. The lowest fraction of n-3 fatty acids was found in the fillet part with the highest lipid content. Only small variations were found in proximate composition of the halibut liver.

Note: Diets were lean capelin, fat capelin, lean and fat capelin (alterations every third day), moist feed from capelin silage, dry salmon feed, and moist feed from ground capelin. Exp. from 7 Nov 88 to 31 May 90. All feeds with 43-46% protein, 20-23% lipid and 10-11% starch (dry wt. basis) Temp. maintained at 7°C and salinity at 32.5‰.

Hjertnes, T., and J. Opstvedt. 1990. Effects of dietary protein levels on growth in juvenile halibut (*Hippoglossus hippoglossus* L.), p. 189-193. *In*: M. Takeda and T. Watanabe (Eds.). The current status of fish nutrition in aquaculture. Proceedings of the Third International Symposium on Feeding and Nutrition in Fish, August 28-September 1, 1989, Tokyo, Japan.

The preliminary results are presented of a feeding experiment conducted with juvenile halibut (*Hippoglossus hippoglossus*) to test the effects of different levels of dietary

protein in dry feed. Findings indicate that the juveniles have a growth potential, when fed diets with 58% protein, similar to or higher than that commonly found for salmon of the same size and held at a similar water temperature.

Holmefjord, I., and S. Bolla. 1988. Effect of mechanical stress on Atlantic halibut eggs at different times after fertilization. Aquaculture 68: 369-371.

Farming techniques involve frequent manipulations of fish eggs and therefor the sensitive stages must be known to avoid unnecessary mortality. Eggs from Atlantic halibut (*Hippoglossus hippoglossus*) were given a standard mechanical stress at different times after fertilization. Shocks were applied every 2 hours during the first 12 hours, and then every day until hatching started at day 12. The mechanical shock caused increased mortality when applied during the first 6 days after fertilization, and the most sensitive period was the first 2 days. Shock applied later than 6 days after fertilization (stage of blastopore closure) did not cause any mortality or decreased hatching rate.

Holmefjord, I., and I. Lein. 1990. Natural spawning of Atlantic halibut (*Hippoglossus hippoglossus*) in captivity. Int. Council Explor. Sea. C.M. 1990/F:74. 5 p.

A broodstock of Atlantic halibut (*Hippoglossus hippoglossus*) was established in 1984 at The Institute of Aquaculture Research, Sunndalsoera, Norway. This broodstock has produced eggs by stripping since 1985. In 1989 and 1990 successful natural spawning has been registered in one of the broodstock ponds (1 m deep, 10 m diameter) More than 30 liters of eggs were collected during the season of 1989, and high fertilization rates were registered (up to more than 90%). Eggs from these spawnings have produced larvae of good quality. These larvae have later been fed and brought through to metamorphosis.

Huse, I. 1988. Culture of halibut. Proceedings of the Aquaculture International Congress and Exposition, Vancouver, B. C. Canada, September 6-9, 1988. 32 p.

Culture experiments with Atlantic halibut (*Hippoglossus hippoglossus* L.) have been carried out in Norway since 1974, and on a large scale since 1983. Many problems in fry production have been overcome, and halibut is today on the verge of commercialization. Growth is good, and a market size of 5-15 kg will be reached in 3-4 years. Remaining problems are related to egg quality, microbial activity, live prey nutrition, and growout technology. Fry from commercial hatcheries are expected to become available in 1989, and adult fish will be on the market from 1993. A bottleneck in escalation of production will be fry availability due to lack of quality egg supply and competent hatchery staff.

Ingram, M. 1987. The flatfish are coming. Aquaculture magazine. May/June, 1987. 44-47.

This paper concentrates on turbot and sole, but does mention research activity aimed at production of Atlantic halibut, indicating that the fish demand a high price on the European market. The author indicated that rearing requirements for Atlantic halibut are expected to be "virtually identical" to those for turbot (*Scophthalmus maximus*). The hatching and larval rearing stages of halibut were acknowledged to be a great deal more difficult than turbot.

Jelmert, A., and A. Mangor-Jensen. 1987. Antibiotic treatment and dose-response of bacterial activity associated with flatfish eggs. Int. Council Explor. Sea. C.M. 1987/F:19. 6 p.

Newly stripped and fertilized eggs from plaice (*Pleuronectes platessa*) and Atlantic halibut (*Hippoglossus hippoglossus*) were incubated in 34‰ salinity seawater. One hundred fifty eggs (plaice), 30 eggs (halibut) or 20 glass beads were incubated in 30 ml of seawater in light at 5.5°C. The antibiotics oxytetracycline (HCl) and flumiquil were added to end concentration ranges 0 to 105 ppm and 0 to 60 ppm, respectively. With a method modified from Somville and Billen (1983) it was found that the activity on egg surfaces was significantly higher than the activity of a comparable surface area of the glass beads. The activity on the egg surfaces was greater than the activity in a water volume corresponding to the combined egg volume.

Jelmert, A., and K. E. Naas. 1990. Induced deformities on larvae of the Atlantic halibut (*Hippoglossus hippoglossus* L.). A new experimental approach. Int. Council Explor. Sea. C. P. 1990. 12 p.

Two days before estimated hatching, halibut (*Hippoglossus hippoglossus*) eggs from one egg batch were transferred to sterile polystyrene plates. Chorion of the eggs was removed within one day after hatching and 5 ml of the seawater was renewed. Four temperatures, four light intensities, four levels of oxygen concentrations, and four levels of H^2S concentrations were chosen as stressors. Overall survival in the control groups was somewhat lower (33% at 286 day-degrees and 45% at 215 day-degrees) than the rest of the egg batch reared in a "silo" (33% at 235 day-degrees). The percentage of H^2S and light groups were significantly lower ($p < 0.05$) for low oxygen, H^2S, and light groups compared to controls. Low dissolved oxygen caused higher prevalence of yolk sac edema, abnormal jaw articulation, and head deformities ($p < 0.05$) than in controls. Elevated temperature (10°C) did not increase prevalence of deformities compared to controls (7.5°C and 5.5°C; $p = 0.05$).

Jelmert, A., and H. Rabban. 1987. Upwelling incubators for eggs of the Atlantic halibut (*Hippoglossus hippoglossus* L.). Int. Council Explor. Sea. C.M. 1987/F:20. 8 p.

Incubators with upwelling water for eggs of the Atlantic halibut (*Hippoglossus hippoglossus*) are described. Tending and fate of the eggs were monitored, with special emphasis on egg mortality and bacterial activity. Bacterial activity in the incubators was compared to bacterial activity in unfiltered and filtered (0.4mμ) seawater.

King, M. J., M. H. Kao, J. A. Brown, and G. L. Fletcher. 1989. Lethal freezing temperatures of fish: Limitations to seapen culture in Atlantic Canada. Proceedings of the Annual Meeting 1989, Aquaculture Association of Canada. Bull. Aquacult. Assoc. Can. 47-49.

The two major factors determining the freezing temperature of the blood plasma and hence the fish are the concentration of plasma electrolytes (NaCl) and the presence and concentration of plasma antifreeze polypeptides. Species of fish lacking antifreeze peptides (salmon, char, halibut, lumpfish) have a limited degree of freeze protection (-0.7 to -0.9°C). Adult cod (*Gadus morhua*), which have low antifreeze levels freeze at approximately -1.2°C, while juveniles with higher antifreeze concentrations can survive down to -1.55°C. Ocean pout (*Macrozoarces americanus*) and wolffish (*Anarhichas lupus*) possess high antifreeze concentrations and can survive down to -1.6 to - 1.7°C.

Kjørsvik, E. 1990. The effect of different incubation conditions on the eggs of halibut, *Hippoglossus hippoglossus* (L.). J. Fish Biol. 37: 655-657.

Recent field investigations have shown that Atlantic halibut, *Hippoglossus hippoglossus*, eggs are bathypelagic. The eggs are buoyant in salinities between 33.8 and 35‰, and they develop under constant environmental conditions in the sea. The present study describes some biological properties of egg batches with good and low viability, with some comparison to our results on other pelagic fish eggs. It also attempts to compare properties of artificially fertilized halibut eggs with eggs captured in the plankton.

Lie, Ø., G-I. Hemre, G. Sigurthorsson, and B. Bjørnsson. 1992. Fatty acid composition of glycerophospholipids in different tissues of halibut (*Hippoglossus hippoglossus*). Fisk. Dir. Skr. Ser. Ernæring, 5: 99-109.

Halibut were fed at constant temperature (7 ± 0.2°C) with lean and fat capelin for five months. The fish had a mean weight of 3.7 Kg at sampling. White muscle, liver, gill, heart, spleen, and red blood cells were collected. The lipids were extracted and the fatty acid composition of the glycerophospholipids: phosphatidylcholine (PC), phosphatidylethanolamine (PE), phosphatidylinositol (PI), and phosphatidylserine (PS) were analyzed. The patterns of fatty acid distribution within each of the individual phospholipids from the different tissues of halibut showed some general similarities. PC had the highest level of 16:0, PE the highest total PUFA (polyunsaturated fatty acids), PI showed the highest level of 18:0 and 20:4n-6 and had the lowest n-3/n-6 ratio. PS had the lowest ratio of 20:5n-3/22:6n-3.

Lien, I., and I. Holmefjord. 1990. Larval age at first feed intake in Atlantic halibut (*Hippoglossus hippoglossus*). Int. Council Explor. Sea. C.M. 1990/F:73. 12 p.

The aim of this study was to determine at which age the Atlantic halibut (*Hippoglossus hippoglossus*) larvae actively start feeding. Thirty-eight days after hatching, one group of larvae was offered food (algae and rotifers) and examined for gut content after 48 hours. Forty days after hatching and subsequently every other day, new groups of larvae were offered food and sampled after 48 hours. The highest frequency of larvae with algae in the gut was found between 210 and 245 day-degrees (days*temperature). The highest frequency of rotifers in the larval gut were found among larvae offered food between 245 and 325 day-degrees. Larvae offered food at 355 day-degrees died before the time of sampling arrived.

Liu, H. W. 1988. Seasonal changes in sex steroids of Pacific Halibut *Hippoglossus stenolepis*. M. S. Thesis, University of Washington, Seattle. 33 p.

Blood samples were collected from captive Pacific halibut, *Hippoglossus stenolepis*, at intervals of about six weeks from early December, 1986 to late November, 1987. Concentrations of plasma testosterone and estradiol in Pacific halibut were determined by radioimmunoassay (RIA). In mature females, the concentrations of estradiol and testosterone began to rise in September and reached peaks averaging 3451 pg/ml (December) and 2613 pg/ml (January) for the two respective hormones. Concentrations of steroids fell rapidly about one month before spawning. In a mature male, the testosterone began to rise in August, increased between September (388

pg/ml) and November (1580 pg/ml) and reached a peak of 7045 pg/ml in early December. One month before spawning the testosterone concentration fell to 161 pg/ml. Estradiol concentration in the male varied little during the year. In four females that did not spawn in 1987, both estradiol and testosterone concentrations reached about 1500 pg/ml in January, 1987. From April 1987 the two steroids started another cycle and reached a high in excess of 2000 pg/ml; subsequently all four females released eggs between February and April, 1988. In immature fish neither testosterone nor estradiol changed significantly throughout the year. In one mature female, concentrations of both testosterone and estradiol were much lower in the 1988 spawning season than in the 1987 spawning season. This suggests that adult Pacific halibut may not spawn every year following initial maturation.

Liu, H. W. 1991. Laboratory studies on the spawning and the early life history of Pacific halibut (*Hippoglossus stenolepis*). Ph.D. Thesis, University of Washington, Seattle. 205 p.

There is a growing interest in halibut research in many countries because of its market and scientific value. The first successful spawning of Pacific halibut in captivity in the United States was conducted during February and March, 1988, and eight larvae were produced in that spawning season.

Wild-caught adult halibut have been successfully maintained since 1986. They have been fed with frozen herring, squid, and shrimp. Their growth was moderate, 7.5 cm/year for immature, and 2.5 cm/year for mature fish. Both young male and female fish became mature and produced viable gametes. Low water temperature accelerated final oocyte maturation or triggered ovulation for halibut. First spawning over the past five years has occurred at temperatures below 9°C. The timing of stripping of halibut was critical as the fish have a very narrow spawning "window" for maximum egg fertilization. Halibut gametes could be maintained for 28 hours (eggs) and 14 days (sperm) with moderate fertilization success.

High columns of seawater with several salinity gradients produced the best hatching results. The optimum hatching temperatures for halibut were between 6°C and 8°C while salinity had limited effect on embryo and larval development. Light intensities between 5 and 15 lux did not affect hatching success but high light intensity (15 lux) and red and blue light (5 lux) produced high rates of larval abnormalities. Low concentrations of iodine (30-60 ppm) were lethal to developing embryos.

During the first 20 days of larval life, halibut larvae had an overall daily length increment of 0.17 mm. The dry weight of the larval body increased from an average 210 µg at hatching to 570 µg at Day 20. In the meantime, the yolk sac decreased from 1390 µg to 646 µg, which gave an efficiency of yolk to body conversion of 48.5%. Larvae started first feeding at an age of 25-35 days with a total length of about 12 mm.

Salinity of neutral buoyancy (SNB) of halibut eggs progressively increased from 29.9‰ at fertilization to 33.4‰ on the 6th day after fertilization. During the remainder of development the SNB was declining until it reached 29.8‰ at hatching. The SNB of halibut larvae was stable at about 30‰ from hatching to Day 3. There was a gradually increasing trend from 29.8‰ on Day 5 to 34.2‰ on Day 14, then the increase in SNB was accelerated and massive mortality of larvae occurred.

Liu, H. W., R. R. Stickney, and S. D. Smith. 1990. A note on the artificial spawning of Pacific halibut *Hippoglossus stenolepis*. Prog. Fish-Cult. 53:189-192.

Adult Pacific halibut (*Hippoglossus stenolepis*) taken from the wild were held in captivity beginning in 1986. The first successful captive spawning with subsequent development of Pacific halibut larvae in the USA was conducted during February and March 1988. One of the eight larvae produced survived for 6 d, by which time eye pigment was visible.

Liu, H. W., R. R. Stickney, and W. W. Dickhoff. 1991. Changes in plasma concentration of sex steroids in adult Pacific halibut, *Hippoglossus stenolepis*. J. World Aquacult. Soc. 22: 30-35.

Blood samples were collected from captive Pacific halibut, *Hippoglossus stenolepis*, at intervals of about six weeks from early December 1986 to late November 1987. Concentrations of plasma androgen and estradiol-17b were determined by radioimmunoassay. The plasma concentrations of steroid were highest during autumn and winter in halibut that matured during late winter. The concentrations of steroids in samples collected in December were above 2 ng/ml (estradiol) or 1 ng/ml (androgen) in maturing females and below 0.5 ng/ml for both steroids in non-maturing females. The levels of steroids decreased rapidly about one month before spawning. In a mature male, androgen began to rise in August and November, and reached a peak of 7 ng/ml in early December. One month before spawning, the androgen concentration fell 0.16 ng/ml. Estradiol concentrations were detectable in the male and varied little during the year. These results suggest that the concentrations of estradiol or androgen measured in blood samples taken during December may be used to determine the sex and state of maturation of Pacific halibut.

Liu, H. W., R. R. Stickney, W. W. Dickhoff, and D. A. McCaughran. In Press. Early Larval Growth of Pacific Halibut (*Hippoglossus stenolepis*). J. World Aquacult. Soc.

Growth of Pacific halibut (*Hippoglossus stenolepis*) larvae was studied in the laboratory during 1989 and 1991. Larvae increased in length from 6.3 mm at hatching to 9.9 mm 20 days post-hatch. The average daily length increment was 0.17 mm. Dry weight of the larvae increased from an average 210 µg at hatching to 570 µg on day 20, providing a specific growth rate of 4.99. During the same period, mean yolk sac weight decreased from 1390 µg to 646 µg, resulting in a yolk to body conversion efficiency of 48.5%. At hatching, the larval body made up only 13% of total dry weight. On day 20, the larval body made up 46.9% of the total weight. Larvae started feeding at a length of 12 mm after about 90% of their yolk sac had been absorbed.

Liu, H. W., R. R. Stickney, W. W. Dickhoff, and D. A. McCaughran. In Press. Neutral Buoyancy Salinity of Pacific Halibut (*Hippoglossus stenolepis*) Eggs and Larvae. J. World Aquacult. Soc.

Samples of halibut eggs in nature have led to theories that development occurs near the seabed and, alternatively, well up in the water column. Resolution of the conflicting theories and information which should assist culturists in providing the proper environmental conditions for egg development and hatching were the subjects

of this study. The neutral buoyancy salinity (NBS) of Pacific halibut eggs and larvae ranged between 29.8‰ and 34‰. Eggs and larvae with higher NBS (>35‰) were usually abnormal or stressed. Thus, eggs found near the seabed may be nonviable.

Liu, H. W., R. R. Stickney, D. A. McCaughran, and W. W. Dickhoff. In Press. Effects of Environmental Factors on Egg Development and Hatching of Pacific Halibut (*Hippoglossus stenolepis*). J. World Aquacult. Soc.

Eggs of Pacific halibut were incubated under various environmental conditions. Optimum hatching occurred over a temperature range from 6°C to 8°C, whereas temperatures of 3°, 10°, and 11°C were lethal. Development time from fertilization to 50% hatching varied from 250 hr (9°C) to 320 hr (6.5°C). Salinity effects on hatching were not as critical as temperature as long as eggs were floating during the incubation period. Light intensity between 5 and 15 lux did not affect hatching success but high light intensity (15 lux) and red and blue light (5 lux) produced high levels of larval abnormality. Simulated transport of unfertilized eggs demonstrated that the eggs can be safely moved during the first 12 hr after collection with low mortality (8.3%) and high subsequent fertility (92.3%).

Liu, H. W., R. R. Stickney, W. W. Dickhoff, and S. D. Smith. 1988. Preliminary results of spawning Pacific halibut (*Hippoglossus stenolepis*). Northwest Envir. J. 5: 180.

Wild-captured Pacific halibut (*Hippoglossus stenolepis*) in excess of 60 cm long were held for 36 months and fed frozen Pacific herring (*Clupea harengus pallasi*) year round. The fish represented brood stock. Their eggs and sperm will be used to produce larvae and juveniles from which some basic biological characteristics of young Pacific halibut can be determined. Growth of approximately 10 captive adult fish was moderate at 7.5 cm/yr for immature, and 2.5 cm/yr for mature fish. Large differences in egg size and quality occurred among five female spawners, but successful spawning was achieved in February and March 1988. Eight larvae were produced, one of which survived for six days when eye pigmentation was present.

Blood samples were collected from the large fish, at intervals of several weeks, from December 1986 through November 1987. Concentrations of plasma androgen and estradiol (sex hormones) in blood plasma were determined by a technique known as radioimmunoassay. In mature females, steroid hormone concentrations began to rise in September, peaking in December and January. Steroid levels fell precipitously prior to spawning in February and March.

In the mature male, the androgen (male sex hormone) level began to increase in August and peaked in December, after which the plasma concentration of the steroid declined to a low that was reached about one month before sperm were obtained (late January and February). Estradiol (female sex hormone) was found in the male blood plasma, but little change was observed seasonally. Four captive females failed to spawn in 1987 and all showed relatively low levels of steroids in January of that year. Those fish did have elevated steroid levels beginning in April 1987 and all four spawned in 1988. The data indicate that adult Pacific halibut may not spawn every year, though confirmation of this hypothesis is needed.

Lønning, S., E. Kjorsvik, T. Haug, and B. Gullisen. 1982. Early development of the halibut, *Hippoglossus hippoglossus* (L.), compared with other marine teleosts. Sarsia 67: 85-91.

Eggs were artificially fertilized and incubated in seawater of various salinities and temperatures. Both the ultrastructure of the exceptionally large eggs (average diameter: 2.92 mm) and the embryonic development suggest that the early developmental stages of the halibut are pelagic. Light and electron microscope studies of the halibut eggs showed a thin, homogeneous, lamellated chorion with small pores on the outer surface. However, neutral buoyancy determinations indicated that eggs would float only in salinities greater than ca. 37‰. The halibut embryo, which develops very slowly, hatches at an apparently premature stage.

Mangor-Jensen, A., and I. Huse. 1991. On the changes in buoyancy of halibut, *Hippoglossus hippoglossus* (L.), larvae caused by hatching - a theoretical view. J. Fish Biol. 39: 133-135.

Atlantic halibut, *Hippoglossus hippoglossus* (L.), eggs are bathypelagic with a distribution above the pycnocline. Buoyancy in pelagic teleost eggs has been ascribed to their large bulk of diluted yolk. This is also the case for the halibut, although a mechanism for light-induced water loss has been found that keeps the halibut eggs from reaching the surface in their ascent from the spawning grounds (V. Valkner and A. Mangor-Jensen, unpublished). In recent years much effort has been put into the collection of the natural spawn of the halibut. Only a modest number of eggs have been found, but still sufficient to indicate their vertical distribution. Larvae are, however, with one exception absent in the catches although large volumes of water have been thoroughly searched. The larva found was caught at a depth of 10 m at an age of about 45 days after hatching. This apparent absence of newly hatched halibut larvae has initiated a discussion on where the larvae are to be found after hatching. The present communication presents a simple physical model and a discussion on the topic.

Mangor-Jensen, A., and A. Jelmert. 1986. The effect of ambient salinity on the buoyancy of eggs from the Atlantic halibut *Hippoglossus hippoglossus*. Int. Council Explor. Sea. C.M. 1986/F:52. 7 p.

The effect of ambient salinity on the buoyancy and the formation of perivitelline fluid in eggs from the Atlantic halibut *Hippoglossus hippoglossus* have been investigated. The results clearly demonstrate that the water balance of the eggs is independent of the ambient salinity the first days after fertilization. The water loss from eggs fertilized in 17‰ salinity sea water was not less than from eggs fertilized in 34‰ sea water in spite of a reduced osmotic gradient. Neither was the egg buoyancy altered by fertilization in low salinity sea water. For proper fertilization, the eggs from the Atlantic halibut need concentrations of calcium near the concentration found in sea water.

Mangor-Jensen, A., T. Harboe, S. Tuene, K. Boxaspen, and L. Skjolddal. 1990. Intensive production of halibut fry, p. 153-159. *In*: R. L. Saunders (Ed.) Proceedings of Canada-Norway finfish aquaculture workshop, September 11-14, 1989. Can. Tech. Rep. Fish. Aquat. Sci. No. 176.

A production line for full-scale intensive production of halibut fry (*Hippoglossus hippoglossus*) is described. The experiments demonstrate that halibut larvae can be reared at low temperature through the yolk-sac stage in small closed systems.

However, initial feeding of halibut larvae on the cultivated zooplankton species Artemia and Brachionus in closed systems has not given satisfactory results in spite of application of standardized zooplankton enrichment with marine oils (HUFAs).

Mangor-Jensen, A., A. Jelmert, K. E. Naas, T. Harboe, and A. B. Skiftesvik. 1987. A biotest system for optimalization of the environmental parameters for production of halibut fry. Int. Council Explor. Sea. C.M. 1987/F21. 15 p.

A system for controlled testing of different environmental parameters in seawater was made. Both the biotest system and an experimental set-up using larvae of the Atlantic halibut (*Hippoglossus hippoglossus*) are described.

McFarlane, G. A., J. O. T. Jensen, W. T. Andrews, and E. P. Groot. 1991. Egg and yolk sac larval development of Pacific halibut (*Hippoglossus stenolepis*). Int. Pac. Halibut Comm. Tech. Rep. 24: 22 p.

Pacific halibut (*Hippoglossus stenolepis*) were reared from the egg stage through full yolk sac absorption. Fertilization success and egg and larval development were monitored. Four percent fertilization was achieved and hatching success ranged from 15 to 40%. Eggs hatched between 312 and 434 hours at temperatures ranging from 5 to 7°C. At 6°C, the yolk sac was fully absorbed by day 55 from hatch. Salinity of neutral buoyancy was measured and estimates of the location of developing eggs and larvae in the natural environment were made.

Methven, D. A., L. W. Crim, B. Norberg, J. A. Brown, G. P. Goff, and I. Huse. 1992. Seasonal reproduction and plasma levels of sex steroids and vitellogenin in Atlantic halibut (*Hippoglossus hippoglossus*). Can. J. Fish Aquat. Sci. 49: 754-759.

Atlantic halibut (*Hippoglossus hippoglossus*) collected off Newfoundland first mature at about 80 cm fork length (FL) for males and about 115-120 cm FL for females. Captive Newfoundland halibut did not release milt or eggs or have detectable levels of estradiol-17ß of 11-ketotestosterone until exceeding 80 cm (males) and 115-120 cm (females). Estradiol-17ß and testosterone increased to highest levels in females during gonadal recrudescence before spawning. Lower levels were observed in spawning fish. Individual maturing halibut can be sexed by rising levels of estradiol-17ß and VTG (females) and 11-ketotestosterone (males) in late fall and early winter.

Naas, K. E. 1990. Extensive startfeeding of marine fry, p. 137-141. *In*: R. L. Saunders (Ed.). Proceedings of Canada-Norway finfish aquaculture workshop, September 11-14, 1989. Can. Tech. Rep. Fish. Aquat. Sci. No. 176.

Recent progress with startfeeding larvae of cod, Gadus morhua; turbot, Scophthalmus maximus; and halibut, *Hippoglossus hippoglossus* in extensive systems has induced an increased commercial interest for cultivation of these fishes in Norway. Due to the superior nutritional quality of natural zooplankton, zooplankton-fed larvae grow faster and experience higher survival rates, compared with traditional startfeeding diets; i.e., Brachionus plicatilis and Artemia salina. Present research focuses on the possibility of managing biological production in the enclosures used for extensive rearing of larvae. The aim is to rear the larvae at high concentrations and to increase the yield of the systems.

Naas, K. E., and A. Mangor-Jensen. 1990. Initial feeding rates of Atlantic halibut larvae (*Hippoglossus hippoglossus*) at different prey densities. Int. Council Explor. Sea. C. P. 1990. 7 p.

At the end of yolk sac stage (36 days after hatching), halibut (*Hippoglossus hippoglossus*) larvae were offered the prey organism Artemia salina at different densities ranging from 1 to 100,000/liter. The feeding experiment was carried out in 11 black plastic tanks (10 liter) each containing 20 larvae. The optimal prey concentration in the initial first feeding situation was found to be in the range of 700 to 7,000 Artemia/liter.

Naas, K. E., L. Berg, J. Klungsoeyr, and K. Pittman. 1987. Natural and cultivated zooplankton as food for halibut (*Hippoglossus hippoglossus*) larvae. Int. Council Explor. Sea. C.M. 1987/F:17. 23 p.

Natural zooplankton were pumped into a collector and size-fractionated. The zooplankton smaller than 350 µm were fed on a diatom dominated algal suspension cultured in 3 m deep outdoor plastic bags. Halibut (*Hippoglossus hippoglossus*) larvae were kept through the yolk sac stages in large temperature-regulated bags, and when ready to start first feeding, they were offered both enriched and non-enriched natural zooplankton. The quality of the food was analyzed with respect to fatty acid composition.

Næss, T., Ø. Berg, T. Harboe, K. E. Naas, H. Rabben, and L. Skjolddal. 1990. Green water in larviculture - an experiment with natural phytoplankton in tanks for first feeding of halibut larvae (*Hippoglossus hippoglossus*). Int. Council Explor. Sea. C.M. 1990/F:61. 22 p.

At 232 day-degrees, halibut (*Hippoglossus hippoglossus*) larvae were transferred from indoor tanks to outdoor tanks for first feeding. Three tanks were continuously given algal suspension ("green water") and supplied non-enriched *Artemia* instar II. Six tanks were given filtered deep water ("clear water"). Three of the six were supplied non-enriched *Artemia* prefed in green water. Feeding incidence at day 3 was 47% in green water and 0% in clear water. Larval growth was significantly higher in green water compared to clear water, while no significant difference was found between the clear water groups given prefed and non-enriched *Artemia.* The survival rates were also much higher in green water.

Norberg, B., V. Valkner, J. Huse, I. Karlsen, and G. G. Leroey. 1991. Ovulatory rhythms and egg viability in the Atlantic halibut (*Hippoglossus hippoglossus*). Aquaculture 97: 365-371.

Female Atlantic halibut (*Hippoglossus hippoglossus*) were stripped for eggs during two consecutive reproductive seasons, 1988 and 1989. In 1988, no attempt was made to monitor the individual spawning cycles. The following year, the ovulatory rhythm of each individual female was closely followed to optimize the yield of viable eggs from each fish. Careful monitoring of the individual spawning cycles resulted in a 120% increase in total egg yield and a 220% increase in the amount of eggs showing

high (greater than or equal to 80%) fertilization rates. Handling stress had no apparent effect on the yield of eggs. The results show the importance of careful surveillance of individual, female halibut during the spawning season, in order to establish ovulatory rhythms and optimize the yield of eggs.

Øiestad, V., and A. S. Haugen. 1980. Rearing of halibut larvae (*Hippoglossus hippoglossus*) to metamorphosis and beyond. Int. Council Explor. Sea. C. M. 1980/F:9: 7p.

A female halibut caught by gill-net was stripped and the eggs were immediately fertilized and incubated in the laboratory. About 50% of the eggs hatched when incubated in a refrigerator in stagnant water treated with antibiotics and with increased salinity. Of the about 1700 larvae kept in the refrigerator, about 35% were alive after 30 days, the temperature being about 5°C. The salinity of the water was about 37‰ and was treated with antibiotics as before.

A functional mouth started to develop 25 days after hatching. The last larvae in the refrigerator died on 5 May at an age of 60 days. At an age of 40 days larvae were transferred to a large basin and two black plastic bags with 50 larvae in each enclosure. In one of the plastic bags two of the halibut larvae survived and reached metamorphosis at the end of May at an age of 80-90 days and at a length of about 3.0 cm.

Opstad, I., and Ø. Bergh. 1990. Effects of continuous flow rate on development and mortality of halibut yolk sac larvae. Int. Council Explor. Sea. C.M. 1990/F:41: 11 p.

Halibut (*Hippoglossus hippoglossus*) yolk sac larvae were raised in incubators with different rates of continuous flow. Most larvae died between days 10 and 29 after hatching. Rate of mortality increased with increasing rate of flow, but in a stagnant incubator, there were no larvae beyond day 12 after hatching. Larval dry weight decreased with increasing rate of flow, whereas yolk sac dry weight did not differ significantly. Yolk sac utilization efficiency was higher with lower flow.

Opstad, I., and A. J. Raae. 1986. Physical stress on halibut larvae. Int. Council Explor. Sea. C.M. 1986/F:18. 13 p.

Halibut (*Hippoglossus hippoglossus*) larvae were exposed to physical stress in the form of different levels of aeration. Survival rate, development, dry weight, RNA, DNA and protein were measured. At the end of the experiment the larvae exposed to gentle aeration had the highest survival rate, total dry weight, dry weight of the yolk sac, content of RNA and RNA-DNA ratio. However, the group without aeration had the highest dry weight of larval body, growth rate yolk conversion efficiency. The functional jaw development had the same value and were highest in these two groups.

Pittman, K. A. 1988. Progress in rearing halibut larvae to viable fry. Aquaculture International Congress and Exposition, Vancouver Trade and Convention Center, Vancouver, British Columbia, Canada, September 6-9. Proc. Aquacult. Int. Congr. p. 58.

Initial efforts to raise Atlantic halibut from egg to fry have thus far resulted in a few hundred fry, despite national interest and research. A new method of production using land based silos and upstreaming water seems to give greater survival rates and better

distribution of the larvae in the water column. Startfeeding is accomplished in the silos by reducing the flow rate and introducing zooplankton from culture or from collection in the fjord outside. After metamorphosis the fry will be placed in large tanks where mesocosms have been established.

Pittman, K. A. 1989. Progress in raising halibut larvae to viable fry. World Aquaculture 20(2): 58-59.

The findings are presented of a study conducted to investigate the early life history of cultured halibut (*Hippoglossus hippoglossus*). Eggs were incubated at temperatures similar to those of water masses where halibut eggs are commonly found, between 4 and 6°C, and growth rates and developmental stages were followed. The standard length at end-of-yolk-sac stage varied inversely with temperature and the yolk was more efficiently converted to somatic growth when grown at 4°C.

Pittman, K. A. 1990. The Atlantic halibut yolk sac larva: a summary of the results from four years of experimentation, p. 11-168. *In*: R. L. Saunders (Ed.). Proceedings of Canada-Norway finfish aquaculture workshop, September 11-14, 1989. Can. Tech. Rep. of Fish. Aquat. Sci. No. 176.

The developmental behavior and morphology of the yolk sac Atlantic halibut *Hippoglossus hippoglossus* larva has been followed from hatching to beyond metamorphosis. Temperatures near 4°C seem to give best growth, yolk sac absorption efficiency, and normal development. High rates of mortality were observed early in the development and may also be correlated with high flow rates, but have not been directly correlated with bacteria. Biochemical, histological, morphological, and behavior data point to 20-30 day posthatching as the most likely period for initiation of exogenous food uptake, even though this is only half way through the yolk sac stage. Preliminary results from a temperature experiment involving eggs and yolk sac stages indicate that relative protein synthesis at hatching was better when the eggs were incubated at 3°C than at either 6 or 9°C. The presence or absence of Kupffers vesicles in the developing embryo may be a possible indicator of embryo quality.

Pittman, K., L. Berg, and K. Naas. 1987. Morphological development of halibut (*Hippoglossus hippoglossus*) larvae with special reference to mouth development and metamorphosis. Int. Council Explor. Sea. C.M. 1987/F:18: 22 p.

Halibut (*Hippoglossus hippoglossus*) larvae were raised from hatching to beyond metamorphosis in 11.5 m^3 plastic bags with a temperature stable around 6°C. Standard length, myotome height, eye diameter and yolk sac length were measured on live or freshly preserved material. Mouth development and funtionality, pectoral and pelvic fin development, intestinal development and the initiation of peristaltic contractions, and eye pigmentation and migration were observed from live material. The gape of the jaws was limited by an oral membrane which appeared coincident with the developing mouth and which persisted in either full or remnant form up to around the time of first feeding.

Pittman, K., A. B. Skiftesvik, and L. Berg. 1990. Morphological and behavioral development of halibut, *Hippoglossus hippoglossus*, larvae. J. Fish. Biol. 37: 455-472.

Live yolk-sac halibut, *Hippoglossus hippoglossus* (L.) larvae from rearing experiments at Austevoll Aquaculture Station, Norway, were examined from hatching to past first feeding for developmental morphology and behavior. The findings include development of the respiratory and circulatory organs, eye pigmentation, mouth formation, organs of the digestive system and the process of yolk absorption, as well as swimming speed and activity levels.

A stomodeum is not present at hatching although drinking is possible through a pair of branchial pits which gradually develop into the operculum and gill basket. The mouth normally opens slowly, the gape being restricted by a transverse septum until bones are formed. The amount of time spent swimming varies from less than 15% of the observation period during the first 2 weeks after hatching to between 70 and 100% around the seventh week after hatching, when individual differences become more apparent. Speed and duration of swimming seems to be correlated with development of eye pigment, heart size and fin formation. The yolk-sac is divided into four stages.

Pittman, K., A. B. Skiftesvik, and R. Harboe. 1989. Effect of temperature on growth rates and organogenesis in the larvae of halibut (*Hippoglossus hippoglossus* L.), p. 421-430. *In*: J. H. S. Blaxter, J. C. Gamble, and H. von Westernhagen (Eds.). The early life history of fish. The third ICES symposium, Bergen, Norway, October 3-5, 1988. Rapp. P. V. Réun. Ciem. 191.

Growth of halibut larvae at 9°, 6°, and 4°C was monitored during the yolk-sac stage in three 15 m^3 silos with gentle upwelling. Jaw deformations and edema were most common at 9°C, while growth and yolk absorption were better at 4° than either 9° or 6°. Fewer day degrees were necessary to reach end-of-yolk-sac-stage in cold water than in warm water. Scanning electron microscopy revealed the absence of a stomodeum but the presence of a pair of branchial pits with many pores at about 3 days after hatching. These cavities eventually expanded to expose a small part of the naked gill arches at about 20 days after hatching. Mouth development, normal and abnormal, was also followed using scanning electron microscopy. The behavior of larvae at two densities is described from hatching onwards. Increases in duration of swimming period are apparent about 35 days after hatching, after the duration of resting periods has decreased. Mean swimming speed changes with development. Changes in behavior are related to the developmental stages.

Pittman, K., Ø. Bergh, I. Opstad, A. B. Skiftesvik, L. Skjolddal, and H. Strand. 1990. Development of eggs and yolk sac larvae of halibut (*Hippoglossus hippoglossus* L.) J. Appl. Ichthyol. 6: 142-160.

Timing of development in halibut eggs and larvae from one female was monitored at 3°, 6°, and 9°C. Total and viable count of free-living bacteria in the incubators was monitored from hatching until termination of the experiment and water quality was recorded. Differences in development rates were apparent from the first cell divisions. At 9°C there were significantly more Kupper's vesicles in embryos and RNA content was lowest. At 3° embryos had the highest RNA content but often showed incomplete development of the caudal fin. At 6°C egg mortality was lowest and larval growth was intermediate. DNA was significantly different between all temperature groups. At 9°C, larvae grew faster, but developed abnormalities associated with sublethal stressors. A rise in larval mortalities occurred at the same

stage of development at 6° and 9°C. Significantly more jaw deformities occurred at 9°C than at 6°C. There was no significant difference in bacterial numbers between groups. An increase in larval mortalities leads to an increased amount of bacteria which preceded an increase in ammonia levels. Optimal temperatures for egg and larval development probably lie between 3° and 6°C, although there may be different optima for different stages. The experiment was terminated due to uncontrolled temperature fluctuations.

Rabben, H. 1986. Developments in the culture of halibut, turbot and cod in Norway, p. 57-60. *In*: Proceedings of International Conference: Norway. The Development of Its Fish Farming Industry. Imperial Hotel, Cork, Ireland, November 6-7.

An examination is made of future prospects for the development of the culture of Atlantic halibut (*Hippoglossus hippoglossus*), turbot (*Psetta maxima*) and cod *(Gadus morhua)* in Norway in order to expand the current fish farming industry.

Rabben, H. 1987. A stripping method for Atlantic halibut (*Hippoglossus hippoglossus* L.). Int. Council Explor. Sea. C.M. 1987/F:40: 6 p.

A stripping-board was built and tested on a broodstock of halibut (*Hippoglossus hippoglossus*) ranging from 8 to 150 kg body weight. The smooth surface of the neoprene mattress minimized the loss of mucous and reduced the stripping stress considerably. The electric tackle eliminated the heavy lifting of the animals and improved the working conditions.

Rabben, H., and A. Jelmert. 1986. Hatching of halibut (*Hippoglossus hippoglossus* L.) eggs under different light conditions. Int. Council Explor. Sea. C. P. 1986: 10 p.

Halibut (*Hippoglossus hippoglossus*) eggs were hatched in total darkness and in illumination (60 lux light). A simultaneous hatching to a final hatching of 99%, and positive buoyant larvae in the dark hatching jars were experienced. In the illuminated group the hatching was postponed, hatching curve progressed more slowly to a final hatching of 72 and 80% in two experiments. Both eggs and larvae developed a slightly negative buoyancy.

Rabben, H., A. Jelmert, and I. Huse. 1987. Production experiment of halibut fry (*Hippoglossus hippoglossus*) in silos. Int. Council Explor. Sea. C.M. 1987/F:42: 10 p.

Silos with conical bottoms and a volume of approximately 3.5 m^3 were tested as storage units for halibut (*Hippoglossus hippoglossus*) yolk-sac larvae. The silos were run in three different ways: A) stagnant water with a saltplug till day 10 and later slow upwelling, B) continuous upwelling, and C) stagnant with saltplug. High survivals in the silos with constant renewal of water (as a slow upstream) were observed. A negative effect of the saltplug on yolk-sac larvae the second week after hatching was clearly demonstrated.

Rabben, H., T. O. Nilsen, I. Huse, and A. Jelmert. 1986. Production experiment of halibut fry in large enclosed water column. Int. Council Explor. Sea. C. P. 1986. 27 p.

Halibut (*Hippoglossus hippoglossus*) eggs were hatched in 21 floating enclosures and the larvae stored through the yolk sac period under 5 different environmental

conditions, each with 4 parallels. The effect of the different environments was examined as survival rates of larvae and on morphometric measurements at day 31 and day 49, when one of each type was emptied. Half of the initial number of enclosures, with their content of remaining larvae, were continued in the first feeding trial to bottom settling of the metamorphosed fry. An estimated number of 300 larvae reached metamorphosis, and at the end of the experiment a total of 68 were captured and transferred to tanks at the station. Light exposure was shown to be unfavorable both during hatching and development of larvae.

Rabben, H., T. Harboe, T. H. Næss, K. E. Naas, and L. H. Skjolddal. 1990. Startfeeding success of halibut larvae (*Hippoglossus hippoglossus* L.) as a function of temperature regime. Int. Council Explor. Sea. C.M. 1990/F:57: 6 p.

Halibut (*Hippoglossus hippoglossus*) larvae at an age of 250 day degrees post hatching were transferred to outdoor units and startfed. The larvae were offered a combined diet of wild zooplankton and *Artemia* (instar II). Measurements of feeding incidence, growth and survival were done. The results showed increasing growth with increasing temperature. Survivals were, however, lower at 15°C than at 12° and 9°C.

Reitan, K. I., J. R. Rainuzzo, and L. Joergensen. 1989. Yolk utilization in larvae of halibut (*Hippoglossus hippoglossus*), p. 328. *In*: R. Billard, and N. de Pauw (Comps.). Aquaculture Europe '89 short communications and abstracts of review papers. Spec. Publ. Europ. Aquacult. Soc. No. 10.

Planktonic larvae of marine teleosts have a voluminous yolk-sac as energy reserve on which they depend until they are able to catch and digest food. Decreases of carbon and nitrogen content were shown during the yolk-sac stage under both light and dark incubation. Fatty acid analysis of individual halibut (*Hippoglossus hippoglossus*) larvae showed a very low variance between samples. The results indicate a gradual consumption of some fatty acids during the yolk-sac stage.

Riis-Vestergaard, J. 1982. Water and salt balance of halibut eggs and larvae (*Hippoglossus hippoglossus*). Mar. Biol. 70: 135-139.

Eggs of halibut [*Hippoglossus hippoglossus* (L.)] have a negative buoyancy in sea water of 35‰ salinity, in contrast to eggs of most flatfish species. The cause of this was investigated. The osmolality of the yolk is 350-420 mOsm during embryonic development. This is within the range for marine teleost serum and for yolk of pelagic eggs. Concentrations of major inorganic ions are comparable with those of pelagic plaice eggs [*Pleuronectes platessa* (L.)]. The values for Na^+, K^+, and Cl^- are 6, 85, and 64 mmol.(l H_20)$^{-1}$ after fertilization, and at the time of hatching the corresponding values are 17, 11, and 80. Large amounts of other inorganic constituents are excluded for osmotic reasons. Malfunction in the regulation of osmolality or of inorganic constituents is thus unlikely to be the cause of negative buoyancy. The relative dry weight of the chorion ("egg shell") in halibut eggs is less than in several pelagic egg types, excluding the chorion as the main contributor of negative buoyancy. It is concluded that a high content or organic matter in the rest of the egg is the cause of the negative buoyancy.

Rollefsen, G. 1935. The eggs and the larvae of the halibut (*Hippoglossus vulgaris).* Kgl. Norske Vidensk. Selsk., Forh. 1934. 7: 20-23.

This paper describes the first studies on artificial fertilization of Atlantic halibut eggs at the Trondheim Biological Station in Norway. Eggs obtained from fish held in an aquarium were incubated and some larvae were kept alive for 10 days post-hatch.

Ronnestad, I. (Ed.). 1991. Rearing of halibut (*Hippoglossus hippoglossus* L.). Can. Transl. Fish. Aquat. Sci. No. 5524.

This report presents a summary of the status of knowledge of halibut (*Hippoglossus hippoglossus* L.) rearing based on ongoing research at the Austevoll aquaculture station, Norway.

Rubben, H., and I. Huse. 1986. Growth of juvenile halibut (*Hippoglossus hippoglossus* L.) in captivity. Int. Council Explor. Sea. C. P. 1986. 11 p.

The growth and substrate preference of collected wild juvenile halibut (*Hippoglossus hippoglossus*) under culture conditions were investigated. The size of collected fish conformed well with year class data from earlier studies. Halibut growth in nature is slower than, for example, for cultured salmon up to the III-group. The present study showed that halibut can grow much faster in culture than what is normal in nature. The substrate studies were contradictory in terms of growth and will have to be extended. The fish without substrate did, however, develop a dark coloration on the underside.

Serigstad, B. 1987. Oxygen uptake of developing fish eggs and larvae. Sarsia 72: 369-371.

The oxygen uptake of cod (*Gadus morhua* L.) eggs is about 6 nl O^2/egg per hour during the first 24 hours after fertilization. Uptake increases slightly but significantly until about 48 hours post hatching. A steep increase in oxygen uptake then occurs, due to increased activity at the time of first feeding. At the time of final yolk absorption , day 6 to 8 post hatching, there is a peak value of 125 to 150 nl O^2/larvae per hour in the oxygen uptake. A following drop in the oxygen uptake reflects the lack of nutrition in unfed larvae. In halibut (*Hippoglossus hippoglossus* L.) larvae there is a homologous peak oxygen uptake of about 1100 nl O^2/larvae per hour at the time of final yolk absorption (day 36 to 42 post hatching).

Skiftesvik, A. B., I. Opstad, Ø. Bergh, K. Pittman, and L. H. Skjolddal. 1990. Effects of light on the development, activity and mortality of halibut (*Hippoglossus hippoglossus* L.) yolk sac larvae. Int. Council Explor. Sea. C.M. 1990/F:43: 16 p.

Halibut yolk sac larvae were kept at different light intensities from Day 1 posthatch. Measurements of activity and swimming speed showed that larvae that were kept in darkness were more active, but had lower swimming speed than those kept in light. Larvae kept at 1000 lux had lower yolk sac utilization than larvae kept at lower light intensities, probably due to stress caused by light. Larvae kept at 1 and 10 lux had higher body dry weight when the experiment was terminated. Differences in pigmentation were found. An autecological model is discussed, suggesting that halibut yolk sac larvae are distributed in relatively shallow waters during the first week posthatch, thereafter sink into deeper waters, and rise again when the time of first feeding approaches.

Skjolddal, L. H., T. Harboe, T. Næss, K. E. Naas, and H. Rabben. 1990. A comparison of growth rate of halibut larvae (*Hippoglossus hippoglossus* L.) fed wild zooplankton and enriched *Artemia.* Int. Council Explor. Sea. C.M. 1990/F:60: 13 p.

Halibut (*Hippoglossus hippoglossus*) larvae at an age of 267 day-degrees post hatching were prepared through first feeding. There were three feeding regimes: wild zooplankton, *Artemia* enriched on algae *Isochrysis galbana*, and *Artemia* enriched with "Super Selco." The larval growth was very low the first three weeks, probably due to low temperature and high larval age at onset of exogenous feeding. At day 16, the mean myotome height and dry weight were significantly higher for the group fed wild zooplankton than for the *Artemia* groups, and the larvae fed Super Selco enriched *Artemia* had a significant higher myotome height and dry weight than the larvae fed *Isochrysis* enriched *Artemia.*

St-Pierre, G. 1992. Visual determination of sex in live Pacific halibut. ICES J. mar. Sci., 49: 373-376.

A procedure to determine the sex of live Pacific halibut is fast, accurate and consists of visually examining the shape of the genital vent. The procedure was tested on 1708 live halibut with an accuracy rate of 98%. The procedure is effective for halibut 52 cm or longer but unsuitable for halibut under that length because the bulk of the genital vent is inadequate to evaluate with the naked eye. This procedure aids in populaiton assessment and is valuable in establishing the sex of tagged fish and brood stock in halibut rearing programmes.

Stickney, R. R., and H. W. Liu. 1991. Spawning and egg incubation of Pacific halibut. World Aquaculture 22(4): 46-48.

This paper reviews the biology of Pacific halibut (*Hippoglossus stenolepis*) and research that has been conducted into the aquaculture of the species. Subjects include broodstock maintenance, spawning, egg incubation, larval development, and future needs.

Stickney, R. R., H. W. Liu, and S. D. Smith. 1991. Recent advances in halibut (*Hippoglossus* spp.) culture, p. 9-13. *In*:: R. S. Svrjcek (Ed.). Marine ranching: proceedings of the seventeenth U.S.-Japan meeting on aquaculture; Ise, Mie Prefecture, Japan, October 16, 17, and 18, 1988. NOAA Tech. Rep. NMFS 102.

The Atlantic halibut (*Hippoglossus hippoglossus*) is currently receiving a significant amount of research attention in Norway, Iceland, and Scotland and interest in the culture of that species is developing in North America (particularly Nova Scotia and Newfoundland, Canada). Success in spawning and larval rearing has been achieved by Norwegian scientists though the numbers of postlarvae produced to date are small. On the west coast of the United States, our research in conjunction with the International Pacific Halibut Commission, the United States Fish and Wildlife Service, and the National Marine Fisheries Service has led to the captive spawning of Pacific halibut (*H. stenolepis*). We have also investigated seasonal patterns in circulating hormone levels. Future work with Pacific halibut will be aimed at production of postlarvae and determination of nutritional and environmental requirements of larvae and juveniles.

Stickney, R. R., W. W. Dickhoff, S. Smith, H. W. Liu, and D. Grosse. 1988. Culture of Pacific halibut: brood stock maintenance and spawning. J. of World Aquacult. Soc. 19:67A.

Adult Pacific halibut (*Hippoglossus stenolepis*) of up to 40 kg were tagged for individual identification and held in a flow-through circular tank for from several months to over a year in advance of the 1986-87 winter spawning season. A black plastic cover was placed over the tank to simulate the low light levels assumed to be present on the spawning grounds. Gonadal development in females during the late fall and early winter, 1986-87, was apparent from distension of the visceral cavity and was confirmed from changes in circulating hormone levels and the level of egg-yolk protein precursor, vitellogenin, in blood.

Eggs were obtained from spontaneous spawning within the tank and by stripping. The one available male produced motile sperm, but attempts at fertilization were unsuccessful. Egg collections were made no more frequently than twice weekly; thus the eggs obtained may not have been at the proper stage of ripeness for fertilization. The work to date has been valuable in that we have learned a great deal about handling adult Pacific halibut and about changes in their hormone patterns with the approach of and following spawning. The experience and information collected will serve as a backdrop for additional spawning attempts in 1988.

Tilseth, S. 1990. New marine fish species for cold-water farming. Aquaculture 85: 235-245.

The most promising new species for fish farming in Norwegian waters are the marine species Atlantic halibut (*Hippoglossus hippoglossus*), Atlantic cod (*Gadus morhua*), ocean wolf fish (*Anarhichas lupus*), and spotted wolf fish (*A. minor*). The main constraints in the commercialization of these species are primarily related to mass rearing of fry. This paper gives a short review of the restrictions on mass rearing of cold-water marine fish fry and the main results from recent research on these four species in broodstock handling, egg and larval rearing.

Tomlinson, N., and E. G. Baker. 1973. Sexual ripening of Pacific halibut (*Hippoglossus stenolepis*) in captivity. J. Fish. Res. Bd. Can. 30: 1255-1256.

Five female Pacific halibut, ranging between 89 and 105 cm long and between 10.4 and 17.9 kg, and three males, between 79 and 99 cm and 6.34 and 13.3 kg became sexually ripe after being held in captivity for 21 months. This apparently is the first record of this development in the species in captivity.

Tytler, P., and J. H. S. Blaxter. 1988. Drinking in yolk-sac stage larvae of the halibut, *Hippoglossus hippoglossus* (L.). J. Fish Biol. 32: 493-494.

Recent work has found that the larvae of herring, *Clupea harengus* L.; plaice, *Pleuronectes platessa* L.; and cod, *Gadus morhua* L. drink as part of the process of osmoregulation. Since halibut larvae can osmoregulate, it is not clear how water balance is maintained in the yolk-sac stage. The purpose of this study was to examine alternative routes of water intake.