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Cataract Development in Atlantic Salmon (*Salmo salar* L) in Fresh Water

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Bjerkås, E., R. Waagbø, H. Sveier, O. Breck, I. Bjerkås, E. Bjørnestad and A. Maage: Cataract development in Atlantic salmon *(Salmo salar* L) in fresh water. Acta vet. scand. 1996, 37, 351-360. – Irreversible bilateral cataracts were diagnosed by slit-lamp biomicroscopy in 178 of 200 farm-raised Atlantic salmon *(Salmo salar* L) fed a standard diet over a five-month period. Initial changes were anterior polar opacities, progressing to involve both the anterior and posterior cortex before changes in the lens nucleus were seen. The lens changes were recorded and given scores according to the severity of the cataracts. At each of 3 samplings, after 2, 4 and 5 months, 200 fish were measured, weighed and examined by slit-lamp biomicroscopy. At all 3 samplings, there was a significant correlation between body length and both cataract incidence and cataract severity. There was also a significant correlation between body weight and cataract incidence and severity for the 2 last samplings. There was a significant correlation between K-factor as a measure of the shape of the fish, and both cataract incidence and severity, at all 3 samplings. Evaluation of specific growth rate in the periods between the examinations showed that the rapidly-growing fish were most susceptible to cataract formation. After cataract developed, however, the growth rate slowed. Follow-up examination of severely affected fish 3 months after transfer to sea water showed a normal cortical zone in the periphery of the lens in 24 out of 28 fish.

aquaculture; growth rate; lens.

Introduction

Cataracts in farmed Atlantic salmon *(Salmo salar* L) caused by nutritional deficiencies *(Barash* 1982, *Cowey et al.* 1992, *Hughes et al.* 1981, *Hughes* 1985, *Ketola* 1979, *Page* 1978, *Poston et al.* 1977, *Richardson et al.* 1986), parasitic invasions *(Ashton et al.* 1969, *Hargis* 1991), poor water quality, including toxic agents and high salinity *(Clarke* 1982, *Fraser* 1993, *Krise & Smith* 1993, *Weinstock & Scott* 1967), variations in water temperature *(Bruno & Raynard* 1994), exposure to sunlight *(Allison* 1963), trauma, infections, genetic factors *(Kincaid* 1989, *Wall & Richards* 1992) and rapid growth *(Kincaid* 1989) have been reported. The localization and progression of the changes have been reported to differ, dependent on the initial cause *(Millichamp* 1991). Cataracts caused by a change in water salinity, and by experimentally induced temperature changes may be reversible, while cataracts caused by other factors are considered irreversible *(Hargis* 1991). The Atlantic salmon is dependent upon effective eyesight for feeding, and a reduction in growth rate in fish with cataract has been suggested *(Page* 1978).

Pathological changes of the fish lens resemble those seen in mammals, with hydropic swelling of lens fibers, lysis of fibers and attempted fiber regeneration resulting in epithelial hyperplasia, especially at the anterior pole, and capsular reduplication *(Wilcock & Dukes* 1989).

Cataract development has been a factor of concern in a number of Atlantic salmon farms during the last years. The present study was carried out after an increase the previous year in the frequency of cataract in smolt of the MOWI strain in an Atlantic salmon smolt production farm, despite normal farming conditions. Lens opacities were diagnosed in fish of weight 100 g or more. The aim of the study was to investigate a possible correlation between growth rate and cataract formation under normal farming conditions.

Materials and methods

This study was carried out between December 1993 and August 1994. Fish from the MOWI strain, hatched in January 1993, were used for the project. The fish weighed about 70 g at the initial examination and had been raised under normal farming conditions, with the same feeding as the previous year, commercial feed of 3 mm extruded pellets (FK-Start, Felleskjøpet, Norway) by automatic feeders. A total of 50 randomly caught fish were anaesthetized in a solution of tricaine methane-sulfonate (MS-222), 0.05-0.1 mg/ml, for examination. Eye examinations were performed in dim light by slit-lamp biomicroscopy *(Kowa* SL-5), 15× magnification, and the results were recorded. The fish were weighed and measured before killing.

After the initial recording of data, fish were randomly distributed into 8 outdoor tanks, each containing 1500 fish. The diameter of the tanks was 3 m, the depth of the water 1 m. The fish were maintained in heated freshwater with 1‰ seawater added. The water temperature was recorded daily and ranged between 8 and 10°C, but with short periods of lower temperatures. The water oxygen and pH were recorded regularly. During the study, the fish were fed with the same diet as earlier (FK-Start), with extra zinc, manganese, copper, vitamin E and riboflavin added. The diet was analysed at the start and twice during the study at the Institute of Nutrition, Directorate of Fisheries, Norway (Table 1).

Twenty-five fish from each tank were randomly caught from all layers of fish in the tanks and examined after 2, 4 and 5 months. The fish were anaesthetized and held by an assistant during examination to prevent corneal damage which might obscure the evaluation of lens changes. The localization and distribution of the cataract changes were drawn on charts for further classification. Other data were obtained in the same manner as at the initial examination.

After 5 months, 500 fish were transferred to an indoor sea water tank to observe eventual changes in the cataracts. Feeding consisted of standard FK with added minerals and vitamins, with approximately 10% overfeeding according to standard feeding tables *(Austreng et al.* 1987). Three months after sea water transfer, 50 of these fish were examined, following the protocol described above. In addition, eyes from fish with cataracts at different stages were collected and fixed in 3% glutaraldehyde before processing and staining by haematoxylin and eosin for histopathologic evaluation.

Fish with cataracts were graded after the following system according to the localization and severity of the lens changes.

0: No signs of cataracts in any eye.

1: Unilateral cataracts with changes in the anterior and/or posterior cortex, or: Bilateral cataracts with changes only in the anterior or posterior cortex.

2: Bilateral cataracts with changes both in the anterior and posterior cortex. Normal transparency of the nucleus.

3: Bilateral cataracts with changes both in the anterior and posterior cortex. Reduced transparency of the nucleus.

The specific growth rate of the fish, the per cent weight gained per day *(Hovde & Schekter* 1981), was calculated for the periods between examinations, and the weight and length as well as condition factor (K-factor), as a value for the shape of the fish, was evaluated. The formula for the condition factor is: weight (in gram)×length^{-3} (in cm)×100. A Spearmann Rank Order Correlation test was used for statistical analyses.

To differentiate the appearance of the cataractous changes diagnosed in the present study from osmotic cataracts caused by an increase in water salinity, an additional study was performed. A total number of 35 randomly caught fish from each tank were held in water containing 32‰-35‰ salt for 24 h before examination. This was done at the start of the project and at the second collection of data. These fish are not included in the main study.

Table 1. Mean proximate composition and analysed concentration of selected micro nutrients in the batches of feed (FK-Start, Felleskjøpet, Norway) used during the study.

Dietary component	$g \cdot kg^{-1}$
Dry matter	939
Protein (N×6.25)	481
Lipid	201
Ash	94
	$mg \cdot kg^{-1}$
Ca	19 200
P	15 250
Mg	1 775
Fe	145
Zn	433
Cu	23
Mn	124
Vitamin A	11
Vitamin E	315
Riboflavin	48
Inositol	440

Results

None of the fish examined at the start of the study showed signs of cataract.

After 2 months, a total of 24 fish with cataracts of 199 examined (one fish was not weighed and was therefore excluded) was found in 5 of 8 tanks (Table 2). The cataracts were located in the cortex, at the anterior and posterior poles of the lens. The anterior changes also involved the subcapsular region and was considered to represent a proliferation of lens epithelium. Twelve fish had unilateral changes while in the rest the cataracts were bilateral. The mean fish weight had increased in all tanks during the first period, except in Tank 1.

Four months after the start of the study, cataracts were diagnosed in 90 of 200 fish, all tanks being represented (Table 2). The lens changes were bilateral in 73 fish and unilateral in 17 fish. After 5 months, cataracts were found in 178 of 199 fish (one fish was not weighed and measured and was therefore excluded), 156 showing bilateral changes and 22 unilateral changes (Table 2).

After 3 months in sea water, 50 fish were examined. Bilateral cataracts were diagnosed in 48 of the fish. In 28 fish, the nucleus was involved. However, in 24 of these, a clear zone of cortical material in the periphery of the lens could be observed, but with the thickening at the anterior pole still visible (Fig. 1).

The localization of lens changes at the different collections of data are shown in Fig. 2. In a majority of the fish, initial changes were confined to the anterior pole of the lens, involving both the cortex and the subcapsular area (Fig. 3). Extended cortical changes, both in the anterior and posterior cortex, could be seen combined with a clear nucleus. Only in late stages of cataract de-

Table 2. Mean (SD) weight (g), length (cm) and condition factor (K-factor) and correlation between weight, length, K-factor and cataract incidence and severity after 2, 4 and 5 months.

Examination	Number	Weight and Cataract	Weight and Cataract score	Length and Cataract	Length and Cataract score	K-factor and Cataract	K-factor and Cataract score
2 months							
Examined fish	199						
Cataract-fish	24						
Cataract score	35						
Correlation coefficient		–	–	0.25	0.25	–0.44	–0.44
Significance		ns	ns	p<0.001	p<0.001	p<0.001	p<0.001
Mean (SD)							
weight g			128,2 (29,3)				
length cm					22.5 (1.8)		
K-factor							1.11 (0.12)
4 months							
Examined fish	200						
Cataract fish	90						
Cataract score	146						
Correlation coefficient		0.42	0.44	0.52	0.54	–0.32	–0.35
Significance		p<0.001	p<0.001	p<0.001	p<0.001	p<0	p<0
Mean (SD)							
weight g			192.9 (57.1)				
length cm					25.7 (2.4)		
K-factor							1.11 (0.09)
5 months							
Examined fish	199						
Cataract-fish	178						
Cataract score	339						
Correlation coefficient		0.16	0.19	0.19	0.23	–0.20	–0.20
Significance		p<0.05	p<0.01	p<0.01	p<0.005	p<0.005	p<0.005
Mean (SD)							
weight g			222.7 (72.1)				
length cm					27.3 (2.7)		
K-factor							1.06 (0.08)

Table 3. Specific growth rate (SGR) in Atlantic salmon with and without cataract. SGR = $\ln w^2 - \ln w^1 \div t(\text{days}) \cdot 100$

	SGR first period (Dec – Feb)	SGR second period (Feb – April)	SGR third period (April – May)
Normal	0.86	0.50	0.35
Cataract	0.95	0.80	0.11

velopment was the nucleus involved (Fig. 4). In 3 fish, the cataracts were present only in the anterior cortex in one eye and in the posterior cortex in the other. The fish with unilateral changes all had only minor cataracts in the affected eye. One case of posterior luxation of a cataractous lens was observed, but signs of cataract resorption were not diagnosed in any of the fish.

One eye of one fish was injured and impossible to evaluate, although the other eye showed changes both in the anterior and posterior cortex. This fish therefore was listed as a "score 2" cataract. In 4 of the other fish, smaller corneal injuries were visible, without disturbing the evaluation of lens changes. Small haemorrhages in the iris were found in a few fish, although the number was not noted.

The severity of the cataract changes were compared to weight and length as well as a combination of these (K-factor). The results are shown in Table 2. At all examinations, there was a statistically significant correlation between the length of the fish and cataract frequency, with the longest fish being most severely affected. Except from the examination after 2 months, there also was a significant correlation between weight and cataract frequency as well as between weight and the severity of the changes. There was a significant correlation between both K-factor and cataract frequency as well as K-factor and cataract severity at all examinations.

The results of the specific growth rates in fish with and without cataracts are shown in Table 3. The fish that developed cataracts showed the highest growth rate in the initial phase, but with a marked reduction in growth after cataract formation.

A total number of 35 fish that had been kept for 24 h in 32‰-35‰ salt-water at the start of the project and after 2 months were examined. Minor cataract changes were diagnosed in 13 fish, involving the anterior cortex in 9 and the posterior cortex in 5. The anterior changes were opaque and cloudy, most often with a clefted anterior suture-line (Fig. 5), and with slight corneal oedema.

Parasitic invasion was not diagnosed in any of the examined fish, neither at slit-lamp examination, nor at histopathology. Histopathologic examinations of the lenses corresponded with the clinical findings, with epithelial proliferation at the anterior poles and degenerative changes of the cortex and nuclei, depending on the progression of the changes. Apart from the cataracts the examined eyes were found to be normal.

Discussion

In the present study, a correlation between growth and cataract formation in Atlantic salmon was shown. The highest correlation was found between the body length and cataract formation ($p<0.01$). A statistically significant correlation between K-factor and cataract was also found and, apart from the examination after 2 months, there was also a significant correlation between body weight and cataract formation. *Kincaid* (1989) reported of cataract in trout, the cataract phenotype in his study associated with higher weights as yearlings, and he concluded that faster growing trout were most susceptible to cataract development. He also reported that trout with cataracts grow slowlier once the lens changes have developed. This is considered to be the result of reduced feed intake due to visual impairment. A reduced growth rate was also shown in the fish with cataracts in this study.

Cataract in the early sea-water phase has been reported from several salmon farms. In the literature, there are many reports on nutritionally induced cataracts in farmed salmon, although most of these have been in younger fish where a nutritional deficiency could be identified.

The cause of the cataract in the fish in the present study has not been determined. The fish

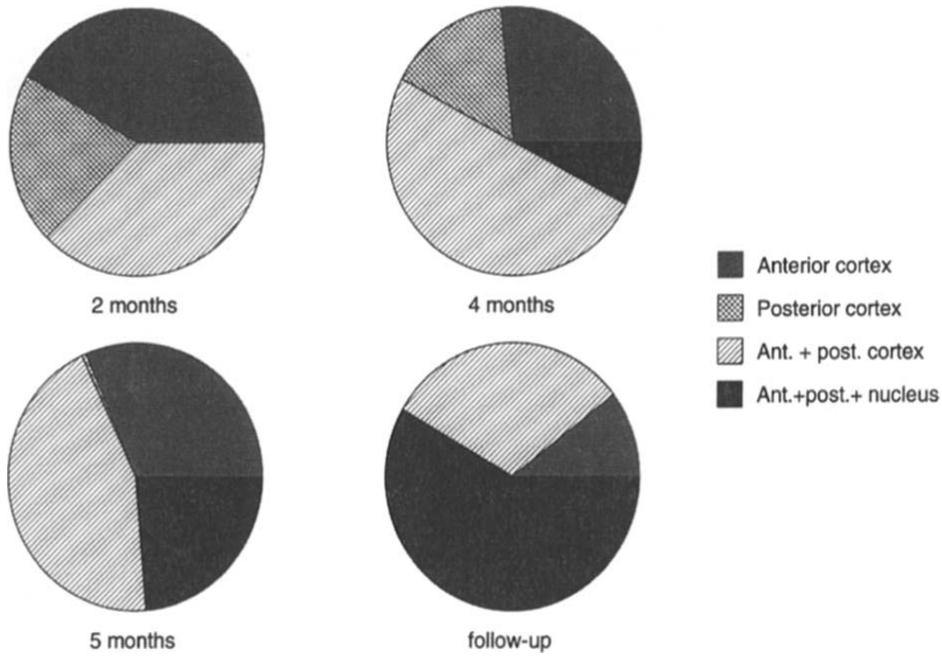

Figure 2. Localization of lens changes after 2, 3, 4 and 7 months. Initial changes were found in the cortex, mostly at the anterior pole. The nucleus was affected only in fish with extended cortical changes.

were fed a standard commercial fish feed, according to standard feeding tables considered to meet the fish's need for growth and maintenance. The fish were kept in tanks where the water was heated to 8-10 °C. This temperature is higher than what is common in other farms during the winter season. It is known that fish reared in warmer water grow faster than those fed the same diet in colder water *(Poston et al.* 1977). The possibility of a relative deficiency caused by an inadequate ability to digest or metabolize nutrients cannot be excluded. The quality of the feed was repeatedly tested during the study, and the cataract development in the present study could not be directly related to a dietary deficiency of a single nutrient.

There are variations in the lens metabolism of different species *(Gum* 1991). Fish eyes increase greatly in size during juvenile life *(Richardson et al.* 1986), and the metabolic activity in the piscine lens is considered high *(Wei & Augusteyn* 1994). This may also make the piscine lens susceptible to metabolic changes caused either by malnutrition or by a deficiency in absorption of essential nutritients. The outer cortical fibers show maximum growth activity. The presence of a (transient) harmful factor, or the adaption to such a factor, in the fresh-water phase may explain the growth of a zone of normal cortical fibers found in the periphery of the lenses at the follow-up examination, when the growth rate of the fish was more moderate. Nutritionally induced cataracts cannot be reversed, but can be arrested by correcting the feed insufficiences *(Orme & Lemm* 1974).

A major goal in modern fish farming has been to increase the growth rate. Excessive feeding, however, has been shown to cause cataract formation in other species. A study on the effects of feeding a high galactose diet in young beagle dogs showed development of cortical changes *(Wyman et al.* 1988). After 12 months' feeding,

Figure 1. Cataract involving the whole lens apart from a zone of normal cortex in the periphery (arrow).

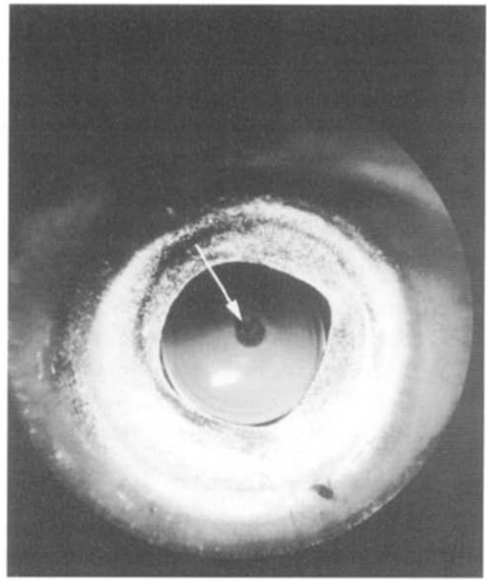

Figure 3. Changes in the lens epithelium and cortex at the anterior pole (arrow).

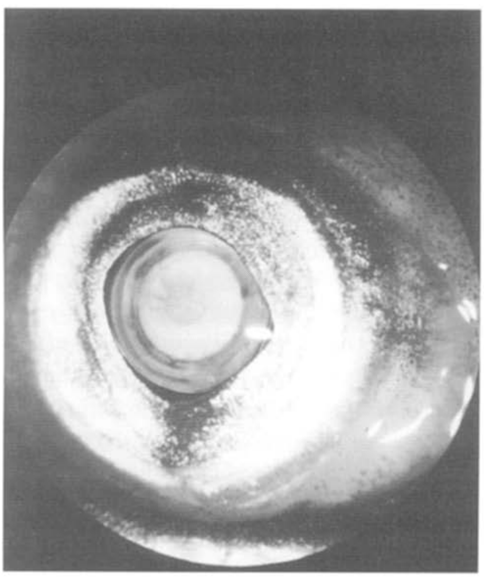

Figure 4. Complete cataract.

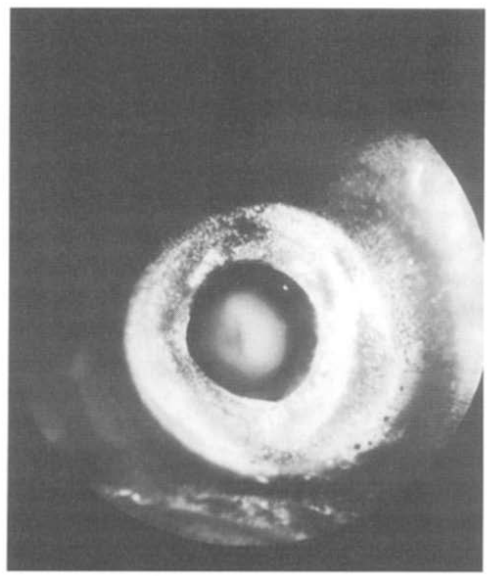

Figure 5. Salt-water induced lens changes with swelling of fibers along the anterior suture line.

the lesions decreased in progression, resulting in clearing of the outer cortex. Studies of rats fed a galactose-rich diet show that they may develop many of the complications of diabetes mellitus, including cataracts, and still remain within a normal blood glucose level *(Lightman* 1993). Diabetes mellitus with elevated blood glucose, frequently causes cataracts in dogs *(Basher & Roberts* 1995). Glucose-dependent cataract formation is also known in humans. This occurs mainly because of osmotic swelling of lens fibers due to the accumulation of sorbitol, but also by glucose-induced changes of lens proteins *(Kamei* 1991).The glucose tolerance in Atlantic salmon has been studied by *Hemre et al.* (1995), with higher toleration and utilization of dietary starch in high water temperatures (10-12°C) than at low temperatures. Blood glucose values were also significantly higher in fish fed a high starch diet at higher temperatures than in fish fed a low starch diet. Rapidly developing cataracts with swelling of lens fibers, similar in appearance to what is observed in dogs with diabetes mellitus-induced cataracts have been observed i Atlantic salmon fed a high energy diet at water temperatures of 16-18 °C (personal observation). A possible relationship between impaired glucose metabolism and cataract in Atlantic salmon has to the authors' knowledge not been studied, but a connection cannot be excluded. Caloric restriction has been shown to delay cataract formation in the Emory mouse, which is an animal model for senile cataract in the man *(Taylor et al.* 1989). Food restricted animals had lower serum glucose values, and it was suggested that a lower glucose level was involved in the delay of cataracts.

Regardless of the aetiology, the lens shows very much the same reaction to injury. The initial changes may be located in different parts of the lens, dependent of the causal factor *(Millichamp* 1991). Lens changes in slowly developing cataracts would be expected to eventually show mainly the same appearance regardless of the cause. An increased speed of progression, however, would aggravate changes like swelling of fibers, capsular reduplication and the risk of lens luxations. The majority of the cataracts in this study were bilateral with the initial signs seen in areas with the highest metabolic activity i.e. at the anterior pole and later in the posterior cortical zone. The nucleus was involved only when cortical changes became severe, and both the anterior and posterior cortex were affected. More than one aetiologic factor for cataract development cannot be excluded from the appearance of the lens changes in the present study.

Mean fish weight increased in all tanks during the study, except in Tank 1 during the first period. This tank was, however, placed such that disturbance due to staff movement was noticeable, and the fish may, initially, have been stressed.

Each tank in the study contained only 1500 fish, the low density minimizing the risk of corneal damage. The tanks were also shallow enough to permit sampling from all layers in the water. Blind fish tend to swim in surface water, and in deeper tanks a random sampling of fish might be difficult.

Genetic factors responsible for cataract formation have been discussed by *Kincaid* (1989) and *Wall & Richards* (1992). As one of the criteria for selection of breeding stock is rapid growth, it cannot be excluded that the genetic disposition for cataract formation is present in the same fish as those with the fastest growth rate. Parasitic invasion has also been reported as a common cause of cataract *(Hargis* 1991). In the present study, no cases of parasitic cataract was diagnosed, neither by slit-lamp examination nor by histologic evaluation. Nor had the fish undergone any antiparasitic treatment, which also has been reported to cause cataracts *(Fraser* 1982). Parasitic invasion or antiparasitic agents as an explanation of the cataract formation in the present study is therefore considered unlikely.

The additional study of the effect of 24 h of saltwater exposure showed a poorly demarcated swelling of the anterior portion of the lens in 9 of 14 salmon developing lens changes. *Wilcock & Dukes* (1989) state that the corneal epithelium is the major determinant of stromal hydration. The anterior chamber is shallow in fish, with the anterior part of the lens situated adjacent to the cornea. Changes in water salinity may lead to a temporary imbalance between aqueous humour and the surrounding water, thus leading to corneal and lens changes. These cataracts may be reversible, although this was not investigated in the present study.

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Sammendrag

Kataraktutvikling hos oppdrettslaks (Salmo salar L) i ferskvannsfasen

Irreversibel bilateral katarakt ble diagnostisert med spaltelampe-biomikroskop hos 178 av 200 oppdrettslaks *(Salmo salar* L) foret med en standarddiett i 5 måneder. De tidligste kataraktforandingene var lokalisert til fremre linsepol med progresjon til bakre cortex før utvilking av forandringer i linsekjernen. To hundre fisk ble undersøkt etter 2, 4 og 5 måneder. Ved alle 3 prøveuttak var det signifikant korrelasjon mellom kroppslengde og kataraktinsidens og utbredelse av forandringene i linsen. Det var også signifikant korrelasjon mellom kroppsvekt og kataraktforandinger ved de 2 siste uttakene. Det var signifikant korrelasjon mellom K-faktor som et mål på fiskens fasong og kataraktinsidens og utbredelse ved alle 3 uttak. Etterkontroll av fisk med store linseforandinger 3 måneder etter overflytting til sjøvann viste vekst av normalt linsevev i periferien av linsen hos 24 av 28 fisk. Rasktvoksende fisk var mest utsatt for katarakt, men etter utvikling av linseforandringer, ble det påvist redusert veksthastighet.

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