

# Atlantic dogfish silage vs. herring silage in diets for Atlantic salmon (*Salmo salar*): growth and sensory evaluation of fillets

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## Abstract

The preparation of silage-based diets from dogfish waste suitable for Atlantic salmon was studied because of a concern that the urea in the dogfish would affect either diet acceptability by salmon and/or consumer-sensory evaluation of the salmon muscle. The dogfish liver was not included in the waste utilized. The protein content of dogfish silage was adequate (~14.9%, Kjeldahl nitrogen corrected for urea nitrogen). The fat in dogfish silage included triglycerides at approximately 81% of total lipid. The high level of polyunsaturated fatty acids (~28% of total fatty acids) in this lipid was comparable to that of other fish lipids employed in salmonid diets. Two sets of experiments were conducted with Atlantic salmon to evaluate the suitability of dogfish-silage-based diets. In both, three moist diets based on ground herring (control), on herring silage, and on dogfish silage were tested for 9 weeks. The studies were conducted in two phases based on salmon averaging respectively 190 or 490 g. These were fed twice daily to apparent satiation (water temperature range 5–14°C, 12 h photoperiod). Although the urea content was nearly 0.5% in the dogfish silage diet, there was no apparent decrease in palatability for salmon in the experiment with larger fish. However, there was a decrease in the palatability of both herring and dogfish silage diets fed to the smaller fish, probably due to their being stored for 8 weeks at room temperature prior to diet formulation. The addition of natural tocopherols in the preparation of silage for the larger fish kept the lipid oxidation levels acceptable (peroxide value < 5 mEq/kg) for the 15 days of storage before making the diets. In the second study with larger fish, there were no significant differences among the diets in weight gain, feed efficiency, and protein efficiency ratio. These parameters had been significantly higher in the smaller fish fed the ground herring control diet. A sensory evaluation was conducted with the salmon fillets from both studies where the fish fed on different diets were compared. No significant differences were detected in either experiment. The lipid, protein and *n*-3 fatty acid levels of the muscle of the larger salmon fed the three different diets did not exhibit any significant differences ( $P > 0.05$ ). Our results show that

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dogfish offal, an environmental waste problem, can be made into a fish silage acceptable for salmon farming if proper storage conditions are employed.

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## 1. Introduction

A major goal for the fish nutritionist is to prepare feeds which give fast growth, optimal fish health and product quality at the lowest possible cost. Because feed is the single most expensive item in the operating costs of a salmon farming operation, there is a need for low-cost feed. These facts have been reflected in Atlantic Canada by the installation of new conventional feed-manufacturing plants. On the other hand, roe herring carcass and spiny dogfish (*Squalus acanthias*) industries have developed in Nova Scotia in the proximity of the salmon farms. These industries have created an environmental problem, due to the large volumes of waste which were originally buried in land or dumped at sea. These methods not only pollute the environment and waste a source of protein, but also cannot be used currently in Nova Scotia because of government regulations (Richard, 1987).

Silage for fish feed has been traditionally produced wherever raw materials were available. One possible solution for the dogfish waste problem could be the production of fish silage from dogfish offal. This can easily be incorporated into semi-moist and moist feeds which in this area are a popular type of feed for salmonids. This would both help the dogfish industry solve the disposal issue and help the salmon farmers produce a less expensive feed. Fish silage as a dietary ingredient for salmonids has been discussed by several authors (Åsgård and Austreng, 1981; Jackson et al., 1984; Lall, 1987). In previous experiments, our laboratory had successfully tested herring silage as feed for Atlantic salmon (Parrish et al., 1991). Dogfish contain urea, but no local data were available on the palatability of diets containing dogfish silage for salmon. The consequences of feeding silage diets containing urea on the flavor of salmon fillets also were unknown. This paper describes a series of experiments performed to assess the use of the ensiled dogfish offal from the fisheries industry to prepare diets suitable for Atlantic salmon. With herring-based diets for reference, both fish growth and sensory evaluation of fish muscle in salmon fed dogfish silage were objectives.

## 2. Materials and methods

### *Preparation of silage*

Spiny dogfish (*Squalus acanthias*) offal, mainly composed of heads and some viscera, but excluding the liver, were donated by Ocean Pride Fisheries, Wedgeport, NS, and whole herring was purchased from Karlson Fisheries, Blandford, NS. Upon arrival, they were immediately ground and frozen at  $-35^{\circ}\text{C}$ . After thawing, the ground fish were made into silage by the addition, with thorough mixing, of 3.5% (w/w) of 85% formic acid. During the initial pilot trial, ethoxyquin at 200 mg/kg was added. This silage was stored at room temperature for 8 weeks before preparing the diets. Based on the results of the effect of different levels of tocopherols in the oxidative stability of dogfish silage (Heras and Ack-

Table 1

Composition of experimental diet used in both experiments, in % (w/w)

Ingredient	Diets		
	Ground herring	Herring silage	Dogfish silage
Herring meal	22.0	22.0	24.6
Soybean meal	12.0	12.0	12.0
Wheat middlings	16.8	16.8	12.5
Pre-gelatinized starch	3.0	3.0	3.0
Vitamin premix <sup>1</sup>	0.7	0.7	0.7
Mineral premix <sup>2</sup>	0.5	0.5	0.5
Herring oil	5.0	5.0	6.6
Fish product	40.0	40.0	40.0

<sup>1</sup>Vitamins added to supply the following per kg diet: retinyl acetate, 5000 IU; cholecalciferol, 2500 IU; *dl*- $\alpha$ -tocopheryl acetate, 300 IU; menadione sodium bisulfite, 30 mg; thiamine hydrochloride, 50 mg; riboflavin, 40 mg; *d*-calcium pantothenate, 120 mg; biotin, 0.8 mg; folic acid, 10 mg; vitamin B<sub>12</sub>, 0.03 mg; niacin, 180 mg; pyridoxine, 40 mg; ascorbic acid, 800 mg; inositol, 300 mg; *dl*-methionine, 1 g; choline chloride, 1 g.

<sup>2</sup>Minerals: MnSO<sub>4</sub> (32.5% Mn), 231 mg; ZnSO<sub>4</sub> (22.7% Zn), 530 mg.

man, unpublished results), 900 ppm of a natural mixture of tocopherols (Covi-ox T-70, Henkel Corp., LaGrange, IL) was added when preparing subsequent ground herring or silages. The pH of silages was recorded during the 15 days of ensiling.

#### *Preparation of diets*

Three moist diets were made at the Department of Fisheries and Oceans, Halifax, in the first or pilot study. Ground raw herring was used in a reference diet and two test diets were prepared, one with silage from the same herring, and the other with silage from dogfish. The ingredients were the same in all three diets (Table 1) except for the wet component source of protein (fish silage or ground herring). Herring oil was supplemented as needed to keep the lipid percentage the same in all diets. All diets were supplemented with  $\alpha$ -tocopheryl acetate at 300 IU/kg. In the second experiment, Covi-ox T-70 was added to the silages instead of ethoxyquin, but the rest of the formulation was kept the same. Pellets were prepared with a California Model CL-2 pellet mill (California Pellet Mill Co., San Francisco, CA) with a 5-mm screen (pilot study). For the second trial the diet was extruded through a 9-mm screen at room temperature and immediately frozen at  $-35^{\circ}\text{C}$  in 300-g polyethylene bags. Prior to the actual feeding these diets were stored at  $-20^{\circ}\text{C}$ . Before feeding the extruded diet it was thawed and cut so that the final size of the extruded diet matched that of the compressed pellets. To avoid rejection and wasteful disintegration of the diets, the diameter and length of pellets or pieces were kept as close as possible to a uniform size appropriate to fish size (Knights, 1985). The diets were analyzed for ash, moisture, tocopherols, fatty acids, lipid and protein content.

#### *Lipid analysis*

The lipid content of the silages, diets and salmon was determined according to the procedure of Bligh and Dyer (1959). Lipid classes were analyzed on silica gel Chromarods-III (Iatron Laboratories, Tokyo, Japan) by the procedure of Parrish and Ackman (1985).

The Iatroscan TH-10 Mark III analyzer of the same company, equipped with flame ionization detection (FID), was used for quantitation. The air flow was 2 l/min and the detector hydrogen flow rate 160 ml/min. The scanning speed was 0.42 cm/s. Peak areas were measured using an SP-4200 (Spectra Physics, St. Albans, UK) electronic integrator. The lipid sample was dissolved in chloroform, and 1  $\mu$ l of this solution was spotted on type S-III Chromarods using 1- $\mu$ l Microcap (Drummond Scientific Co., Broomall, PA) disposable pipettes. Phosphatidylcholine, tristearin, monoglyceride, free fatty acids and free cholesterol were used for the calibration of the Chromarods. Before developing the rods, the samples were focused for 1 min in acetone and dried in a constant humidity chamber for 5 min. The solvent mixture employed was hexane/diethylether/formic acid (97:3:1 v/v/v) for 45 min. After developing, the Chromarods were dried for 4 min at 110°C and then fully scanned. The set of Chromarods was divided into lots containing 4 or 5 rods. Each lot was considered one analytical unit and calibrated independently. To avoid the effects of intrarod variability, the replicate samples were spotted in the same analytical unit.

#### *Fatty acid analysis*

Fatty acid methyl esters lipids were prepared with BF<sub>3</sub>-MeOH according to the method of Morrison and Smith (1964). The analyses were made by gas chromatography (GC) using a Perkin-Elmer (Norwalk, CT) model 900 GC fitted with a SUPELCOWAX-10 fused silica column, 30 m  $\times$  0.32 mm, with 0.2  $\mu$ m phase (Supelco Canada Ltd, Oakville, ON). The weight percentage of each fatty acid was calculated according to Ackman and Eaton (1978). Peaks were identified by comparing the retention times with those of a known mixture of fatty acid methyl esters.

#### *General analyses*

Ash and moisture analyses followed IAFMM procedures (IAFMM, 1979). The peroxide values were determined on extracted lipids by the acetic acid/chloroform method (AOCS, 1992a). The protein content was analyzed by a modified Kjeldahl nitrogen determination method (AOCS, 1992b). The urea content of ground dogfish and of dogfish silage was determined using a kit (No. 542.946, Boehringer Mannheim, Mannheim, Germany); 20 ml of 1M perchloric acid were added to 10 g of sample and homogenized with a Polytron Kinematica GMBH (Brinkman Inst., Rexdale, ON) for 2 min. The sample was quantitatively transferred into a beaker with 40 ml of distilled H<sub>2</sub>O and the pH adjusted to 7.2 with KOH. The contents were then transferred quantitatively into a 100-ml volumetric flask. For separation of the fat layer and precipitation of the potassium perchlorate, the sample was kept at 4°C for at least 1 h. Afterwards it was filtered, discarding the first few milliliters. The filtrate was used for analysis. If the solution was still not clear we found it appropriate to freeze and thaw the sample once, filter it again, and centrifuge for 10 min before transferring the top layer into a new tube; 100  $\mu$ l were used for analysis with the kit.

For the determination of tocopherols, the samples were prepared according to Pocklington and Dieffenbacher (1988) with some modifications. Analyses were conducted by high-performance liquid chromatography (HPLC) using a normal phase Partisil-5 silica column (12.5 cm  $\times$  4.6 mm Chromatographic Specialties, Brockville, ON) with a UV detector set at 295 nm (Waters Associates, Milford, MA). The solvent was hexane/isopropanol alcohol 98:2 (v/v) and the flow 1 ml/min.

### *Salmon holding*

The salmon (*Salmo salar*) were maintained in the Dalhousie University Aquatron Laboratory, Halifax. The seawater supply was drawn from Northwest Arm of Halifax Harbour and passed through 4 pressure sand filters. The salmon were held in 2-m<sup>3</sup> cylindrical fibreglass tanks at a fish density of approximately 5 kg/m<sup>3</sup> with a water flow of 7–9 l/min and a 12-h photoperiod. Aeration was provided and tanks were cleaned daily.

### *Experimental design*

Both the fall 1990 and fall 1991 feeding experiments were designed according to a 3 × 2 factorial plan with three diets, and two replicates. The experiment was thus repeated, although feed preparations and water temperatures were different.

In the preliminary experiment of 1990, using fish of ~190 g that were hatched at the beginning of 1990, 40 salmon were placed in each experimental tank for 9 weeks, beginning in October, and fed twice daily. The second experiment started in September, 1991 and also lasted 9 weeks. The salmon had an initial mean weight of 490 g. Each group consisted of 42 fish which had previously been fed a commercial diet (Fundy Choice, Corey Feed Mills, Fredericton, NB) for 1 month, so their nutritional status was presumed good and fairly equal. Fish were individually tagged with a dye (Alcian Blue 86X (Sigma), 65 mg/ml) employing a Madajet XL (Mada) injector (Herbinger et al., 1990). Feed was hand-fed twice daily to apparent satiation. In order to focus the energy expenditure of the fish into growing, fish density was kept lower than that of intensive culture (Li and Brocksen, 1977) and feeding was concentrated in time and space. Fish were acclimated to the presence of feeding personnel and no appreciable fright reaction was observed provided personnel did not come too close to the tanks. Deaths were recorded and the animals identified and weighed. Unless otherwise stated, the results refer to the second experiment, and only growth and sensory panel results are given for the first experiment.

### *Data recording*

Seawater temperature varied between 5.5 and 12.0°C in Experiment 1, and from 10.4 to 14.3°C in Experiment 2. All fish were individually weighed at the beginning and end of the experiment. Length was also recorded. During the experiment, subsamples of 5–8 fish from each tank were also weighed every two weeks (Experiment 1) and at 21 and 42 days (Experiment 2). To facilitate weighing, they were anesthetized with methoxyethanol (Sigma Chem. Co., St. Louis, MO), at each measuring point.

### *Sensory evaluation*

At the end of the experiments, 5 fish from each tank were killed by a blow to the head, gutted and filleted. All fillets were wrapped in aluminium foil and frozen at –35°C until needed. The experienced sensory panelists were staff and students of the Canadian Institute of Fisheries Technology (CIFT). The fillets were thawed, skinned and the meat minced in a Cuisinart food processor. Approximately 15–20 g of flesh mixed from different fish from each tank were formed into a patty, placed in a covered glass Petri dish, and cooked in a domestic microwave oven before presentation to the panelists (Ernst et al., 1989). A triangle test (Larmond, 1977) was used. The results were evaluated statistically by analysis of

variance and differences between means by Tukey's multiple comparison test at the 5% level (Larmond, 1977).

### 3. Results and discussion

#### *Dogfish silage*

Herring silage has been documented and used for some time, but dogfish offal silage is less well known (Jangaard, 1991). It is not always clear if dogfish "offal" includes the liver. The proximate compositions of the two silages for the second study are shown in Table 2. In the herring silage urea was below reproducible analytical limits. The urea content of the dogfish silage was  $0.95 \pm 0.13\%$  w/w, which is relatively low compared to other dogfish silage (Kaushik et al., 1983). The urea content of the dogfish-based diet was found to be  $0.33 \pm 0.05\%$  w/w ( $n = 3$ ). This is probably due to the fact that the silage was ensiled and stored at room temperature for 15 days before diet preparation, and the urease-producing organisms may have converted some urea into ammonia (Mowbray et al., 1988). Table 2 also shows the major fatty acid classes (%w/w) of both silages after 15 days of ensiling. The high level of polyunsaturated fatty acids (PUFA) present is comparable to other salmonid diets employing fish and/or fish oils. In the diets the main lipid class found was triglyceride (Fig. 1); it accounted for  $\sim 81\%$  of total lipids in all diets. This, together with the PUFA levels, brought the energy value of fat to an acceptable level (Lall, 1987, 1991). The diet *n-3* fatty acid contents (see Table 3) of  $> 13\%$  were higher than expected from previously reported dogfish silage diets (Mowbray et al., 1988). The amount of *n-3* fatty acids provided by the diets was 1.5–2.0%, similar to the dietary requirements of salmonids given as  $\sim 1\%$  of *n-3* fatty acids (Cowey and Sargent, 1977; Castell, 1979; Bell et al., 1986). The protein contents were also adequate (Table 4). No attempt was made to analyze

Table 2  
Composition feature of silages prepared for Experiment 2

	Silage type	
	Herring	Dogfish
<i>Proximate composition (w/w %)</i> <sup>1</sup>		
Moisture	71.81 $\pm$ 0.55	82.76 $\pm$ 0.28
Protein	16.28 $\pm$ 0.60	14.93 $\pm$ 1.81 <sup>a</sup>
Lipid	7.69 $\pm$ 0.45	3.68 $\pm$ 0.29
Ash	2.45 $\pm$ 0.13	2.23 $\pm$ 0.25
<i>Major fatty acid groups (w/w%)</i> <sup>2</sup>		
$\Sigma$ Saturated	26.68 $\pm$ 0.87	22.55 $\pm$ 0.23
$\Sigma$ Monounsaturated	44.78 $\pm$ 1.03	48.75 $\pm$ 0.64
$\Sigma$ Polyunsaturated	28.54 $\pm$ 1.31	28.74 $\pm$ 1.17
$\Sigma$ <i>n-3</i> fatty acids	22.39 $\pm$ 0.75	22.37 $\pm$ 0.82

<sup>1</sup>Average of duplicate analyses for ash and protein, triplicates for moisture and lipid.

<sup>2</sup>Average of triplicate analyses.

<sup>a</sup>Protein content of dogfish corrected for urea content.

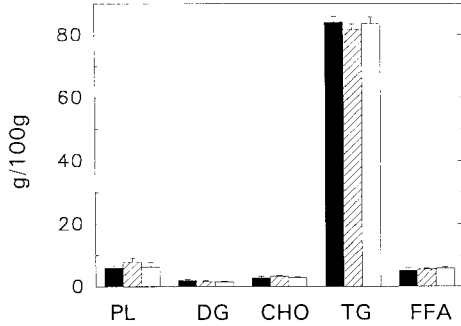


Fig. 1. Lipid class composition of the three diets of Experiment 2. ■ Ground herring; ▨ Dogfish silage; □ Herring silage. PL = polar lipids; DG = diacylglycerol; CHO = cholesterol; TG = triacylglycerol; FFA = free fatty acids. Values are the mean of 3 determinations  $\pm$  1 s.d.

the amino acid composition, but results from other studies (Åsgård and Austreng, 1985) showed that dogfish silage has all the essential amino acids required by salmonids. High urea contents reportedly cause palatability problems in salmon (Satia and Brannon, 1975; Jackson et al., 1984).

In the pilot trial, the storage of the silage for 8 weeks at room temperature yielded a product which was not very well accepted by the fish. Feeds including oxidized lipid are accepted by fish (Koshio et al., 1994) but may cause reduction of feed intake through reduced palatability resulting from off-flavors. Oxidation may also cause destruction of important nutrients (Lall, 1991). We have found that the addition of a natural mixture of tocopherols to silage in lieu of ethoxyquin controlled oxidation of lipids to an adequate degree over a 2-week period, the final peroxide value being  $<5$  mEq/kg (Heras and Ackman, unpublished results). Covi-ox T-70 was therefore incorporated into the diets for Experiment 2 (Table 4). This benefit was reflected in the second experiment in the comparable growth of the salmon fed the three different diets.

### Diets and lipids

Table 4 shows the proximate composition of the three diets and Fig. 1 the lipid classes. In Experiment 2, the extrusion and further processing of the diets was done at room temperature to avoid an increase in lipid oxidation due to heating during pelleting. The fatty acid compositions of the total lipids of the three diets are given in Table 3 in full since the composition of dogfish waste (excluding liver) is little known. This omnivorous fish feeds on herring, among other local fish species. Table 2 shows that the offal combination of head, muscle and viscera has lipids with the basic fatty acid composition of marine lipids common to herring and similar north Atlantic fish (Ackman et al., 1988; Ackman, 1989). The lower fat content of the dogfish silage (Table 2) was supplemented with herring oil to match the other diets (Table 4). The herring meal (Table 1) would contribute about 1.5–2.0% fat to the overall added fat in all three diets, and this plus the herring oil ensured that the fatty acids of the three diets of Table 3 were virtually identical. The muscle triglycerides of Atlantic salmon do respond to extreme changes in dietary fats and fatty acids (Polvi and Ackman, 1992) but in this case differences in total lipids and fatty acids (Table 5) were negligible.

Table 3  
Fatty acid composition<sup>1</sup> of total lipid of diets (% w/w) used in Experiment 2

Fatty acid <sup>2</sup>	Ground herring	Dogfish silage	Herring silage
14:0	6.91 ± 0.18	5.82 ± 0.21	6.99 ± 0.14
I 15:0	0.21 ± 0.01	0.21 ± 0.01	0.21 ± 0.01
AI 15:0	0.08 ± 0.01	0.08 ± 0.01	0.08 ± 0.00
15:0	0.32 ± 0.01	0.32 ± 0.00	0.34 ± 0.02
Pristanic	0.11 ± 0.01	0.12 ± 0.00	0.11 ± 0.03
7-Me16:0	0.30 ± 0.01	0.28 ± 0.01	0.30 ± 0.00
16:0	12.91 ± 0.33	13.20 ± 0.55	12.57 ± 0.08
I 17:0	0.07 ± 0.01	0.09 ± 0.01	0.07 ± 0.00
17:0	0.20 ± 0.02	0.24 ± 0.01	0.21 ± 0.01
18:0	1.06 ± 0.03	1.32 ± 0.04	1.01 ± 0.01
20:0	0.14 ± 0.01	0.15 ± 0.01	0.17 ± 0.01
22:0	0.14 ± 0.06	0.15 ± 0.02	0.11 ± 0.01
24:0	0.27 ± 0.15	0.12 ± 0.00	0.11 ± 0.00
Σ saturated <sup>3</sup>	24.23 ± 1.19	23.42 ± 1.14	23.50 ± 0.43
Σ14:1	0.16 ± 0.01	0.15 ± 0.01	0.19 ± 0.10
16:1 <i>n</i> -7	5.32 ± 0.16	5.46 ± 0.18	5.38 ± 0.04
16:1 <i>n</i> -5	0.18 ± 0.01	0.23 ± 0.01	0.20 ± 0.01
18:1 <i>n</i> -9	6.92 ± 0.23	8.49 ± 0.13	6.85 ± 0.01
18:1 <i>n</i> -7	1.68 ± 0.03	2.05 ± 0.01	1.63 ± 0.00
18:1 <i>n</i> -5	0.39 ± 0.01	0.48 ± 0.13	0.38 ± 0.01
20:1 <i>n</i> -9	12.89 ± 0.35	13.22 ± 0.60	13.59 ± 0.11
20:1 <i>n</i> -7	0.34 ± 0.01	0.51 ± 0.06	0.37 ± 0.04
20:1 <i>n</i> -5	0.04 ± 0.01	0.07 ± 0.03	0.10 ± 0.06
22:1 <i>n</i> -11 + <i>n</i> -13	17.18 ± 0.30	17.44 ± 0.95	18.28 ± 0.13
22:1 <i>n</i> -9	1.03 ± 0.07	1.32 ± 0.09	1.04 ± 0.01
22:1 <i>n</i> -7	0.30 ± 0.11	0.28 ± 0.06	0.26 ± 0.04
22:1 <i>n</i> -5	0.14 ± 0.15	0.07 ± 0.02	0.07 ± 0.02
24:1 <i>n</i> -9	0.78 ± 0.12	0.69 ± 0.01	0.70 ± 0.04
Σ monoenes <sup>3</sup>	47.46 ± 1.58	50.63 ± 2.32	49.17 ± 0.67
16:2 <i>n</i> -4 + phytanic	0.59 ± 0.04	0.55 ± 0.03	0.62 ± 0.02
16:3 <i>n</i> -4	0.32 ± 0.01	0.26 ± 0.02	0.32 ± 0.00
16:3 <i>n</i> -3 + <i>n</i> -1	0.28 ± 0.10	0.19 ± 0.01	0.26 ± 0.08
16:4 <i>n</i> -3	0.09 ± 0.01	0.06 ± 0.00	0.08 ± 0.00
16:4 <i>n</i> -1	0.77 ± 0.01	0.57 ± 0.04	0.78 ± 0.01
18:2 <i>n</i> -6	6.19 ± 0.19	5.87 ± 0.54	5.94 ± 0.02
18:2 <i>n</i> -4	0.13 ± 0.01	0.14 ± 0.03	0.14 ± 0.01
18:3 <i>n</i> -6	0.09 ± 0.01	0.07 ± 0.01	0.12 ± 0.01
18:3 <i>n</i> -4	0.10 ± 0.04	0.08 ± 0.00	0.07 ± 0.03
18:3 <i>n</i> -3	1.25 ± 0.03	1.01 ± 0.06	1.25 ± 0.01
18:4 <i>n</i> -3	2.62 ± 0.02	1.53 ± 0.01	2.66 ± 0.01
18:4 <i>n</i> -1	0.14 ± 0.01	0.16 ± 0.05	0.16 ± 0.00
20:2 <i>n</i> -6	0.15 ± 0.00	0.16 ± 0.01	0.18 ± 0.03
20:3 <i>n</i> -6	0.05 ± 0.02	0.04 ± 0.00	0.05 ± 0.01
20:3 <i>n</i> -3	0.07 ± 0.01	0.12 ± 0.02	0.10 ± 0.00
20:4 <i>n</i> -6	0.29 ± 0.04	0.47 ± 0.04	0.27 ± 0.04
20:4 <i>n</i> -3	0.39 ± 0.02	0.41 ± 0.01	0.40 ± 0.04
20:5 <i>n</i> -3	5.91 ± 0.03	5.55 ± 0.10	5.85 ± 0.10
21:5 <i>n</i> -3	0.34 ± 0.08	0.23 ± 0.00	0.27 ± 0.02
22:4 <i>n</i> -6	0.31 ± 0.20	0.22 ± 0.06	0.13 ± 0.01
22:4 <i>n</i> -3	0.24 ± 0.11	0.13 ± 0.01	0.14 ± 0.02

Fatty acid <sup>2</sup>	Ground herring	Dogfish silage	Herring silage
22:5n-6	0.27 ± 0.21	0.15 ± 0.03	0.10 ± 0.01
22:5n-3	0.92 ± 0.13	0.90 ± 0.00	0.81 ± 0.09
22:6n-3	6.68 ± 0.11	6.99 ± 0.16	6.54 ± 0.14
Σ PUFA <sup>3</sup>	28.31 ± 1.47	25.95 ± 1.28	27.33 ± 0.71
Calculated iodine value	131.52 ± 2.37	126.87 ± 1.11	129.61 ± 0.70

<sup>1</sup>Samples were analyzed in triplicate.

<sup>2</sup>I = iso; AI = anteiso; pristanic = 2,6,10,14-tetramethylpentadecanoic; phytanic = 3,7,11,15-tetramethylhexadecanoic.

<sup>3</sup>Totals include minor fatty acids not listed.

Table 4  
Proximate composition and the tocopherol contents of diets used in Experiment 2

	Diet type		
	Ground herring	Herring silage	Dogfish silage
<i>Proximate composition (w/w %)</i> <sup>1</sup>			
Moisture	35.3 ± 0.4	34.7 ± 0.4	33.9 ± 0.4
Protein	31.5 ± 1.4	31.6 ± 0.9	33.1 ± 0.9
Lipid	8.0 ± 0.1	8.8 ± 0.5	8.1 ± 0.5
Ash	5.6 ± 0.6	4.5 ± 0.1	4.9 ± 0.1
<i>Tocopherol</i> <sup>2</sup>			
α	569	474	534
β	17	24	26
γ	234	203	213
δ	150	124	137

<sup>1</sup>Values are expressed as % w/w ± s.d. Samples were analyzed in duplicate (ash, protein) or triplicate (moisture, lipid).

<sup>2</sup>Values are mean of 2 determinations expressed as mg/kg diet.

Table 5  
Lipid, protein and fatty acid group contents<sup>1</sup> of salmon fillets from Experiment 2

Diet	Lipid	Protein	Σ Saturates	Σ Monounsaturated	Σ PUFA	Σ n-3 PUFA
Ground herring	4.9 ± 0.7	20.8 ± 0.5	23.10 ± 0.73	48.80 ± 0.68	28.10 ± 1.51	19.1 ± 1.0
Herring silage	4.7 ± 0.5	21.2 ± 1.0	22.48 ± 0.96	48.62 ± 1.00	29.15 ± 1.21	20.1 ± 1.1
Dogfish silage	4.4 ± 0.8	21.4 ± 0.6	25.75 ± 1.51	47.75 ± 2.01	26.50 ± 0.79	19.5 ± 1.1

<sup>1</sup>Values are expressed as % wet weight ± s.d. of muscle for lipid and protein, and as % w/w ± s.d. of total fatty acids for n-3 PUFA. Protein n = 2; lipid and fatty acid n = 4.

The content of the different tocopherols in the diets is shown in Table 4. The accepted local addition of α-tocopherol acetate to commercial feeds for Atlantic salmon is 300 IU/kg feed. The basic level may be as low as 35 mg/kg feed (NRC, 1993), and 30 mg/kg has shown satisfactory growth (Waagbø et al., 1991). However, evaluation of sensory attributes of fillets encourages higher dietary levels (Waagbø et al., 1993; Sigurgisladdottir et al.,

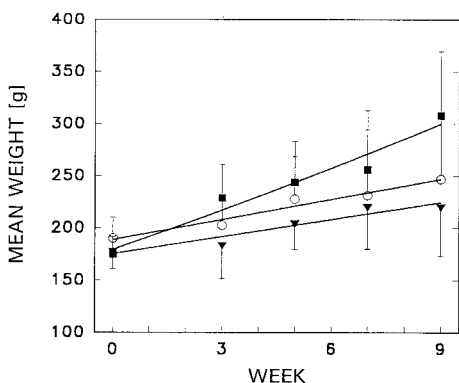


Fig. 2. Weight increase of salmon, Experiment 1. ■ Control; ○ Dogfish-fed; ▼ Herring-fed. Values are the mean of 2 tanks (40 fish each)  $\pm$  1 s.d.

1994). Other salmonids need about 30 mg/kg diet of vitamin E (Bell and Cowey, 1985). In the second study the diets included more  $\alpha$ -tocopherol in the total tocopherols than the minimum required. It has been shown that this should confer added quality benefits in Atlantic salmon (Waagbø et al., 1993). The sensory attributes of trout muscle are not affected by different levels of  $\alpha$ -tocopherol (Boggio et al., 1985). However, Pozo et al. (1988) found that increasing the level of tocopherol to 500 mg/kg diet increased the deposition of canthaxanthin in trout flesh, and Sigurgisladottir et al. (1994) have shown that the tocopherols of Covi-ox can be deposited in salmon flesh with probable increased stability against oxidation.

#### Salmon growth study

All moist feeds had an acceptable consistency, and were not sticky during storage. No deaths were recorded, except for 3 fish from one of the tanks being fed the dogfish diet, which died 2 days before the termination of the experiment for no obvious reason. In both experiments, the mean weight gain and growth rate were highest in the tanks fed the control herring diet (Figs. 2 and 3), although only in the first (pilot) experiment was the difference significant ( $P < 0.05$ ) for control fish fed ground herring compared to the two silage-based diets. We presume that this was due to a decreased palatability of old silage and therefore a lower feed consumption by the small fish fed the silage-based diets. Although the results did not reach statistical significance, the fish fed dogfish silage consistently grew better (pilot study) or slightly better (second experiment) than those fed the herring silage.

No significant difference in the final experiment was observed between the urea content of the muscle of the control salmon ( $0.03 \pm 0.003\%$  (w/w)), and of the dogfish fed salmon ( $0.03 \pm 0.009\%$ ). De Long et al. (1959) found that chinook salmon were unable to metabolize urea. Moreover, Kaushik et al. (1983) found that although trout digested more than 98% of the urea present in diets, they passively excreted it without any increase in energy demand. These findings are in agreement with our experimental results, where no difference in the urea content was found in the flesh of the salmon fed different starting amounts of urea.

In the first experiment (Table 6) the average FE (feed efficiency ratio) and PER (protein efficiency ratio) were significantly higher in the control group compared with the fish fed

Table 6

Protein efficiency ratio, weight gain, daily gain and feed efficiency in salmon from the two experiments

	Diet	Weight gain (g)	Daily gain (%)	PER	FE
Expt. 1	Ground herring	133	1.20 ± 0.12	2.37 ± 0.82	1.17 ± 0.41
	Herring silage	42	0.38 ± 0.11	1.57 ± 0.18	0.78 ± 0.14
	Dogfish silage	57	0.33 ± 0.08	1.55 ± 0.23	0.76 ± 0.11
Expt. 2	Ground herring	308	1.04 ± 0.22	1.62 ± 0.22	0.80 ± 0.10
	Herring silage	265	0.88 ± 0.41	1.62 ± 0.28	0.74 ± 0.03
	Dogfish silage	288	1.01 ± 0.36	1.54 ± 0.14	0.74 ± 0.07

PER = protein efficiency ratio; wet weight gain (g)/protein fed (g). FE = food efficiency ratio; wet weight gain (g)/dry weight diet fed (g).

silage-based feeds. There was no difference in feed pellet textures, so taste preferences seems to have been the determining factor. However, in the second experiment, the acceptance of the three types of semi-moist feed by all fish was immediate and they preferred it over the previously fed dried pellets (commercial diet), probably because its softer texture is more acceptable to salmon (Stradmeyer et al., 1988). The lack of preference by the fish for any of the different semi-moist diets was reflected in the growth FE and PER (Table 6) which exhibited no significant differences between the diets and comparable growth (Fig. 3). In both experiments, there were no significant difference between the replicate tanks, so data were pooled for Figs. 2 and 3.

The fatty acid compositions of the fillet lipids reflected those of the dietary lipids, and thus only minor variations were observed between the groups (Table 5). The total lipid content of the fillets of approximately 5% is less than the 10–14% that may be found in market-sized fish (Roch et al., 1988; Ackman, 1989). However, it is in the same range as that of smaller Atlantic salmon fed various fat sources in an attempt to detect the impact of fat type or fatty acid proportions on flavor (Polvi et al., 1991; Polvi and Ackman, 1992). Our procedure of cooking fish muscle tissue by microwaving in glass Petri dishes has an advantage over other cooking methods. The glass remains cool, condensing and trapping

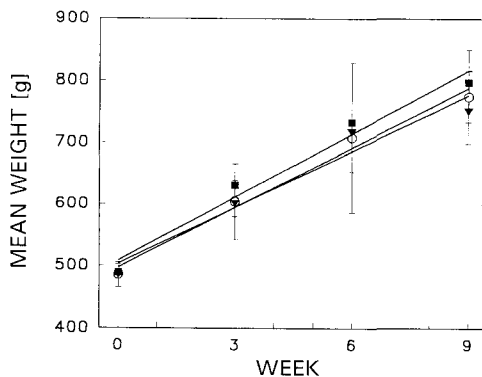


Fig. 3. Weight increase of salmon, Experiment 2. ■ Control; ○ Dogfish-fed; ▼ Herring-fed. Values are the mean of 2 tanks (42 fish each) ± 1 s.d.

Table 7  
Sensory evaluation of salmon fillets from the two experiments

	Comparison	No. of panelists	Correct answers	Significance <sup>1</sup>
Expt. 1	Herring vs. Control	20	7	n.s.
	Dogfish vs. Control	20	9	n.s.
	Dogfish vs. Herring	20	9	n.s.
Expt. 2	Herring vs. Control	19	7	n.s.
	Dogfish vs. Control	19	10	n.s.
	Dogfish vs. Herring	20	10	n.s.

<sup>1</sup> $P > 0.05$ ; n.s. = not significant.

volatiles. Lifting the lid carefully elicits an immediate and total olfactory response. The sensory evaluation (Table 7) showed no significant difference in flavor between the fillets of the salmon fed the different diets in both experiments. In a separate study with Atlantic salmon the feeding of oxidized vegetable and herring oils was without effect on similar sensory evaluations of fillets (Koshio et al., 1994). Urea transfer is therefore not a factor and dogfish silage is consequently a possible route to waste utilization if the source is in reasonable proximity to salmon farms. The addition of a natural antioxidant (tocopherol isomer mixture) in silage preparations warrants further examination since different tocopherols have different antioxidant effects, are deposited at different rates, and may act as stabilizing materials post mortem (Sigurgisladottir et al., 1994).

Our results show that dogfish offal can be made into a fish silage acceptable for salmon farming if proper storage conditions are available. This would enable the diet producer to efficiently utilize a protein source which is unsuitable for direct human consumption by conversion into a high-quality human food product, and also help to overcome a serious environmental problem.

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