Aquaculture, 86 (1990) 19–23
Elsevier Science Publishers B.V., Amsterdam — Printed in The Netherlands

Saltwater-Induced Decreases in Weight and Length Relative to Seasonal Gill Na^+-K^+ ATPase Changes in Coho Salmon (*Oncorhynchus kisutch*): a Test for Saltwater Adaptability

W.S. ZAUGG[1] and B.R. BECKMAN

Coastal Zone and Estuarine Studies Division, Northwest and Alaska Fisheries Center, National Marine Fisheries Service, National Oceanic and Atmospheric Administration, 2725 Montlake Boulevard East, Seattle, WA 98112-2097 (U.S.A.)

(Accepted 19 July 1989)

ABSTRACT

Zaugg, W.S. and Beckman, B.R., 1990. Saltwater-induced decreases in weight and length relative to seasonal gill Na^+-K^+ ATPase changes in coho salmon (*Oncorhynchus kisutch*): a test for saltwater adaptability. *Aquaculture*, 86: 19–23.

Juvenile coho salmon challenged for 24 h in 31 ppt seawater experienced decreases in weight and length. These decreases became significantly less pronounced during the period of rise in gill Na^+-K^+ ATPase activity induced during parr-smolt transformation. It is suggested that these saltwater-induced changes in weight and length could be used as simple tests of seawater readiness.

INTRODUCTION

Rearing of anadromous salmonids in marine net pens has become an important commercial venture in many areas of the world. This method of producing marketable fish focuses attention on the importance of successful adaptation to seawater to minimize mortalities.

Fish culturists agree that the ability of juvenile fish to adapt successfully to seawater is dependent upon prior development of a smolt condition and that a knowledge of smolt status is useful in determining times for transfer to seawater. Smolting involves a series of complex biological changes, many of which can be used to measure developmental progress (Folmar and Dickhoff, 1980; Wedemeyer et al., 1980; Bern and Mahnken, 1982; Thorpe et al., 1985). Measurements of these indicators range in degree of procedural difficulty from a simple visual assessment of loss of parr marks and development of silvery co-

[1]Present address: National Marine Fisheries Service, Cook Field Station, Cook, WA 98605 (U.S.A.)

0044-8486/90/$03.50

loration to rather complex physiological, biochemical, and radiochemical determinations.

One of the common biochemical indicators of smolting is an increase in Na^+-K^+ ATPase activity in gill tissue. Although reliable and useful, the assay of this activity requires special equipment and training which are not readily available at most rearing facilities. Moreover, Aida et al. (1984) reported that masu salmon (*O. masou*) smolts lost 8.25% body weight when held for 24 h in artificial seawater (25 ppt, 10°C), whereas parr lost 13.26%. They suggested that change in body weight upon exposure to saltwater was an adequate indicator of adaptability. Blackburn and Clarke (1987) have also made similar observations with coho salmon, steelhead and rainbow trout (*Oncorhynchus mykiss*). In this study, we have examined further the possibility of using changes in length and weight following a 24 h exposure to seawater as a simple, yet effective, method of measuring saltwater adaptability. We compared changes in gill ATPase activity during the time of smolting with decreases in length and weight observed during a 24-h saltwater challange and found these changes to be good indicators of hypoosmoregulatory capacity.

METHODS

Yearling coho salmon (*Oncorhynchus kisutch*) (n=9–15) were netted approximately biweekly in early morning (prior to first feeding) from a freshwater production pond at the Willard National Fish Hatchery (U.S. Fish and Wildlife Service, Washington) and placed in a 1.5-m diameter concrete tank containing flowing water (35 cm deep) ranging from 6–8°C during mid-February to June and from the same source (Little White Salmon River) as used at the hatchery. Fish were kept without food for 24 h to reduce weight loss from defecation during saltwater exposure, netted, anesthetized with 0.005% *m*-aminobenzoate methanesulfonate (MS-222), given individual identifying fin clips, measured to the nearest 1.0 mm, weighed to the nearest 0.01 g, and allowed to recover in freshwater. After recovery, the fish were placed in a Living Stream[1] aquarium (Frigid Units, Inc., Toledo, OH) containing artificial seawater (Marine Environment, San Francisco, CA) at 31 ppt and 10°C. After 24 h, fish were removed, killed by a blow to the head, measured, and weighed. To determine Na^+-K^+ ATPase activity, gill filaments were removed and assayed according to Zaugg (1982), but with the following modifications: no water was added to the first gill homogenate, and stock solutions A and B were diluted 1:1.625 with deionized water before use.

[1]Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

RESULTS AND DISCUSSION

Coho salmon used in this study developed maximum enzyme activity during late spring (16 and 29 April, 13 May; Fig. 1). At that time, a 24-h exposure to artificial seawater, which does not affect the ATPase activity, resulted in significantly less loss of length and weight (based on 95% confidence intervals) than in early spring (13 February, 18 March) or early summer (2 and 16 June; Fig. 1, Table 1). Losses in weight ranged from about 13% (test-group average loss 2.01–4.28 g) in fish exposed to seawater prior to and after peak gill Na^+-K^+ ATPase activity to about 6% (1.50–1.53 g) for fish exposed during the period of higher enzyme activity (Fig. 1). A small amount of weight loss was due to defecation, but this was assumed to be relatively constant from one group to another and not affected by the season in which the fish were tested.

Changes in fork length resulting from saltwater exposure were likewise related to changes in gill Na^+-K^+ ATPase activity (Fig. 1, Table 1). During tests from 13 February to 1 April and again from 2 June to 16 June, only 8 fish of 61 tested failed to show a decrease in fork length (test group average loss 0.8–2.2 mm); for the period 16 April to 13 May, only 8 of 38 fish showed a decrease (0.1–0.3 mm).

Correlations between changes in length and ATPase activity and changes in

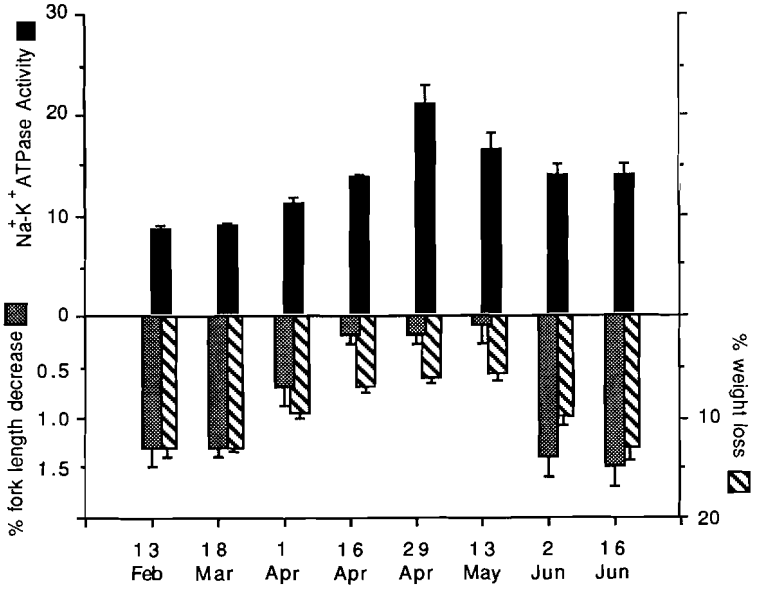

Fig. 1. Gill Na^+-K^+ ATPase activity, fork length, and weight loss for coho salmon exposed to seawater (bars represent one-half of 95% confidence intervals). Percent loss in weight and decrease in fork length are shown for yearling coho salmon after 24 h in artificial seawater (31 ppt) along with enzyme activities (μmoles P_i·mg protein $^{-1}$·h^{-1}) for the same fish.

TABLE 1

Mean fork lengths (FL) and weights of fish before 24-h exposure to saltwater and length and weight losses after exposure

1986	n[a]	Before saltwater				Loss after saltwater			
		FL (mm)		Wt (g)		FL (mm)		Wt (g)	
		Mean	s.e.[b]	Mean	s.e.	Mean	s.e.	Mean	s.e.
13 Feb.	15	120.4	3.0	20.60	1.80	1.5	0.2	2.62	0.19
18 Mar.	9	120.6	4.6	20.71	2.45	1.6	0.2	2.62	0.27
1 Apr.	13	122.0	3.4	21.03	1.74	0.8	0.3	2.01	0.21
16 Apr.	12	124.1	2.3	21.59	1.37	0.2	0.1	1.50	0.11
29 Apr.	13	130.3	2.4	25.23	1.18	0.3	0.1	1.53	0.12
13 May	13	136.5	3.2	28.10	1.75	0.1	0.2	1.51	0.11
2 Jun.	12	141.5	3.4	29.96	2.09	1.9	0.3	3.07	0.35
16 Jun.	12	143.8	3.0	33.13	2.13	2.2	0.3	4.28	0.49

[a]Number of fish.
[b]Standard error.

weight and ATPase activity resulted in coefficients (r) of 0.40 ($P<0.05$) and 0.49 ($P<0.01$), respectively, with $n=98$. Coefficients were not higher mainly because ATPase levels did not return to pre-elevated levels, whereas in the final two samples, decreases in percent weight and length more closely approximated initial values (Fig. 1).

Several studies have shown that elevated gill Na^+-K^+ ATPase activities in freshwater are associated with increased ability of anadromous salmonids to survive when transferred to seawater (Adams et al., 1975; Lasserre et al., 1978; Harache et al., 1980; Boeuf et al., 1985; McCormick et al., 1985). Our present results suggest that gill Na^+-K^+ ATPase activity, which develops as coho salmon undergo parr–smolt transformation, is involved in osmotic and ionic balance of salmonids in seawater. The pronounced reduction in saltwater-induced loss in weight and length during the period of elevated enzyme activity lends support to this conclusion. Preliminary experiments (data not shown) with subyearling chinook salmon (*O. tshawytscha*) also show a trend toward less weight loss upon saltwater exposure as gill Na^+-K^+ ATPase activity becomes elevated. It may be necessary, however, to test more fish (n greater than 15) when using small subyearlings.

Measurement of changes in weight or length after a 24-h saltwater exposure may provide a simple and inexpensive tool to evaluate hypoosmoregulatory ability and to determine seawater entry times for anadromous salmonids. When applied to a routine monitoring situation, it would not be necessary to identify individual fish, but to simply use the total decrease in length or loss in weight of a tested group. If length decrease rather than weight loss is the parameter

used, the amount of residual food in the gut would be of no consequence in the analysis.

ACKNOWLEDGEMENTS

We thank personnel at the Willard National Fish Hatchery, U.S. Fish and Wildlife Service, for providing fish for this study; also Dr. W. Dickhoff for preparing the figure.

REFERENCES

Adams, B.L., Zaugg, W.S. and McLain, R.L., 1975. Inhibition of saltwater survival and Na-K-ATPase elevation in steelhead trout (*Salmo gairdneri*) by moderate water temperatures. Trans. Am. Fish. Soc., 104(4): 766-769.

Aida, K., Kato, T. and Awaji, M., 1984. Effects of castration on the smoltification of precocious male masu salmon (*Oncorhynchus masou*). Bull. Jpn. Soc. Sci. Fish., 50(4): 565-571.

Bern, H.E. and Mahnken, C.V.W. (Editors), 1982. Salmonid Smoltification, Special Issue. Aquaculture, 28(1/2): 270 pp.

Blackburn, J. and Clarke, W.C., 1987. Revised procedure for the 24 hour seawater challenge test to measure seawater adaptability of juvenile salmonids. Can. Tech. Rep. Fish. Aquat. Sci., 1515: 1-35.

Boeuf, G., Le Roux, A., Gaignon, J.L. and Harache, Y., 1985. Gill (Na^+-K^+)-ATPase activity and smolting in Atlantic salmon (*Salmo salar* L.). Aquaculture, 45: 73-81.

Folmar, L.C. and Dickhoff, W.W., 1980. The parr-smolt transformation (smoltification) and seawater adaptation in salmonids. A review of selected literature. Aquaculture, 21: 1-37.

Harache, Y., Boeuf, G. and Lasserre, P., 1980. Osmotic adaptation of *Oncorhynchus kisutch* Walbaum. III. Survival and growth of juvenile salmon transferred to sea at various times of the year. Aquaculture, 19: 253-273.

Lasserre, P., Boeuf, G. and Harache, Y., 1978. Osmotic adaptation of *Oncorhynchus kisutch* Walbaum. I. Seasonal variations of gill Na^+-K^+ ATPase activity in coho salmon, 0^+-age and yearling, reared in fresh water. Aquaculture, 14: 365-382.

McCormick, S.D., Naiman, R.J. and Montgomery, E.T., 1985. Physiological smolt characteristics of anadromous and nonanadromous brook trout (*Salvalinus salar*). Can. J. Fish. Aquat. Sci., 42: 529-538.

Thorpe, J.E., Bern, H.A., Saunders, R.L. and Soivio, A. (Editors), 1985. Salmonid Smoltification II, Special Issue. Aquaculture, 45: 403 pp.

Wedemeyer, G.A., Saunders, R.L. and Clarke, W.C., 1980. Environmental factors affecting smoltification and early marine survival of anadromous salmonids. Mar. Fish. Rev., 42: 1-14.

Zaugg, W.S., 1982. A simplified preparation for adenosine triphosphatase determination in gill tissue. Can. J. Fish. Aquat. Sci., 39: 215-217.