Critical Salinity Maxima and Salinity Endurance in Splittail

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The range of splittail, *Pogonichthys macrolepidotus*, has decreased due to loss or alteration of habitats (Herbold *et al* 1992; Moyle and Yoshiyama 1992; Moyle *et al* 1995). We have studied environmental tolerances and requirements of splittail to assist in effective water and habitat management and restoration of this species. This report on critical salinity maxima (CS_{max}) and salinity endurance of young-of-the-year (0.2-4 g), juvenile (19-42 g), and subadult (81-170 g) splittail is part of the study.

CS_{max} were measured by subjecting the fish to increasing levels of salinity (3-4‰/h) starting at 0‰ through a rock salt brine drip system until fish have complete loss of equilibrium (endpoint). Salinity endurance was measured by slowly (5-6 minutes) introducing a concentrated rock salt brine solution into each test vessel until the desired salinity level (12 [YOY only], 14 [YOY only], 16, 20, 24, and 28‰) was reached. Immediately after the endpoint, the time to loss of equilibrium (TLE) was recorded. If TLE was not observed for >120 hours, the experiment was ended.

Although fish were acclimated to fresh water, mean CS_{max} values were high (20-29‰; Figure 1). Mean CS_{max} (22-27‰) for 17°C-acclimated fish increased with increase in fish weight described by CS_{max} = 21.89 + (0.05 x wet weight). Increase in acclimation temperature did not significantly affect the CS_{max}.

Mean time to loss-of-equilibrium in all age groups generally decreased as salinity increased (Figure 2; regression equations in Table 1). At 16 and 20‰, mean TLE was significantly lower for young-of-the-year than for other age groups. From the regressions (Table 1), salinity tolerance levels were estimated for different TLE periods for different age groups of splittail (Table 2). Young-of-the-year had the lowest CS_{max} and also the lowest estimated salinity tolerance levels for different TLE periods.

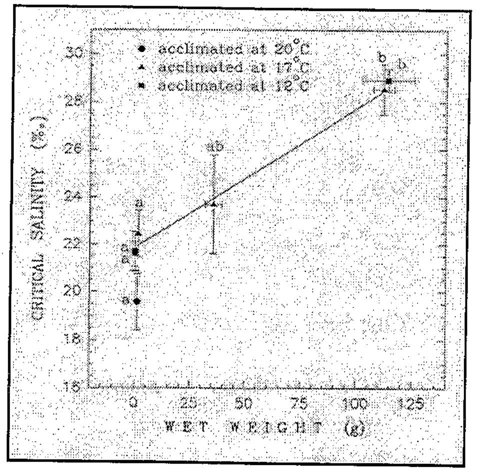

Figure 1
MEAN CRITICAL SALINITY MAXIMA OF SPLITTAIL IN RELATION TO MEAN WEIGHT AT DIFFERENT ACCLIMATION TEMPERATURES
Regression line is plotted for 17°C fish only.
N=4-8
Symbols with different letters are significantly different.

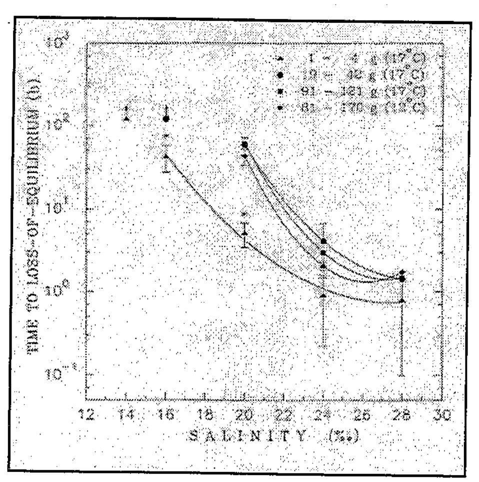

Figure 2
MEAN TIME TO LOSS OF EQUILIBRIUM IN RELATION TO SALINITY LEVEL IN DIFFERENT AGE GROUPS OF SPLITTAIL
N=3-4
** indicates significantly lower TLE value at the same salinity level.*
Arrow indicates survival for more than 120 hours.

Cyprinids are typically stenohaline freshwater fishes, although a few California species have been reported to tolerate salinity levels of 12-16‰. However, splittail have an unusually high salinity tolerance, even when freshwater-acclimated. They are found in the estuary, living in environments where salinity fluctuates due to flooding, drought, and tidal and seasonal cycles. For example, salinity levels in Suisun Marsh (where most of the juveniles and subadults used in these studies were collected) seasonally range over 0-17‰ (Baracco 1980) and can increase at 1‰/hour over a 6-hour tidal change (L. Millet, DWR, personal communication). They have also been captured in water with salinity as high as 18‰ (Meng and Moyle 1995).

In nature, adult splittail migrate upstream into fresh water to spawn in flooded vegetation. The larvae remain in shallow, weedy areas and young-of-the-year (size probably greater than our YOY) migrate downstream with streamflow into shallow, productive waters of the estuary (Wang 1986; Meng and Moyle 1995). Results of the salinity endurance tests confirmed that our young-of-the-year were much more sensitive than the juveniles and subadults to increased salinity levels. The longer-term TLE results (Table 2) are recommended for determining splittail salinity requirements.

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Table 1
RELATIONSHIP BETWEEN SALINITY (S, in ‰) AND TIME TO LOSS OF EQUILIBRIUM (TLE, in hours) FOR SPLITTAIL AGE GROUPS

Age Group	Acclimation Temperature	N	Equation	r^2	P
YOY	17°C	15	$\log_{10}$ TLE = 13.720 - 1.087 (S) + 0.021 (S^2)	0.836	<0.001
Juveniles	17°C	11	$\log_{10}$ TLE = 5.946 - 0.210 (S) - 0.0001 (S^2)	0.999	<0.001
Subadults	17°C	12	$\log_{10}$ TLE = 9.473 - 0.520 (S) + 0.007 (S^2)	0.971	<0.001
	12°C	10	$\log_{10}$ TLE = 10.346 - 0.613 (S) + 0.009 (S^2)	0.944	<0.001

Table 2
MEAN CRITICAL SALINITY MAXIMA (CSmax±SEM) AND ESTIMATED SALINITY TOLERANCE LEVELS (‰) FOR DIFFERENT TIMES TO LOSS OF EQUILIBRIUM OF SPLITTAIL AGE GROUPS
Salinity tolerance levels were estimated based on TLE regression equations from Table 1.

Criterion	Young-of-Year (17°C)	Juvenile (17°C)	Subadult (17°C)	Subadult (12°C)
CS_{max}	22.4 (±1.0)	23.7 (±2.1)	27.4 (±1.2)	28.8 (±0.5)
6-hour TLE	20	24	24	23
12-hour TLE	19	23	24	22
24-hour TLE	18	22	22	21
48-hour TLE	17	21	21	20
72-hour TLE	16	20	20	20
96-hour TLE	16	19	19	19

Literature Cited

Baracco, A. 1980. *Aquatic Resources of Suisun Marsh with an Analysis of the Fishery Effects of a Proposed Water Quality Maintenance Plan.* Department of Fish and Game, Anadromous Fisheries Branch Administrative Report.

Herbold, B., A.D. Jassby, P.B. Moyle. 1992. *Status and Trends Report on Aquatic Resources in the San Francisco Estuary.* Public Report of the San Francisco Estuary Project.

Meng, L., and P.B. Moyle. 1995. Status of splittail in the Sacramento-San Joaquin estuary. *Transactions of the American Fisheries Society* 124:538-549.

Moyle, P.B., and R.M. Yoshiyama. 1992. *Fishes, Aquatic Diversity Management Areas, and Endangered Species: A Plan to Protect California's Native Aquatic Biota.* The California Policy Seminar, University of California.

Moyle, P.B., R.M. Yoshiyama, J.E. Williams, and E.D. Wikramanayake. 1995. *Fish Species of Special Concern in California. Second Edition.* Department of Fish and Game. Final Report for Contract 2181F.

Wang, J.C.S. 1986. *Fishes of the Sacramento-San Joaquin Estuary and Adjacent Waters, California: A Guide to the Early Life Histories.* Department of Water Resources, Interagency Ecological Study Program Technical Report 9, Sacramento.