An Overview of Otolith Thermal Marking

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Otoliths have been a primary focus of salmonid mass-marking efforts as they are the first calcified elements to form, are well-known recorders of environmental fluctuations, and induced structural or chemical marks are permanent. In particular, dramatic effects on otolith increment width and optical density have been tied to temperature changes (Campana and Neilson1985; Neilsen and Geen 1985; Mosegaard et al. 1987; Brothers1990; Volk et al.1990, 1994; Munk et al. 1993), and investigators have utilized this fundamental connection to place internal otolith marks on large numbers of hatchery salmonids including lake trout (Brothers 1985, 1990; Bergstedt et al. 1990), Arctic charr (Mosegaard et al. 1987), and all species of Pacific salmon (Volk et al. 1990; 1999; Munk et al. 1993).

Hatchery-incubated salmonids are particularly well suited for thermal marking because incubation and yolk absorption stages are protracted, large numbers of fish are concentrated in hatchery incubators, and otoliths begin growing in embryos. As a result, there is a lengthy period during which multiple marks may be administered, and this includes both the pre- and post-hatch otolith regions. Nearly all salmon otolith-marking endeavors mark fish between the eyed-egg and fry stages, and there are few marking alternatives if embryos must be marked, such as when eyed-eggs are placed in remote site incubators.

The basis of otolith thermal marking is that short-term temperature manipulations alter the appearance of one or more otolith increments, producing an obvious pattern of events that could be recognized at any life stage. Depending upon the mean ambient temperature, water may be heated or chilled to produce the desired effect, and exposure times have varied from as little as two hours (chilled water) to heated water exposures lasting several days. The magnitude of the temperature change typically is governed by capacity for producing heated or chilled water, and generally ranges from 2°C to 5°C with larger changes producing more apparent effects (Volk et al. 1999).

Since there is a close relationship between accumulated temperature units and the spacing between induced thermal events, it is easy to create patterns based upon the number and relative spacing of induced events. The two coding schemes currently employed are the bar code (Volk et al. 1994) and the RBr code (Munk and Geiger 1998). Both of these systems utilize band number as well as the spacing between bands or groups of bands induced in different otolith regions to describe a pattern. While large numbers of unique patterns are theoretically possible using either of the coding methods, practical limitations associated with hatchery operations, fish development and visual recognition place important limits on the number of possible patterns (Hagen 1999). Though many marking objectives can be achieved with no organized rules for pattern assignment, a standardized system of organizing pattern information on otoliths potentially offers a larger number of patterns, and also provides the opportunity for coordinating marks between agencies and countries so that duplicates may be avoided in mixed-stock recovery areas (Urawa et al. this volume).

Because we depend upon skilled human readers to detect marks errors are inevitable, and may arise from poor otolith marks, natural mimics of induced patterns, and poor preparations. Patterns of dark increments are easily induced into growing otoliths using temperature changes, but otolith mark recognition is dependent not only upon the effect of planned thermal events on the otolith, but also on the background or ambient increment characteristics against which they must be recognized. Otolith mark recognition is a signal and noise problem where the induced mark signal must be distinguished against the background incremental "noise" created by the ambient temperature regime and other physical disturbances. Thus, the ultimate quality of the otolith mark, and the likelihood of mis-classifications, depends not only on the pattern induced, but also on how easily that pattern is discriminated from background increment characteristics resulting from ambient temperature conditions.

The potential for errors in recognizing otolith marks has been studied using known mark status specimens. Bergstedt et al. (1990) reported that among juvenile lake trout held six months after marking, marked and unmarked controls were accurately recognized in 85–98% of the samples (N= 41). Most errors misclassified non-marked fish. Hagen et al. (1995) accurately identified 64–100% of known marked and non-marked adult pink salmon otoliths (N = 36). Among 1,852 chinook and coho salmon otoliths that were known to be marked or non-marked, Volk et al.

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(1999) reported an overall mean error rate for known marked fish of 2%. However, for non-otolith marked control fish, there was a discrepancy rate of 6–11% between mark determinations and their true status. Both Volk et al. (1999) and Bergstedt et al. (1990) suggested that the presence of a pattern is more easily recognized than its absence, highlighting the importance of the background otolith pattern in the ultimate success of discerning an induced pattern.

Unfortunately, evaluating the magnitude of these discrepancies in most cases is difficult because there is usually no "gold standard" of known mark status specimens with which to compare mark determinations, and findings are usually reached using several readers to examine each otolith. Recently, Blick and Hagen (in press) discussed the use of agreement measures and latent class models for evaluating the precision of otolith mark determinations. Agreement measures, such as *kappa,* can be useful as a relative measure of the reliability of determinations with two independent readings, but the proportion of marked fish can influence its magnitude. With a third reader, latent class models can provide estimates of the of the error rates for each reader. If key assumptions are met, these methods provide a means to evaluate the precision of mark group composition where no error free standards exist.

Currently some 5 billion juvenile salmon are released by hatcheries into the North Pacific annually, with some 20% carrying thermally induced otolith marks (Urawa et al. this volume). Management of hatchery stocks for harvest coupled with increasing concerns over their impacts on wild fish have placed a growing premium on identification of hatchery-reared fish. A variety of large-scale otolith marking efforts have demonstrated that it is practically feasible and economically viable to mark all hatchery production in the North Pacific with thermal codes. However, the utility of thermal marking for discerning the origins of fish captured in high seas, mixed-stock fisheries may be limited by the number of possible codes available, requiring the use of secondary marks or tags to maintain the necessary number of unique marks.

REFERENCES

Bergstedt, R.A., R.L. Eschenroder, C. Bowen, J.G. Seelye, and J.C. Locke. 1990. Mass-marking of otoliths of lake trout sac fry by temperature manipulation. Am. Fish. Soc. Symp. 7: 216–223.

Blick, D.J., and P.T. Hagen. In press. The use of agreement measures and latent class models to assess the reliability of thermally marked otolith classifications. Fish. Bull.

Brothers, E.B. 1985. Otolith marking techniques for the early life history stages of lake trout. Final report to Great Lakes Fishery Commission. October, 1985. 34 p.

Brothers, E.B. 1990. Otolith Marking. Am. Fish. Soc. Symp. 7: 183–202.

Campana, S.E., and J.D. Neilson. 1985. Microstructure of fish otoliths. Can. J. Fish. Aquat. Sci. 42: 1014–1032.

Hagen, P., K. Munk, B. Van Alen, and B. White. 1995. Thermal mark technology for in-season fisheries management: a case study. Alaska Fish. Res. Bull. 2: 143–155.

Hagen, P. 1999. A modeling approach to address the underlying structure and constraints of thermal mark codes and code notation. (NPAFC Doc. 395) 12p. Alaska Dept. of Fish and Game, Juneau, Alaska, 99801-5526.

Mosegaard, H., N.G. Steffner, and B. Ragnarsson. 1987. Manipulation of otolith microstructure as a means of mass-marking salmonid yolk sac fry. Proceedings of the Fifth Congress of European Ichthyologists 1985: 213–220.

Munk, K.M., W.W. Smoker, D.R. Beard, and R.W. Mattson. 1993. A hatchery water-heating system and its application to 100% thermal marking of incubating salmon. Prog. Fish Cult. 55: 284–288.

Munk, K.M., and H.J. Geiger. 1998. Thermal marking of otoliths: the "RBr" coding structure of thermal marks. (NPAFC Doc. 367) 19p. Alaska Department of Fish and Game-CWT & Otolith Processing Lab, Box 25526, Juneau, Alaska, 99802.

Neilson, J.D., and G.H. Geen. 1985. Effects of feeding regimes and diel temperature cycles on otolith increment formation in juvenile chinook salmon *Oncorhynchus tshawytscha*. Fish. Bull. 82: 91–101.

Urawa, S., P.T. Hagen, D. Meerburg, A. Rogatnykh, and E. Volk. This volume. Compiling and coordinating salmon otolith marks in the North Pacific. N. Pac. Anadr. Fish Comm. Tech. Rep. No. 3.

Volk, E.C., S.L. Schroder, and K.L. Fresh. 1990. Inducement of unique otolith banding patterns as a practical means to mass-mark juvenile Pacific salmon. Am. Fish. Soc. Symp. 7: 203–215.

Volk, E.C., S.L. Schroder, J.J. Grimm, and H.S. Ackley. 1994. Use of a bar code symbology to produce multiple thermally inducedmarks. Trans. Am. Fish. Soc. 123: 811–816.

Volk, E.C., S.L. Schroder, and J.J. Grimm. 1999. Otolith thermal marking. Fish. Res. 43: 205–219.