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Migratory History Recorded in Otoliths of the Japanese Eel, *Anguilla Japonica*, Elvers as Revealed from SEM and WDS Analyses

Wann-Nian Tzeng

Department of Zoology, College of Science, National Taiwan University, Taipei, Taiwan 106, R.O.C.

The environmental history of the Japanese eel, *Anguilla japonica* (Temminck & Schlegel), during its migration from the spawning ground to the rivers of Taiwan, was studied by examining otolith microstructure with SEM, and the strontium (Sr) and calcium (Ca) contents measured from wavelengths of x-rays emitted from the otoliths with WDS (Wavelength dispersive spectroscopy). The Sr/Ca changes in the otoliths in relation to environmental and physiological changes of the fish are discussed.

LIFE HISTORY OF THE EEL

The Japanese eel is one of the most important culture species in Taiwan. Large numbers of eel elvers are caught for cultivation from November to March during their upstream migration in estuaries (Tzeng 1985). The eel is a catadromous fish, spawning in the North Equatorial Current west of the Mariana Islands (15°N, 140°E) during the period from June to July (Tsukamoto 1992). The eel larvae, a willow-leaf-shaped leptocephali, drift with the current from their oceanic spawning ground, and metamorphose into transparent glass eel, or elvers, before entering the estuaries. After upstream migration, the elvers become young eels and live in the rivers for 5-20 years. During late autumn, the maturing eel migrates downstream to the ocean to spawn.

OTOLITH MICROSTRUCTURE AND DAILY AGE

Since Pannella (1971) discovered primary growth increments in otoliths of fish, ageing technique by examining daily growth increments in otoliths has been applied widely to study the age of ths fish (Campana and Neilson 1985). There are three pairs of otoliths in fish's otic vesicles, functioning as hearing and body balance of the fish. Otolith is a biogenic aragonite, alternatively consisted of a calcium-rich incremental zone and an organic-rich discontinuity zone. When otoliths are ground with fine mesh polishing paper, polished with alumina paste, and etched with 5% EDTA (ethylene diamine tetra-acetate; pH adjusted with NaOH to 7.4). The above-mentioned two zones become the "crest and trough" on the polished otolith, which could then be viewed under SEM (Fig.1). The otolith incremental and discontinuity zones are deposited on a daily basis (Tzeng and Yu 1988). This permitted the time required for migration of the eel larvae from the spawning ground to the coasts, and the spawning season of the eel, to be estimated (Table 1).

OTOLITH MICROCHEMISTRY AND MIGRATORY HISTORY

Recent studies have indicated that past environmental history of the fish can be reconstructed from analysis of the ratio of trace element, especially Sr, incorporated during the process of otolith growth (Radtke et al. 1990, Secor 1992). Sr can inter-change with Ca in otoliths during the depositional process because Sr has the same valence as Ca, as well as a similar ionic radius (Amiel et al. 1973). The Sr content in the otolith of diadromous fish was found to differ between freshwater and seawater phases (Casselmam 1982, Radke et al. 1988, Kalish 1990). The incorporation of Sr into the otolith is a physiological process controlled by many interactive factors including temperatrue, salinity, ontogeny and migration (Kalish 1989, Sadovy and Severin 1992, Smith et al. 1979,

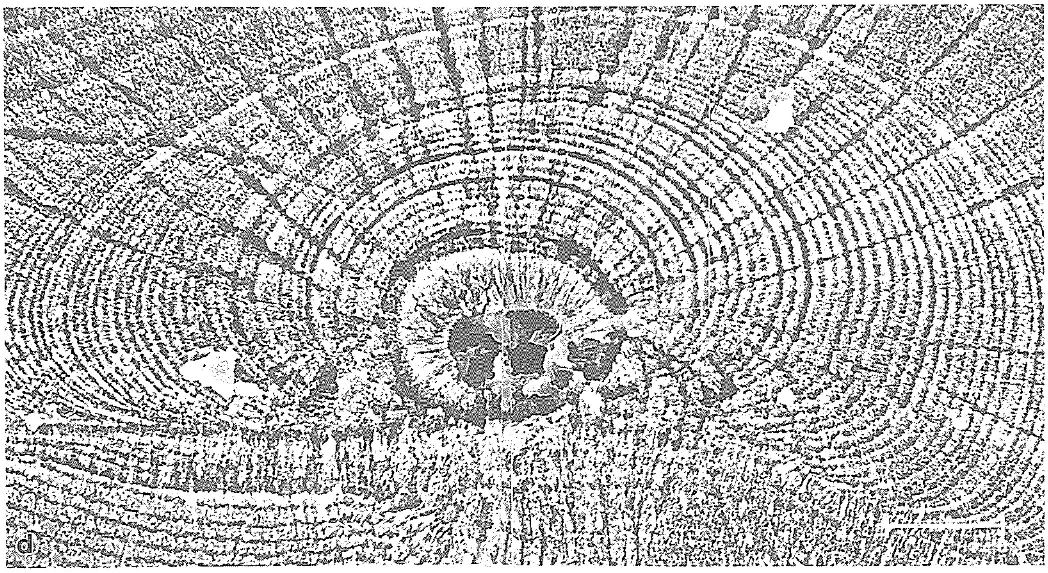

Fig. 1. SEM micrograph illustrating daily growth incremental (light band) and discontinuity zones (dark band) in otolith of a 56.0 mm TL elver. Scale bar = 10 μm. (from Tzeng 1990).

Table 1. Daily ages and birth date of elvers collected from four estuaries (SA, SL, LS and TK) in the eastern and western coasts of Taiwan on 22 December 1989 and 22 and 23 January 1990. (from Tzeng and Tsai 1992)

Sampling site	Sampling date	Sample size	Total length (mm)	Otolith radius (μm)	Age (days)	Birth date
SA	22 Dec. 1989	9	56.39±1.39	141.25±8.85	169.3±14.9	18 June-24 July
SL	22 Jan. 1990	5	56.66±2.84	129.44±10.21	175.6±27.8	26 June-9 Sept.
LS	22 Jan. 1990	5	56.20±2.21	56.20±2.21	165.6±22.6	10 July-3 Sept.
TK	23 Jan. 1990	6	56.80±2.15	56.80±2.15	171.7±26.2	7 July-22 Sept.

Townsend et al. 1992, Tzeng 1994). Quantitative measurements of the concentration of Sr in otolith relative to that of Ca was made using a WDS for the elver collected in a river estuary of northern Taiwan.

The Sr/Ca concentration ratio was lower in the primordium of the otolith, then increased gradually and reached a maximum at an area approximately two-thirds of the otolith radius from the primordium, and dramatically decreased to a low level at the otolith edge during the fish migrated to the freshwater (Fig. 2). The otoliths of freshwater fishes typically have lower Sr levels than those of seawater fishes (Odum 1975). The low Sr content in the primordium, probably due to the sources of deposition, were of maternal or freshwater origin of the oocyte. The dramatic decrease in Sr/Ca ratio most likely corresponds to the period when leptocephalus metamorphoses into an elver. When finishing metamorphosis, the fish will migrate from the strong Kuroshio Current into coastal waters. Leptocephalus is known to contain extensive amounts of gelatinous extracellular matrix composed of sulfated glycosaminoglyscans (GAG) which are broken down during the process of metamorphosis (Pfeiler 1984). Since GAG indicates an affinity to alkali earth elements, particularly high to Sr (Nishizawa 1978). GAG breakdown may reduce the absorption Sr from seawater and result in a drastic decrease of otolith Sr content and, consequently, Sr/Ca ratios (Otake et al. 1994).

In conclusion, otoliths are like a biological CD ROMs recording information about the environment the fish experienced and about how the fish lived. The information on them is never lost and can be retrieved potentially in any temporal sequence.

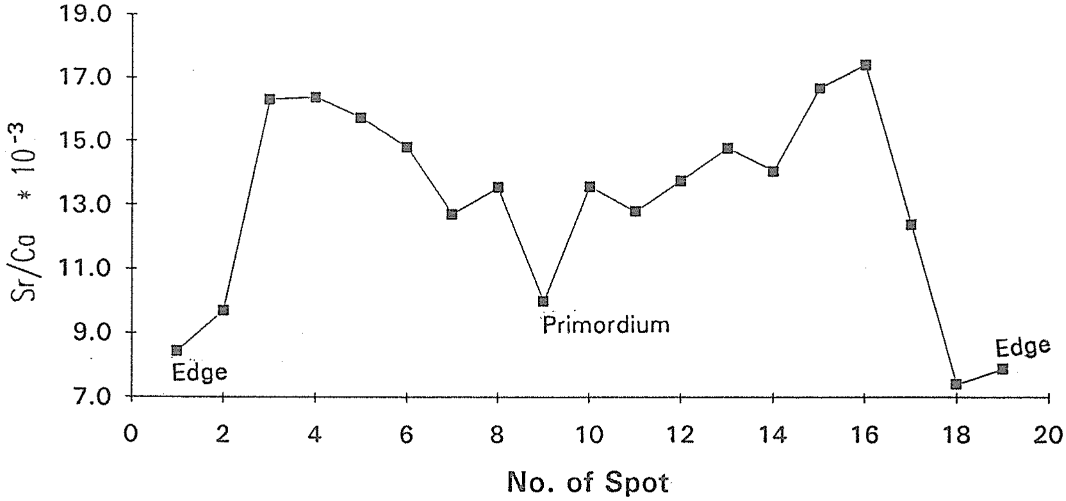

Fig. 2. Changes in strontium/calcium concentration ratio measured through the maximum edge-primordium-edge axis (spots 1-19) of a sectioned otolith of a 56.2 mm TL elver with a maximum otolith diameter of 142 µm, collected in a river estuary of northern Taiwan on 22 January 1990. (from Tzeng and Tsai 1994)

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