



Detecting and tracing farmed salmon with otolith tags: developing and validating multiple mark delivery techniques

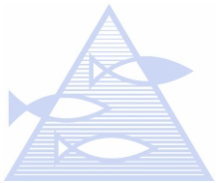


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Detecting and tracing farmed salmon with otolith tags: developing and validating multiple mark delivery techniques

- I. Overview of geochemical marking techniques
- II. Rare Earth Elements via feed
- III. Otolith marking via vaccination
- IV. Otolith marking via maternal transfer
- V. Otolith marking via egg immersion
- VI. Summary and application



Mass Marking Fish for Identification

Why?

Collecting information for:

- * Stock enhancement
- * Mark recapture studies
- * Understanding population connectivity
- * Fish migratory patterns



Mass Marking Fish for Identification

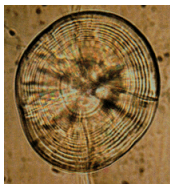
Why?

Collecting information:

- * Stock enhancement
- * Mark recapture programs
- * Understanding population connectivity
- * Fish migratory patterns

- * **Norway:** Identifying and tracing farmed salmon escapees

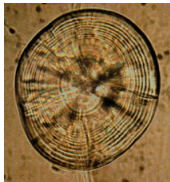




Identification using geochemical “otolith fingerprinting”

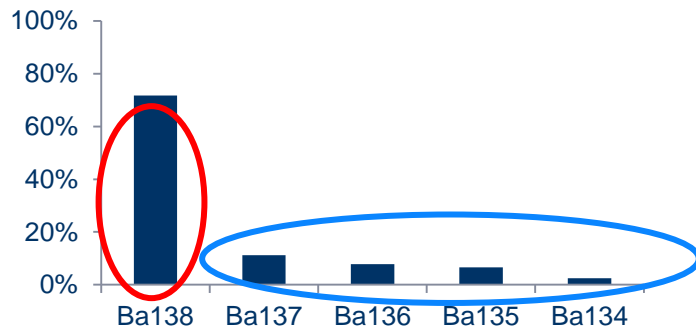
- Technique has potential for both 100% marking and traceability
- Otolith formed during embryogenesis
- Grow continuously
- Metabolically inert
- Incorporate other elements (e.g. Ba, Sr, Mg)
- Labelling with element mixtures to create unique fingerprints



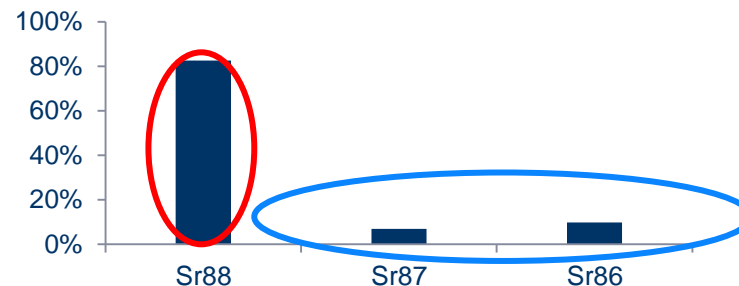


Barium and Strontium

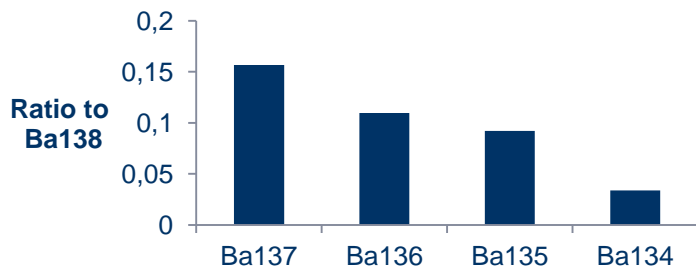
Natural occurrence of barium



Natural occurrence of strontium

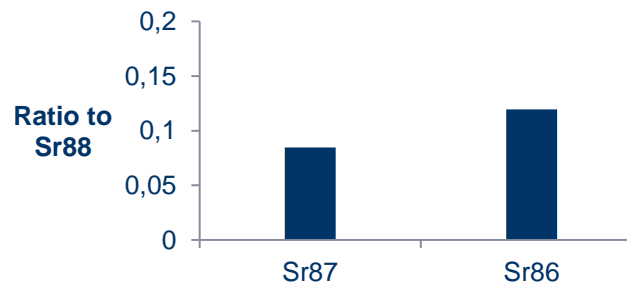


Natural ratios relative to Ba138

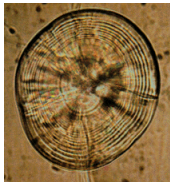


Invariant in nature

Natural ratios relative to Sr88

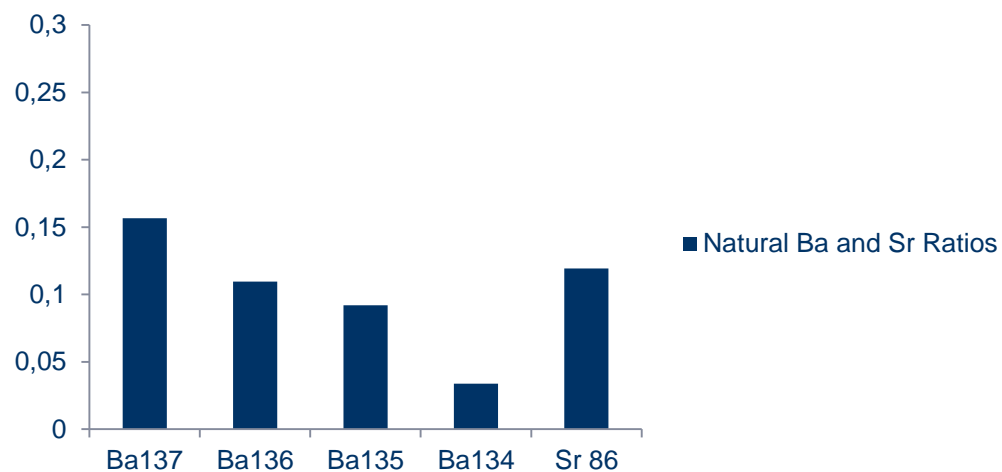


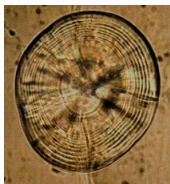
Invariant in nature



Creating a Fingerprint tag

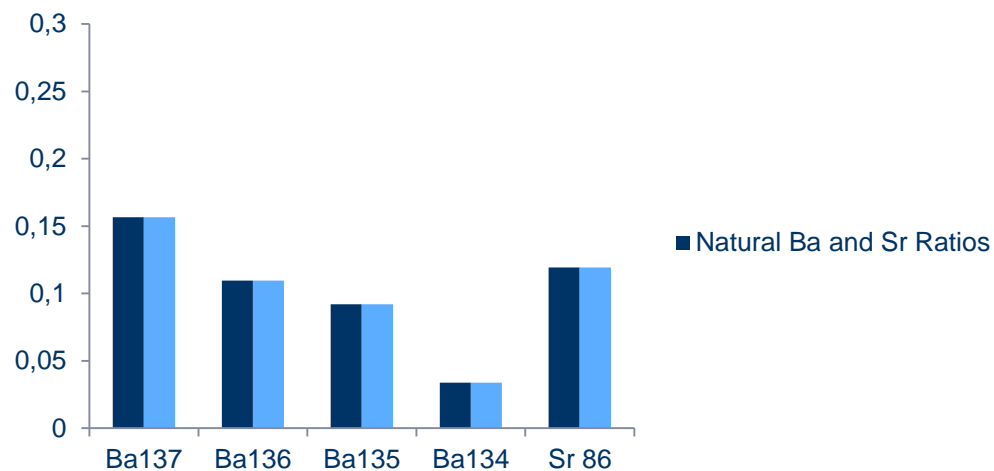
Natural Ratios of Ba and Sr

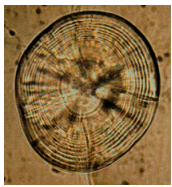




Creating a Fingerprint tag

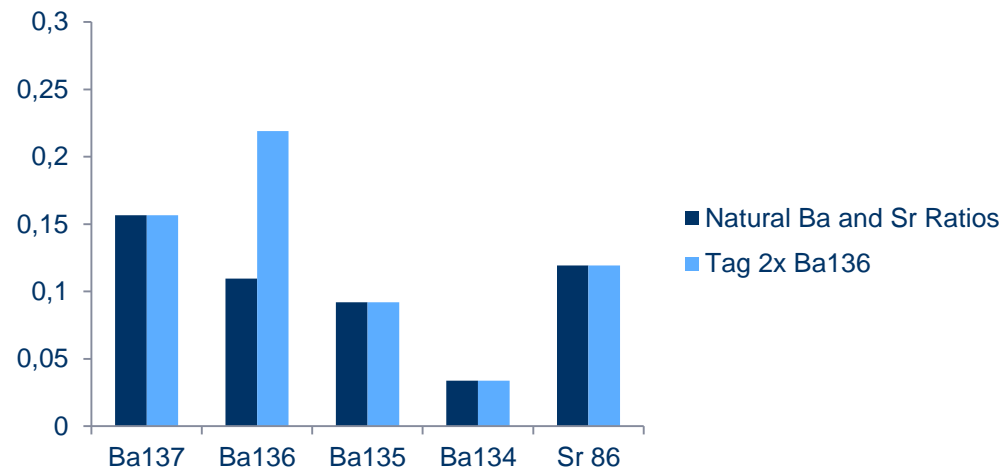
Fingerprint tag (#markers = 0)

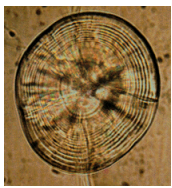




Creating a Fingerprint tag

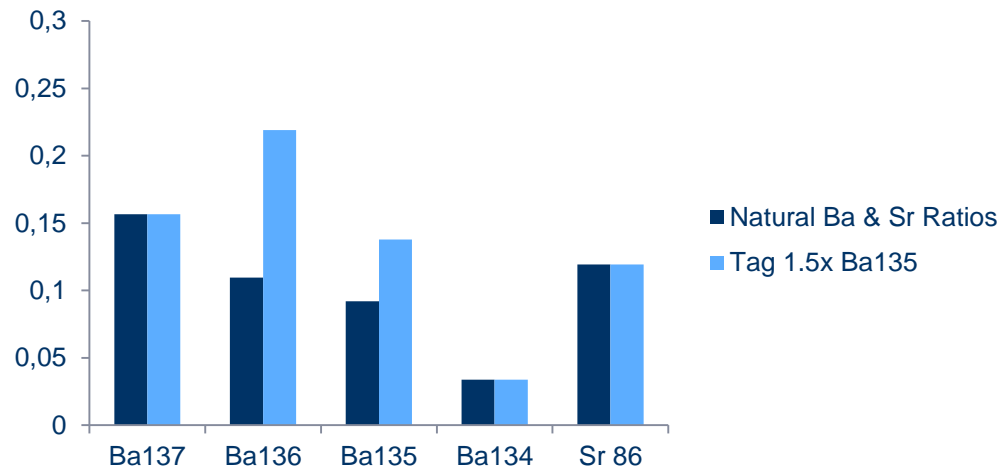
Fingerprint tag (#markers = 1)

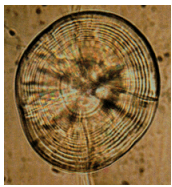




Creating a Fingerprint tag

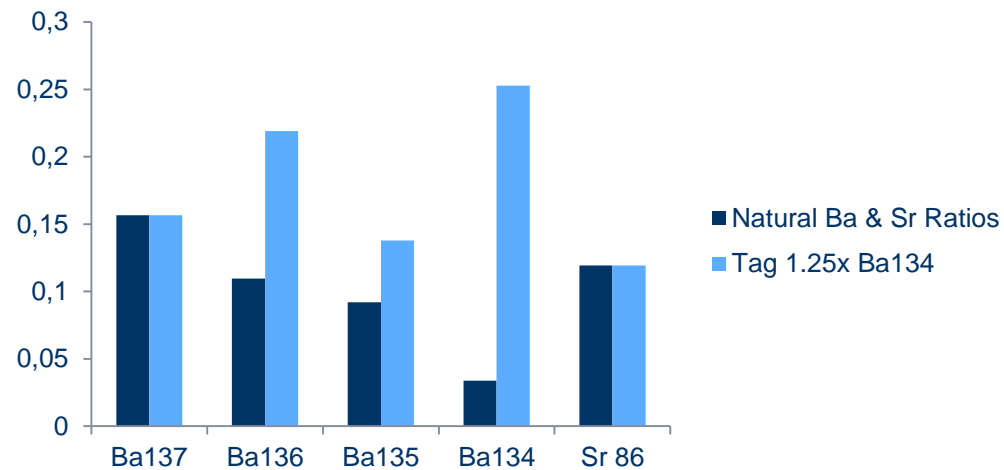
Fingerprint tag (#markers = 2)

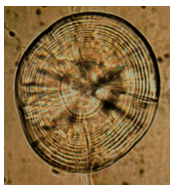




Creating a Fingerprint tag

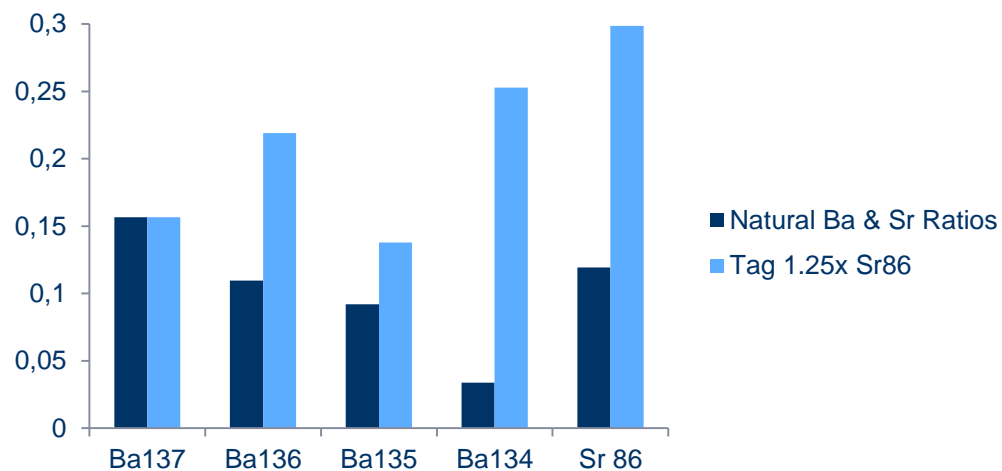
Fingerprint tag (#markers = 3)

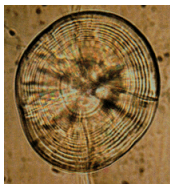




Creating a Fingerprint tag

Fingerprint tag (#markers = 4)





How many different fingerprint tags?

1 markers $(2^1 - 1) = 1$ tag

2 markers $(2^2 - 1) = 3$ tags

3 markers $(2^3 - 1) = 7$ tags

7 markers $(2^7 - 1) = 127$ tags

Number of possible tags = $(2^{\text{number of markers}} - 1)$

Possible to create > 1000 combinations

*Enough for every fish farm to have their own individual
unique fingerprint tag*

Common Geochemical Markers

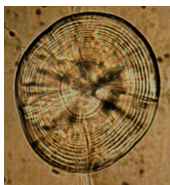
- Ba – 6 rare forms
- Sr – 3 rare forms
- Mg – 2 rare forms
- Cr – 3 rare forms
- Fe – 3 rare forms



Periodic

1 1.01 H Hydrogen																	2 4.003 He Helium						
3 6.94 Li Lithium	4 9.01 Be Beryllium																	5 10.81 B Boron	6 12.01 C Carbon	7 14.01 N Nitrogen	8 15.999 O Oxygen	9 18.998 F Fluorine	10 20.18 Ne Neon
11 22.99 Na Sodium	12 24.31 Mg Magnesium																	13 26.98 Al Aluminum	14 28.09 Si Silicon	15 30.97 P Phosphorus	16 32.06 S Sulfur	17 35.45 Cl Chlorine	18 39.96 Ar Argon
19 39 K Potassium	20 40.08 Ca Calcium	21 44.96 Sc Scandium	22 47.88 Ti Titanium	23 50.94 V Vanadium	24 51.996 Cr Chromium	25 54.94 Mn Manganese	26 55.85 Fe Iron	27 58.93 Co Cobalt	28 58.70 Ni Nickel	29 63.55 Cu Copper	30 65.37 Zn Zinc	31 69.72 Ga Gallium	32 72.59 Ge Germanium	33 74.92 As Arsenic	34 78.96 Se Selenium	35 79.90 Br Bromine	36 83.80 Kr Krypton						
37 85.47 Rb Rubidium	38 87.62 Sr Strontium	39 88.91 Y Yttrium	40 91.22 Zr Zirconium	41 92.91 Nb Niobium	42 92.91 Mo Molybdenum	43 98.91 Tc Technetium	44 101.07 Ru Ruthenium	45 102.91 Rh Rhodium	46 106.42 Pd Palladium	47 107.87 Ag Silver	48 112.41 Cd Cadmium	49 114.82 In Indium	50 118.69 Sn Tin	51 121.75 Sb Antimony	52 127.60 Te Tellurium	53 126.90 I Iodine	54 131.30 Xe Xenon						
55 132.9 Cs Cesium	56 137.33 Ba Barium	57 138.91 La Lanthanum	72 178.49 Hf Hafnium	73 180.95 Ta Tantalum	74 183.85 W Tungsten	75 186.21 Re Rhenium	76 190.20 Os Osmium	77 192.22 Ir Iridium	78 195.09 Pt Platinum	79 196.97 Au Gold	80 200.59 Hg Mercury	81 204.37 Tl Thallium	82 207.19 Pb Lead	83 208.98 Bi Bismuth	84 (209) Po Polonium	85 (210) At Astatine	86 (222) Rn Radon						
87 (223) Fr Francium	88 (226) Ra Radium	89 227.03 Ac Actinium	104 (261) Rf Rutherfordium	105 (262) Ha Hahnium	106 (266) Sg Seaborgium	107 (262) Bh Bohrium	108 (265) Hs Hassium	109 (266) Mt Meitnerium	110 (271) Ds Darmstadtium	111 (272) Rg Roentgenium	112 (277) Cn Copernicium	(113)	(114)	(115)	(116)	(117)	(118)						

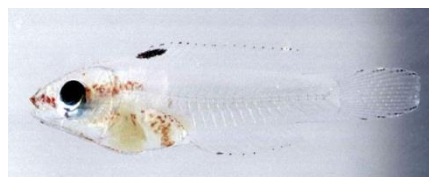
58 140.12 Ce Cerium	59 140.91 Pr Praseodymium	60 144.24 Nd Neodymium	61 (145) Pm Promethium	62 150.40 Sm Samarium	63 151.96 Eu Europium	64 157.25 Gd Gadolinium	65 158.93 Tb Terbium	66 162.90 Dy Dysprosium	67 164.93 Ho Holmium	68 167.26 Er Erbium	69 168.93 Tm Thulium	70 173.04 Yb Ytterbium	71 174.97 Lu Lutetium
90 232.04 Th Thorium	91 231.04 Pa Protactinium	92 238.03 U Uranium	93 237.05 Np Neptunium	94 (244) Pu Plutonium	95 (243) Am Americium	96 (247) Cm Curium	97 (247) Bk Berkelium	98 (251) Cf Californium	99 (252) Es Einsteinium	100 (257) Fm Fermium	101 (260) Md Mendelevium	102 (259) No Nobelium	103 (262) Lr Lawrencium



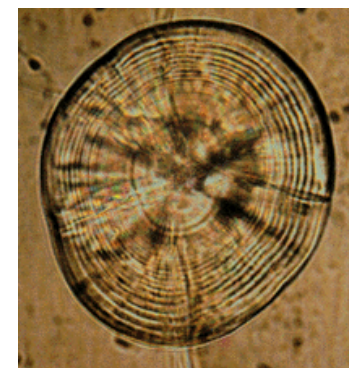
Uptake of Geochemical Markers



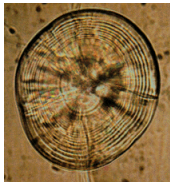
[Me⁺⁺], °C, PSU



Uptake



Incorporation



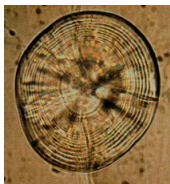
Geochemical marking examples

- **Clown fish, *Amphiprion melanopus*** (Thorrold et al., 2006) Mark recapture experiment with ^{86}Sr and ^{137}Ba

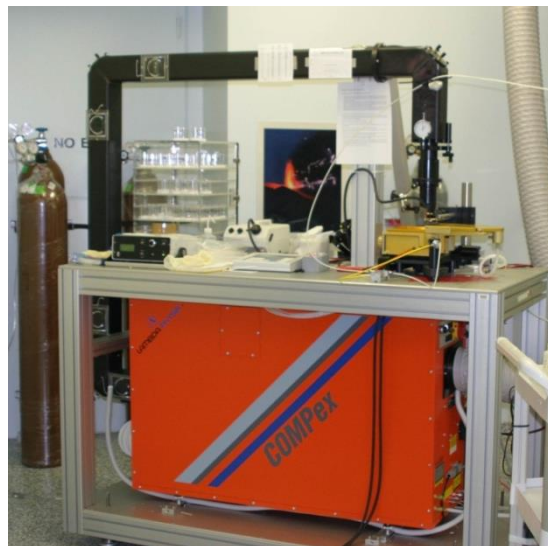
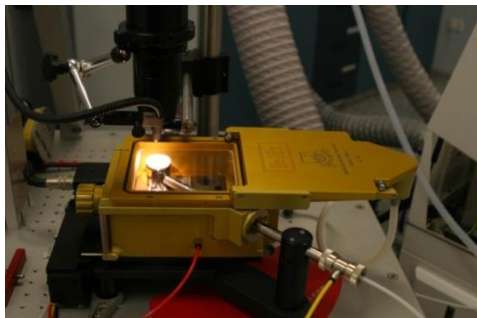


- **Brown-marbled grouper, *Epinepheus fuscoguttatus*** (Williamson et al. 2009) Lab experiments using ^{137}Ba

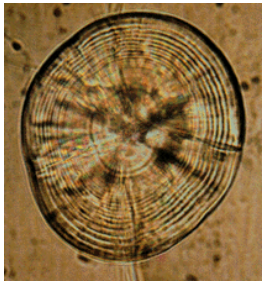




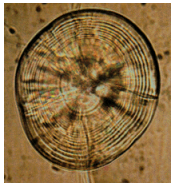
LA-ICP-MS analysis of fish otoliths



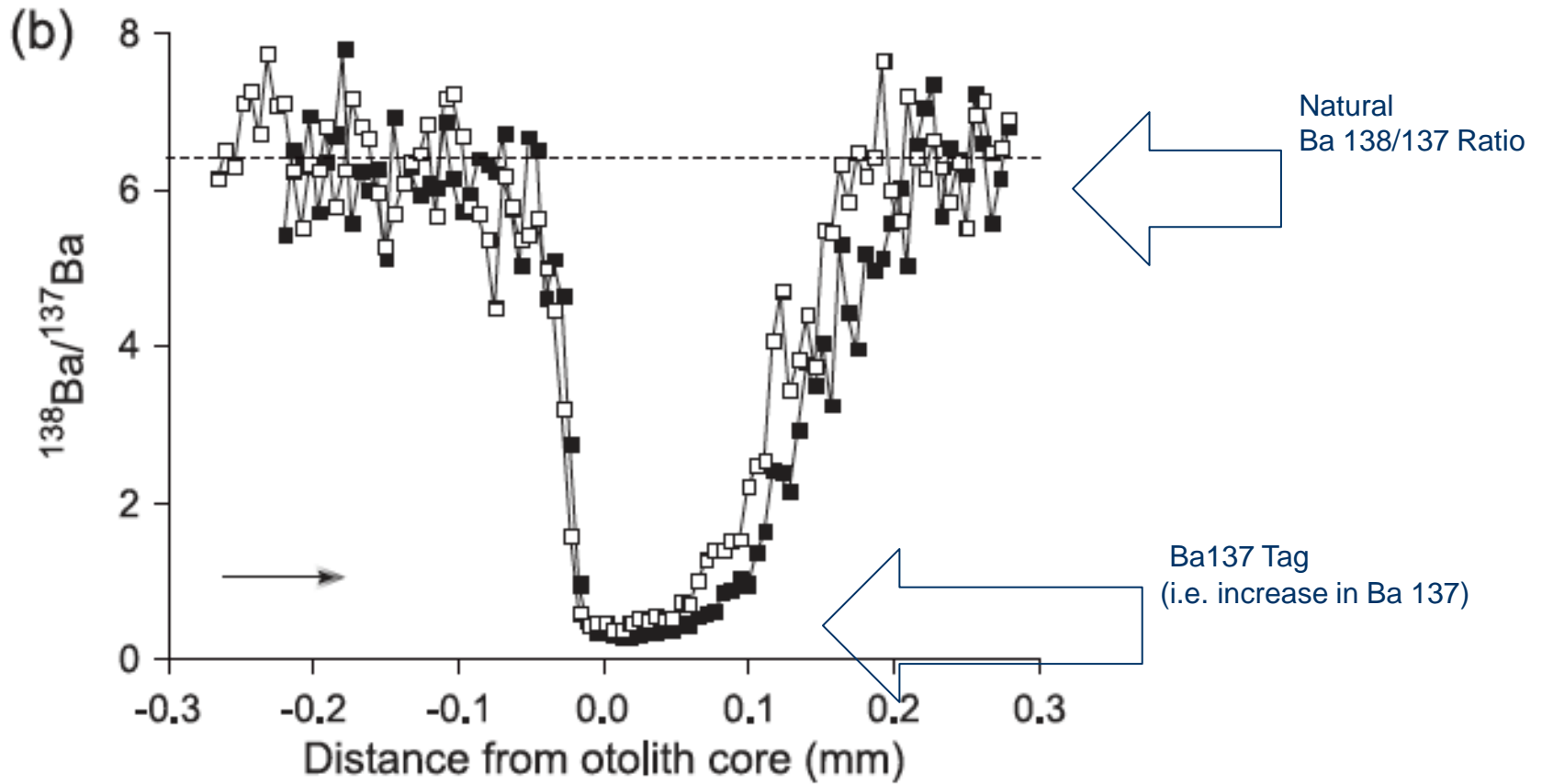
LA-ICP-MS analysis of fish otoliths



- Spot scans
- Transverse scans



Detecting tags





Research Approach

- Conduct large scale marking experiments using 3 different delivery techniques in a way that can be replicated at a commercial level.
- Experiments run at the IMR in Matre, Norway.
- Experiments covered the full production lifetime to assess welfare parameters.





Benefits

- Permanent and unambiguous
- Difficult to fake
- Level of accuracy can be controlled
- No animal health/welfare/production issues
- No human health issues
- Potential to create >1000 unique tags down to the farm level- # depends largely on cost
- Cost per fish is negligible depending on tag used
- Multiple delivery methods during the production cycle with negligible handling costs to the producer

Proportion of elemental abundance

