The feasibility of lead-radium dating opakapaka (*Pristipomoides filamentosus*) otoliths

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Introduction

Age determination for Hawaiian snapper or opakapaka (*Pristipomoides filamentosus*) has been an ongoing problem because otoliths lack well developed annual growth zones. Early growth has been well documented and validated otolith growth rates were successful for the first few years of growth using daily increments (Ralston and Miyamoto 1983, Radtke 1987). Rates have been refined with the use of smaller age classes (DeMartini et al. 1994), but the determination of age for the largest and oldest adults is still in question (Moffitt 2005). Ralston and Miyamoto (1983) developed a relationship called numerical integration of daily increment widths as a model for age prediction from otolith dimensions, which led to a maximum reported age of 18 years; however, the largest fish in that study were less than the maximum length for this species (greater than 70 cm FL for the region). This age has been reported as the maximum age for this species (e.g. Manooch III 1987), but this estimate was: 1) based on assumptions about otolith growth during adult stages; 2) was not applied to the largest fish, and 3) should be tested due to limitations of the technique at great ages (Morales-Nin 1988, Stevenson and Campana 1992). A method that can provide an independent estimate of age for adult otoliths is lead-radium dating, but the applicability of such a technique is limited by a number of considerations.

Lead-radium dating is a geochronological technique that has been used to date recent geological formations, such as accretionary carbonates (e.g. Condominesa and Rihs 2006). Use of this system as a chronometer relies on the decay of the relatively long-lived radioisotope radium-226 (^{226}Ra), a naturally occurring product of the uranium-238 (^{238}U) decay series (Figure 1), to the relatively short-lived granddaughter product lead-210 (^{210}Pb). Because the half-life of radium-226 is much greater (~1600 years) than lead-210 (22.26 years) the disequilibrium of the lead-radium system can function as a natural chronometer as lead-210 builds into equilibrium with radium-226. Once radium-226 is incorporated and isolated by some kind of structure (e.g. crystalline lattice), it is the ingrowth of lead-210 activity relative to radium-226 activity that provides a measure of time. In an ideal system there would be no exogenous source of lead-210 and the lead-radium ratio would increase purely from ingrowth. This ingrowth would exponentially approach a ratio of one, at which time the rate of lead-210 decay would be equal to the rate of lead-210 ingrowth from radium-226 (Figure 2). In this line of research, it is the radioactivity (often expressed simply as "activity") of each isotope that is measured in decays per minute (dpm) per unit mass (g), expressed as $dpm \cdot g^{-1}$. This dynamic equilibrium is called secular equilibrium and is achieved to within 1% in a period of 156 years or seven lead-210 half-lives.

For fish, lead-radium dating depends on the incorporation of radium-226 from the environment, where it is locked into the otolith matrix and subsequently decays to lead-210. The otolith lead-radium system can be used to provide an independent estimate of age, as well as a form of age validation for age estimation methodologies (Smith et al. 1991, Panfili et al. 2002).

The feasibility of lead-radium dating otolith material depends heavily on the levels of radium-226 uptake. For a successful application to work on small quantities of otolith material, radium-226 levels need to be relatively high. Measured levels of radium-226 from otoliths of marine fishes can vary by approximately two orders of magnitude (~0.01 to 1.0 $dpm \cdot g^{-1}$). This was demonstrated in two recent age and growth papers on bocaccio rockfish (*Sebastes paucispinis*; Andrews et al. 2005) and Atlantic tarpon (*Megalops atlanticus*; Andrews et al. 2001). The bocaccio rockfish study exemplified the limits of detection and applicability of the technique by providing only rough estimates of age; the levels for radium-226 (consequently lead-210) were too low to provide a low margin of error associated with the calculated radiometric age. Conversely, the Atlantic tarpon study exemplified use of low sample size for meaningful lead-radium dating because ^{226}Ra levels were some of the highest reported from otoliths; as a result of this and other factors, individual fish could be aged using lead-radium dating.

Estimating the limitations of lead-radium dating for the opakapaka feasibility study were based on several factors: 1) individual and collective sample mass availability for juvenile otolith material; 2) potential radium-226 activity; and 3) total sample age (estimated age plus time since capture). This approach was similar to most other studies performed by this laboratory in that initial sample masses were chosen to provide a good indication of lead-210 and radium-226 activity, given a best guess at the lowest case scenario. Typical radium-226 activity in otolith material is 0.03 to 0.05 $dpm \cdot g^{-1}$. Based on this estimate, a minimum of 0.5 grams of core material was targeted for each group to collect sufficient counts at the alpha-spectrometer (α-spectrometer).

The focus of this project was to: 1) test the feasibility of lead-radium dating on whole otolith material from juvenile opakapaka otoliths; and 2) apply lead-radium dating to an adult group of opakapaka greater than 70 cm FL. Two juvenile groups of otoliths were pooled from collection years that differed by 10 years. The aim of this portion of the study was to: 1) test the closed system assumption for otoliths stored over long periods; and 2) test for baseline levels of radium-226 for this species and potentially other regional species of interest. Age estimates for the juvenile groups were made previously by otolith readers at the Pacific Islands Fisheries Science Center and it was hypothesized that age was less in question for the youngest fish than for the largest fish. To follow up on the findings for the juvenile otolith groups, a group of cored adult otoliths were processed as the final part of this feasibility study to determine radiometric age for some of the largest representatives of this species.

Methods

For the juvenile portion of this study, an age group collected in 1987 and an age group collected in 1997-98 were selected (Appendix 1). The groups were similar in composition and differed in minor ways (Table 1). The 1987 group consisted of 14 otoliths collected in November 1987. The estimated age was 2+ years for these otoliths and the average weight was 0.087 g per otolith. The 1997-98 group consisted of 19 otoliths collected December of 1997 and February of 1998. These otoliths were estimated as 1+ years with an average otolith weight of 0.031 g. The sample mass was optimal for the 1987 group because it was greater than 1 g and less optimal for the 1997-98 group because of limited otolith availability and a sample mass of about 0.6 g.

A set of otoliths from the largest fish available (average = 72.0; range = 70.0 to 74.6 cm FL), and collected within a year of each other, were available for an adult group analysis (Appendix 2). Age was not known for these fish and all were collected in late 2007 to early 2008 (Table 1). The average dimensions and weight from the 14 juvenile otoliths (OP 1987), 11.4 mm L x 7.0 mm W x 1.2 mm T and 0.88 g, was used as a target for coring the adult otoliths. Each core was extracted by: 1) grinding on a lapidary wheel; and 2) comparing the core microscopically to two reference 2+ otoliths collected in 2008. Growth zones visible in the otolith at hand were used to verify the concentric structure of each core to the first few years of growth.

A detailed protocol describing sample preparation, chromatographic separation of radium-226 from barium and calcium, and analysis of radium-226 using mass spectrometry was described elsewhere (Andrews et al. 1999b). These procedures have not changed for this study, except for two aspects of the analysis: 1) radium recovery was improved by shifting the collection interval on the final chromatography column to begin at 200 μL (as opposed to 250 μL); and 2) purified radium samples were analyzed using an improved ICP-MS (Inductively Coupled Plasma-Mass Spectrometry) technique. Other than these details, only an overview of the radium-226 procedures is given here with details on the determination of lead-210 activity. Because the levels of radium-226 and lead-210 typically found in otoliths were extremely low (femtograms (10^{-15} g) for radium-226 and attograms (10^{-18} g) for lead-210) and the great potential for contamination of various forms and sources, trace-metal clean procedures and equipment were used throughout sample preparation, separation, and analysis. All acids used were ultra-pure, double distilled (GFS Chemicals®) and dilutions were made using Millipore® filtered Milli-Q water (18 MΩ cm^{-1}).

Dried and weighed samples were dissolved in TFE beakers on hot plates at 90°C by adding 8N HNO_3 in 1-2 mL aliquots (Figure 3). Alternation between 8N HNO_3 and 6N HCl, with an aqua regia transition, several times resulted in complete sample dissolution. The dried sample, after dissolution, formed yellowish precipitate. To reduce remaining organics (otolin), and to put the residue into the chloride form required for the lead-210 activity determination procedure, the samples were redissolved in 1 mL 6N HCl and taken to dryness five times at 90-120°C. A whitish residue indicated that sufficient amounts of the organics have been removed. These samples were used to determine lead-210 activity prior to ICP-MS analysis.

To determine lead-210 activity in the otolith samples, the α-decay of polonium-210 (^{210}Po) was used as a daughter proxy for lead-210. To ensure that activity of ^{210}Po was due solely to ingrowth from lead-210, the time elapsed from capture to polonium-210 determination was greater than 2 yr, with the exception of the adult age group; because the adult age group consisted of otolith cores, the 2 yr waiting period was not necessary. Samples prepared for polonium-210 analysis were spiked with polonium-208, a yield tracer. The amount of polonium-208 added was estimated based on observed radium-226 levels in other studies of deepwater fishes. This amount was adjusted to about 5 times the expected polonium-210 activity in the otolith sample to reduce error in the lead-210 activity determination. The spiked samples were redissolved in approximately 50 mL of 0.5N HCl on a hot plate at 90°C covered with a watch glass. The polonium-210 and polonium-208-tracer was autodeposited for 4 hours onto a silver planchet. The activities of these isotopes were determined using α-spectrometry on the plated samples (Figure 4). Additional procedural and system details are described elsewhere (Andrews et al. 1999a). The solution remaining after polonium plating was dried and saved for radium-226 analyses.

To prepare the samples for radium-226 activity determination each sample was spiked with radium-228, a yield tracer, and an ion-exchange separation technique was used to separate radium from calcium and barium (Figure 3; Andrews et al. 1999b). The purified samples were processed using ICP-MS (Figure 4) and the measured ratios of radium-226:radium-228 were used to calculate radium-226 activity.

Age was estimated from the measured lead-210 and radium-226 activities (Equation 1). Because the activities were measured using the same sample, the calculation was independent of sample mass; an advantage over older lead-radium studies (Andrews et al. 1999a). Radiometric age was calculated as follows for whole juvenile otoliths using the following equation,

$$t_{\text{age}} = \frac{\ln\left(1 - \frac{A_{210}}{A_{226}}\right)}{-\lambda}, \qquad \text{(Eq. 1)}$$

where t_{age} was the radiometric age at the time of analysis, A_{210} was the lead-210 activity at time of analysis, A_{226} was the radium-226 activity measured using ICP-MS, and λ was the decay constant for lead-210 (Smith et al. 1991). The age of the adult sample was determined taking into consideration the core age gradient (Smith et al. 1991). A radiometric age range, based on the analytical uncertainty, was calculated for each sample by using error propagation through to the final age determinations (2 SE). Calculated error included the standard sources of error (i.e. pipetting, spike and calibration uncertainties, etc.), α-counting statistics for lead-210 (Wang et al. 1975), and the ICP-MS analysis routine.

Results

Radium-226 levels were slightly lower than expected, but meaningful lead-210 and radium-226 activities were acquired (Table 2). Because the logistics of sample processing for lead-radium dating leads to measurement of lead-210 (polonium-210 by proxy) before radium-226 determinations, it was determined early in the study that sample activities were at viable counting levels on the alpha-spectrometer with 4 to 6 counts per day for the juvenile age groups and 10 counts per day for the adult group. After a count period of 49.9 days for the juvenile samples and 76.9 days for the adult sample the counts acquired were sufficient for determination of ^{210}Pb activity. Radium-226 activity was measured for both samples and was used to determine an activity ratio, which was used to determine radiometric age.

Radiometric age was in close agreement with the known age of each juvenile age group (Table 3). The total sample age was calculated based on the average time since collection for each group plus half the average estimated age for the otoliths within each group to compensate for an ingrowth gradient for lead-210:radium-226 that would form for the first 1-2 years of growth. Comparison of the known age of each sample with the expected ingrowth model provided support for: 1) conservation of the lead-radium system isotopes during long storage times; and 2) accurate age determinations for core material extracted from adult otoliths (Figure 5).

Lead-radium dating of the adult otolith group provided an average group age close to 50 years (Table 3). Based on the measured ratio, a maximum age of close to 20 years can be eliminated because of the wide divergence from a proper fit to the ingrowth curve (Figure 5). Projecting the vertical error bars (2 SE) horizontally to the ingrowth curve provided the range of age uncertainty (42.3 to 64.5 years).

Discussion

These findings provide an encouraging basis for the application of lead-radium dating to opakapaka and other regional species. The test for potential loss of isotopes during storage time was successful by showing that no significant loss of radium-226 daughter products occurred during the 11.3 to 20.5 year storage time. Studies have voiced concerns about the possible violation of the closed otolith system and may have measured large losses of radon-222 (Gauldie and Cremer 2000), but no rigorous studies to date have provided losses that were considered significant relative to the determination of age from lead-radium dating and such losses have been considered temporary (e.g. Whitehead and Ditchburn 1995, Baker et al. 2001, Andrews *unpublished data*). This finding provides further support for the notion that no significant loss of lead-radium isotopes occurs for otoliths, whether *in vivo* or stored dry, and that lead-radium dating is a viable and accurate option for age determination using otoliths. The findings also provided strong support for an application of lead-radium dating to extracted otolith core material from adults of this species.

Radium-226 levels were at the low end of what was expected (0.3 to 0.5 $dpm \cdot g^{-1}$), but this was understandable in the broader context of radium-226 fluxes to the environment. The flux of radium-226 is typically greatest near continental margins and sea floors with low sedimentation rates (Broeker and Peng 1982, Fanning et al. 1982); the location of Hawaii as a central Pacific island provides a reasonable basis for the relatively low radium-226 values, as has been recorded for the surface waters of the Pacific (Broeker and Peng 1982). Although values were low in otolith material, the activity of ^{226}Ra provided a basis for a minimum of 1.5 grams of otolith cores for any given age group.

The lead-radium results from the adult otolith group provided a first look at an independent estimate of age for some of the largest opakapaka representatives from the region. The consistency of the measured radium-226 activity (0.0311 ± 0.0072 SD $dpm \cdot g^{-1}$) in the three samples and the well measured lead-210 activity from carefully extracted adult otolith cores provided for a high degree of confidence in this age estimate. An average age of 51.5 years (42.3 to 64.5 years, 2 SE) was considerably greater than the greatest estimated age of 18 years from numerical integration of daily increment widths; however, the largest fish for this species have not been evaluated until now. This species could exhibit a growth pattern that has become increasingly common with tropical and temperate deep-water fishes; a pattern of relatively rapid growth followed by little or no change in fish length for many decades (e.g. Ewing et al. 2007). The problem of accurate age determination for large adults has been a restated problem for managing opakapaka fisheries (Ralston and Williams 1988, DeMartini et al. 1994, Moffitt 2005, Moffitt et al. 2007); therefore, it is recommended that additional opakapaka otoliths be tested using radiometric methods to confirm the findings of this single sample.

A full application of lead-radium or bomb radiocarbon dating or both could provide detailed information on the age and growth of adult opakapaka. Lead-radium dating could be applied to a series of fish-length groups between the juvenile and large adult (70+ cm FL) groups tested here to fill in the gap and to provide verifiable support for these findings. In addition, the estimated age of this species (greater than 42 years) makes it a strong candidate for an application of bomb radiocarbon dating. A series of otoliths collected over time and covering otolith or fish size classes would provide well refined age estimates for individual fish. Use of both techniques has provided robust support for the age and growth of some fishes (e.g. canary and yelloweye rockfishes; Andrews et al. 2002, Kerr et al. 2004, Andrews et al. 2007) and opakapaka is an excellent candidate.

It was also of interest to assess the applicability of lead-radium dating to other regional fishes. Based on the findings of this study, it is reasonable to assume that radium-226 levels would be similar for fishes of the Hawaiian Islands and that applications to other species would be successful, given reasonable otolith mass and sample availability. Regions like the Mariana Archipelago, where assessments have been made for numerous deep-slope species (Ralston and Williams 1988), may give rise to greater radium-226 fluxes because of geological subduction. The species analyzed in Ralston and Williams (1988) could provide otoliths with elevated radium-226, providing an opportunity to use less material in more flexible applications of lead-radium dating.

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Table 1. Summary of characteristics for opakapaka otolith samples processed in this study. Estimated age composition and average capture date for each group with resultant pooled sample number and weight are given. Age was not known for the OP 70+ group (fish length based).

Sample	Age group (yr)	Average capture date	Number of otoliths	Sample weight (g)[1]	Average core weight (g)
OP 1987	2+	4 November 1987	14	1.16539	0.087[2]
OP 1997	1+	8 January 1998	19	0.57914	0.031[2]
OP 70+	Unknown	11 November 2007	16	1.55380	0.097[3]

[1] Cleaned and dried sample weight prior to processing.

[2] Whole otoliths

[3] Extracted otolith cores

Table 2. Radiometric results for opakapaka juvenile whole otolith groups and the cored adult otolith group. Listed are the measured lead-210 and radium-226 activities for the samples (± 2 SE). Calculated activity ratios and their corresponding margin of error were used to calculate sample age and uncertainty (Table 3).

Sample	Age group (yr)	^{210}Pb (dpm·g^{-1}) ± % error[1]	^{226}Ra (dpm/g) ± % error[1]	^{210}Pb:^{226}Ra activity ratio	2 SE
OP 1987	2+	0.0126 ± 7.0	0.0259 ± 13	0.484	0.072
OP 1997	1+	0.0117 ± 9.2	0.0393 ± 22	0.299	0.071
OP 70+	Unknown	0.0224 ± 4.6	0.0282 ± 7.1	0.797	0.067

[1] Calculation based on propagation of 2 SE using the delta method (Knoll 1989) and the ICP-MS analysis routine (± 2 SE).

Table 3. Comparison of estimated age and radiometric age for opakapaka. Radiometric age was calculated from the measured lead-210:radium-226 activity ratios and corrected for time since capture date. Radiometric age range was based on the analytical uncertainty and error propagation (2 SE).

Sample	Age group (yr)	Total sample age (yr)[1]	Radiometric age (yr)	Radiometric age range (yr)	Corrected age (yr) (range)
OP 1987	2+	20.5 + 1 = 21.5	22.3	18.1 – 27.0	1.8 (-2.4 – 6.5)
OP 1997	1+	11.3 + 0.5 = 11.8	11.9	8.8 – 15.3	0.6 (-2.5 – 4.0)
OP 70+	Unknown	Unknown	51.5	42.3 – 64.5	n.a.

[1] Time since collection plus half the estimated average fish age for each sample.

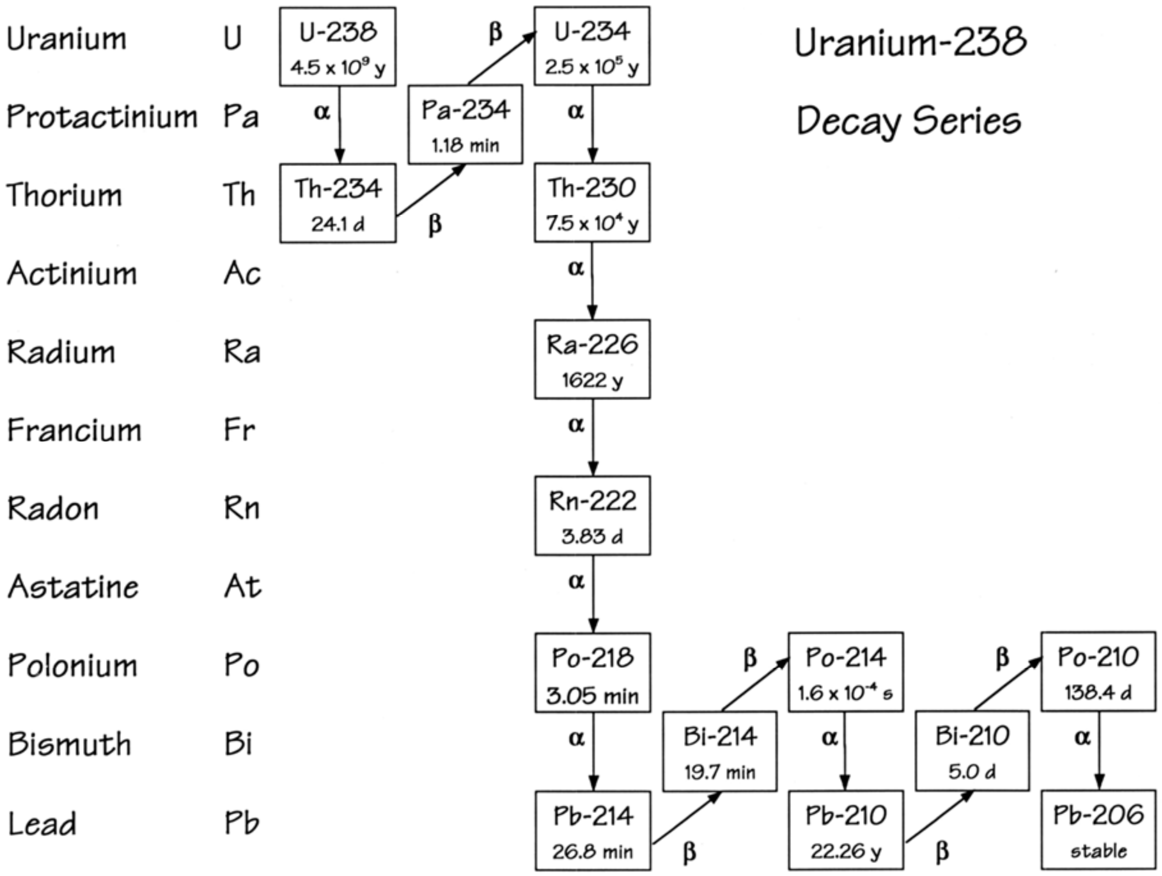

Figure 1. Diagram of the uranium-238 decay series with the half-life for individual isotopes given in each cell. Of interest to lead-radium dating is the isolation of radium-226 from the environment and its subsequent decay to lead-210. Note that the half-lives of the intermediate isotopes are far less than the half-life of lead-210, hence the decay of radium-226 over the period of interest for fishes (decades) can be simplified to a direct decay to lead-210 and a disequilibrium relative to time (see Figure 2).

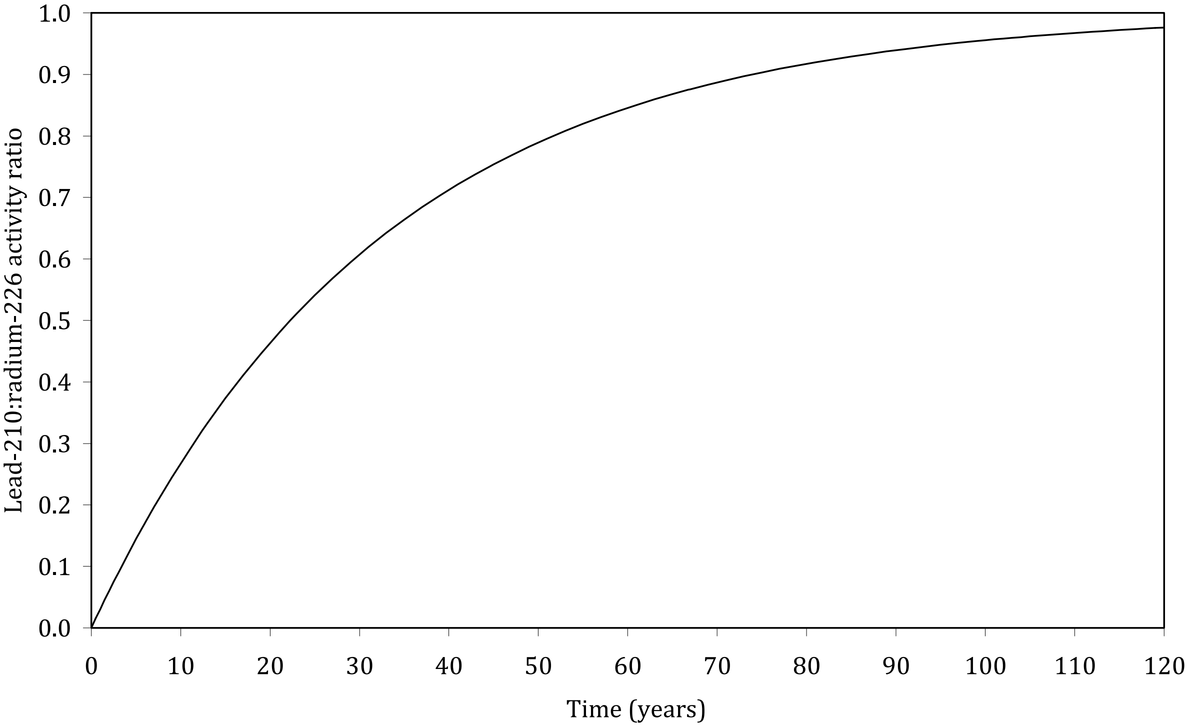

Figure 2. The relationship used for lead-radium dating begins with the ingrowth of lead-210 activity at time zero from radium-226. Over a period of up to approximately 120 years the activity ratio of lead-210 to radium-226 approaches secular equilibrium or a ratio of one. It is the measured disequilibria of lead-210 and radium-226 activities that provide a measure of time or age in the case of fishes.

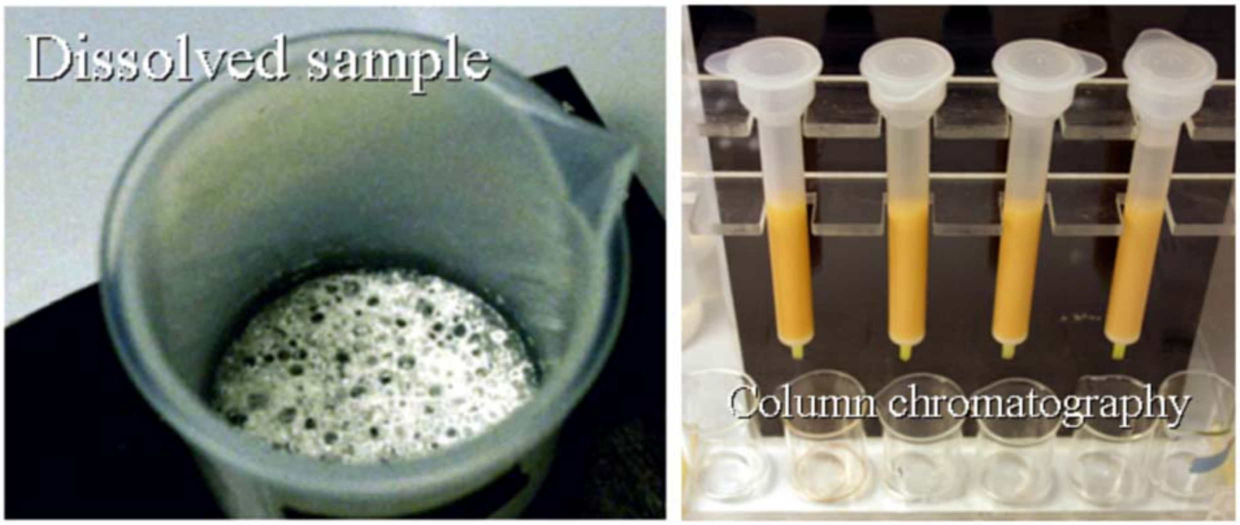

Figure 3. Dissolved otolith sample in a TFE beaker prior to plating polonium isotopes for α-spectrometry. After plating, the sample remnant was processed to isolate radium using column chromatography. On the right is a photograph of the first of three chromatographic columns used to isolate and purify the radium sample that is analyzed with ICP-MS.

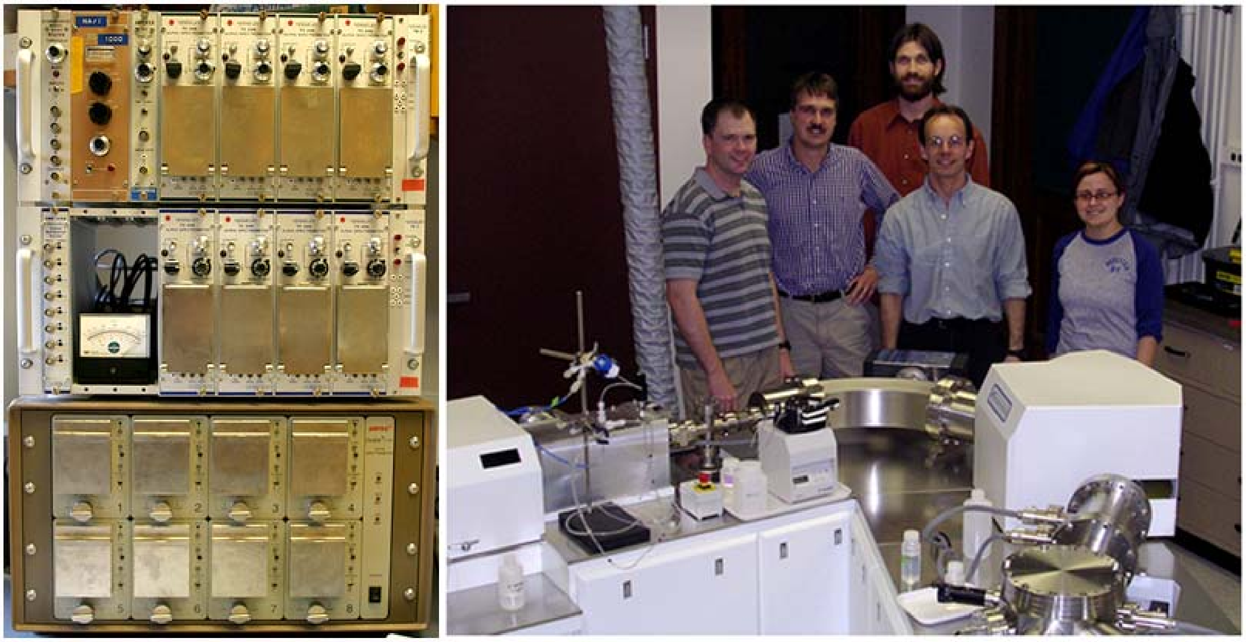

Figure 4. Photograph of the α-spectrometer (left) used in polonium-210 determinations (proxy for lead-210). The system consists of the classic Tennelec® TC-256 α-spectrometers and a newer Ortec® Octete Plus unit. On the right are members of the mass-spectrometry research group in the Department of Geology at University of Illinois, Urbana-Champaign with the Perkin-Elmer ICP-MS used to determine radium-226 in the purified samples processed at the Age and Longevity Research Laboratory, Moss Landing Marine Laboratories.

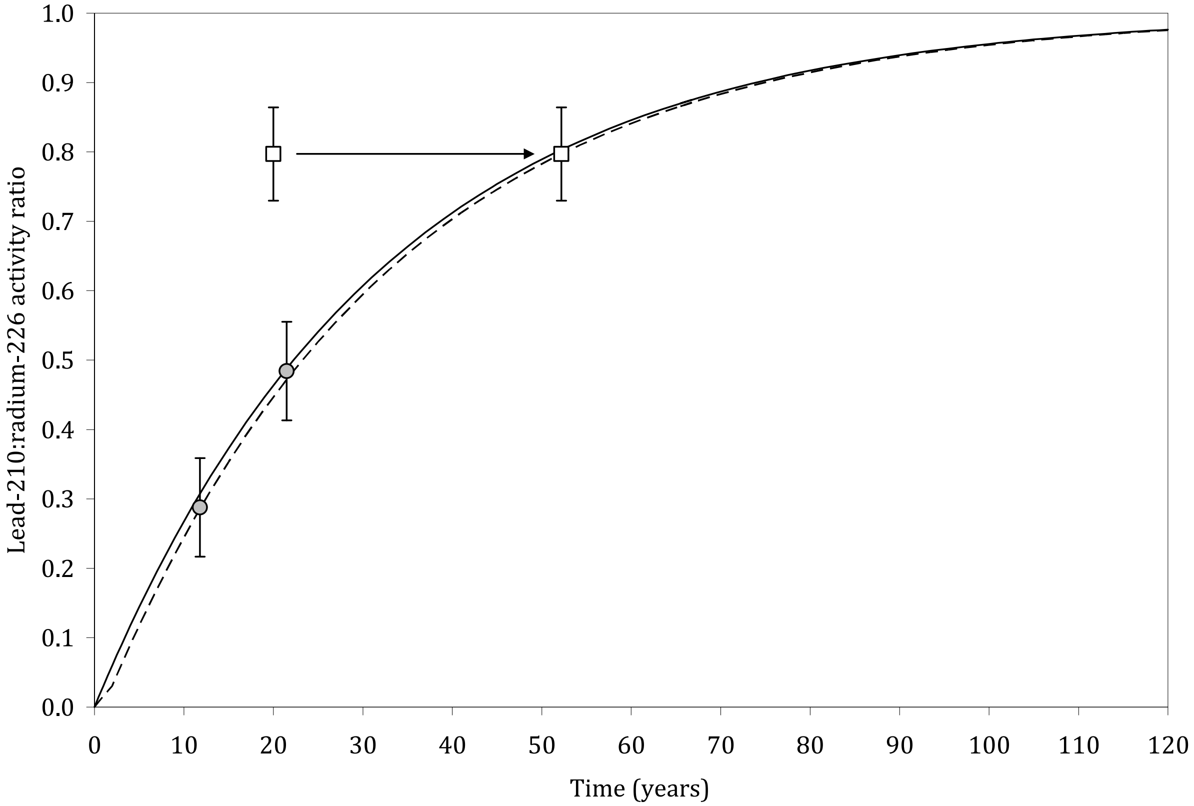

Figure 5. Total sample age for each juvenile group (time since collection plus half of the average fish age) was plotted (open grey circle) relative to measured lead-radium activity for each sample. Comparison with the ingrowth model for lead-radium ingrowth provided a baseline assessment of the radium-226 daughter product conservation within the otolith over time spent in storage. Placing the measured ratio for the adult age group (open squares) near 20 years demonstrates the wide divergence from the ingrowth curve. The measured lead-radium ratio from the cored adult otolith sample meets the ingrowth curve at an age of 51.5 years. The solid line represents straight ingrowth of ^{210}Pb from ^{226}Ra and the dashed line represents the core compensated (2 years) ingrowth curve.

Appendix 1: Data associated with juvenile otolith samples.

Opakapaka - Juvenile whole otolith groups

Sample	**ID**	**FL(cm)**	**Date caught**	**Location**	**Otolith Wt (g)**	**MLML Wt (g)**
OP 1987	176	34.2	11/4/1987	Oahu	0.0802	0.0779
	193	34.4	11/4/1987	Oahu	0.0931	0.0924
	194	32.2	11/4/1987	Oahu	0.0892	0.0857
	195	32.4	11/4/1987	Oahu	0.0822	0.0822
	196	33.5	11/4/1987	Oahu	0.0858	0.0857
	197	33.7	11/4/1987	Oahu	0.0838	0.0835
	198	32.6	11/4/1987	Oahu	0.1005	0.0995
	199	32.3	11/4/1987	Oahu	0.0823	0.0780
	200	32.9	11/4/1987	Oahu	0.0889	0.0874
	201	32.4	11/4/1987	Oahu	0.0928	0.0913
	202	34.4	11/4/1987	Oahu	0.0965	0.0932
	203	33.7	11/4/1987	Oahu	0.0866	0.0853
	204	34.7	11/4/1987	Oahu	0.0906	0.0885
	219	34.6	11/5/1987	Oahu	0.0832	0.0829
	Average	33.4	11/4/1987	Total	1.2357	1.2135

Sample	**ID**	**FL(cm)**	**Date caught**	**Location**	**Otolith Wt (g)**	**MLML Wt (g)**
OP 1997	2 OP	20.5	12/26/1997	Oahu	0.049	0.0487
	5 OP	13.8	12/27/1997	Oahu	0.0208	0.0208
	6 OP	15.6	12/27/1997	Oahu	0.026	0.0260
	7 OP	18.5	12/27/1997	Oahu	0.0389	0.0383
	12 OP	19.2	12/21/1997	Oahu	0.0368	0.0364
	13 OP	20.4	12/18/1997	Oahu	0.041	0.0410
	14 OP	21.4	12/18/1997	Oahu	0.0413	0.0413
	15 OP	13.6	12/23/1997	Oahu	0.022	0.0218
	18 OP	20.6	12/23/1997	Oahu	0.0491	0.0491
	20 OP	20.4	12/22/1997	Oahu	0.0445	0.0445
	21 OP	20.8	12/22/1997	Oahu	0.0456	0.0456
	22 OP	19.0	12/22/1997	Oahu	0.0455	0.0452
	32 OP	19.0	12/22/1997	Oahu	0.0422	0.0420
	49 OP	10.6	1/27/1998	Oahu	0.0137	0.0137
	54 OP	13.2	2/10/1998	Oahu	0.0194	0.0194
	55 OP	14.3	2/10/1998	Oahu	0.0231	0.0228
	62 OP	14.0	2/19/1998	Oahu	0.0201	0.0201
	63 OP	12.5	2/19/1998	Oahu	0.0163	0.0163
	64 OP	10.6	2/19/1998	Oahu	0.0141	0.0140
	Average	16.7	1/8/1998	Total	0.6094	0.6070

Appendix 2: Data associated with cored adult otolith samples.

Sample	ID	FL(cm)	Date caught	Location	Otolith Wt (g)[1]
OP 70+	LA2-222 PAKA	74.6	4/23/2007	Pioneer	0.4964
	LA3-278 PAKA	71.8	6/8/2007	Gardner	n.a.
	LA4-337 PAKA	74.5	7/15/2007	Gardner	n.a.
	LA4-338 PAKA	71.8	7/15/2007	Gardner	0.3278
	LA5-420 PAKA	71.9	9/21/2007	N. Hampton	n.a.
	KP5-366 PAKA	71.8	11/2/2007	E. Twin	0.3250
	LA6-441 PAKA	73.0	11/8/2007	Gardner	n.a.
	M3-131 PAKA	71.6	12/31/2007	Kauai	n.a.
	IM3-274 PAKA	70.7	1/4/2008	W. Nihoa	n.a.
	M5-219 PAKA	73.0	1/20/2008	Kauai	0.4660
	KP6-391 PAKA	70.6	2/16/2008	West Twin Banks	n.a.
	M10-269 PAKA	71.2	2/28/2008	Niihau	0.3774
	M10-379 PAKA	72.5	2/28/2008	Niihau	0.3521
	M11-471 PAKA	70.0	3/2/2008	Kauai	n.a.
	M11-481 PAKA	72.1	3/1/2008	Niihau	n.a.
	CK10-12-PAKA	70.8	3/9/2008	124- Penguin Bank	n.a.
	Average	72.0	11/21/2007		

1. Whole otolith weight prior to extraction of core material. Some otoliths were not weighed (n.a. = not available) because of prior damage and mass loss.