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Natural Radioisotopes of Polonium and Lead in the Edible Muscle of Cultured Seabass *(Lates calcarifer)*

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Abstract

Activity levels of ^{210}Po and ^{210}Pb were determined in the edible tissue of seabass *(Lates calcarifer)* from 23 cages located in the west, south and east coasts of Peninsular Malaysia. The concentration levels of ^{210}Po and ^{210}Pb in fish varied from 5.10 ± 0.36 Bq/kg to 15.53 ± 5.40 Bq/kg dry weight and 7.09 ± 0.54 Bq/kg to 21.72 ± 2.64 Bq/kg dry weight, respectively. The highest concentrations of ^{210}Po and ^{210}Pb were found at Stations S3 and S23 due to rapid development at the upper stream. In addition, the ratio between ^{210}Po and ^{210}Pb shows a distinction between stations of each sampling location. The ^{210}Po/^{210}Pb activity ratio at the Tebrau Strait was higher than the unity value (1.04) compared to the west and east coasts of Peninsular Malaysia. Most of the samples contain slightly lower ^{210}Po/^{210}Pb activity ratios which are related to the high input of lead from watersheds in neighboring areas.

Keywords: ^{210}Po; ^{210}Pb; seabass; pollution; Tebrau Strait; Malacca Strait; East Coast of South China Sea

1. Introduction

Peninsular Malaysia is surrounded by the Straits of Malacca, the Tebrau Strait and on the east coast, the South China Sea. These coastal areas experience increasing aquatic pollution due to rapid development and a sudden increase of urbanization (Tan and Yap, 2006). According to Garrison (2005), more than three-quarters of marine pollution occur due to substances from various human activities originating inland. Inland activities contaminate the three major water bodies surrounding Peninsular Malaysia. The Malacca Straits is seriously contaminated by shipping activities, industrialization, urbanization and oil spills (Eng *et al*., 1989; Abdullah *et al*., 1999). The third busiest port, Port Klang, is situated on the Straits of Malacca. Apart from that, another area that has been marked as a potential contaminant of the Malacca Straits is Langkawi Island. Langkawi Island is located at the northern end of the Malacca Straits and faces rapid tourism development. Numerous hotels and facilities have been developed on the island's shores, contributing to negative impacts on the coastal area. Meanwhile, in the south of Peninsular Malaysia, there is a significant water pollution problem in the coastal waters of the Tebrau Straits due to rapid development and industrialization i.e. in south Johore and Singapore (Koh *et al*., 1991). The Tebrau Strait, which acts as a border between Singapore and Malaysia, is being contaminated by pollutants from tributaries like Sungai Perepat, Sungai Bahan, Sungai Melayu and Sungai Skudai (Shamila Azman *et al*., 2012). According to Mohamed *et al*. (2012), the east coast of Peninsular Malaysia cannot avoid marine pollution which is one the main sources of natural radionuclide pollution such as ^{210}Po and ^{210}Pb. It is also known that the coastal waters along Peninsular Malaysia are involved in mariculture activities. The high level of this radioactive element may deteriorate human health via ingestion of food contaminated in the water bodies where this mariculture is conducted (Ariffin and Mohamed, 2010). Fish is a marine organism that is greatly consume thus radioisotope monitoring is necessary for human safety.

^{210}Po and ^{210}Pb are produced from the ^{238}U decay chain and occurs naturally in environments with half lives of 138.4 days and 22.2 years, respectively. ^{210}Po is extensively being studied in the marine environment because it represents a major natural source of internal irradiation for marine organisms (Cherry and Shannon, 1974; Carvalho, 1988; Brown *et al*., 2004). ^{210}Po is considered the most important contributor of radiation received by humans via fish and shellfish consumption (Aarkrog *et al*., 1997). Several studies have demonstrated that the natural alpha emitting radionuclide ^{210}Po is accumulated to exceptionally high levels in tissues of a variety of marine organisms; well above levels of the parent radionuclide ^{210}Pb (Carvalho and Fowler, 1994 ; Stepnowski and Skwarzec, 1999). Meanwhile, ^{210}Pb is also of great importance because it is toxic for living organisms and is involved in the biological cycle and is normally present in high concentrations (Nonova *et al*., 2009). These radionuclides are proven to be assimilated through the food chain, posing a threat to living organisms and humans (Nonova *et al*., 2009). Background levels of natural radionuclides such as ^{210}Po and ^{210}Pb in fish are dependent on several factors such as species, fish location, diet, metabolism and type of exposure. Radioisotope activities are released naturally or artificially in water bodies either directly (in both fresh water and seawater) or indirectly from freshwater which then ends up in seawater. When large amounts of radioisotopes are discharged into the marine environment, it may increase beyond a natural level and affect marine organisms. Marine organisms such as fish and molluscs may accumulate radioisotopes in water bodies and become incorporated in marine organisms which are later consumed by humans. In this study, cultured fish were exposed to pollution as it inhabited a confined environment and were affected by human activities in terrestrial areas.

Lates calcarifer, also known as white seabass in the Asia-Pacific and barramundi in Australia, is cultured in several countries such as India and China and are commonly found in Malaysia, Thailand and Australia (MOA, 2010; Grey, 1987). It has been a seafood favorite in Malaysia, Indonesia, Singapore and Thailand since the 1970's (Grey, 1987). Productive estuarine ecosystems along the Malaysian coastline provide a suitable environment for aquaculture activities especially for sea bass farming (DOF, 2006). Sea bass are able to tolerate a variety of salinities from freshwater, brackish water to saline water, where the cages and ponds of cultured sea bass are found. The production of sea bass in Malaysia is a significant contributor to the Malaysian economy (MOA, 2010).

In turn, fish consumption has also played a significant role in the transfer of radionuclides to humans (Suriyanarayanan *et al*., 2008). Therefore the aim of this study is to determine the activity of ^{210}Po and ^{210}Pb in the muscle of sea bass from Peninsular Malaysia coastal areas parting order to evaluate radioactivity transfers to humans from the food chain. The activities of both radionuclides in sea bass muscle were investigated due to the impact of terrestrial anthropogenic activities. The specimens studied were divided into three groups: Malacca Straits, Tebrau Strait and the South China Sea on the east coast. In addition, the ratio of ^{210}Po/^{210}Pb can also be used as an indicator to identify the source and dominance of radionuclides.

2. Materials and Method

2.1. Study area

Sample collection was carried out between November 2007 and March 2008 (Table 1). A total of 127 samples were purchased from 23 cages along the coasts of Peninsular Malaysia as shown in Fig. 1. The fish cages were located near local urban and industrialized areas. Effluent discharge from these activities, both treated and untreated, will affect aquaculture activity. The two main types of fish feed used at every cage are moist feed or trash fish (e.g., Scombridae), alternated with dry pellets.

The average weight and length of the samples were taken as well as a description of each sampling site as shown in Table 1, where about 23 sampling stations were divided into three groups; groups A, B and C for the Malacca Straits, Tebrau Straits and the South China Sea, respectively, based on the location of the cultured sea bass. The Malacca Straits is populated with 60% of the Malaysian population and is the most developed region in Malaysia, especially along the coastline (Ismail *et al*., 1993). The Straits of Malacca is also one of the world's busiest supertanker routes and tanker derived oil spills occur frequently. In addition, domestic oil spills have been increasing due to growing industrialization. Coastal waters in southern Johor and the Tebrau Strait are polluted to various degrees. Major pollution sources are domestic wastes from human settlements, agro-based wastes from palm oil mills and rubber processing factories, industrial effluent from industrial estate and discharge from animal farms (Hock Lye Koh *et al*., 1991). The eastern states of Peninsular Malaysia are also not spared from the marine pollution problem. The South China Sea is also affected by this problem, with contamination of popular tourism beaches such as Pantai Sri Tujuh and Pantai Cahaya Bulan in Kelantan (Mohamed *et al*., 2012).

2.2. Analysis of ^{210}Po and ^{210}Pb

Radiochemical separation was used to estimate ^{210}Po and ^{210}Pb in the samples (Flynn, 1986; Harley, 1978). Briefly, the fish samples were dissected to obtain the muscle and oven dried at 60ºC temperature. About 0.5g of the dried sample was taken and ^{209}Po of known activity and 20mg of Pb carrier [$Pb(NO_3)_2$] was added as a yield tracer. A mixture of concentrated HNO_3, $HClO_4$, HCl acids and H_2O_2 were used for digestion (Yamamoto *et al*., 1994). Polonium was then spontaneously deposited onto polished and pre-cleaned silver foil (2.0 x 2.0 cm) in 0.5M of HCL solution for a period of 3-4 hours at a temperature of 70-90ºC. The activities of ^{210}Po in the samples were determined using alpha spectrometry (Alpha Analyst Spectroscopy system with a silicon-surface barrier detector by Canberra, Inc) immediately after being deposited. Next, lead isotopes (^{210}Pb) were

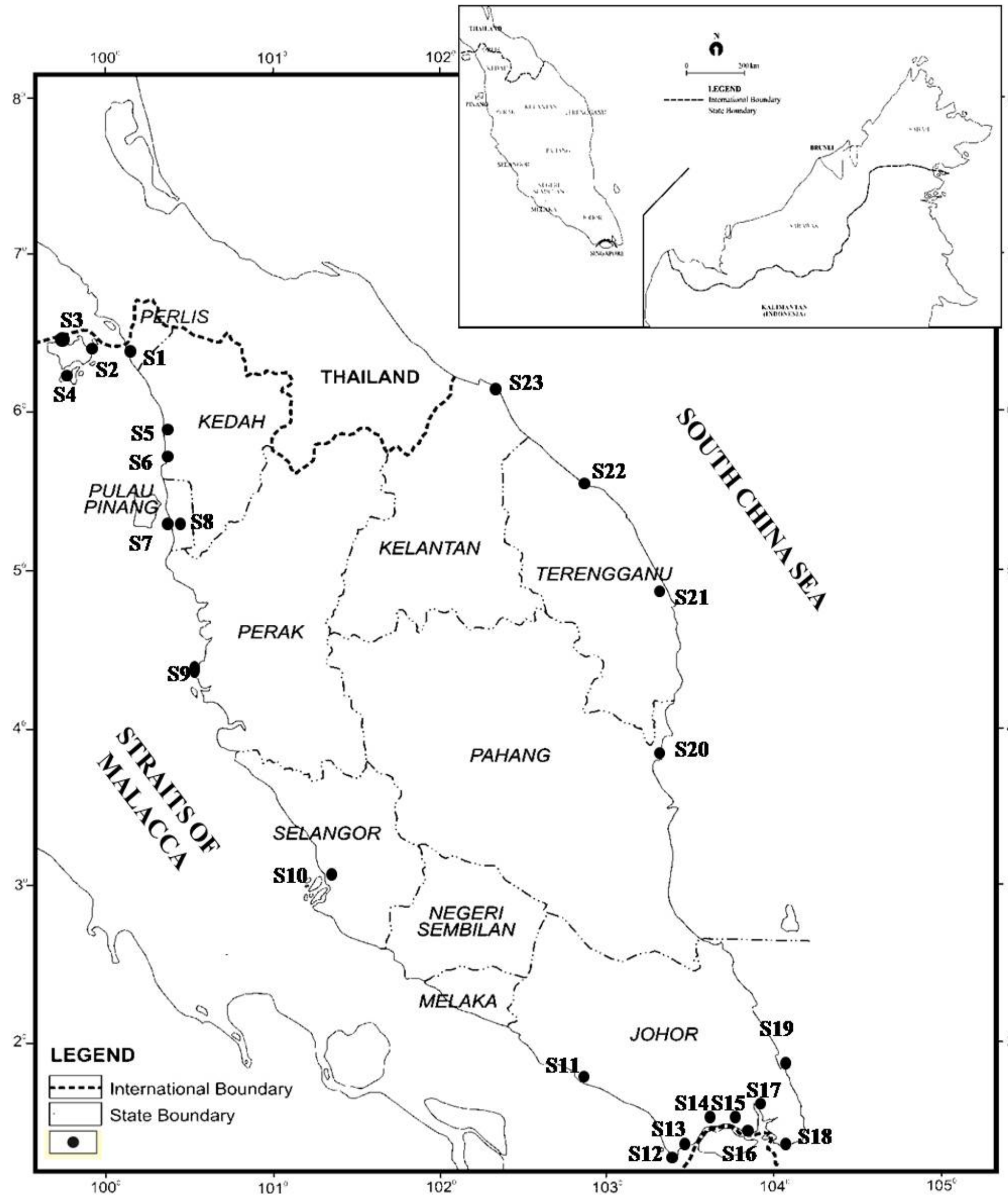

Figure 1. Sampling stations where the fishes were purchased from fish cages along the coast of Peninsular Malaysia

collected via an electrodeposition process by forming lead sulphate ($PbSO_4$) precipitation. The precipitate was wrapped onto plastic discs and counted for ^{210}Pb via ^{210}Bi beta activity using the gross alpha/beta counting system (Tennelec Series 5-XLB low background gas-flowing anti-coincidence alpha-beta counter) after one month to allow bismuth ingrowths. A quality control procedure was applied using a fish standard reference material supplied by the IAEA-414 and the recovery is shown in Table 2.

3. Results and Discussion

3.1. Concentrations of ^{210}Po and ^{210}Pb in edible tissues of seabass

The activity of ^{210}Po and ^{210}Pb in seabass muscles ranged from 5.10 ± 0.36 Bq/kg to 15.53 ± 5.40 Bq/kg and 7.09 ± 0.54 Bq/kg to 21.72 ± 2.64 Bq/kg, respectively (Fig. 2). Higher accumulations of ^{210}Po and ^{210}Pb were recorded from stations S3 and S23. According to Jamaluddin and Kadaruddin (1997) and Zakaria *et al*. (2012), the development of tourist attractions in coastal areas has a negative impact in terms of pollution. A previous study by Mohamed *et al*., (2012) found that beaches in the east coast of Peninsular Malaysia such as Kelantan (station S23) have recently been facing an increase in marine pollution from numerous hotel and facilities developed along the shore. Direct waste from restaurants might increase nutrient and organic inputs in the water body of station S3 (in Langkawi Island) as the fish were reared in cages next to a floating restaurant. In this study, the development of tourism is shown to have a negative impact on fish

Table 1. Average length and weight of samples with descriptions for all sampling locations

Group (Location)	Station	Location	Sampling Date	n	Salinity (psu)	Average Length (cm)	Average Weight (g)	Description
A (west coast of Peninsular Malaysia – Malacca Strait)	S1	Kuala Perlis	5-Jul-08	4	18.6	37.33 ± 3.91	733.50 ± 294.51	Urbanization area
	S2	Kilim	17-Jan-08	5	31.7	33.96 ± 2.25	437.00 ± 101.77	Ubanization area
	S3	Kubang Badak	17-Jan-08	8	29.6	32.25 ± 1.98	379.25 ± 98.69	Fish reared in restaurants cages
	S4	Dayang Bunting	17-Jan-08	5	31.5	43.58 ± 2.55	1109.00 ± 125.62	Tourism centre
	S5	Kuala Muda	1-Sep-07	4	0.1	190.30 ± 3.66	4305.00 ± 301.81	Near jetty and urbanization area
	S6	Sg. Petani	27-Apr-08	5	16.8	41.16 ± 2.99	814.02 ± 119.23	Urbanization area
	S7	Pulau Aman, Juru	28-Apr-08	5	29.0	34.98 ± 0.65	524.60 ± 32.61	Near Juru industrial area
	S8	Nibong Tebal	4-Jul-08	6	11.2	36.27 ± 1.05	703.67 ± 36.6	Urbanization area with influence from Sg Udang
	S9	Larut Matang	3-Jul-08	8	23.6	38.87 ± 3.41	716.83 ± 217.15	State mangrove reserve area
	S10	Port Klang	4-Mar-08	6	31.2	45.03 ± 1.75	1433.33 ± 129.10	Urbanization area
	S11	Muar	17-Nov-07	6	5.3	31.83 ± 1.00	412.67 ± 28.04	Urbanization area with influence from Muar river
B (southern coast of Peninsular Malaysia - Tebrau Strait)	S12	Kukup	4-Sep-07	7	29.9	31.83 ± 1.41	463.00 ± 38.11	State mangrove reserve area
	S13	Gelang Patah	15-Nov-07	6	25.6	34.77 ± 2.50	527.00 ± 99.74	Opposite live firing area , boats routes to Indonesia
	S14	Sg. Danga	20-Mar-08	6	23.4	33.67 ± 2.00	490.67 ± 56.85	Near Danga Bay, recreational beach
	S15	Teluk Jawa	15-Nov-07	5	21.3	43.23 ± 2.10	1092.33 ± 161.20	Opposite industrial area of Sembawang
	S16	Teluk Sengat	20-Mar-08	6	22.9	32.08 ± 2.17	433.00 ± 93.93	Downstream of Johor river, urbanization area
	S17	Sg. Penderam	14-Nov-07	4	19.4	34.40 ± 1.56	529.67 ± 60.10	Upstream of Johor river, urbanization area
	S18	Pengerang	21-Mar-08	7	27.4	30.80 ± 2.24	622.33 ± 111.53	Influence by Sebina river, mangrove reserve area
C (east coast of Peninsular Malaysia – South China Sea)	S19	Sedili Kechil	22-Mar-08	6	19.8	36.15 ± 2.14	558.33 ± 85.05	Estuary of Sedili Kechil river, mangrove reserve area
	S20	Tanjung Agas	22-Mar-08	3	0.1	47.80 ± 3.55	1295.00 ± 269.35	Tributaries of Pahang river
	S21	Paka	24-Apr-07	5	31.4	32.54 ± 1.86	489.20 ± 101.68	Near urbanization area
	S22	Setiu	21-Apr-07	6	33.1	39.79 ± 2.68	838.71 ± 199.09	Developed mangrove area and near urbanization area
	S23	Tumpat	24-Mar-07	4	29.0	35.95 ± 0.98	631.20 ± 39.20	Near the boundaries of Thailand and recreational beach
		Total Sampel		127				

n – number of sample

Table 2. Result of ^{210}Pb and (^{210}Po#) activity in Fish Reference Sample IAEA-414

Certified Value (Bq/kg d.w)	Measured Value (Bq/kg d.w)	Recovery (%)
1.8 - 2.5	1.08 ± 0.18	83.74

^{210}Po is in equilibrium with ^{210}Pb at the time of measurement

cages near station S23. Radioactivity levels are related to sampling locations and the anthropogenic activities in the surrounding area, whose effluents may increase the concentration of naturally occurring radionuclides in the environment (El Samad *et al*., 2010; Zakaria *et al*., 2012). Urbanization at both stations has led to a lot of heavy metal and radioactive material input into the river which is then channeled to the sea. This explains why the highest concentrations of ^{210}Po and ^{210}Pb were found at stations S3 and S23, as there is a lot of tourism development in the area. According to Jothy (1976) the marine pollution problem in Malaysia is due to effluent input in rivers, especially given land based development and the concurrent increase in population density in these areas. Differences between radioactivity levels in different locations could be due to differences in feeding patterns, metabolism and human activities (Al-Masri *et al*., 2000).

3.1.1. The behavior of ^{210}Po and ^{210}Pb activity concentrations in Malaysian sea bass

Generally, activity concentrations of ^{210}Po in muscle is always higher than ^{210}Pb. A study by Suriyanarayanan *et al*., (2008) found that the value of ^{210}Po ranged from 21.4 to 137.7 Bq/kg and ^{210}Pb ranged from1.8 to 49.7 Bq/kg in fish muscle. It has been explained that higher concentrations of ^{210}Po in fish is due to its benthic habits and detritivore feeding which leads to ^{210}Po accumulation (Suriyanarayanan *et al*., 2008). In contrast, our results showed an opposite trend in almost all samples (Table 3). It is noteworthy that our results were in agreement with other literature such as for little tunny (*Euthynnus alletteratus*) (Al-Masri *et al*., 2000), lake trout (*Salvelinus namaycush*) and lake whitefish (*Coregonous clupeaformis*) (Clulow *et al*., 1998), and golden threadfin bream (*Nimipterus delegoae*), yellowtail scad (*Atule mate*) and frigate mackerel (*Auxis thazard*) (Zal U'yun *et al*., 2005). Only S1, S8 and S18 stations showed higher concentrations of ^{210}Po than ^{210}Pb.

The range of activity concentration of ^{210}Po and ^{210}Pb in fish muscle were comparable to those reported in other countries as shown in Table 4. This comparison is complicated because very little data is available on ^{210}Po and ^{210}Pb in cultured fish and tropical fish environments. Noshkin *et al*., (1994) showed the variation in ranges observed in Marshall Island fishes studied at different trophic levels as well as in the same trophic level and could not explain the variation within the same trophic level. Data obtained from the equatorial region are generally higher than the mean level of polonium encountered in different species of fish from colder, northern European waters (Noshkin *et al*., 1994). The highest concentrations of ^{210}Po and ^{210}Pb reported in the Batroun region may be due to industrialisation in this area (El Samad *et al*., 2010).

Differential behavior of ^{210}Po and ^{210}Pb in seabass muscles can also be attributed to ^{210}Po/^{210}Pb activity ratios. The ^{210}Po/^{210}Pb ratio is often a sensitive indicator of biological processes. In the present study, almost all the ^{210}Po/^{210}Pb activity ratio was found to be lower than unity (Table 3). The results of the ratio of ^{210}Po/^{210}Pb were between 0.28 and 1.98. A quotient of less than 1 would indicate that ^{210}Po has not equilibrated with its parent ^{210}Pb. A lower activity ratio may be due to higher concentrations of ^{210}Pb than ^{210}Po and can be attributed to the metabolism of a particular tissue and feeding pattern (Al-Masri *et al*., 2000). Though the samples accumulated high levels of ^{210}Pb, the reflected variability in the accumulation is evidently due to the ability of ^{210}Pb to exist in the environment (Hameed *et al*., 2004). While the ^{210}Po/^{210}Pb ratio for Stations S1, S8 and S18 was found to be more than unity, this indicates that the ^{210}Po in fish is not only due to decay of ^{210}Pb but that selective uptake from its surroundings has occurred (Al-Masri *et al*., 2000). A similar type of finding has been reported by many authors indicating that the larger concentrations of ^{210}Po in each species come from the environment (Carvalho and Fowler, 1994; Germain *et al*., 1995). Thus, the ^{210}Po data presented here was also less affected by the decay of its progenitor, ^{210}Pb, which is the same as previous findings by Ugur *et al*., (2002). This finding was agreed upon by Shannon and Cherry (1967), showing that the majority of ^{210}Po accumulation in marine biota is unsupported, indicating that ^{210}Po is selectively accumulated relative to its precursor. The same result was reported by Germain *et al*., (1995) whereby the ^{210}Po/^{210}Pb ratio was in the range of 6-40, indicating that a large part of the ^{210}Po in each individual specimen comes from the environment. According to a study by Young *et al*., (2002), the ^{210}Po/^{210}Pb quotients for this natural radionuclide in fish ranged from 3.5 to 240. It would appear that there are differences in the uptake and metabolism of ^{210}Po by cultured fish and wild sea fish which is possibly a reflection of their different diets.

In addition, the study also shows no significant variation between fish sizes to the ^{210}Po and ^{210}Pb activity concentrations. The diagram in Fig. 3 shows good growth of sea bass in their cages. The relationship between length and weight of sea bass in this study showed a significant positive correlation (*r=0.90, p<0.01*) (Fig. 3). The correlation test was performed to determine whether the concentrations of ^{210}Po and ^{210}Pb mutually influenced each other. We found that ^{210}Pb activity does not really influence ^{210}Po activity in seabass.

3.2. Regional differences of the ^{210}Po and ^{210}Pb activity concentration

A site specific comparison of sea bass rearing locations was carried out to determine possible reasons and sources of radioactive pollution. The sampling stations were divided into three groups: as Groups A, B and C referring to the Malacca Straits, Tebrau Straits and South China Sea respectively (Table 5). Activity concentrations of ^{210}Po in sea bass from Group B had the highest mean compared to those from Groups A and C. The Tebrau Straits is one of the important aquaculture areas in Malaysia, and is a major seafood producer of fish and shellfish. Meanwhile, the presence of major ports (Tanjung Pelepas, Johor Port and Tanjung Langsat as a new chemical port) and the latest new and larger economic zone (Iskandar Malaysia) are expected to grow and accelerate high impact development (industrial, urban, agriculture, etc.) in this area (Zulkifli *et al.*, 2010). In the city-state of Singapore, much its land has already been developed into industrial, urban, agriculture and aquaculture areas. Massive development along both sides of the Tebrau Strait could lead to significant

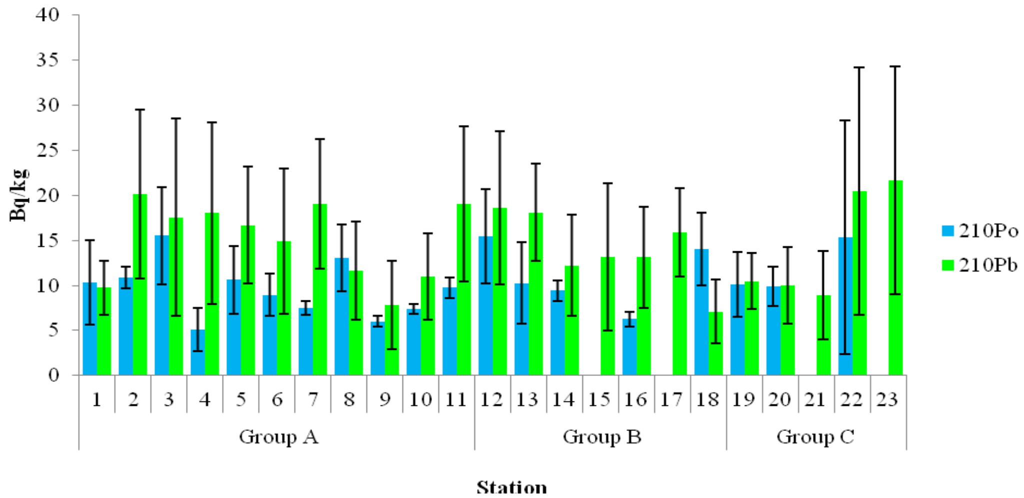

Figure 2. Graph ^{210}Po and ^{210}Pb in the muscle of cultured sea bass in Peninsular Malaysia

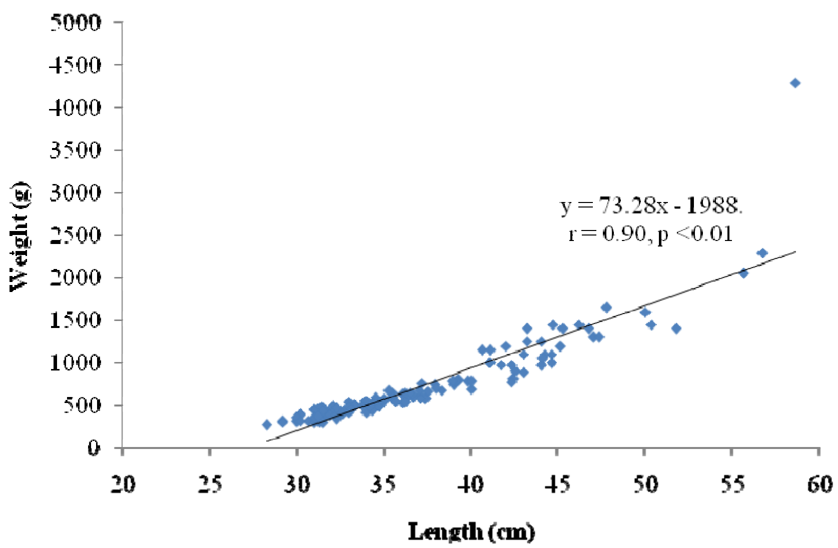

Figure 3. Correlation graph between length (cm) and weight (g) of sea bass samples

Table 3. The average values of ^{210}Po and ^{210}Pb activity and ratio $^{210}Po/^{210}Pb$ in sea bass (*Lates calcarifer*) muscle

GROUP	Stesen	n	^{210}Po	^{210}Pb	$^{210}Po/^{210}Pb$
A	S1	4	10.36 ± 4.68	9.74 ± 2.98	1.06
	S2	5	10.90 ± 1.18	20.15 ± 4.41	0.54
	S3	8	15.53 ± 5.40	17.58 ± 0.96	0.88
	S4	5	5.10 ± 0.36	18.04 ± 0.10	0.28
	S5	4	10.63 ± 3.75	16.70 ± 3.52	0.64
	S6	5	8.95 ± 2.36	14.89 ± 2.06	0.60
	S7	5	7.50 ± 0.73	19.05 ± 2.18	0.39
	S8	6	13.06 ± 3.75	11.60 ± 1.45	1.13
	S9	8	6.03 ± 0.58	7.85 ± 4.93	0.77
	S10	6	7.43 ± 0.53	10.97 ± 4.77	0.68
	S11	6	9.76 ± 1.12	19.09 ± 3.63	0.51
B	S12	7	15.44 ± 5.23	18.65 ± 3.51	0.83
	S13	6	10.25 ± 4.53	18.12 ± 2.36	0.56
	S14	6	9.44 ± 1.16	12.24 ± 1.60	0.77
	S15	5	BDL	13.15 ± 2.18	-
	S16	6	6.26 ± 0.79	13.14 ± 1.64	0.48
	S17	4	BDL	15.90 ± 2.88	-
	S18	7	14.04 ± 4.06	7.09 ± 0.54	1.98
C	S19	6	10.11 ± 1.57	10.49 ± 3.07	0.96
	S20	3	9.91 ± 1.17	9.99 ± 1.25	0.99
	S21	5	BDL	8.95 ± 1.93	-
	S22	6	15.38 ± 2.95	20.50 ± 3.74	0.75
	S23	4	BDL	21.72 ± 2.64	-

Table 4. Range of ^{210}Pb and ^{210}Po activity concentrations in fish muscle from different countries

Location	**Species**	**^{210}Po (Bq/kg)**	**^{210}Pb (Bq/kg)**	**References**
Malaysia (Range)	*Lates calcarifer*	5.10-15.30	7.09-21.72	This study
Kemaman, Malaysia	m.s	4.79-146.05	4.81-146.54	ZalU'yun *et al*., 2005
Besut, Malaysia	m.s	7.93	7.96	ZalU'yun *et al*., 2005
Kuala Selangor, Malaysia	m.s	0.10-11.77	0.13-4.00	Mohamed *et al*., 2006
Kapar, Malaysia	*Arius maculatus*	0.06-5.64	-	Alam and Mohamed 2011
Lebanon	m.s	0.22-47.82	1.31-45.00	El Samad *et al*., 2010
Syria	m.s	0.27-27.48	0.05-0.38	Al-Masri *et al*., 2000
Japan	m.s	0.6-26	0.04-0.54	Yamamoto *et al*., 1994
Australia	m.s	0.9-44.1	-	Smith and Towler 1993
Portugal	m.s	0.2-11	-	Carvalho 1988
South Africa	m.s	2.2-20.3	-	Cherry *et al*., 1994
America	m.s	0.4-153.3	0.1-7.0	Noshkin *et al*., 1994

m.s – multi species

physical and chemical changes in the environment (Zulkifli *et al*., 2010). Higher activity concentrations of ^{210}Po in the Tebrau Straits in our results compared to the northwest may have been influenced by industrial waste (Ugur *et al*., 2002), as well as shipping and port activities. According to Koh (2004), the Tebrau Straits receive uncontrollable discharge from coastal areas which lead to eutrophication and make it unsuitable for drinking. According to Bernama (2009), pollution levels in the Tebrau Straits have such a significant

Table 5. Regional differences in the activity of ^{210}Po and ^{210}Pb

Group	Region	Station	^{210}Po	^{210}Pb	^{210}Po/^{210}Pb
A	Malacca Straits	S1-S11	9.71 ± 2.49	14.75 ± 4.88	0.66
B	Tebrau Straits	S12-S18	12.79 ± 2.84	12.25 ± 3.15	1.04
C	East Coast	S19-S23	10.03 ± 2.20	13.78 ± 6.09	0.73

impact that it could threaten the livelihoods of the people who depend on it.

The highest ^{210}Pb activity was recorded in group A, followed by group C and B. The Straits of Malacca is subject to a great variety of pollutants due to its strategic location as a major international shipping lane and the concentration of agriculture, industry and urbanization on the west coast of Peninsular Malaysia (Abdullah *et al*., 1999). According to the Department of Environment, Malaysia, 20,702 water pollution point sources were recorded in 2009, which comprise manufacturing industries (9,762), sewage treatment plants (9,676), animal farms (769) and agro-based industries (495). A total of 10,311 sources were identified as manufacturing industry and agro-based industry pollution where 9,513 sources were in West Malaysia and 798 sources were in East Malaysia (DOE, 2009). The difference between a previous study on the activity of ^{210}Po and ^{210}Pb in fish muscle and this research might be due to the variation of sample types (golden threadfin bream (*Nimipterus delegoae*), yellowtail scad (*Atule mate*) and frigate mackerel (*Auxis thazard*) etc.) and geographical location. Shannon (1973) reported that pelagic fish (those that live and feed in the water column such as mackerel) contain five times more ^{210}Po than demersal species (those that live and feed at the sea bottom such as plaice).

Discriminant function analysis (DFA) was used to classify the suitability of the group to its sampling locations. DFA classified 45% for group A, 68% for group B and 48% for group C (Figure 4). The significant difference of ^{210}Po and ^{210}Pb grouped by source and anthropogenic influences was based on 51.9% of the original group cases being correctly classified by region of sample collection. Thus, this suggests that the effects of these radioisotopes can be considered and may be used for future monitoring of fish in Malaysia.

4. Conclusions

This study provides a general view of activity levels of natural radioisotopes such as polonium and lead in edible fish tissue of cage cultured seabass from the coastal areas of Peninsular Malaysia. The highest concentrations and ratios were due to effluents from terrestrial activities. These findings also suggest that monitoring should be done to mitigate possible risks to human and environmental health.

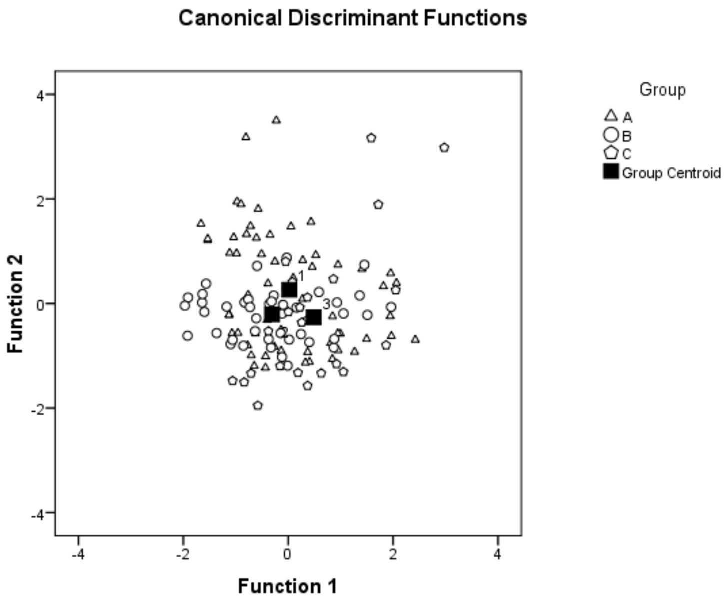

Figure 4. Canonical relationship between ^{210}Po, ^{210}Pb and the sampling location grouping

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