



Distribution of ^{210}Po in body organs of bigeye scad and greater lizardfish species at Binh Thuan, Vietnam

Van-Hao Duong¹ · Thanh-Duong Nguyen¹ · Thanh-Nam Nguyen^{2,3} · Thanh-Dong Nguyen⁴ · Tan-Dung Pham² · Viet-Dung Luu^{5,6} · Dang-Quy Tran^{5,6} · Van-Thiep Vo⁷ · Thanh-Luan Pham⁸ · Saiyad Musthafa⁹ · Dang-Minh Nguyen¹⁰ · Van-Dung Nguyen¹ · Van-Loat Bui⁸

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Abstract

^{210}Po activity was investigated in the eleven organs of two marine fish species, bigeye scad and greater lizardfish at Binh Thuan, Vietnam by alpha-spectrometry. The ^{210}Po concentration significantly varied among organs, where the highest ^{210}Po activity of 278 and 512 Bq/kg.w.wt were observed in intestine and lowest of 12.9 and 2.8 Bq/kg.w.wt in muscle tissue of those fish species organs, respectively. The ^{210}Po bioconcentration factor (BCF) ranged from 9.3×10^3 to 20×10^4 for bigeye scad and from 2.0×10^3 to 37×10^4 for greater lizardfish. The BCF and annual committed effective dose values showed a high radiation potential and higher than the limit value of 1000 $\mu\text{Sv/y}$.

Keywords ^{210}Po · Marine fish species · Bioconcentration · High ACED · High ^{210}Po activity in intestine

✉ Thanh-Nam Nguyen
nguyenthanhnam@hus.edu.vn

Van-Hao Duong
duongvanhao@humg.edu.vn

Thanh-Duong Nguyen
nguyenthanhduong@humg.edu.vn;
nguyenvandung@humg.edu.vn

Thanh-Dong Nguyen
thanhdongm2m@gmail.com

Tan-Dung Pham
phamtandung1_t62@hus.edu.vn

Viet-Dung Luu
dungluuviet@hus.edu.vn

Dang-Quy Tran
quytrandang@hus.edu.vn

Van-Thiep Vo
vovanthiepqbu@gmail.com

Thanh-Luan Pham
luanpt@hus.edu.vn

Saiyad Musthafa
saiyad_musthafa@rediffmail.com

Dang-Minh Nguyen
minhnd.qb@gmail.com

Van-Loat Bui
buiivanloat@hus.edu.vn

- ¹ Hanoi University of Mining and Geology (HUMG), Hanoi, Vietnam
- ² Faculty of Biology, University of Science, Vietnam National University, Hanoi, Vietnam
- ³ Center of Life Science Research (CELIFE), University of Science, Vietnam National University, Hanoi, Vietnam
- ⁴ Institute of Engineering Technology, Hanoi, Vietnam
- ⁵ Key Laboratory of Geoenvironment and Climate Change Response, University of Science, Vietnam National University, Hanoi, Vietnam
- ⁶ Faculty of Geology, University of Science, Vietnam National University, Hanoi, Vietnam
- ⁷ Institute of Agriculture and Environment, Quang Binh University, Dong Hoi, Vietnam
- ⁸ Faculty of Physics, University of Science, Vietnam National University, Hanoi, Vietnam
- ⁹ Unit of Research in Radiation Biology and Environmental Radioactivity (URRBER), P.G. and Research Department of Zoology, The New College (Autonomous), University of Madras, Chennai, Tamilnadu 600 014, India
- ¹⁰ Center for Environment Treatment Technology, High Command of Chemistry, Hanoi, Vietnam

Introduction

The actual environment is seriously polluted by natural factors and human activities such as heavy metal pollution in coastal sediments, weathering layers, micro-plastics, and construction of nuclear power plants [1–8]. Natural factors that pollute the environment include volcanic activity, young tectonic movements, and mineral resources [9–11]. Marine environment harboring various kinds of pollution is no way an exception to natural radionuclide pollution, especially polonium (^{210}Po) that had allured significant attention of the researchers in recent decades. The presence of ^{210}Po can be attributed to the atmospheric deposition of ^{210}Po itself and the decay of its grandparent ^{210}Pb as well as human activities such as ore-processing, ore-exploitation, oil/gas industries [12–16]. Accumulation of ^{210}Po in marine species has been reported by previous studies [13, 17–19]. The ^{210}Po also significantly contributes to the natural radiation dose to population due to the consumption of seafood [19–28]. ^{210}Po , a progeny of ^{210}Pb primarily belonging to the ^{238}U decay series, is well known as one of the most toxic natural radionuclides, which has a half-life of 138.4 days. Baseline studies of ^{210}Po movement, distribution in marine fish has been studied in recent years [29, 30]. Although, the study of ^{210}Po concentration in seafood and its contribution to human dose calculation are of great interest for researchers around the world, there are scarce researches on the distribution of ^{210}Po concentration in organs and muscle tissue of marine fishes.

In Vietnam, the studies regarding ^{210}Po activity in organs of marine species is still limited. Recently, Van et al. [31] investigated the activities of gross alpha and beta in eleven marine species on coast, North Vietnam. The research results showed that the increase in trophic level of selected marine species may result in a decrease in gross alpha activity. Van. [32] and Nguyen et al. [33] studied the ^{210}Po activity and annual effective dose (AED) due to ingestion of muscle tissues of seafood species which were contaminated of ^{210}Po from the coast of Vinh to Nha Trang and Binh Thuan towns of Vietnam. The results indicated that the average ^{210}Po concentration in studied marine species was near 17 Bq/kg w.wt and the average AED of ^{210}Po due to ingestion of seafood was near 400 $\mu\text{Sv/y}$ which was slightly higher than the global value. These investigations generally focused on the level of ^{210}Po in muscle of marine species and its contribution to human dose calculation via seafood consumption. There is no study on the distribution of ^{210}Po in different organs, bio concentration factor (BCF) for ^{210}Po of marine fish in Vietnam. This work will provide the baseline data on the distribution of ^{210}Po concentration in different organs and BCF of the most common marine fish species with high economic value, namely bigeye scad (*Selar crumenophthalmus*) and greater lizardfish (*Saurida tumbil*). These marine species have different feeding habits and lives in a monsoon tropical environmental coast close to the titanium

placer bearing rich natural radionuclides. Binh Thuan with monsoon tropical climate is located on the coast of South Central Vietnam [34], not only there is a large fishing ground with rich aquatic resources, the output of annual fishing reaches over 199.000 tons per year, but also has an abundant distribution of titanium placer [35]. There was a report of high gross alpha and beta activities in this local sea water contaminated and related to titanium mining [36]. Thus, the research on the ^{210}Po distribution and their bioaccumulation factor are of great importance which will be contributed as the novel knowledge of the ^{210}Po activity distribution in different organs of two commercial, typical, and popular fish species. The research results also provide an information to understand the pathway and ^{210}Po distribution in different organs of two of the different marine fish species in the same tropical monsoon climate conditions. Besides, the present study can give a baseline data as a proof to assess the impact of titanium placer exploration to the marine environment in this study area.

Materials and methods

The bigeye scad (*Selar crumenophthalmus*) and greater lizardfish (*Saurida tumbil*) species are two of the commercial fish in Vietnam Sea as well as in aboard. *Selar crumenophthalmus*—bigeye Scad is distributed in the Indo-Pacific: East Africa to Rapa, north to southern Japan and the Hawaiian Islands, south to New Caledonia; Eastern Pacific: Mexico to Peru, including the Galapagos Islands; Western Atlantic: Nova Scotia, Canada and Bermuda through the Gulf of Mexico and the Caribbean to São Paulo, Brazil; Eastern Atlantic: Cape Verde to southern Angola, they present in 145 countries/islands: 36 in Africa, 33 in Asia, 1 in Europe (Russia), 36 in North America, 28 in Oceania, 11 in South America [37]. As estimated, the global fishing yield for this species is more than 200.000 tonnes in 2016 [38]. While the *Saurida tumbil*—greater lizardfish distribution in the Indo-West Pacific: Red Sea and east coast of Africa (except Kenya), including Madagascar to the Persian Gulf, Arabian Sea, and further east to southeast Asia and Australia, they are present in 36 countries/islands: 8 in Africa, 25 in Asia, 3 in Oceania [37]. The global fishing yield for this species is more than 20.000 tonnes in 2016 [39]. Many countries around the world used fish organs (stomach, intestine, liver, heart, eyes,...) as food (meal), such as countries in Southeast Asia, Japan, Canada, China, Russia, Sri Lanka, ... [40, 41]. Ten mature individual samples of bigeye scad and greater lizardfish were collected from local fishermen daily. Additionally, we chose the bigeye scad (3.8—trophic level, a omnivorous feeding habit) and greater lizardfish (4.4, a carnivorous feeding habit) with higher trophic levels which factor may be biomagnified of ^{210}Po concentration in almost all marine biota [30]. The GPS was got for center

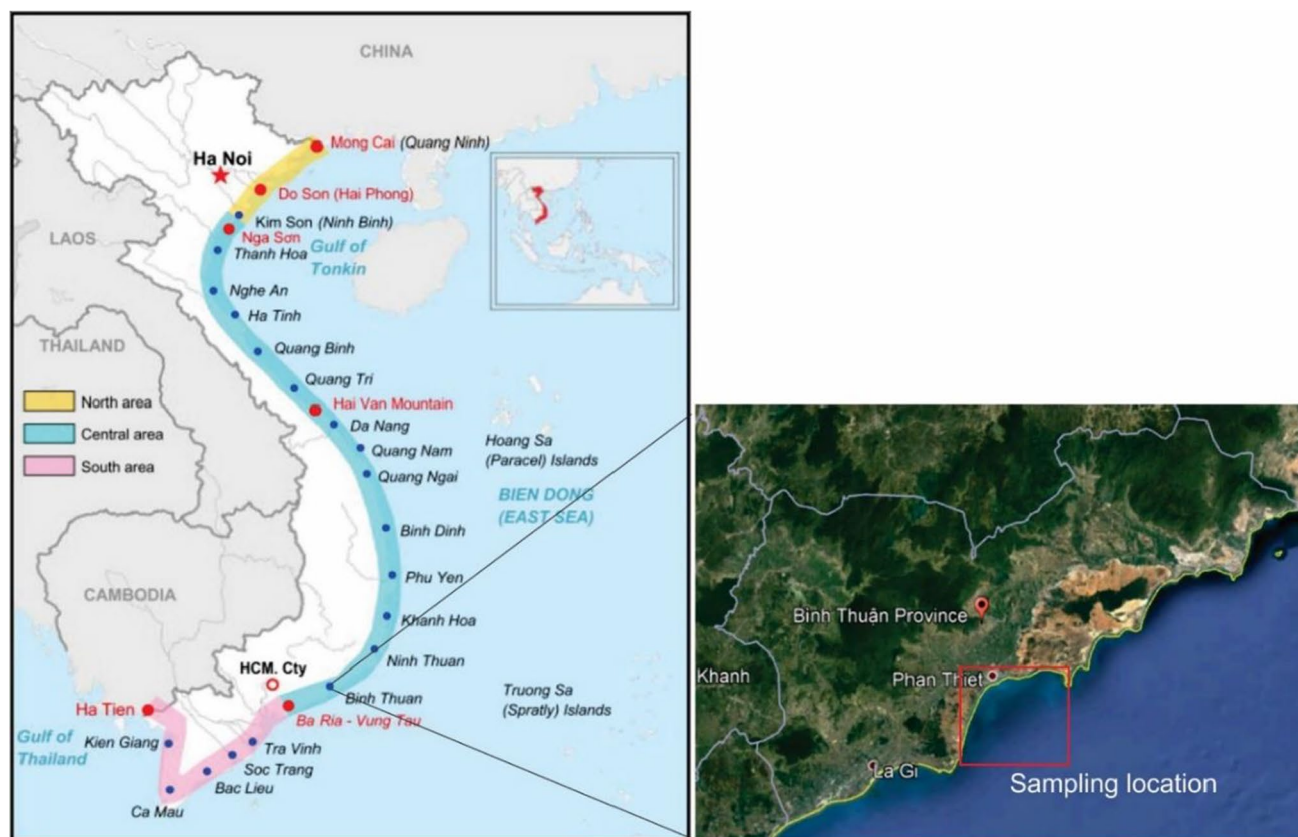


Fig. 1 Sampling location [33]

point of area of the catch ($10^{\circ}52'18.3''\text{N}$ $108^{\circ}08'32.3''\text{E}$) (Fig. 1). Then the fishes were kept in frozen ice box and directly transported to laboratory for bio-separation, preparing and radioactivity analysis. Three locations at vertex side of equilateral triangle 1 km and mutual mix at five of different from 5 to 25 m in depth, surrounding the center point were chosen for sea water sampling by core water sampling batomet (WILDCO, USA- DORN type). Duplicate samples were selected and acidified by HCL 5 M to avoid precipitation. They were then transferred to laboratory the same day for analysis.

Before ^{210}Po measurements, the fishes were washed with distilled water. Eleven samples of organ and stomach content of each fish species, including muscle, gill, intestine, liver, stomach, heart, scales, skin, eye, stomach content, and bone were separated. Each of sample was weighed in fresh and labelled with name and date of collection with utmost care (for calculating the elapsed time of ^{210}Po decay).

The edible muscle tissues, organs and stomach content were prepared for ^{210}Po measurement following the procedure of Van [32]. Each of the study samples was added with 100 mBq of ^{209}Po tracer and then was wet-digested by strong mix acid $\text{HNO}_3\text{—HCl}$ (1:3), and H_2O_2 till complete digestion. The co-precipitation of ^{210}Po at $\sim 90^{\circ}\text{C}$ with MnO_2

was achieved through adding of MnCl_2 (0.1 M) and KMnO_4 (0.1 M) solution after the addition of ammoniac solution at $\text{pH} > 9$. The obtained sample was mixed for 0.5 h by the magnetic stirrer and were stored overnight. The precipitate was decanted and washed by distilled water and then dissolved in HCL 9 M and dried in glass bottom. The separation of ^{210}Po concentrates was achieved by dissolving it in HCL acid 0.5 M, after which it was absorbed on a silver disc. The obtained silver disc sample was dried at room temperature and then was measured by PIPS ORTEC detector, with a detectable limit < 0.5 mBq. The efficiency of chemical separation procedure was about 90%, and the IAEA-414 mixed fish reference material was used for quality control procedure. Next procedure of the co-precipitation step involved the addition of sea water and ^{209}Po tracer.

Bioconcentration factor (BCF) is often used to evaluate the absorption of chemical substance by an organism from the ambient environment [42]. In this study, BCF is defined as the ratio of the ^{210}Po concentration in fish organs to that in seawater at steady state.

Before the trials, the normal distribution of the residuals was checked to meet the required tests (Friedman and Paired sample T-test, $p > 0.05$, for hypothesis testing, the alpha was 0.05). Then the differences of ^{210}Po concentration

in organs from both species were tested using analysis of the Friedman and Paired sample T-test. The Friedman test is a non-parametric statistical test and the Paired sample T-test is used to compare the means of two measurements taken from the same individual ($p < 0.05$). The Pearson correlation was also used to verify the correlation between ^{210}Po concentrations and the individual weights. The analyses were performed by SPSS V20.0.

The annual committed effective dose (ACED) contributed by ^{210}Po due to the ingestion of muscle, digestive system (intestine, liver, heart, stomach, and stomach content) and all organs of the two marine species can be calculated based on the following expression:

$$\text{ACDE} = A \times D \times X \times F \times Y$$

where A is the average activity concentration of ^{210}Po (Bq/kg w.w), D is the average daily consumption rate of seafood (kg)—For Vietnamese people, the average consumption of marine fish is estimated at 27 kg/person/year in 2015 (<https://www.vietnam-briefing.com/news/seafood-industry-vietnam-aquaculture-year-plans-tpp.html/>), X is the factor of ^{210}Po dose conversion per unit intake for adults ($X = 1.2 \mu\text{Sv/Bq}$ for ^{210}Po) [43], F is decay factor for ^{210}Po depending on the time between catching and consumption (In this study, the seafood was assumed to be consumed right after catching, so the $F = 1$), Y is 1 year.

Table 1 Average ^{210}Po concentration with standard deviation in different organs of bigeye scad and greater lizardfish

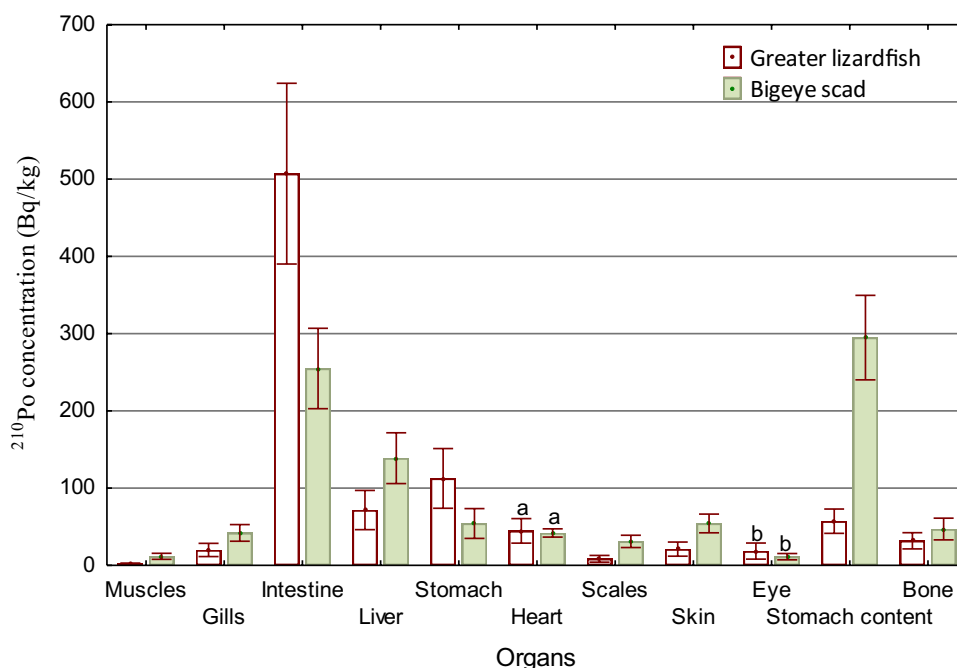
Organs (n = 10)	^{210}Po concentration (Bq/kg w.w) (average $\pm$ std)	
	bigeye scad	Greater lizardfish
Muscle	12.9 ± 3.71	2.81 ± 1.13
Gill	43.0 ± 10.2	21.0 ± 8.03
Intestine	278 ± 49.4	512 ± 111
Liver	159 ± 31.2	75.9 ± 24.0
Stomach	63.3 ± 18.3	107 ± 36.6
Heart	45.1 ± 5.02	37.8 ± 15.0
Scales	32.1 ± 7.55	8.68 ± 4.14
Skin	54.6 ± 11.5	16.0 ± 8.66
Eye	14.1 ± 3.90	21.6 ± 9.86
Stomach content	276 ± 51.9	55.1 ± 14.9
Bone	41.8 ± 13.3	28.4 ± 9.95
Min	12.9 ± 3.71	2.81 ± 1.13
Max	278 ± 49.4	512 ± 111

Results and discussions

The analysis results of sea water showed the average ^{210}Po concentration to be around $1.4 \pm 0.15 \text{ mBq/kg}$ in average (The seawater density of $1,020 \text{ kg/L}$). Average concentrations of ^{210}Po in the organs of bigeye scad and greater lizardfish are shown in Table 1. The ^{210}Po concentration varied from 12.9 ± 3.71 to 278 ± 49.4 and 92.7 Bq/kg in average. For Greater lizardfish species, the ^{210}Po concentration ranged from 2.8 ± 1.13 to 512 ± 111 and 80.6 Bq/kg in average. It can be noted that the ^{210}Po concentration in the organs of two fish species is far higher than that in seawater ($1.4 \pm 0.15 \text{ mBq/kg}$). In general, the average ^{210}Po concentration in different organs of bigeye scad species is higher than that of greater lizardfish species. According to Froese and Pauly [37], the two fish species was reported often live in reef-associated zone with omnivorous feeding habit for bigeye scad and carnivorous feeding habit for greater lizardfish. Although both species live together in reef-associated zone, bigeye scad accumulated more ^{210}Po than greater lizardfish due to significant differences in their feeding habits. The omnivorous species often eat nekton, detritus, zoobenthos, zooplankton etc. which contain a high ^{210}Po concentration [21, 44–46]. Thus, the concentration of ^{210}Po in omnivorous feeding habit species could be higher than carnivorous species. Some previous studies also reported that the omnivorous type of feeding habit species often accumulated more ^{210}Po than the carnivorous type of feeding habit species [20, 32, 46–49].

The variation of ^{210}Po concentration in different organs of two fish species is shown in Fig. 2. For both fish species, the lowest concentrations of ^{210}Po were found in the muscle of $12.9 \pm 3.71 \text{ Bq/kg}$ in bigeye scad and $2.81 \pm 1.13 \text{ Bq/kg}$ in greater lizardfish. The results met the trends of the previous study with the lowest ^{210}Po , being detected in the muscle of Small scale weakfish, *Congro-rosa* in the Brazilian coast [26]. The highest average concentrations found in the intestine were $278 \pm 49.4 \text{ Bq/kg}$ in bigeye scad and $512 \pm 111 \text{ Bq/kg}$ in greater lizardfish. Additionally, the high concentration of ^{210}Po was also found in the organs of digestive system such as liver, stomach (without food), and stomach content (fish food) for both types of fish. Some previous studies have shown a similar tendency with highest concentration of ^{210}Po observed in liver, intestine, stomach, stomach content and the lowest in muscle [13, 19, 26, 50]. As reported by Carvalho [45], the ^{210}Po concentration measured in marine fish liver can reach upto 800 Bq/kg . Skwarzec (1988) found the highest ^{210}Po concentration in the intestines of Herring (*Clupea harengus*), Cod (*Gadus morhua*), and Flounder (*Bothus mancus*) in Baltic sea with the values of 48 ± 2.0 , 206 ± 6.0 , and $16 \pm 2.0 \text{ Bq/kg w.wt}$ respectively. The highest concentration of ^{210}Po was also observed in the intestines of

Fig. 2 ^{210}Po concentration in different organs of greater lizardfish and bigeye scad. **a, b** The same letter shows no significant difference ($p > 0.05$)



Smallscale weakfish (*Cynoscion microlepidotus*), Congriro-rosa (*Genypterus brasiliensis*) [26]. The high concentration of ^{210}Po in the fish intestine was often found in contaminated areas. In the uranium mining area in Tajikistan and in Kairakkum reservoir, Skipperud et al. [51] showed that the ^{210}Po concentration in Goldfish (*Carassius auratus*) liver was 3700 Bq/kg w.wt and much higher than that in muscle. The wide range level of ^{210}Po concentration in different organs and species of marine fishes depend and vary according to different study areas, the pollution in the marine environment, metabolism, trophic levels, habitats, feeding types, and climate [13, 15, 20, 26, 32, 50]. The results were counted in average for different size of each species and for mature individuals of quite similar size. So there is weak relation between size and ^{210}Po activity in organs of those fishes. Thus in this study, though the samples were collected from the similar study area with the contamination in the marine environment, habitats (in reef-associated zone) and climate condition (monsoon tropical climate), main parameters responsible for variation in recorded ^{210}Po levels for different organs of species were variations in metabolism, feeding types (omnivorous food for bigeye scad and carnivorous food for greater lizardfish), and trophic levels (3.8 for bigeye scad and 4.4 for greater lizardfish refer from Froese, R. and D. Pauly., 2019) [37].

As shown in Fig. 2, the ^{210}Po concentration in stomach content of bigeye scad species is about 5 times higher than that of greater lizardfish ($p < 0.05$). As mentioned above, the feeding habit of bigeye scad is omnivorous while that of greater lizardfish is carnivorous, leading to a high concentration of ^{210}Po accumulated in the stomach content of

bigeye scad. However, it can be seen that although the ^{210}Po concentration in the stomach content of bigeye scad is much higher than that of greater lizardfish, the ^{210}Po concentration in the intestine of greater lizardfish is about 2 times higher than that in the intestine of bigeye scad. This can be due to better absorption of ^{210}Po from food by greater lizardfish intestine than the intestine of bigeye scad. The concentration of ^{210}Po in other digestive organs of greater lizardfish species such as liver, the stomach is also higher than that in stomach content. Thus, the concentration of ^{210}Po clearly depends on the metabolism of each organ in each species and it meets the previous studies [14, 20]. Based on the distribution of ^{210}Po concentration in the observed two fish species, the digestive organs such as the intestine, stomach, liver should not be used for human consumption to avoid getting high internal dose.

In general, the organs of bigeye scad species accumulated ^{210}Po concentration greater than those of greater lizardfish, except for intestine and stomach (therein, insignificant difference in the ^{210}Po content in heart and eye, $p > 0.05$). This indicates that the accumulation of ^{210}Po in fish organs depends not only on the feeding habit, but also on the metabolism of each organ. For both species, the organs such as gills, scales, skin, eyes which directly contact with seawater often contain a low concentration of ^{210}Po . The phenomenon could be explained that the ^{210}Po concentration in these organs may relate from seawater which contains a low concentration of ^{210}Po or due to half-life of the ^{210}Po and heavy element (138 days and 210 of atom mass) which will impact the transfer from digestion organs to above organs.

Fig. 3 Distribution of ^{210}Po concentration and BCF in greater lizardfish species

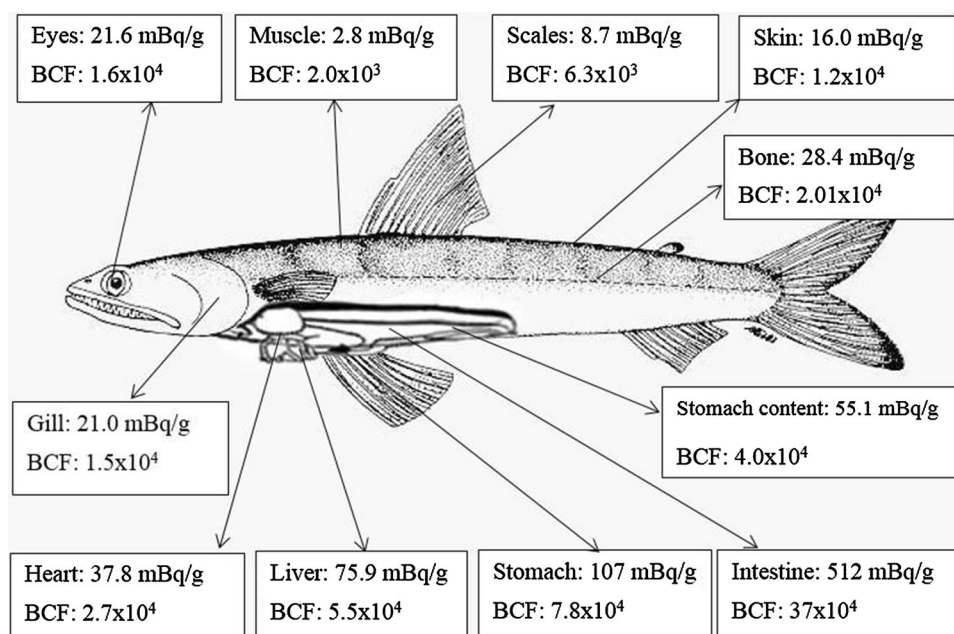
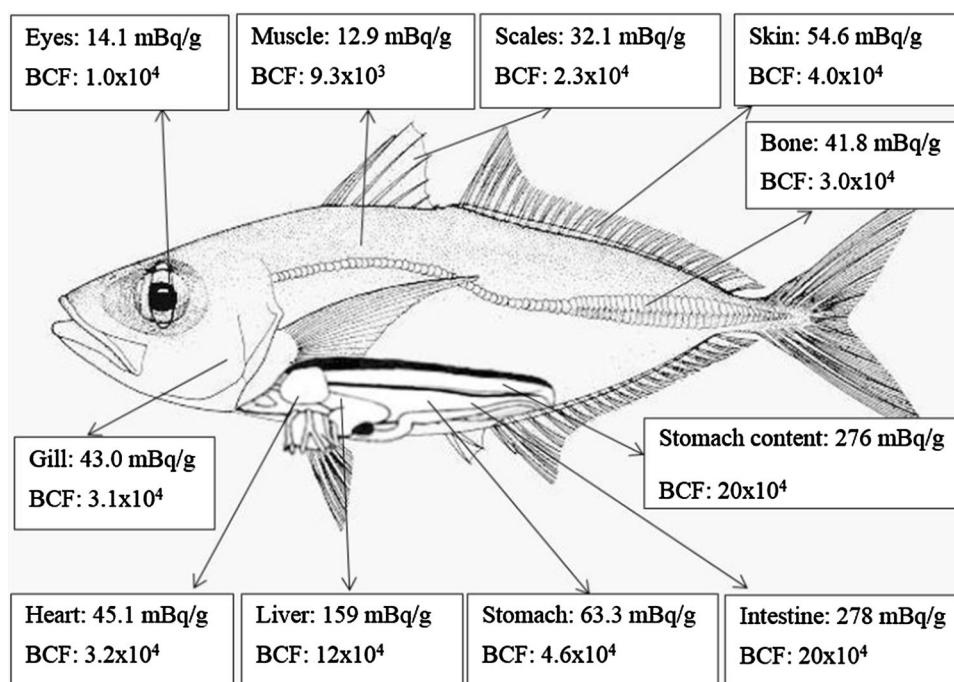


Fig. 4 Distribution of ^{210}Po concentration and BCF in big-eye scad species



The BCF can be calculated as the ratio of ^{210}Po concentration in fish (Bq/kg) to that in seawater (Bq/kg). The distribution of ^{210}Po concentration and BCF values in different fish organs is shown in Figs. 3–4. As shown, the ^{210}Po BCF for fish organs in this study varied from 9.3×10^3 to 20×10^4 Bq/kg w.wt for bigeye scad and from 2.0×10^3 to 37×10^4 Bq/kg w.wt for greater lizardfish. For both fish species, the highest BCF value was found in fish intestine while the lowest one was observed in the muscles. These results demonstrate that concentration of ^{210}Po is not simply a result of absorption

from seawater, but the food chain transfer plays an important role in absorption of ^{210}Po [52]. The results of previous studies also showed that the BCF values for different tissues of marine species can reach several orders of magnitude [19, 24, 30, 50]. As reported by Skwarzec, [50], in Baltic sea, the ^{210}Po BCF for Cod species ranged from 2.0×10^3 to 41×10^4 Bq/kg w.wt, for Herring species ranged from 2.0×10^3 to 10^5 Bq/kg w.wt, and for Flounder species ranged from 5.0×10^3 to 3.2×10^4 Bq/kg w.wt. In Kudankulam, India, the ^{210}Po BCF for Indian squid (*Uroteuthis duvaucelii*)

Table 2 Radionuclide intake and associated ACED

Organs	Greater lizardfish		Bigeye scad	
	²¹⁰ Po (Bq/kg w.w)	ACED (μSv/y)	²¹⁰ Po (Bq/kg w.w)	ACED (μSv/y)
Muscle	2.81	91.0	12.9	420
Digestive organs	158	5104	164	5320
All organs	80.6	2610	92.7	3003

was found to be from 3.6×10^3 to 20×10^4 Bq/kg w.wt [19]. Fowler [30] presented that ²¹⁰Po BCF values in digestive tissues of crustaceans, molluscs, and fish significantly varied from 4×10^4 to 9×10^5 Bq/kg w.wt and in fish muscle ranged from 2.0×10^3 to 9.0×10^3 Bq/kg w.wt. According to the standard BCF values in IAEA (2009) [53], the BCF values being higher than 1000 s indicates a high radiation potential. Thus, in this study, the BCF observed for all fish organs of two fish species shows high radiation potential.

Regarding the annual committed effective dose (ACED), as mentioned above, the average consumption of sea food for adults is about 27 kg/person/year in Vietnam. It is impossible to determine the consumption rate for each type of seafood. Thus, in this study, it is assumed that the maximum consumption rate of different organs of the two marine species is 27 kg/person/year. It means that if one person consumes this rate, the ACED will be received as this report. The AECD calculated based on the consumption rate and ²¹⁰Po concentration is shown in Table 2. As shown, the ACED contributed by ²¹⁰Po via ingestion of muscle is 91.0 μSv/y for greater lizardfish and 420 μSv/y for bigeye scad. The ACED due to ingestion of digestive organs (intestine, liver, stomach, heart, stomach content) is 5104 μSv/y for greater lizardfish and 5320 μSv/y for bigeye scad. In case of eating all organs, the ACED is 2610 μSv/y for greater lizardfish and 3003 μSv/y for bigeye scad. It can be seen that the ACED due to ingestion of muscle of bigeye scad is about 4.5 times higher than that of greater lizardfish. In cases of digestion of digestive organs and all organs, the ACED contributed by ²¹⁰Po in greater lizardfish is slightly higher than that in bigeye scad. In each marine species, it is shown that among three types of ingestion, the ingestion of digestive organs will generate the highest value of ACED with 5104 for greater lizardfish and 5320 μSv/y for bigeye scad. Compared to the limit value of ACED, the ACED due to the ingestion of muscle of both marine species is lower than the limit value of 1000 μSv/y [33]. In contrast, the ACED due to the ingestion of digestive organs and all organs of greater lizardfish and bigeye scad is about 5 and 3 times higher than the limit value of ACED, respectively. Thus, it is

recommended that the consumption rate of digestive organs and all organs of the two marine species should be limited.

As reported by Nguyen et al. [33], the ACED contributed by ²¹⁰Po due to ingestion of muscle of different types of seafood in Binh Thuan, Vietnam was in the range from 99 to 2550 μSv/y. In this study, the ACED due to ingestion of muscle of the two marine species is within this range.

Conclusions

A comprehensive investigation of ²¹⁰Po distribution in the two of the most traded marine fish species, namely bigeye scad (*Selar crumenophthalmus*) and greater lizardfish (*Saurida tumbil*) in Binh Thuan coast, Vietnam has been conducted. The results showed that although two fish species are living in the same zone of reef-associated, the marine environment, and climate condition but the average ²¹⁰Po concentration in bigeye scad is higher than that in greater lizardfish. It could be due to the difference in feeding type and the metabolism. The highest ²¹⁰Po concentration was found in the digestive system of both fish species such as intestine, liver, stomach, stomach content, especially in the fish intestine. Therein, the organs in the digestive system of greater lizardfish show a higher ability of ²¹⁰Po absorption from ingested food than that of bigeye scad. Regarding the BCF, the ²¹⁰Po BCF values for different fish organs of two study species indicate a high radiation potential. The greater lizardfish species showed a high potential of ²¹⁰Po absorption rather than bigeye scad species, especially for internal organs such as liver, heart, intestine, stomach. A notice has been provided that, people should not use the digestive organs such as the intestine, liver, for feeding.

Regarding the ACED, the ACED due to ingestion of muscle of bigeye scad is significantly higher than that of greater lizardfish. While the ACED values due to the digestion of digestive organs and all organs of greater lizardfish are slightly higher than those of bigeye scad. In general, the highest ACED contributed by ²¹⁰Po is due to the consumption of digestive organs, followed by all organs and muscle. Thus, it is recommended that the ingestion of digestive organs and all organs of greater lizardfish and bigeye scad should be limited.

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