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NOTE: SAMPLING FREQUENCY EVALUATION OF THE MARINE FLORA MONITORING PROGRAM AT ALMIRANTE ÁLVARO ALBERTO NUCLEAR COMPLEX, RIO DE JANEIRO, BRAZIL

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ABSTRACT

Almirante Álvaro Alberto Nuclear Complex (CNAAA) uses seawater in the cooling system of its nuclear power plants. This water returns to the environment with a 2 °C to 8 °C temperature increase. To understand the effects of this thermal effluent, there is a large environmental monitoring program that analyses physicochemical and biological parameters, including a survey of brown algae at sampling site 32B, the nearest to the thermal discharge. This work compares monthly and seasonal variations of the specific composition of brown algae to evaluate the feasibility of changing the sampling frequency of the CNAAA monitoring program. The evaluation is performed by following two approaches: a species accumulation curve and comparisons between species richness values obtained from monthly and seasonal sampling. Species accumulation curve structure indicates that brown algae diversity at site 32B is well covered. Species richness measurements indicate that there are no significant differences between monthly and seasonal samples. These results suggest that it is possible to reduce brown algae sampling frequency for the CNAAA monitoring program without significant data loss. Furthermore, it would allow the company to cut costs, thus improving the distribution of resources within its environmental monitoring program.

KEY WORDS: Angra dos Reis, Brown algae, Environmental monitoring, Nuclear power plant, Piraquara de Fora Cove.

RESUMEN

Evaluación de la frecuencia de muestreo del programa de monitoreo de flora marina en la Central Nuclear Almirante Álvaro Alberto, Rio de Janeiro, Brasil. La Central Nuclear Almirante Álvaro Alberto (CNAAA) utiliza agua de mar en el enfriamiento de sus plantas nucleares. Esta agua retorna al ambiente con un aumento de temperatura de 2 °C a 8 °C. Para conocer los efectos de ese efluente térmico, se ha desarrollado un amplio programa de monitoreo ambiental que incluye, entre parámetros físico-químicos y biológicos, el estudio de algas pardas en el punto de muestreo 32B, ubicado junto a la zona de descarga térmica. Este trabajo compara las variaciones mensuales y estacionales de la composición específica de algas pardas para evaluar la viabilidad de cambiar la frecuencia de muestreo del programa de monitoreo de la CNAAA. Para esto, se elaboró una curva de acumulación de especies y se compararon los valores de riqueza obtenidos en colectas mensuales y estacionales. La estructura de dicha curva indica que la diversidad de algas pardas en el punto 32B es suficientemente conocida. Los valores de riqueza específica indican que no hay diferencias significativas entre los valores mensuales y estacionales. Por lo tanto, los resultados sugieren que es posible reducir la frecuencia del muestreo de algas pardas enmarcada en el monitoreo ambiental de CNAAA sin que ocurra una pérdida significativa de la información. Esto permitiría a la compañía disminuir costos y distribuir mejor sus esfuerzos como parte del programa de monitoreo ambiental.

PALABRAS CLAVES: Algas pardas, Angra dos Reis, Ensenada de Piraquara de Fora, Monitoreo ambiental, Planta nuclear.

Eletrobras Eletronuclear, the company that runs two operational nuclear power plants in Brazil – Angra 1 Nuclear Power Plant (A1) and Angra 2 Nuclear Power Plant (A2) –, is responsible for the construction of Angra 3 Nuclear Power Plant. These three power plants constitute the Almirante Álvaro Alberto Nuclear Complex (CNAAA), located on Itaorna Cove, in the western part of Rio de Janeiro state, Brazilian Atlantic Coast (Figure 1). CNAAA is situated between Serra do Mar and Ilha Grande Bay, Angra dos Reis county , approximately 133 km from Rio de Janeiro, 216 km from São Paulo, and 343 km from Belo Horizonte, three of the largest Brazilian cities (MRS, 2005).

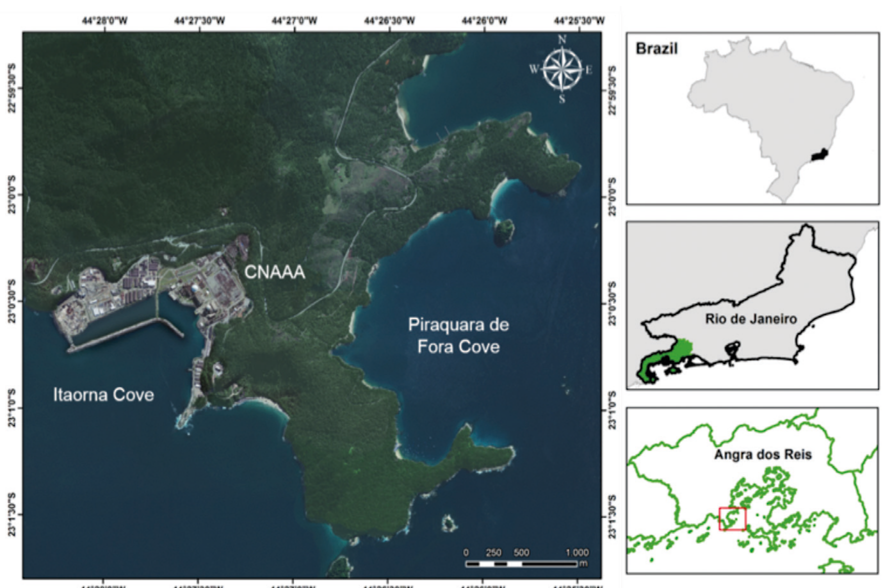

Figure 1. Location of the Almirante Álvaro Alberto Nuclear Complex (CNAAA). Geographic coordinate system SIRGAS 2000.

In a nuclear power plant, the reactor is the main source of heat generation. It operates in a similar way to a conventional thermoelectric power plant, providing thermal energy to generate the steam that moves the turbines, producing electric power. However, in a nuclear power plant, heat is released by the nuclear fission of Uranium 235 (Murray and Holbert, 2015).

A1 and A2 power plants rely on Pressurized Water Reactors (PWR) that use light water (demineralized water) as moderator and coolant. Due to the high temperature, it is necessary to keep the reactor cooling water submitted to high pressure to avoid vaporization and to ensure heat transference. This water passes through the primary circuit, inside the nuclear reactor, removing the heat released by the nuclear fission. The heat from the primary circuit is transferred to an insulated secondary circuit, which is connected to steam generators, where the water turns into dry saturated steam. The steam is directed to rotate a turbine that converts thermal energy from steam into mechanical energy; finally, the latter is transformed into electrical energy (Eletronuclear, 2013).

In a third circuit, isolated from the others, water flows to condense the steam that comes from the turbines, providing liquid water to the secondary circuit. Known as cooling water, this water is captured from a cold source. In the CNAAA case, this is seawater, which is then returned to the sea. Figure 2 represents the primary, secondary, and tertiary circuits of A2, a common PWR nuclear plant (Eletronuclear, 2013).

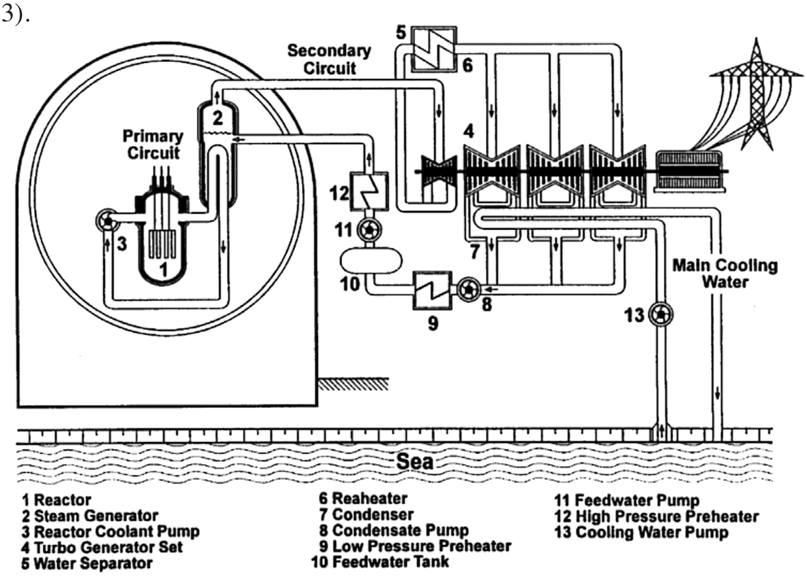

Figure 2. Arrangement of the primary, secondary and tertiary (main cooling water) circuits of Angra 2 Nuclear Power Plant, a common pressurized water reactor nuclear plant (from Final Safety Analysis Report, Rev. 13, April 13th 2013. Reproduced with permission of Eletronuclear.).

As described above, the main function of the tertiary circuit is to remove heat from the steam generators by using seawater. This water is captured in Itaorna Cove, then passes through the condensers and is discharged in Piraquara de Fora Cove (Figure 1), with a 2 ºC to 8 ºC temperature increase. Due to this increase, Eletronuclear has to monitor several physicochemical and biological parameters in Piraquara de Fora Cove.

Environmental studies regarding CNAAA started in the 1970s and were carried out by the Federal University of Rio de Janeiro. Control (Itaorna Cove) and impacted sites (Piraquara de Fora Cove – where the heated water from the nuclear plants is released) were selected and aimed at constructing an environmental monitoring program for CNAAA.

One of such studies focused on brown algae (Phaeophyceae, Ochrophyta) surveyed at 32B sampling site. It began in 1980, before A1 started operating. The study recommended that after A1 started operating, a monthly brown algae survey for short (2-3 years) and long term periods (> 2-3 years) should be performed (FUJB, 1981).

Eletronuclear followed this recommendation and gathered data continuously between 1980 and 2015, except for the period between 1984 and 1987, when a massive landslide hit the 32B site and prevented the surveys (Furnas, 1986; Eletronuclear, 2015). However, this gap did not hinder a large database accumulation. This data has been sent to environmental agencies through annual reports made by Eletronuclear.

Koutsoukos (2015) analyzed brown algae data gathered from 1980 to 2012 and compared algal occurrence patterns in three distinct phases: pre-operational phase (when none of the nuclear plants was operating), A1 operational phase and A2 operational phase (when both A1 and A2 were operating). There were no differences in the specific composition of the brown algae when comparing pre-operational and A1 operational phases. Nevertheless, significant differences were registered between A1 and A2 operational phases. These findings indicate that algal specific composition data must be treated separately, i.e. each operational phase on its own.

This work will compare monthly and seasonal variations of brown algae specific composition to evaluate the feasability of changing the CNAAA monitoring program sampling frequency. This evaluation is performed according to Koutsoukos (2015) and is thus based on two approaches: the analysis of species accumulation curve and the comparison between monthly and seasonal species richness values.

In the CNAAA monitoring program, brown algae samples were collected and processed according to Eletronuclear's protocols (Eletronuclear, 2014a, 2014b, 2014c, 2016). Specimens were identified with the works of Joly (1965), Paula (1988) and Nunes and Paula (2000, 2001, 2004). The taxonomic classification presented in this work follows Guiry and Guiry (2016).

The species accumulation curve was set up using data from 1980 to 2014, obtained from Eletronuclear annual reports. The sample size (n = 290) is equivalent to the number of field campaigns at the sampling site. The objective of this curve is to evaluate the sufficiency of the sampling effort on site 32B, based on species richness of the brown algae assemblage.

To compare monthly and seasonal species richness values, only data from 2002 - 2014 were used (A2 operational phase), because of the temporal differences observed by Koutsoukos (2015). This ensures that data were collected under the same conditions (both nuclear plants in operation). It is worth to mention that these operational conditions remain the same up to date, and they will continue so until the beginning of Angra 3 Nuclear Power Plant operation. Data from 2003 and 2004 were discarded since there were no records of brown algae for this period at 32B sampling site. Eight years were randomly chosen from the remaining eleven years dataset. Data were tested for normality (Shapiro-Wilk test) and homoscedasticity (Levene's test). Student's t-tests and Kruskal-Wallis tests were also performed according to each dataset properties. All statistical analyses were carried out at PAST 3.0 (Hammer *et al*., 2001).

A preliminary analysis was performed with the whole dataset to search for significant differences between monthly species richness results. Then, these values were grouped by year and an annual comparison was done, using data from monthly (n = 12) and seasonal (n = 4) samplings. For the seasonal sampling, February, May, August, and November were chosen to represent southern hemisphere summer, autumn, winter and spring, respectively. The same months were also used in other environmental programs conducted by Eletronuclear.

A total of 26 brown algae species were recorded (Table 1) in the species accumulation curve (Figure 3). Seventeen species were recorded during the pre-operational phase (27 samples), whereas a plateau of 25 species was recorded in the A1 operational phase (120 samples). Only one species was added to the curve during the A2 operational phase with the 266th sample. Despite this last addition, the wide plateau observed for A1 operational phase suggests that the diversity of brown algae assemblage was well covered (Magurran, 2011).

Figure 4 shows monthly mean values for brown algae species richness. Kruskal-Wallis test did not show significant differences between monthly median values of brown algae species richness ($H = -11.87$; $H_{corrected} = -12.88$; $p = 1.000$). As monthly differences were not detected, we could compare brown algae species richness values obtained annually, based on monthly and seasonal samplings. The Student's t-test displayed no significant differences between monthly and seasonal

Table 1. Brown algae species (Phaeophyceae, Ochrophyta) registered at 32B sampling site during the Almirante Álvaro Alberto Nuclear Complex monitoring program. Taxonomic classification follows Guiry and Guiry (2016).

ORDER	FAMILY	SPECIES
Dictyotales	Dictyotaceae	*Canistrocarpus cervicornis* (Kützing) De Paula & De Clerck
		Dictyopteris delicatula J.V. Lamouroux
		Dictyopterys plagiogramma (Motagne) Vickers
		Dictyota bartayresiana J.V. Lamouroux
		Dictyota ciliolata Sonder ex Kützing
		Dictyota menstrualis (Hoyt) Schnetter, Hörning & Weber-Peukert
		Dictyota mertensii (Martius) Kützing
		Dictyota pulchella Hörning & Schnetter
		Padina antillarum (Kützing) Piccone
		Padina gymnospora (Kützing) Sonder
		Spatoglossum schroederi (C. Agardh) Kützing
Ectocarpales	Acinetosporaceae	*Feldmannia indica* (Sonder) Womerlsey & A. Bailey
		Feldmannia irregularis (Kützing) G. Hamel
		Feldmannia mitchelliae (Harvey) H.S. Kim
	Scytosiphonaceae	*Colpomenia sinuosa* (Mertens ex Roth) Dèrbes & Solier
		Rosenvingea intrincata (J. Agardh) Børgesen
		Rosenvingea sanctae-crucis Børgesen
Fucales	Sargassaceae	*Sargassum filipendula* C. Agardh
		Sargassum stenophyllum Martius
		Sargassum vulgare C. Agardh
Ralfsiales	Neoralfsiaceae	*Neoralfsia expansa* (J. Agardh) P.E. Lim & H. Kawai ex Cormaci & G. Furnari
Scytothamnales	Asteronemataceae	*Asteronema breviarticulatum* (J. Agardh) Ouriques & Bouzon
	Bachelotiaceae	*Bachelotia antillarum* (Grunow) Gerloff
Sphacelariales	Sphacelariaceae	*Sphacelaria brachygona* Montagne
		Sphacelaria rigidula Kützing
		Sphacelaria tribuloides Meneghini

mean values of brown algae species richness ($t = 1.305$; $p = 0.213$). In opposition to our observations, there are records of seasonal variations in macroalgal assemblages' species richness in other Ilha Grande Bay localities (Figueiredo and Tâmega, 2007; Széchy and Sá, 2008). It is possible that the CNAAA thermal effluent interferes with the natural seasonal variability at 32B sampling site. This could help to explain the absence of a significant temporal variation in species richness.

Raffaelli and Hawkings (1996) argue that in long-term studies at rocky shores, as the Eletronuclear environmental monitoring, sampling frequencies do not need to be high: four to six samplings are enough to observe seasonal differences

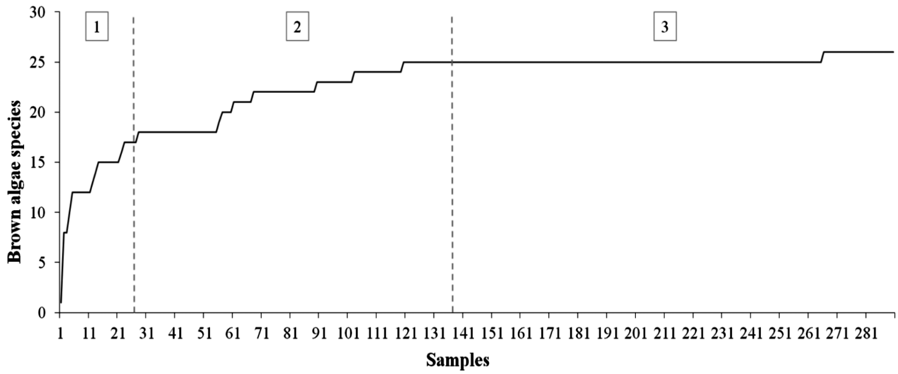

Figure 3. Species accumulation curve of brown algae species from 32B sampling site. (1) Pre-operational phase, (2) Angra 1 Nuclear Power Plant Operational Phase, and (3) Angra 2 Nuclear Power Plant Operational Phase.

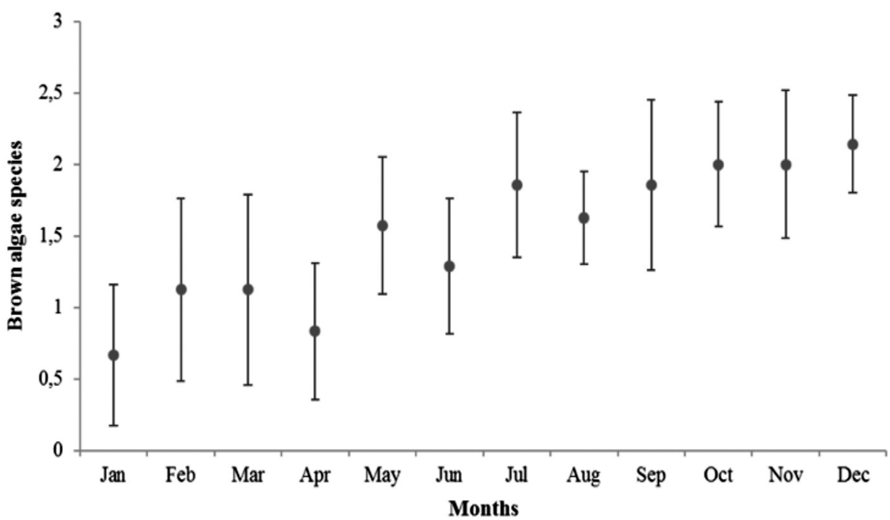

Figure 4. Monthly mean values of brown algae species richness from 32B sampling site. The means were calculated based on eight years randomly chosen from the 2002-2014 period. Error bars indicate ± 1 standard error.

among the years. They further add that a smaller effort reduces the impacts of the sampling process.

Other benthonic community studies of Eletronuclear environmental monitoring program were also performed with a monthly sampling frequency. Periodicity has changed since 2009, with the consent of the Brazilian Environmental Agency (IBAMA): from monthly to seasonal samplings. No differences were observed in the results of these studies due to this reduction in the sampling frequency.

Besides the technical reasons associated with a change in brown algae sampling frequency, there are practical reasons involving the CNAAA environmental licensing. Eletronuclear has a legal obligation to review its environmental monitoring program as a whole in the coming years. Therefore, considering we did not observe differences between monthly and seasonal samplings, it would be a favorable period to change the sampling frequency until the reviewed program is ready. It would give Eletronuclear more time to work on reviewing the program as well as reduce the current monitoring costs, without losing the quality of the collected information.

It is important to highlight Eletronuclear's role in gathering environmental data at Ilha Grande Bay. In comparison to that in other companies, the Eletronuclear marine ecosystem monitoring program is the oldest in the area and its database can be a useful tool to improve the coastal management at Ilha Grande Bay.

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