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Analysis of environmental stressors on ecosystems of Xuan Thuy National Park, Vietnam

Phân tích các mối đe dọa môi trường hệ sinh thái tại Vườn Quốc Gia Xuân Thủy, Việt Nam

Research paper

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Above-ground biomass was allometrically estimated to quantify the amount of mangrove species in selected quadrats of Xuan Thuy National Park. Physicochemical properties of surrounding waters and soils were measured and treated stochastically by correlational analysis with estimated biomass values. Correlation results suggested that qualities of surrounding waters and soils are not the principal inhibitors of mangrove growth in Xuan Thuy. The available historical records infer that the main factor of mangrove loss in the past lay on land reclamation for shrimp aquaculture. In addition, results of correlation analysis showed geographical coincidence of mangrove fragmentation with influence area of water channeling used for aquaculture activities. Furthermore, the distribution of anomalous values of metals concentration was corresponding with anthropological activities associated to clam aquaculture and sand extraction. Based on the aforementioned analysis and the information on anthropological activities in the buffer zone of Xuan Thuy, were provided basic information on inherent environmental stressors of ecosystems in Xuan Thuy National Park.

Sinh khối trên mặt đất đã được ước tính theo phương pháp tương quan sinh trưởng để đưa ra số lượng các loài đước trong các mẫu vuông được lựa chọn tại Vườn quốc gia Xuân Thủy. Các đặc tính hóa-lí của những vùng nước và đất xung quanh đã được đo đạc và xử lí ngẫu nhiên bằng cách phân tích tương quan với những giá trị sinh khối ước tính. Kết quả tương quan cho thấy rằng chất lượng nước và đất xung quanh không phải là những thước đo chính cho tốc độ phát triển cây đước ở Xuân Thủy. Những ghi chép cũ đã kết luận rằng việc sử dụng đất để nuôi tôm là tác nhân chính dẫn tới suy giảm loài đước trong quá khứ. Bên cạnh đó, kết quả phân tích tương quan cho thấy sự trùng hợp về mặt địa lý giữa sự phân mảnh của loài đước và những vùng nước bị ảnh hưởng do việc nuôi trồng thủy sản. Hơn nữa, sự phân bố bất thường của các giá trị đo mức độ tập trung kim loại cũng tương ứng với các hoạt động nuôi trồng thủy sản và khai thác cát của con người. Những phân tích nêu trên và nghiên cứu về hoạt động của con người tại vùng đệm của Xuân Thủy sẽ cung cấp những thông tin cơ bản về những mối đe dọa môi trường hệ sinh thái tại Vườn Quốc Gia Xuân Thủy.

Keywords: Xuan Thuy National Park, mangroves, biomas, environmental stressors

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1. Introduction

Xuan Thuy National Park (XTNP) is located at right bank side of Red River estuary in Nam Dinh Province, Vietnam.

Mangroves in the XTNP are mainly distributed in the northern area of XTNP, dominated by the species *Aegiceras corniculatum*, *Sonneratia caseolaris* and *Kandelia candel* and significant communities of *Acanthus ilicifolius*, *Avicennia marina*, *Excoecaria agallocha*, and *Rhizophora stylosa* are also present (Hong et al., 2004; Wösten et al., 2003). The planted mangrove forests are mainly distributed in the southern part of XTNP constituted by *K. candel*, *S. caseoralis*, and *R. stylosa* (Cuc, 2004; Hong and Dao, 2003; Tue et al., 2012).

In Vietnam, losses of the original mangrove area are estimated at 37% (Spalding et al., 1997; Valiela et al., 2001; Alongi, 2002). More than two-thirds of the country's mangroves were destroyed by defoliants during the Vietnam War while development activities, particularly shrimp aquaculture, subsequently continued the process (Macintosh, 1996).

Census of plant species and measurement of physical properties at XTNP were conducted during three weeks in December of 2012 by the staffs of the Institute of Ecology and Biological Resources and the Institute of Chemistry of Vietnam Academy of Science and Technology (VAST) as requirement of the Biodiversity Conservation Agency (BCA) of Vietnam.

The present work consisted on to provide basic information for the development of biodiversity indicators, finding environmental stressors of ecosystems in XTNP, taking into account the analysis of collected data from the aforementioned surveys.

2. Materials and methods

Census of plant species was conducted in seven quadrats of 400 m^2 (20 m × 20 m). Locations of quadrats are shown in Figure 1. Measured parameters for surface waters and soils are shown in Table A (Appendix).

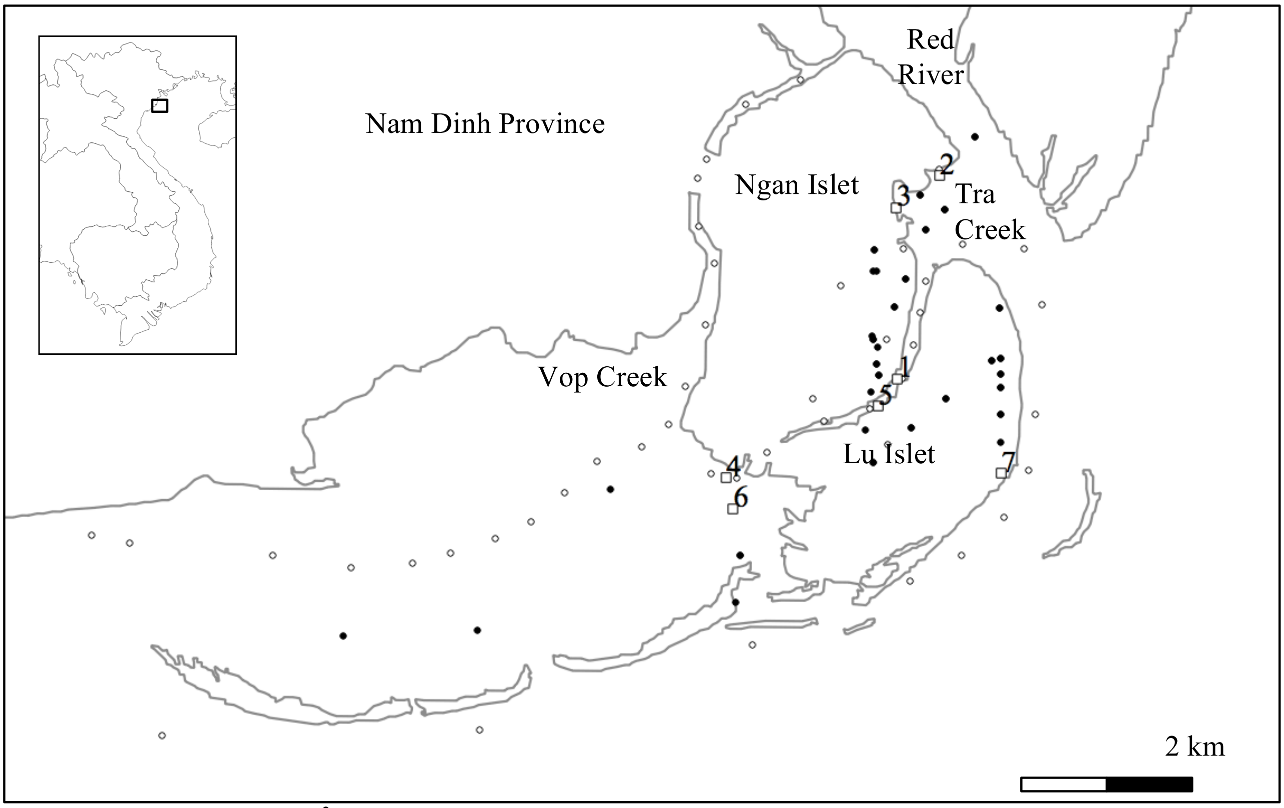

Figure 1. Location of 400 m^2 quadrats (square shapes) for the census of plants and the measurement of surface water (empty balloons) and soil (black-filled balloons) properties

Census of mangrove species was performed, by total counting of identified species, measuring their heights, and stem diameter at breast height. Above-ground biomass of mangrove species was estimated using the allometric equations proposed by Komiyama et al. (1988).

Based on that mangrove species seems to depend entirely on water in the top 50 cm of soil, in which 70% of its fine roots are deployed (Sternberg and Swart, 1987), it was judged relevant to measure water and soil properties within this limit.

Deterministic stochastic values, resulted from dataset of surface water and soil properties, were assigned to aforementioned seven quadrats using Inverse Distance Weighting (IDW) method of interpolation.

Pearson's bivariate linear correlation analysis was performed considering as variables above-ground biomass, Shannon index, Simpson index of dominance, and identified species of mangroves above-ground biomass assigning properties of surface waters and soils; and significant analysis on resulted correlation coefficients were tested under the criteria of two-tailed distribution.

In order to visualize the geographical distribution of measured physicochemical properties, raster maps of distribution were performed applying interpolation tool of IDW method available in Quantum-GIS® software.

3. Results

Inventoried mangrove species was quantified using the estimated above-ground biomass for each surveyed quadrat. Table 1 lists the biomass quantification for each quadrat and Shannon and Simpson indexes taking into account plant species existing in each quadrat based on estimated above-ground biomass and population respectively.

Table 1. Above-ground biomass (AGB) of mangrove species (unit: kg/400 m²) and species abundance and dominance in selected quadrats

Mangrove species		Quad. 1	Quad. 2	Quad. 3	Quad. 4	Quad. 5	Quad. 6	Quad. 7
A. corniculatum	AGB	2,110	858	708	0	28	10	0
	population	1,116	3,012	2,638	0	99	46	0
K. candel	AGB	181	9	46	509	624	72	0
	population	63	44	188	1,106	1,532	488	0
S. caseoralis	AGB	0	770	586	635	0	0	0
	population	0	16	22	32	0	0	0
R. stylosa	AGB	0	0	0	0	0	13	0
	population	0	0	0	0	0	20	0
Index		Quad. 1	Quad. 2	Quad. 3	Quad. 4	Quad. 5	Quad. 6	Quad. 7
Shannon index	Biomass based	0.120	0.314	0.354	0.298	0.078	0.309	N.A.
	Population based	0.091	0.047	0.125	0.056	0.099	0.190	N.A.
Simpson index	Biomass based	0.854	0.496	0.472	0.506	0.917	0.609	N.A.
	Population based	0.899	0.962	0.862	0.945	0.886	0.784	N.A.

A. corniculatum seems to be the most characteristic of the seaward mangal fringe and occurs typically as an isolated low shrub (Tomlinson, 1986). This mangrove species is distributed mainly in northern zone of XTNP, showing its dominance in Quadrat 1. *K. candel* is widely distributed in all mangrove areas of XTNP, especially along the banks of Tra Creek, showing its dominance in Quadrat 5. The characteristic habitat of *S. caseoralis* is riverbanks and tidal areas with mud banks. This species is common in the inner mangroves and extends inland along tidal creeks as far as the influence of salinity extends (Tomlinson, 1986). *S. caseoralis* was inventoried in Quadrats 2, 3, and 4; showing co-dominance with *A. corniculatum* in Quadrats 2 and 3, and co-existence with *K. candel* in Quadrat 4. *Rhizophora* is a pantropical genus in climatically rather uniform coastal environment, but with limited extension into to the subtropics (Tomlinson, 1986). *R. stylosa* was found only in Quadrat 6 which is dominated by *K. candel*, and co-existing with *A. corniculatum*.

The Table A (Appendix) lists the assigned values of surface water and soil properties using IDW method of interpolation based on measured dataset. Higher values of Shannon index were exhibited in Quadrats 2 and 3 based on above-gound biomass, but biased result showed when expressed in terms of population. Small numerous individuals of *A. corniculatum* and non-numerous but big indviduales of *S. caseoralis* occupying these areas explain the situation. And due to biased feature of monoculture dominance or few species richness in all quadrats, the Simpson index of dominance shown higher values compared with correspondent values of Shannon index (Table 1).

Table B (Appendix) shows the correlation matrix arrangement resulted from Pearson's bivariate analysis performed considering as variables above-ground biomass of mangrove species, Shannon index, Simpson index of dominance, and stochastically assigned values of properties of surficial waters and soils. Shaded values on Table B correspond to the foremost significance (0.05 level of significance) correlations. In addition, slight correlations (0.333 level of significance) were squared by dotted lines. According to these results salient behaves of the variables are as follows:

Correlation feature of *A. corniculatum* are partially coincident with those for total mangrove above-ground biomass values, denoting its dominance in the surveyed area. Positive correlation was shown with arsenic. Positive correlation for *K. candel* exhibited significance with water temperature. While negative correlation was shown for copper. Soil pH, antimony and chromium correlated positively with *S. caseoralis*. *R. stylosa* correlated positively with water salinity.

Mangrove species are likely to be found within a certain range of pH ratios (Vaiphasa et al., 2006). Even though soils pore water of XTNP showed low variance in assigned pH values (ranged between 6.30-6.42) *S. caseoralis* exhibited positive correlation within these limits.

XTNP is located in the northern hemisphere tropic of Indo-Malesia biogeographical region of Indo-West Pacific (IWP) zone. The geographical distribution of mangrove species and of mangrove habitat is limited by temperature. More specifically, the 20°C winter sea-temperature isotherm, with few exceptions, circumscribes the range of mangroves throughout the world. Mangroves rarely occur outside the range delimited by the winter position of the 20°C isotherm, and number of species tends to decrease as this limit is approached (Hogarth, 2007). Water temperature in XTNP measured in winter season (December) ranged 21.4-21.6°C, been higher than the threshold isotherm, explaining the natural spread of mangroves in the area.

Mangrove soils are often virtually anoxic (Hogarth, 2007). Measured values of DO in porus water of surficial soil of XTNP ranged between 0.4 and 7.7 mg/L (assigned values using IDW-interpolation method ranged between 2.79 and 3.69 mg/L). Extremely low values were shown at waterlogged soils in where is suspected high bacterial activity. High positive correlation of DO was shown with Shannon index and negative correlation with Simpson index, both based on mangrove above-ground biomass.
Mangrove species differ in the extent of their salt tolerance. *A. corniculatum* is one of the pioneer mangroves which can thrive in 30‰ salinity (Fu et al., 2005), and can be sustained and propagated under low salinity conditions, showing tolerance to the changes in salinity gradients (Parida et al., 2004). Species of genus *Sonneratia* show to grow best at 5-50% sea water (Hutchings and Saenger, 1987; Ball, 1988). The salinity in XTNP ranged 17.3-18.7‰ (around 50% sea water), which is in the upper-limit of its best growth zone.

Mangrove clearance for shrimp aquaculture can drive severe environmental consequences (Macintosh, 1996). When pond-reared shrimps are artificially fed, around 30% of the food remains uneaten. The rest –together with a rich brew of chemicals and antibiotics– ends up as effluent (Robertson and Phillips, 1995; Kautsky et al., 1997). However, if effluent production is greater than can be readily assimilated by surviving mangroves, its ecological impact can be disastrous (Hogarth, 2007). In the case of XTNP higher values of BOD and COD are overlapping with water flowing channels of shrimp ponds, and also with the area impacted by notorious fragmentation of mangroves as shown in Figure 2. In addition, relatively negative correlations between BOD and COD values with Shannon index resulted in the analysis (Table B in Appendix, dotted squares for BOD and COD) suggesting some relation with the phenomena of fragmentation.

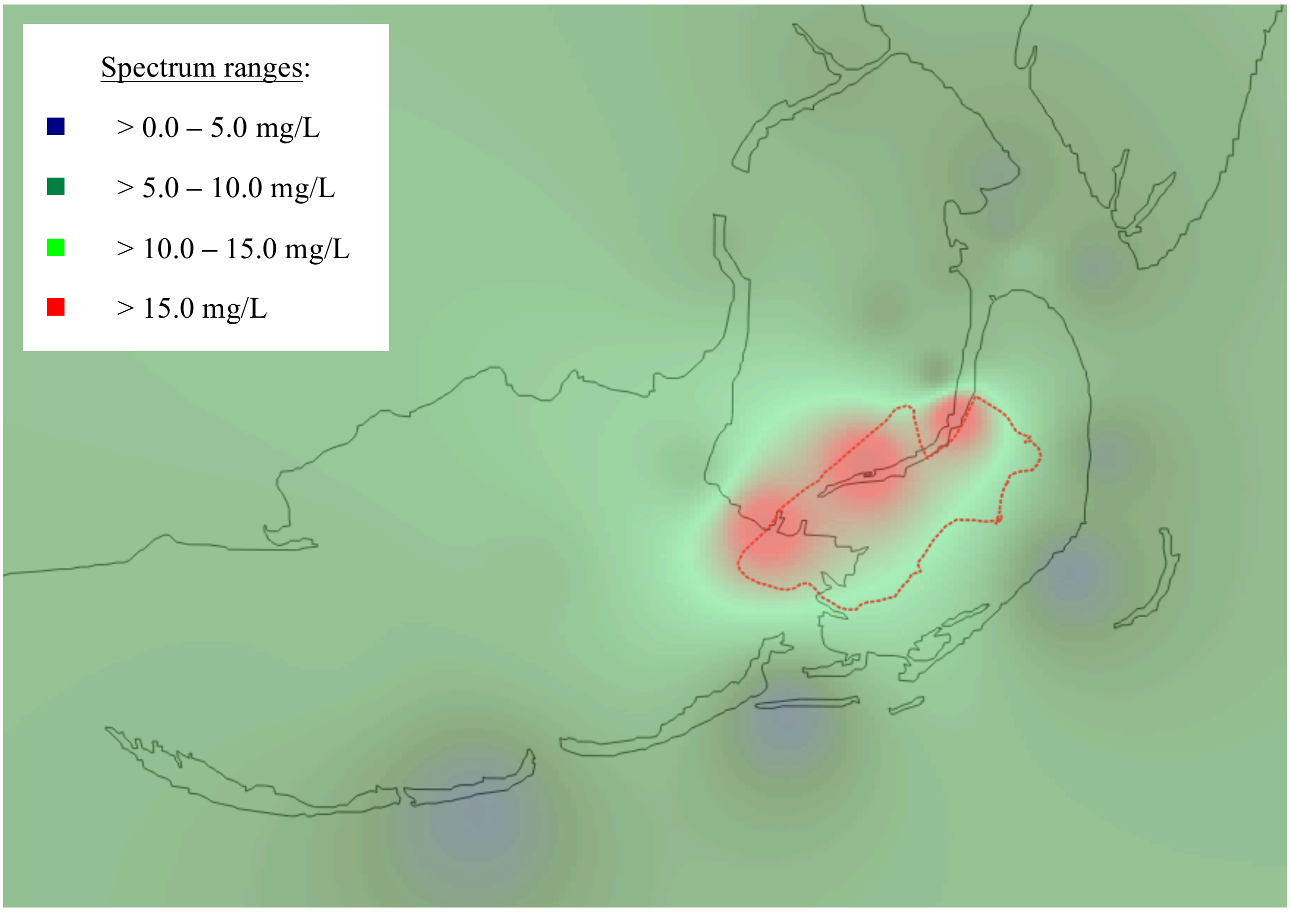

Figure 2. Distribution of BOD values in surficial waters and distribution of areas with mangroves fragmentation (zone circumscribed by red dotted line)

Mangrove trees themselves may be relatively immune to the toxic effects of heavy metals, but the mangrove fauna may be more vulnerable. Mercury, cadmium, and zinc are acutely toxic to crab larvae and heavy metals in general cause physiological stress and reduced reproductive success, even at sub-lethal concentrations (Ellison and Farnsworth, 1996; Peters et al., 1997). Lewis et al. (2011) have been compiled toxicity tests conducted with mangroves and trace metals by other researchers, in which seedlings of species *A. corniculatum*, *R. stylosa*, and *K. candel* showed inhibition of root development under copper concentration of 3.8 mg/L; and specifically for *K. candel* species first effect on growth at copper concentration of 2.5 mg/L and zinc of 25 mg/L; furthermore, its lethality at more than 10 mg/L of copper. Fortunately, these levels of metal concentrations are too far from those found in XTNP. Nevertheless, although the scarcity of evident correlations resulted in the present analysis, elements such as cadmium, copper, lead, and zinc requires further analysis due on that their measured values exceed or are close to the threshold values recommended under the Aquatic Life Criteria of the United States Environment Protection Agency (USEPA).

The Criterion Continuous Concentration (CCC) is an estimate of the highest concentration of a material in surface water to which an aquatic community can be exposed indefinitely without resulting in an unacceptable effect. Table 2 shows actual measurements in XTNP compared with respective CCCs.

Table 2. Anomalous metal concentrations observed in surficial waters of XTNP

Parameter	CCC (µg/L)*		Maximum observed concentration (µg/L)	Frequency of anomalous observations
	Freshwater	Saltwater		
Cadmium	0.25	8.8	0.29	2/35
Copper	9.0	3.1	3.9	7/35
Lead	2.5	8.1	3.5	18/35
Zinc	120	81	78.1	0/35

* Source: USEPA, 2006

Arithmetic average of CCC rated indexes of metals showing excess concentrations with respective criteria was calculated and IDW interpolation was used for to simulate their distribution. As can show in Fig. 3, locations of high metal concentrations are coincident with docking zones for ships used by clam aquaculture and sand extraction activities. Also, can be inferred that the progressive mechanization of clam aquaculture is impacting with metal pollution.

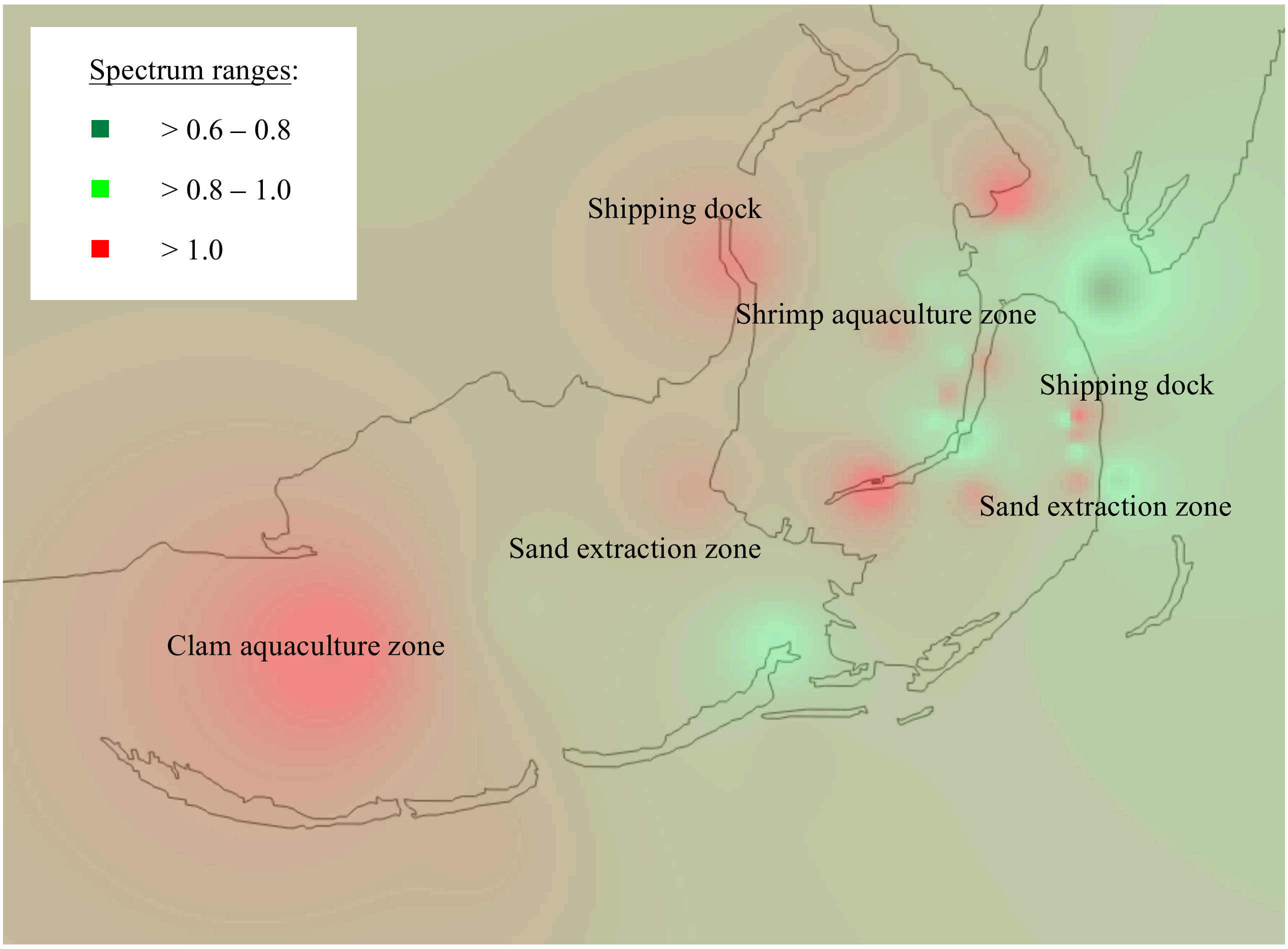

Figure 3. Distribution of anomalous metal concentrations (exceeding CCC thresholds in red spectrum) and geographical locations of anthropological activities

4. Discussion

4.1. Understanding behavior of mangrove habitats

Based on the result of performed correlation analysis, it is possible to infer that water and soil qualities are not the main stressors on mangroves species in XTNP. Nutrients availability, pH, water temperatures and salinities are in allowable ranges for the mangroves growth.

Generally, a major cause of mangrove deforestation is aquaculture expansion in coastal areas. In Asia, aquaculture contributes 58% to mangrove loss with shrimp farming accounting for 41% of total deforestation (Walters et al., 2008). A similar situation was found in XTNP by Seto and Fragkias (2007).

Pond systems remove mangrove forests and with that impact, populations of marine and estuarine organisms; water pollution from ponds negatively affects adjacent mangrove ecosystems. Furthermore, mangrove conversion for shrimp culture represents a trade-off with coastal fisheries production as mangrove forests are considered critical nursery habitats for the juvenile stages of commercially important species of fish and invertebrates (Bush et al., 2010).

Resuming the analysis, the behavior of mangrove species suggests that their historical loss was driven basically by land reclamation for shrimp aquaculture; meanwhile, measured properties did not showed evidence that is affecting their abundance nor dominance of a specific species.

4.2. Elucidation of causes of mangroves fragmentation

The water pollution is largely associated with the use and discharge of water in shrimp ponds (Anh et al., 2010). This water usage in shrimp ponds associated to tide cycles may be is impacting with mangroves fragmentation.

Higher values of BOD and COD were shown surrounding the effluent discharge points of shrimp ponds. Thus, can be inferred that sources of anomalous higher values of these indicators lay on them. However, other factors bearing the effluents or extreme changes on hydrological regime caused by the channelized water flow could be the concomitant reasons of mangroves fragmentation. In fact, factors such as remnant antibiotics in effluents, changes on hydrological regime due to channeled inflow and outflow of water among shrimp ponds and the surrounding environment are candidates for further analysis.

4.3. Impact of transportation activities associated to clam aquaculture and sand extraction

Because of the coincidence of zones with relatively high concentration of metals in surrounding waters of XTNP with the locations of shipping docks used for clam aquaculture and sand extraction, it might be inferred that these activities are the sources of pollution.

Regardless of several metals exceeding threshold values for aquatic life are not evidently affecting the mangrove habitats, they can affect mangal associated fauna. Because of these anomalous metal concentration spots are distributed on the ship-transportation paths related to clam aquaculture and sand extraction and commercialization, vigilance of these activities are imperative.

5. Conclusions

Based on the correlational analysis, it can be inferred that water and soil qualities surrounding XTNP are in allowable ranges for mangroves growth. Meanwhile, the historical records suggest that land reclamation for the construction of aquaculture ponds and related facilities affected with deforestation of mangrove species (Seto and Fragkias, 2007). In that sense, appropriate administration of land reclamation for shrimp aquaculture in XTNP can avoid additional loss of mangrove areas.

Higher values of BOD and COD are evidently caused by the effluents of aquaculture ponds and was recognized that these zones of higher values of BOD and COD are coincident with the area of mangrove fragmentation, suggesting that is necessary to conduct further studies on the causes of mangrove fragmentation taking into account water dynamics and water quality. Hence, complementary studies considering water regime and water quality changes caused by the water flow channeling should conduct, in order to identify the real causes of mangrove fragmentation.

Regardless of measured metals concentrations in water is compliant with Vietnamese standards, due that several values are exceeding the threshold values for aquatic life under the CCC of USEPA, the monitoring of these metals is recommended. Although affection on mangroves is not evident, uncontrolled situation of transportation systems – suspected as source of metal contamination – can impact on surrounding associated fauna and also on the sustainability of aquaculture products.

Further studies taking into account behaves of mangroves considering climatic, topographical, hydrological, and tidal-cycle properties are desirable to be conducted in order to complement the conclusions herein. In addition, is necessary to recognize in detail all anthropological activities in buffer zone of XTNP; especially the aquaculture of shrimps and clams in order to recognize the level of pressure caused by those activities to the ecosystems in XTNP.

APPENDIX

Table A. Assigned surficial water and soil properties estimated with IDW-interpolation method

Parameter	CCC (mg/L)		Quadrat					
	Freshwater	Saltwater	1	2	3	4	5	6
Soil pH	N.A.	N.A.	6.30	6.42	6.40	6.35	6.33	6.34
Soil N content (mg/kg)	N.A.	N.A.	664	735	698	624	621	609
Soil P content (mg/kg)	N.A.	N.A.	474	511	506	459	460	450
Soil K content (mg/kg)	N.A.	N.A.	17072	18923	18242	16901	16866	16567
Soil TOC content (mg/kg)	N.A.	N.A.	13178	15947	14987	11482	12252	10827
Water temperature (^{o}C)	N.A.	N.A.	21.60	21.51	21.52	21.62	21.60	21.54
Water pH	6.5 - 9	6.5 - 8.5	7.69	7.80	7.80	7.80	7.74	7.83
DO (mg/L)	N.A.	N.A.	2.79	3.63	3.62	3.55	3.00	3.69
Salinity (‰)	N.A.	N.A.	17.33	17.70	17.81	17.79	17.61	18.66
BOD_5 (mg/L)	N.A.	N.A.	13.14	5.05	6.13	12.15	9.44	9.87
COD (mg/L)	N.A.	N.A.	19.68	7.07	8.78	18.43	14.07	14.79
Total nitrogen (mg/L)	N.A.	N.A.	0.0257	0.0265	0.0242	0.0267	0.0235	0.0249
Total phosphorus (mg/L)	N.A.	N.A.	0.0558	0.0705	0.0600	0.0535	0.0565	0.0563
Coliforms (MPN/100 mL)	N.A.	N.A.	980	1541	1148	581	862	771
Aluminum (mg/L)	0.087	N.A.	0.00995	0.00924	0.00924	0.01044	0.00969	0.00993
Antimony (mg/L)	N.A.	N.A.	0.00169	0.00192	0.00177	0.00178	0.00155	0.00172
Arsenic (mg/L)	0.150	0.036	0.00231	0.00221	0.00204	0.00201	0.00213	0.00204
Barium (mg/L)	N.A.	N.A.	0.0905	0.0802	0.0866	0.0800	0.0935	0.0849
Cadmium (mg/L)	0.00025	0.0088	0.000167	0.000172	0.000166	0.000185	0.000177	0.000181
Chromium (mg/L)	N.A.	N.A.	0.00618	0.00746	0.00712	0.00716	0.00628	0.00694
Cobalt (mg/L)	N.A.	N.A.	0.00222	0.00187	0.00203	0.00230	0.00209	0.00220
Copper (mg/L)	0.009	0.0031	0.00267	0.00281	0.00274	0.00267	0.00264	0.00272
Lead (mg/L)	0.0025	0.0081	0.00237	0.00299	0.00265	0.00260	0.00260	0.00255
Manganese (mg/L)	N.A.	N.A.	0.1461	0.0949	0.1620	0.1179	0.1990	0.1627
Nickel (mg/L)	0.052	0.0082	0.00250	0.00224	0.00246	0.00254	0.00270	0.00264
Strontium (mg/L)	N.A.	N.A.	3.63	4.42	4.06	3.69	3.83	3.95
Tin (mg/L)	N.A.	N.A.	0.00287	0.00270	0.00263	0.00246	0.00293	0.00264
Vanadium (mg/L)	N.A.	N.A.	0.0867	0.0731	0.0850	0.0788	0.0873	0.0831
Zinc (mg/L)	0.120	0.081	0.0328	0.0324	0.0351	0.0339	0.0337	0.0346

CCC: Criterion Continuos Concentration; N.A.: Not Available

Table B. Standardized correlation coefficients and significances

Variables		Mangroves above-ground biomass	Shannon index		Simpson index		Species above-ground biomass			
			Biomass based	Population based	Biomass based	Population based	*A. corn.*	*K. candel*	*S. case-oralis*	*R. stylosa*
Soil pH	c	0.002	0.724	-0.267	-0.778	0.319	-0.228	-0.460	0.843	-0.173
	s	0.997	0.104	0.609	0.069	0.538	0.664	0.359	0.035	0.744
Soil N	c	0.637	0.353	-0.465	-0.428	0.499	0.500	-0.627	0.656	-0.484
	s	0.174	0.493	0.353	0.397	0.313	0.313	0.183	0.157	0.331
Soil P	c	0.560	0.401	-0.394	-0.470	0.426	0.409	-0.595	0.679	-0.502
	s	0.248	0.430	0.440	0.347	0.399	0.421	0.213	0.138	0.310
Soil K	c	0.467	0.455	-0.451	-0.535	0.490	0.281	-0.568	0.752	-0.452
	s	0.350	0.364	0.370	0.274	0.323	0.589	0.239	0.085	0.368
Soil TOC	c	0.607	0.259	-0.454	-0.336	0.480	0.466	-0.535	0.607	-0.557
	s	0.202	0.621	0.366	0.514	0.335	0.352	0.274	0.201	0.251
Water temp.	c	0.074	-0.616	-0.235	0.544	0.184	-0.016	0.819	-0.389	-0.242
	s	0.889	0.193	0.653	0.264	0.727	0.976	0.046	0.445	0.644
Water pH	c	-0.610	0.862	0.293	-0.810	-0.239	-0.688	-0.329	0.497	0.490
	s	0.198	0.027	0.574	0.051	0.648	0.131	0.525	0.315	0.324
DO	c	-0.436	0.942	0.182	-0.910	-0.123	-0.549	-0.439	0.628	0.390
	s	0.388	0.005	0.730	0.012	0.816	0.260	0.384	0.182	0.444
Salinity	c	-0.818	0.536	0.750	-0.379	-0.716	-0.614	-0.293	-0.132	0.921
	s	0.047	0.273	0.086	0.458	0.110	0.195	0.573	0.803	0.009
BOD_5	c	0.084	-0.512	0.042	0.514	-0.083	0.170	0.500	-0.561	0.087
	s	0.875	0.299	0.937	0.297	0.875	0.748	0.313	0.247	0.869
COD	c	0.066	-0.505	0.046	0.507	-0.087	0.148	0.509	-0.558	0.096
	s	0.902	0.307	0.931	0.305	0.869	0.779	0.302	0.250	0.857
N in water	c	0.439	0.355	-0.582	-0.462	0.614	0.225	-0.186	0.543	-0.143
	s	0.384	0.489	0.225	0.356	0.195	0.668	0.724	0.265	0.787
P in water	c	0.267	0.351	-0.344	-0.396	0.387	0.180	-0.579	0.566	-0.195
	s	0.609	0.495	0.504	0.437	0.448	0.733	0.228	0.242	0.712
Coliforms	c	0.459	0.216	-0.306	-0.251	0.338	0.431	-0.639	0.448	-0.307
	s	0.360	0.681	0.555	0.632	0.512	0.394	0.172	0.373	0.555
Aluminum	c	-0.162	-0.210	-0.014	0.191	-0.010	-0.198	0.557	-0.292	0.193
	s	0.760	0.690	0.980	0.717	0.986	0.707	0.251	0.575	0.713
Antimony	c	0.319	0.781	-0.364	-0.839	0.424	0.135	-0.652	0.825	-0.067
	s	0.537	0.067	0.478	0.037	0.402	0.799	0.161	0.043	0.900
Arsenic	c	0.704	-0.589	-0.343	0.553	0.324	0.834	-0.172	-0.275	-0.332
	s	0.118	0.219	0.506	0.255	0.532	0.039	0.744	0.598	0.520
Barium	c	-0.001	-0.807	0.311	0.869	-0.368	0.241	0.338	-0.780	-0.098
	s	0.998	0.052	0.548	0.025	0.473	0.646	0.512	0.068	0.854
Cadmium	c	-0.689	0.087	0.082	-0.090	-0.080	-0.787	0.536	-0.059	0.421
	s	0.130	0.870	0.878	0.866	0.881	0.063	0.273	0.911	0.406
Chromium	c	-0.120	0.915	-0.183	-0.954	0.245	-0.350	-0.452	0.854	0.083
	s	0.821	0.011	0.729	0.003	0.640	0.496	0.368	0.030	0.876
Cobalt	c	-0.163	-0.208	0.248	0.242	-0.277	-0.092	0.440	-0.450	0.271
	s	0.757	0.692	0.635	0.644	0.595	0.862	0.382	0.371	0.603
Copper	c	0.145	0.684	-0.084	-0.676	0.144	0.117	-0.816	0.618	0.085
	s	0.784	0.134	0.874	0.141	0.786	0.825	0.048	0.191	0.872
Lead	c	-0.022	0.490	-0.420	-0.569	0.466	-0.259	-0.288	0.742	-0.190
	s	0.967	0.324	0.407	0.238	0.352	0.620	0.580	0.091	0.718
Manganese	c	-0.469	-0.522	0.608	0.631	-0.653	-0.229	0.388	-0.739	0.208
	s	0.349	0.288	0.200	0.179	0.159	0.662	0.447	0.093	0.693

Variables		Mangroves above-ground biomass	Shannon index		Simpson index		Species above-ground biomass			
			Biomass based	Population based	Biomass based	Population based	*A. corn.*	*K. candel*	*S. case-oralis*	*R. stylosa*
Nickel	c	-0.629	-0.485	0.561	0.578	-0.606	-0.443	0.624	-0.765	0.391
	s	0.181	0.330	0.247	0.229	0.202	0.379	0.185	0.076	0.444
Strontium	c	-0.052	0.542	-0.096	-0.543	0.147	-0.111	-0.598	0.566	0.036
	s	0.923	0.266	0.856	0.265	0.781	0.834	0.210	0.241	0.947
Tin	c	0.197	-0.834	0.047	0.862	-0.090	0.423	0.148	-0.640	-0.177
	s	0.708	0.039	0.929	0.027	0.866	0.403	0.779	0.171	0.737
Vanadium	c	-0.110	-0.585	0.522	0.680	-0.574	0.147	0.303	-0.774	0.073
	s	0.835	0.223	0.288	0.137	0.233	0.781	0.560	0.071	0.891
Zinc	c	-0.606	0.417	0.701	-0.300	-0.696	-0.518	-0.034	-0.083	0.421
	s	0.202	0.411	0.121	0.564	0.124	0.292	0.949	0.876	0.406

c - correlation coefficient; s - significance

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