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ECOSYSTEMS

Implementation of modified protocols under the principle of sustainability for seismic acquisition in lentic systems

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Abstract: In order to use sustainable methodologies in the exploration of oil and gas in lentic aquatic systems, a modified methodology (MTR) was implemented in each phase. Simultaneously, water quality, sediment, and organisms were evaluated to detect possible effects. Results included non-compaction of the sediment and less resuspension of dissolved solids and nutrients. Effects such as the increase in blue-green algae and the decrease in benthic macroinvertebrates showed rapid recovery (<15 days) as well as the resuspension of sulfates. Finally, MTR Methodology was feasible, of low magnitude, punctual effect, and rapid recovery for the intervened aquatic systems.

Key words: Protocols, sustainability, seismic acquisition, aquatic systems.

INTRODUCTION

In Colombia, a total of 23 sedimentary basins have been identified: Amagá, Caguán Putumayo, Catatumbo, Cauca-Patía, Cesar-Ranchería, Chocó, Chocó Offshore, Colombia, Colombian Deep Pacific, Eastern Cordillera, Eastern Plains, Guajira, Guajira Offshore, Los Cayos, Sinú San Jacinto, Tumaco, Tumaco offshore, Urabá, Vaupés -Amazon. Upper Magdalena Valley, Middle Magdalena Valley, and Lower Magdalena Valley (Cooper et al. 2010). These areas are occupied by freshwater aquatic systems, which is why the integrity of the ecosystem and the quality of the water in the aquatic system in the river basin, constitute a condition of relevance for the development of industrial activities in countries where diversity at all levels is an invaluable resource (Cunningham et al. 2010).

In a model of the industry-environment relationship, and with the interest of assuming social responsibility involved in sustainable development, the Colombian oil company ECOPETROL (from Spanish: *Empresa Colombiana de Petróleos*) allowed a joint initiative between companies and scientists interested in studying alternatives of unconventional procedures that would allow the seismic acquisition for oil and gas (ANH 2020, ANLA 2018, Corpoamazonia 2017) in aquatic-terrestrial transition systems and aquatic systems, specifically, lentic systems in the middle and lower basin of its main tributary, the Magdalena River, where hydrocarbon potentials could be located under areas with abundance in surface waters (Wang et al. 2020).

In the absence of authorization and, consequently, regulations for work in wetlands in Colombia, the need arises to implement a rigorous process to determine the effect that the seismic acquisition can have on each of the constituents of the environmental matrices in vulnerable areas. Under this scope, a collaborative group linking the industry with its experts in seismic exploration and acquisition and expert researchers in aquatic system ecology from the *Universidad del Atlántico* started the pilot projects of the process.

Biological monitoring protocols were established in order to identify the impact of conventional seismic acquisition in terrestrial and aquatic ecosystems with the purpose of modifying the parameters of accessing, marking, drilling, detonation, and restoration in the environmental matrices (sediment, water, and biotic) inside the aquatic lentic systems: MTR Methodology (MTR SAS 2011). This is important to maintain the homeostasis of the ecosystems under prospecting and the quality of the seismic information acquired, considering that the latter is the object of most of the investigations carried out in the area of application (Jeong et al. 2020). In addition, maintaining the homeostasis of these ecosystems is relevant for the tranquility of human communities depending on the environmental goods and services generated in these ecosystems.

MATERIALS AND METHODS

Studied areas

The first stage of the study used an impact matrix (Maza et al. 2007) carried out in the lentic body of water called *Ciénaga* de Méndez (Figure

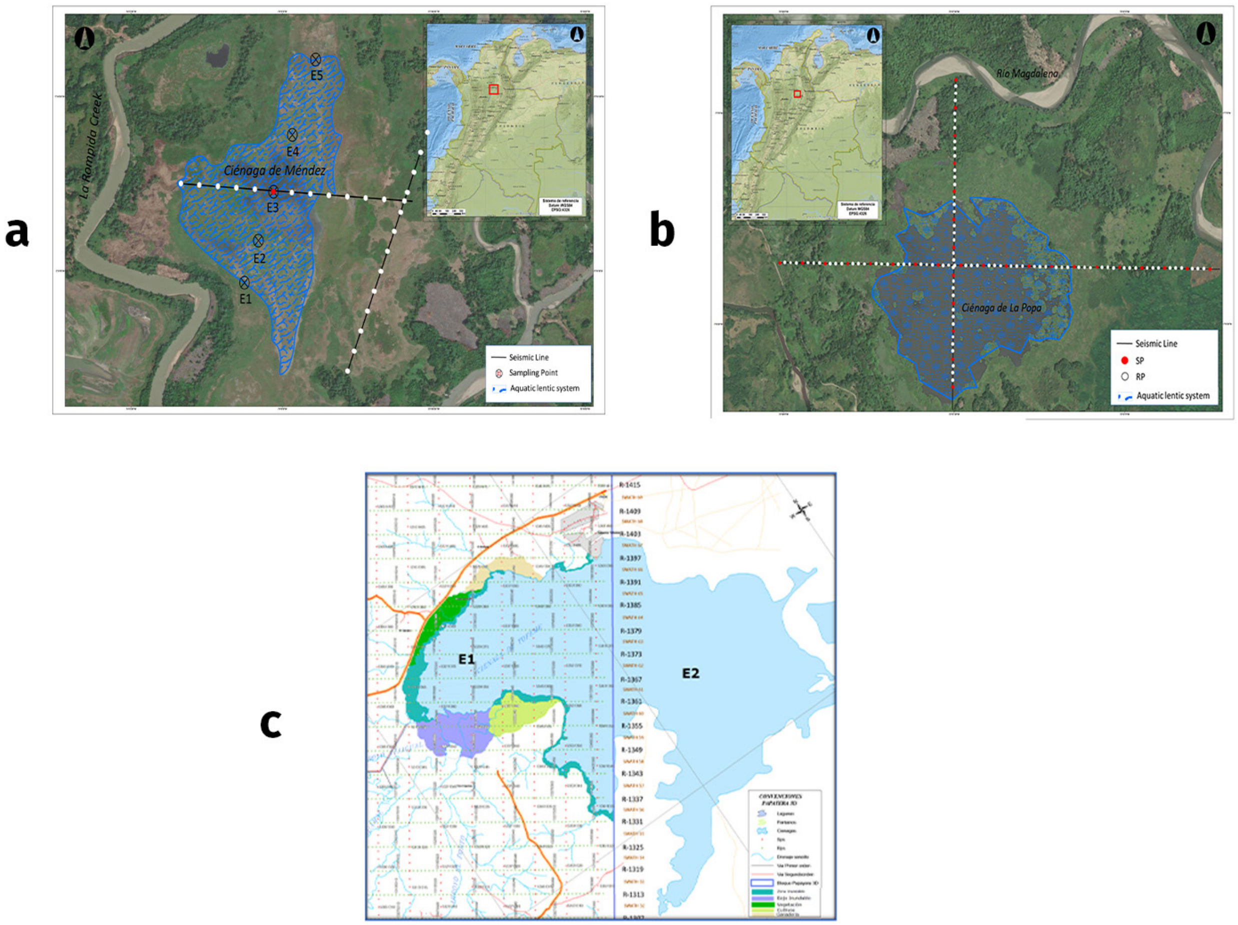

Figure 1. Scheme of the location of the sampling stations to monitor limnological variables in the water bodies intervened by seismic acquisition; (1a) Ciénaga de Méndez intervened for one line of acquisition; (1b) Ciénaga La Popa intervened for one line of acquisition; (1c) Ciénaga Tofeme intervened in two lines of acquisition in the 3 projects.

1a) given the lesser anthropic intervention compared to the other systems included in the *"Cantagallo 2D"* project, by recommendations of the *Corporación Autónoma* del Sur de Bolívar (CSB, the regional environmental authority). This process allowed the implementation of the procedures under the parameters and requirements for leveling seismic lines in the water of the lentic system (Table I) and ensuring compliance with environmental safety specifications and the effectiveness of the information for exploration in this type of system.

The modified protocol (MTR) was replicated in other bodies of water subjected to seismic activity *(Ciénaga La Popa, Ciénaga Las Cruces, Ciénaga Tofeme)* (Figures 1a–1c) considering the different limnological types of the basin: lentic and isolated bodies, lentic bodies connected to tributaries, and lentic bodies connected to

Table I. Physical-chemical variables and standardized methods are used to detect the effects of seismic acquisition in the intervened aquatic systems.

VARIABLE	CONVENTION	METHOD (APHA AWWA-WPCF 2012)
Physicochemical		
Depth (cm)	Dep	SM Bathymetric 2130 B
Transparency (cm)	Tran	SM Bathymetric 2130 B
pH (pH unit)	pH	SM Electrometric 4500 H+B
Temperature (°C)	T	SM Electrometric 2550B
Dissolved Oxygen (mg/L)	DO	SM Azida Modification 4500-O C
Conductivity (uS/cm) (in situ)	Cdv	SM Electrometric 2510 B
Salinity (UPS)	Sal	SM Potenciometric B
Biochemical oxygen demand (mgO2/L)	BOD5	SM Test BOD 5210 B
Suspended solids (mg/L)	SS	SM Gravimetric 2540 D
Dissolved solids (mg/L)	SD	SM Electrometric 2540 B
Sulphates (mg SO4-2/L)	SOx	SM Acetic acid Turbidity 4500 SO4-E
Nitrates (mg NO3/L)	NOx	SM Spect. Uv 4500 NO3-B
Nitrites (mg NO2/L)	NOx	SM Calorimetric 3256 B
Acidity (mg/L)	Ac	SM Volumetric 121 A
Hardness (mgCaCO3/L)	Har	SM Volumetric 121 A
Chemical oxygen demand (mgO2/L)	COD	SM Volumetric 121 A
Ammonia nitrogen (mg NH3-N/L)	NHx	SM NH3-N 4500 C
Phosphates (mg P-PO4/L)	POx	SM Spect. 4500 P-E
Organic material (%)	OM	ASTM Sieving D422
Calcium carbonate (%)	CaCO3	AASHTO T Calcimeter 267
Hydrobiological		
Macrophytes Associated Macroinvertebrates	AM	SM 10500 A, B, C, D
Benthos Associated Macroinvertebrates	B	
Phytoplankton		SM 10200 B, F
Macrophytes		SM 10400 B,C,D
Fishes		GTC 25 EPA-841-B-99-002
Birds		

other lentic systems. *La Popa* and *Las Cruces* are aquatic lentic systems located in the middle basin of the Magdalena River, as well as the *Ciénaga de Méndez* (Middle Magdalena Valley) while the *Ciénaga de Tofeme* belongs to the lower Magdalena basin. The differences in localizations are to evaluate the behavior of aquatic ecosystems in any lentic aquatics system. To validate that the implemented methodology minimized the impact in each phase of the seismic exploration and is functional in any shallow lentic system.

The sampling sites, called stations (E), were located on a line perpendicular to the seismic record line, to detect the extent of the potential impacts of the intervention along with the vertical zoning of the water body and detect the influence on the gradient, which has the edge zone (Water-Soil Transition). The stations were projected to cover the entire flood zone, with a total of 7 points, called E1, E2, E3, E4, E5, E6, and E7, where E3 corresponds to the point of intersection between the seismic record line and the monitoring line. The distance between stations fluctuated between 50 and 100 linear meters (Figure 1a-1c).

To determine the effect of seismic acquisition activities on the epicontinental aquatic system, it is necessary to include the monitoring of the land-water transition areas, where variables related to water and sediments are determined to show the effects of detonations with the source material used (Cooper et al. 2010). Neighboring aquatic systems were used without seismic intervention as a control/target and comparing tool, but the results obtained by limnological singularities (Castellanos-Romero et al. 2017, Pinilla et al. 2010, Ramírez & Viña 1998), showed greater differences within these systems than the differences obtained from the comparison throughout the intervention process. Consequently, the sampling points were localized and distributed perpendicularly to the exploration line (intervened area) within the same system to detect a potential gradient of alterations, it was most effective for detecting disturbances.

Biological monitoring campaigns to monitor the effects of seismic activity were established according to the stages of seismic activity, starting from the baseline, including monitoring before and after each stage of surveying, drilling, acquisition, restoration, and at the end with a compensation stage. The experimental design contemplated a coordinated sampling stratified by the station which was adjusted to randomization techniques to avoid bias. In the case of the biological component, species accumulation curves were applied; for the physical and chemical components, standardized replication techniques were used (Table I) (APHA 2012).

The Biological Monitoring design considered the spatial and temporal changes of the ecosystems before, during, and after the seismic acquisition processes. The components considered were water, sediments, benthos, fishes, aquatic birds, plankton, macrophytes, and macroinvertebrates. These indicators of water quality are required by the environmental corporations of the region, and the group of experts in the field of aquatic ecology.

Previous exploration activities phases in aquatic lentic systems of medium and low basins (baseline: Base)

In this phase, planning is carried out using the cartographic projections established for the project and identifying the seismic acquisition lines that will intervene in the aquatic systems in the area of influence. Subsequently, for the recognition of the field, an interdisciplinary team that includes geologists, sociologists, surveyors, and biologists socialize the details of the project to the communities (after obtaining the necessary licenses) and then allows to start the baseline monitoring and characterization limnology of the aquatic systems to intervene. With this information, together with the historical data of the wetland (generated by authorities and environmental institutions in the area), the point of comparison is obtained to detect possible changes that occurred after each phase of seismic exploration.

Social Insurance

The activities included in this protocol started during the preoperational stage of the project and were maintained continuously throughout the process, with the aim of involving the community in all the activities of the project as an active part of the check and balance of the intervention activities to be carried out. The environmental authorities that have jurisdiction in the area also played an important role in the verifications of each stage. Before entering the body of water, all the personnel involved (community, authorities, operators) sign certificates of verification of environmental and safety conditions.

Biological monitoring

For the monitoring of the effects of seismic activity, it is established at a frequency involving the lifting of a baseline that will characterize each water system (adjusted according to each limnological typology) and pre-monitoring and post-monitoring activities typical of this activity (entry to the area, topography, drilling, acquisition, restoration, and compensation). The sampling involved corresponds to a layered coordinated model. Records and sampling are performed by monitoring local point records, which are adjusted perpendicular to the matrix of exploration lines (project grid) to avoid bias. In the case of the biological component, species accumulation curve techniques are applied (the collection of specimens for scientific, and non-commercial research purposes, was supported by resolution 00949 of August 31, 2016, granted by the National Government of Environmental Licenses - In Spanish: *Autoridad Nacional de Licencias Ambientales* – ANLA to *Universidad del Atlántico)*; and for physical and chemical components standard methods are used (APHA 2012) (Table I).

Topography phase (Topo)

This phase requires staff to be selected through an evaluation mechanism that responds to the aquatic group profile; personnel with an attitude to implement environmental and water safety measures such as the use of personal protective equipment (PPE) and passing a buoyancy test. All selected staff must receive training about the aquatic system, functions, services, and environmental values. Each designated group must pass the aquatic system test before starting the topographic stage.

The initial activities of this stage include the delimitation of the lentic system in the field (supported by a biologist) to define the change of conventional demarcation and the implementation of the instructions taking into account the regulations of water transport. The topographic phase begins with the establishment of the seismic information receivers and the detonation points. These are marked with clean recycled plastic bottles (free of oils and other contaminants) with a minimum capacity of 1L; tied to a 3/8 fique rope over 4m long on the surface regardless of the depth of the water column. This system is anchored to the bottom of the shallow system using a 40cm stake buried in the bottom, thus avoiding the loss of stagnation in the event of inundation (Figure 2)

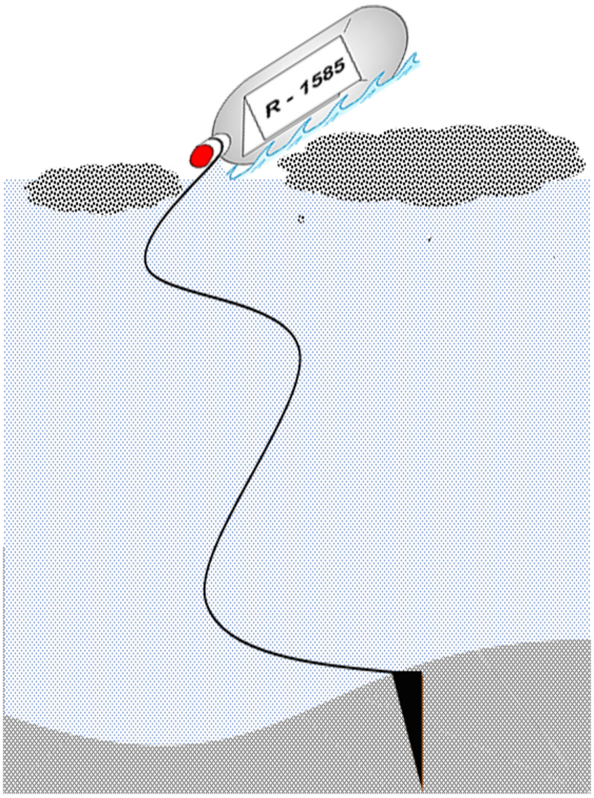

Figure 2. New signaling structure implemented for the stk's y Sp's in aquatic system submitted to seismic acquisition.

The quality and safety control of the card marking is carried out through the use of a bottle collar joined in the order of location of the demarcation stakes of the scan line (stk's) and the detonation points (Sp's). Each stk is buried from the boat, with the help of a cylindrical metal tube that has a support washer at one end to prevent the stake from sinking inside instead of allowing it to be fully buried to the bottom of the aquatic system.

The logistics necessary for the zone are sufficient for all personnel following the contingency plan for the area. The edge vegetation of the lentic system, in no case, should be used for signaling. Staff should be aware of animal sightings given the presence of alligators, snakes, etc., and notify the environment and security departments (locating line and stake) in the case of identifying their presence. This information is used to feed the database of the risk landscape map.

Drilling phase (Drill)

The staff passes an evaluation according to the profile of the aquatic work staff. All personnel that works on the seismic lines must wear Personal Protective Equipment (PPE) and must have received initial QHSE induction. Every driller must receive general training focused on the risks inherent to the activity to be carried out, including fuel handling, before starting the fieldwork. The given supplies are from the coordination of Quality, Health, and Environmental Safety (QHSE). In this phase, the operators must transport the material of denotation Sismigel® with the caution of using in a different vessel than the one used to transport the rest of the staff.

The platform on which the drilling equipment works must be wide, safe, with solar protection, and must be able to move through open water and aquatic vegetation. When drilling Sismigel® loading wells, the well's wall must be protected with 4 PVC tubing long enough to allow sediments that are washed and resuspended to reach the containers on the boat. The protected walls of the wells are also allowed to lower the load (1800 g of Sismigel®) and facilitate the well sealing without leaving air chambers (minimum depth of Well 11.2 m, the cover of 10m with the rounded stone of 3/4 "). The sludge must always be recovered, to avoid the removal and contamination of the water, due to its resuspension (Figure 3).

Well-loading

Before moving seismic material, compliance with Colombian transport normative must be ensured; Decrees 2335 of 1993 on weapons, ammunition, and explosives; 1609 of 2002 Automotive Land Handling and Transport of

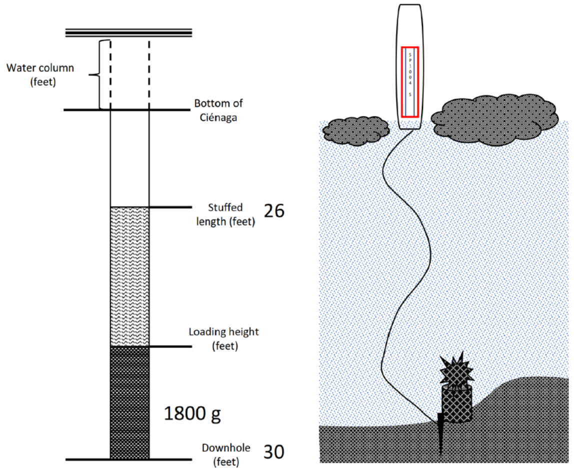

Figure 3. Well structure and tack parameter (a); signaling implemented for the Sp's after of tack in aquatic system submitted to seismic acquisition (b).

Dangerous Goods, and; Law 1242 of August 05, 2,008 National Code of Navigation and Fluvial Port Activities.

Before starting the wells loading activity, the QHSE professional should visually review the worksite where the well to be loaded is located, ensuring that the work area remains free of spark-generating elements or static energy. The personnel cannot carry equipment that generates galvanometric load. Those materials include cells, radios, cameras, battery clocks, etc. If the use of any of this equipment is required, the user must remain at a minimum distance of 30 m from the area of use of the seismic material in accordance with the provisions of Decree 2222 of 1993.

In the places where the water depth does not exceed 3 m, the drilling rig will be removed from the well, and the wells loading platform will enter and perform the loading procedure. In places where the water depth exceeds 3 m, the staff should withdraw from the area a minimum distance of 30 m, leaving the drilling rig anchored to continue the wells loading.

It is relevant not to carry out any work during storms. If this situation occurs, the communication coordinator should be informed of the novelty of the suspension of the loading of wells, which avoids the handling of seismic material.

Wells loading is a critical activity that begins by lengthening the seismographic electrical ignition cable. The load continuity control is carried out on this cable, which is verified with a galvanometer. After that, the cable is installed to the source material reaching to the bottom of the well. Once this is complete, the well is sealed and removed from the protective tube. The outgoing cable is fixed to the biodegradable rope and the buoy that was previously installed during the Typography phase. Before withdrawing from the well, a fique shore is placed, filled with material from the edge of the aquatic system as an additional security measure for the exact location of the Sp; this bag is always to the right of Sp as a pattern (Figure 3).

It is imperative that the sealing of the well reaches ground level and is made with small rocky material (3/4 "round), making sure not to leave air chambers (Figure 3). Simultaneously, the detailed documentary control of the procedures performed is carried out (sheet of each well).

Recording phase (Rec)

All staff who carry out registration activities in the lentic aquatic system must use PPE and pass the tests for the profile. The activities start with several checks that include the verification of the environmental conditions, the integrity of the boats, the specific instruments for acquisition, the stakes where the material is secured, and the tripods to locate the battery and buoys (Figure 4)

The staff must have received the training of QHSE and consequently minimize the number of people per wiring and acquisition work. They should be transported into the aquatic system

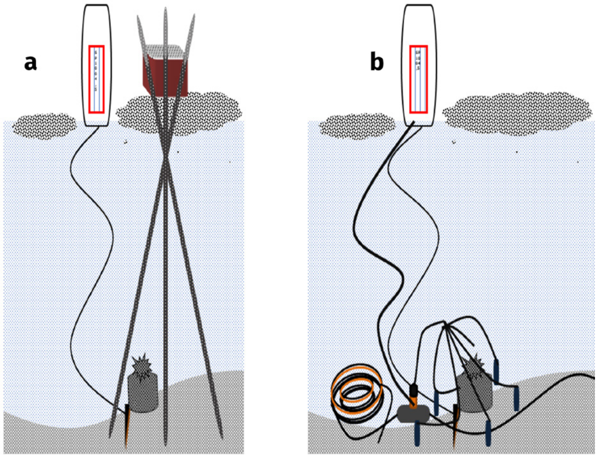

Figure 4. Battery structure (a); watering system for cables and hydrophones for seismic acquisition (b).

in canoes or other suitable floating vehicles to avoid walking inside the bottom or border. The cables, batteries, and other elements of the stage should be placed on the surface to minimize the affectation of the landscape. It is relevant to avoid the removal of the bottom of the swamp during the laying and collection of the cables (Figure 4).

On the day of recording in the bodies of water, the process starts in wells that are on the ground and advance progressively in a single direction; the direction of the ingress of water flow in the system. The protocol allows fish to be chased away by noise and vibration, which decreases the chance of biota involvement.

Restoration phase (Res)

This phase aims to ensure that the intervened area of the aquatic system recovers environmental conditions similar to those found before entering the acquisition seismic activity. It is necessary to minimize the number of people who enter the boats to remove the non-biodegradable material from the bodies of water (plastic demarcation bottles). The same recording staff, in this stage, enters to remove buoys from stk's and Sp's. The acquisition group goes after the collection staff, verifying the removal of all buoys from stk's and Sp's. Finally, the boarding points, mobile area of the boat fuel tank, evacuation points, and all activity carried out in the operation are restored.

Information analyses

The information of variables determined after each seismic phase was analyzed using statistical descriptors of measures of central tendency and dispersion of the data. Kolmogorov-Smirnov normality tests and the Bartlett homoscedasticity test were applied. The results obtained allowed the application of parametric statistical methods (ANOVA) using GraphPad Prism®.

The hydrologic behavior of the lentic aquatic system was analyzed by Pearson's Correlation Coefficient Test (CCP), which allows for identifying linear relationships between pairs of physicochemical variables and determining patterns between them. In addition, it was incorporated with Fisher's test which guarantees the level of significance used (which for all tests was 5%).

The taxonomic groups were separated for the biotic analysis. The representative group in the population was associated with the terrestrial border or the water system. According to the available information, the groups were organized on ecological aspects such as habitat use, time spent in the environment, and trophic function. The variation of the population was estimated by applying the following ecological indices: Hill number (Hill 1972, Ripple et al. 2014), and the Diversity of Shannon (Kraft et al. 2015).

RESULTS

Physical-chemical variables during acquisition phases

The results were present as relevant variables with significant changes in the dynamics of the lentic aquatic systems under seismic exploration.

The depth of the water column presented values between 3 and 189 cm, which generates a significant variation between the baseline and the seismic exploration phases, due to the concentration of mineral salts, and nutrients in the system. In the baseline sampling, the aquatic system presented an average depth of 125 cm, which decreased with time, reaching a 4.5 cm average. This variation did not discriminate between sampling points (Table II, Figure 5, Supplementary Material - Figure S1), as confirmed by the comparison of means.

The sampling points E6 and E7 could only be monitored during the baseline phase since the dry season decreased the level of water in these points. In these zones, there was a complete drought; therefore, it was impossible to monitor the water component. Even within the exploration phases, the water column disappeared at E5. This water loss is characteristic in the lentic aquatic systems during the dry period of the Colombian Caribbean (Gutiérrez et al. 2009).

Transparency values between 1 and 74 cm were presented, with an average of 22 cm. The maximum values appear during the baseline sampling and the minimum ones after the recording (Table II, Figure S2). The means per point do not show significant differences between them, which indicates that their transparency varied similarly between sampling points. The temporality monitoring showed differences between the values reported for the baseline and the rest of the phases. The transparency values decreased before the acquisition activities, coinciding with the dry period of the region, which drastically affects the decrease in the water column.

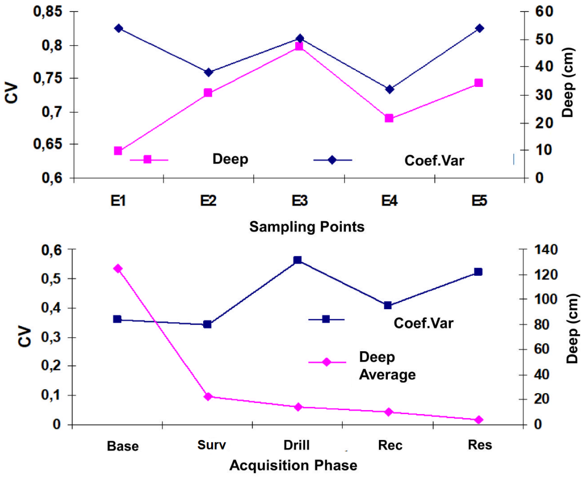

Figure 5. Correspondence of the coefficient of variation of the system with the depth at the sampling point (a) in contrast to the general coefficient of variation of the system, during acquisition phases (b).

Other variables closely linked with transparency were analyzed together to infer more decisively about their behavior. The fraction of dissolved solids showed a significant variation, while the suspended solids only presented values that could contribute to the totals in the restoration phase (Table II, Figure S3-S4). The average concentration of the total solids tends to increase during the period of study throughout the acquisition phases (time); however, no spatial differences are evident (sampling points), which suggests that the increase in the concentration of solids corresponds to a generalized event in the system that is not necessarily a consequence of the seismic acquisition.

The suspended solids show that point E3, localized in the exploration line, is presented as one of the stations with values into the upper ranges; however, this is not the only area of the body of water where a similar result is shown. Other points far from the seismic line have suspended solid values equal to or higher than those registered in E3. The intermediate points between E3 and the other points presented the lowest historical concentration range, showing no increment associated with seismic exploration. This is supported by the absence of a dispersion gradient on the

Table II. General Results of the physical-chemical variables in the intervened aquatic lentic systems during acquisition seismic phases.

VARIABLES	Ciénaga Méndez					Ciénaga La Popa				Ciénaga Las Cruces				Ciénaga Tofeme			
	Base	**Surv**	**Dril**	**Rec**	**Res**	**Base**	**Dril**	**Rec**	**Res**	**Base**	**Dril**	**Rec**	**Res**	**Base**	**Dril**	**Rec**	**Res**
Tw (°C)	32,5±2,5	35,5±2,5	31,9±1,5	34±1,5	31,7±2,0	31,9±1,2	32,3±1,4	33,95±2,1	34,7±1,5	29,32±2,5	33,02±2,0	33,46±1,0	34,8±0,5	33,5±0,5	29,3±1,0	31,7±3	31,1±0,5
Deep (cm)	125±5	22±4	15±2	10±2	4,5±2	151,5±7	117,26±11	102±4	92±8	179,6±4	96,11±10	87,33±3	121±8	**	**	**	**
Transp (cm)	53,4±5	17,5±1	9,5±1	4,5±1	4,6±1	33,16±2	23,2±1	25,93±1,5	21,83±1,5	41,6±1,5	28,28±2,0	24,3±1,5	28±2,5	**	**	**	**
pH	6,98±0,5	7,6±0,2	6,98±0,3	6,92±0,6	4,3±0,3	7,59±2	7,93±1	8,01±1,5	7,52±1	7,35±1	8,03±2	7,87±2	8,56±2	6,8±3	6,4±7	7±4	7,05±2
Áci (mg.L-1)	0,84±0,02	0,91±0,02	1,18±0,03	0,02±0,02	0,25±0,04	50,2±0,5	17,1±0,1	16,1±0,1	16,6±0,3	50±9	16,6±3	16,6±3	13,3±1	54,8±2	31,6±3	34,8±2	9,8±3
Dur (mg.L-1)	1,5±0,5	2,2±0,5	2,3±0,5	2,25±0,1	0,9±0,1	89,2±0,1	99,3±0,5	104,4±0,5	101,8±0,5	89,76±1,5	100±2,5	98,16±1,0	168,5±1,0	229,7±2,5	250,6±9	95,8±3	50,1±5
TSS (mg.L-1)	25,5±7	27±0,4	29±0,3	31±0,1	33±0,5	**	**	**	**	**	**	**	**	**	**	**	**
TDS (mg.L-1)	11±2	38±4	42±2	590±5	180±5	64±2	224±5	266±4	249±5	69,5±1	281±9	276±2	259±2	**	**	**	**
Cdv (mg.L-1)	10±2	95±4	110±9	149±7	211±10	64,1±2	175,4±3	141,8±10	138,9±3	69,6±4	184,6±1	149,2±3	148±5	45,1±2	50,2±2	50,2±5	39,3±5
OD (mg.L-1)	1,5±0,5	4±06	1,8±0,3	3,6±0,2	4,1±0,1	5,66±0,1	5,49±0,1	5,92±0,1	4,97±',3	3,35±0,2	6,51±0,5	5,44±0,2	5,36±0,9	2±0,2	2,1±0,1	1,95±0,4	2,2±0,2
NOx (mg.L-1)	1,9±0,2	2,4±0,2	1,60±0,1	1,6±0,1	10±0,1	2,4±0,1	0,0075±0,09	0,0075±0,04	0,0075±0,01	4,81±0,02	0,0075±0,01	0,007±0,0075	0,0075±0,02	0,61	1,40	0,80	0,11
NO (mg.L-1)	0,03±0,01	0,04±0,01	0,13±0,01	0,050±0,01	0,03±0,01	0,004±0,001	0,008±0,002	0,008±0,001	0,008±0,002	0,005±0,001	0,008±0,001	0,008±0,001	0,008±0,001	0,02	0,01	0,01	0,01
SOx (mg.L-1)	102±0,8	97±0,5	107±0,11	271±0,10	142±0,2	3,4±0,2	3,1±0,08	13,8±0,1	5,65±0,05	6,17±0,3	19,71±0,5	3,12±0,2	23,09±0,5	2,10	9,00	12,00	11,30
POx (mg.L-1)	**	**	**	**	**	0,006±0,001	0,085±0,0015	0,24±0,002	0,639±0,001	0,014±0,002	0,07±0,03	0,119±0,01	0,143±0,02	0,06	0,04	0,03	0,03
DBO (mg.L-1)	**	**	**	**	**	**	**	**	**	**	**	**	**	12,1±1	10,6±1	11,5±2	10,8±2
DQO (mg.L-1)	**	**	**	**	**	2,5±0,1	2,5±0,08	2,5±0,1	2,5±0,1	2,7±0,5	2,5±0,3	2,5±0,7	4,15±0,04	**	**	**	**
NHx (mg.L-1)	**	**	**	**	**	0,13±0,002	0,116±0,005	0,15±0,004	0,13±0,002	0,26±0,001	0,08±0,004	0,1±0,001	0,15±0,005	0,53±0,6	1,2±0,1	1,3±0,5	0,92±0,3
Sal (ppm)	**	**	**	**	**	4,88±0,5	6,67±0,1	3,75±0,3	7,1±0,7	3,77±0,5	6,55±0,3	4,22±0,5	4,41±0,5	4,1±0,8	4,48±0,5	5,43±0,3	4,5±0,5
CaCO3 (mg.L-1)	**	**	**	**	**	3,65±0,5	10,58±1	9,55±0,5	5,73±0,5	2,27±0,6	11,83±0,4	4,97±0,7	5,15±0,6	18,6±0,5	16,8±0,2	17±0,6	17,5±0,8
MOsed (%)	1,7±0,01	4±0,01	4,6±0,02	4,7±0,02	**	19,88±0,5	19,86±0,4	17,8±0,09	17,9±0,5	21,48±0,9	15,37±0,1	19,48±0,6	19,04±0,4	3,45±0,2	3±0,2	3,6±0,9	4,3±0,6
** ND																	

sampling line (Figures 1a-1c, Table II, Figure S3-S4). The evidence shows that the values are not statistically significantly associated with the disturbance due to the resuspension of solids in drilling or loading activities.

The dissolved oxygen concentrations (mg.L-1) during all the sampling phases, ranged between 0.3 mg.L-1 (reported in E5 after drilling) and 6.1 mg.L-1 as a value in the baseline. It can be highlighted that during the baseline sampling, the lower dissolved oxygen concentrations presented (Table II, Figure S5) tended to recover in later phases because oxygen is incorporated into minor water. The physical oxygen values reported in the intervened systems are considered lower than the ones on the records of other bodies of water with similar characteristics that behave as Type II lentic systems (with direct connection to a lotic system) (CRA 2012, Varcárcel et al. 2011)

Nitrate concentrations showed values ranging between 0 - 5.6 mg.L-1. These values were respectively obtained during the registration phases and the baseline activities (Table II, Figure S6).

The minimum value of nitrate was found at the sampling point E5, while the maximum one at the sampling point E2. The comparison of means shows that there are no significant spatial or temporal differences in the concentrations of this form of nitrogen, despite the high value presented in E2 in the phase prior to the seismic acquisition activities.

Nitrites show a minimum concentration of 0.013 mg.L-1 in E2 during baseline sampling, and a maximum of 0.296 mg.L-1 in E3 after the drilling phase (Table II), with a general average of 0.058 mg.L-1. Although the ANOVA for nitrites (Figure S7) does not differentiate the sampling points, it does show a very significant difference between the post-drill sampling in relation to the other acquisition phases. The result is more interesting if it is considered that the high values of nitrate (above 0.05 mg.L-1) are toxic to organisms. In addition, they are presented at E3, where 0.296 mg.L-1 is a toxic value, turning the station located on the exploration line into an accumulation zone for this nutrient.

Sulfate concentrations ranged from 66 - 494 mg.L-1 with an average of 143.8 mg.L-1, presenting the minimum value in E2 and the maximum in E3 and E2, corresponding to the phases prior to all activity and after recording (Figure S8). Despite these variations, the ANOVA did not show a significant spatial difference, but it did place the registration phase as the one with values above the maximums presented in comparison with the previous phases (Table II, Figure S8).

Modified Protocols (MTR Protocol)

The procedures presented resulted from a decade of tests in different seismic exploration projects in wetlands, where the learning was obtained from the observation, monitoring, and evaluation of potential environmental effects caused by the seismic acquisition processes. The projects that took place in the lentic systems of the lower and middle basins of the Magdalena River led to modifications and adjustments of protocols, equipment, and supplies used in the exploratory seismic. MTR methodology (MTR SAS 2011) is a series of actions that give relevance to the environment in structure and function, the active participation of the community as auditors of the process, as well as the safety of the operators and the permanent monitoring of the environmental effects.

Surveying phase

The major intervention carried out by the surveying affects components such as the macrophytes in the border area (Figure S11). The effect was minimized with the chance of the opening of trails and the demarcation from the water with the buoy nailing device at the bottom (Figure 2). These modifications made it possible to avoid the compaction of the sediment due to the effects of the passage of groups and the resuspension of solids in the water-sediment interface (Table IIIa).

Drilling and well-loading phase

The drilling phase showed the greatest results by minimizing the negative effects on the system, leading to the following successes: 1) The safety of the personnel and the conformity of the community during the drilling, and transportation of source material. 2) Safer operation with the use of a platform without entering the aquatic system. 3) Work without removals at the water-sediment interface. 4) The most important positive effect; was the reduction of the amount of cargo (from 3,600 to 1800 g) and the assurance that the wells remained well covered, without the walls collapsing. 5) Additionally, the fall of the sludge extracted into the system is eliminated with the use of recovery trays, as reflected in the behavior of nutrients and the impact matrix in the different systems studied (Tables II and IIIb; Figure 3; Figure S12)

Recording phase

The location protocol of recording material added security values, such as the security of the batteries in tripods, and avoided the loss of wiring material and geophones (Figure 4). Additionally, with no removal of sediment, the proximity of the biota during the phase was avoided, and thus any effect on fish, birds, and other fauna associated with the aquatic system (Tables II and IIIc, Figure S13).

Restoration phase

The results of the restoration consist of the elimination of the material used during the operation (marking and signaling bottles),

Table III. Impact Matrix for topographic, post-drilling, post-recording, post-restoration phase and final impact; III(a) Impact Matrix for topographic phase effect on the components of the lentic aquatic system; III(b) Impact Matrix for drilling and loading phase effect on the components of the lentic aquatic system: III(c) Impact Matrix for recording and loading phase effect on the components of the lentic aquatic system; III(d) Impact Matrix for restoration and loading phase effect on the components of the lentic aquatic system and III(e) Total Impact Matrix for seismic effect on the components of the lentic aquatic system.

FACTORS	SURVEYING PHASE (a)									Total score	Partial Impact		POST-DRILLING PHASE (b)																				Total score	Partial Impact		POST-RECORDING PHASE (c)									Total score	Partial Impact		POST-RESTORATION PHASE (d)									Total score	Partial Impact		FINAL IMPACT (e)	
	Activities												Activities																							Activities												Activities													
	Topography												Drlling									PARTIAL IMPACT		Loading Wells												Recording												Restoring													
Hydrogeological	In	Ex	Mo	Pe	Rv	Si	Ac	Pr	Mc		I	M	In	Ex	Mo	Pe	Rv	Si	Ac	Pr	Mc	I	M	In	Ex	Mo	Pe	Rv	Si	Ac	Pr	Mc		I	M	In	Ex	Mo	Pe	Rv	Si	Ac	Pr	Mc		I	M	In	Ex	Mo	Pe	Rv	Si	Ac	Pr	Mc		I	M	I	M
Water Quality	2	2	4	2	1	2	1	4	1	18	24	2	4	2	4	2	2	1	1	4	4	34	2	1	1	4	1	2	2	1	2	1	15	18	1	4	2	4	2	2	2	1	2	2	21	31	2	2	2	4	1	2	2	1	2	2	19	25	2	26,4	1,8
Sediments	2	1	4	1	2	2	1	4	4	19	24	1	4	2	2	2	2	2	1	4	4	33	2	2	2	4	2	2	1	1	2	4	20	26	2	4	2	4	1	2	1	1	4	4	23	33	2	2	1	4	2	1	2	1	2	4	21	26	1	28,4	1,6
Hydrobioogist																																																													
Fish	1	1	4	1	1	1	1	4	1	13	18	1	2	2	4	2	1	2	1	4	4	28	2	1	1	4	1	1	2	1	2	4	17	20	1	4	2	4	1	2	2	1	4	4	24	34	2	2	1	4	1	1	1	1	1	1	15	18	1	23,6	1,4
Birds	2	2	4	1	1	1	1	4	4	14	19	2	2	1	4	1	1	1	1	2	4	22	1	1	1	4	1	1	1	1	1	1	12	15	1	2	2	4	1	1	1	1	4	4	20	26	2	2	1	4	1	1	1	1	2	1	20	26	1	21,6	1,4
Macroinvertebrates	2	1	2	1	2	1	1	4	4	18	24	1	4	4	2	2	2	2	1	4	4	37	4	2	1	4	2	2	2	1	2	4	20	25	1	4	2	4	2	2	2	1	4	4	25	35	2	2	2	2	2	2	1	1	2	4	18	23	2	28,8	2,0
Phytoplankton	2	2	4	2	2	1	1	4	1	18	24	2	4	2	4	2	2	2	1	4	2	33	2	2	1	4	1	2	1	1	2	4	18	23	1	4	2	4	1	2	1	1	4	2	21	31	2	2	2	4	1	2	2	1	2	2	19	25	2	27,2	1,8
Macrophytes	2	1	4	1	1	2	1	4	4	18	23	1	2	2	4	1	2	2	1	2	4	26	2	1	1	4	1	1	1	1	1	1	12	15	1	2	1	4	1	1	2	1	4	4	20	25	1	2	1	4	2	1	2	1	1	4	20	25	1	22,8	1,2
Totals	13	10	26	9	10	10	7	28	19	118	22,286	1,429	22	15	24	12	12	12	7	24	26	30,429	2,14	10	8	28	9	11	10	7	12	19	114	20,29	1,43	24	13	28	9	12	11	7	26	24	154	30,71	1,86	14	10	26	10	10	11	7	12	18	132	24	1,43	25,54	1,60

wiring and geophones from the recording phase, entrances and temporary boarding structures, information signs, etc. (Tables II and IIId)

DISCUSSION

The magnitude and intensity of the impacts generated by seismic exploration activities should be predicted by recording the ranges of variation of the concentrations of the selected factors and the dispersion of the change in a monitoring network, which is located perpendicular to the intervention line. The spatial and temporal monitoring was established considering that there are two types of environments in the lentic ecosystems, one corresponding to the limnetic zone and the other the littoral zone (Figure 5). For the case of study, stations that cover these two environments were located (Tables IIIa – IIIe).

The depth level was less than 20 cm during measurements before exploration activities (In the point E5; to 27°C) in the sampling that corresponds to the so-called post-drilling phase, this measurement was made at 7:30 h (Table II, Figure S1)

During the monitoring, the mean water temperature was 33.12 °C. The maximum value (38ºC) was in E3 and E2. This atypical value for the water column is consistent with the radiation levels that affect the water mirror, with a clear sky and the time of the record (11:00 h). The ANOVA results ($P < 0.05$) for the water temperature shows that two points (E3 and E2) present dissimilar behavior in the monitoring, presenting the highest ranges for this factor; however, when monitoring the sampling schedule, the results are consistent with the timing of the data recording, to the extent that the incidence of solar radiation increased towards the end of the sampling day. These results can be interpreted as the normal system changes for a daily cycle of radiation incidence on the water system (Duque et al. 2012)

The range of temperature oscillation in the water column does not represent a limiting factor for the recruitment and establishment of a biological community, according to the reports of the limnological studies of shallow lentic systems in the lowlands of the Colombian Caribbean (Ramírez & Viña 1998).

The analysis of the data produced by the physical and chemical characteristics of the water, before, during, and after the seismic exploration activities, shows that there is a natural tensor that regulates the dynamics of the temporal and spatial behavior of most of the studied variables. This natural tensor corresponds to the process of flooding and drying of the water basin of the lentic system that is recognized by several authors and expert limnologists such as Junk & Wantzen (2003) (Castellanos-Romero et al. 2009). This flood phenomenon is detected in changes in the depth of the column of water and in the horizontal extension of the water (Figure 5).

The results of the solids show that there are major events such as the continuous loss of the water column and drought in the region that are associated with greater fidelity to an increase in time. Therefore, no evidence was found to determine an impact of the exploratory activity that significantly changes the trend in suspended solids, which are observed in the wetland and which may be more associated with loss of depth. The values presented in E3 are values in the upper ranges during the execution of the study, including samplings prior to exploration activities (Table II, Figure S3-S4).

In general, the oxygen values registered are lower than the optimal criteria established in the regulations for the conservation of wildlife (MINMINAS 2012). These aquatic systems are characterized by dynamic or rapid changes in oxygen concentrations, moving from saturated environments to environments with oxygen deficiency (Table II, Figure S5). These events are the result of the oxygen demand of the organic matter of autochthonous or allochthonous origin, and the respiration of the existing fauna and flora. While the oxygenation of the system is presented by the phenomena of physical oxygenation of atmospheric origin due to the effect of the mobility or currents of the water body. The biological oxygenation generated by the photo-synthesizers also occurs, achieving changes that are even recorded in short periods as daily cycles with high oxygenation during daylight and hypoxia at night (Jorgen et al. 2007).

The relatively low concentrations of oxygen in the aquatic system during the dry period can reflect large amounts of organic matter (table II, Figure S9), which consume oxygen in the water, generating the characteristics of aquatic systems with evident periods of localized hypoxia and during some periods of time. These stochastic dynamics of oxygen concentrations and the low or high registers not associated with the exploration activities, do not allow for independently establishing the oxygen demand of the water generated by the exploratory activity. However, the values that are presented before, during, and after the exploration activities show that the effect of variation in the oxygen concentration that can be associated with the different phases has no significant impact that is cushioned by the system, depending on its location (border zone or limnetic zone, or by time (Alba-Tercedor et al. 2016)

Although the statistical estimates do not show significant differences in nitrate values, it is important to highlight that values of 5.6 mg.L-1 compared to values of 0 mg.L-1 is considered normal from a trophic point of view. In accordance with evidence of horizontal stratification of the system, this inhomogeneous behavior of the mirror of water is a very regular and typical event of shallow lentic systems (Table II, Figure S6). These conditions can occur due to local runoff, the effect of winds, or localized natural or anthropic activities (Pinilla 2010). In this case, it was possible to detect the causes of this sectorization phenomenon to the extent that a particular sector of nesting and perching of birds was detected in E2, which generates a greater entry of nitrogenous substances by the excreta of the birds in abundance (Figure S10). The material deposited by birds is quickly oxidized and generates differential nitrate values (Alba-Tercedor et al. 2017)

It is important to note that one of the first intermediate products between uric waste from birds and nitrates are ammonium and nitrites, the latter with the possibility of representing toxicity risks depending on the concentrations and exposure time of aquatic individuals. However, when observing the behavior of nitrites in the same samples where high values of nitrates are registered, nitrites present values that do not exceed the limits registered with risky concentrations (Table II, Figure S7). This fact would be associated with rapid oxidation, explained by the availability of oxygen and temperatures ranging between approximately 27 and 39ºC, which are optimal for accelerating physical-chemical and biological processes of transformation of nitrogenous substances (Maroñas et al. 2010, Clews et al. 2010)

Simultaneous analysis of the temporal (Drill) and spatial (E3) increase shows that there is an effect of sediment removal during the phase in which wells are drilled for seismic exploration. This fact and the organic matter values detected in the sediments allow inferring that the nitrites deposited under anoxic conditions in the sediments are incorporated into the water column. The interface sediment-water facilitates the accumulation of non-oxidized nitrogenous compounds and the removal or resuspension of the sediments facilitates their dissolution in the water column. This phenomenon is characteristic of the areas of low extension adjacent to the exploration line. Therefore, the strategy included in the methodology used the well jacketing design and the incorporation of a collection tray for the sludge extracted during the drilling phase to avoid the return of the organic matter to the water column (Figure 3, Figure S12).

It should also be clarified that the event is punctual for the system. It is evident that after the drilling operations, the values of concentration of nitrites in the water returned to the initial values (Table II and III, Figure S12). These temporary or punctual increases in nitrite levels that exceed the limits of the toxicity values recorded are an explanation for the fact that there was no mortality of fish or other aquatic animals perceptible to the naked eye in the system. Furthermore, when appropriate dispersal measures are taken, the chances of free-moving animals in the wetland being affected are low, since they keep the animals within an average range of 50m from the drill line (Tables II and III).

There is the possibility of an impact on the microbiota of the system, detected by the monitoring design that was implemented. It was found that the increase in nitrites and nitrates during the drilling phase generated a rapid change in the percentage composition of the phytoplankton community (Tables II and III). Species with predominance and rapid growth, are favored by the removal of sediments, such as cyanophytes; However, the return to the initial conditions or decrease of nitrogenous substances, restores the competitiveness possibilities of other species, and the phytoplankton community is reestablished (Table IV)

These events can be explained by considering the rapid oxidation of nitrites to nitrates in hot environments, reducing the risks of nitrite toxicity due to rapid oxidation, which reverts to substances that can be assimilated by phytoplankton (Bertelsmeier et al. 2013). This significant increase in organic matter in sediments is directly related to the decrease in-depth and sedimentation in the water inlet zone, rather than to contributions from organisms or the activities of the seismic acquisition line.

CONCLUSIONS

It should be considered that the studies of monitoring and evaluation of the impact of seismic exploration in shallow lentic ecosystems require baselines to discriminate the effects due to the natural variations of the system or to the intervention activities. Considering monitoring factors associated with the flood pulse events that develop simultaneously with the activities, among which the variation in depth stands out.

The most important effects are caused by the drilling and registration phases (Table IIIb – IIIc), which had a marked effect on the levels of ammonia, sulfates, and nitrates (Table II, Figure S6-S9). However, these changes were of little significance, low magnitude, and intensity, allowing the ecosystem to recover its initial conditions in the short term (Table IIIa – IIIe). One evidence of this is that the benthic macroinvertebrate population presented a homogeneous behavior during the phases of seismic activity, showing that there were no considerable modifications due to said activity (Table V).

The analysis of the fish populations regarding the diversity of the lentic systems studied presented a heterogeneous distribution behavior with the relative abundance of individuals per station into the seismic

Table IV. **Wealth and abundance phytoplanktonic in the water systems under acquisition seismic.**

Wealth (%)																
Taxon	**Ciénaga Mendez**				**Ciénaga Tofeme**				**Ciénaga La Popa**				**Ciénaga Las Cruces**			
	Base	**Pre**	**Tal**	**Reg**	**Pre**	**Per**	**Reg**	**Res**	**Base**	**Tal**	**Reg**	**Res**	**Base**	**Tal**	**Reg**	**Res**
Clorophyta	58%	49%	40%	56%	18	20	17	17	17	11	15	16	16	8	16	11
Euglenophyta	21%	21%	27%	17%	14	10	11	6	11	17	17	15	14	15	12	7
Cianophyta	13%	80%	19%	12%	2	2	5	2	8	6	4	4	6	1	2	2
Crisophyta	70%	18%	12%	13%	2	0	2	0	0	0	0	0	0	0	0	0
Criptophyta	10%	20%	10%	10%	0	0	0	0	0	0	0	1	0	0	0	0
Dinophyta	0%	20%	10%	10%	0	1	1	1	1	1	1	1	1	1	0	0
Xantophyta	0%	0%	0%	0%	0	0	1	0	1	0	0	0	1	0	0	0
Coscinodiscophyta	0%	0%	0%	0%	0	0	0	0	2	3	2	2	2	3	2	2
Bacillariophyta	0%	0%	0%	0%	4	7	1	7	3	0	0	1	2	2	3	3
Total					40	40	38	33	43	38	39	40	42	30	35	25
Abundance (%)																
Taxon	**Ciénaga Mendez**				**Ciénaga Tofeme**				**Ciénaga La Popa**				**Ciénaga Las Cruces**			
	Base	**Pre**	**Tal**	**Reg**	**Pre**	**Per**	**Reg**	**Res**	**Base**	**Tal**	**Reg**	**Res**	**Base**	**Tal**	**Reg**	**Res**
Clorophyta	40%	69%	41%	28%	2000	3500	3700	5500	5484	26100	6500	9000	4291	75000	37000	39383
Euglenophyta	44%	23%	54%	68%	3000	1500	3700	4500	8166	72500	71500	74250	800	58631	112000	24800
Cianophyta	9%	0%	0%	1%	0	100	300	2000	8333	13400	22083	20500	17151	12250	650	12350
Crisophyta	3%	8%	4%	4%	0	0	0	0	0	0	0	0	0	0	0	0
Criptophyta	4%	0%	1%	0%	0	0	0	0	0	0	0	0	0	0	0	0
Dinophyta	0%	0%	0%	0%	0	50	100	4000	500	2250	0	77500	0	0	0	0
Xantophyta	0%	0%	0%	0%	0	0	25	0	0	0	0	0	0	0	0	0
Coscinodiscophyta	0%	0%	0%	0%	0	0	0	0	0	106250	8250	5250	4291	287500	62350	22350
Bacillariophyta	0%	0%	0%	0%	5000	3950	100	14000	0	0	0	0	0	350	0	0
Totals					10000	9100	7925	30000	22483	220500	108333	186500	26533	433731	212000	98883

acquisition phases (Table VI). A similar behavior way it happened for the values of specific wealth. The disturbances caused during the recording phase presented greater intensity on the fish population, which are considered of moderate importance and medium environmental magnitude.

In general, the macrophyte composition and distribution of the coverage percentages are merely subject to the dynamics of the lentic system, and these changes have no relation to the work carried out in each of the seismic phases.

The number of phytoplanktonic species and individuals shows differences between the seismic stages related to the evolution of the rainy period that initially produces contributions from foreign species and a dilution effect on phytoplankton densities, the subsequent increase in opportunistic species. The diversity,

Table V. Macroinvertebrates in the water systems under acquisition seismic.

Family	Ciénaga Mendez												Ciénaga Tofeme				Ciénaga La Popa				Ciénaga Las Cruces			
	Base		Total	Topo		Total	Drill		Total	Rec		Total	Base	Drill	Rec	Res	Base	Drill	Rec	Res	Base	Drill	Rec	Res
	AM	B		AM	B		AM	B		AM	B													
Belostomatidae	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ceratopogonidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	5	2
Chironimidae	3	5	8	0	31	31	0	72	72	0	9	9	0	0	0	0	4	5	15	2	0	7	16	4
Conchostraca	1	0	1	9	0	9	0	5	5	0	24	24	0	0	0	0	0	0	0	0	0	0	0	0
Corixidae	0	0	0	0	5	5	5	0	5	8	0	8	0	0	0	0	0	0	0	0	0	0	0	0
Corydalidae	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Curculionidae	2	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cydopoidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Dytiscidae	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Elmidae	4	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Gerridae	0	0	0	12	0	12	3	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hirudiniidae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydracnidae	20	0	20	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Hydrobiidae	0	0	0	0	0		0	0		0	0		35	0	0	25	0	0	0	0	0	0	0	0
Hydrophilidae	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Hydrophilinidae	24	0	24	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leptoceridae	0	0	0	0	3	3	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Leptophlebiidae	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Libellulidae	5	0	5	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0
Naididae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Naucoridae	3	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Nematoda	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Noteridae	7	0	7	0	1	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Notonectidae	0	0	0	0	0	0	0	6	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Physidae	2	0	2	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0
Planorbiidae	71	0	71	0	0	0	0	0	0	0	0	0	0	42	0	0	0	20	3	3	1	3	4	2
Polycentropodidae	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0	0	0	0	0	0	0	0	0
Polymitarcidae	0	0	0	0	2	2	0	2	2	0	0	0	0	0	12	0	0	0	0	0	0	4	3	2
Ptilodactylidae	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pyralidae	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sphaerridae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	21	0	0	0	0	0	0	0	0	0
Tabanidae	2	0	2	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Tanypodinae	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	1	0	0	0	0	0
Tubificidae	13	6	19	0	7	7	0	21	21	0	17	17	10	0	0	0		13	12	2		3	3	5
Totals	162	11	173	21	53	74	9	107	116	10	50	60	57	57	33	25	4	40	31	7	1	19	31	15

dominance, and uniformity values do not present a statistically significant difference between the seismic phases (Table IV).

Is remarkable that during the development of the activities, communities of the area of influence expressed total agreement with the management that was given to the reservoir during each of the stages, and they affirmed it from the follow-ups carried out from the entrance to the aquatic system. Community participation, especially in the seismic registration phase, provides compliance with it, and the possibility of leaving evidence that the goods and services demanded by the community will not be significantly affected by the operation (Figure S13).

The implementation of environmental measures in sensitive lentic systems allows the application of transparency policies, even in the potential occurrence of environmental events.

Table VI. Fishes in the water systems under acquisition seismic.

Family	Specie	Ciénaga Tofeme				Ciénaga La Popa				Ciénaga Las Cruces				Ciénaga San Rafael					Ciénaga Martinete					Ciénaga Cantagallo				
		Base	**Drill**	**Rec**	**Res**	**Base**	**Drill**	**Rec**	**Res**	**Base**	**Drill**	**Rec**	**Res**	**S.I**	**Per**	**Pre-R**	**Reg**	**Post-R**	**S.I**	**Per**	**Pre-R**	**Reg**	**Post-R**	**Top**	**Per**	**Reg**	**Res**	**Mon**
Anastomidae	*Abramites eques*	0	3	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Leporinus muiscorum	0	2	3	0	1	1	4	2	3	1	0	3	0	0	0	0	0	0	0	0	0	0	0	3	0	2	6
	Astyanax sp	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	70	193	253	101	287
Characidae	*Astyanax magdalenae*	0	0	0	0	0	0	3	11	0	0	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Cynopotamus magdalenae	0	0	0	0	0	0	2	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Triportheus magdalenae	12	3	0	5	0	15	65	12	15	9	21	25	0	0	0	0	0	0	0	0	0	0	33	37	0	21	1
	Roeboides dayii	1	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	34	6	3	0	3
Curimatidae	*Curimata magdalenae*	0	0	0	0	0	0	0	0	0	0	0	0	5700	350	10350	1600	3925	0	0	0	0	0	0	0	0	0	0
	Curimata mivartii	0	0	0	0	6	22	10	6	2	14	0	0	0	0	0	0	0	0	0	0	0	0	17	28	32	11	1
	Chypocharax magdalenae	5	0	1	2	3	4	15	0	30	12	0	23	0	0	0	0	0	0	0	0	0	0	60	26	135	75	108
Erythrinidae	*Hoplias malabaricus*	0	1	0	0	0	0	1	1	1	0	2	0	0	0	0	200	0	0	0	0	0	0	0	0	0	0	0
Auchenipteridae	*Trachelyopterus insignis*	0	0	0	0	0	0	10	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Ageneiosus pardalis	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Ageneiosus caucanus	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Pimelodidae	*Pseudoplatystoma fasciatum*	0	0	0	0	0	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sorubim cuspicaudus	0	0	0	0	0	0	1	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Pimelodus blochii	9	1	2	4	0	4	11	7	0	5	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Ctenoluciidae	*Ctenolucius hujeta beani*	0	0	0	0	0	0	0	0	0	0	0	0	20	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Cichlidae	*Aequides pulcher*	0	0	0	0	0	0	0	0	0	0	0	0	200	100	100	200	250	0	0	0	0	0	6	27	16	19	8
	Caquetaia krausii	0	1	0	2	1		1	1	2	10	2	10	180	200	200	200	100	300	2000	0	0	0	24	33	37	52	45
	Geophagus steindachneri	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Orechromis niloticus		1			0	0	0	0	0	2	1	0	100	0	0	0	0	2200	2200	0	0	0	150	0	7	3	0
Megalopidae	*Megalops atlanticus*					0	0	0	0	0	0	0	0	250	6400	750	0	0	0	0	0	0	0	0	0	0	0	0
Prochilodontidae	*Ichthyoelephas longirostris*					0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Prochilodus magdalenae					24	36	13	4	15	38	15	20	0	0	0	0	0	0	0	0	0	0	21	9	22	19	14
Loricaridae	*Crossoloricaria variegata*					0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Sternopygidae	*Sternopygus aequilabiatus*					0		3		0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Sternopygus macrurus					0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
Scianidae	*Plagioscin surinamensis*		1			0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Tricogaster pectorales					0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	19	26	18
Totals		29	13	6	18	35	84	140	52	69	92	55	84	6450	7050	11400	2200	4275	2500	4200	0	0	0	415	375	524	329	491

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SUPPLEMENTARY MATERIAL

Figure S1-S13.

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