Final Report

Variation of Water Quality Variables at Six Stations in Guayanilla Bay

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Introduction

EcoEléctrica, L.P. (EcoEléctrica) is a private energy cogeneration company with main its facilities located on the southwest coast of Puerto Rico, in the Municipality of Penuelas.. Itoperates a 540-megawattelectric energy plant fired by natural gas, a liquefied natural gas (LNG) terminal with a 1-million capacity LNG tank, and a desalination plant, among other equipment.

EcoElectrica's cooling tower blowdown is discharged into the Guayanilla Bay through Outfall (001), which is regulated under 40 CFR 125.123- "Criteria and Standards for the National Pollutant Discharge Elimination System (NPDES) Ocean Discharge Criteria". As part of the NPDES process, EcoElectrica Biological Monitoring Program Plan (BMPP) requires the measurement of physical/chemical variables at the discharge of the facilities in order to comply with their present permit (**No. PR0025984).** The measurements reported here were conducted at the discharge site (Outfall 001) as well as in other 5 sites, to maintain consistency of water-quality monitoring with previous monitoring efforts and reports.

This report describes results on water quality variables examined during four monthly sampling trips from September to December 2011 under EcoElectrica's Purchase Order Number S-18896. The report includes a description of the methods used, raw data files, processed data files, associated data graphs, interpretations and conclusions.

Objectives

The study objectives were:

1. Measure water quality variables in waters of Guayanilla and Tallaboa Bay.
2. Evaluate the spatial and temporal variation of water quality variables.
3. Discuss the relationship of water quality observations in relation to the outflow and inflow of EcoElectrica cooling water system.

Methods

Sampling

Sampling was conducted on board a 22 ft boat (Boston Whaler), operated by EcoElectrica, at 6 stations (FIG. 1). Samples were collected at predetermined locations (Table 1) on 16 September, 18 October, 18 November and 27 December 2011. The following determinations were made at each monitoring station: Secchi Depth, Photosynthetic Active Radiation (PAR) and Temperature, pH, Turbidity and Dissolved Oxygen concentration (DO) and depth (YSI 6000 Series Sonde fitted with a 650 Handheld Logger). Participants included: Alvin Ortíz (Captain), Wilfredo Sánchez (Captain Assistant), Krystal Martínez (Student-COOP UPRM), Ermelindo Banchs (Environmental Engineer, EcoElectrica), Damaris Negrón (Environmental Compliance Manager, EcoElectrica) and Ernesto Otero (Consultant).

TABLE 1. POSITION OF STATIONS IN WATER QUALITY STUDY

STATION	LATITUDE DECIMAL DEGREES N	LONGITUDE DECIMAL DEGREES W
Discharge (1)	17.97283	-66.76155
Intake (2)	17.97518	-66.75923
Recipient (3)	17.97802	-66.74832
Donor (4)	17.97543	-66.76322
Maria Langa (5)	17.96838	-66.75724
Kapitan Egorov (6)	17.96132	-66.76734

Figure 1: Study area indicating location of stations

The waters of Guayabilla Bay are classified as Class SC , that is, coastal waters supporting primary human contact from the intertidal zone to 3 miles seaward and secondary recreational contact from 3-10 miles seaward as well as suitable for the propagation and preservation of desirable species including those threatened or in danger of extinction (PR EQB; http://www2.pr.gov/agencias/jca/Documents/Leyes%20y%20Reglamentos/Reglamentos/Reglamentos/Reglamento%20Est%C3%A1dares%20Calidad%20de%20Agua%202010.pdf ; Downloaded on 21 March 2012).

Secchi Depth

Secchi depth was estimated based on Megard and Berman (1989) using a 20cm diameter oceanographic disc by recording the depth (m) at which the disc disappears from view while being lowered into the water by the side of the boat towards the sun, using a calibrated line.

PAR Determination

A 192S cosine underwater PAR sensor (Licor) and a pressure sensor (Sensus Ultra, ReefNet Inc.) were lowered into the water using an inverted T-shaped frame linked to a black line in order to estimate PAR at different depths. Light measurements were recorded using a LI-1400 data logger. Four to 6 readings were collected after lowering the underwater sensor in a 1m stepwise fashion down to a maximum of 7m.

YSI 6000 DataSonde Series Determinations

Calibration of the YSI DataSonde for pH and dissolved oxygen (DO) were conducted per manufacturer instruction using pH 7 and 10 standards, and water-saturated air, respectively. Calibration buffers for pH were provided by the manufacturer. Factory settings for temperature and depth were used. The factory calibration of turbidity was not changed in order to avoid unwanted shifts in instrument settings for this parameter. Instead, AMCO clear turbidity standards were used to construct calibration curves. Different dilutions were made using filtered distilled water to get 0, 1, 2, 5, and 126 nephelometric turbidity units (NTU). Pearson regression analysis was used to convert instrument readings to calibrated NTU as in Otero (2009). In the field, samples were collected from at least two depths at approximately 0.3 and 3m at each station.

Estimates of PAR Attenuation Coefficient

Parameters defined as the attenuation coefficient of PAR (Kd_{PAR}) and the attenuation coefficient of PAR at a specific depth interval ($Kd_{PAR\Delta d}$) were estimated as they allow for the calculation of light penetration at the different locations during the time of sampling. The estimates were conducted following two independent methods:

The first method estimates Kd_{PAR} using the following equation between different depth segments (Kirk, 2011):

$Kd_{PAR\Delta d}$= [ln(E_{z1}/E_{z2})]÷(Z2-Z1); (equation 1)

where:

$Kd_{PAR\Delta d}$ is the attenuation coefficient of PAR at a specific depth interval,
Z1 and Z2 are the shallower and deeper depths (in m) within a depth interval at which underwater light measurements are conducted and,
E_{Z1} and E_{Z2} are underwater PAR measurements (µmoles photons/m2/s) at their corresponding depths.

Each station's Kd_{PAR} was estimated as the average $Kd_{PAR\Delta d}$ of the different depth intervals at each station.

The second method of estimating each station's Kd_{PAR} was based on Cardona-Maldonado (2008), using the regression of ln(E_z) vs depth based on:

ln(E_z)= ln(E_0) - Kd_{PAR} x d; (equation 2)

where:
E_z is PAR at depth (d=meters),
E_0 is E_z when d is just beneath the water surface,
Kd_{PAR} is the attenuation coefficient of PAR.

Results and Discussion

A summary of all water quality variables per stations are presented in Table 2. The average standard errors of PAR, temperature, salinity, pH, DO and turbidity, in their respective units, were 32, 0.004, 0.009, 0.0003, 0.0035 and 0.031, respectively.

Table 2. Summary of water quality data collected at Stations 1-6 from September to December 2011.

Station	Date (dd-mm-yy)	Temp (deg C)	Sal PSU	pH unitless	ODO mg/L	Turbidity NTU	AVERAGE KPAR (1/m)	Kpar Slope (1/m)	Secchi depth (m)
1	16-Sep-11	29.80	31.60	8.14	6.50	1.1	0.48	0.48	2.50
1	18-Oct-11	29.68	33.59	8.18	6.19	1.0	0.33	0.51	4.50
1	18-Nov-11	29.06	34.16	8.13	6.01	1.7	0.26	0.33	3.50
1	27-Dec-11	27.74	36.02	8.26	7.01	1.1	0.78	0.70	2.00
2	16-Sep-11	30.09	30.94	8.14	6.66	1.6	0.62	0.62	2.25

Table 2. Summary of water quality data collected at Stations 1-6 from September to December 2011.

2	18-Oct-11	29.56	33.48	8.15	6.11	1.0	0.38	0.37	3.00
2	18-Nov-11	28.87	33.10	8.13	6.16	2.0	0.50	0.49	2.00
2	27-Dec-11	27.18	36.46	8.23	6.70	4.3	0.75	0.72	1.50
3	16-Sep-11	29.89	31.88	8.15	6.70	0.5	0.44	0.43	3.75
3	18-Oct-11	29.73	32.83	8.16	6.13	1.3	0.40	0.38	3.75
3	18-Nov-11	28.89	33.59	8.14	6.39	0.7	0.38	0.38	4.00
3	27-Dec-11	27.35	36.29	8.23	6.31	0.3	0.31	0.27	5.50
4	16-Sep-11	29.78	32.03	8.14	6.20	1.8	0.52	0.53	2.00
4	18-Oct-11	29.89	33.25	8.16	5.87	0.5	0.17	0.10	5.00
4	18-Nov-11	29.63	34.33	8.13	6.05	0.5	0.25	0.24	5.00
4	27-Dec-11	27.57	35.51	8.22	6.42	-0.1	0.36	0.44	5.00
5	16-Sep-11	30.05	31.58	8.19	7.52	0.4	0.32	0.32	3.50
5	18-Oct-11	29.85	33.26	8.20	7.27	0.3	0.26	0.26	5.00
5	18-Nov-11	29.08	34.71	8.18	7.08	0.4	0.26	0.26	8.50
5	27-Dec-11	27.13	36.54	8.23	6.53	3.2	0.30	0.31	5.75
6	16-Sep-11	29.67	32.22	8.15	6.44	0.2	0.36	0.31	4.50
6	18-Oct-11	29.89	33.42	8.16	6.22	0.2	0.13	0.15	9.50
6	18-Nov-11	29.38	34.36	8.14	6.25	0.4	0.21	0.17	9.50
6	27-Dec-11	27.55	36.22	8.23	6.36	-0.5	0.14	0.10	10.00

Optical Quality of Water

Secchi depth, which is inversely proportional to light penetration, ranged from 1.5 to 10m throughout the sampling area. Overall, the lowest values were associated with Station 2 (Intake Station) followed by Station 1 (Outfall or Discharge Station), which showed the least fluctuations among sampling dates (FIG. 2). In average, the remaining Stations displayed Secchi depths higher than the previous stations. Temporally, the lowest Secchi depths were observed

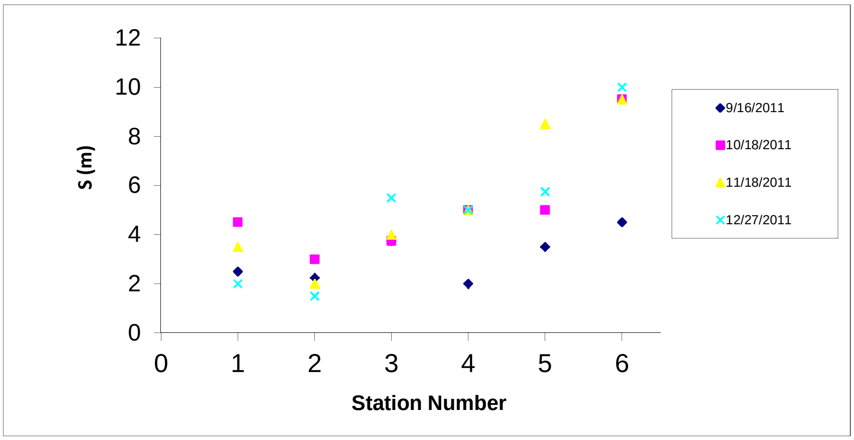

Figure 2. Secchi depth at the different stations during four sampling events in Guayanilla and Tallaboa Bays.

at Stations 3-6 in September 2011,andat Stations 1 and 2 in December 2011. This pattern was probably due to a combination of rain events and wind induced re-suspension of bottom sediments.

As expected, estimates of $Kd_{PAR\Delta d}$ showed an inversely proportional behavior to Secchi depth (the higher $Kd_{PAR\Delta d}$, the lower Secchi depth) as evidenced in (FIG 3). A significant inverse correlation at P<0.05 was found between these variables (FIG 4).

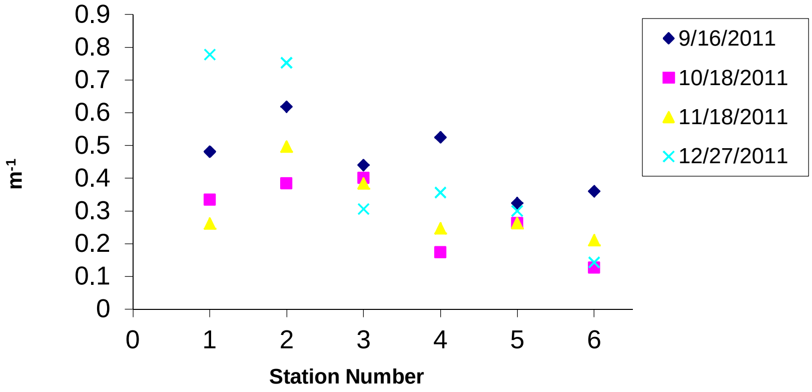

Figure 3. Distribution of $Kd_{PAR\Delta d}$ at stations examined in Guayanilla and Tallaboa Bay

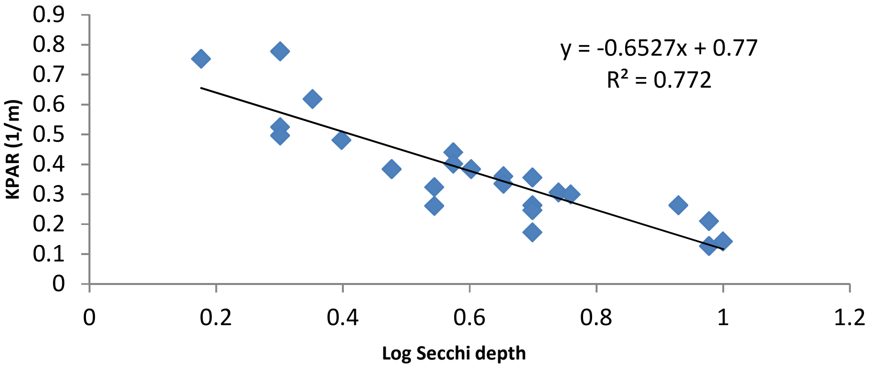

Figure 4. Regression of K_{PAR} vs log Secchi at stations located in Guayanilla and Tallaboa Bays.

A comparison between both methods of estimating K_{PAR} demonstrated to be equivalent, attaining also a significant correlation (r= 0.95, n=24, P<0.05).

We calculated the Ecological Compensation Depth (ECD) for *Thalassia testudinum* (Turtle Grass), that is, the depth at which production and respiration is balanced for this representative important specie (RIS). The estimates of K_{PAR} from this work and a value of 16% below surface PAR were used for this purpose based on previous studies conducted in Tampa Bay, Florida (Dixon, 1999). Our results indicate that in average the ECDs at Stations 1 through 6 were 4.7, 3.5, 4.9, 6.7, 6.4, 10.3m, respectively. Observations of the seagrass conditions at Stations 1 and 2 suggest that light attenuation and depth at these sites contribute to the observed abundance of seagrasses in the vicinity of the EcoElectrica Pier, that is, deeper sites show different growth characteristics (i.e. sites shallower than 2m show healthier coverage than sites approaching depths of 4-5m.

Turbidity, one of the variables evaluated by the Puerto Rico Environmental Quality Board, was 98% of the time below 2 NTU. In two occasions values reached an average of 3.2 and 4.3 NTU at Stations 2 and 5 during the 27 December sampling event (FIG 5). The higher levels of turbidity observed at these two stations, during December, were probably related to shifts in the wind pattern that increased sediment resuspension in nearby shallow areas associated to Stations 2 and 5. However, all turbidity levels are lower than the present water quality standards applied in Puerto Rico (≤10NTU, for 'Class SC' waters). However, it is important to realize that levels of turbidity of as low as 1-2 NTU may constitute a significant impairment in water clarity (quality) that may affect benthic species in coral reef associated habitats as evidenced by previous work conducted by Otero and Carbery (2005) and Otero (2009).

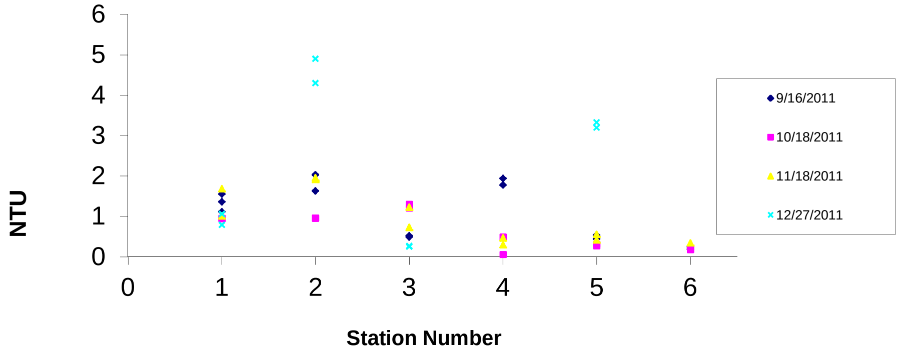

Figure 5. Distribution of turbidity at stations of Guayanilla and Tallaboa Bay

A comparison of Secchi and K_{PAR} vs the turbidity values was conducted for all stations. Regression results indicated a significant covariation of K_{PAR} and Secchi values with an R of approximately 0.6. The covariation of turbidity and K_{PAR} became slightly better when excluding the two extreme turbidity values mentioned above, while it increased strongly for Log (Secchi depth) and Turbidity with a R= 0.80 (FIG 6).

In summary, all optical measurements conducted (Secchi depth, PAR profiles and Turbidity) covary persistently. This may allow for the intercalibration of these variables, thus providing the opportunity to estimate some of these using measurements of one of the optical variables. Further data should be collected to derive stronger regressions that will allow simplification of future monitoring efforts and the more efficient use of resources without diminishing the value of the collected data. All three optical water quality indicators suggest that water clarity at the Outflow Station was higher or very similar to that of the Intake Station, thus supporting the notion of lack of significant effect of EcoElectrica's outflow on the bulk optical quality of the receiving waters.

Other Water Quality Variables

Figure 7 shows the temporal change of temperature, salinity, pH and dissolved oxygen in waters of the different stations. Temperature shows a uniform inter-station level. The major variation observed is consistent with the general regional pattern observed as a cooling effect from temperatures between 29-30 deg C in early autumn to temperatures of 27-28 deg C in early winter. The largest temperature difference between the Outflow and the Inflow Stations was observed during December (ca. 0.5 deg C). A smaller difference was observed between the Outer Shelf Station (#6), which represents more closely regional patterns as is not influenced as much by inner bay variability, thus suggesting that the differences observed do not depart significantly from the normal regional pattern in southern PR. At no time, measurements of water temperature within the plume of the outfall exceeded those allowed by PREQB for Class SC waters.

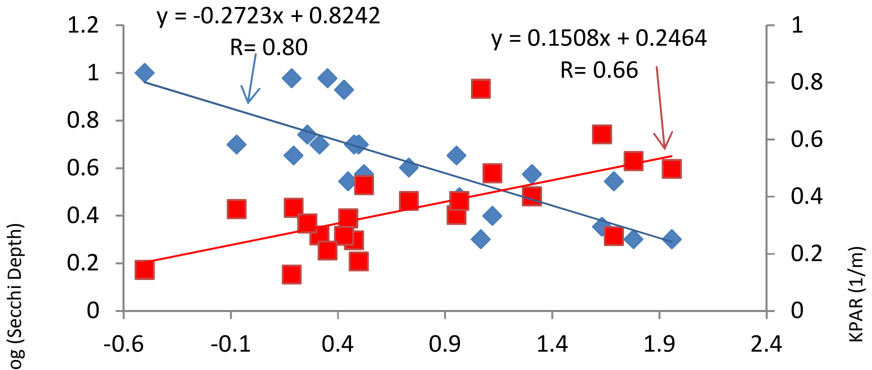

Figure 6. Regression of Turbidity with the log transformed Secchi depth (light blue) and $Kd_{PAR\Delta d}$ (red).

The pattern observed in salinity levels was opposite to that of temperature. There were only slight differences of salinity with depth at each station. The largest of these differences was observed at Station 2 during September. This was probably due to the influence of rains, which occurred during the days previous to sampling as recorded by a nearby USGS weather station ((http://waterdata.usgs.gov/nwis/dv?cb_00060=on&format=html&begin_date=2011-09-01&end_date=2011-12-31&site_no=50124200&referred_module=sw ; downloaded on 21 March 2012).

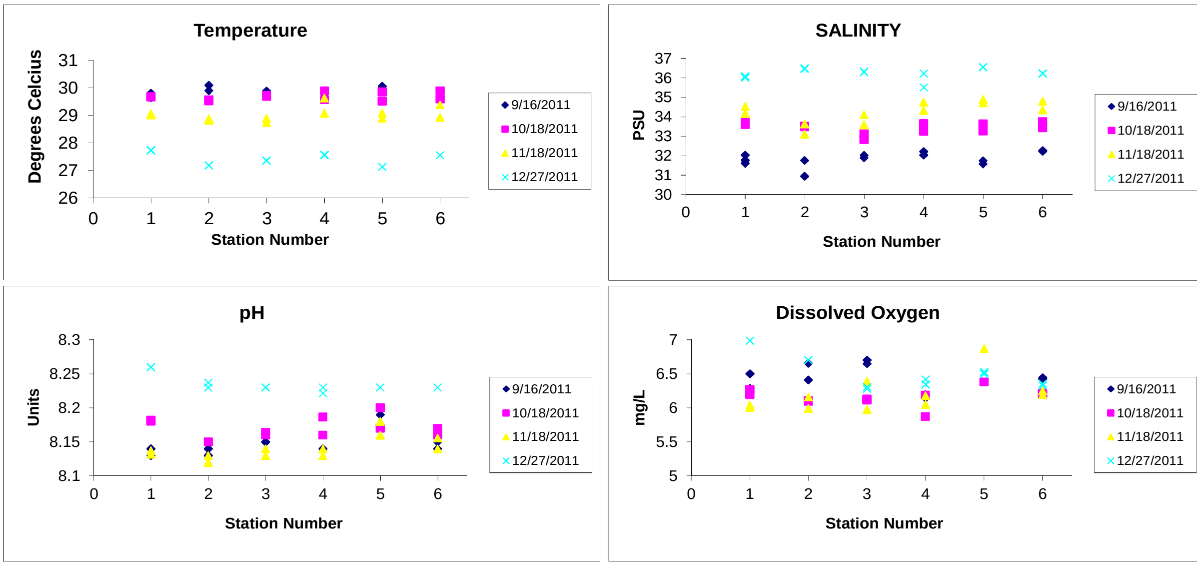

Figure 7. Temporal variation of temperature, salinity, pH and dissolved oxygen at the 6 stations monitored by EcoElectrica, LP.

These rain events induced the intrusion of freshwater via the Tallaboa River towards the east of Station 2. A similar intra-station variation was observed at Station 4 in December. As for temperature, the largest variation in salinity was temporal and reflected a generalized increased in salinity, which responded to a decrease in rain activity towards the end of the year. The preliminary river discharge data from the Guayanilla USGS station mentioned earlier, used here as a proxy of pluviosity in the area, shows that the total river discharge during the 4 days previous to each sampling date was approximately 383 (September), 84 (October), 85 (November) and 40 (December) millions of gallons per day (MGD's), confirming the decreased effect of freshwater intrusion on salinity.

The pH observed at the stations also showed a significant temporal pattern within a minimal spatial one. It is well established that pH changes according to bethic and planktonic primary production following a clear diel and seasonal pattern (Frankignoulle and Bouquegneau, 1990). The heterogenous nature of the seascape at Guayanilla/Tallaboa Bay is probably responsible for the observed patterns. These shallow marine systems count with substantial coverage of benthic primary producers and abundant phytoplanktonthat may modulate pH spatial fluctuation to an unknown degree. Most importantly, the pH values are within the natural range of 8.1 and 8.25. The range of pH changes observed during this work is within those observed earlier by Pelejero et al (2005) at decadal scales. Overall, there is no consistent pattern that indicates that the pH level within the outfall area is being affected by EcoEelctrica's operation. At no time, the pH observed exceeded the range of values accepted by PREQB (7.3-8.5) Class SC waters.

The average DO ranged from 5.9-7.5 mg/L. The largest temporal fluctuation was observed at Station 1 (Outflow), with levels similar to those of Station 2 (Inflow). The lowest concentration was measured at Station 4, the station located in the westward portion of Tallaboa Bay, to the southeast of Station 2. The DO was well over the accepted limit established by PREQB for Class SB coastal waters (5 mg/L).

Conclusions

Turbidity, DO, pH and temperature were all within the limits allowed by the Puerto Rico Environmental Quality Board for Class SC waters, or even more strict limits such as Class SB waters. None of these variables were outside the established guidelines.

The variability observed for those variables were well within the expected natural variability, whereas seasonal or associated to natural phenomena such as river discharge.

Measurements of light penetration in these waters by two different means are in good agreement between each other and the water quality variable of turbidity. Good statistical relationships were derived among these variables, but further work should be conducted in order to examine the robustness of these relationships and, thus, be able to modify future sampling plans towards a more efficient and cost effective analysis.

Estimates of light attenuation coefficient suggest that the distribution of the present seagrass beds is tightly regulated by light availability at the depths surrounding EcoElectrica facilities.

The present results should be incorporated in the future as part of a time series record in order to establish a long term status of the environment surrounding EcoElectrica's operation, which will help during evaluation by regulatory agencies.

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