Impingement and Entrainment by EcoEléctrica LNG Power Plant, Guayanilla, Puerto Rico: December 2011.

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By

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Introduction

The average daily flow of water at the intake of EcoElectrica's cooling water system was close to 53,000 m^3 or 14MGD (Based on EcoElectrica's 2011 hourly flow data provided by E. Banch). Considering a simple closed system, this flow would use a volume of water within a radius of 167m (548ft) of the intake to a depth of 6m. This radius includes seagrass and reef habitats considered of value for many marine species including some of intrinsic commercial value. The adverse impacts of the of cooling water intake systems are considered in the Clean Water Act section 316(b) and are divided into two main components, impingement and entrapment.

Impingement have been defined as the trapping of aquatic organisms against exclusion screens of cooling water intake systems (CWIS) as water flows into facilities resulting in mortality by various reasons including improper gill function, exhaustion, starvation and injuries (71 Fed. Reg. 116, 16 Jun 2006). As stated earlier by Vicente (2001 and 2008), the design of EcoElectrica intake facilities minimizes the speed at the water intake using a 3 x 36 inch diameter T-shaped wedge wire screens mounted horizontally which renders the speed of water to about <1ft/s . Previous observations have not found fish species impinged upon the CWIS screens.

Entrainment is the other important factor that facilities affect marine life that is associated to CWIS of power generation facilities. As organisms are pulled into the cooling system a diversity of factors increase their mortality either during transit or after exiting the power plant facilities as part of the outfall (71 Fed. Reg. 116, 16 Jun 2006). These effects are associated to mechanical, thermal and chemical factors associated to the operation of the cooling system which usually results in significant mortality of the organisms associated with the volume of water. These organisms are usually of minute size, mostly considered part of the planktonic community, including organisms supporting ecosystem production and fish and shellfish populations either as food sources or as larval recruits.

Purpose

- To present recent observations on impingement and entrainment based on visual observations on fish species surrounding the existing intake structures and on plankton collections.

- To compare the present results with previous efforts

Methods

Study Area

The study area is located in the interface of Guayanilla and Tallaboa Bay in southern Puerto Rico. Water samples were collected in three sites associated to the operation of EcoElectrica. The sites examined were the intake, outfall and helper cooling tower (Fig. 1).

Figure 1. General location of study site in the interfase of Guayanilla and Tallaboa Bay. Sampling stations are indicated in the right.

Impingement

The evaluation of impingement was conducted during two dates and was based on visual observations by divers to confirm previous results discussed previously by Vicente and Associates which suggested no significant impingement by EcoElectrcia's intake system. The present observations were:

1. Video transects along the length of intake screen assemblages and fish species observations were conducted during 2 December 2011.
2. Observations of fish movement nearby intake screens using stand-alone video were conducted on 21 December 2011.

Video Transects of Intake Screens

A diver shot video at an angle recording the condition of the along the upper, lateral (southeastern) and lower surface of the intake screens. The videos were recorded in two directions (eastward and westward). Observations of impingement were recorded on an arm-slate and recording and video/photos were taken of the observation.

Fish Species Observations

Two divers surveyed and identified fish species adjacent or near the intake cement structure as a measure of fish species exposed to impingement. Visibility was poor due to natural environmental conditions, which did not allow for the collection of good video/photography. However, visual documentation was feasible and recorded on arm-slates.

Stand Alone Video to Detect Fish Movement

A high definition camera was installed at about 10 ft looking at an angle and upwards to the space between the intake screen and the seawater intake pump building. The angle of the camera selected as to maximize the optical depth of field and pointing towards the location of the highest fish aggregation observed at the time. The camera was programmed to take photos at a 5 second interval. A time lapse video was reconstructed from 10:50 to 2:45PM.

Entrainment

Sampling

The data to calculate entrainment uses a series of estimates of zooplankton and phytoplankton species. Plankton abundance estimates at both the intake and outfall sites were used to evaluate effects of the CWS on plankton species. To avoid the potential mixing of plankton from the environment with those present in the outfall and thus biasing the possible estimates of entrainment, samples for plankton analysis were collected from the closest access point prior to the discharge of cooling water into coastal waters (Fig. 2). That access point was identified at the exit of the helper cooling tower and is here thereafter as the HCT station. The access point consisted of a 7.6 cm flexible pipe outflowing from the larger pipes feeding water to the helper cooling tower from the main cooling tower. The flow rate out of the pipe was estimated to be 292L/minute by determining the time needed to fill a volume of 146L in a fiberglass cylinder.

Figure 2. Plankton sampling at the Helper Cooling Tower Station

Sampling at the above sites was conducted at different times to evaluate how plankton numbers changes over time and to some idea of temporal variability in these counts. Samples were collected as most as possible at times before or near sunset and afterwards. The exact time of sampling was dictated by field conditions (i.e. clogging of nets, sampling activities between stations).

Phytoplankton Sampling and Counts

A 15L Shindler-Patalis sampling apparatus (SPSA), fitted with a 20µm side net was lowered to 1m at the Intake and Outfall stations on board of a 25ft Whaler and used to concentrate phytoplankton to a final volume of 100-150mL (Otero 2007). Samples collected at the HCT station were collected by passing 15L collected from the access point described above using the same type of net coupled to the SPSA. The phytoplankton concentrates were transferred to polypropylene bottles by adding seawater buffered formalin to a final concentration of ca. 5%. Samples were kept in a cooler and transported to the laboratory after sampling.

Examination of phytoplankton species was conducted using an inverted microscope equipped with phase contrast and digital camera and a Sedgewik Rafter. A collection of photos was archived to be used as reference. Identification of phytoplankton was conducted based on Tomas (1997).

Zooplankton Sampling and Counts

Samples were collected using a standard conical 0.5m i.d. and 2m long with 202µm mesh plankton net and a calibrated flow meter. Plankton tows were conducted at each station at an approximate depth of 1-2m to collect plankton from a minimum of 15m^3. At the outfall station, the net was kept as much as possible within the plume of the diffuser. Samples were collected at the HCT by passing the total water flow from the HCT access point through the same type of plankton net which was kept suspended and submerged in the HCT pool using wooden frame (Fig 2). Samples were fixed with buffered formalin (in seawater) to a final concentration of 5% immediately after retrieval of net in wide-mouth jars.

Mean average zooplankton and ichthyoplankton abundance was estimated from two subsamples drawn with a Stemple pipette and counted under a dissecting microscope. The following zooplankton groups (among others) were counted as described previously (Vicente, 2008):

- Holoplankton (Calanoid, Cyclopoid and Harpacticoid Copepods; Chaetognatids, Larvaceans, Amphipods, Sergestoid Shrimps, Forams, and Cumaceans).
- Meroplakton (Decapod Larvae; Veliger Larvae, Cirriped Larvae, Medusae, Fish Larvae)

Final numbers of individuals per m^3 were calculated as follows:

(Average # Individuals counted in two subsamples) X (DF)/FV

Where:
DF = the laboratory dilution factor
FV = Volume filtered in the field= [3.14 X (Net Diameter)^2 (X) Distance]/4
Distance (m)
Net Diameter (m)

Entrainment Estimates

Both phytoplankton and zooplankton species were used to assess entrainment effects on different trophic levels. Planktonic species were conducted as changes in these populations affect different trophic levels. Different estimates of entrainment were conducted using plankton counts from samples collected at the intake, outfall and HCT sites. Three estimates of entrainment were done assuming different mortalities to have a range of potential values:

a. all planktonic species present at the intake station are suffer 100% mortality by the CWIS (M_{in});
b. mortality calculated as the difference between the outfall and inflow planktonic species (M_{io}) is representative of CSIW effects;
c. mortality calculated as the difference of plankton populations between Intake and HCT (M_{HCT}) samples is representative of CSW effects.

Using the above estimates (M_{ni}, Mio and M_{HCT}), entrainment will be calculated as:

$E = C \times Q \times M$
Where:
E = entrainment in cells per unit time;
C = ind per unit volume at the intake;
Q = CWIS flow rate in unit volume per unit time;
M = estimated mortality for entrained species as described above.

Results

Impingement

Video Transects

As indicated by video and photographs (Figure 3) the exclusion screens were minimally biofouled during the observations. The accumulated material was mostly small pieces of brown algae (*Dyctiota* sp) and pieces of Turtle grass (*Thalassia testudinum*). One specimen of jelly fish (Cnidaria, Class Scyphozoa; *Aurelia* sp.) was the only impinged animal.

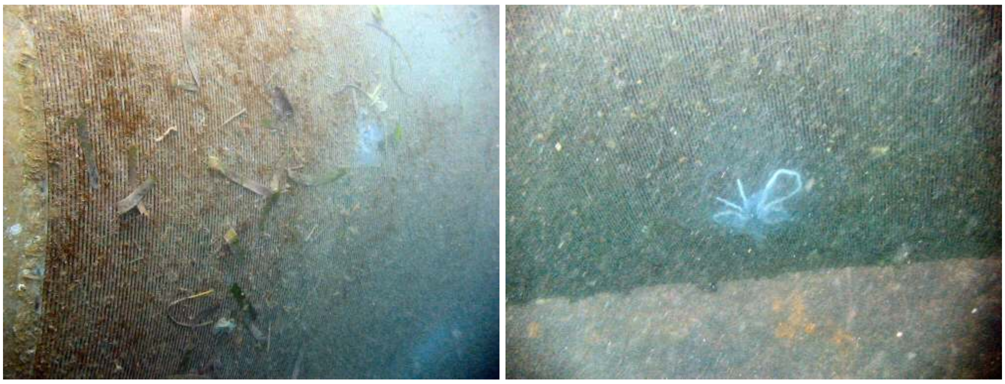


Figure 3. Impingement on exclusion screen of CWIS. Pieces of seagrasses (Left) and small numbers of jellyfishes (Right) were observed along natural growth of folamentous microalgae.

Fish Species Observations

The 17 fish species found close to or associated with the intake structure are indicated in Table 1. Many of these species were observed swimming intermittently beside the exclusion screens. There is a large variation of body size of the species observed several feet to a few inches, no impingement of any of these species was observed.

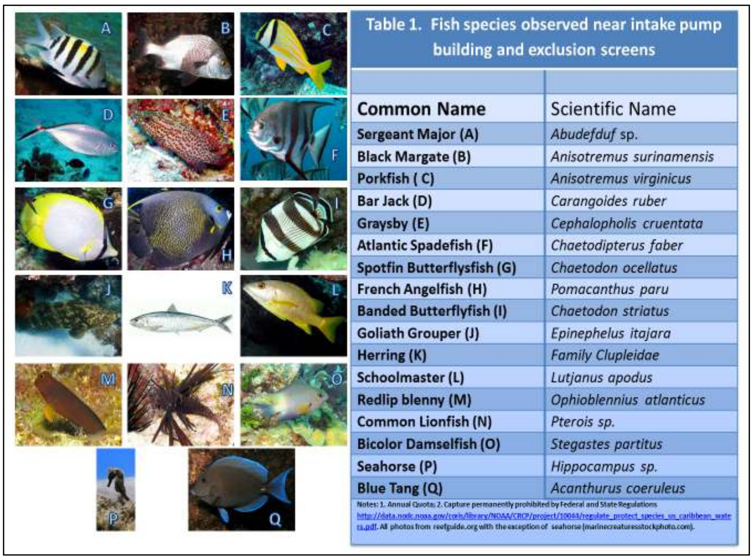


Table 1. Fish species observed near intake pump building and exclusion screens

Common Name	Scientific Name
Sergeant Major (A)	*Abudefduf* sp.
Black Margate (B)	*Anisotremus surinamensis*
Porkfish (C)	*Anisotremus virginicus*
Bar Jack (D)	*Carangoides ruber*
Graysby (E)	*Cephalopholis cruentata*
Atlantic Spadefish (F)	*Chaetodipterus faber*
Spotfin Butterflysfish (G)	*Chaetodon ocellatus*
French Angelfish (H)	*Pomacanthus paru*
Banded Butterflyfish (I)	*Chaetodon striatus*
Goliath Grouper (J)	*Epinephelus itajara*
Herring (K)	*Family Clupleidae*
Schoolmaster (L)	*Lutjanus apodus*
Redlip blenny (M)	*Ophioblennius atlanticus*
Common Lionfish (N)	*Pterois sp.*
Bicolor Damselfish (O)	*Stegastes partitus*
Seahorse (P)	*Hippocampus sp.*
Blue Tang (Q)	*Acanthurus coeruleus*

Notes: 1. Annual Quota; 2. Capture permanently prohibited by Federal and State Regulations http://data.nodc.noaa.gov/coris/library/NOAA/CRCP/project/10044/regulate_protect_species_us_caribbean_waters.pdf. All photos from reefguide.org with the exception of seahorse (marinecreaturesstockphoto.com).

Stand Alone Video to Detect Fish Movement

The photographs captured during the period of almost 4 hours (see method description) show fish swimming effortlessly at different distances from the exclusion screens. Some examples of the video images are shown in Fig 4). The complete set of photographs is available on a separate CD for reference.

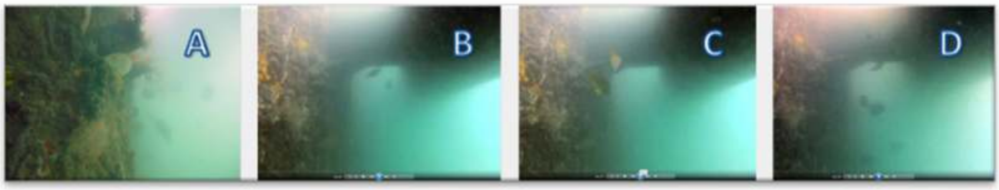


Figure 4. Pictures of fishes captured using a high density stand-alone camera. A. A Schoolmaster swimming along the bank of the pump house building. B, C, D are screen shots at different times of a compressed version of a time lapse movie that shows all the collection of photographs taken from 11:50AM to 2:45PM. The silhouettes of fishes can be observed at different distances from the exclusion screens.

Entrainment

Phytoplankton counts (Appendix 1)

During the study 28 and 14 and 1 genera of Diatoms, Dinoflagellates and Cyanobacteria were accounted for (Fig. 5). The average concentration of phytoplankton cells were 28,704, 23304 and 2409 ind L^{-1} at the intake, outfall and HTC station, respectively. The variability introduced by sampling time was examined by separating samples collected before or near sunset and those collected afterwards during the night. T-test analysis for intake, outfall and HCT stations indicated no significant difference among times of sampling ($P > 0.8$, $N=3$; Appendix 2). The dominant genera. *Chaetoceros,* a chain forming form of diatom, accounted for ca. 80% of all phytoplankton at the Intake and Outfall stations while ca. 40% in the HCT (Fig. 5). Within the Dinoflagellates, *Protoperidinum sp*. was the most abundant being 1.5-4.9% off all the phytoplankton (Fig. 5). Statistical analysis for these two Genera did not show significance differences between sampling periods (day vs. night). Thus all samples were pooled for further analysis. Multiple comparison Analysis of Variance (M-ANOVA) on total numbers showed significance difference only between HCT and the other two stations (Appendix 3), representing a 90-92% reduction of phytoplankton abundance relative to the outfall or intake station. Overall these results indicate a significant effect on phytoplankton populations by EcoElectrica's CWIS which is not discernible at the outfall station due to mixing of outfall waters with background coastal waters.

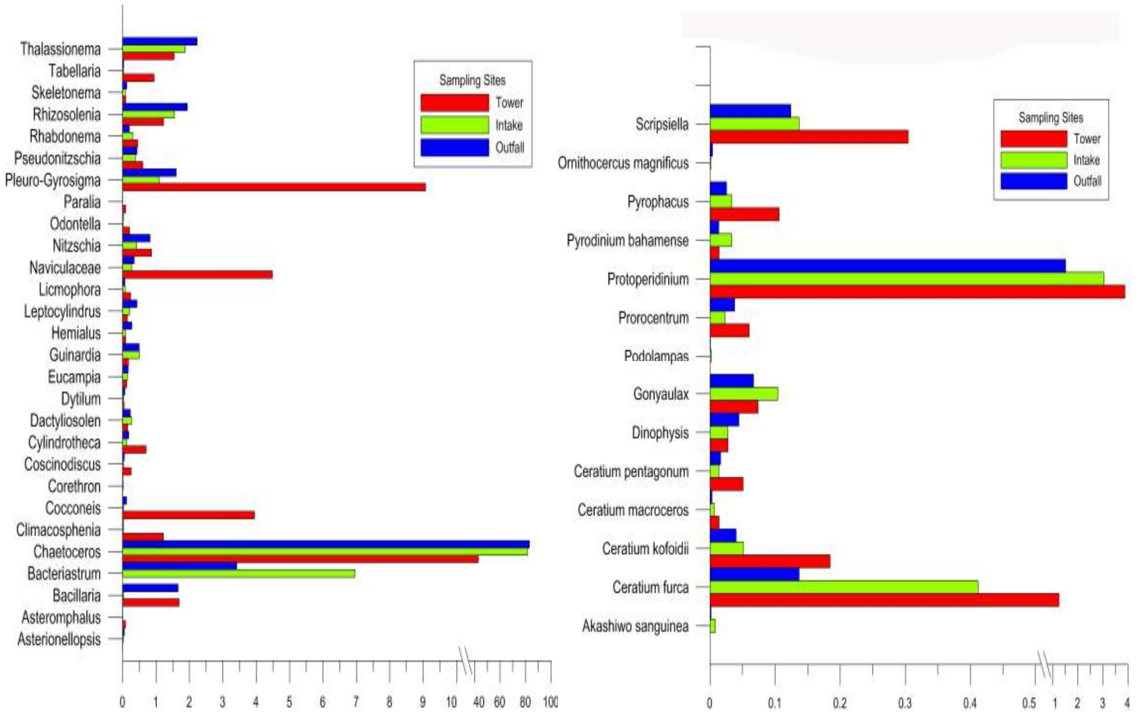


Figure 5. Percent Diatoms (Top) and Dinoflagellates (Bottom) within the total phytoplankton community examined at different stations during 15 December 20011.

Zooplankton Abundance and Taxonomic composition (Appendix 4)

Collection of zooplankton samples took approximately 20-30 minutes at the outfall and intake stations per sample due to net clogging caused by water particles, including phytoplankton. At the HCT stations samples took from 1-1.7 hrs due to flow conditions. Other than for these operational differences, samples are considered representative of sampling of sampling stations and representing the natural fluctuations of the system.

The average abundance of zooplankton was 6781, 3955 and 23 ind/m^3 at the intake, outfall and HCT sites (Fig 6). A M-ANOVA (Appendix 5) did not found significant differences between the intake and outfall zooplankton abundances. This was probably due to large variability found in replicate samples most probably due to sampling conditions (and patchiness). As expected based on the phytoplankton data (see above) the HCT abundances were significantly lower.

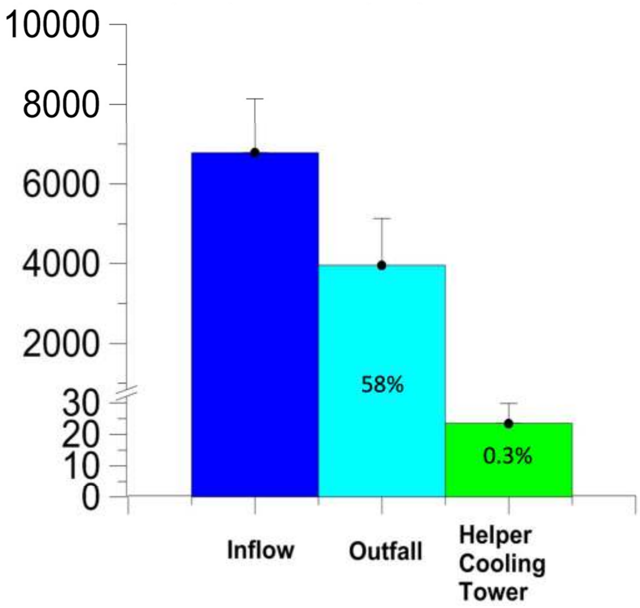


Figure 6. Average zooplankton abundance at the three sampling stations. Bars represent 1 standard error. The y-axis has been broken to help with the visualization of Helper Cooling Tower results. Numbers on bars represent percentage of zooplankton abundance relative to the Inflow station.

The relative composition of zooplankton is shown in Table 2. The total of zooplankton groups identified was 23, 25 and 19 at the Intake, outfall and HTC. The Intake and Outfall stations contained a similar fraction of holoplankton (ca. 70% of the total) while at the HTC was proportionally similar to the meroplankton (ca. 50%). Holoplankton was numerically dominated by Calanoid copepods at the Intake and Outfall stations, representing 42 % and 48% of the total zooplankton, respectively. Other numerically important compoenents of the holoplnakton at the Intake and Outfall stations were Cyclopoid and Harpacticoid copepods, and Larvaceans (Class Appendicularia) . Sergestoid shrimps, Foraminiferans and Chaetognath worms were also present, but represented a small fraction (< 7% and 5%) of total zooplankton. In contrast, Calanoid copepods represented only 3.1% of theb total plankton collected at the HTC station while Harpacticoid copepods were numerically dominant (23%). Foraminiferans, Calanoid and Cyclopoid copepods, and Amphipods followed in abundance at the HTC station. Other organisms such as Pycnogonids, Isopods, Cumaceans and Sergestoid shrimps were also present, but represented a small fraction (< 2 %) of total the holoplankton at the HTC station.

Table 2. Summary of major groups of zooplankton found at three locations associated to EcoElectrica's operation.

			Holoplankton		**Meroplankton**	
Station	**Number of Groups**	**Average Zooplankton Abundance (m^{-3})**	**Major Group**	**% Major Group**	**Major Group**	**% Major Group**
Intake	23	6781	Amphipods	0	barnacle larvae	16.0
			Calanoid copepods	42	crabs larvae (Brachyura and Anomura)	0.8
			Chaetognaths	0.7	decapod eggs	1.3
			Cumaceans	2.8	fish eggs	2.7
			Cyclopoid copepods	11	fish larvae	0.1
			Foraminiferans	3	mollusk (veliger)	2.8
			Harpacticoid copepods	7	polychaete	0.9
			Isopods	3.75	shrimps (Caridea and Penaeoidea)	2.4
			Larvaceans (Appendicularia)	5	Tanaidaceans	0.0
			Pycnogonids	0.0		
			Sergestoid shrimps	3		
Outfall	25	3955	Amphipods	0.0	barnacle larvae	11.4
			Calanoid copepods	48.0	crabs larvae(Brachyura and Anomura)	3.4
			Chaetognaths	1.8	decapod eggs	3.9
			Cumaceans	0.0	fish eggs	3.4
			Cyclopoid copepods	9.5	fish larvae	0.1
			Foraminiferans	1.6	mollusk (veliger)	4.4
			Harpacticoid copepods	3.0	polychaete	0.2
			Isopods	1.4	Shrimps (Caridea and Penaeoidea)	1.0
			Larvaceans (Appendicularia)	4.2	Tanaidaceans	0.0
			Pycnogonids	0.0		
			Sergestoid shrimps	2.6		
Helper Cooling Tower	19	23	Amphipods	1.6	barnacle larvae	20.5
			Calanoid copepods	3.1	crabs larvae(Brachyura and Anomura)	1.1
			Chaetognaths	0.0	decapod eggs	1.6
			Cumaceans	0.0	fish eggs	1.8
			Cyclopoid copepods	0.8	fish larvae	0.0
			Foraminiferans	16.2	mollusk (veliger)	22.0
			Harpacticoid copepods	23.1	polychaete	2.0
			Isopods	0.1	shrimps (Caridea and Penaeoidea)	0.1
			Larvaceans (Appendicularia)	0.0	Tanaidaceans	4.0
			Pycnogonids	0.2		
			Sergestoid shrimps	0.1		

The meroplankton, composed by larval forms of invertebrates and fish, accounted for 27%, 28% and 54% of total zooplankton at the Intake, Outfall and HTC stations. Barnacle (cirriped) larvae were the most abundant component at the Intake and Outfall, representing 16% and 11% of the zooplankton. Fish eggs followed in relative abundance at the Intake station while larval mollusks (veligers) at the Outfall. Other components of the invertebrate meroplankton assemblage included Decapod eggs, crabs (Brachyura, Anomura), polychaete worms, and shrimps (including representatives of the Sections Caridea and Penaeoidea; Table 2). Larval stages of mollusks (veliger larvae) and Barnacle (cirriped) larvae were the most abundant components at the HTC station, representing 80 % of the total meroplankton. Tanaidaceans followed in relative abundance. Other meroplanktonic organisms such as Polychaete worms, crabs (Brachyura and Anomura), shrimps (including representatives of the Sections Caridea and Penaeoidea), fish eggs and decapod eggs were also present, but represented a small fraction (< 7 %) of total the meroplankton assemblage.

The ichthyoplankton component at the Intake, comprised by fish eggs and fish larvae, presented a combined abundance of 194.63 Ind/m^3, representing 2.9 % of the total zooplankton. Abundance of fish eggs averaged 189.13 Ind/ m^3, while larval fishes averaged 5.5 Ind/ m^3. Larval fishes were unidentifiable, un-pigmented, early pre-flexion yolk-sac and pre-flexion larvae. At the Outfall, ichthyoplankton was comprised by fish eggs and fish larvae, with a combined abundance of 145.49 Ind/m^3, representing 3.69 % of the total zooplankton.

Abundance of round fish eggs averaged 126.6 Ind/ m^3 and oval fish eggs 7.99 Ind/ m^3, while larval fishes averaged 10.9 Ind/ m^3. Larval fish assemblage was composed by 0.14 % unidentifiable, un-pigmented, early pre-flexion yolk-sac and pre-flexion larvae; another 0.14 % was composed of post-flexion of Serranids, Gobids and Leptocephalii (Anguiliformes) larval fishes. The ichthyoplankton component was very low at the HCT station, and was comprised of round fish eggs and fish larvae, with a combined abundance of 1.06 Ind/m^3, representing 1.8 % of the total zooplankton. Abundance of round fish eggs averaged 1.03 Ind/ m^3, while larval fishes averaged 0.03 Ind/m^3 accounting for a 0.06 % of the total zooplankton; those were unidentifiable, un-pigmented, early pre-flexion yolk-sac and pre-flexion larvae (Table 2).

Entrainment Calculations

Hourly flow measurements through CWIS were provided by EcoElectrica and used to calculate daily, monthly and yearly flows (Table 3). The average yearly flow of 19.24 million m^3 was used during entrainment calculations during the present work. Entrainment estimates for phytoplankton and zooplankton based on M_{in}, M_{HCT} and M_{io} are shown on Table 4.

Table 3. 2011 Intake Flows at EcoElectrica LP Power Plant

Flow	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Mean
million m^3/mo	1.5	1.5	1.5	1.6	1.7	1.5	1.6	1.6	1.7	1.6	1.6	1.6	1.6
thousand m^3/d	49.1	48.7	51.5	54.5	55.0	51.2	52.5	51.8	56.2	54.1	53.9	53.7	52.7
million gal/mo	389.3	385.8	408.2	432.3	436.3	406.2	416.2	410.4	445.6	428.8	426.9	426.0	417.7

Table 4. Entrainment Estimates based on 2011 plankton abundance estimates based on a CWIS flow (Q) of 19.24 million m3/yr .

Type of Organisms	Mortality rate (%)	M (ind/m3)	E (billions per year)	E (millions per day)	Notes[1]
Zooplankton	41.7	2,826	54.376	148.976	M_{io}
	99.7	6,758	130.034	356.257	M_{HCT}
	100	6,781	130.476	357.469	M_{in}
Phytoplankton	18.8	5,400,000	103,904	284668	M_{io}
	91.6	26,295,000	505,954	1386175	MHCT
	100	28,704,000	552,307	1513169	M_{in}
Fish Eggs	41.7	76	1.467	4.020	M_{io}
	99.7	182	3.509	9.614	MHCT
	100	183	3.521	9.647	M_{in}
Fish Larvae	41.7	3	0.055	0.149	M_{io}
	99.7	7	0.130	0.357	MHCT
	100	7	0.131	0.358	M_{in}

1: M_{io}, M_{HCT}, and M_{in} are defined in the Methods section.

Discussion

Impingement

A previous report (Vicente and Associates, 2008) has indicated nonexistent impingement impacts on adult fish communities. The present observations of impingement verify those findings. Only small fragments of seagrasses and jellyfishes carried into the immediacies of the CWIS were also observed on the screens. The time lapse photography verified the improbability of impingement of fish species on CWIS screens. During the time-lapse photography video, various species of fishes were observed swimming freely close and even feeding on the exclusion screen This observation is significant and attest the very low intake velocities (<<1ft per second), which were actually imperceptible to divers during fieldwork.

Phytoplankton Abundance

Previous work conducted during September 2002 and November 2007 by Otero (2002 and 2007) related to EcoElectrica Biological Monitoring Program Plan suggests the presence of significant spatial and temporal variations in phytoplankton abundance and composition. The work of September 2002 found average phytoplankton abundances of 52,033, 39,056 and 31,349 at the intake, outfall and a reference station to the south. The abundances at the same stations during 2007 were 17-30X lower than those of 2002. Total phytoplankton abundance during the present study was ca. 2 and 1.7X lower than those reported during 2002 at the intake and outfall stations. Other dissimilarities can be observed in the composition of the phytoplankton communities. During 2002 47% of all phytoplankton consisted of *Thalasionema*, Naviculaceae and *Protoperidinium* species. During 2007, 67% of the community was accounted for by *Guinardia*, *Pseudonitzchia* and *Chaetoceros* . In contrast, the current study indicates that *Chaetoceros* represented 82% of the total abundance.

Large scale fluctuations of phytoplankton abundances in tropical coastal systems are generally modulated by seasonal rains. Even though the southwestern area of PR is considered dry, the yearly fluctuation of pluviosity with a bimodal yearly distribution peaking during April-May and in Sept-November (See data for Guanica and Ponce at http://www.srh.noaa.gov/sju/?n=climo01). Otero (2007) suggested that the average pluviosity two months previous to sampling was proportional to phytoplankton abundance. Unfortunately, at present the connection of pluviosity with phytoplankton abundance cannot be corroborated as no USGS data is available for the 2011 sampling period. However, Otero (2012) reported on water quality at stations in Guayanilla Bay and indicates the intrusion of river water to areas associated to the intake station which may influence fertilization and modify the abundance and community composition of phytoplankton.

Zooplankton Abundance and Composition

During the baseline studies for the construction of EcoElectrica facilities, García et al (1995) studied the zooplankton community composition and reported fluctuations of 313-3595 ind/m3. García (2012) presented data for samples collected in 2002, 2004, 2005, 2006, 2007, 2008, 2009 and 2010 with total zooplankton numbers of 268-1,370 ind/m3. The zooplankton abundance reported in the present work for December 2011 was ca. 1.8-4.8 times the maximum abundances found in the previous works by García (2012) and García and collaborators (Table 4). A detailed look of the number of fish eggs reported in the above prior work for Guayanilla suggests a maximum number of larval fishes (Ichthyoplankton) of 61 Ind/m^3 , representing 1/3 of the numbers found during the present study at the intake station. This contrast may be due to temporal, spatial and diel factors differences between this and previous works. As for the phytoplankton, the abundance of zooplankton can be influenced by terrestrial inputs to coastal waters, which may increase the productivity of the microbial food web (including phytoplankton) thus providing increased food sources to zooplankton (Salonen and Hammar 1986; Bouillon et al, 2000). Increased pluviosity as evidenced by the increase in river input from the Guayanilla River a few days prior to sampling (Otero 2012) provided opportunity for coastal fertilization with a probable increased of plankton abundance. However, the effects of tidal and wind driven currents on the distribution of zooplankton are unknown at present. Also unknown are the effect of different sampling regimes on these comparisons including the inclusion of diel effects on plankton community abundance and composition (García, 2002).

As in the present study, the zooplankton community composition reported for Punta Guayanilla Bay by García et al (1995) was dominated by Calanoid copepods. However, the number of Calanoids was proportionally higher during the former study (74% of the total vs 42% at the intake during December 2011). In addition, consistently with previous studies two groups of the meroplankton, the barnacles and veliger larvaewere also dominant. This is not surprising due to the large number of mature representatives of these groups found in these shallow coastal areas that include *Balanus* sp and numerous mollusks species. Similarly to Vicente (2008), no larvae of lobster were found during this work.

Entrainment

The present work presents 3 calculations of entrainment based on different mortality estimates. The most conservative of the estimates of plankton mortality due to CSIW effects, $M_{io,}$ disregards mixing effects of outfall water with the background water resulting in 42 and 19 % mortality for zooplankton and phytoplankton based on total numbers (Table 4). In addition, to mixing effects, sampling of outfall derived water may be prone to additional biases depending on the type of sampling. For instance, although efforts were done to maintain plankton nets within the outfall plume, there is no means to account for the period of time the net was outside the plume due to boat navigation constraints.

This work also verified the assumption that mortality of plankton approaches 100% by evaluating the difference of plankton numbers at HCT against the intake. The results indicate 92%mortality for phytoplankton and ca. 100% for zooplankton. Thus the assumption of 100% mortality was verified as valid. This high mortality is caused by various factors including chemical treatments, pressure gradients and mechanical disruption (Bamber and Seaby, 2004).

A comparison of the present results indicate a significant increase of entrainment over estimates of past years (Table 5). That increase was defined mostly by the increase in zooplankton abundance during the December 2012 sampling.

Table 5. Comparison of Annual Entrainment and Equivalent Fish Loss from previous years (García, 2012) and the present work (in bold)

	Mean Flow	T. Zoo	T.Ichthyo	T. Zoo Entrainment	T.Ichthyo Entrainment	Eq. Fish Loss
Dates	**(m^3/d)**	**(Ind/m^3)**	**(Ind/m^3)**	**(x 10^6 Ind)**	**(x 10^6 Ind)**	**(x 10^6 Inds)**
Mar-02	44,914	593	4.3	5,628	240.9	6.9
Aug-04	47,242	268	0.72	5,273	14.2	0.5
Mar-05	45,134	479	6.4	7,499	100.1	1.4
Oct-05	28,921	803	4.84	8,360	50.4	0.9
Oct-06	50,340	435	1.54	7,987	28.5	0.5
Oct-07	49,810	277	1.38	5,031	25.1	0.3
Oct-08	54,389	1370	6.86	27,199	136.4	1.5
Oct-09	55,132	1050	4.82	17,986	95.8	2.4
Oct-10	55,131	1038	4.23	20,595	85.1	0.9
Dec-11	**52,697**	**6780**	**189.8**	**129,986**	**3,651**	**48.1**
Dec-11	**52,697**	**6780**	**189.8**	**130,409**	**3,652**	**48.3**

An analysis similar to that of García (2012) on the effects of entrainment of adult populations of fish was not conducted as the final conclusions would be similar. García's analysis is based on homogenous distribution of zooplankton, tidal volume (4.3X 10^6 m^3, and Guayanilla Bay volume (4.43 X 10^{7}m^3). That means that the proportion of the total volume of Guayanilla Bay and tidal exchange (based on García 2012) to the daily inflow of cooling water at EcoElectrica's facilities (for December 2011= 5.27X10^4 m^3) is 922. Thus, as a first approximation, the zooplankton entrained by EcoElectrica's CWIS should be in the order of 1/922 or 0.11% of the total zooplankton if zooplankton concentrations are considered spatially uniform. If spatial differences in zooplankton concentration are included in entrainment estimates such as those considered by Garcia's for 2010, the entreinmenmt estimate relative to the total zooplankton at the Bay increases only to 0.26%. Thus, using the volume of water used by the CWIS gives a good global estimate of the relative zooplankton entrainment within Guayanilla Bay.

The net effect of entrainment on adult fishes, assuming a 10% efficiency for each trophic step (egg to larvae and larvae to adult) and the same abundance of larvae at the intake and other sites of Guayanilla Bay, is in the order of 1/922 (0.11%) of the total adult fishes in Guayanilla Bay. That compares well with the estimates given by García (2012). However, in order to evaluate a maximum percent of adult fish mortality, an adhoc value of ½ the minimum ichthyoplankton abundance reported by Vicente (2008) was used as representative for Guayanilla Bay (larvae= 0.095; eggs=0.27 ind/m^3) while keeping the abundance observed during December 2011 as the zooplankton abundance at the intake (larvae=6.8; eggs=183 ind/m^3). Assuming as a first approximation a steady state, the total fish adult recruitment in Guayanilla Bay would be 17.7 x 10^6 individuals while the loss due to the CWIS of 1.3 x 10^5 individuals would represent a total loss of 0.73% of the total adult fish population. Therefore, the daily loss of plankton due to EcoElectrica's CWIS is estimated to be < 0.2% and the maximum fish adult loss, under maximum egg+larvae differences between the intake and overall Guayanilla Bay concentration is about 0.7% of the total adult fish population.

Conclusions

Previous studies consider the design of EcoElectirca's cooling water intake system (CWIS) efficient in avoiding damage to important components of the nekton and planktonic communities, which represent a substantial portion of the coastal richness within Guayanilla Tallaboa Bays ecosystems. The present work confirms that effects on the total numbers of these populations are minimal. Observations of adult fishes surrounding the CWIS indicates the presence of numerous numbers of various fish species and no impingement. Actually, photographic evidence appears to indicate that some of the fish species are capable to swim freely very close to the intake screen since flows are imperceptible to divers during the period of observation. Only a very limited number of pieces of seagrass and macroalgae leaves and a couple of jellyfishes were observed to be impinged during the present work.

As in other CWIS, planktonic organisms cannot avoid being mechanically impacted. Phytoplankton and zooplankton volumetric loss is about 90 and 99%, respectively. However, system wide impacts are estimated to range from 0.1-0.7%. The high water usage efficiency of EcoEléctrica (ca. 25MW/MGD) in comparison to other fossil fuel operated plants (ca. 2.5 MW/MGD) explains the minimal entrainment impact on plankton communities of Guayanilla Bay (USEPA 2009; Irizarry-Rivera 2012; Vicente and Associates, 2010).

References

Bamber, R.N. and R.M.H. Seaby. 2004. The effects of power stations entrainment passage on therr species of marine planktonic crustacean, Acartia tonsa (Copepoda), Crangon crango (Decapoda) and homarus hammarus (Decapoda). Mar. Environ. Res. 57: 2181-294.

Bouillon, S., Chandra Mohan, P., Sreenivas, N., Dehairs, F., 2000. Sources of suspended matter and selective feeding by zooplankton in an estuarine mangrove ecosystem, as traced by stable isotopes. Mar. Ecol. Prog. Ser. 208, 79–92.

García, J. R., E. Ojeda and A. González. 1995. Zooplankton/ichthyoplankton communities of Guayanilla and Tallaboa Bays: Taxonomic structure and spatial/temporal patterns. Report submitted to Gramatges and Associates. EcoEléctrica Power Plant Studies. San Juan, P. R. December, 1995. 91 p.

Garcia, J.R. 2012. Analysis of zooplankton entrainment by the EcoElectrica LNG Power Plant in Guayanilla Bay, P.R. during October, 2010. Submitted to EcoElectrica. March 2012.

Irizarry Riverra, A.A., Energía electrica en Puerto Rico: generación, transmisión y conservación. http://aceer.uprm.edu/pdfs/pres_airizarry.pdf (downloaded on 20 July 2012)

Otero, E. 2012. Variation of Water Quality Variables at Six Stations in Guayanilla Bay. Submitted to EcoElectrica, LP. March 2012.

Otero, E. 2007. Abundance and Phytoplankton Community Composition in Areas Associated to the Cooling Water Intake/Discharge System of an Electric Power Co-Generator, Guayanilla PR. Submitted to Vicente and Associates . November 2007.

Otero, E., 2002. Abundance and Phytoplankton Community Composition in Guayanilla, Puerto Rico. First Report for the biological Monitoring Program. Submitted to Vicente and Associates. September 2002.

Salonen, K. and T. Hammar. 1986. On the importance of dissolved organic matter in the nutrition of zooplankton in some lake waters. Oecologia (Berlin) 68: 246-253.

Tomas, C.R. 1997. Identifying Marine Phytoplankton. Academic Press. San Diego, CA. USA.

USEPA, 2009. EPA requires New Pipe at PREPA South Coast; Grants Water Discharge Permit. http://yosemite.epa.gov/opa/admpress.nsf/4f88b25ea20ccbf985257359003f5345/08a66a118b9453cd8525761d0061108d!OpenDocument (downloaded on 20 July 2012)

Vicente and Associates, 2001. Biological Monitoring Plan: EcoElectrica Co-Generation Project. Cooling Water Intake/Discharge Off the LNG Terminal Pier, Punta Guayanilla, Peñuelas, Puerto Rico.

Vicente and Associates, 2008. Biological Monitoring Program Plan Implementation 2005-2008.

Appendices

Appendix 1. Summary of Phytoplanktonn counts at the three stations (ind/L)

Phytoplankton Abundance at the Helper Cooling Tower Station (Ind/L)								
		HTC			**HTC**			
Genus, Species or Family		Rep			Rep		Mean	SE
	day	day	day	night	night	night		
Phyllum Chrysophyta (Diatoms)								
Asterionellopsis	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Asteromphalus	1.3	2.0	0.0	2.0	2.7	4.0	2.0	0.5
Bacillaria	5.3	229.5	0.0	5.3	1.3	2.7	40.7	37.8
Bacteriastrum	99.3	2200.0	177.3	137.3	326.7	220.0	526.8	336.2
Chaetoceros	821.2	27.3	1420.0	1137.5	1394.4	1422.2	1037.1	223.5
Climacosphenia	10.7	75.3	22.7	16.7	31.3	20.0	29.4	9.6
Cocconeis	39.3	0.0	112.0	140.0	155.3	124.0	95.1	25.1
Corethron	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Coscinodiscus	3.3	24.7	4.0	1.3	3.3	0.0	6.1	3.8
Cylindrotheca	15.3	6.0	21.3	16.7	26.0	16.0	16.9	2.7
Dactyliosolen	2.7	0.7	0.0	6.7	6.0	5.3	3.6	1.2
Dytilum	0.7	4.7	0.0	0.7	0.0	0.0	1.0	0.7
Eucampia	2.7	3.3	4.0	4.0	2.7	1.3	3.0	0.4
Guinardia	6.0	4.0	8.0	3.3	0.7	2.7	4.1	1.1
Hemialus	0.0	2.0	8.0	0.0	2.7	0.0	2.1	1.3
Leptocylindrus	2.0	4.7	8.0	0.0	2.7	2.7	3.3	1.1
Licmophora	2.7	20.0	2.7	2.0	4.0	2.7	5.7	2.9
Naviculaceae	16.7	110.7	148.0	78.0	169.3	125.3	108.0	22.3
Nitzschia	14.7	16.0	10.7	33.3	26.0	24.0	20.8	3.5
Odontella	1.3	7.3	9.3	2.0	2.0	8.0	5.0	1.5
Paralia	1.3	0.0	2.7	4.7	4.0	0.0	2.1	0.8
Pleuro-Gyrosigma	154.7	236.2	186.7	219.3	315.0	200.0	218.6	22.4
Pseudonitzschia	12.7	17.3	10.7	30.0	12.7	4.0	14.6	3.6
Rhabdonema	10.0	16.0	12.0	16.7	5.3	5.3	10.9	2.0
Rhizosolenia	30.0	32.0	41.3	31.3	20.0	22.7	29.6	3.1
Skeletonema	1.3	1.3	2.7	0.0	4.7	2.7	2.1	0.7
Tabellaria	12.0	27.3	18.7	22.0	32.0	24.0	22.7	2.8
Thalassionema	49.3	67.3	78.7	15.3	9.3	2.7	37.1	13.2
	28.0							
Phyllum Pyrrophyta (Dinoflagellates)								
Akashiwo sanguinea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Ceratium furca	24.7	24.7	33.3	27.3	33.3	36.0	29.9	2.0
Ceratium kofoidii	2.0	4.0	8.0	4.0	4.7	4.0	4.4	0.8
Ceratium macroceros	0.0	0.7	0.0	0.0	0.0	1.3	0.3	0.2
Ceratium pentagonum	1.3	1.3	2.7	0.7	1.3	0.0	1.2	0.4
Dinophysis	0.0	0.0	2.7	0.0	1.3	0.0	0.7	0.5
Gonyaulax	0.7	0.0	4.0	2.0	4.0	0.0	1.8	0.8
Podolampas	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Prorocentrum	0.7	0.0	0.0	2.0	3.3	2.7	1.4	0.6

Phytoplankton Abundance at the Helper Cooling Tower Station (Ind/L)								
Protoperidinium	38.0	52.0	134.7	83.3	121.3	132.0	93.6	17.2
Pyrodinium bahamense	0.0	0.7	0.0	0.0	0.0	1.3	0.3	0.2
Pyrophacus	2.7	3.3	1.3	4.0	2.7	1.3	2.6	0.4
Ornithocercus magnificus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Scripsiella	0.7 14	6.7	8.0	0.0	19.3	9.3	7.3	2.9
Phyllum Cyanophyta (Blue-green algae)								
Oscillatoria	16.7	10.0	9.3	8.0	10.0	10.7	10.8	1.2

Phytoplankton Abundance at the Intake Station (Ind/L)								
	Intake			Intake				
Genus, Species or Family	Rep			Rep			Mean	SE
	day	day	day	night	night	night		
Phyllum Chrysophyta (Diatoms)								
Asterionellopsis	13.3	6.7	6.7	0.0	0.0	6.7	5.6	2.0
Asteromphalus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bacillaria	33.3	0.0	13.3	6.7	0.0	0.0	8.9	5.4
Bacteriastrum	953.3	1153.3	1160.0	746.7	3520.8	4451.0	1997.5	643.1
Chaetoceros	33222.2	29333.3	10259.3	19416.7	25555.6	22666.7	23409.0	3293.5
Climacosphenia	13.3	0.0	6.7	0.0	6.7	20.0	7.8	3.2
Cocconeis	0.0	20.0	13.3	0.0	0.0	13.3	7.8	3.6
Corethron	6.7	6.7	13.3	0.0	0.0	0.0	4.4	2.2
Coscinodiscus	6.7	20.0	0.0	13.3	6.7	0.0	7.8	3.2
Cylindrotheca	26.7	93.3	40.0	0.0	20.0	26.7	34.4	12.9
Dactyliosolen	13.3	100.0	46.7	0.0	173.3	140.0	78.9	28.7
Dytilum	13.3	26.7	0.0	13.3	0.0	0.0	8.9	4.4
Eucampia	13.3	40.0	6.7	80.0	33.3	66.7	40.0	11.8
Guinardia	253.3	153.3	53.3	206.7	73.3	120.0	143.3	31.5
Hemialus	6.7	26.7	20.0	6.7	20.0	66.7	24.4	9.1
Leptocylindrus	33.3	113.3	53.3	106.7	33.3	13.3	58.9	17.0
Licmophora	20.0	26.7	40.0	0.0	13.3	26.7	21.1	5.6
Naviculaceae	40.0	86.7	86.7	13.3	46.7	200.0	78.9	26.9
Nitzschia	220.0	180.0	0.0	153.3	113.3	53.3	120.0	33.5
Odontella	13.3	6.7	0.0	0.0	0.0	0.0	3.3	2.3
Paralia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pleuro-Gyrosigma	260.0	306.7	133.3	293.3	553.3	333.3	313.3	55.9
Pseudonitzschia	133.3	0.0	66.7	93.3	253.3	100.0	107.8	34.4
Rhabdonema	280.0	213.3	20.0	13.3	0.0	0.0	87.8	51.1
Rhizosolenia	706.7	446.7	133.3	573.3	606.7	206.7	445.6	94.0
Skeletonema	40.0	20.0	6.7	53.3	6.7	6.7	22.2	8.2
Tabellaria	0.0	6.7	13.3	0.0	13.3	13.3	7.8	2.7
Thalassionema	440.0	446.7	140.0	493.3	933.3	773.3	537.8	114.0
Phyllum Pyrrophyta								

Phytoplankton Abundance at the Intake Station (Ind/L)								
(Dinoflagellates)								
Akashiwo sanguinea	1.3	0.0	0.0	2.7	5.3	4.7	2.3	0.9
Ceratium furca	86.0	22.7	10.7	44.0	178.7	366.7	118.1	55.6
Ceratium kofoidii	15.3	20.7	12.7	6.7	16.0	17.3	14.8	1.9
Ceratium macroceros	2.7	2.0	0.7	2.7	0.7	2.0	1.8	0.4
Ceratium pentagonum	2.0	2.7	0.0	6.7	2.7	9.3	3.9	1.4
Dinophysis	6.0	8.0	4.7	8.7	10.0	9.3	7.8	0.8
Gonyaulax	16.0	60.7	28.0	8.0	21.3	45.3	29.9	8.0
Podolampas	0.7	0.7	0.0	0.0	1.3	0.7	0.6	0.2
Prorocentrum	2.0	12.0	2.7	3.3	14.0	6.0	6.7	2.1
Protoperidinium	357.3	767.3	233.3	257.9	2444.4	1177.8	873.0	347.7
Pyrodinium bahamense	20.7	2.0	0.0	9.3	10.7	14.7	9.6	3.2
Pyrophacus	21.3	7.3	4.0	2.7	12.0	10.0	9.6	2.8
Ornithocercus magnificus	1.3	0.0	0.7	0.0	0.0	0.0	0.3	0.2
Scripsiella	6.7	45.3	32.7	8.0	58.0	84.7	39.2	12.3
Phyllum Cyanophyta (Blue-green algae)								
Oscillatoria	0.0	6.7	0.0	0.0	1.3	13.3	3.6	2.2

Phytoplankton Abundance at the Outfall Station (Ind/L)								
		Outfall			**Outfall**			
Genus, Species or Family		Rep			Rep		Mean	SE
	day	day	day	night	night	night		
Phyllum Chrysophyta (Diatoms)								
Asterionellopsis	13.3	20.0	0.0	13.3	20.0	0.0	11.1	3.7
Asteromphalus	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Bacillaria	13.3	0.0	1146.7	13.3	0.0	1146.7	386.7	240.3
Bacteriastrum	1026.7	1360.0	0.0	1026.7	1360.0	0.0	795.6	258.8
Chaetoceros	25111.1	18066.7	14866.7	25111.1	18066.7	14866.7	19348.1	1913.8
Climacosphenia	0.0	13.3	0.0	0.0	13.3	0.0	4.4	2.8
Cocconeis	66.7	0.0	13.3	66.7	0.0	13.3	26.7	12.9
Corethron	6.7	0.0	0.0	6.7	0.0	0.0	2.2	1.4
Coscinodiscus	0.0	6.7	26.7	0.0	6.7	26.7	11.1	5.1
Cylindrotheca	26.7	100.0	0.0	26.7	100.0	0.0	42.2	18.9
Dactyliosolen	0.0	133.3	26.7	0.0	133.3	26.7	53.3	25.8
Dytilum	26.7	20.0	0.0	26.7	20.0	0.0	15.6	5.1
Eucampia	13.3	60.0	40.0	13.3	60.0	40.0	37.8	8.5
Guinardia	173.3	80.0	93.3	173.3	80.0	93.3	115.6	18.4
Hemialus	60.0	80.0	53.3	60.0	80.0	53.3	64.4	5.1
Leptocylindrus	120.0	73.3	106.7	120.0	73.3	106.7	100.0	8.8
Licmophora	0.0	20.0	26.7	0.0	20.0	26.7	15.6	5.1
Naviculaceae	13.3	40.0	186.7	13.3	40.0	186.7	80.0	34.1
Nitzschia	180.0	326.7	66.7	180.0	326.7	66.7	191.1	47.6
Odontella	6.7	6.7	0.0	6.7	6.7	0.0	4.4	1.4

Paralia	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Pleuro-Gyrosigma	560.0	346.7	213.3	560.0	346.7	213.3	373.3	63.9
Pseudonitzschia	86.7	106.7	106.7	86.7	106.7	106.7	100.0	4.2
Rhabdonema	86.7	53.3	0.0	86.7	53.3	0.0	46.7	16.0
Rhizosolenia	646.7	373.3	333.3	646.7	373.3	333.3	451.1	62.3
Skeletonema	53.3	20.0	13.3	53.3	20.0	13.3	28.9	7.8
Tabellaria	0.0	6.7	13.3	0.0	6.7	13.3	6.7	2.4
Thalassionema	420.0	486.7	653.3	420.0	486.7	653.3	520.0	43.9
Phyllum Pyrrophyta (Dinoflagellates)								
Akashiwo sanguinea	0.7	0.0	0.0	1.3	0.0	0.0	0.3	0.2
Ceratium furca	32.0	12.7	22.7	38.7	59.3	26.0	31.9	6.6
Ceratium kofoidii	15.3	5.3	10.0	6.0	19.3	0.0	9.3	2.9
Ceratium macroceros	0.0	1.3	0.7	0.0	1.3	0.7	0.7	0.2
Ceratium pentagonum	4.7	3.3	1.3	2.7	5.3	5.3	3.8	0.7
Dinophysis	5.3	14.0	11.3	8.0	13.3	10.0	10.3	1.3
Gonyaulax	10.7	20.7	14.7	14.7	10.7	22.0	15.6	2.0
Podolampas	0.0	0.0	0.0	0.0	0.0	0.7	0.1	0.1
Prorocentrum	17.3	6.7	6.0	6.7	14.0	2.0	8.8	2.3
Protoperidinium	444.1	384.1	403.7	221.1	363.5	290.3	351.1	33.3
Pyrodinium bahamense	10.0	2.0	2.7	1.3	0.0	2.7	3.1	1.4
Pyrophacus	6.7	2.7	2.7	6.0	10.7	6.7	5.9	1.2
Ornithocercus magnificus	1.3	0.0	0.0	0.7	1.3	2.0	0.9	0.3
Scripsiella	11.3	32.0	41.3	15.3	39.3	34.0	28.9	5.1
Phyllum Cyanophyta (Blue-green algae)								
Oscillatoria	0.0	2.0	0.0	0.0	2.0	0.0	0.7	0.4

Appendix2. Comparison of phytoplankton abundance during day and evening hours.

t-Test Result for Protoperidinium: Intake Station

Descriptive Statistics

Variable	Mean	Std Dev.	Std Err	Lower 95% CL	Upper 95% CL	N
Day	452.333	279.473	161.354	-241.917	1146.584	3
Night	1293.000	1098.026	633.946	########	4020.648	3

2-tailed t-Test

Ho. Diff	Mean Diff.	SE Diff.	T	DF	P
0.000	-840.667	654.158	-1.285	4.000	0.268

F-Test for Equality of Variances

Variable	Variance	F	DF 1	DF 2	P
Day	78105.333	15.436	2	2	0.061
Night	1205661.000				

Sample variances don't differ at the specified alpha of 0.0500
so the following pooled variance was used in the t-Test.

Pooled Variance = 641883.167

t-Test Result for Datasets: Chaetoceros : Intake Station

Descriptive Statistics

Variable	Mean	Std Dev.	Std Err	Lower 95% CL	Upper 95% CL	N
Chaetoceros	24271.333	12289.841	7095.543	########	########	3
Chaetoceros	22546.333	3071.778	1773.492	########	########	3

2-tailed t-Test

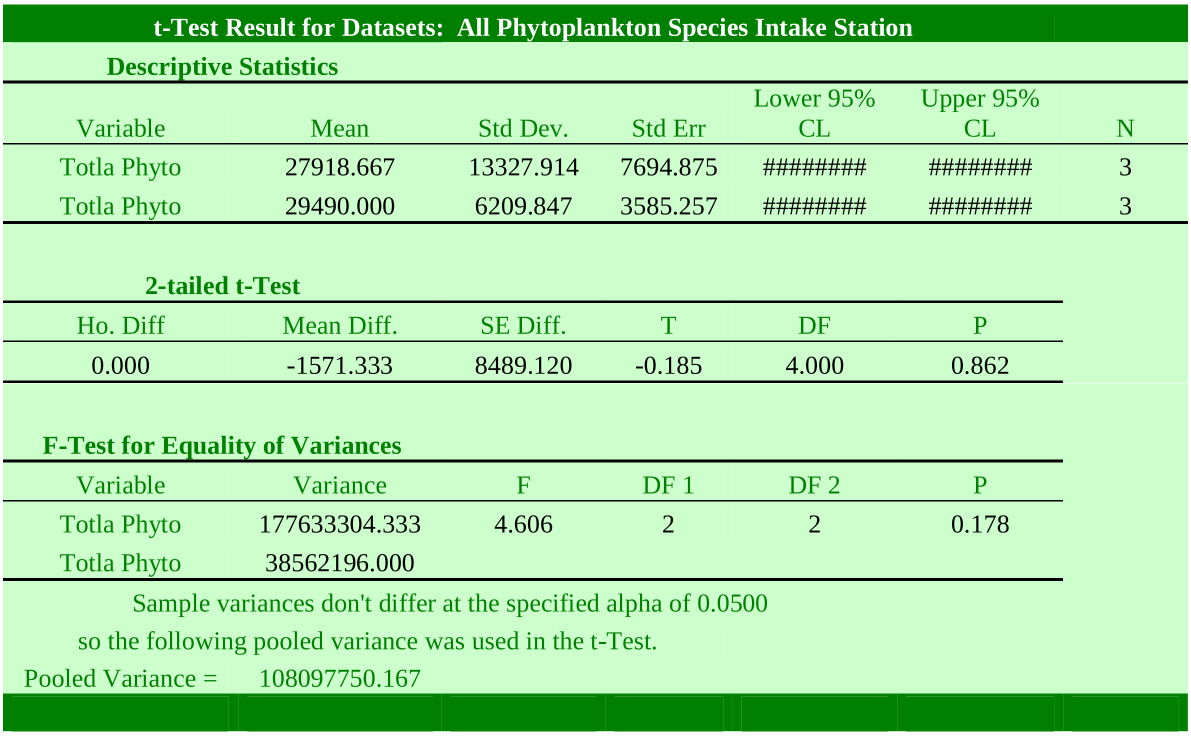
Ho. Diff	Mean Diff.	SE Diff.	T	DF	P
0.000	1725.000	7313.823	0.236	4.000	0.825

F-Test for Equality of Variances

Variable	Variance	F	DF 1	DF 2	P
Chaetoceros	151040194.333	16.007	2	2	0.059
Chaetoceros	9435820.333				

Sample variances don't differ at the specified alpha of 0.0500
so the following pooled variance was used in the t-Test.

Pooled Variance = 80238007.333



t-Test Result for Datasets: All Phytoplankton Species Intake Station

Descriptive Statistics

Variable	Mean	Std Dev.	Std Err	Lower 95% CL	Upper 95% CL	N
Totla Phyto	27918.667	13327.914	7694.875	########	########	3
Totla Phyto	29490.000	6209.847	3585.257	########	########	3

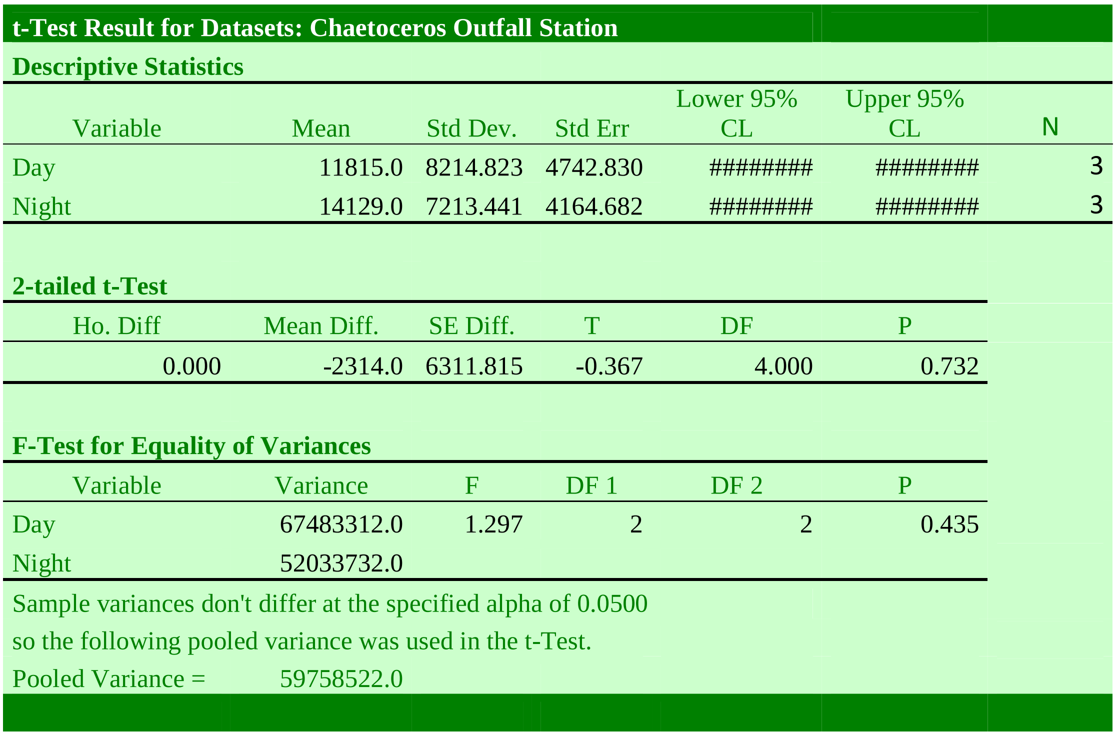
2-tailed t-Test

Ho. Diff	Mean Diff.	SE Diff.	T	DF	P
0.000	-1571.333	8489.120	-0.185	4.000	0.862

F-Test for Equality of Variances

Variable	Variance	F	DF 1	DF 2	P
Totla Phyto	177633304.333	4.606	2	2	0.178
Totla Phyto	38562196.000				

Sample variances don't differ at the specified alpha of 0.0500
so the following pooled variance was used in the t-Test.
Pooled Variance = 108097750.167



t-Test Result for Datasets: Chaetoceros Outfall Station

Descriptive Statistics

Variable	Mean	Std Dev.	Std Err	Lower 95% CL	Upper 95% CL	N
Day	11815.0	8214.823	4742.830	########	########	3
Night	14129.0	7213.441	4164.682	########	########	3

2-tailed t-Test

Ho. Diff	Mean Diff.	SE Diff.	T	DF	P
0.000	-2314.0	6311.815	-0.367	4.000	0.732

F-Test for Equality of Variances

Variable	Variance	F	DF 1	DF 2	P
Day	67483312.0	1.297	2	2	0.435
Night	52033732.0				

Sample variances don't differ at the specified alpha of 0.0500
so the following pooled variance was used in the t-Test.
Pooled Variance = 59758522.0

t-Test Result for Datasets: Protoperidinium Outfall Station

Descriptive Statistics

Variable	Mean	Std Dev.	Std Err	Lower 95% CL	Upper 95% CL	N
Day	410.7	30.551	17.638	334.775	486.558	3
Night	291.7	71.515	41.289	114.015	469.319	3

2-tailed t-Test

Ho. Diff	Mean Diff.	SE Diff.	T	DF	P
0.000	119.0	44.899	2.650	4.000	0.057

F-Test for Equality of Variances

Variable	Variance	F	DF 1	DF 2	P
Day	933.3	5.480	2	2	0.154
Night	5114.3				

Sample variances don't differ at the specified alpha of 0.0500
so the following pooled variance was used in the t-Test.
Pooled Variance = 3023.8

t-Test Result for Datasets: Total Phytoplankton Outfall Station

Descriptive Statistics

Variable	Mean	Std Dev.	Std Err	Lower 95% CL	Upper 95% CL	N
Day	23354.0	5462.228	3153.619	9785.072	########	3
Night	18469.3	7265.876	4194.956	419.896	########	3

2-tailed t-Test

Ho. Diff	Mean Diff.	SE Diff.	T	DF	P
0.000	4884.7	5248.139	0.931	4.000	0.405

F-Test for Equality of Variances

Variable	Variance	F	DF 1	DF 2	P
Day	29835939.0	1.769	2	2	0.361
Night	52792960.3				

Sample variances don't differ at the specified alpha of 0.0500
so the following pooled variance was used in the t-Test.
Pooled Variance = 41314449.667

t-Test Result for Datasets: Total Phytoplankton HTC Station

Descriptive Statistics

Variable	Mean	Std Dev.	Std Err	Lower 95% CL	Upper 95% CL	N
Day	2399.4	901.995	520.767	158.739	4640.101	3
Night	2419.9	352.439	203.481	1544.437	3295.452	3

2-tailed t-Test

Ho. Diff	Mean Diff.	SE Diff.	T	DF	P
0.000	-20.5	559.109	-0.037	4.000	0.972

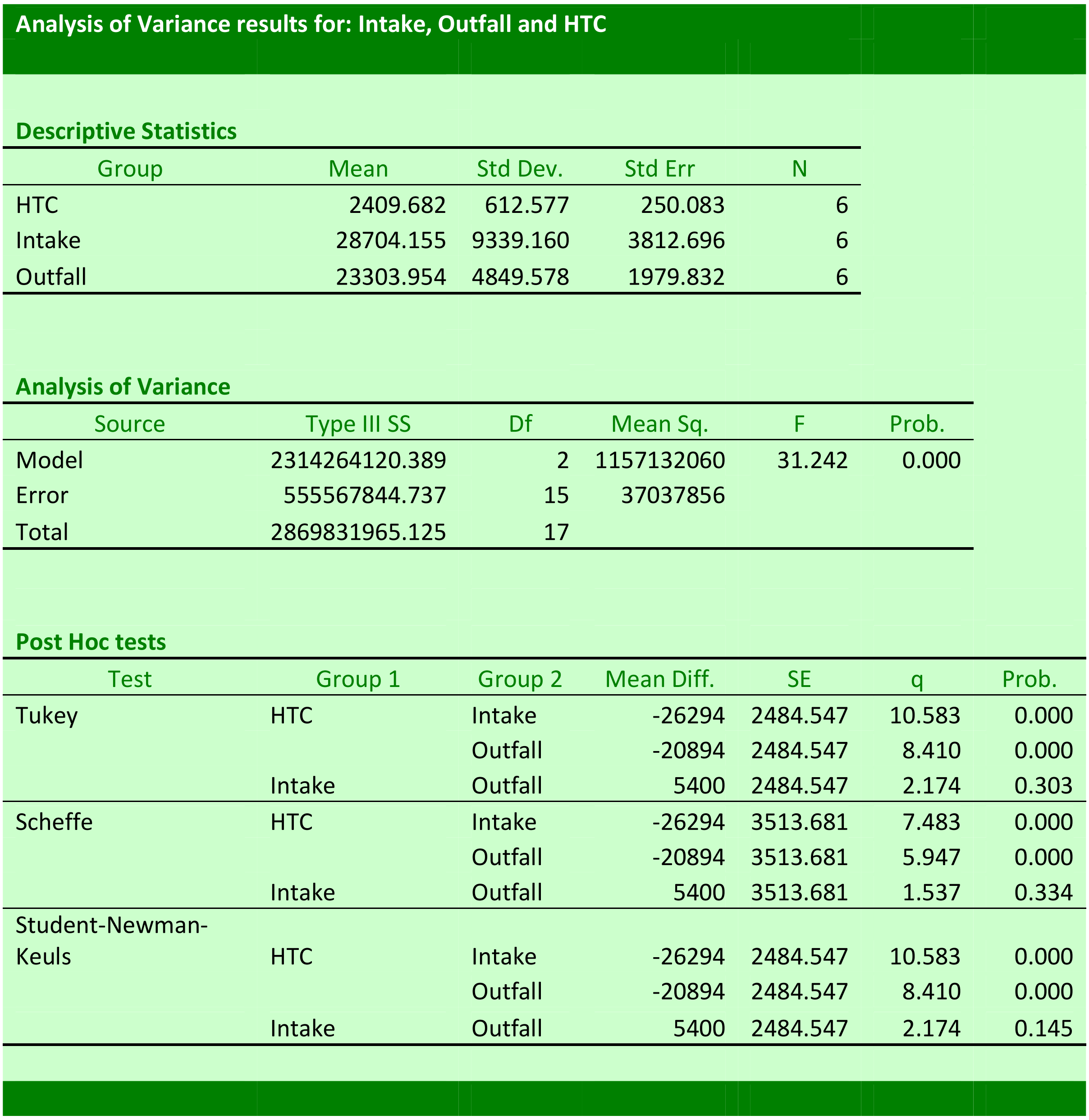
F-Test for Equality of Variances

Variable	Variance	F	DF 1	DF 2	P
Day	813595.8	6.550	2	2	0.132
Night	124213.4				

Sample variances don't differ at the specified alpha of 0.0500
so the following pooled variance was used in the t-Test.

Pooled Variance = 468904.6

Appendix 3. Multiple –ANOVA comparing total phytoplankton abundance among stations.



Analysis of Variance results for: Intake, Outfall and HTC

Descriptive Statistics

Group	Mean	Std Dev.	Std Err	N
HTC	2409.682	612.577	250.083	6
Intake	28704.155	9339.160	3812.696	6
Outfall	23303.954	4849.578	1979.832	6

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	2314264120.389	2	1157132060	31.242	0.000
Error	555567844.737	15	37037856		
Total	2869831965.125	17			

Post Hoc tests

Test	Group 1	Group 2	Mean Diff.	SE	q	Prob.
Tukey	HTC	Intake	-26294	2484.547	10.583	0.000
		Outfall	-20894	2484.547	8.410	0.000
	Intake	Outfall	5400	2484.547	2.174	0.303
Scheffe	HTC	Intake	-26294	3513.681	7.483	0.000
		Outfall	-20894	3513.681	5.947	0.000
	Intake	Outfall	5400	3513.681	1.537	0.334
Student-Newman-Keuls	HTC	Intake	-26294	2484.547	10.583	0.000
		Outfall	-20894	2484.547	8.410	0.000
	Intake	Outfall	5400	2484.547	2.174	0.145

Appendix 4. Summary of zooplankton counts at the three stations

Zooplankton abundance results for replicates collected at the Intake station (Ind/m^3)

Sampling Time	**16:40**	**0:25**	**17:10**	**1:11**	**17:28**
HOLOPLANKTON TAXA	**IR1D**	**IR1N**	**IR2D**	**IR2N**	**IR3D**
Calanoid Copepods	1032.52	4532.78	966.18	4371.28	3424.09
Cyclopoid Copepods	150.93	1708.51	87.22	1264.88	660.07
Harpacticoid Copepods	277.85	557.88	214.71	669.64	715.07
Monstrilloid Copepod	0.00	0.00	0.00	0.00	27.50
Caligoid Copepod	0.00	0.00	0.00	0.00	0.00
Copepod Nauplii	0.00	0.00	0.00	0.00	0.00
Chaetognath Worms	65.18	87.17	36.90	0.00	55.01
Larvaceans	140.64	784.52	171.10	688.24	68.76
Cnidarians	13.72	0.00	10.06	0.00	41.25
Syphonophores	0.00	0.00	10.06	0.00	0.00
Amphipods	0.00	0.00	0.00	0.00	0.00
Sergestoid Shrimps	236.69	226.64	164.39	130.21	233.77
Isopods	0.00	17.43	1.34	0.00	0.00
Pycnogonids	0.00	0.00	0.00	0.00	0.00
Cumaceans	0.00	0.00	0.00	0.00	13.75
Ostracods	0.00	0.00	0.00	0.00	27.50
Foraminiferans	257.27		325.42	18.60	288.78
Ctenophores	0.00	0.00	0.00	0.00	0.00
Mysids	0.00	0.00	0.00	0.00	0.00
Bryozoans	0.00	0.00	0.00	0.00	0.00
Total Holoplankton	**2174.81**	**7914.92**	**1987.39**	**7142.86**	**5555.56**

MEROPLANKTON TAXA					
Decapod Larvae					
Penaeoid	89.19	122.04	80.52	14.88	426.29
Caridean	2.06	0.00	3.35	20.46	41.25
Anomuran	0.00	0.00	0.00	11.16	0.00
Macruran	0.00	0.00	0.00	0.00	0.00
Brachyuran	10.98	122.04	4.70	85.57	27.50
Decapod Eggs	13.72	17.43	33.55	18.60	343.78
Veliger Larvae	198.96	34.87	137.55		398.79
Polychaete Larvae	41.16	34.87	40.26	111.61	82.51
Cirriped Larvae	939.90	1063.46	802.69	799.85	1856.44

Zooplankton abundance results for replicates collected at the Intake station (Ind/m^3)

Ascidean Larvae	0.00	0.00	0.00	0.00	0.00
Stomatopod Larvae	0.00	0.00	0.00	3.72	13.75
Actinotrochs					
Echinoderm (Ophiuroidea)	24.01	17.43	33.55	18.60	13.75
Tanaidaceans	0.00	0.00	0.00	1.86	0.00
Fish Eggs					
Round	133.78	122.04	201.29	186.01	302.53
Pointed	0.00	0.00	0.00	0.00	0.00
[redacted]	[redacted]	[redacted]	[redacted]	[redacted]	[redacted]
Fish Larvae (Unknown)	0.00	0.00	0.00	0.00	0.00
Pre flexion	0.00	0.00	0.00	0.00	27.50
Post flexion					
Serranidae	0.00	0.00	0.00	0.00	0.00
Gobiidae	0.00	0.00	0.00	0.00	0.00
Leptocephalii	0.00	0.00	0.00	0.00	0.00
Total Meroplankton	**1453.76**	**1534.17**	**1337.45**	**1272.32**	**3534.10**
TOTAL ZOOPLANKTON	**3628.57**	**9449.09**	**3324.83**	**8415.18**	**9089.66**

Zooplankton abundance results for replicates collected at the Outfall station (Ind/m^3)

Sampling Time	**20:30**	**23:20**	**22:35**	**23:45**
HOLOPLANKTON TAXA	**OR1D**	**OR1N**	**OR2D**	**OR2N**
Calanoid Copepods	771.81	3322.37	1072.80	2370.54
Cyclopoid Copepods	212.53	537.28	298.30	450.89
Harpacticoid Copepods	25.17	131.58	30.10	285.71
Monstrilloid Copepod	0.00	0.00	0.00	0.00
Caligoid Copepod	0.00	0.00	0.00	0.00
Copepod Nauplii	0.00	0.00	0.00	0.00
Chaetognath Worms	19.57	120.61	8.21	133.93
Larvaceans	95.08	235.75	139.57	200.89
Cnidarians	2.80	21.93	5.47	0.00
Syphonophores	5.59	32.89	0.00	0.00
Amphipods	0.00	0.00	0.00	0.00
Sergestoid Shrimps	83.89	158.99	54.73	107.14
Isopods	5.59	0.00	0.00	0.00

Zooplankton abundance results for replicates collected at the Outfall station (Ind/m^3)

Pycnogonids	0.00	0.00	0.00	0.00
Cumaceans	0.00	0.00	0.00	0.00
Ostracods	0.00	5.48	2.74	0.00
Foraminiferans	19.57	115.13	32.84	80.36
Ctenophores	0.00	0.00	0.00	0.00
Mysids	30.76	0.00	19.16	40.18
Bryozoans	0.00	0.00	0.00	0.00
Total Holoplankton	**1272.37**	**4682.02**	**1663.93**	**3669.64**

MEROPLANKTON TAXA				
Decapod Larvae				
Penaeoid	0.00	27.41	0.00	0.00
Caridean	16.78	21.93	27.37	53.57
Anomuran	16.78	32.89	24.63	75.89
Macruran	0.00	0.00	0.00	0.00
Brachyuran	50.34	180.92	71.15	98.21
Decapod Eggs	47.54	312.50	136.84	116.07
Veliger Larvae	55.93	148.03	57.47	428.57
Polychaete Larvae	2.80	16.45		8.93
Cirriped Larvae	100.67	564.69	87.58	1044.64
Ascidean Larvae	0.00	0.00	0.00	0.00
Stomatopod Larvae	1.00	10.96	0.00	0.00
Actinotrochs				
Echinoderm (Ophiuroidea)	0.00	65.79	0.00	49.11
Tanaidaceans	0.00	0.00	0.00	0.00
Fish Eggs				
Round	120.25	252.19	84.84	49.11
Pointed	5.59	16.45	5.47	4.46
Fish Larvae (Unknown)	0.00	0.00	2.74	0.00
Pre flexion	5.59	0.00	0.00	13.39
Post flexion				
Serranidae	0.00	5.48	2.74	0.00
Gobiidae	0.00	10.96	0.00	0.00
Leptocephalii	0.00	0.00	2.74	0.00
Total Meroplankton	**423.26**	**1666.67**	**503.56**	**1941.96**
TOTAL ZOOPLANKTON	**1695.63**	**6348.68**	**2167.49**	**5611.61**

Zooplankton abundance results for replicates collected at the Helper Cooling Tower station (Ind/m3)

Sampling Time	**16:15**	**20:45**	**18:20**	**22:07**	**19:30**	**23:10**
HOLOPLANKTON TAXA	**PR1**	**P-R1**	**PR2**	**P-R2**	**PR3**	**P-R3**
Calanoid Copepods	0.94	2.08	2.11	0.66	1.74	3.02
Cyclopoid Copepods	0.07	0.00	1.77	0.00	0.37	0.60
Harpacticoid Copepods	11.18	15.58	20.95	8.23	15.12	9.67
Monstrilloid Copepod	0.00	0.00	0.00	0.00	0.00	0.00
Caligoid Copepod	0.00	0.00	0.06	0.00	0.00	0.00
Copepod Nauplii	0.00	0.00	0.00	0.00	0.00	0.00
Chaetognath Worms	0.00	0.00	1.00	0.00	0.00	0.00
Larvaceans	0.00	0.00	0.00	0.00	0.00	0.00
Cnidarians	0.00	0.00	0.11	0.13	0.00	0.00
Syphonophores	0.00	0.00	0.00	0.00	0.00	0.00
Amphipods	0.00	1.34	1.43	1.12	1.16	0.60
Sergestoid Shrimps	0.20	0.00	0.00	0.00	0.11	0.00
Isopods	0.00	0.27	0.06	0.00	0.00	0.00
Pycnogonids	0.03	0.07	0.00	0.07	0.00	0.60
Cumaceans	0.00	0.00	0.06	0.00	0.00	0.00
Ostracods	0.00	0.00	0.00	0.00	0.00	0.00
Foraminiferans	8.16	11.69	9.65	9.68	9.91	6.65
Ctenophores	0.00	0.00	0.00	0.00	0.00	0.00
Mysids	0.00	0.00	0.00	0.00	0.00	0.00
Bryozoans	0.00	1	1	1	1	1
Total Holoplankton	**20.58**	**32.03**	**38.19**	**20.89**	**29.40**	**22.16**

MEROPLANKTON TAXA						
Decapod Larvae						
Penaeoid	0.00	0.07	0.11	0.00	0.05	0.00
Caridean	0.03	0.00	0.00	0.00	0.05	0.00
Anomuran	0.00	0.07	0.00	0.00	0.00	0.00
Macruran	0.00	0.00	0.00	0.00	0.00	0.00
Brachyuran	0.84	0.20	0.74		0.26	
Decapod Eggs	0.34	0.87	0.51	0.72	0.63	2.42

Zooplankton abundance results for replicates collected at the Helper Cooling Tower station (Ind/m3)

Veliger Larvae	5.00	21.22	9.19	17.98	14.12	8.46
Polychaete Larvae	0.27	2.01	1.08	1.05	0.79	1.81
Cirriped Larvae	3.22	14.30	16.10	5.34	11.06	20.55
Ascidean Larvae	0.00	0.00	0.00	0.00	0.00	0.00
Stomatopod Larvae	0.00	0.00	0.00	0.00	0.00	0.00
Actinotrochs						
Echinoderm (Ophiuroidea)	0.00	0.00	0.00	0.00	0.00	0.00
Tanaidaceans	1.14	2.89	1.48	2.44	1.69	4.23
Fish Eggs						
Round	0.24	1.41	0.68	0.66	0.79	2.42
Pointed	0.00	0.00	0.00	0.00	0.00	0.00
Fish Larvae (Unknown)	0.03	0.00	0.00	0.00	0.00	0.00
Pre flexion	0.00	0.00	0.00	0.00	0.00	0.00
Post flexion						
Serranidae	0.00	0.00	0.00	0.00	0.00	0.00
Gobiidae	0.00	0.00	0.00	0.00	0.00	0.00
Leptocephalii	0.00	0.00	0.00	0.00	0.00	0.00
Total Meroplankton	**11.11**	**43.05**	**29.91**	**28.19**	**29.45**	**39.89**
TOTAL ZOOPLANKTON	**31.70**	**75.08**	**68.10**	**49.09**	**58.85**	**62.05**

Appendix 5. Multiple Comparison ANOVA comparing differences in zooplankton abundance among stations. No significant differences (Prob >0.05) were found between intake and outfall stations.

Analysis of Variance results Zooplankton abundance among Intake, Outfall and HTC

Descriptive Statistics

Group	Mean	Std Dev.	Std Err	N
Intake	6204.418	3180.273	1590.136	4
Outfall	3955.852	2364.601	1182.301	4
HTC	57.477	15.363	6.272	6

Analysis of Variance

Source	Type III SS	Df	Mean Sq.	F	Prob.
Model	96605000.31	2	48302500.16	11.277	0.002
Error	47117605.43	11	4283418.68		
Total	143722605.74	13			

Post Hoc tests

Test	Group 1	Group 2	Mean Diff.	SE	q	Prob.
Tukey	Intake 1	Outfall 1	2248.565	1034.821	2.173	0.312
		HTC1	6146.941	944.658	6.507	0.002
	Outfall 1	HTC1	3898.376	944.658	4.127	0.034
Scheffe	Intake 1	Outfall 1	2248.565	1463.458	1.536	0.343
		HTC1	6146.941	1335.948	4.601	0.003
	Outfall 1	HTC1	3898.376	1335.948	2.918	0.043
Student-Newman-Keuls	Intake 1	Outfall 1	2248.565	1034.821	2.173	0.153
		HTC1	6146.941	944.658	6.507	0.002
	Outfall 1	HTC1	3898.376	944.658	4.127	0.014