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Original research article

Operational, water quality and temporal factors affecting impingement of fish and shellfish at a Texas coastal power plant

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HIGHLIGHTS

- Fish and shellfish impingement factors were evaluated at a Texas coastal power plant.
- Total impingement was associated with dissolved O_2, month, time, and temperature.
- Temperature and sampling month were most important for fish impingement.
- Sampling month and sampling time were most important for shellfish impingement.
- Flow and number of operating screens were not significant predictors of impingement.

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ABSTRACT

The Barney M. Davis Power Plant in Corpus Christi, Texas, withdraws large quantities of water from the Laguna Madre for non-contact cooling. As a result, fish and shellfish may be harmed when impinged against screens intended to remove debris and wrack (floating sea grass). To reduce impingement it is important to understand related factors and their interrelationships. Several operational, water quality, and temporal factors were correlated with the total number of impinged organisms when the plant is pumping water. In this study, operational factors included hourly average flow and the number of screens in operation during sampling. Water quality factors included temperature, dissolved oxygen, pH, conductivity and salinity. Temporal factors included month and time of day of impingement sampling. Over the course of a year, fish and shellfish impinged on Passavant traveling drum screens were collected, classified, and counted. Multiple regression analyses were conducted and the number of organisms impinged was the response variable. Total impingement was most associated with dissolved oxygen concentration, sampling month and sampling time. For fish, sampling month and dissolved oxygen were most associated with impingement, while for shellfish, sampling month and sampling time were most important. Hourly flow and number of operating screens were not significant predictors of impingement.

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1. Introduction

Impingement and entrainment of fish and shellfish can occur at facilities that withdraw large quantities of water from rivers, lakes, estuaries and other biologically active water bodies. The United States Environmental Protection Agency (EPA) noted that the most visible impact of these withdrawals is the loss of large numbers of aquatic organisms, but that there are also potential ecosystem effects (EPA, 2014). On October 14, 2014, new EPA rules to reduce impingement and entrainment mortality became effective. The rules cover six industrial categories that account for 99% of all cooling water withdrawals in the United States. Categories include utility and non-utility steam electric, chemical and allied products, primary metals industries, petroleum and coal products, and paper and allied products (EPA, 2014). Rules subject an existing facility, withdrawing at least 25% of its water for cooling purposes and with a design intake flow greater than 2 million gallons per day (MGD) (8 million liters), to an upper mortality limit of 24% for non-fragile fish and shellfish pinned against intake screens (impingement). Each facility operator is to choose among six options considered the best methods for meeting the limit, or a facility may demonstrate that its intake design or actual intake flow is less than 0.5 ft (15 cm) per second, the velocity at which EPA estimates that most fish can escape impingement (EPA, 2014).

In proposing the regulations, EPA took the position that flow reduction is strongly correlated to reductions in the total numbers of fish and shellfish impinged, and thus mortality rates. However, water quality and biological factors can be more important predictors for impingement than flow rates or design factors (King et al., 2010; Loar et al., 1977; Saalfeld, 2006). It is therefore important for facility mangers to understand how various factors interact to increase or decrease impingement.

The purpose of this study was to examine relationships between operational factors (hourly flow rate and number of operating screens); water quality factors (dissolved oxygen, pH, conductivity, and temperature); temporal factors (sampling month and sampling time) and the number of fish and shellfish impinged at the Barney M. Davis power plant in Corpus Christi, Texas.

2. Methods

Site description

Plant cooling water is pumped through two sets of screens (Fig. 1). Each set of screens uses two circulating water pumps. One circulating water pump of each set is rated at 97,500 gallons per minute (gpm) (390,000 liters per minute [Lpm]) and the second is rated at 81,000 gpm (324,000 Lpm). One service water pump, rated at 9000 gpm (32,000 Lpm), serves each set of screens. The total design flow for each set of screens is 187,500 gpm (750,000 Lpm) and both sets together pump up to 540 million GPD (2.16 billion Lpd).

Impingement sampling

Monthly impingement monitoring was conducted from March 14, 2006 through February 21, 2007 (52 individual samples). Each of four sets of screens was sampled each month for 12 months (48 individual samples). Because previous studies conducted at the facility demonstrated that impingement was highest during February (PBS&J, 2007), when early juvenile life stages are most abundant in the Laguna Madre, and at the request of the Texas Commission on Environmental Quality, an additional sampling event was conducted in February ($4 + 48 = 52$ individual samples). After February, impingement decreases significantly (PBS&J, 2007). During March one of four samples was not collected because the screen was not operating, while during August an additional sample was collected because one of the four screens was taken out of service for maintenance and later restarted. It was decided that the additional August screen sample should be counted as a separate sample, rather than counting it as the same sample, thus keeping the total number of sampling events at 52.

During monitoring, information was collected on operational, water quality, and temporal factors. Operational factors included hourly average intake flow and the number of operating screens. Water quality factors included temperature, pH, salinity, conductivity, and dissolved oxygen. Temporal factors included sampling month and the clock hour when sampling began.

Passavant traveling drum screens are used to keep fish and debris from entering intakes and piping. These screens are constructed using polyester mesh baskets mounted together. Each screen contains 53 semicircular screening baskets, with a rectangular nylon mesh size of 1 × 2 mm. The screen panels are removable and have a shovel-type lip to aid in the retention of screened material (Fig. 2). Flow through the screens is inside-to-outside with the submerged portion functioning as a screening surface (Murray and Jinnette, 1978). High pressure water is used to clear impinged fish from the screens into a concrete sluiceway and subsequently to a fish return system that empties into a cooling pond.

Fish and shellfish impinged on four separate Passavant traveling screens, were collected from wash water in the sluiceway of each screen using custom, 1-mm square mesh plankton nets (Aquatic Research Instruments, Hope, ID). Nets covered the entire area of wash water discharge and were held in place for 5 min, after which the nets were emptied into collecting containers, and again held in place for another 5 min. Three 5-min samples constituted a sample. The 5-min sample protocol was necessary to limit the sample weight due to large quantities of wrack accumulated in nets. Samples were collected only from screens in service. Organisms were classified according to the lowest identifiable biological taxon. Adults, larvae, and juveniles were separated, because differences in morphology and spatial distribution impact response to impingement variables (Dahlberg and Odum, 1970; Fisher et al., 2005; Llopiz and Cowen, 2009; Østergaard et al., 2005).

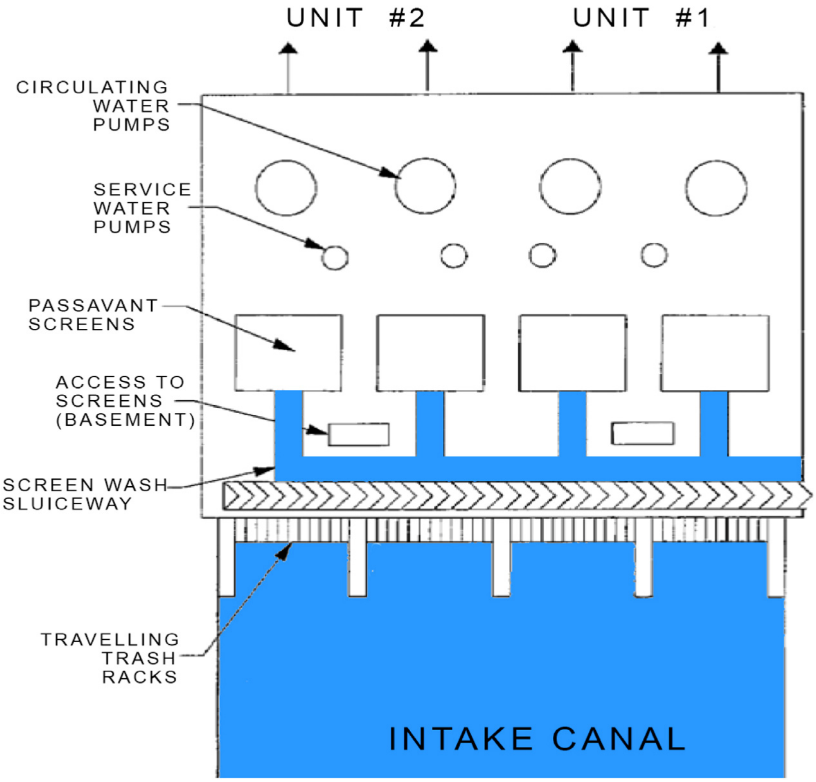

Fig. 1. Intake structure showing the location of Passavant screens.

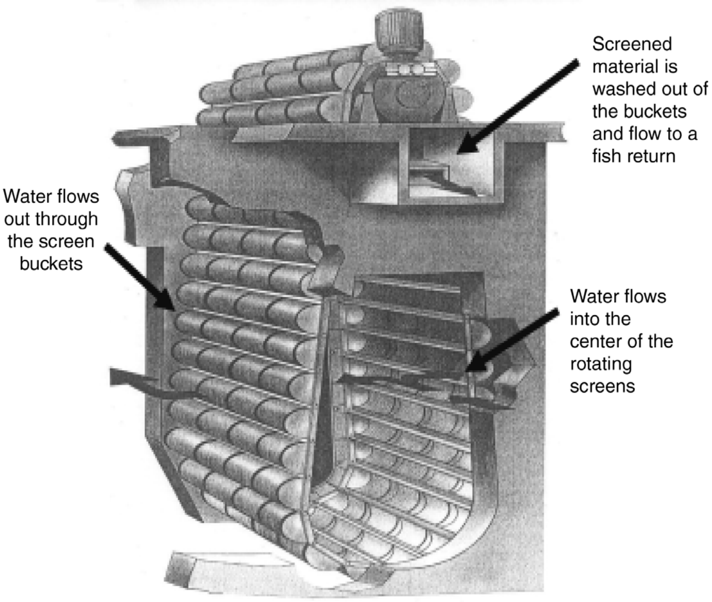

Fig. 2. Traveling drum screens used at the Barney M. Davis power plant in Corpus Christi, Texas.

After sampling, all organisms were sorted by size and preserved in 10% formalin. Larger organisms were processed by a marine biologist and smaller organisms were processed at the University of Texas at Austin Marine Science Institute, Port Aransas, Texas (PBS&J, 2007). The first 25 individuals of each species were enumerated, measured for length (mm), and organisms over 76 mm in length were weighed. The remaining organisms were counted and a bulk weight obtained. For larval and juvenile organisms, only lengths were measured. A digital platform scale with a resolution of at least ±1 g was used for weights. Accuracy of the scale was checked before and after each sampling event (PBS&J, 2007).

Operational factors

Estimates of hourly average flow through all screens were based on number of operating pumps during sampling and pump ratings. The number of operating screens was obtained from logs maintained by plant employees.

Water quality factors

Water quality monitoring was conducted using a multi-probe system (YSI Incorporated, Yellow Springs, Ohio) to measure dissolved oxygen (mg/L), pH, temperature (°C), conductivity (μmho/cm) and salinity (parts per thousand). Water quality samples were collected concurrently with impingement sampling, at each screen, for a total of four readings for each variable in a 24-h period.

Temporal factors

Impingement sampling was conducted one day each month from March 2006 through February 2007. Samples were collected over a 24-h period. Sample collections corresponded to the time periods: 18:00–19:59, 00:00–01:59, 06:00–07:59, and 12:00–13:59. Three 5-min samples were collected from each sluiceway such that the total sampling time, for each hour and for each screen, was 15 min.

Statistical analysis

For each sampling event, data were collected for nine independent factors, including operational variables (hourly average flow rate and number of screens operating during sampling), water quality variables (salinity, pH, temperature, dissolved oxygen and conductivity), and temporal variables (sampling month and sampling time).

As a first step to determine whether operational, water quality, or temporal variables were associated with impingement, correlations among the nine independent factors were identified using Pearson correlation analysis (SPSS version 22, IBM, Armonk, NY). To test for autocorrelation among independent variables, a Durbin–Watson test was used. A Durbin–Watson value near two was considered to indicate no autocorrelation among variables.

Multicollinearity was subsequently determined by calculating variance inflation factors (VIF) for independent variables. Multicollinearity decreases the explanatory value of individual predictor variables and the explanatory power of the model. To calculate VIF, linear regression was conducted to determine how much of the variation in each predictor variable was associated with the variation in other independent variables. Variables with a VIF > 5 were considered collinear and removed from the model.

Multiple regression analyses were then conducted, with the total number of impinged organisms (fish, shellfish or fish + shellfish) as the response variable. Estimated regression error residuals were right-skewed for the dependent variables, a characteristic associated with the lognormal distribution, and thus the data were $\log_e$ transformed. The categorical variable sampling month was converted to a number from one to twelve prior to inclusion in the regression model. Interactions with categorical variables were evaluated graphically and by adding interaction terms to the multiple regression models. None of the interaction terms were significant at $p = 0.05$.

Boxplots were used to illustrate variability in total impingement, number of taxa impinged throughout the year, and the change in total impingement by clock hours.

Because average hourly flow was constant from March through June, two shorter time periods were examined during which there was greater variation to determine if it affected regression results. The first period was July through December and the second was July through October, when most of the flow variation occurred. Similarly, for operating screens regression results were examined for the January through October data.

3. Results

Impingement sampling

A total of 70,834 impinged marine organisms were recovered and identified from 52 samples during the year-long impingement study: 42,286 fish and 28,418 shellfish. Seventy-nine percent were identified to the species or genus level, 12% to family level, and less than 8% at higher taxonomic levels. Twenty-one percent were identified by life stage (juvenile, larval, leptocephalus). Table 1 shows that 11 taxa (15 groupings) comprise 92% of the impinged organisms. Spot (*Leiostomus xanthurus*) were impinged in the greatest numbers (16,269) and were the greatest mean number recovered per sample (1017). Bay anchovy (*Anchoa mitchilli*) appeared most frequently (48 of 52 sampling days) with a mean of 299 per impingement sample. Shrimp and crab were the only shellfish reported during the study.

Fig. 3 shows that the highest number of taxa impinged in a month ranged from 4 to 26. May had the highest number (26) and October had the lowest (4). The range of impinged taxa overlapped for all months. For all months except October and November, the number of fish taxa impinged was greater than the number of impinged shellfish taxa. From January through March the number of fish taxa impinged far exceeded the number of shellfish taxa. The mean total number of shellfish impinged in a month never exceeded the mean for fish, similar to earlier sampling at the facility (Murray and Jinnette, 1978).

Operational factors

Hourly average flow ranged from 6.39 to 20.52 million gallons (24–78 million L). The highest possible flow using all cooling water pumps is 20.5 million gallons (78 million L) per hour, which only occurred 7.5% of the time. Only during the highest possible flow periods were all four screens operating. Fifty percent of the time hourly average flow was less than 7 million gallons (26 million L) and 70% of the time hourly average flow was less than 9.72 million gallons (37 million L).

Table 1
Total number and percentage of the most frequently impinged taxa at the Barney M. Davis power station in Corpus Christi, Texas.

Species		Total number impinged	Percent (%)	Cumulative percent (%)
Spot	*Leiostomus xanthurus*	16,269	23.0	23.0
Bay anchovy	*Anchoa mitchilli*	14,074	19.9	42.8
Post-larval brown shrimp	*Farfantepenaeus aztecus*	9,200	13.0	55.8
Grass shrimp	*Palaemonetes pugio*	4,548	6.4	62.3
Brown shrimp	*Farfantepenaeus aztecus*	3,812	5.4	67.6
Blue crab megalops	*Callinectes sapidus*	2,902	4.1	71.7
Penaeid shrimp	*Penaeid* spp.	2,557	3.6	75.3
Mysid shrimp	*Americamysis bahia*	2,167	3.1	78.4
Ladyfish	*Elops saurus*	2,114	3.0	81.4
Clupeidae larvae	*Clupeidae* spp.	1,953	2.8	84.1
Atlantic croaker	*Micropagonias undulatus*	1,829	2.6	86.7
Gulf menhaden	*Brevoortia patronus*	1,629	2.3	89.0
Pinfish	*Lagodon rhomboids*	820	1.2	90.2
Blue crab	*Callinectes sapidus*	793	1.1	91.3
Clupeidae species	*Clupeidae* spp.	716	1.0	92.3
Total		65,383	92.3	92.3

Table 2
Descriptive statistics for water quality and operational factors ($n = 52$).

Factor	Minimum	Maximum	Mean	CV
Dissolved oxygen (mg/L)	3.2	10.2	6.7	27
pH (standard units)	7.9	9.0	8.3	–
Salinity (ppt)	29.3	55.1	41.6	19
Conductivity (μS/cm)	22,755	79,117	60,710	22
Temperature (°C)	7.1	32.2	23.9	2

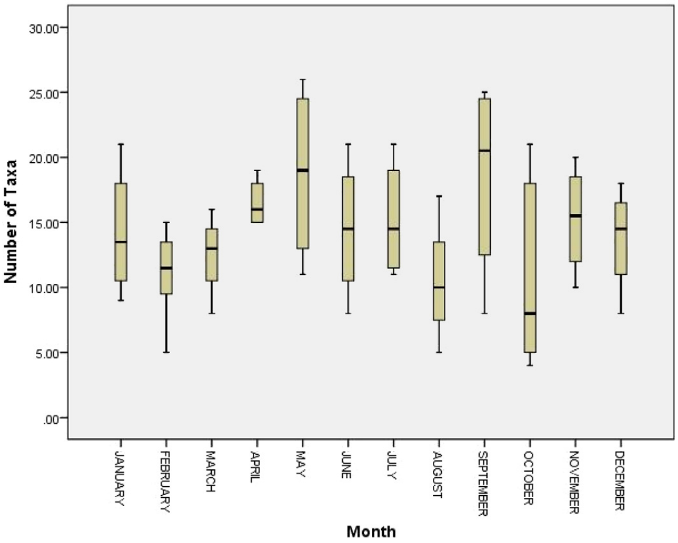

Fig. 3. Number of taxa impinged per month at the Barney M. Davis power plant in Corpus Christi, Texas. May and September had the greatest number of taxa per sample. The range of taxa overlapped for all months and shows a strong seasonal trend.

Two screens were operating during 71% of the sampling hours and one screen during 15% of the sampling hours. The use of three or four screens occurred during 14% of the sampling hours when the hourly average flow was highest.

Water quality factors

Table 2 provides descriptive statistics for water quality factors monitored during the study. Dissolved oxygen, salinity and conductivity showed the greatest variability while temperature showed very little variation.

Temporal factors

Fig. 4 illustrates the total number of organisms impinged by sampling month. January through March accounted for 70% of all impinged fish and shellfish. Fig. 5 shows the overall number of impinged fish and shellfish at four sampling times. Total impingement was greatest at time $= 0:00$ h (midnight) and continues to decrease through 12:00 h (midday), when total

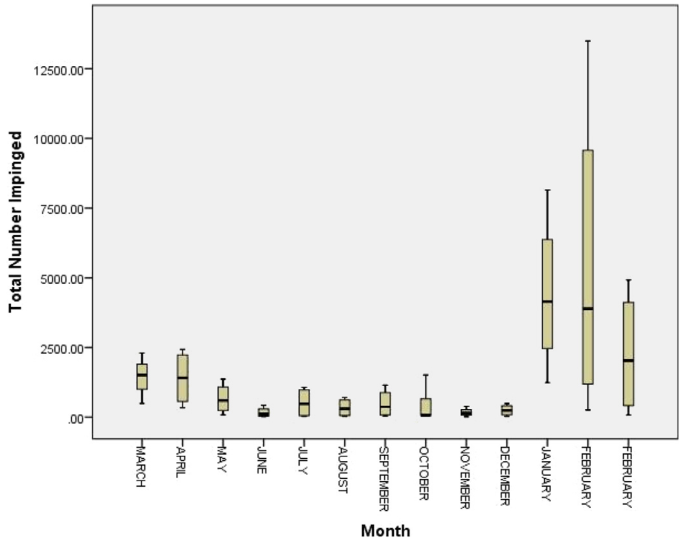

Fig. 4. Total number of impinged fish and shellfish by month. January and February were the highest impingement months.

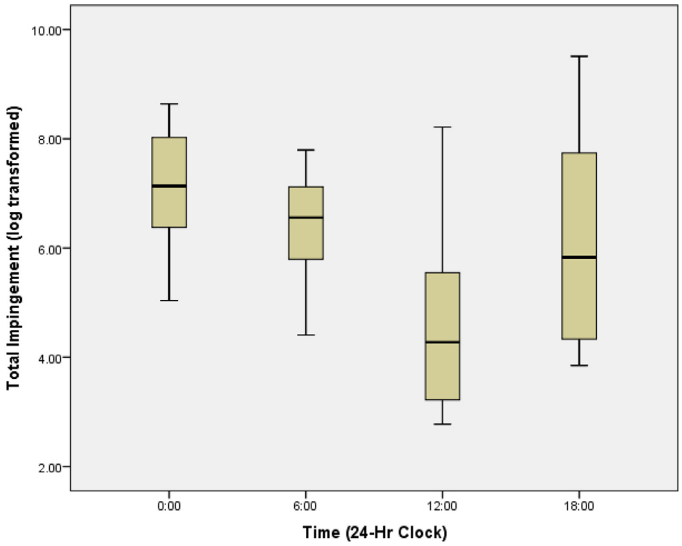

Fig. 5. Total number of impinged fish and shellfish by sampling hour.

impingement was lowest. Impingement increases again between 12:00 h and 18:00 h. The decrease between the greatest and lowest impingement is three orders of magnitude.

Correlation among variables

Table 3 shows the Pearson correlation matrix for the nine independent variables, and the total, fish and shellfish impinged. Salinity was highly correlated with conductivity, as expected, because it was estimated from conductivity. The number of operating screens was highly correlated with hourly average flow because operators operate more screens when flows are increased.

Water quality and temporal variables

With the exception of salinity and number of operating screens, none of the other independent variables were autocorrected or demonstrated multicollinearity. When salinity was included in the model, the VIF was greater than 5, indicating multicollinearity. Thus, salinity was removed from the model. Interestingly, the number of operating screens was autocorrelated with hourly flow, but did not result in a VIF greater than 5, implying that, while autocorrelated, the number of operating screens was not collinear with hourly average flow.

Models using each operational variable separately or simultaneously did not explain fish, shellfish or total impingement. However, multiple regression revealed that sampling month was significant (Table 4). Sampling time was significant for shellfish and total impingement, while dissolved oxygen was significant for fish and total impingement. There was no

Table 3
Pearson correlation matrix for the nine independent variables, total, fish and shellfish impingement at the time of impingement measurements ($n = 52$).

	Temp	Conductivity	Salinity	pH	DO	Month	Time	Operating screens	Hourly flow
Total Im	−0.454**	−0.155	−0.314*	−0.187	0.243	−0.594**	−0.33*	−0.173	−0.256
Fish Im	−0.493**	−0.170	−0.287*	−0.178	0.359**	−0.562**	−0.13	−0.197	−0.267
Shellfish Im	−0.112	−0.009	−0.163	−0.083	−0.089	−0.388**	−0.48**	−0.110	−0.167
Temp	1								
Conductivity	0.620**	1							
Salinity	0.729**	0.868**	1						
pH	0.641**	0.621**	0.765**	1					
DO	−0.432**	−0.588**	−0.491**	−0.235	1				
Month	0.408**	0.094	0.231	0.007	−0.228	1			
Time	−0.009	−0.155	−0.032	−0.075	0.339*	−0.014	1		
Operating screens	0.077	−0.173	−0.226	−0.165	−0.027	0.296*	−0.135	1	
Hourly flow	0.427**	0.025	0.075	0.227	−0.102	0.345*	−0.085	0.714**	1

* Significant at $p = 0.05$ (2-tailed).
** Significant at $p = 0.01$ (2-tailed).

Table 4
Variables significantly impacting impingement as determined by multiple regression analysis ($\log_e$-transformed data).

Variables	B	Sig
Impinged fish ($R^2 = 0.414$)		
Constant	11.561	0.109
Sampling month	−0.184	0.005
Dissolved oxygen	0.352	0.017
Impinged shellfish ($R^2 = 0.343$)		
Constant	22.469	0.016
Sampling month	−0.270	0.001
Sampling time	-4.06×10^{-5}	<0.001
Total impinged organisms ($R^2 = 0.498$)		
Constant	16.832	0.013
Sampling month	−0.233	<0.001
Sampling time	-3.08×10^{-5}	<0.001
Dissolved oxygen	0.266	0.047

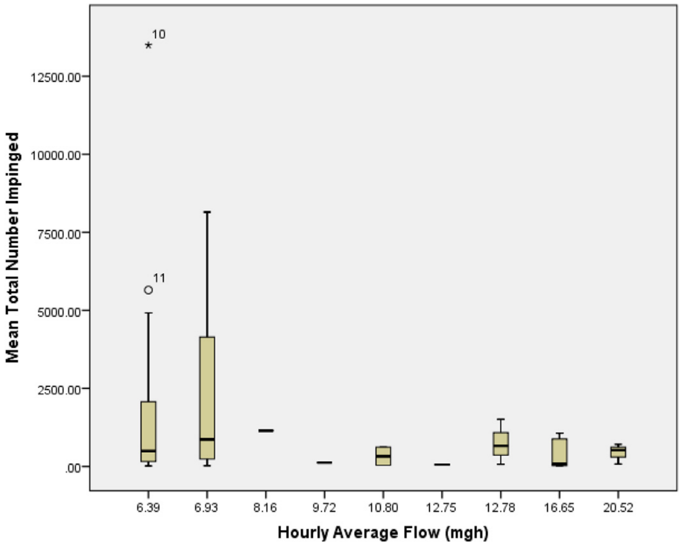

Fig. 6. Total number of fish and shellfish impinged (all taxa) at various hourly flow rates (million gallons per hour). * 10 &° 11 are outliers resulting primarily from the number of fish impinged.

association between total impingement and average hourly flow. Fig. 6 shows the mean number of impinged organisms across all screens at various flows.

4. Discussion

Various types of fine-mesh screens are used at power plant facilities to keep debris from entering intakes and clogging piping and equipment. Fine mesh screens reduce entrainment but increase impingement of fish and shellfish. Fish trapped on the screen surface may suffer injury, asphyxiation, and mortality (Azila and Chong, 2010). The force of water holding fish to screens, when concurrent with movement of the fish, can result in descaling, eye injury, and other soft tissue injuries (Shaw, 2010). The EPA indicated that impingement mortality also occurs from starvation, exhaustion, asphyxiation, and physical damage (EPA, 2002). Cold stress is a factor for some species because they can become lethargic and succumb to water currents, resulting in impingement (Mclean et al., 1982). An understanding of associated factors may help reduce impingement and thereby decrease impingement mortality.

Operational factors

A primary reason for examining operational factors is that they are more tractable for impingement mitigation. Hourly average flow, however, was not a significant predictor of total impingement, fish impingement, or shellfish impingement. Water quality and temporal factors appear more important in determining what is impinged and when. There are several possible reasons for this finding. During the study there was little variation in average hourly flow. It is uncertain whether greater variation in flow would reveal a stronger association. Analysis of shorter time periods, with more variable flow, produced similar results. Moreover, hourly average flow is an indirect measure of approach velocity, which is a more important risk factor for impingement (Boreman, 1977; Peake, 2004). Approach velocity has been defined as the average water velocity measured a few centimeters in front of the screen, taken in the same direction as general flow (EPRI, 2000). Thus, hourly average flows may have a range of approach velocities depending on the number of operating screens, screen blockage and water elevation, among other factors. Information on the variation in approach velocity at different flows and number of operating screens may clarify the relationship between average hourly flow rate and impingement.

There was also no significant association between fish, shellfish or total impingement and the number of operating screens. Similar to flow, this may be due to the small variation in the number of operating screens. A study that includes greater variation in the number of operating screens may reveal a stronger relationship with impingement.

The small variation in flow and number of operating screens may have helped discern the effects of water quality and temporal factors on impingement. The results show those effects when flow and the number of operating screens are nearly constant.

Water quality factors

A positive relationship between fish or total impingement and oxygen concentration appears counterintuitive, but may be related to swimming performance for some fish species (Herbert and Steffensen, 2005). One study noted that Atlantic herring increased swim speed during severe hypoxia to find more favorable conditions, even shifting position within a school of fish (Domenici et al., 2000). This suggests that oxygen concentrations may act through behavioral cues in which increased oxygen concentrations attract fish. Another study pointed to the role dissolved oxygen plays in predator–prey interactions and escape behavior, as well as swimming and feeding behaviors of predators (Breitburg et al., 1997; Kolar and Rahel, 1993). In the present study, dissolved oxygen was not significantly associated with shellfish impingement.

Temperature was not significantly associated with fish, shellfish or total impingement. However, it was significant when all other variables except month were removed from the model. Temperature may acts as a weak abiotic cue or in combination with month in affecting migration and spawning (McCleave, 1978). With every 10 °C rise in water temperature above 7.1 °C, there was an approximate 1% decrease in the rate of fish impingement. Other studies confirm the importance of temperature as a predictor of fish impingement (King et al., 2010). Temperature corresponds to seasonal changes in migration and recruitment patterns (Humston et al., 2000; Sims et al., 2004).

Fish in higher abundance near the power plant when temperature is optimal are also at higher risk of impingement. Low water temperature (< 10 °C) increases impingement because it reduces fish motility (Rulifson, 1977; Saalfeld, 2006). The correlation between impingement and temperature in the present study is likely a function of monthly abundance related to fish spawning (Claridge et al., 1986).

Temporal factors

The decrease in shrimp impingement between 6:00 and 18:00 h is likely related to nocturnal activity patterns. Several studies have shown increased activity among Penaeid and Caridean shrimp at night (Grave et al., 2006; (Matthews, 1991); Robertson et al., 1993; Unsworth et al., 2010). Vance (1992) found that impingement of juvenile Penaeid shrimp was greatest at night near high tide. Primavera and Lebata (1995) showed that shrimp burrowed during the day and emerged at night. The increased nocturnal activity of shrimp may help reduce impingement because power generation is often reduced at night. This reduces the volume of cooling water and number of screens needed, especially during the winter when water temperature is lower. Reductions in flow and screen usage occur when most shellfish and several fish taxa rise from the benthos into the water column, resulting in less impingement.

The number of impinged fish and shellfish was correlated with sampling month, an indication that changes in populations are seasonal. Total impingement was highest from January to March and decreased approximately 20% for each successive month from January through December. Declines in fish impingement were similar to those of total impingement, although shellfish numbers increased slightly in July and September. Changes in life stage abundance may best explain monthly impingement observations. For example, the annual movement of larval Gulf Menhaden into estuaries along the Gulf of

Mexico during the winter is well documented (Lyczkowski-Shultz et al., 1990). Also, the abundance of brown shrimp, accounting for 18% of impinged organisms in this study, peaks during the winter (Matthews, 1991).

Strengths and limitations

The complex relationship between study factors and impingement makes selection of models, model variables, and interpretation difficult. A study of five power plants in Alabama used 12 factors in evaluating impingement (Saalfeld, 2006); a study of three power plants in Belgium used four (Maes et al., 1998), and yet another of two power plants in Indiana used three (Lewis and Seegert, 2000). Saalfeld (2006) reported that several biological, water quality, and hydrological factors likely influence impingement, but little is known about their specific impacts. One study pointed out that biological and water quality factors are much stronger indicators of impingement risk at power plants than operational and design factors (King et al., 2010). Some researchers also have indicated that water quality and temporal factors affect behavior, which in turn affects impingement. For example, the presence of a response hierarchy to water quality signals may account for postlarval Penaeid Shrimp migration into estuaries with different hydroperiods and salinity regimes (Matthews et al., 1991; Vance, 1992). The complex interactions among factors is not unexpected because the structure of aquatic communities is diverse and often exhibits both cyclical and linear changes in abundance (Gido et al., 2013; Schaffler et al., 2013).

It is also important to note that comparisons between this study and other impingement studies can be difficult. The industry standard cooling water intake structure mesh size is 3/8 in (9.5 mm), whereas, the Davis Power Plant employs fine-mesh (1 × 2 mm) screens. Early life stages that would normally entrain at most facilities are impinged at the Davis Power Plant. The sudden abundance of early life stages associated with an estuarine system may be the most important variable because at these stages many organisms cannot overcome the water current, even when approach velocities are relatively low.

The Laguna Madres is a large, shallow bay with abundant seagrass. During this study the most commonly collected species were manatee grass (*Cymodocea filiformis*), shoal grass (*Halodule beaudettei*), and turtle grass (*Thalassia testudinum*). Seagrass loading on intake screens may be another complicating factor when evaluating variables. Some organisms use the floating seagrass as cover (Tunnell and Judd, 2002). As a result, impingement of certain taxa may be associated with the extent of seagrass loading.

5. Conclusions

Dissolved oxygen, sampling month and sampling time were correlated with the total number of impinged organisms. Temperature was also significantly correlated with the number of impinged fish. Month and temperature are likely important factors affecting the abundance of fish and shellfish (i.e., what is available to be impinged). Sampling time reflects periods of increased activity when shellfish swim higher into the water column and are at greater risk of impingement.

The number of operating screens and average hourly flow were not correlated with total impingement, fish, or shellfish impingement. Reasons for the lack of association may be related to the low variation in these factors throughout the study period. Further study with more variation in both flow and the number of operating screens is necessary to determine whether changes in operating regimes will be useful in reducing impingement.

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