APPLICATION OF INTERVENTION ANALYSIS TO POWER PLANT MONITORING DATA

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Introduction

During the 1960's and 1970's, public awareness and concern developed over the effects of industry on the environment. Such awareness prompted governmental regulation of power plant construction and operation. Many of the resulting regulations stipulated requirements for environmental monitoring and impact assessment studies. Some of these studies have produced long time-series of data. This paper describes the result of a research effort that summarizes long-term biological monitoring data collected at a nuclear power plant and applies intervention analysis to the data series for assessing impact.

The power station

The Millstone Nuclear Power Station (MNPS) complex is located on the north shore of Long Island Sound (LIS) (Fig. 1) in Waterford, Connecticut (Fig. 2), and is a Northeast Utilities (NU) facility. Three power plants are located on Millstone Point, which is bounded on the west by Niantic Bay, on the east by Jordan Cove and on the south by Twotree Channel (Fig. 3). Electric generating capacities (MW-e), cooling water flow rates (m^3/s) and important dates are listed in Table 1.

Table 1. Capacities and dates of construction and operation for the three power plants at Millstone Nuclear Power Station.

	Capacities		Start dates	
Unit	MW-e	m^3/s	Construction	Operation
1	652	26.48	12/15/65	11/29/70
2	870	34.55	6/30/70	10/17/75
3	1150	56.63	6/30/75	4/28/86

All three plants have once-through condenser cooling water systems. The necessary water is drawn by separate shoreline intakes located along Niantic Bay (Fig. 3). The intake structures have trash racks and traveling screens to remove larger items from the cooling water. The water is heated no more than 12°C above ambient and returned to LIS through an abandoned granite quarry. The warmed water exits the quarry at a high velocity, mixes with ambient water and, within 150 m of the quarry outlet, the surface water temperature of the thermal plume has cooled to 6°C above ambient (NUSCo 1982). Beyond this distance the configuration and extent of the plume varies with tidal currents (NUSCo 1983a).

Several processes associated with the construction and operation of the Millstone power plants could impact local biota. During construction, nearshore habitats were physically altered when coffer dams were built or removed and when critical shoreline areas were stabilized with accreted riprap. Population levels could be affected during operation because larger organisms are impinged on the intake screens and smaller organisms are entrained through the condenser cooling water system. The distributions of local biota could change because their habitat could be altered or influenced by the velocity or condition of the effluent.

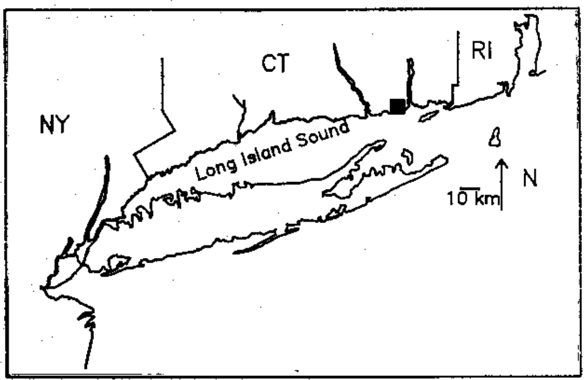

Figure 1. Location of the Millstone Nuclear Power Station in Long Island Sound.

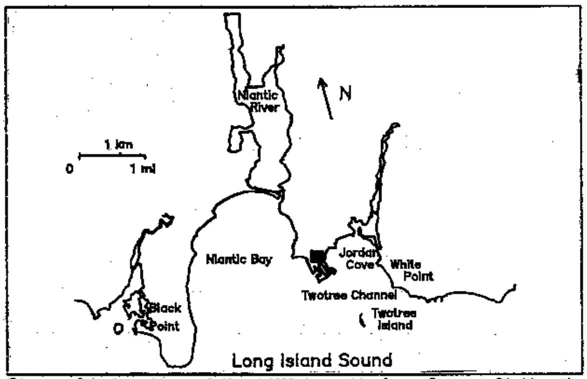

Figure 2. Location of the Millstone Nuclear Power Station in Greater Millstone Bight.

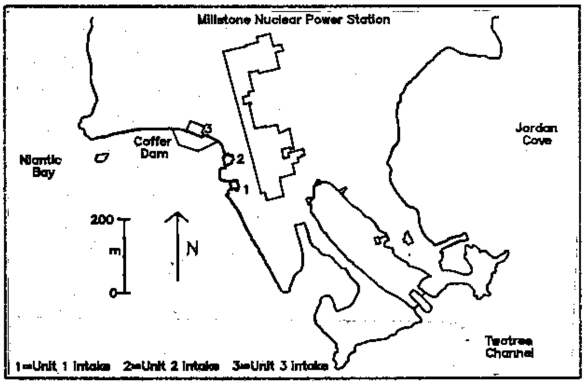

Figure 3. Site plan of the Millstone Nuclear Power Station.

The monitoring program

In the late 1960's, NU began a research program that would address the impact assessment needs and ecological monitoring at Millstone. A basic assumption made in establishing the studies was that the number of individuals of a species in a sample was a relative index of that species population level. The objectives of these studies were to: identify and enumerate the different species of plant and animal life that inhabit the Greater

Millstone Bight; describe historical fluctuations of potentially impacted populations; and evaluate whether variations are the result of natural variability or the result of power plant operation. These programs currently include studies of both benthic and fish ecology.

The problem

In general, observed changes in a population may result from natural or human-induced changes in the environment. To assess impact it is necessary to distinguish the effects of human activities on the environment from those fluctuations representing natural variability. Data from monitoring programs provide the basis for what kinds and how many organisms should occur in a given area at a certain time of the year--the natural variability. Typically, the magnitude of human-induced changes has been assessed through the use of statistical analyses based on normal distribution theory. Several problems existed that limited the applicability of this approach at MNPS. First, MNPS data had non-homogeneous variances and came from severely skewed, non-normal distributions. Second, the data were serially correlated. Normal-theory tests are very sensitive to failures in the assumption of independence of observations (Glass et al. 1972). If significant serial dependence does exist in the data, then confidence levels for probability statements will be inaccurate (Glass et al. 1975). Further, a statistically significant change may or may not be related to a biologically significant change. Consequently, it is difficult, using these methods, to determine whether an observed statistically significant change is the result of an impact or part of a biological pattern (Patrick 1977; Cushing 1979; Green 1984).

For these reasons, we searched for an alternate method to analyze fluctuations and assess impact. We found that for some series of fish catch data, predictive variables could be combined into the transfer function of an ARIMA model to explain observed catch fluctuations. In particular, the number of fish impinged at the intake of Unit 2 could be explained by a combination of cooling water flow volume and seasonal parameters. Additonal fluctuations could be explained by using intervention variables that corresponded to certain events that occurred during the construction and operation of Unit 3. The objectives of this paper are to:

1. Describe the methodology used to explain long-term variation in the number of fish impinged at MNPS Unit 2.

2. Hypothesize a relationship between changes in the number of fish impinged and the construciton and operation of Unit 3.

3. Describe the application of intervention analysis to show that some fluctuations could be attributed to an intervention effect.

Description of Unit 2 Data Series

Unit 2 cooling water

Water is drawn from Niantic Bay and circulated through condenser tubes to cool the steam that generates the electricity at Unit 2. Although the rated flow is 34.55 m^3/s, plant operating conditions cause the actual flow to vary somewhat. For example, during periods when the plant is shut down for refueling, cooling water requirements may drop to zero. In January 1976, an automated data acquisition system began to store actual flow rates in a computerized database. Average monthly flow rates are plotted in Figure 4; the entire series of total cooling water volume (million m^3/d) is shown in Figure 5.

To protect the four cooling water circulating pumps and the condenser tubes, the intake structure contains screens that can be rotated and washed. Screenwashes are initiated manually every 8 h, or automatically when a sufficient pressure differential exists from the accumulated material. Organisms and debris larger than the mesh size (9.5 mm) are retained by the screens and washed into a metal basket. Some organisms survive this process, but others may be injured or killed.

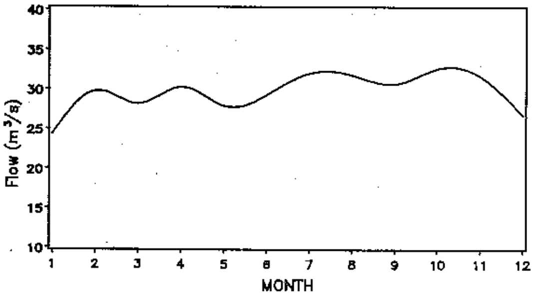

Figure 4. Mean monthly flows (m^3/s) for MNPS Unit 2, 1976 - 1985.

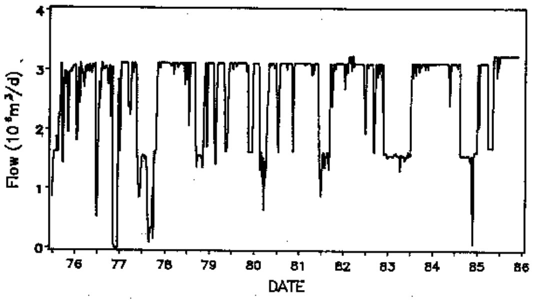

Figure 5. Total cooling water volume used (million m^3/d) at MNPS Unit 2, January 1976 through May 1986

Impinged fish

The numbers and kinds of fish impinged on the travelling screens at MNPS Unit 2 have been monitored since the plant became operational in 1975. Material washed from the screens accumulates for 24 h. At the end of the period, fish are counted and identified. During 1975 and 1976 a complete census (seven 24-h counts per week) of fish was conducted. In May 1977, the monitoring effort was reduced to three 24-h counts per week. After an extensive evaluation of the program, the frequency was reduced again in January 1985. The sampling effort was stratified to maximize the information obtained on a targeted fish species (winter flounder) and minimize overall sampling effort. Since then, 24-h impingement samples have been collected according to the following schedule: December and January, 2 samples per week; February, 4 samples per week; March 3 samples per week; and April through November 1 sample per week.

Of the more than 60 species of fish collected from the intake of Unit 2, I selected three to discuss here: winter flounder (*Pseudopleuronectes americanus*), silversides (*Menidia* spp.) and cunner (*Tautogolabrus adspersus*). These species made up 16%, 9% and 3%, respectively, of the fish impinged from 1976 through 1985 (Appendix 1). The winter flounder was chosen because the species is an abundant resident fish that has a demersal (bottom-dwelling) nature and seasonally migrates between deep and shallow waters. The silversides taxon was chosen to represent an abundant resident that seasonally migrates between habitats: shore zone in summer and deeper water in winter. The cunner was chosen because it is a relatively abundant resident that is dormant in winter.

Winter flounder, *Pseudopleuronectes americanus*. The winter flounder is a benthic fish found primarily in shallow coastal areas, bays and estuaries from Nova Scotia to New Jersey (Perlmutter 1947; Bigelow and Schroeder 1953). It is an important sport and commercial fish in Long Island Sound, Narragansett Bay, and adjacent estuaries (Pearcy and Richards 1962; Richards 1963; Oviatt and Nixon 1973). Winter flounder form discrete populations associated with individual coastal areas or estuaries (Saila 1961). In southern New England, winter flounder move into the nearshore area during late winter and spring to spawn and feed (Howe and Coates 1975). Individuals seldom stray far from breeding grounds (Saila 1961).

The winter flounder resident in the Greater Millstone Bight appear to follow the migration pattern typical for southern New England fish (Bireley 1985). Fish move into the Niantic River from December through March and historically were impinged in greatest numbers during this time (Fig. 6). However, during the winter of 1985-1986, fewer winter flounder were impinged than we would expect from the historical series (Fig. 7).

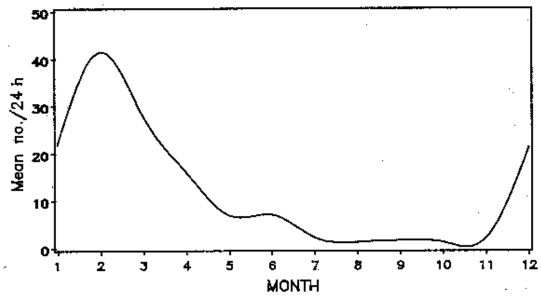

Figure 6. Monthly mean number of winter flounder impinged per day at MNPS Unit 2, 1976 - 1985.

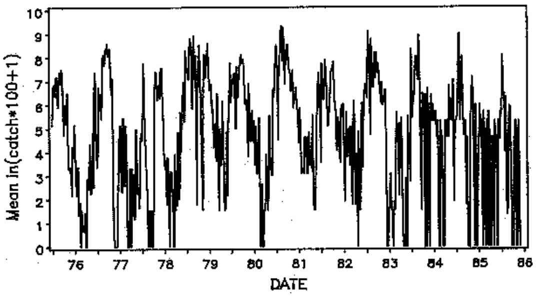

Figure 7. Number of winter flounder impinged per day at MNPS Unit 2, January 1976 - May 1986.

Silversides, *Menidia* spp. Although two species of silversides are found in the MNPS collections, over 80% are the Atlantic silverside, *Menidia menidia*. This species inhabits the coastal zone from Canada to Florida. It is a dominant shore-zone that moves into deeper water during winter (Bigelow and Schroeder 1953).

In the Greater Millstone Bight, silversides are found in shore zones off sandy beaches during spring, summer and fall, and in deeper waters during winter (Bireley 1985). They are most likely to be impinged during late fall and winter (Fig. 8) when they are, typically, in deeper water. As with winter flounder, fewer were impinged in the winter of 1985-1986 (Fig. 9).

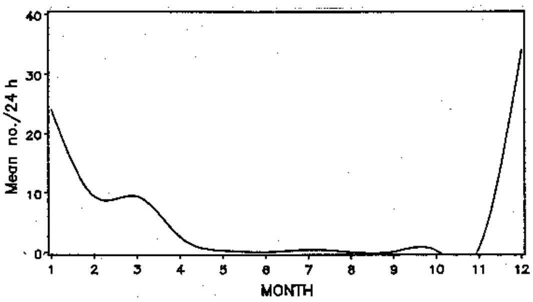

Figure 8 Monthly mean number of silversides impinged per day at MNPS Unit 2, 1976 - 1985.

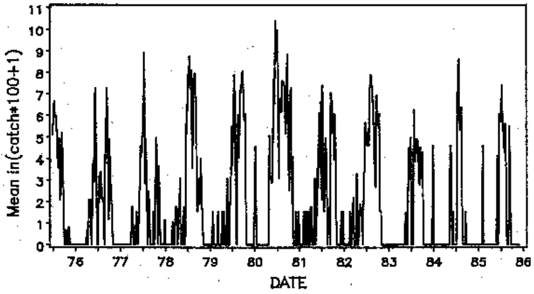

Figure 9. Number of silversides impinged per day at MNPS Unit 2, January 1976 through May 1986.

Cunner, *Tautogolabrus adspersus*. The cunner ranges from Newfoundland to Chesapeake Bay (Leim and Scott 1966) and is generally an inshore fish that lives near the bottom, close to rocks, vegetation, pilings or other reef-like structures (Bigelow and Schroeder 1953). Individuals are essentially solitary with small home ranges (Green 1975; Olla et al. 1975). In cold weather, cunner activity declines to a dormant state at a temperature of about 5 to 8°C. They then lie torpid among and under rocks (Green and Farwell 1971; Dew 1976).

Cunner resident in the Greater Millstone Bight favor areas close to shore and are most likely to be impinged during May, June and July (Bireley 1985). They are rarely impinged in the winter (Fig. 10). The whole series used is shown in Figure 11. As with the other species, fewer were impinged after November 1985 (Fig. 11).

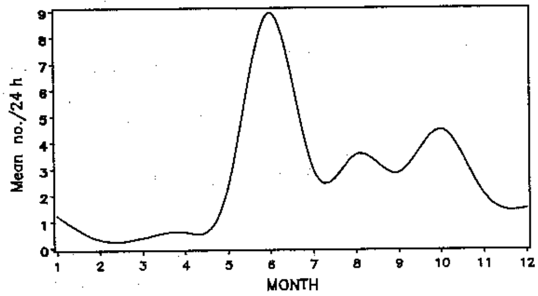

Figure 10. Monthly mean number of cunner impinged per day at MNPS Unit 2, 1976 - 1985.

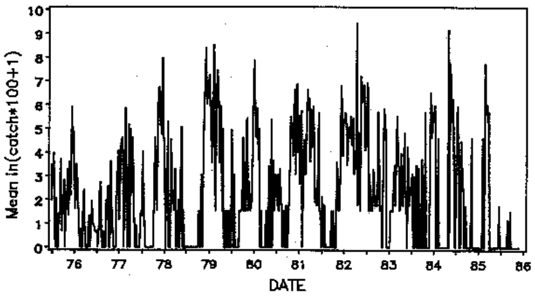

Figure 11. Number of cunner impinged per day at MNPS Unit 2, January 1976 through May 1986.

Data Analysis

Data handling

The data series available for analysis began in January 1976 and ended in May 1986. Although many factors determine whether an individual organism is impinged, flow was considered a major factor contributing to the impingement of fish at Unit 2. When more water was used, it seemed reasonable to expect that passing fish might experience a greater exposure to the risk of being impinged. Further, if no water were being used, no fish should be impinged. Because the true sampling interval varied from daily to weekly, all data were arbitrarily assigned to have been collected on one date during the week (Sunday). All collections made within the following week were considered replicate samples. The flow associated with each 24 h fish collection was the total volume of cooling water used by Unit 2 during that collection period.

Previous investigations (NUSCo 1983a, 1983b) revealed that the catches of impinged fish came from highly skewed, non-normal distributions, with non-homogeneous variances. For these reasons the data were log transformed (see Glass et al. 1975):

$$Y = \ln((\text{Catch} * c)+1).$$

The constant, c, was chosen so that incrementing (Catch*c) by 1 added less that 1% to the overall mean catch of the species. The catches of all three species discussed here were multiplied by 100. Because the median is a better choice than the arithmetic mean as a measure of central tendency in highly skewed distributions and because the geometric mean is an estimate of the median in a log-normal distribution (Sokal and Rohlf 1969), all catches in a week were averaged after transformation. The 24 h cooling water volumes associated with the catches were also averaged weekly.

It seemed reasonable to conclude from the seasonal pattern of impingement observed (see Figs. 7 -11) that, besides flow, some sort of seasonal factor might affect the numbers of fish impinged. Harmonic functions of time were used to describe this cyclic nature of the fish catch series. The actual argument of the sine and cosine functions was the time (in days from the beginning of the series) expressed as radians scaled for the number of days in the cycle that was being described (Bliss 1958; Lorda and Saila 1986):

$$\sin(x)=\sin(t*2pi*x*365.25/12)$$
$$\cos(x)=\cos(t*2pi*x*365.25/12)$$

where t=number of days from the beginning of the series, pi=3.1416, x= number of months in the cycle being described. The numbers 365.25 and 12 are the number of days and months in a year, respectively. It did not make any biological sense to include a cycle that was not completed a whole number of times a year. Thus the values of x were restricted to even fractions (harmonics) of a basic period of one year. Multi-year harmonic terms were considered if the cycle they described could be completed twice in the series.

Intervention series

Three possible activities that occurred during the construction and operation of Unit 3 could have affected the number of fish impinged at Unit 2: the presence or absence of a coffer dam around the Unit 3 intake structure; construction activities associated with the installation of the coffer dam; and the operation of three or more of the six Unit 3 circulating water pumps.

Construction of the coffer dam around the Unit 3 intake structure was completed about the time Unit 2 began operation. While it was present, it provided an ideal rocky habitat in close proximity to the Unit 2 intake. Cunner are known to prefer this type of habitat and the Unit 3 coffer dam might attract them near the Unit 2 intake. Thus, I hypothesized that the catches of cunner at Unit 2 might be affected by the presence or absence of the coffer dam. Further, the coffer dam altered the configuration of the shoreline in the vicinity or the Unit 2 intake. It, therefore, also seemed reasonable to expect that fish moving past the intake area (winter flounder or silversides) might alter their patterns of movement as a result of the presence (or absence) of the coffer dam.

In April 1983, demolition of the coffer dam began. For the next five months removal and dredging activities eliminated the rocky habitat and altered the soft-bottom habitat. It seemed reasonable to expect that the removal of the coffer dam and associated dredging would significantly alter the habitat proximal to the Unit 2 intake. This might affect fish distributions in at least two ways. Some fish might avoid the area in response to suspended silt, noise or general disruption (cunner or silversides); bottom-feeding fish (winter flounder) might be attracted to the area to feed on animals churned up from the mud. Since September 1983 the shore-line configuration has remained stable and is quite different from the configuration that existed during most of the Unit 2 impingement series. Although Unit 3 began commercial operation on March 27, 1986, preoperational testing required that the circulating water pumps be operated fairly consistently during late 1985 and early 1986. Since Unit 3 began commercial operation, the circulating water pumps have run consistently.

Because of these Unit 3 activities, I included intervention variables for coffer dam presence, coffer dam construction (or demolition) and the operation of Unit 3 circulating water pumps to potentially describe fluctuations in the number of fish impinged at Unit 2. These series are represented as either 1 (coffer dam present, presence of construction activities associated with the installation or removal of the coffer dam, Unit 3 pumps running) or 0 (coffer dam absent, no coffer dam construction activities, no Unit 3 pumps operating) (Fig. 12).

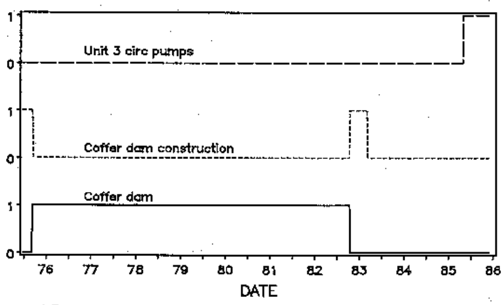

Figure 12. Intervention series for presence of a coffer dam and operation of three or more Unit 3 circulating water pumps, January 1976 through May 1986.

Model building

This technique has been successfully applied to other series of biological monitoring data and is described in detail for those in Bireley (1985). A summary of the application to impingement data follows.

The first step was to find the best possible mathematical description of the historical (1976 through 1984) Unit 2 fish catch series. The principal regression variables considered at this stage were flow and harmonics describing cycles from 3 mo to 5 y. However, because activities associated with the Unit 3 intake coffer dam might also affect the numbers of fish impinged at Unit 2 during this period, intervention terms for coffer dam presence and coffer dam construction were also included.

PROC STEPWISE of the SAS® system was used to find the best combination of predictor variables. The analysis followed the maximum R^2 improvement technique developed by James Goodnight (SAS 1985). For the three species considered, flow alone was the best one-variable model. Both the sine and cosine functions are needed to accurately describe a harmonic function. Thus when one of a pair of sine/cosine functions entered the model the other was forced to enter the model (by using INCLUDE=) before other explanatory variables were allowed to enter. Model selection stopped when the F-statistic for the the variable that just entered the model was less than two (or the sum of the F-statistics for a harmonic pair was less than 4).

Once the best combination of predictor variables was selected this combination was then used as a transfer function in the SAS/ETS® system, PROC ARIMA (SAS 1984). The autocorrelation (ACF), partial autocorrelation (PACF) and inverse autocorrelation functions (IACF) were used to identify the error structure of the residuals from the transfer function model (see Brocklebank and Dickey 1986). Because the responses of the series to the coffer dam activities were expected to be immediate shifts to new levels, no lagged polynomials were included in either the numerator or denominator of the input statement describing the transfer function for these interventions. When all (transfer function, autoregressive and moving average) parameters were estimated simultaneously, the t-statistics for some parameters frequently dropped below 2 (or the sum for a harmonic pair dropped below 4). Such terms were dropped from the model one (or one pair) at a time beginning with the smallest t-statistic until all remaining parameters were significantly different from 0. Other statistics were also considered in this model selection process. Generally, the Akaike Information Criterion (AIC) (Akaike 1976) and variance estimate (s^2) were minimized when the previous selection process was followed.

I was particularly interested in explaining a drop observed in the impingement of fish at Unit 2. Although the drop was not immediately obvious from the data series (see Figs. 7, 9 and 11), it seemed to coincide with the initiation of Unit 3 circulating water pump operation. Thus the next step was to include an intervention term for Unit 3 pump operation and model the entire (January 1976 through May 1986) series. As in the previous intervention cases, I hypothesized an immediate shift in the level of the impinged fish series, so no ratio of lagged polynomials was specified in the INPUT part of PROC ARIMA's ESTIMATE statement. The statements used for the time series model building for each of the three species are listed in Appendix 2.

Results and Discussion

Winter flounder

The model selection process for historical winter flounder series (1976-1984) resulted in a "best" model that contained the following terms (in the order they entered the model during the STEPWISE procedure): flow, one-year cycle, coffer dam presence, coffer dam demolition, and five-year cycle. The last three dropped out during the ARIMA modeling leaving the terms listed in Table 2 to best describe the historical pattern of winter flounder impingement (r^2=0.92). This model accounted for 88% of the variance of the data series (January 1976 - May 1986), and January 1984 through May 1986 is plotted in Figure 13. The parameter estimates for the intervention model that included Unit 3 circulating water pump operation (PUMPON) are presented in Table 3. This intervention model accounted for 89% of the variance of the data series (January 1976 - May 1986) and is plotted in Figure 14.

Table 2. Parameter estimates for the model that best described historical (1976-1984) winter flounder impingement catches.

Parameter	Estimate	Std. Err.	T ratio	Lag	Variable
MA1,1	0.47789	0.07921	6.03	1	Z
AR1,1	0.79673	0.05446	14.63	1	Z
SCALE1	1.01100	0.14200	7.14	0	FLOW
SCALE2	1.90344	0.23625	8.06	0	SIN_1Y
SCALE3	1.05491	0.23413	4.51	0	COS_1Y

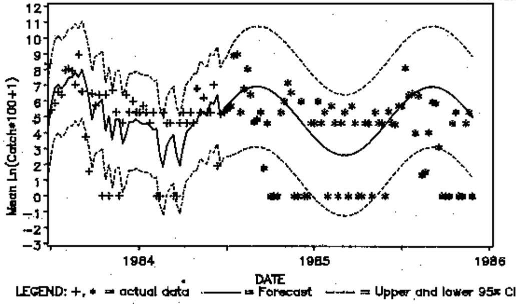

Figure 13. Plot of historical model of winter flounder, January 1984 through May 1986. Data represented by (+) were used to build the model; data represented by (*) did not contibute to parameter estimates.

Table 3. Parameter estimates for the intervention model that best described winter flounder impingement catches, January 1976 - May 1986.

Parameter	Estimate	Std. Err.	T ratio	Lag	Variable
MA1,1	0.49199	0.08018	6.14	1	Z
AR1,1	0.78124	0.05762	13.56	1	Z
SCALE1	1.09100	0.14200	7.67	0	FLOW
SCALE2	-2.23974	0.69304	-3.23	0	PUMPON
SCALE3	1.70383	0.22475	7.58	0	SIN_1Y
SCALE4	1.13157	0.22330	5.07	0	COS_1Y

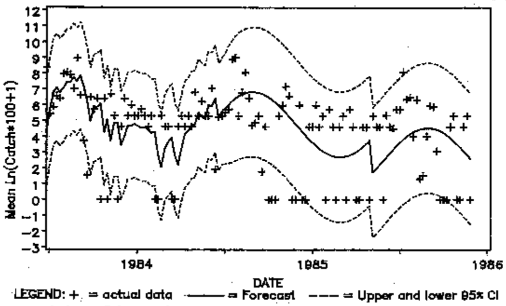

Figure 14. Plot of intervention model of winter flounder, January 1984 through May 1986.

At first inspection it might not seem that accounting for an additional 1% of the variance in the whole data series is much of an improvement. However, consider that the series has 540 observations and that the technique was sensitive enough to detect a shift in level of 5% of the observations, the last 30 data points. The intervention model accounted for 28% more of the variation from January 1985 and May 1986 than did the historical model. Further, for this particular species of fish, the magnitude of the effect as estimated by the parameter estimate was greater than the effects associated with the seasonal (sine and cosine) terms. Because significant autocorrelation does exist in the series, these parameter estimates would have been imprecisely estimated by conventional regression techniques.

Silversides.

The model selection process for silversides series (1976 - 1984) resulted in a "best" model that contained the following terms (in the order they entered the model during the STEPWISE procedure): flow, one-year cycle, six-month cycle, intervention variable describing the presence of the Unit 3 coffer dam and two-year cycle. The intervention and the two-year cycle terms dropped out during the ARIMA modeling leaving the terms listed in Table 4 to best describe the historical pattern of silversides impingement (r^2=0.79). This model accounted for 75% of the variance of the data series (January 1976 - May 1986) and January 1984 through May 1986 is plotted Figure 15. The parameter estimates for the intervention model that included Unit 3 circulating water pump operation (PUMPON) are presented in Table 5. This intervention model accounted for 76% of the variance of the data series (January 1976 - May 1986) and is plotted in Figure 16.

Table 4. Parameter estimates for the model that best described historical (1976-1984) silversides impingement catches.

Parameter	Estimate	Std. Err.	T ratio	Lag	Variable
AR1,1	0.51004	0.03995	12.77	1	Z
AR1,2	0.11812	0.04090	2.89	12	Z
SCALE1	0.63992	0.13803	4.64	0	FLOW
SCALE2	0.64288	0.15516	4.14	0	SIN_6M
SCALE3	0.22418	0.15475	1.45	0	COS_6M
SCALE4	1.40976	0.19405	7.26	0	SIN_1Y
SCALE5	2.15247	0.19209	11.21	0	COS_1Y

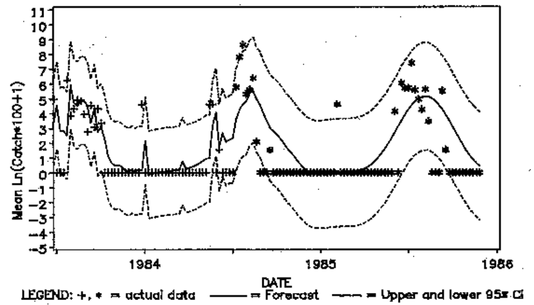

Figure 15. Plot of historical model of silversides, January 1984 through May 1986. Data represented by (+) were used to build the model; data represented by (*) did not contibute to parameter estimates.

Table 5. Parameter estimates for the intervention model that best described silversides impingement catches, January 1976 - May 1986.

Parameter	Estimate	Std. Err.	T ratio	Lag	Variable
AR1,1	0.50901	0.03685	13.81	1	Z
AR1,2	0.10605	0.03708	2.86	12	Z
SCALE1	0.65659	0.12884	5.10	0	FLOW
SCALE2	-1.32990	0.63645	-2.09	0	PUMPON
SCALE3	0.59863	0.14809	4.04	0	SIN_6M
SCALE4	0.41279	0.14775	2.79	0	COS_6M
SCALE5	1.30297	0.18356	7.10	0	SIN_1Y
SCALE6	2.16587	0.18220	11.89	0	COS_1Y

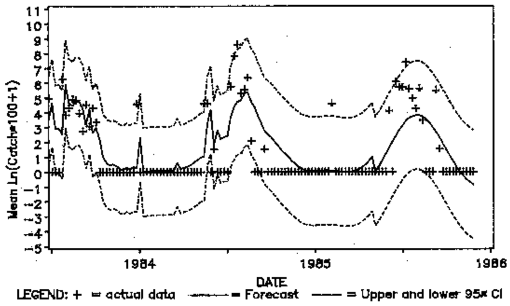

Figure 16. Plot of intervention model of silversides, January 1984 through May 1986.

One reason the silversides series was selected for analysis was because these fish, like winter flounder, tend to be impinged during the winter. Because the effect of Unit 3 pumps was first observed in winter I hoped that another species collected frequently during that time would also show the effect. Even though silversides make up a much smaller fraction of the impingement catch than do winter flounder, the modeling process revealed a significant effect associated with the operation of the Unit 3 circulating water pumps. In addition, the intervention model explained 27% more of the variation that occurred from January 1985 through May 1986 than did the historical model. As with winter flounder, the magnitude of the effect was similar to the seasonal effects. Because significant autocorrelation does exist in the series, these parameter estimates would have been imprecisely estimated by conventional regression techniques.

Cunner.

The selection process for cunner series (1976-1984) resulted in a "best" model that contained the following terms (in the order they entered the model during the STEPWISE procedure): flow, six-month cycle, one-year cycle and four-year cycle. The four-year cycle terms dropped out during the ARIMA modeling leaving the terms listed in Table 6 to best describe the historical pattern of cunner impingement (r^2=0.73). This model accounted for 66% of the variance of the data series (January 1976 - May 1986). A plot of the model is presented in Figure 17. The parameter estimates for the intervention model that included Unit 3 circulating water pump operation (PUMPON) are presented in Table 7 This intervention model accounted for 68% of the variance of the data series (January 1976 - May 1986) and is plotted in Figure 18.

Table 6. Parameter estimates for the model that best described historical (1976-1984) cunner impingement catches.

Parameter	Estimate	Std. Err.	T ratio	Lag	Variable
MA1,1	0.56564	0.06855	8.25	1	Z
AR1,1	0.85757	0.04249	20.18	1	Z
SCALE1	0.89100	0.08100	11.03	0	FLOW
SCALE2	-0.50409	0.20212	-2.49	0	SIN_6M
SCALE3	0.65688	0.20052	3.28	0	COS_6M
SCALE4	-0.43202	0.27826	-1.55	0	SIN_1Y
SCALE5	-0.90780	0.27432	-3.31	0	COS_1Y

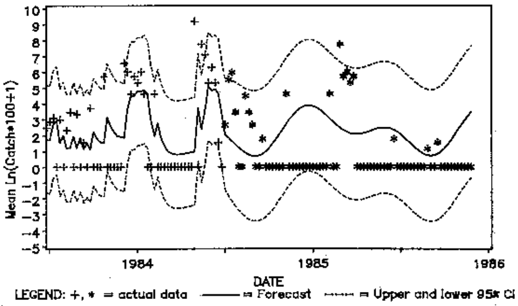

Figure 17. Plot of historical model of cunner, January 1984 through May 1986. Data represented by (+) were used to build the model; data represented by (*) did not contibute to parameter estimates.

Table 7. Parameter estimates for the intervention model that best described cunner impingement catches, January 1976 - May 1986.

Parameter	Estimate	Std. Err.	T ratio	Lag	Variable
MA1,1	0.53308	0.06531	8.16	1	Z
AR1,1	0.84209	0.04169	20.20	1	Z
SCALE1	0.88400	0.07600	11.66	0	FLOW
SCALE2	-2.11208	0.81365	-2.60	0	PUMPON
SCALE3	-0.35873	0.19361	-1.85	0	SIN_6M
SCALE4	0.53439	0.19307	2.77	0	COS_6M
SCALE5	-0.41124	0.26047	-1.58	0	SIN_1Y
SCALE6	-0.72263	0.25681	-2.79	0	COS_1Y

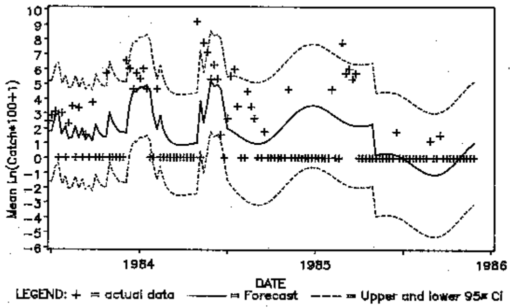

Figure 18. Plot of intervention model of cunner, January 1984 through May 1986.

The cunner series was originally selected for two reasons. I suspected that its behavior of inhabiting rocky areas (such as the Unit 3 coffer dam) and remaining dormant in winter made it less likely to be impinged during the season for which most of the Unit 3 pump data occurred. This made the species a likely candidate for showing an intervention effect due to the presence of the coffer dam but not due to the operation of Unit 3 circulating water pumps. This, however, was not the case. As with winter flounder, the intervention model that included an estimate of the parameter associated with the intervention variable (PUMPON) accounted for 34% more of the variance in the series from January 1985 through May 1986 than did the historical model. Also like winter flounder the magnitude of the effect associated with the intervention variable was larger than any parameter estimates associated with seasonal (sine and cosine) terms.

Summary and Conclusions

Three series of fish catches from MNPS Unit 2 impingement were selected for intervention analysis: winter flounder, silversides and cunner. These species were selected because they represented different habitats (benthic, shore zone and reef-like) and exhibited different behaviors (most active in nearshore areas in winter, migrate to deeper waters in winter and dormant in winter). It was suspected that the time series of their impingement at Unit 2 might have responded differently to the presence or absence of the Unit 3 coffer dam, or coffer dam construction or demolition, or the initiation of the operation of the Unit 3 circulating water pumps. The data from 1976 through 1984 were used to develop historical models that best described catch fluctuations during that period. Not unexpectedly, the catches of all three were significantly influenced by Unit 2 cooling water volume, which varied from 0 to 3 x 10^6 m^3/d, and harmonic parameters (to describe seasonal fluctuations). None of the series were influenced during this period by an intervention variable for the presence or absence of a coffer dam or coffer dam construction activities. When the entire series of all three species were analysed for an effect due to the operation of the Unit 3 circulating water pumps, all three models included paramter estimates for the intervehtion variable. In all cases the magnitude of the effect due to Unit 3 pumps was of the same order of magnitude as those describing seasonal fluctuations. Further, during the period of intervention, the intervention models accounted for 27 to 34% more of the variation than did the historical models. If the fluctuations in these series are well described by flow and seasonal parameters, the successful modeling of these series with an intervention term suggests the technique provides a sensitive way of assessing change.

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Appendix 1. Major fish species impinged at MNPS Unit 2, 1976 through 1985.

Species	Number	Percent
Pseudopleuronectes americanus	44,686	15.78
Myoxocephalus aenaeus	37,062	13.09
Anchoa spp.	33,455	11.81
Gasterosteus aculeatus	31,189	11.01
Microgadus tomcod	25,520	9.01
Menidia spp.	25,493	9.00
Gasterosteus wheatlandi	14,084	4.97
Syngnathus fuscus	10,285	3.63
Tautogolabrus adspersus	9,779	3.45
Peprilus tricanthus	9,427	3.33
Merluccius bilinearis	5,127	1.81
Scophthalmus aquosus	4,642	1.64
Morone americana	4,303	1.52
Tautoga onitis	3,762	1.33
Cyclopterus lumpus	3,404	1.20
Other	24,756	8.74

Appendix 2. Statements used in time series model building for winter flounder, cunner and silversides.

```
TITLE1 'Unit 2 impinged winter flounder, log transformed'
TITLE2 '1976-1984'
PROC ARIMA DATA=SUGI.FLOUNDR4;
   IDENTIFY VAR=FLOW NLAG=12 CENTER NOPRINT;
   ESTIMATE P=1 NOINT METHOD=ML;

   IDENTIFY VAR=Z
   CROSSCORR=(FLOW  SIN_1Y COS_1Y)
           NLAG=12 NOPRINT;
   ESTIMATE P=1 Q=1
   INPUT=(FLOW SIN_1Y COS_1Y)
   PRINTALL PLOT NOINT ALTPARM METHOD=ML;
   FORECAST LEAD=74 BACK=0 ID=WDATE INTPER=7;

TITLE1 'Unit 2 impinged winter flounder, log transformed'
TITLE2 '1976-May 1986'
PROC ARIMA DATA=SUGI.FLOUNDR6;
   IDENTIFY VAR=FLOW NLAG=12 CENTER NOPRINT;
   ESTIMATE P=1 NOINT METHOD=ML;

   IDENTIFY VAR=Z
   CROSSCORR=(FLOW PUMPON SIN_1Y COS_1Y)
           NLAG=12 NOPRINT;
   ESTIMATE P=1 Q=1
   INPUT=(FLOW PUMPON SIN_1Y   COS_1Y)
   PRINTALL PLOT NOINT ALTPARM METHOD=ML;
   FORECAST LEAD=74 BACK=74 ID=WDATE INTPER=7;

TITLE1 'Unit 2 impinged cunner, log transformed'
TITLE2 '1976-1984'
PROC ARIMA DATA=SUGI.CUNNER4;
   IDENTIFY VAR=FLOW NLAG=12 CENTER NOPRINT;
   ESTIMATE P=1 NOINT METHOD=ML;

   IDENTIFY VAR=Z
   CROSSCORR=(FLOW SIN_6M COS_6M SIN_1Y COS_1Y)
           NLAG=12 NOPRINT;
   ESTIMATE P=1 Q=1
   INPUT=(FLOW SIN_6M COS_6M SIN_1Y COS_1Y)
   PRINTALL PLOT NOINT ALTPARM METHOD=ML;
   FORECAST LEAD=74 BACK=0 ID=WDATE INTPER=7;

TITLE1 'Unit 2 impinged cunner, log transformed'
TITLE2 '1976-May 1986'
PROC ARIMA DATA=SUGI.CUNNER6;
   IDENTIFY VAR=FLOW NLAG=12 CENTER NOPRINT;
   ESTIMATE P=1 NOINT METHOD=ML;

   IDENTIFY VAR=Z
   CROSSCORR=(FLOW PUMPON SIN_6M COS_6M SIN_1Y COS_1Y)
           NLAG=12 NOPRINT;
   ESTIMATE P=1 Q=1
   INPUT=(FLOW PUMPON SIN_6M COS_6M SIN_1Y  COS_1Y)
   PRINTALL PLOT NOINT ALTPARM METHOD=ML;
   FORECAST LEAD=74 BACK=74 ID=WDATE INTPER=7;

TITLE1 'Unit 2 impinged silversides, log transformed'
TITLE2 '1976-1984'
PROC ARIMA DATA=SUGI.SLVRSID4;
   IDENTIFY VAR=FLOW NLAG=12 CENTER NOPRINT;
   ESTIMATE P=1 NOINT METHOD=ML;

   IDENTIFY VAR=Z
   CROSSCORR=(FLOW SIN_6M COS_6M SIN_1Y COS_1Y)
           NLAG=12 NOPRINT;
   ESTIMATE P=(1,12)
   INPUT=(FLOW  SIN_6M COS_6M SIN_1Y COS_1Y)
   PRINTALL PLOT NOINT ALTPARM METHOD=ML;
   FORECAST LEAD=74 BACK=0 ID=WDATE INTPER=7;

TITLE1 'Unit 2 impinged silversides, log transformed'
TITLE2 '1976-May 1986'
PROC ARIMA DATA=SUGI.SLVRSID6;
   IDENTIFY VAR=FLOW NLAG=12 CENTER NOPRINT;
   ESTIMATE P=1 NOINT METHOD=ML;

   IDENTIFY VAR=Z
   CROSSCORR=(FLOW PUMPON SIN_6M COS_6M
               SIN_1Y COS_1Y)
           NLAG=12 NOPRINT;
   ESTIMATE P=(1,12)
   INPUT=(FLOW PUMPON SIN_6M COS_6M
             SIN_1Y   COS_1Y)
   PRINTALL PLOT NOINT ALTPARM METHOD=ML;
   FORECAST LEAD=74 BACK=74 ID=WDATE INTPER=7;
```

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