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Comparison of Trends in the Finfish Assemblage of Mt. Hope Bay and Narragansett Bay in Relation to Operations at the New England Power Brayton Point Station.

By

Mark R. Gibson
Principal Fisheries Biologist
RI Division Fish and Wildlife
Marine Fisheries Office
Wickford, RI 02852
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Executive Summary

A detailed study of the Mt. Hope Bay fish population in the vicinity of the New England Power Brayton Point Station (NEPBPS) was undertaken. Early work by the Rhode Island Division of Fish and Wildlife (RIDFW) suggests that sharp reductions in the abundance of several fish species were coincident to operational changes at NEPBPS. These changes involved conversion of generating unit 4 from closed cycle to open cycle cooling which resulted in a 45% increase in coolant flow drawn from Mt. Hope Bay. The coincidental declines in fish stocks were at odds with industry prediction during the permitting process of no impact. Further, interest has recently been shown by the industry in relaxing summer generation limits imposed by the current permit. Consultants to New England Power have suggested that the fish declines were simply consistent with those occurring throughout the region as a result of overfishing, habitat loss, and natural variations. If so, concerns about increased summer generation would be greatly reduced.

A number of statistical procedures were used to compare the hypothesis that fish population trends in Mt. Hope Bay were the same as in Narragansett Bay and other New England marine waters. Data from trawl surveys conducted throughout the region were compared. Species were compared individually and in aggregate. In 16 of 21 species compared, rates of decline in abundance were steeper in Mt. Hope Bay near NEPBPS. Moreover, aggregate resource abundance declined sharply in Mt. Hope Bay. In other areas, species replacements have occurred so that net abundance has been stable. A time series model showed that the sharp drop in abundance of fish in Mt. Hope Bay was coincident to the sharp increase in coolant flow at NEPBPS. While there was no evidence of species loss, reduced diversity in Mt. Hope Bay was apparent. More individuals are now concentrated in fewer species.

Other explanations such as overfishing and changes in natural mortality rate were rejected owing to the abrupt nature of the abundance declines. The most parsimonious hypothesis to explain the decline is that the large change in coolant flow has modified environmental conditions in Mt. Hope Bay to the detriment of the fish population. The available data suggest a temperature and/or oxygen mediated effect. Causality with NEPBPS cannot be demonstrated on the basis of current monitoring data. An

experimental approach is required which is problematic since large scale interruptions in power generation are not feasible. A simulated experiment is required. This will require a detailed modeling capability which is currently unavailable. This should be developed before any increase in summer power generation is allowed.

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Introduction-

Adverse impacts to finfish in Mt. Hope Bay by power generation at the New England Power Brayton Point Station (NEPBPS) have been suggested by Gibson (1994). He implicated entrainment of larval winter flounder as a factor additive to high fishing mortality which had reduced the abundance of winter flounder in Mt. Hope Bay, an upper reach of Narragansett Bay. Among the evidence were empirical trawl data which showed a steeper decline than anywhere else in the region, an abnormally low stock-recruit slope, and simulation modeling which showed that a stock subject to both high fishing mortality and prerecruit loss would collapse to very low levels. The study also indicated that other finfish species were showing symptoms of collapse coincident to modifications at unit 4. NEP converted the unit from closed to piggyback cooling in 1981 and to open cycle cooling in 1985. To affect the conversion, a new intake structure on the Lee River was required. These modifications potentially had great impacts on the local environment by boosting coolant flow from 730 million to over 1 billion gallons per day and adding additional heat to the Bay which was formerly dissipated to the atmosphere. In addition to increasing entrainment and impingement levels, this large increase in coolant flow could have modified circulation patterns, increased water temperatures during critical periods, and/or affected oxygen profiles in the bay. The original study has been reviewed several times by the technical advisory committee, 3% and 10% of the RIDFW seasonal tows have fallen in Rhode Island waters of Mt. Hope Bay. A monthly survey at 13 fixed stations in Narragansett Bay, including 2 in Mt. Hope Bay, was added in 1990. RIDFW trawling in Mt. Hope Bay is limited to strata south of Spar Island and does not overlap the MRI survey. The URIGSO trawl survey is conducted at two fixed stations in the lower west passage of Narragansett Bay on a weekly basis. The survey, described in Jeffries et al. (1989), dates back to 1959. Recent data were provided by G. Escanero, URIGSO- pers. comm. Fixed stations in the various trawl surveys are plotted on an appendix map. There are several differences in vessel and net characteristics, the most relevant of which is cod end mesh size. The MRI trawl uses 38 mm mesh, the RIDFW survey 6 mm mesh, and the URIGSO survey 25 mm mesh. Although the RIDFW survey will retain a higher percentage of small fish, the purpose of this study was to examine long-term trends in catch per tow within surveys so differences in selection pattern are of secondary importance. Impingement of fish at NEPBPS has been monitored by MRI using periodic screen wash samples since 1972 (NEPMRI 1995). MRI also conducts a monthly beach seine survey in Mt. Hope Bay from March to October. Two seines, measuring 60 and 300 feet are deployed at each of 4 stations. The 60 foot seine uses 3 mm mesh and the 300 foot seine, 12.5 mm mesh.

A null hypothesis of no significant difference in trawl abundance trends between Mt. Hope Bay and Narragansett Bay/Rhode Island coastal waters was formulated. The alternate hypothesis was that trawl trends in Mt. Hope Bay were not equal to those in Narragansett Bay. In order to test this hypothesis I compared trawl abundance indices by species in both areas. MRI data were taken from tables F-5 to F-21 in NEPMRI (1995) while RIDFW data were taken from Lynch (1995) and the seasonal trawl database (including Mt. Hope Bay tows). Species examined included the 10 most abundant in the MRI survey from 1972-95 (winter flounder, scup, windowpane, weakfish, bay anchovy, hogchoker, tautog, cunner, butterfish, and oyster toadfish). Eleven additional species of recreational/commercial importance or ecological significance were included (Atlantic herring, bluefish, Atlantic menhaden, river herring, rainbow smelt, Atlantic silverside, gadids, striped bass, summer flounder, skates, and searobins). URIGSO data was limited to aggregate number per tow and individual data for eight species (winter flounder, weakfish, scup, butterfish, tautog, windowpane flounder, summer flounder, and sea independent scientists, as well as consultants hired by the industry. Despite changes indicated by the reviews, the primary findings remain. Several species of fish including winter flounder, tautog, windowpane, and hogchoker have exhibited collapse coincident to unit 4 modification despite earlier prediction by the industry of no impact (NEPMRI 1981).

Recently, NEPBPS proposed to the EPA to modify generation protocols during summer months which would enable the industry to generate and supply more power during peak demand periods. A consequence would be the addition of waste heat in excess of license limits to Mt. Hope Bay during this period. With respect to concerns raised about the condition of finfish populations in Mt. Hope Bay vis a vis plant operations, it has been suggested by the utilities and consultants that the declines are simply consistent with declines occurring throughout the region as a result of overexploitation and natural causes. If so, concerns about biological impacts under enhanced generation would be greatly reduced. In this study, the hypothesis of uniform abundance trends between fish stocks in Mt. Hope Bay and Narragansett Bay/ Rhode Island coastal waters was evaluated using trawl data collected by Marine Research Inc. (MRI), the Rhode Island Division of Fish and Wildlife (RIDFW), and the University of Rhode Island Graduate School of Oceanography (URIGSO). Impingement samples and seine survey data from the MRI monitoring program in Mt. Hope Bay were also examined for changes in abundance and diversity.

Methods and Data Sources-

Fish Population Data- Trawl surveys were used as the primary indicator of fish population status in this study. Data from MRI trawling in Mt. Hope Bay and from RIDFW and URIGSO studies in Narragansett Bay-Rhode Island Sound-Block Island Sound were examined from 1979 to 1995. Details of the survey designs and methodology may be found in NEPMRI (1995) and Lynch (1995). Briefly, MRI conducts monthly trawling at 6 fixed stations in Mt. Hope Bay. Five stations are in the upper portion near NEPBPS and one is located mid-bay near Spar Island. The RIDFW conducts spring and fall cruises in Narragansett Bay and nearby coastal waters with a random stratified design and 42 tows per cruise. Stratification is by depth. Annually, between 3% and 10% of the RIDFW seasonal tows have fallen in Rhode

Island waters of Mt. Hope Bay. A monthly survey at 13 fixed stations in Narragansett Bay, including 2 in Mt. Hope Bay, was added in 1990. RIDFW trawling in Mt. Hope Bay is limited to strata south of Spar Island and does not overlap the MRI survey. The URIGSO trawl survey is conducted at two fixed stations in the lower west passage of Narragansett Bay on a weekly basis. The survey, described in Jeffries et al. (1989), dates back to 1959. Recent data were provided by G. Escanero, URIGSO- pers. comm. Fixed stations in the various trawl surveys are plotted on an appendix map. There are several differences in vessel and net characteristics, the most relevant of which is cod end mesh size. The MRI trawl uses 38 mm mesh, the RIDFW survey 6 mm mesh, and the URIGSO survey 25 mm mesh. Although the RIDFW survey will retain a higher percentage of small fish, the purpose of this study was to examine long-term trends in catch per tow within surveys so differences in selection pattern are of secondary importance. Impingement of fish at NEPBPS has been monitored by MRI using periodic screen wash samples since 1972 (NEPMRI 1995). MRI also conducts a monthly beach seine survey in Mt. Hope Bay from March to October. Two seines, measuring 60 and 300 feet are deployed at each of 4 stations. The 60 foot seine uses 3 mm mesh and the 300 foot seine, 12.5 mm mesh.

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Statistical Methods-

Log-linear Abundance Model- Trawl data may be considered a snapshot of the target population since, in age aggregated form, it is a sample from members above the recruited age. A population varies with time due to additions through recruitment and losses due to natural causes and human actions. Following Krebs (1979), a simple differential equation common in ecology is:

$$dN/dt = GN \qquad (1)$$

where: N = *Population size*

G= Instantaneous rate of change per year.

Eq. 1 has as the integral solution:

$$N(t) = N_0 exp(Gt) \quad (2)$$

where: *N= Population size*
N_0= *Initial population size at t=0*
t= Time in years.

The time invariant parameter *G*, or per capita population growth rate, may be decomposed and given fisheries conventions:

$$G = R-(F+M_1+M_2) \quad (3)$$

where: *R= Recruitment rate*
F= Fishing mortality rate
M_1= *Natural mortality rate*
M_2= *Other man induced losses.*

Substituting eq.3 into eq.2 gives:

$$N_t = N_0 \, exp(((R-(F+M_1+M_2)) \, t). \quad (4)$$

A population in year *t* is equal to the initial population, adjusted for losses and accruals compounded from time t_0 *to t*. This is simply a recapitulation of Russell's (1931) mass-balance treatment of fish stock dynamics. As noted by Hilborn and Walters (1992), it is a simple treatment which ignores age-structured, spatial, and density dependent effects. It also assumes that the population is closed. Although many species in Narragansett Bay vary seasonally in abundance, it is not expected that there would be a net change in migrations over time. It is not possible to estimate separately the components of *G* with this formulation. However under the null hypothesis of no difference between areas, they are presumed equal. One additional assumption is needed. Trawl data are a sample from the population and are related as:

$$N_t = I_t/q \quad (5)$$

where: *N= Population size*

I= *Trawl survey index*
q= *Catchability constant*
t= *Year.*

Substituting eq.5 into eq.4, canceling q terms, and taking logarithms yield a form amenable to linear regression analysis:

$$ln(I_t) = ln(I_0) + Gt. \qquad (6)$$

As long as catchability is constant, the estimation of G in eq. 6 is not affected by substitution of I/q for N. Constant q is a reasonable assumption for research trawl surveys with uniform effort and gear. Again, it is not relevant that q may vary between surveys since the terms cancel out in the derivation of eq. 6. Values of G are directly comparable between surveys since they are instantaneous rates with common units of 1/time. Note that use of eq. 5 as an observation model and OLS regression in eq.6 is a "process error" procedure which assumes no measurement error in the survey indices. Although Polacheck et al. (1993) showed that process error estimators can bias fitted stock trends when measurement error is present, between survey comparisons remain useful. Surveys in nearby areas likely have similar sources of measurement error and it is the differences in trend, not absolute magnitude, which are important.

Regressions of log abundance in numbers on time (1979-1995) were computed from the RIDFW and MRI surveys for a number of species which varied in life history and exploitation status. Estimates of G between surveys were compared by t-test. The test statistic in this case is:

$$t = (G_1 - G_2)/S_p \qquad (7)$$

where: S_p is the pooled standard error. It should be noted that this is not a test of $G=0$ but a test of the difference between slopes, either of which might not differ from zero. Under the null hypothesis, no significant differences in estimates of G would be expected between areas if the populations are subject to similar rates of loss and accrual. Significant differences would indicate that one or more factors in eq.3 are not the same between regions. Statistical significance for individual comparisons was assessed at the 95% level. For 30 degrees of freedom, the 95% t value is 1.70. To account for the multiple comparisons and the likelihood of false positives, a Bonferroni test procedure was used. When a joint 1-α confidence interval is desired, individual comparisons should achieve a 1-(α/n) level where n is the number of comparisons and α is the probability of type 1 error (Neter et al. 1983). Type 1 error is the detection of a significant difference when in fact none actually exists. In the case of 21 comparisons, a 99.75% probability level or t=3.03 is needed.

Restructuring of a fish community to smaller individuals by selective exploitation or species replacements could alter overall catchability even if gear and survey methods have been constant. Smaller fish have a lower probability of retention than larger fish. This could lead to an artifact condition whereby a survey with larger mesh gear could indicate steeper declines than a small mesh survey. Since the RIDFW, URIGSO and MRI trawl surveys employ different meshes and in two cases fish similar areas, this possibility could be evaluated. An analysis of variance (ANOVA) was conducted for estimates of *G* calculated from the three surveys for the 8 species in common. If reduced catchability on small fish was operative, one would expect that the URIGSO survey with 25 mm mesh would exhibit steeper declines in abundance than the RIDFW survey with 6 mm mesh.

In addition to individual species, catch per tow of all species was examined over time using log-linear regression (eq.6). Large marine systems have shown strong changes when subject to stressors such as exploitation. On Georges Bank, groundfish and flatfish have been replaced by pelagic species and elasmobranchs (NMFS 1995, Sherman 1994). Total abundance however, has remained relatively steady suggesting that production is unimpaired but merely channeled into other forms. If exploitation is the common factor largely responsible for changes in the Mt. Hope Bay-Narragansett Bay system, the aggregate trawl data should indicate stable biomass even if species shifts have occurred. That is, a null hypothesis of no net change in aggregate system biomass is advanced. Aggregate catch per tow data from the RIDFW, MRI, and URIGSO trawl surveys were analyzed (1979-1995). Aggregate impingement data and MRI seine survey results were tested for abundance trends as well. To provide a more regional perspective on the dynamics of marine fish assemblages, aggregate trawl data from Connecticut, Massachusetts, and the New England region were obtained. Connecticut data were from monitoring at Millstone Nuclear Power Station on Niantic Bay (NUSCo. 1995) and Connecticut Department of Environmental Protection (CTDEP) trawling in Long Island Sound (Simpson et al.

1996). The Massachusetts Division of Marine Fisheries (MADMF) conducts trawl surveys in state waters north and south of Cape Cod (Howe et al. 1995) while the National Marine Fisheries Service surveys federal waters from Maine to Cape Hatteras, North Carolina (NMFS 1995).

Time Series Model- The log-linear regression model used above assumes a constant rate of population change arising from an imbalance between forces of mortality and recruitment. In the case of power plant induced effects, there may be abrupt changes in the population dynamics of affected species. Madenjian et al. (1986) have proposed the use of intervention analysis, a form of time series modeling, to test for significant impacts arising from power generation activities. Recognizing the serial correlation underlying abundance monitoring data, they showed that autoregressive integrated moving average (ARIMA) models coupled with transfer function components could confirm that ANOVA type procedures had not resulted in type 1 error. The MRI Mt. Hope Bay abundance series is short by time series standards (24 years) which limits application of the extensive model selection, fitting and diagnostic checking procedures of Box and Jenkins (1976). However, specification of a plausible model on a priori grounds may be useful in describing fishery time series (Pennington 1986). Autoregressive terms in ARIMA models relate to the survival process such that abundance in a given year consists in part of survivors from the preceding year. Moving average terms relate to random additions to aggregate abundance for example from recruitment. A 1st order ARIMA model was used by Jeffries et al. (1989) to describe winter flounder trawl abundance data in Narragansett Bay. When a power plant is involved, there may be a sudden impact due to changes in operation such as unit 4 modification. Following Madenjian et al. (1986), a preliminary time series model with 1st order AR and MA terms and including an intervention term was used to test for significant differences in abundance between the 1972-1985 and 1986-1995 periods of plant operation:

$$Z_t = \phi_1 Z_{t-1} + \theta_1 a_{t-1} + \omega \; I_t + a_t \qquad (8)$$

where: Z = *Abundance measure*
I = *Intervention variable*

(1972-85 I=0, 1986-1995 I=1)
ϕ_1= *Autoregressive parameter*
θ_1= *Moving average parameter*
ω = *Intervention parameter*
t= *Time in years*
a= *Residual term.*

Eq. 8 was fit to the 1972-1995 Mt. Hope Bay MRI total catch per tow series after log transformation. Differencing was not done since it is the intervention term to detrend the series and log transformation to stabilize variance which establishes stationarity, the statistical condition required to analyze autocorrelation structure. Differencing is useful for removing time series trends (Chatfield 1985), but as the author notes "The analysis of a time series which exhibits long term change in mean depends on whether one wants to (a) measure the trend and/or (b) remove the trend in order to analyze local fluctuations." Differencing is not appropriate in this case since it would eliminate the property most relevant to the problem, i.e. the change in mean. Noakes (1986), in an application of intervention analysis to Dungeness crab landings, also did not difference the data series since he wished to estimate an abrupt change in the mean landings. The Number Cruncher Statistical System time series estimation package was used to fit the model (NCSS 1989). The intervention period above corresponds to unit 4 modifications which increased circulating flow by about 45%. Significance of the ω parameter is a direct test of power plant impact. The periods were varied plus or minus 3 years to examine impacts on the model mean squared error (MSE). For comparative purposes, the same model was fit to the RIDFW and URIGSO aggregate trawl indices with the same 1985-1986 intervention point.

Coolant Flow Model- Given the short time series and the ambiguous action of the intervention effect, an alternative plant impact model was examined. Mean daily coolant flow at NEPBPS was added as a second explanatory variable to the log-linear regression model from above (eq.6). This approach would allow for a change in aggregate resource abundance over time due to normal population dynamics as well as an impact due to power generation as indexed by circulating coolant flow at NEPBPS. It can be seen in eq.4 that extraneous sources of mortality *(M_2)* can be split out and related to coolant flow so that eq. 6 becomes:

$$ln\ (I_{t+1}) = ln(I_t) + G't + M_2 f \qquad (9)$$

where:

I = *Trawl index*
G' = *Population growth rate less effect of power generation*
M_2 = *Rate of population change due to power generation*
t = *Year*
f = *Coolant flow (annual mean).*

Significance of the M_2 coefficient after time effects on population abundance *(G')* are accounted for, would implicate power generation activities as an additional factor influencing fish abundance. The linkage with mean coolant flow provides a finer resolution of effect than the broad intervention term of eq.8.

Species Diversity Methods- Species count over time has declined significantly ($P<0.01$) in the MRI trawl survey in Mt. Hope Bay. No such change is evident in the RIDFW trawl survey in Narragansett Bay/RI coastal waters suggesting that species diversity in Mt. Hope Bay has been reduced. The number of tows in the MRI survey has also declined over time raising the possibility that declining effort is responsible. Hurlbert (1971) has shown that the expected number of species in a sample is an asymptotic function of sample size. To test the hypothesis of reduced species richness in Mt. Hope Bay, I fit a Gompertz curve to the MRI species count and tow data for 1972 to 1995:

$$S_t = S_0\ exp(-exp(B_1(T_t - B_2))) \qquad (10)$$

where:

S = *Number of species observed*
T = *Number of tows made*
t = *Year*
S_0 = *Curve species asymptote*
B_1 = *Curve shape parameter*
B_2 = *Curve inflexion point parameter.*

The Gompertz curve is a flexible growth curve from the same asymptotic family as the logistic, Weibull, and von Bertalanffy. It does not have any mechanistic basis in this application but is merely used to describe the major properties of the empirical data. Selection of the Gompertz over other candidates was based on goodness of fit diagnostics and residual analysis. The model was fit using the NCSS curve fitter program which employs the Levenberg-Marquadt nonlinear regression procedure from Nash (1987). Residuals from the fitted curve were then examined for serial trend. A trend toward negative residuals would indicate declining species count.

Changes in community diversity may be manifested more subtly than in outright species loss. Rarefaction may occur such that more individuals become concentrated in fewer species. Species abundance curves can be developed from a representative sample in the form of a plot of log relative abundance vs. species rank following Whittaker (1965). If species-abundance data follow a logarithmic series as suggested by Fisher et al. (1943), the log abundance curve will be approximately linear (Krebs 1989). The slope of a fitted line is an index of diversity:

$$ln(I_{st}) = y_t + D_t * R_{st} \tag{11}$$

where:

s = *Species identity*
I = *Species trawl abundance*
R = *Species rank*
D = *Diversity index*
y = *Regression intercept.*
t = *Year.*

Steep slopes indicate that individuals are concentrated in relatively few species while shallower slopes indicate more balance (Ludwig and Reynolds 1988). MRI and RIDFW trawl data were ranked by species annual CPUE and analyzed by regression using this approach. Trends in the slope parameter (D) were examined through time and in relation to tow number. Impingement data and seine survey results were analyzed in a similar fashion.

Results-

Estimates of the population per capita growth rate (G) for 21 species are compared for the two surveys in Table 1. Also included are the differences between estimates, values of the t-statistic, and 95% probability levels. In 21 species comparisons, the

RIDFW survey in Narragansett Bay and adjacent coastal waters had significantly ($P<0.05$) higher *G* estimates in 16 cases. In two cases the MRI survey in Mt. Hope Bay had significantly higher estimates and in three cases there was no difference. In general, when the RIDFW survey indicated increasing population size the MRI survey had no trend or was declining. When the RIDFW survey indicated declines, the MRI survey declined faster. Random series of numbers would be expected to show 5 significant differences between pairings in 100 trials at the 95% level. A total of 16 significant differences out of 21 in favor of the RIDFW survey in Narragansett Bay is a wide departure from expectations. Using the Bonferroni criteria for multiple comparisons, the RIDFW survey was significantly greater in 13 cases, significantly less in only 1 case, and not significantly different in 7 cases. Moreover, the sign of the difference in random pairings should follow a binomial distribution with probability of occurrence equal to 0.5. For $n=21$ comparisons, the expected number of positive differences is $p*n$ or 10.5 outcomes. With variance $p(1-p)n$, a 95% confidence bound is 5.9 to 15.1. A total of 18 positive differences is significantly different from binomial expectations. Similarity of key species trends is not supported by the trawl data.

ANOVA and Duncans testing of means indicated that *G* estimates in the RIDFW and URIGSO surveys were not significantly different but both were significantly different from the MRI estimates. For the eight species tested, mean *G* rates for the RIDFW and URIGSO surveys were 0.014 (SE=0.006) and 0.024 (SE=0.009) respectively (Table 2). The MRI survey was negative at -0.187 (SE=0.007). Despite the larger mesh in the URIGSO survey, *G* estimates were similar indicating that lower catchability of small fish had not compromised the ability of that survey to measure changes in abundance relative to the RIDFW small mesh survey. Consequently, the steep negative slopes in the MRI survey are not likely an artifact of larger mesh.

Aggregate abundance indices showed significant positive trends with time in the RIDFW and URIGSO surveys (Figure 1). Declines in abundance for some species were more than offset by increases in others (Table 1). In Narragansett Bay, there has been a replacement of demersal species by pelagic species (Figure 2, see also Jeffries 1994). This was not the case in the MRI Mt. Hope Bay survey. Overall fish abundance declined significantly ($P< 0.01$) over time. The instantaneous rate of decline of G=-0.24

(SE=0.04) corresponds to a loss of 21% per year. Both demersal and pelagic components have declined, with the demersal loss rate (G=-0.28, SE=0.04) slightly greater than the pelagic loss rate (G=-0.20, SE=0.08). Aggregate abundance trends in the various trawl surveys are summarized in Table 3.

The preliminary time series model was a good description of the MRI trawl abundance trend (Figure 3). No patterning of residuals through time indicated an acceptable fit (Figure 4). Examination of the residual autocorrelation and partial autocorrelation functions showed no remaining significant lags. The first order AR and MA terms were estimated at ϕ=0.72 (SE=0.17) and θ=1.00 (SE=0.04), respectively. The intervention term was estimated at $\tilde{\omega}$ =-2.68 (SE=0.22) and highly significant at $P<0.01$. The parameter estimate indicates a negative impact of 2 log units on abundance. This corresponds to an 86% reduction in mean abundance from the 1972-1985 period. The model explained 89% of the observed variability in log abundance. Model MSE was minimized at the 1985-1986 breakpoint for the intervention term (Table 4). Additional work on this approach is needed. A ramp intervention effect may fit better than the step effect used here (Madenjian at al. 1986). This would allow the intervention effect to occur over several years, improving residual behavior near the break point. Another enhancement to the model is to use circulating flow as a covariate in a transfer function format thereby combining the dynamics expressed in eqs. 7 and 8. Refinement of the trawl data to a monthly index could increase the length of the series. The time series model (Eq. 7) could not be fit to the RIDFW or URIGSO series. There was no significant negative intervention effect, in fact both series had positive slopes. This analysis also rejects the null hypothesis of no difference between areas with Mt. Hope Bay showing a drastic reduction in finfish abundance which is not apparent in Narragansett Bay and coastal waters. The log-linear regression model with coolant flow as an auxiliary variable (eq.8) was also a good fit to the data (Figure 5). The regression explained 87% of the variance in log abundance and both slope parameters were significantly less than zero ($P<0.05$). Residual pattern showed no departure from model assumptions although there was a large negative in 1988 (Figure 6). The Durban-Watson statistic indicated no significant residual autocorrelation. The G' parameter was estimated at -0.07 (SE=0.03), a 61% increase over the model without coolant flow. M_2 was estimated at -0.005 (SE=0.001). High significance (P<0.01) of the M_2 term after time effects on abundance were accounted for is strong indirect evidence of plant impact. However, a G' parameter which remains significantly negative indicates that other factors are contributing to the fish decline in addition to the plant.

Finfish impingement at NEPBPS is dominated by Atlantic menhaden, winter flounder, Atlantic silverside and hogchoker which account for about 60% of all fish impinged. Total impingement showed a significant (P<0.05) decline in the log scale from 1972-1994 (Figure 7). However, the significance was due to high leverage of the 1972 menhaden point. When examined on a per hour basis, there was no trend overall. When impingement per hour was partitioned on a seasonal basis, there were opposing trends in winter (Nov-Apr) and summer (May-Oct). These periods correspond to the 6 consecutive months of lowest and highest water temperatures. The log transformed fish per hour data are plotted in Figure 8. There was no significant trend for either season over the 1973 to1984 pre-unit 4 period. However, when restricted to the 1985 to 1994 period which coincides with post unit 4 modification, there were significant and divergent trends. Impingement declined significantly during the May to October period and rose significantly during the November to April period. These data suggest a loss of summer finfishes coincident to unit 4 modification and tend to corroborate the trawl trends although not in the same abrupt manner. The impingement monitoring program is not a standardized abundance survey and should not be directly compared to the trawl program.

Aggregate abundance in the MRI 60 foot seine survey has significantly (P <0.01) increased (Figure 9). No increase is apparent in the 300 foot seine data. The increase in the smaller seine is largely due to Atlantic silverside, which dominate both surveys. Reduced catchability of small silverside in the larger mesh of the 300 foot seine is an unlikely explanation for the disparity. An increase in abundance of juveniles should be reflected in the 300 foot survey as adults with a lag and this does not occur. The apparent increase in the small seine is more likely a displacement. Mean abundance in the 60 foot survey of all species is consistently higher from 1986 to 1994 than in 1972-1983, 1985. The abundance increase in the littoral zone, which is lacking in the trawl and large seine data, suggests a transfer of production from the deepwater zone to the littoral zone coincident to a 1985-1986 intervention. The littoral zone sampled by small seine is very different than the otter trawl habitat. It undergoes wide natural temperature variation and is well mixed through wave action. Plant impacts on water temperature and oxygen concentration would be less likely. Weak rarefaction was evident in the 60 foot seine but not in the 300 foot seine (Figure 10). Increasing abundance of silverside relative to other species causes the trend toward lower diversity. This zone had the lowest diversity indices overall. Low inherent diversity in the littoral beach seine habitat is expected based on limited habitat heterogeny and environmental instability (Valiela 1984).

The Gompertz model was a good fit to the MRI trawl species count and tow number data (Figure 11). Variance explained was 82% and all parameters were highly significant ($P < 0.01$). The asymptote was estimated at 32.97 (SE=1.51) species. Model residuals did not trend downward through time (Figure 12). When the effect of reduced sampling intensity were controlled, there was no evidence of species loss. There was strong evidence of species rarefaction (Figure 13). Slopes of the species abundance curve *(D)* became steeper with time ($P < 0.01$) a result which was not related ($P < 0.05$) to declining tow number. More individuals are now concentrated in fewer species. No species loss was evident in the RIDFW survey and there was no relationship between species count and tow number. However, the pattern of species abundance slopes was significantly correlated ($P < 0.05$) with time. Weak rarefaction is indicated in recent years. Strong rarefaction with time ($P < 0.01$) was observed in the Mt. Hope Bay impingement species abundance slopes (Figure 14).

There was no evidence of declining resource abundance in Connecticut waters (Figure 15). Both the NUSCo and CTDEP trawl surveys had positive or zero slope and no indication of a 1985-1986 intervention. Declines in demersal species such as winter flounder, windowpane, and tautog were matched by increases in pelagics such as butterfish, squid, and scup. A similar balancing was evident in the MADMF and NMFS trawl data (Figure 16). Reductions in principal demersal species (gadids and flatfishes) were offset by increases in pelagics (mackeral-herring) and elasmobranchs (skates-dogfish).

Collectively, the abundance and species diversity data indicate significant differences between the Mt. Hope Bay fish assemblage and those in local and regional marine waters. Species rarefaction seems to be a common feature probably as a result of restructuring to a pelagic based community. However, the overall abundance reduction is limited to Mt. Hope Bay and coincident with a 1985-1986 increase in coolant flow at NEPBPS (Figure 17). Steep declines in trawl abundance after unit 4 modification, declines in summer impingement, and lack of decline in the normally warm and well mixed littoral zone suggest a temperature and/or oxygen mediated habitat impact.

Discussion-

There is compelling evidence that the dynamics of fish populations in Mt. Hope Bay are different than those in Narragansett Bay and nearby Rhode Island coastal waters. Rates of population growth in the former are significantly lower and in general negative. A wide range of exploited and unexploited species of various life histories have collapsed coincident to modifications at unit 4 by NEPBPS. Overexploitation (F in eq.4) is unlikely to be the cause of the abrupt decline. Many species which show differences migrate between the regions and incur fishing mortality over much of their range. The significantly greater loss rate of bluefish, weakfish, winter flounder, and tautog can not be explained by differences in local exploitation. For example, winter flounder and tautog tagged by RIDFW in both Mt. Hope and Narragansett Bays have shown high fishing mortality rates indicative of similar fishing pressures. Gibson (1995), compiled commercial otter trawl and recreational fishing effort for the Rhode Island area. These data show no evidence of an abrupt effort increase in 1985-1986. Further, other exploited species such as striped bass, scup, butterfish, and sea herring are increasing in Narragansett Bay while declining in Mt. Hope Bay. River herring which are the subject of an RIDFW restoration program are increasing in Narragansett Bay but not in Mt. Hope Bay. Finally, bait species like silverside, rainbow smelt, and bay anchovy are increasing in abundance in Narragansett Bay but declining in Mt. Hope Bay. Reductions in catchability in the MRI survey resulting from community restructuring to small individuals is not a viable explanation. The survey formerly caught small species such as river herring, bay anchovy, smelt, grubby, and gobies which are now largely absent. Furthermore, the URIGSO survey in Narragansett Bay measures similar trends as does the RIDFW survey despite having much larger mesh.

Changes in natural mortality rate (M_1 in eq.4) are not likely either. Natural mortality rate has been shown to be a life history characteristic related to longevity (Hoenig 1983), body size (Ursin 1967) and water temperatures (Pauly 1980). Natural mortality cannot change, while fitness is maintained, unless concomitant changes in other life history traits such as growth, age at maturity, fecundity, etc. offset the change. These would require evolutionary time scales, not the 1 or 2 years coincident to unit 4 modification. Although there may be latitudinal variation across a species range, abrupt variation in M_1 in a local area is very unlikely. Reduction in recruitment rate of juveniles (R in eq.4) can occur naturally through compensatory processes at high stock sizes. Since the Mt. Hope Bay populations are in decline, this can be ignored. Depensatory recruitment (reduced recruitment at very low stock size) is theoretically possible but the study of Myers et al. (1995) indicates that it rarely occurs in exploited fish stocks. Climatic events certainly influence spawning success yet it is difficult to see how weather patterns could be sufficiently different from one bay to the next. Recruitment failure can also occur if spawning success has been compromised by entrainment, impingement, and habitat degradation. The first two are known to occur at NEPBPS. Entrainment of tautog and windowpane eggs averages 4.90 billion and 0.86 billion per year at NEPBPS while winter flounder larval entrainment averages 0.89 billion per year (NEPMRI 1995). Using equivalent adult analyses, these egg and larval losses have been estimated to remove 30,885, 20146, and 96,507 pounds of tautog, windowpane, and winter flounder from the local fisheries. Habitat degradation is also likely due to large coolant withdrawals, thermal loading, and pollution by combustion products and/or antifouling agents. Increases in plant related, non-fishing mortality on adults (M_2 in eq.4) are possible although indistinguishable from a change in net immigration-emigration from the bay. Avoidance of an unsuitable area by adults may be more likely. In practice the end result is the same, that is nonfunctional habitat and stock decline. The abruptness of the decline (1985-1986) in Mt. Hope Bay and correlation with flow argues for an increase in M_2 in addition to failed recruitment.

Perhaps the most telling sign is in the aggregate resource abundance trends. Standing biomass, size structure, and species complements (but not proportionality) have been shown to be conservative properties of large marine systems (Gabriel 1992, Murawski and Idoine 1992). Narragansett Bay in this study has shown stable standing biomass over time in two independent surveys despite strong shifting from a demersal assemblage to a more pelagic community. The restructuring has resulted in some species rarefaction but no net loss in production. This is consistent with the results of earlier studies on the bay's finfishes (Jeffries and Terceiro 1985, Jeffries 1994). Stability in aggregate resource abundance is also evident on a regional scale. Trawl surveys conducted to the north and south as well as offshore show similar properties. Mt. Hope Bay demonstrates no such stability despite intimate connections with Narragansett Bay proper. Total finfish abundance has declined significantly since 1979. The only evidence of compensatory production by small pelagics is in the littoral zone sampled by 60 foot seine which coincidently is farthest removed from NEPBPS discharge. The preliminary time series-intervention model has a highly significant intervention effect for 1985-1986 in Mt. Hope Bay but not in Narragansett Bay. The model indicates an 87% reduction in finfish abundance after unit 4 modification which resulted in a 45% increase in coolant flow.

These results suggest very strongly that the Mt. Hope Bay production system has been compromised. Lacking an experimental approach, it is not possible to demonstrate causality with NEPBPS. However, the strong inverse correlation between abundance and coolant flow implicates NEPBPS. Under the principal of parsimony, the simplest explanation which fits the circumstances must remain as the most viable hypothesis until disproved. Habitat degradation by the NEPBPS plant resulting in mortality of or avoidance by finfish is the most likely to date. The plant is large and capable of influencing the local environment through entrainment/ impingement, heat additions, flow pattern changes, pollution, and dissolved oxygen impacts. A loss of finfish restricted to Mt. Hope Bay is coincident to unit 4 modification, not to any other known intervention. This unprecedented loss of a diversity of species cutting across life histories, exploitation status, and migratory nature argue for a powerful impact of local origin which fits NEPBPS. The seasonal impingement data at NEPBPS and the changes in the littoral community suggest that the causal agent involves elevated water temperatures and/or reduced oxygen levels. Lack of a comparable impact at MNPS provides further insight. MNPS is a large facility exposing a comparable fish community to heated effluent. However, rapid dilution of MNPS effluent by Long Island Sound waters is not repeated in Mt. Hope Bay with NEPBPS effluent.

Until the cause of the fish decline is conclusively found and remedial action begun, no modifications to the NEPBPS operating license which result in increased thermal loading should occur. Each time the Mt. Hope Bay system is perturbed, the number of variables multiplies and the likelihood of understanding falls. Any proposals to generate additional power and waste heat during the critical summer season should be withdrawn until a satisfactory explanation for the collapse of finfish stocks in Mt. Hope Bay and a remedial plan are in hand. Further, the ongoing detailed studies of bay hydrodynamics and winter flounder larval entrainment should be broadened in scope since it is now clear that the problem is larger than earlier thought. It involves all species in the Bay and probably causal agents in addition to entrainment. Expanded research should involve revisiting plant thermal impacts, oxygen deficiencies, substrate contamination, and food chain perturbations. Also, operational histories at the Fall River sewage treatment facility and the Montaup Power Station should be reviewed. A comprehensive modeling capability is needed to test competing hypotheses. Such a model should be capable of simulating hydrodynamic, thermal/oxygen and pollutant conditions in Mt. Hope Bay. A biological submodel is needed to examine the responses of the fish community to factors such as entrainment and impingement, changes in critical habitat, overfishing and natural climatic variations. As this model is developed, a careful review of existing monitoring programs will be needed to insure that adequate data is available to drive and validate the model. In hindsight, the decisions to reduce otter trawl sampling intensity and suspend icthyoplankton and entrainment sampling for species other than winter flounder were probably unwise. These elements may need reinstatement. Other work which should be considered includes expanding the RIDFW trawl survey into Massachusetts waters of Mt. Hope Bay, fish population exchange studies between Mt. Hope and Narragansett Bays (marking-acoustics), and comparative mortality studies by species and life stage.

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Table 1- Rates of Population Change for Selected Finfish Species in Mt. Hope Bay and Narragansett Bay and RI Coastal Waters from the RIDFW and MRI Trawl Surveys. Slopes are Estimated from the Regression of Log Abundance on Time (1979-1995).

Species	RIDFW NB Slope	RIDFW NB SE	MRI MHB Slope	MRI MHB SE	Pooled Variance	Pooled SE	Slope Diff	Calc t	95% t	95% Bonft	URIGSO NB Slope	URIGSO NB SE
Bluefish	0.131	0.041	-0.156	0.040	0.002	0.041	0.287	7.086	1.700	3.030		
Winter Flounder	-0.133	0.021	-0.335	0.043	0.001	0.034	0.202	5.970	1.700	3.030	-0.160	0.030
Rainbow Smelt	0.033	0.034	-0.189	0.046	0.002	0.040	0.222	5.489	1.700	3.030		
Bay Anchovy	0.337	0.082	-0.081	0.075	0.006	0.079	0.418	5.320	1.700	3.030		
Scup	0.128	0.033	-0.239	0.101	0.006	0.075	0.367	4.885	1.700	3.030	0.018	0.044
Weakfish	-0.040	0.064	-0.336	0.058	0.004	0.061	0.296	4.847	1.700	3.030	0.122	0.052
Sea Herring	0.306	0.072	0.001	0.059	0.004	0.066	0.305	4.634	1.700	3.030	0.320	0.093
River Herring	0.145	0.040	-0.063	0.051	0.002	0.046	0.208	4.538	1.700	3.030		
Oyster Toadfish	-0.059	0.012	-0.208	0.047	0.001	0.034	0.149	4.344	1.700	3.030		
Tautog	-0.103	0.031	-0.239	0.037	0.001	0.034	0.136	3.985	1.700	3.030	-0.107	0.036
Atlantic Menhaden	0.174	0.082	-0.068	0.033	0.004	0.063	0.242	3.872	1.700	3.030		
Butterfish	0.155	0.042	-0.046	0.072	0.003	0.059	0.201	3.410	1.700	3.030	0.312	0.090
Cunner	-0.139	0.043	-0.277	0.042	0.002	0.043	0.138	3.247	1.700	3.030		
Windowpane Flounder	-0.188	0.020	-0.276	0.037	0.001	0.030	0.088	2.959	1.700	3.030	-0.255	0.032
Atlantic Silversides	0.131	0.084	-0.065	0.049	0.005	0.069	0.196	2.850	1.700	3.030		
Striped Bass	0.012	0.013	-0.025	0.014	0.000	0.014	0.037	2.739	1.700	3.030		
Gadid sp.	-0.098	0.045	-0.169	0.070	0.003	0.059	0.071	1.207	1.700	3.030		
Summer Flounder	-0.014	0.038	-0.026	0.053	0.002	0.046	0.012	0.260	1.700	3.030	-0.058	0.033
Hogchoker	-0.243	0.029	-0.237	0.065	0.003	0.050	-0.006	-0.119	1.700	3.030		
Searobin sp.	-0.088	0.040	-0.007	0.026	0.001	0.034	-0.081	-2.401	1.700	3.030		
Skate sp.	-0.046	0.027	0.063	0.043	0.001	0.036	-0.109	-3.036	1.700	3.030		
All Species	0.123	0.023	-0.241	0.037	0.001	0.031	0.364	33.421	1.700	3.030	0.039	0.014

Table 2- Rates of Population Change for Selected Finfish Species in Mt. Hope Bay and Narragansett Bay and RI Coastal Waters from the RIDFW, URIGSO and MRI Trawl Surveys. ANOVA and Means Testing Results are Also Given.

Species	RIDFW NB Slope	RIDFW NB SE	MRI MHB Slope	MRI MHB SE	URIGSO NB Slope	URIGSO NB SE
Winter Flounder	-0.133	0.021	-0.335	0.043	-0.160	0.030
Weakfish	-0.040	0.064	-0.336	0.058	0.122	0.052
Scup	0.128	0.033	-0.239	0.101	0.018	0.044
Butterfish	0.155	0.042	-0.046	0.072	0.312	0.090
Tautog	-0.103	0.031	-0.239	0.037	-0.107	0.036
Windowpane Flounder	-0.188	0.020	-0.276	0.037	-0.255	0.032
Summer Flounder	-0.014	0.038	-0.026	0.053	-0.058	0.033
Sea Herring	0.306	0.072	0.001	0.059	0.320	0.093
Mean	0.014	0.006	-0.187	0.007	0.024	0.009

ANOVA Results

Source	DF	SSQ	MS	F-Ratio	Prob
Survey	2	0.227	0.113	3.650	0.044
Error	21	0.652	0.031		
Total	23	0.879			

Duncans Testing

Survey	Mean	MRI	RIDFW	URIGSO
MRI	-0.187	NS	P<0.05	P<0.05
RIDFW	0.014	P<0.05	NS	NS
URIGSO	0.024	P<0.05	NS	NS

Table 3- Aggregate Resource Abundance Trends in Various New England Trawl Survey Programs.

Year	MRI/NEP Mt. Hope Bay	RIDFW Narr Bay	URIGSO Narr Bay	NUSCo Niantic Bay	CTDEP Long Is Snd	MADMF Mass Coast	NMFS NE Region
1972	65.2		425.5				100.0
1973	84.9		634.9				99.5
1974	73.3		748.1				95.3
1975	62.4		749.0				108.3
1976	65.0		747.3				116.3
1977	23.9		572.0	38.3			119.2
1978	70.7		463.8	38.8		123.7	120.3
1979	106.1	253.5	661.4	37.4		117.7	122.9
1980	61.9	271.7	470.1	48.0		117.7	130.0
1981	37.8	381.6	490.0	62.0		181.0	130.7
1982	66.6	341.9	557.6	53.0		244.4	126.3
1983	60.3	859.5	991.0	79.5		220.3	126.2
1984	25.5	977.6	717.2	58.0	537.1	184.1	124.3
1985	25.6	618.6	498.4	60.2	407.5	211.2	138.0
1986	8.7	670.2	475.6	71.7	343.1	150.9	137.3
1987	4.7	824.8	607.0	76.0	289.3	132.8	143.0
1988	1.5	2252.5	578.6	46.6	626.9	132.8	154.1
1989	3.6	620.8	852.0	63.1	702.7	138.8	164.6
1990	1.7	1567.9	557.8	50.2	640.3	114.7	179.0
1991	6.9	1061.6	809.3	65.1	850.7	60.3	170.2
1992	6.5	2243.9	635.6	96.1	755.3	150.9	168.7
1993	3.9	3005.7	1255.8	72.2	643.9	132.8	172.0
1994	2.4	736.7	1385.4	35.6	542.1	135.8	167.5
1995	3.4	2331.9	904.0	57.9	698.6		
Mean	36.3	1118.8	699.5	58.4	586.5	150.0	135.4
72-85 Mean	59.2	529.2	623.3	52.8	472.3	175.0	118.4
86-95 Mean	4.3	1531.6	806.1	63.4	609.3	127.7	161.8

Table 4- Parameter Estimates, Standard Errors and Model Statistics for the Mt. Hope Bay Power Plant Impact Models

Model	Parm	Est	SE	CV
Time Series Intervention	Intervention	-2.675	0.217	0.081
	AR1 term	0.721	0.173	0.240
	MA1 term	0.996	0.035	0.035
	MSE	0.237	NA	NA
	R2	0.891		

Time Series Model Intervention Period and MSE

Period	MSE
1982-1983	0.733
1983-1984	0.373
1984-1985	0.289
1985-1986	0.237
1986-1987	0.429
1987-1988	0.662
1988-1989	1.081

Coolant Flow Model	Intercept	144.747	55.456	0.383
	Time slope	-0.069	0.028	0.410
	Flow slope	-0.005	0.001	0.217
	MSE	0.288	NA	NA
	R2	0.874		

Fig.1-Aggregate Resource Abundance in Mt. Hope Bay and Narragansett Bay/Rhode Island Coastal Waters from Trawl Surveys

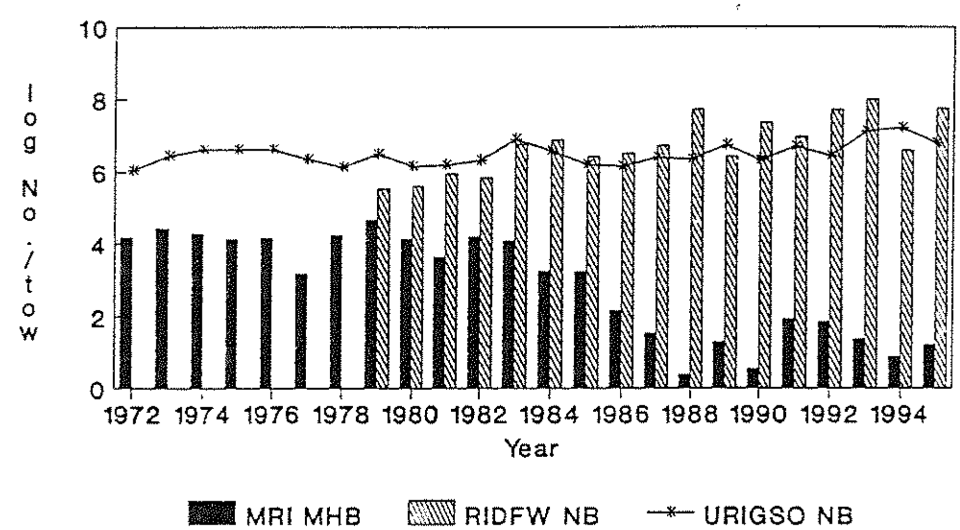


Fig.2- Abundance Trends for Demersal and Pelagic Fish in the RIDFW Trawl Survey

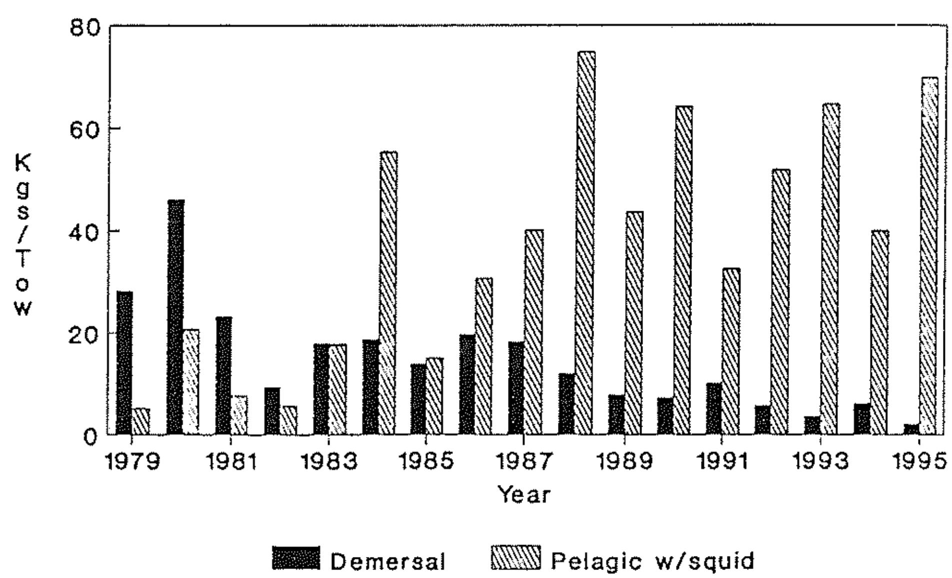


Fig.3- Observed Finfish Abundance Trend in Mt. Hope Bay 1972-1995 and Predicted Trend from Time Series Model

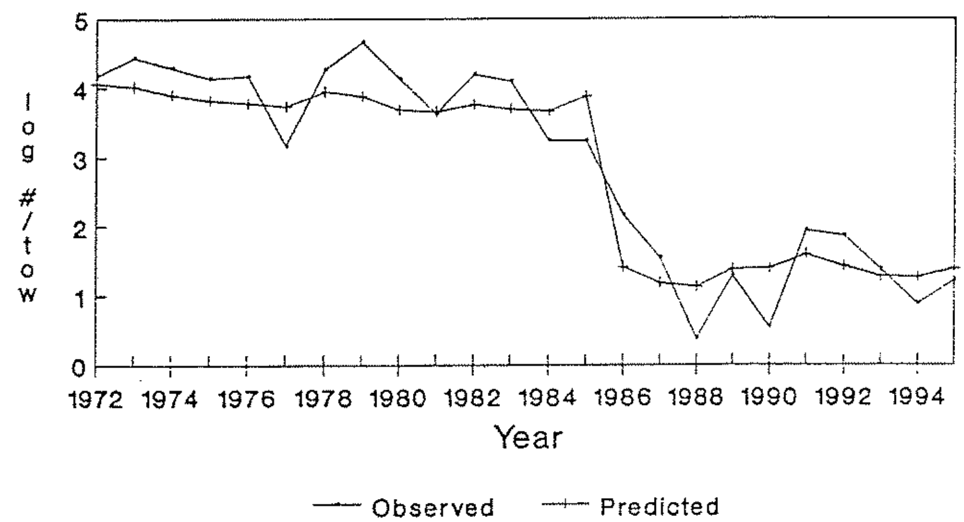


Fig.4- Residual Plot for Mt. Hope Bay Finfish Abundance Intervention Model

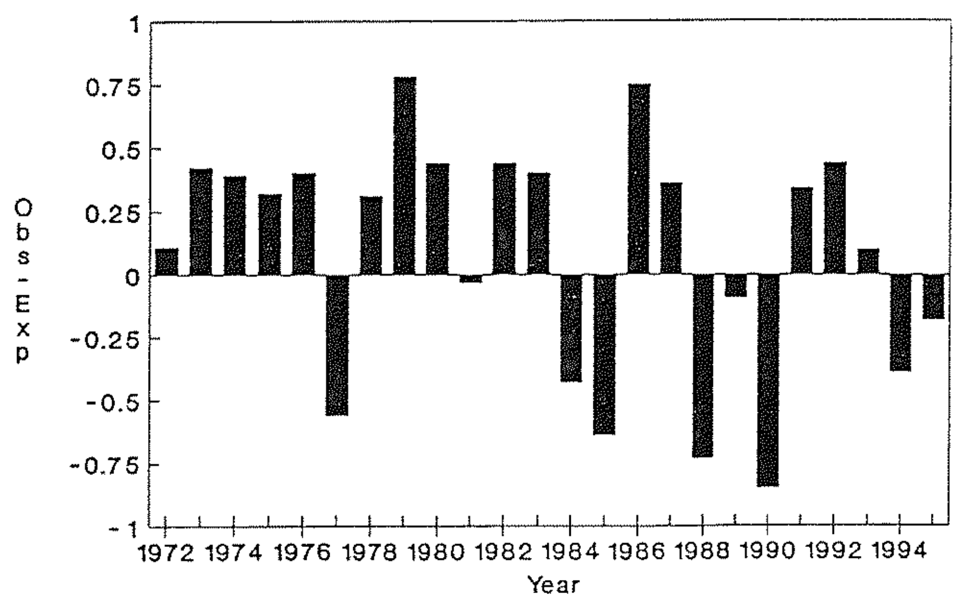


Fig.5- Observed Finfish Abundance Trend in Mt. Hope Bay 1972-1995 and Predicted Trend from Coolant Flow Model

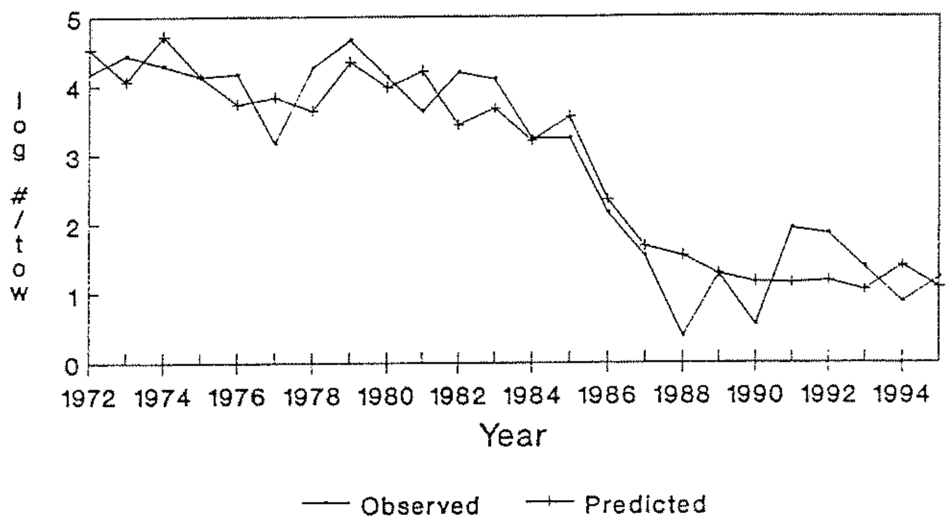


Fig.6- Residual Plot for Mt. Hope Bay Finfish Abundance Coolant Flow Model

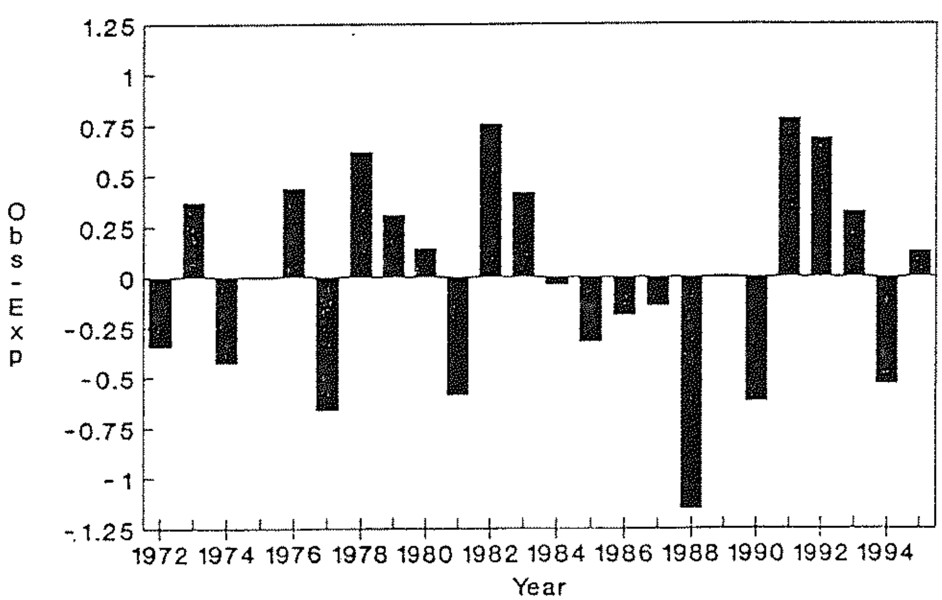
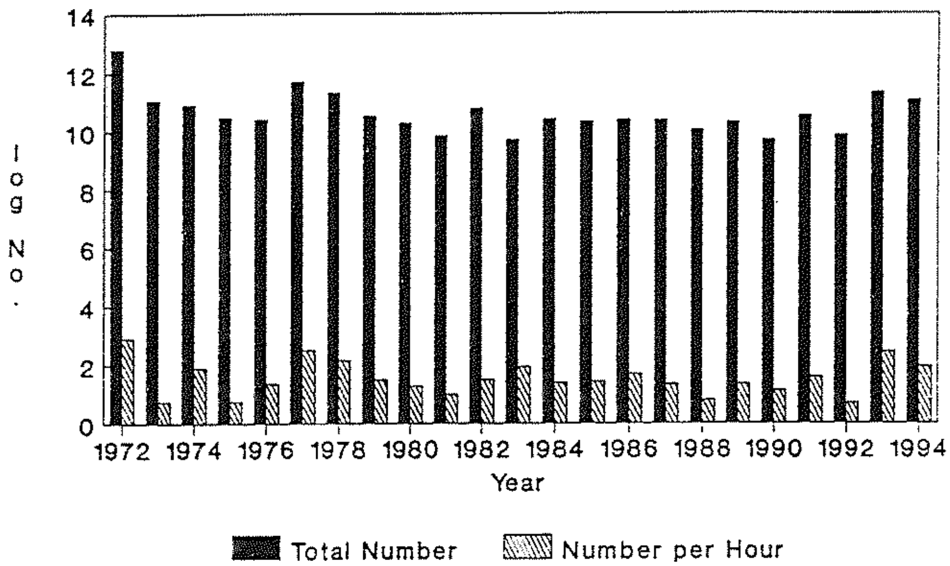
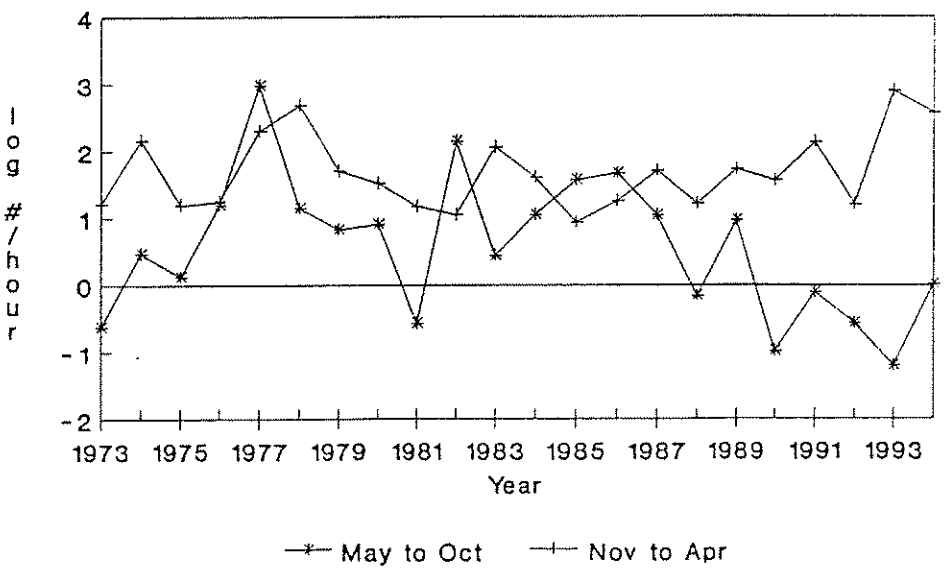


Fig.7- Impingement Levels at Brayton Point Power Station, 1972-1994



MRI Data

Fig.8- Trends in Finfish Impingement at Brayton Point Station by Season



Data from MRI

Fig.9- Aggregate Fish Abundance in Mt. Hope Bay Seine Survey, 1972-1994

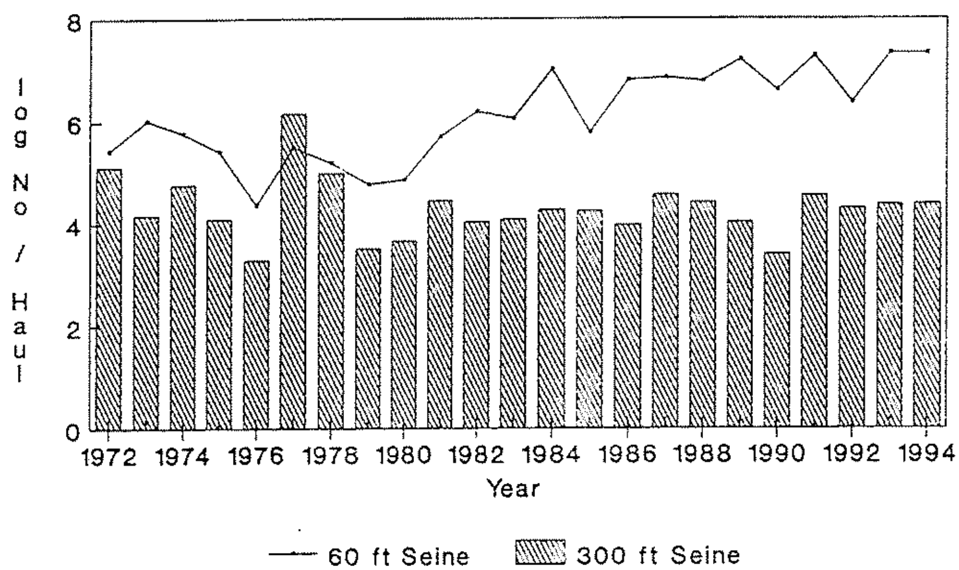


Fig.10- Species Rarefaction Slopes over Time for Mt. Hope Bay Seining

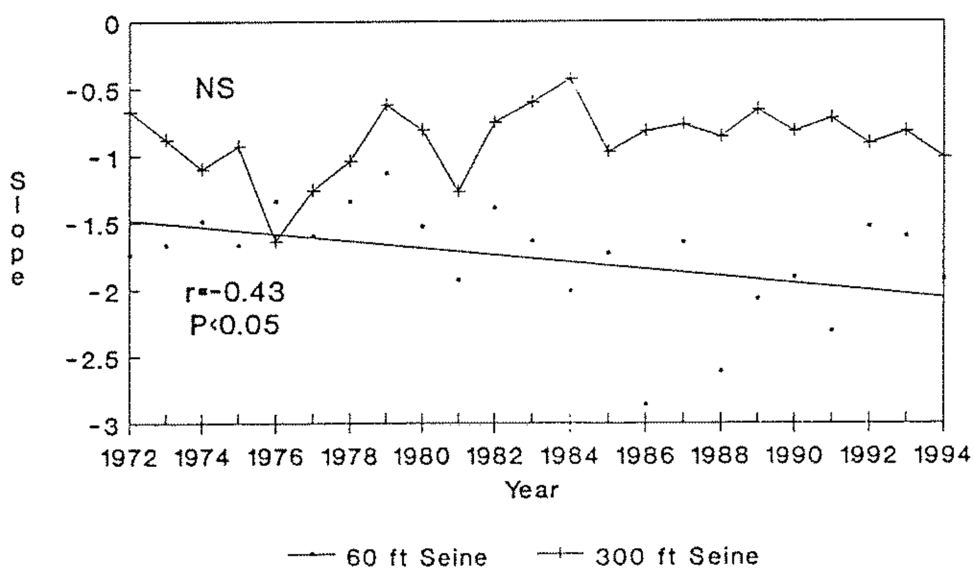
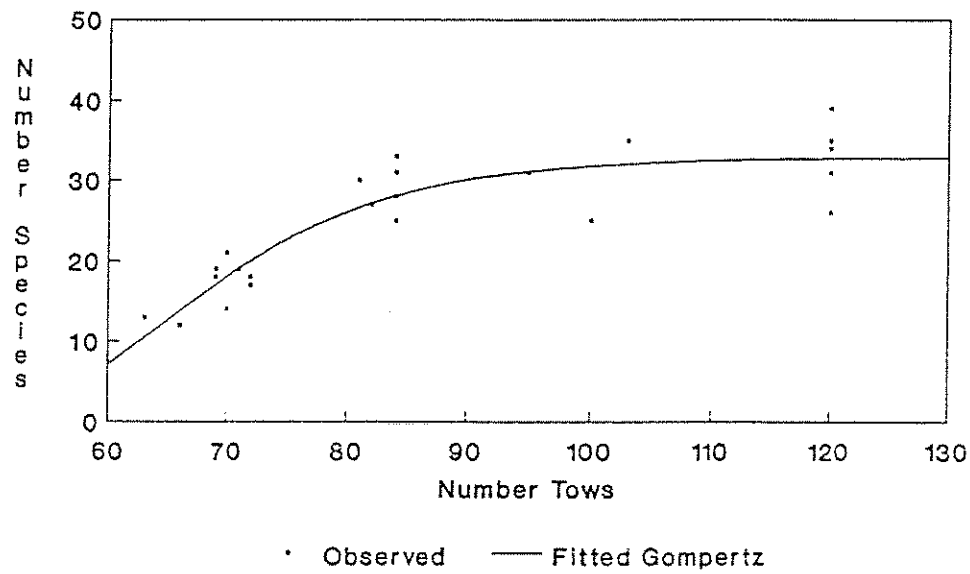


Fig.11- Plot of Species Count vs. Tow Number for Mt. Hope Bay, 1972-1995



MRI Trawl Survey

Fig.12- Residuals from Gompertz Model fit to Species Count-Tow Data vs. Time

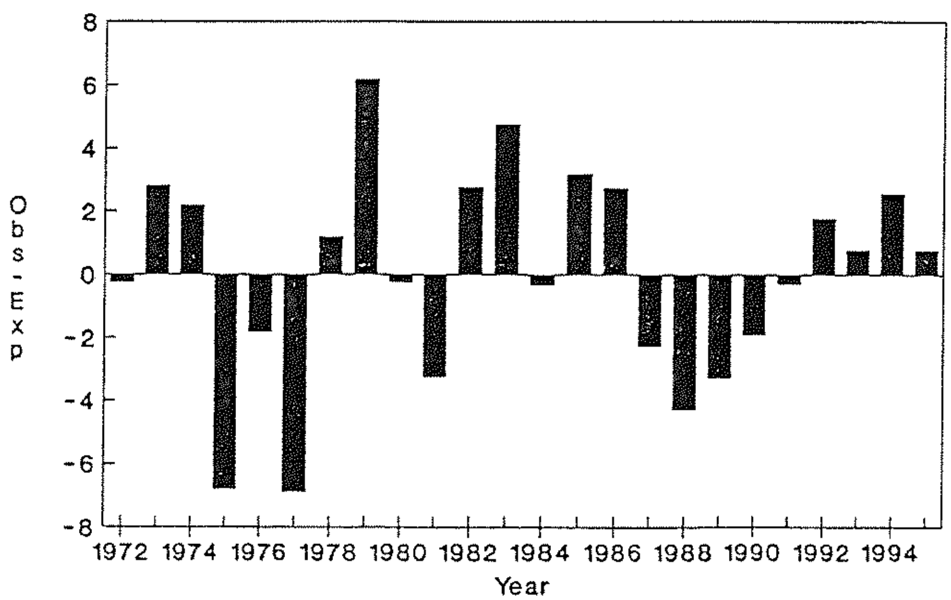
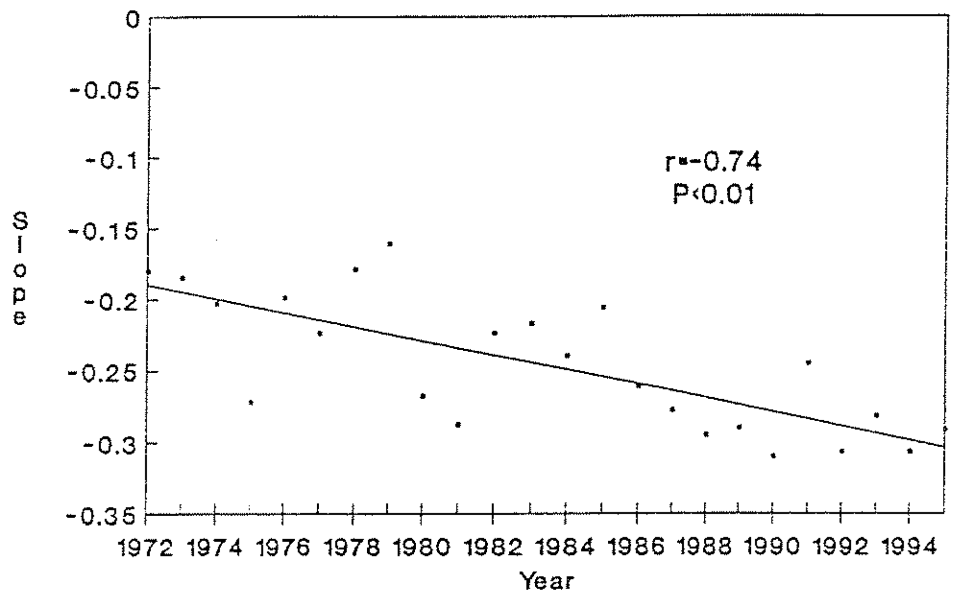
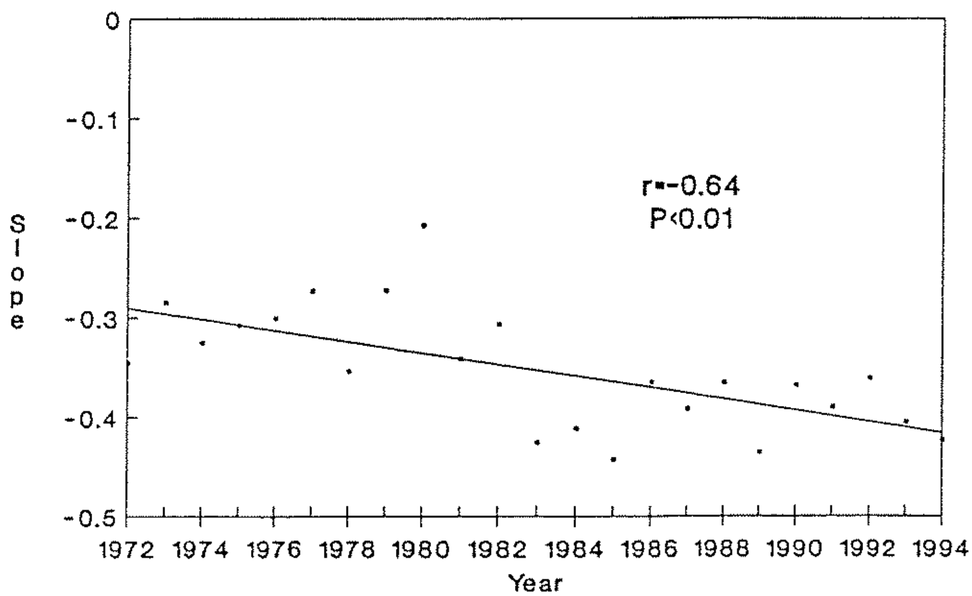


Fig.13- Species Rarefaction Slopes over Time for Mt. Hope Bay Trawl



MRI Data

Fig.14- Species Rarefaction Slopes over Time for Mt. Hope Bay Impingement



MRI Data

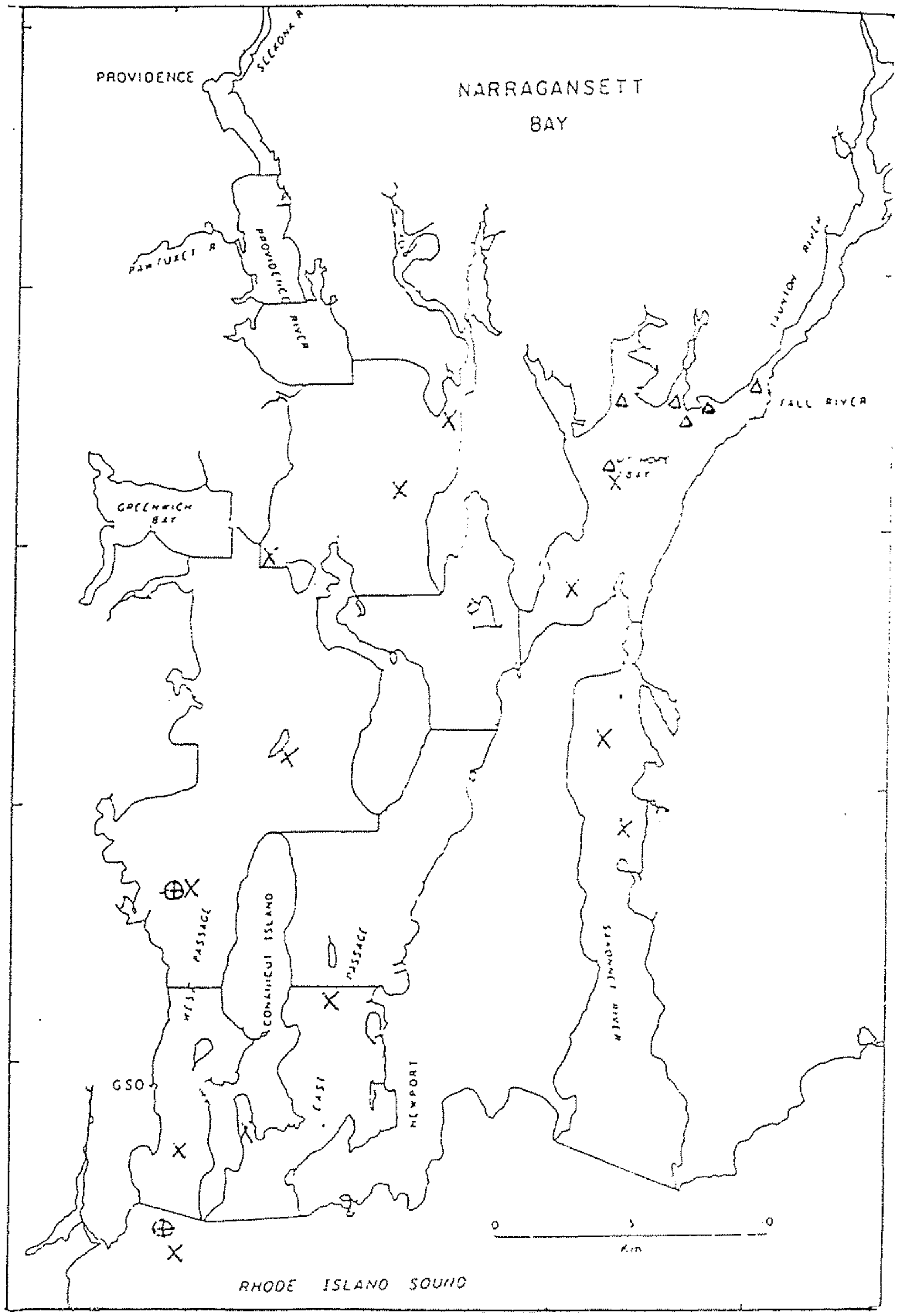


Figure 1. Data management areas of Narragansett Bay.

X - RIDFW Fixed Stations

⊕ - URIGSO Fixed Stations

Δ - MRI Fixed Stations

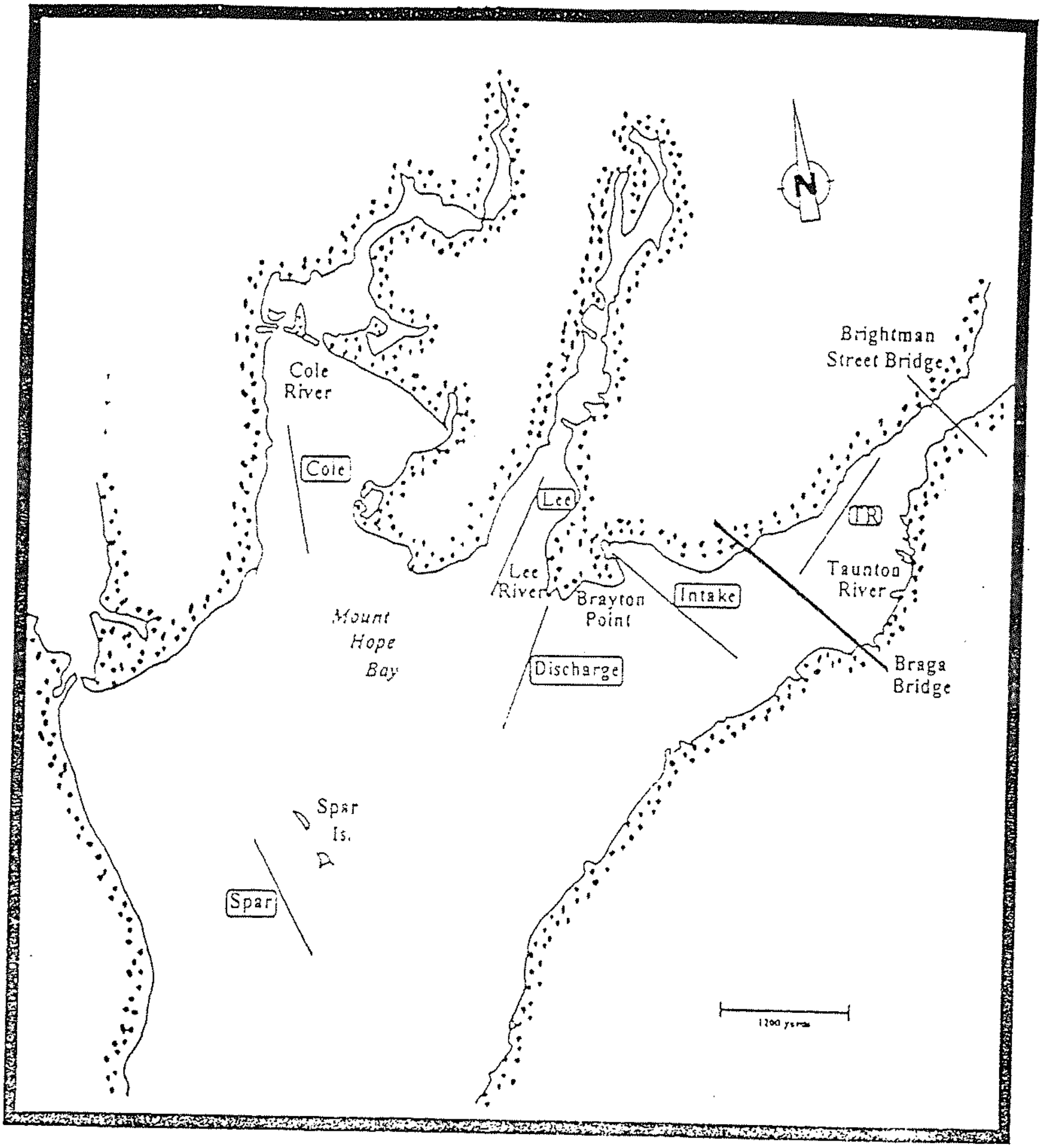


Figure F-1. Location of long-term fixed otter trawl transects in Mt. Hope Bay. Monthly Sampling by MRI.

Fig.15- Aggregate Resource Abundance in Long Island Sound and Connecticut Waters from Trawl Surveys

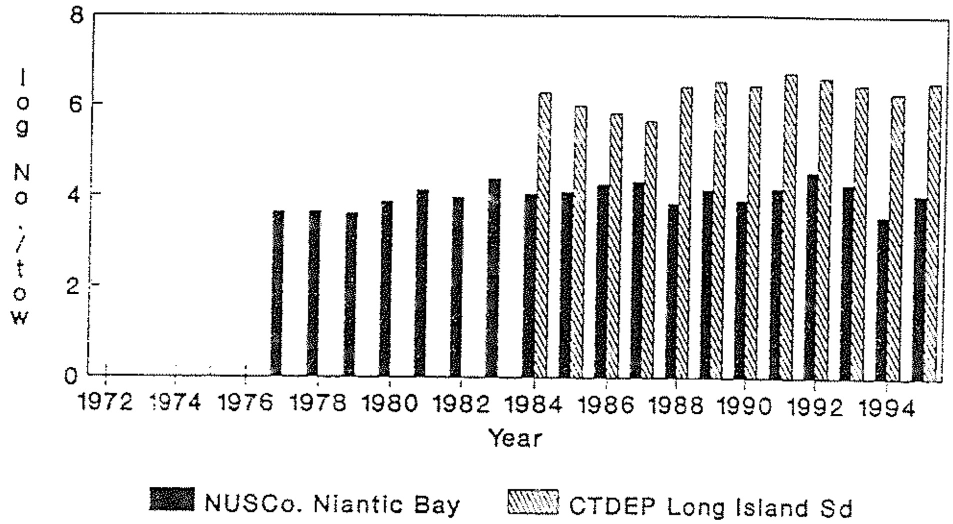


Fig.16- Aggregate Resource Abundance off the Northeastern United States and Massachusetts Waters from Trawl Surveys

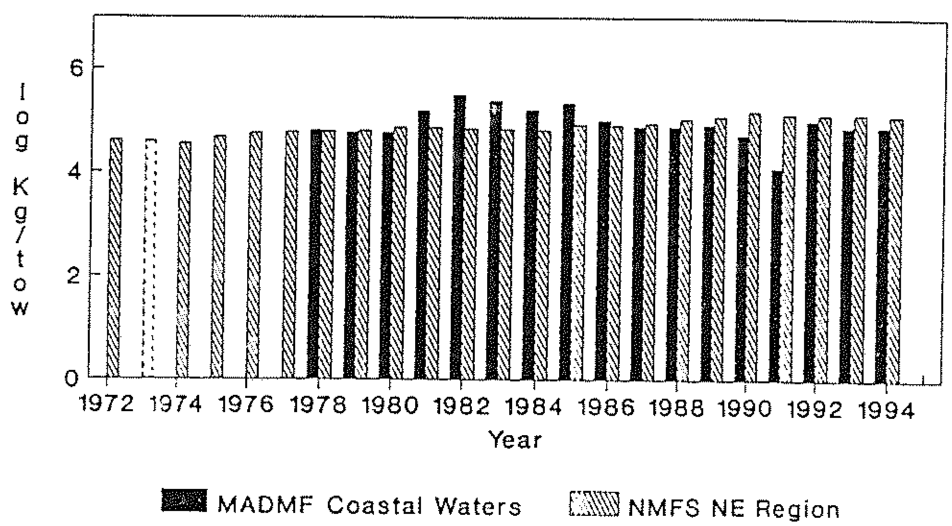


Fig.17-Time Series of NEPBPS Coolant Flow and Trawl Aggregate Fish Abundance