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EVALUATION OF CATCH-PER-UNIT-EFFORT INDICES USED IN AQUATIC MONITORING PROGRAMS AT NUCLEAR POWER PLANT SITES

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ABSTRACT

Catch-per-unit-effort (CPUE) indices, or the catch of fish (in numbers or weight) per defined unit of fishing effort, have been used as a fisheries management tool and in monitoring programs at nuclear power plants. An examination of CPUE techniques was conducted with the purpose of developing guidelines for evaluating monitoring programs and interpreting the resulting information. Data bases were selected for analysis from power plant monitoring programs which: (1) had an extensive data base of at least three years; (2) made use of several fish sampling methods; and (3) had monitoring designs which incorporated replicate samples from the fish communities. Two approaches to analyzing and evaluating data bases were taken. At riverine sites, the emphasis centered on applied biological and field sampling; quantitative aspects were evaluated with graphical presentations and coefficients of variation. At the remaining sites, emphasis was placed on statistical aspects and _a posteriori_ sampling designs and hypotheses. Data analyzed from selected programs do not provide evidence to support basic assumptions of CPUE such as proportionality of CPUE to population abundance, sufficiency of CPUE to detect changes of reasonable magnitude, and capability to assess power plant-induced change through CPUE measurement. The findings indicate that CPUE indices cannot be relied on as the sole bases for assessing population changes. Future approaches should be based on a realistic framework that integrates qualitative and quantitative components and recognizes the shortcomings of CPUE as a monitoring tool.

SUMMARY

The measurement of catch-per-unit-effort (CPUE) has been used by fishery managers and biologists at nuclear power plants to obtain data on local fish populations. This study examines CPUE techniques with the purpose of developing guidelines for evaluating monitoring programs and interpreting the resulting information. Data bases were selected from monitoring programs that had accumulated at least three years of data, had used several sampling techniques, and had monitoring designs which incorporated replicate samples from the fish communities.

Two approches to analyzing and evaluating data bases were taken. For riverine sites, emphasis centered on applied biological and field sampling; quantitative aspects were evaluated with graphical presentations and coefficients of variation. Emphasis at remaining sites was placed on statistical aspects and a posteriori sampling designs and hypotheses.

Results of the study do not provide evidence to support the assumptions underlying applications of CPUE indices. Seasonal population patterns detected by the techniques were inconsistent between sites and species; it was not possible to determine if any of the sampling methods detected actual population fluctuations.

We conclude that current aquatic monitoring programs are providing CPUE indices for which reliable, objective criteria for basing evaluations on existence or magnitude of power plant impacts are unavailable. Utilization of CPUE indices to detect changes in population abundance appears dependent upon development of sampling programs and statistical methodology capable of coping with changes in catchability and variability within and between years. Research on improved sampling programs should focus on ways to estimate catchability or reduce the sensitivity of CPUE indices to this variable. Statistical approaches that can reduce the magnitude of the error variance or increase the ability to detect between-year changes is needed. The evaluation of population changes and cause and effect relationships will likely remain a qualitative process and include evidence drawn from ecological experience, CPUE indices and simulation modeling.

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1.0 INTRODUCTION

This study, sponsored by the U.S. Nuclear Regulatory Commission (NRC), examines the use of catch-per-unit-effort (CPUE) techniques as they are applied in fisheries monitoring programs at nuclear power plants. The objective is the development of guidelines for evaluating such programs and for interpreting the resulting information. It is anticipated that these guidelines will be applicable to current situations within fish monitoring programs at thermoelectric power plants. Evaluation of proposed design and implementation schemes for fisheries monitoring programs at new facilities will be enhanced by the findings from this project. Many nuclear power plant fish monitoring programs have compiled several years of operational history and environmental data. Within these programs it is timely to review and evaluate the data and requirements for continued data collection.

The majority of fish monitoring programs at nuclear power plants appear to have been designed and established based upon techniques adapted from fisheries resource management approaches. A review of fisheries management approaches concluded that CPUE techniques warranted further investigation to evaluate their role in assessment and monitoring programs for fisheries impacts (McKenzie et al., 1979a). This report addresses the findings from fish monitoring program data reviews at several operating nuclear power plants. Prior to examining these results it is necessary to consider the objectives of monitoring programs, characteristics of fish populations subjected to power plant stresses, and a conceptual monitoring framework that would address ecological concerns.

In 1969, Congress instituted the National Environmental Policy Act (NEPA). Simply stated, its goal was to require a systematic evaluation of potential environmental damage which might result from federal agency activities. The wording and interpretations of NEPA imply that its intent is to promote assessments of ecosystem effects. Although rarely stated explicitly, the objectives or intent of programs implemented to fulfill NEPA requirements usually address in situ individual organism effects and occasionally population level effects. Within these programs there appears to be a lack of knowledge or concensus of opinion on what is needed to evaluate potential or measure actual environmental impacts (Reynolds, 1980). In part, this situation is fostered by the difference that exists between what is desired (NEPA) and the ability (scientific state of the art) to implement those objectives (Thomas and McKenzie, 1979).

The fish monitoring programs reviewed by this project can be characterized in the following ways:

- The objectives of monitoring the fish populations are not explicitly established, but appear to be concerned with detection and quantification of changes that are induced by operation of the power plant.
- In the population abundance of selected fish species, implementation of these objectives has resulted in vague monitoring requirements and application of several data collection methods.
- Insufficient understanding of individual techniques and seemingly conflict ing lines of evidence contribute to data sets that are difficult to analyze and interpret; assessments of impact are primarily qualitative and generally have neither detected changes that can be attributed to power plant operation nor provided substantial evidence that such changes have occurred.

These characterizations are consistent with other findings (Gore et al., 1977; Murarka et al., 1976; Adams et al., 1977; McKenzie et al., 1977). However, programs selected for review appear to have produced the best available data on fish populations and CPUE monitoring approaches at nuclear power plants. Thus, review of these programs represents a step in evaluating, understanding and developing the state of the art in fish monitoring programs.

One approach to the evaluation of fish monitoring programs is first to consider an idealized or conceptual monitoring framework. An impact assessment program is expected to document any (or lack of) changes in the ecosystem, and recognize those changes caused by power plant operation. In applying these needs to a monitoring program that addresses impacts at the population level in the fish communities, the following specific informational needs can be identified:

- population size and processes potentially impacted
- detection of changes of size Δ or larger
- separation or isolation of power plant-induced effects
- identification of cause and effect mechanisms if a power plant-induced change is detected
- detection of changes before they become irreversible.

If one is supplied with this information and the associated methodology, it would be relatively simple to assess power plant impact as well as manage the fisheries resources. Comparison of these idealized characteristics with those from studies implemented at power plants can provide valuable insight for interpreting and evaluating fish monitoring programs.

The comparison of monitoring programs based on CPUE techniques with the idealized model can occur on two levels. First, the kind of data collected can be qualitatively examined to evaluate how well it supplies the information needed by the idealized model. Second, the statistical characteristics of data collected can be evaluated to determine if biologically significant changes can be detected. The qualitative and quantitative evaluations are addressed in the following sections.

2.0 QUALITATIVE EVALUATION OF INFORMATION FROM CPUE FISH MONITORING PROGRAMS

As generally implemented, impact assessment programs associated with nuclear power plants have not attempted to produce estimates of fish population size. Although the methodology is readily available for such an application (Seber, 1973), the magnitude of the required effort has been prohibitive. As a result, fish monitoring programs have relied on approaches that use CPUE techniques to produce relative abundance indices of population size. A relative abundance index is an observation (datum) that is proportional to population size. CPUE techniques have been adopted from their development and application in fisheries management problems. In order to evaluate the application of CPUE techniques in power plant monitoring programs, it is necessary to examine the principles underlying successful fisheries management applications.

Catch-per-unit-effort is defined as the catch of fish, in numbers or weight, resulting from the deployment of a defined unit of fishing effort (Ricker, 1975). When two conditions are met it is well established that CPUE is proportional to the number (or weight) of fish in the population that is being fished (Ricker, 1940). The first of these conditions requires that a single population (N) be fished and that all members of the population have an equal chance (P) of being caught. The second necessary condition is that the unit of effort (e.g., hours of fishing, number of fishing licenses, number of fishing trips) be proportional to the exploitation or fishing mortality rate. The success of an application of CPUE techniques for either fisheries management or monitoring near a power plant will depend on the degree to which these two underlying conditions are achieved. Achievement of equal probability for each fish in the population being caught is primarily dependent on the spatial distribution of the population and fishing effort. Failure to achieve this condition complicates the interpretation of catch-per-unit-effort statistics and introduces errors which may be hard to detect. The least tractable fish management situations concern wide ranging oceanic species which appear to vary in proportions at different locations in different years (Ricker, 1975). The best situation occurs when the fishing effort is scattered randomly over the entire range of the fish population.

In sharp contrast to the fishing applications, monitoring applications have used a fixed spatial effort approach and only rarely is the effort applied over the entire range of the population. The fishing efforts are usually allocated to stations based on distance from the power plant site and ability of the gear to fish at that site. Only when dealing with small reservoirs or cooling ponds does the spatial scale of the fishing effort match the fish population spatial scale. Interpretation of the CPUE data therefore must rely on the assumption that the population density in that spatial scale is a constant proportion of the entire population. This report investigates the validity of that assumption and thereby the potential for interpretation of CPUE-based monitoring programs.

The ability of a fish monitoring program to detect changes of size Δ in CPUE indices can be evaluated statistically and are a function of variability, sample sizes, error rates and experimental design. Information on these statistical properties is presented in the following section. The determination of what level or size of change (Δ) a monitoring program should detect is both needed and impossible to do on a generic basis. Some of the factors that need to be considered on a site-specific basis are: biological and economic values associated with the fish species and their trophic and ecosystem relationships; the resources available for the monitoring program; and present state of the art (Thomas and McKenzie, 1979). The explicit evaluation of monitoring objectives and results is needed to ensure that these programs fulfill the environmental concerns expressed by NEPA. Several previously reviewed nuclear power plant fish monitoring programs concluded that no impact was detected in part because of limited on detectability (Gore et al., 1979).

The major problem to be faced in impact assessment is the separation or isolation of power plant-induced effects from those induced by environmental changes, natural variability and other man-induced changes; i.e., pollution, habitat alteration and fishing mortality. A common experimental approach to this kind of problem is to establish a control group or population. The control group's response is the integration of all the experimental conditions (both controlled and uncontrolled) and differs from the treatment group only by a single factor. An experimental approach based on control/treatment ratios has been suggested. This approach mimicks these essentials and permits separation of power plant-induced effects for lower trophic levels; e.g., planktonic and benthic communities (Chapman, 1951; Eberhardt, 1976; Green, 1979; McKenzie, et al., 1979b). However, the concept of a control group or station does not appear applicable for most fish species of interest. Because the range of many fish populations exceeds the zone of power plant effects and their exposure to numerous stresses not related to power plants, it seems unlikely that a suitable control group can be established. A possible exception to this may occur for power plants situated on small cooling reservoirs with adjacent "control" reservoirs (Becker et al., 1979). Thus, alternative approaches need to be developed for future fish monitoring programs and current programs need to be evaluated within this framework.

Little has been done to establish cause-and-effect relationships within monitoring programs. Other than inference by correlation, it does not seem that much that can be done. However, evaluation of alternative power plant cooling systems, mitigation measures and corrective action is dependent upon identification of cause-and-effect relationships (Reynolds, 1980). Although most programs seem to be attempting to obtain information on causal relationships by measuring "everything," this does not seem realistic. Our inability to statistically separate impingement, entrainment, thermal and chemical stresses and their resultant effects suggests that establishing cause and effect relationships should be a secondary objective of monitoring programs. Monitoring data can serve to evaluate laboratory and modeling results, of which the primary objective is causal relationships.

Another desirable characteristic for monitoring programs would be to provide forewarning of major population changes. However, detection of impacts prior to irreversible population changes is dependent upon achievement of an appropriate level of change being detected and knowledge of population and ecosystem processes. Both of these cannot be addressed within a monitoring program. This suggests that detection of change should be the primary objective of the monitoring program. Predictive modeling, although currently capable of providing only unreliable predictions, will need to play a major role in providing the additional information needed to fulfill the objective of predicting major changes (Swartzman et al., 1977).

3.0 QUANTITATIVE EVALUATION OF SAMPLING METHODOLOGY FOR FISH COMMUNITIES IN THE VICINITY OF POWER PLANTS

3.1 INTRODUCTION

For a number of years, monitoring programs have been used as one information source in assessing impacts of power plants on fish communities. These monitoring programs were established to identify the important fauna in the region of the site and to separate and assess changes in the fish communities resulting from an impact and natural variation. Generally, this monitoring has been accomplished by routinely sampling the fish communities using commercial or special monitoring fishing gear or, more recently, by hydroacoustics.

A lack of information on the efficiency of the various fish sampling methods has been combined with vague monitoring objectives and program designs and has generally resulted in the use of a large variety of sampling gears. This variety, in turn, has added to the difficulty of assessing impacts, since each technique may provide different information resulting from differences in sampling gear efficiencies and species selectivity. As a result of inadequate sampling objectives, designs and methods, monitoring programs have generated large quantities of data on fish abundance which are of unknown value in quantifying impacts.

This section examines quantitative information and evaluates the potentials for various fish management and sampling techniques in monitoring fish communities. In the first part of this study (McKenzie et al., 1979a), catch-per-unit-effort (CPUE) and hydroacoustics were identified as potentially promising methods for monitoring fish and shellfish populations. The specific objectives of this effort were:

- to determine the efficiency, selectivity and variability (sampling error) of common sampling methods in monitoring fish populations
- to determine whether alternative sampling methods provide comparable data on species composition and relative abundance of fish

- to determine whether modifications in sampling designs may increase effectiveness and/or decrease sampling error
- to determine if seasonal trends in CPUE exist and whether such trends are consistent enough from year to year to permit the selection of an optimal sampling period
- to examine the spatial distribution of fish populations in the vicinity of power plants to determine the importance of spatial heterogeneity within sampling designs.

To satisfy these objectives, data bases which met the following criteria were selected for analysis from monitoring programs at power plants:

- extensive data bases covering at least three years duration
- use of several fish sampling methods to monitor CPUE
- monitoring designs which incorporated replicate samples from the fish communities
- location in a representative habitat type.

Hydroacoustics is a relatively new technique and consequently we found no data bases that fulfilled these criteria. Advocates of this technique make what appear to be reasonable claims for the technique. However, though monitoring programs proposing to use this technique should be approached as promising, the technique as yet has not been quantitatively evaluated.

Five power plant CPUE data bases were selected for study. These were Pilgrim Nuclear Power Plant (NPP), an ocean site (Boston Edison Company, 1973a,b, 1974a,b, 1975a,b, 1976a,b, 1977a,b, 1978); Nine Mile Point NPP, a large lake site (Niagara Mohawk Power Corporation, 1974, 1975, 1976, 1977, 1978, 1979); and three riverine sites, Susquehanna NPP (Pennsylvania Power and Light Company, 1972, 1973, 1974, 1976a,b, 1977), Quad Cities NPP (Commonwealth Edison Company, 1972, 1973), and Prairie Island NPP (Northern States Power Co., 1974, 1975). For the riverine sites, four fish sampling methods were analyzed: trapnetting, trawl, seine and electrofishing. At Nine Mile Point, the seine, trawl and gill net catches were analyzed. For Pilgrim, the lobster pot and trawl catches were evaluated.

Two somewhat different approaches to analyzing and evaluating these data bases were taken. The riverine sites were examined with a greater emphasis on applied biological and field sampling aspects and the quantitative aspects via graphical presentations and calculation of coefficients of variation. The remaining sites were examined with a greater emphasis on statistical aspects and a posteriori sampling designs and hypotheses. These sites only briefly examined microhabitat variations and seasonal trends characteristic of species under consideration.

Both approaches have merit and represent methodology likely to be applied and reported in environmental impact reports. In addition, this diversity is anticipated to aid in the communication of the scope of the problems to be dealth with when evaluating CPUE data bases for their information on impacts.

3.2 COMPARISON OF TECHNIQUES AT THREE RIVERINE NUCLEAR POWER PLANTS

Methods

Site Descriptions

After reviewing the fish monitoring programs at riverine nuclear power plants throughout the United States, the programs at Susquehanna NPP, Quad Cities NPP, and Prairie Island NPP were selected for the analysis of sampling methods. These studies each used a variety of sampling techniques and each was intensive in terms of sampling frequency or number of sampling stations over a long period (five to eight years). In addition, the three study areas had different site characteristics so that generalizations among sites could be investigated.

The Susquehanna site is located on the North Branch of the Susquehanna River near Berwick, Pennsylvania. At the location of the power plant, the river is relatively small, with an average flow of 13,300 cfs and maximum and minimum flows of 239,000 cfs and 540 cfs, respectively (U.S.A.E.C., 1973a). It flows in a well-defined channel 100 to 480 m wide, and during the summer low-flow period averages only 1 to 3 m deep (Pennsylvania Power and Light Co., 1973).

The Susquehanna River bottom is scoured during periods of high water and consists of gravel, large rocks and bedrock, with some silt in the larger eddies. There is relatively little vegetative growth in the water or along the shore except at the high water mark, and there is very little heterogeneity in habitats other than the riffles, pools and eddies created by variations in gradient and current.

The Quad Cities site, on the Mississippi River above Cordova, Illinois, is very different from the Susquehanna site because the river is large, the current is slow, and the habitats more diverse. This difference in character is caused largely by the river's greater volume (average flow 47,000 cfs; Commonwealth Edison Company, 1972) and lesser gradient, but it is also due to the series of low-head navigation dams which have converted this section of the Mississippi River into a chain of long flowing pools. Located approximately midway along the 47 km long Pool No. 14 at Quad Cities, the site has at least three distinct habitats; main channel, side channel and slough. The main channel averages 375 to 750 m wide and is 6 to 9 m deep with a bottom of scoured sand. The shoreline along the main channel is relatively barren with few submerged stumps and very little overhanging brush or other vegetation. In the side channels, the current is considerbly diminished and the less scoured shorelines characterized by overhanging vegetation, submerged tree stumps, and other vegetation. Sloughs or backwaters lack current and are generally shallow with many submerged stumps and other forms of vegetation over bottoms of mud or fine sand.

The Prairie Island site near Red Wing, Minnesota, is also on the Mississippi River, approximately 480 km above Quad Cites. The river is smaller (15,000 cfs average; U.S.A.E.C., 1973b), than at Quad Cities, but the sampling site is more complex because it includes the swift tailwaters below Lock and Dam No. 3, as well as the deep flowing pool and shallow slough areas above it. Four habitats are evident near the Prairie Island Site: main channel, slough, river-lake, and tailwater. Of these, only the North Lake slough is comparable to the Slough of the Quad Site. The main channel overlaps several Quad Cities classifications, having both the scoured gravel, sand and mud substrate of the main channel and the stumps and overhanging brush characteristic of a side channel. In addition, the Prairie Island main channel has a number of rock wing dams and riprap sections which are not present at the Quad Cities site.

Sturgeon Lake, the Prairie Island river-lake, is a large, shallow, stump-filled water body with a number of connections to the main channel. It is similar to a slough, but has a greater flushing rate and a perceptible current, especially during high water. The tailwaters of Lock and Dam No. 3 have strong currents and are fairly deep, with riprap and rapidly changing bottom contours in most areas. However, they do not extend downstream very far before the river regains the "typical" main channel character.

Species Selection

Because of the great diversity of fish species at the three sites, it was neither feasible nor warranted to analyze the sampling methods for each species. Therefore, five species which were common or abundant at all three sites and which exhibited different life histories and habitat preferences were selected for intensive study. These included carp (*Cyprinus carpio*), channel catfish (*Ictalurus punctatus*), bluegill (*Lepomis macrochirus*), white crappie (*Pomoxis annularis*), and walleye (*Stizostedion vitreum vitreum*).

The carp was selected primarily because of its greater numbers and biomass at all sites. The other species all represent popular sport fish which were present in varying abundances at each site (Appendix A, Table A).

Sampling Methods

Although eight different sampling methods were used at various times in one or more of these monitoring programs, only electrofishing, trapnetting, trawling and seining were analyzed in this study (Table 1). Gillnetting, drifting trammelnets, setlining and midriver seining were not examined because they are unsuitable for generalized riverine monitoring programs. These fishing gears are either unusable in currents (gillnets), they snag on underwater obstructions and are easily lost (drifted trammelnets), they have extremely low CPUE (midriver seine) or they are too species-specific to be used in generalized programs (setlines).

Table 1. Fish Sampling Methods, Frequencies, and Numbers of Stations Used in the Susquehanna, Prairie Island and Quad Cities Monitoring Programs.

Method	Susquehanna	Prairie Island	Quad Cities
Electrofishing	A.C. 1972-74 1972 - 14 stations frequency varied 1973-74 - 10 stations monthly D.C. 1975-77 4 stations monthly	A.C. 1973-77 up to 50 stations 3/year	A.C. 1973-78 12 stations twice/monthly
Trapnet	Framenet 1972-75 1972 - 26 stations frequency varied 1973 - 5 stations monthly 1974 - 4 stations monthly 1975 - 7 stations monthly All years had 2 consecutive sets Oneida net 1972-74 1972 - 5 stations frequency varied 1973-74 - 4 stations monthly All years had 2 consecutive sets	Framenet 1973-77 1973-74 - up to 37 stations 3/year 1975-77 - up to 24 stations 4 consecutive sets, 3/year	Wingnet 1971-72 11 stations twice/month
Trawl		Otter trawl 1974-77 4 stations 3/year	Otter trawl 1971-78 3 stations twice/month
Seine	Common seine 1972-73 11 stations monthly Bag seine 1974-77 4 stations monthly	Bag seine 1974-77 up to 18 stations 3/year	Common seine 1971-77 6 stations twice/month

Electrofishing. Electrofishing utilizes an electric field to immobilize the fish until they can be captured. Either A.C. or D.C. current can be used, but A.C. electrofishing is generally more popular, and was used at all three sites. The equipment was similar among sites; the basic unit consisted of a 230 V A.C. generator and voltage-regulating mechanism mounted on a 4.9 to 5.5 m flat-bottom boat with the booms and electrodes extending forward of the bow. Each site also used different current-regulating mechanisms, so electrical power and current of the various units was probably different. In 1974, electrofishing at Susquehanna was changed to D.C. The same boat and generator as in the A.C. unit were used, but the current was run through a rectifier to transform it to pulsed D.C., and the electrode configuration was changed to permit effective use of D.C. current as recommended (Novotony and Priegel, 1974).

At all sites, the boats were driven slowly along the shoreline, and one or two men standing in the bow collected the stunned fish. Effort per sample was reported as minutes spent shocking and/or length of shoreline travelled and was converted to catch per 15 minute "run." Electrofishing CPUE is affected by the electrode configuration, the conductivity of the water, and the nature of the river bottom, as well as the size and species of the fish (Novotony and Priegel, 1974). Each of these parameters varied from site to site.

Nets. Trapnets were used at each site. "Trapnet" is a more-or-less generic term for any fish sampling device which uses blocking nets or a series of net funnels to guide fish into a central collecting bag or box. The nets are generally set in 1 to 3 m of water with the opening facing downstream or perpendicular to the current, depending on the net design. Specific variations of trapnets include framenets, oneida nets and hoop nets.

Similar framenets were used at both the Susquehanna and Prairie Island sites. They consisted of a 0.9 x 1.8 m frame and two series of mesh funnels to direct the fish into a mesh bag. A 15 m lead was stretched from the mouth of the framenet to divert fish into the trap.

The Susquehanna monitoring program also used an oneida net. This net, which is harder to set because of its larger size and more complex construction, has a 1.8 x 1.8 m frame and three series of funnels. It also has two wing nets extending from the mouth of the net at 45° angles, with floor and ceiling netting between them to prevent the fish from swimming over or under the oneida net once they have been diverted toward the trap by the barrier and wing nets.

A wing and hoop net combination was used in the Quad Cities monitoring program. It was similar to a framenet, but the funnel openings were circular instead of rectangular and the trap had two wing nets extending from the mouth at 45° angles instead of the framenet's perpendicular barrier net. In addition, the hoops also had a slightly larger mesh (2.5 cm^2 mesh) than the framenets (1.25 cm^2 mesh).

Most of the trapnets were fished for 24 hr before the catch was removed. However, a few sets were much shorter. Because there is evidence that trapnet catch is not linear with time (Hansen, 1944; Kennedy, 1951), any data from sets of less than 10 hr were discarded from the analysis. All other catches were adjusted to a 24 hr unit of effort.

Otter trawling was used to sample midchannel fish at Prairie Island and Quad Cities. Both programs used a small trawl (4.9 m headrope with a 0.5 cm^2 mesh-cod end) which was towed behind a single boat. At Quad Cities the river channel was fairly free of obstructions; a 7 minute downstream tow was consistently collected. However, the Prairie Island trawling stations contained many rocks, stumps and other snags which interrupted trawling, and tow duration for individual catches varied considerably. To make CPUE values for the two sites comparable, a 7 minute tow was selected as the standard and all catches were adjusted to this unit of effort.

Although each program used 0.5 cm^2 mesh seines to sample fish along the shoreline, the means and variances of the samples are not directly comparable because each site used different net configurations and techniques. The Susquehanna program used a 3 m common seine from 1971 to 1974, when they switched to a 7.6 m bag seine. The time of sampling time and effort per station varied from daytime only with three hauls per station (1971 to 1972) to day and night with one haul per station (1973 to 1974) to nighttime only sampling with two hauls per station (after 1974; Pennyslvania Power and Light Company, 1972, 1973, 1974, 1976a, 1976b, 1977). The Prairie Island sampling program consisted of a single daytime haul per station with a 15 x 1.2 m bag seine. A 30 x 2.4 m bag seine was used in 1973, but this was discontinued because it was too large to permit effective sampling at all of the stations (Northern States Power Co., 1975). The Quad Cities program also conducted daylight sampling, but with two hauls per station using a 7.6 x 1.8 m common seine (Commonwealth Edison Company, 1973).

Because of the variety of seines and techniques, the results were analyzed as catch/haul for whatever seine or method was being used.

Analysis Procedures

To meet the objectives of the study, the mean monthly CPUE, its variance and coefficient of variation were computed for each of the five species sampled by the various methods at each of the three sites. Monthly periods were used for these initial calculations because the fish populations could be assumed to be relatively constant over time, and months were the shortest periods which had sufficient sampling effort to allow estimates of CPUE and variance. Had longer periods been used, the possibility of combining different populations would have been increased and the variance estimates might have been biased.

From these calculations, a series of graphs of average monthly CPUE versus time was developed for each sampling method and species. The first of these graphs plotted CPUE by replicate for methods with consecutive hauls or sets, such as trawling at Quad Cities and framenetting at Prairie Island. Pseudo-replicates such as day and night electrofishing at Susquehanna were also plotted. These graphs were evaluated to determine if the samples which were considered "replicates" in the monitoring programs were actually replicates, or if there was a bias in the results indicating that different populations or selectivities were being observed. The graphs were also used to evaluate the relative effectiveness of alternative sampling methods, such as day vs. night sampling, and to determine if results showed any consistency between months.

Additional graphs of monthly CPUE per month by method of catch and species were constructed. These were used to identify seasonal trends in abundance and determine whether short periods such as spring or fall would give realistic indications of yearly abundance.

Yearly mean CPUE and CV values were developed to compare various sampling methods and to determine whether observed changes in the five target species were consistent among the different methods. For CPUE this involved averaging the monthly values for those months in which sampling was attempted, including months in which no fish were caught. This did not give the true yearly grand means because the calculation was not weighted for differences in sampling effort between months; however, this computation provided an average index for the populations throughout the year. This computation assumed that identical months were sampled each year for each method. Since sampling dates did change between years, this was not strictly true, but the bias should be minimal since consistent seasonal patterns of abundance or selectivity were not observed.

Mean yearly CV were computed in the same manner as the yearly CPUE, but only nonzero monthly values were included in the computation. This avoided distortion of the CV by months where CPUE was zero.

To evaluate the five species' habitat preferences and their effect on sampling variance, additional tables were developed in which the sampling stations at each site were grouped by habitat types before computing average CPUE, variance and CV. The primary groupings for the Quad Cities site were main channel stations, side channel stations and slough or backwater stations. These groups were based on a combination of substrate, current, and cover differences as explained in the site description. There were five habitat groupings at Prairie Island: silted main channel, riprapped main channel, tailwater, river-lake and slough. In addition, a sixth group was established to include the potentially impacted sites in the immediate plant area. At Susquehanna there were no distinct habitats other than riffle and pool, so the stations were grouped by substrate as either fine to coarse sand, coarse sand to pebble, pebble to cobble, or cobble and boulder.

The potential reduction in sampling variability by grouping the data according to habitat was investigated by comparing the range of CV for each habitat group against the CV for all stations (all habitats) combined. In addition, the combined station CPUEs were compared to determine if different habitat groups corresponded with each other on a monthly or yearly basis. Thus the consistency of the information from sampling all of the habitats for the five species could be examined.

Results and Discussion

Trapnet Replicates

Although most monitoring programs routinely combine consecutive trapnet sets or "replicates," two factors may potentially bias the results. First, the initial set or sets may catch enough fish to reduce the local population significantly, resulting in a smaller CPUE for subsequent sets. This would be particularly important for small populations of resident fish. Additionally, the catchability coefficient may be affected because of an avoidance response by previously captured fish. Some evidence exists that acclimation to the trap will increase some fishes' tendency to enter it (McCammon and LaFaunce, 1961). This, in effect, would increase the catch in the later replicates and result in increasing CPUE through time.

These factors do not appear to be influencing trapnet catches at either Susquehanna or Prairie Island. No consistent trends of increasing or decreasing CPUE between replicates were observed in either the monthly or yearly averages for any of the five species at either site. As Figures 1 and 2 show, there were large (order of magnitude) differences in replicate CPUE values at both Susquehanna and Prairie Island. Since trapnets are passive sampling devices, their CPUE depends upon both the population size and the activity of the fish. The differences between replicates appear most likely to be the result of changes in the activity levels of the fish rather than population abundance. Order of magnitude changes in population within the time between replicates is unlikely. For example, heavy rains could cause a strong feeding response and increase fish activity, providing an apparent increase in abundance using CPUE.

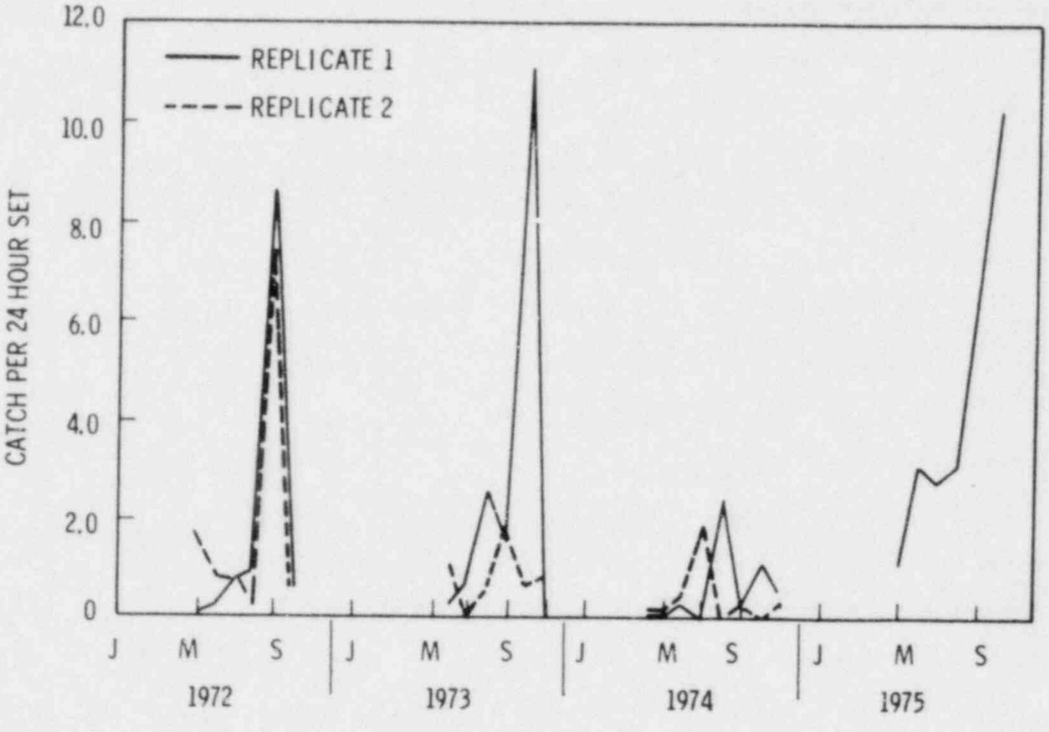

Figure 1. Monthly CPUE of Two Consecutive Framenet Sets for Bluegill Sunfish at Susquehanna.

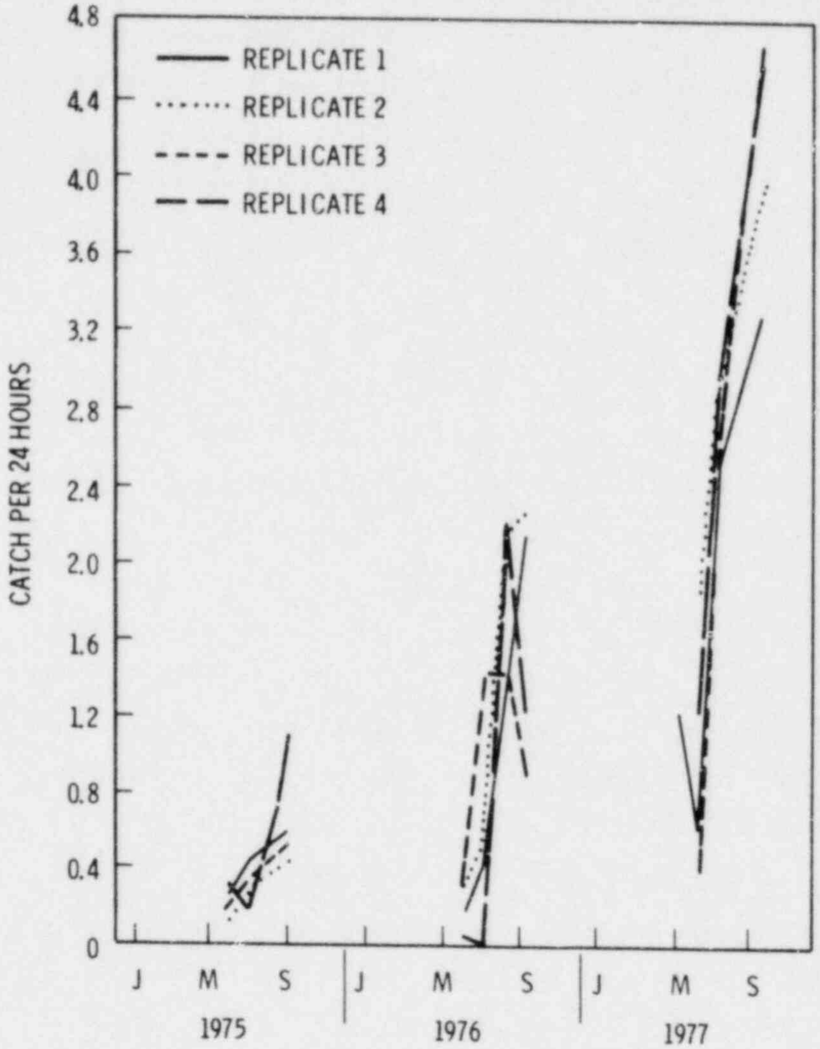

Figure 2. Monthly CPUE of Four Consecutive Trapnet Sets for White Crappie at Prairie Island.

Sampling variability did not seem to be significantly increased by combining the trapnet replicates, since the CV for all replicates combined were well within the range of CV for the four individual replicates for each species at Prairie Island except the channel catfish, which had a very low CPUE. The Susquehanna data were different in that the combined data generally had a larger CV than either of the individual replicate CV's; however, this was probably a result of the small number (only two) of replicates taken per sampling station and the relatively low framenet CPUE for all species at Susquehanna.

With no evidence of CPUE trends between replicates and only weak, inconsistent evidence of increased variability with combined replicates, it seems valid to combine all of the trapnet replicates. This was done for the remainder of the analyses.

Trapnet Variations

Although the monthly CPUE values for framenet and oneida net did not appear correlated during the three years in which they were used concurrently at Susquehanna (Figure 3), the average yearly CPUE trends for the two methods corresponded reasonably well. This suggests that both methods depict the same long-term CPUE changes; however, the oneida net seems to be a more useful fish monitoring technique because it was more effective than the framenet in capturing all five species (Table 2). The increases in average yearly CPUE of the oneida net over the framenet were consistent, ranging from 1.2 to 3.5 times for bluegills and white crappies to greater than 30 times more efficient for channel catfish. Carp and walleye CPUE were also affected significantly, showing three- to sixteen-fold increases. The variability of the oneida net catches was also consistently less than that of the framenets, with the CV varying between 0.75 to 2.96 and 1.56 to 3.61, respectively.

These differences in the effectiveness and variability of the two methods are undoubtedly related to the larger size and more complex construction of the oneida net, but the exact causes of the differences are uncertain. One possibility is that the oneida net, with its larger size, wing nets and ceiling and floor netting, covered more area and diverted the fish into the

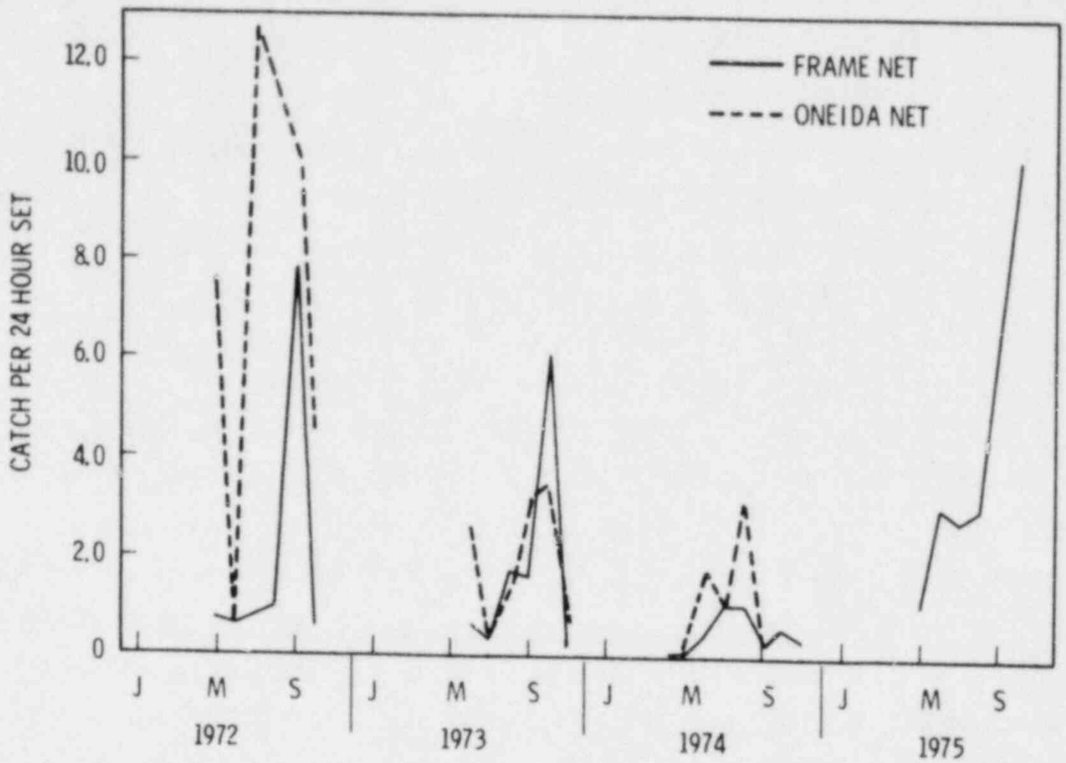

Figure 3. Monthly CPUE of Two Types of Trapnets for Bluegill Sunfish at Susquehanna.

Table 2. Ranges of Average Yearly CPUE and Coefficient of Variation for Framenets and Oneida Nets at Susquehanna, 1972-1974.

	Framenet		Oneida Net	
	CPUE	CV	CPUE	CV
Carp	0.12 - 0.41	2.24 - 2.75	0.47 - 3.20	1.09 - 1.89
Channel catfish	0.00 - 0.06	2.65 - 3.10	0.43 - 1.76	1.22 - 1.98
Bluegill	0.47 - 1.93	1.87 - 2.28	0.84 - 7.13	0.88 - 1.65
White crappie	0.16 - 3.26	1.56 - 2.73	0.22 - 11.80	1.21 - 2.96
Walleye	0.01 - 0.15	1.88 - 3.61	0.09 - 1.96	0.75 - 1.99

trap more efficiently than the framenet. Another possibility is that the addition of another web funnel leading into the central bag of the oneida net made it more difficult for the fish to escape once they were inside the net. Studies have shown, however, that bluegills can swim in and out of a framenet freely (Hansen, 1944), so the additional funnel should not make an appreciable difference. If fish can leave the trap at will, then the larger holding area of the oneida net may be partially responsible for increasing CPUE.

Electrofishing Variations

A.C. vs. D.C. Although much research has been done on electrofishing and a number of authors have compared the effectiveness of A.C. and D.C. electrofishing (Frankenberger, 1960; Novotony and Priegel, 1974; Vincent, 1971), there still seems to be some confusion over the two methods. A.C. electrofishing is the type most commonly used. Its major advantage over D.C. is that it gives the greatest effective sampling area for a given electrical power or voltage. This is important in clear, shallow, or cover-free areas where the fish are frightened easily by the electrofishing boat and must be stunned before they can escape. It is also useful for very fast-swimming fish such as northern pike and muskellunge which may pass through small electrical fields without being completely stunned. Unfortunately, high turbidity or large amounts of cover which reduce the ability to see and capture the stunned fish severely restrict the effectiveness of A.C. electrofishing.

D.C. electrofishing gear samples a smaller area than A.C. for a given generator output, so it is less effective in large clearwater systems, but it has the advantage of causing a swimming reaction toward the negative electrode (galvanotaxis). This makes D.C. effective in turbid water or dense cover because it can draw the fish to the surface where they can be seen and captured.

Both A.C. and D.C. electrofishing were used at the Susquehanna site, but no direct comparisons of efficiency or variability could be made since the two techniques were not used concurrently. Indirect comparisons of CPUE between A.C. and D.C. were also thwarted because of large year-to-year fluctuations and a lack of correlation between electrofishing CPUE and other methods such as trapnetting or seining. Variation between A.C. and D.C. electrofishing was determined by comparing the average yearly CV for the two techniques. Because the two methods were used at different times, the annual values for three years were averaged for each method so that unusual sampling conditions during a single year would not appreciably affect the results (A.C. 1972 to 1974, D.C. 1975 to 1977).

As Table 3 demonstrates, D.C. electrofishing was consistently less variable than A.C. for all five species in the turbid Susquehanna River. The decreases in the CV occurred during both day and night sampling and ranged from 4% for carp in the nighttime samples to 46% white crappie in daytime samples. The average decrease in the CV was about 28% for both day and night samples, with the CV for walleye, white crappie and channel catfish having the greatest reductions.

Assuming that the fish population sampled by the two methods were similar, this information is enough to recommend the use of D.C. instead of A.C. for monitoring turbid rivers such as the Susquehanna and Mississippi.

Day vs. Night Sampling. There is evidence for increased fish movements during the night (Bailey and Harrison, 1948; Hansen, 1951; Morgan, 1954) and life history information on fish such as channel catfish and walleye indicating movements from deep water to shallow water at night (Carlander and Clearly, 1949; Davis, 1959). Therefore, it seems reasonable that night electrofishing would be more effective than daytime sampling because more fish would be available to the gear. In addition, fish in the shallows are probably less frightened by the boat in the dark than they are during daylight, so fewer fish escape before they encounter the electric field. These hypotheses were investigated at Susquehanna where day and night sampling were conducted concurrently from 1974 to 1977.

The results, which are compiled in Table 4, indicate that sampling at night is at least as effective as sampling during the day for all five species. For walleye, channel catfish and bluegill, the night sampling is much more effective and less variable than day sampling. These increases in nighttime efficiency (annual CPUE) over daytime values ranged from 2.9 times

Table 3. Average Yearly Coefficient of Variation for Daytime and Nighttime Sampling with A.C. and D.C. Electrofishing at Susquehanna Steam Electric Station (A.C. - 1972-1974, D.C. - 1975-1977).

	Day		Night	
	A.C.	D.C.	A.C.	D.C.
Carp	1.41	1.05	1.07	1.03
Channel catfish	2.76	1.55	2.57	2.27
Bluegill	2.15	1.59	1.77	1.31
White crappie	2.98	1.60	1.90	1.66
Walleye	2.29	1.35	1.66	0.97

Table 4. Range in Average Yearly CPUE and Coefficient of Variation for Day and Night Electrofishing at Susquehanna, 1974-1977.

	Day		Night	
	CPUE	CV	CPUE	CV
Carp	.53 - 2.63	.65 - 1.51	.36 - 4.16	.67 - 1.47
Channel catfish	.00 - .07	2.27 - 2.90	.05 - .30	1.55 - 2.76
Bluegill	.11 - 1.82	1.59 - 1.93	.16 - 2.09	1.31 - 1.77
White crappie	.03 - 4.35	1.60 - 2.00	.00 - 5.21	1.66 - 1.90
Walleye	.09 - 1.74	1.35 - 2.82	1.22 - 3.51	.97 - 1.66

for bluegill, 3.5 times for channel catfish and 13.0 times for walleye. At the same time, the annual average CV for the three species decreased by as much as 18% for bluegill, 32% for channel catfish and 41% for walleye.

Carp and white crappie catches exhibited no trends in either CPUE or CV between day and night electrofishing. Carlander (1953) found the same lack of diel differences for carp and white crappie using gillnets, so it seems unlikely that there is an advantage or disadvantage to sampling for these species at night.

Although the trends in monthly CPUE for daytime and nighttime electrofishing do not appear correlated (Figures 4 and 5), the annual trends were generally correlated for all five species. This indicates that either day or night sampling can be used for monitoring the fish populations. However, the increase in numbers caught and the decrease in variability observed during night sampling for three of the five species in this study strongly encourage the use of nighttime sampling in future monitoring programs.

<u>Seasonal Fluctuations in CPUE</u>

Most fish exhibit some type of seasonal variation of CPUE in response to yearly reproductive cycles or changes in environment. However, observed fluctuations may also reflect real population changes which occur from migration or mortality. There may also be apparent population changes caused by changes in the catchability of the species. These can occur because behavioral factors during such as periods of spawning, feeding activity or movements from deep to shallow water alter the effectiveness of the various gears. Gear efficiency may change as the fish grow and are able to avoid sampling equipment. Apparent population changes can also be produced by variations in environmental parameters such as water level, velocity or turbidity, since these affect the performance of the fishing gear. Regardless of the cause of the CPUE variations, a number of studies have shown consistent annual cycles for various species at specific locations (Hansen, 1953; Kelly, 1953; Morgan, 1951; Morgan, 1954; Muncy, 1957; Scott and Crossman, 1973).

Although there were obvious differences between months, the sampling methods for adult fish (electrofishing and trapnetting) showed no consistent

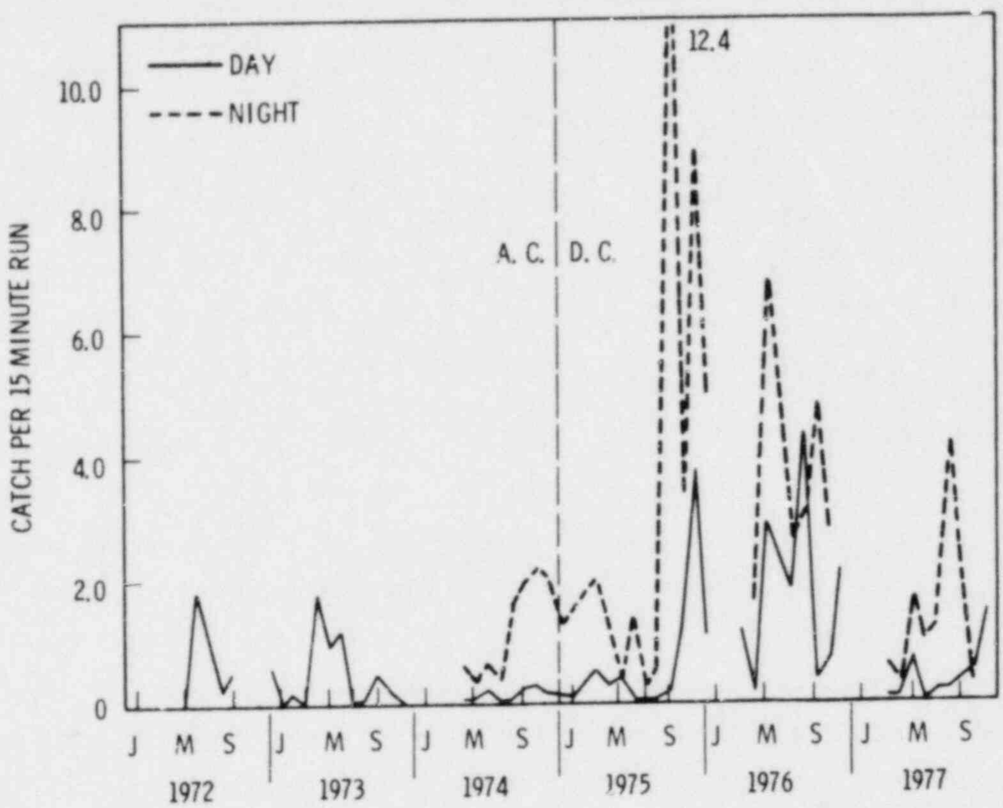

Figure 4. Monthly CPUE for Day and Night Electrofishing for Walleye at Susquehanna.

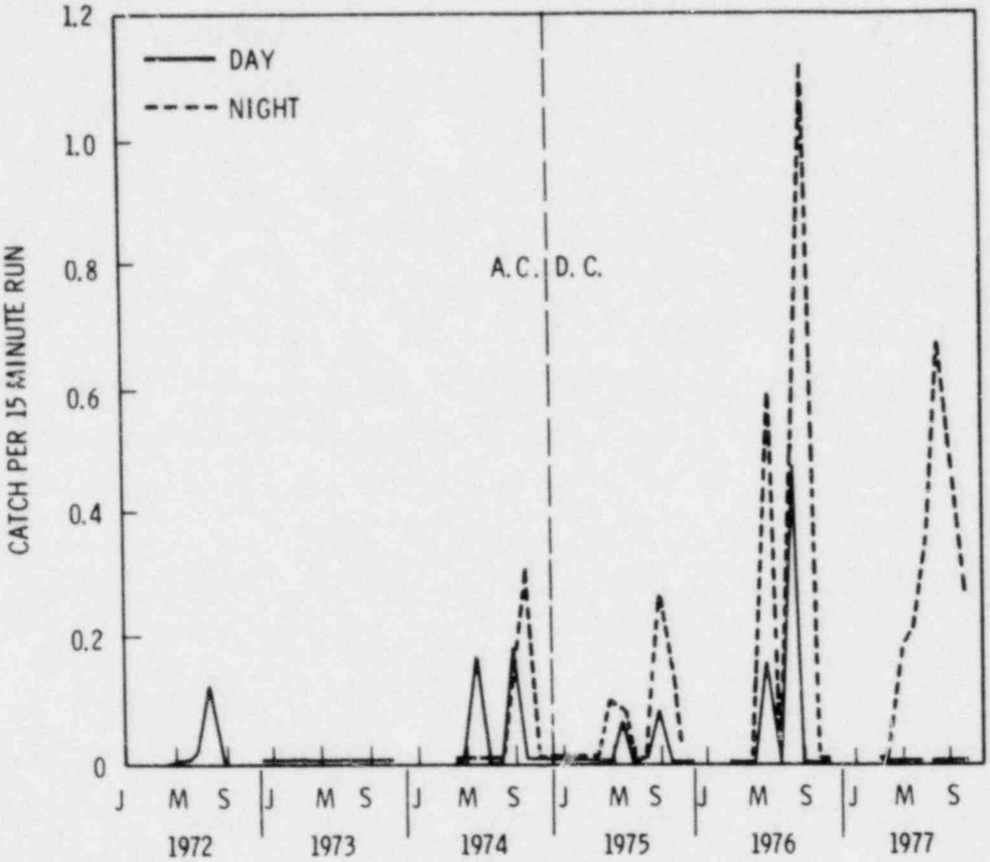

Figure 5. Monthly CPUE for Day and Night Electrofishing for Channel Catfish at Susquehanna.

seasonal fluctuations in CPUE for any species at the three study sites. Some species, such as bluegill and white crappie, did seem to have definite peaks of CPUE in most years, but, as Figures 6 and 7 show, the timing and shape of the yearly curves varied a great deal from year to year; therefore, no single sampling period could accurately represent the CPUE of the species. This suggests that frequent samples be collected in order to represent the yearly populations.

Young-of-the-year CPUE (seining and trawling) showed more consistent yearly cycles than adult CPUE for many of the species; however, enough variability remained so that sampling only one or two months would not be sufficient to determine yearly trends (Figure 8). Therefore, sampling the young-of-the-year fish throughout the time they are present (approximately May through October) at the three study sites is suggested.

Unfortunately, even this type of sampling may misrepresent the yearly abundance of young fish if there are fluctuations in the growth rate between years, because catchability for seines and trawls generally decreases as fish size increases. In years with slow growth rates for fish, the gears may collect fish more efficiently, but in years with faster growth a lower CPUE may result, indicating a smaller population than is actually present.

Habitat Groupings

Fish preference for certain substrates, current velocities, or cover characteristics has been well documented. In a river, this is translated into a preference for particular types of habitat, such as shallow weedy slough areas or relatively swift deep mainstream channels. Within the four major riverine habitats (slough, side channel, main channel border, and main channel bottom) there may also be gradients of "preference" as factors such as substrate and current change.

The combination of habitat preferences and the numerous habitats available to the fish in large rivers could increase the difficulty of obtaining a representative index of yearly abundance. These factors can introduce a high degree of patchiness in population abundance. However, the presence of a species-specific habitat preference in fish also holds a potential for reducing

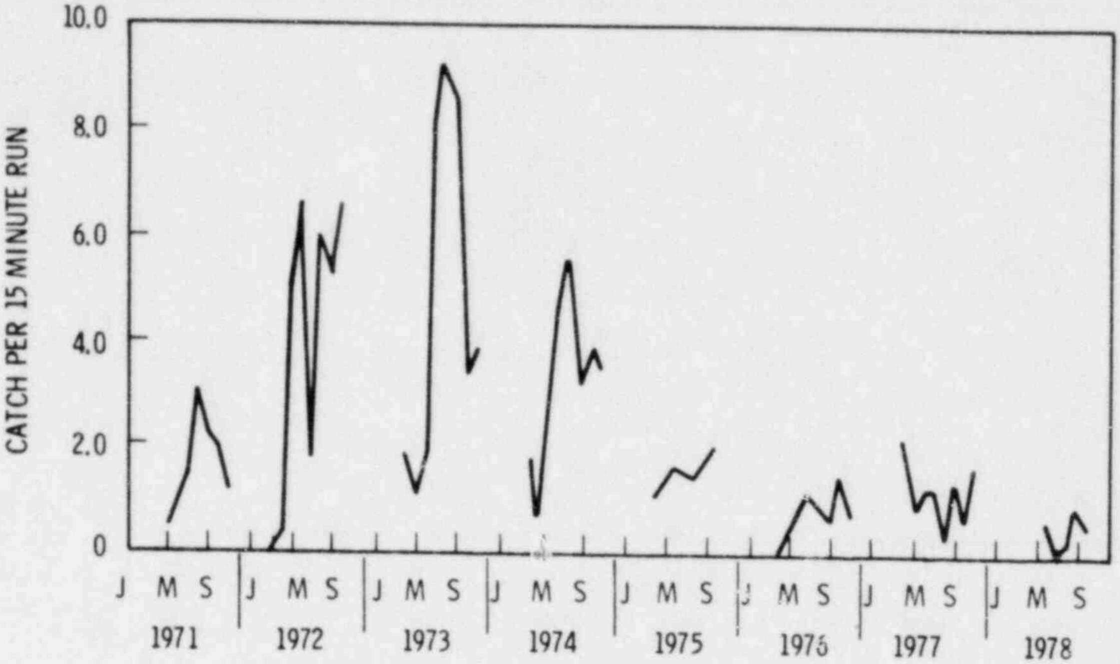

Figure 6. Seasonal Change in Electrofishing CPUE for Bluegill Sunfish at Quad Cities.

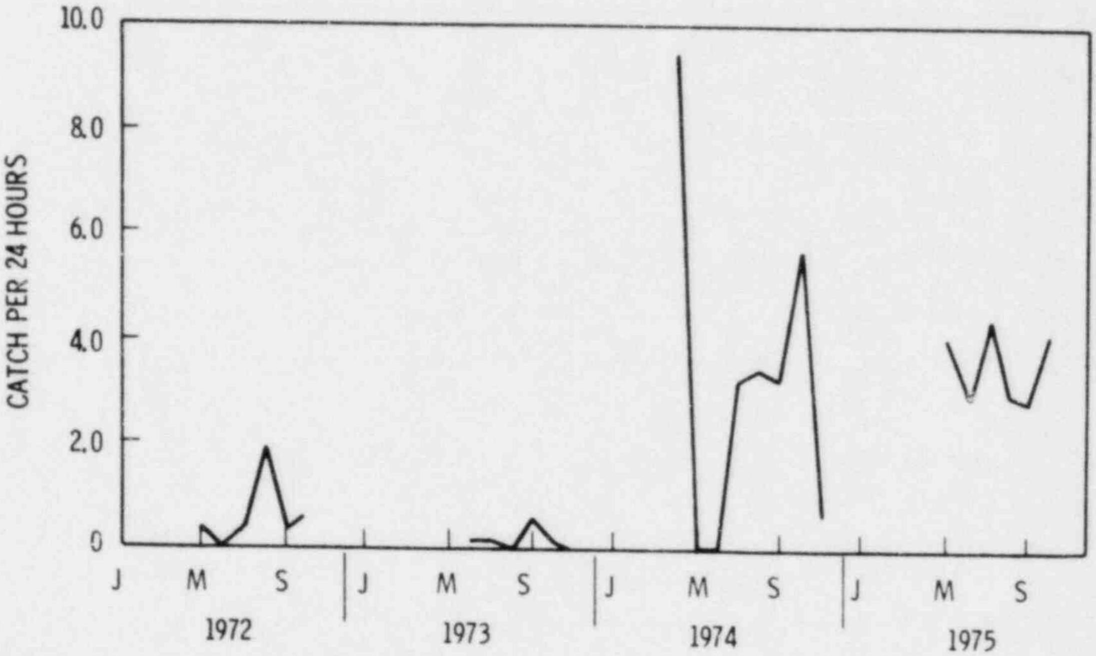

Figure 7. Seasonal Change in Trapnetting CPUE for White Crappie at Susquehanna.

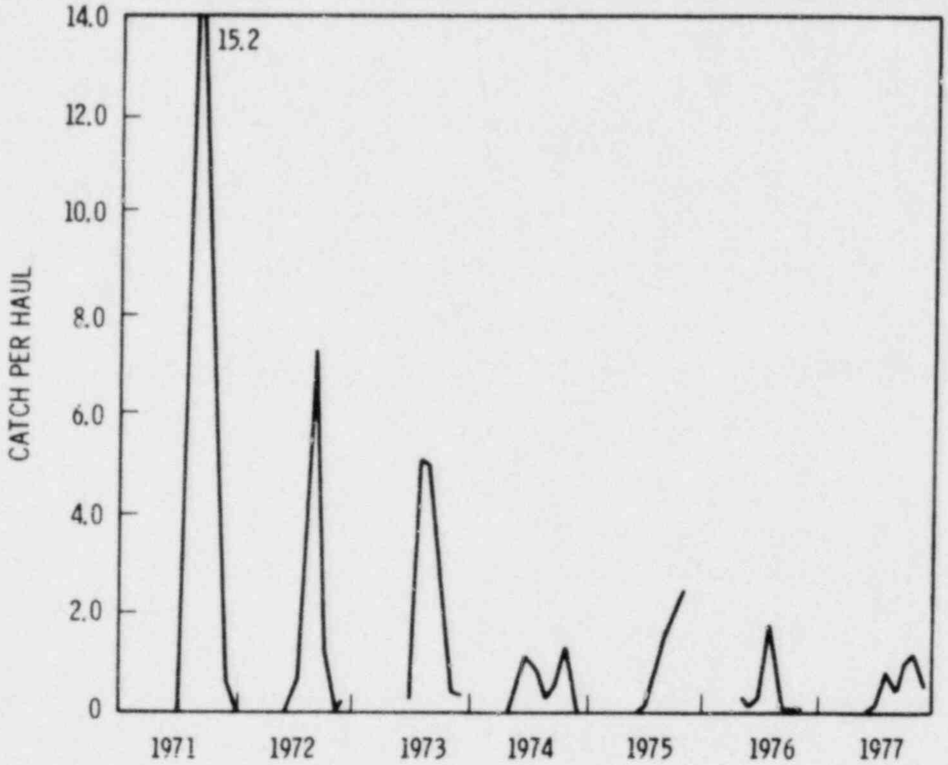

Figure 8. Seasonal Change in Seine CPUE for Bluegill at Quad Cities.

the amount of effort necessary to obtain representative indexes of yearly abundance. A sample from a single habitat may provide less variable results than combining samples across stations in different habitats.

The relation between habitat preference and CPUE should be manifested in a higher CPUE in the preferred habitat. The mean yearly CPUE for the five species separated into broad habitat categories (e.g., slough, side channel, main channel border, etc.) were extremely variable and no consistent pattern of preference emerged (Tables 5 and 6; Figures 9 and 10). In less than 25% of all of the cases (species, gear, habitat combination) there was a consistent pattern in the mean yearly CPUE, e.g., one habitat type had the highest CPUE for all the years of sampling and another habitat type was consistently low. In an additional 25% of the cases, the CPUE for one habitat group was consistently either highest or lowest. For the remaining cases there were no consistent patterns in CPUE between habitat groups, suggesting changes in habitat preference between years.

This apparent lack of consistent habitat selection by any of the five species may have resulted from actual changes in the preference for particular substrates, current velocities or covers. It is more likely that the microhabitats were modified by additional environmental factors such as river level, temperature or oxygen. These environmental factors, specifically river level and turbidity, also have a differential effect on the efficiency of sampling gears in the various habitats; e.g., high water makes electrofishing along the river channels more difficult while making the sloughs more accessible. Variability of environmental parameters may produce apparent differences in habitat selection rather than real changes in fish behavior.

Associated with the lack of any consistent habitat preferences among the five species there was a lack of correlation between the mean yearly CPUE for all stations (habitats) combined and the average yearly CPUE for the individual stations (Tables 5 and 6, Figures 9 and 10). In only about 50% of the cases did the CPUE for more than half of the individual habitat groups follow the combined total CPUE trends. Further, in less than 30% of the cases did the CPUE for all the individual habitat groups correspond with the CPUE

Table 5. Average Yearly Bluegill CPUE for Electrofishing (15 min run) and Trapnetting (24 hr set) from Five Habitats at Prairie Island.

	1973		1974		1975		1976		1977	
	Trap.	Electro	Trap.	Electro	Trap.	Electro	Trap.	Electro	Trap.	Electro
All stations combined	.34	2.71	.58	7.43	.29	2.60	.43	3.50	4.36	6.10
Slough (North lake)	.45	1.50	.40	2.03	.38	3.06	.28	2.46	.24	3.74
River-lake	.00	.25	1.22	.66	.27	.44	.27	.73	.72	3.61
Main channel - silt, sand	.63	.00	1.27	.51	.29	.15	.73	.34	6.11	1.33
Main channel - riprap	.25		.60	5.02	.13	1.67	.22	1.98	2.00	1.67
Tailwaters	.58	8.83	.00	28.00	.19	10.60	.08	16.30	.00	27.30

Table 6. Average Yearly Walleye CPUE for Electrofishing (15 min run) and Trapnetting (24 hr set) from Five Habitats at Prairie Island.

	1973		1974		1975		1976		1977	
	Trap.	Electro	Trap.	Electro	Trap.	Electro	Trap.	Electro	Trap.	Electro
All stations combined	.47	.41	.28	.86	.18	1.38	.41	1.35	.39	.38
Slough (North lake)	.70	.33	.67	.27	.20	.90	.55	.38	.22	.18
River-lake	.28	.13	.29	.31	.38	.69	.44	.55	.44	.26
Main channel - silt, sand	.00	1.00	.15	.63	.04	.93	.13	.76	.72	.23
Main channel - riprap	.70		.07	1.40	.12	2.22	.56	3.33	.25	1.27
Tailwaters	.42	.17	.56	.92	.60	1.56	.50	4.11	.42	1.00

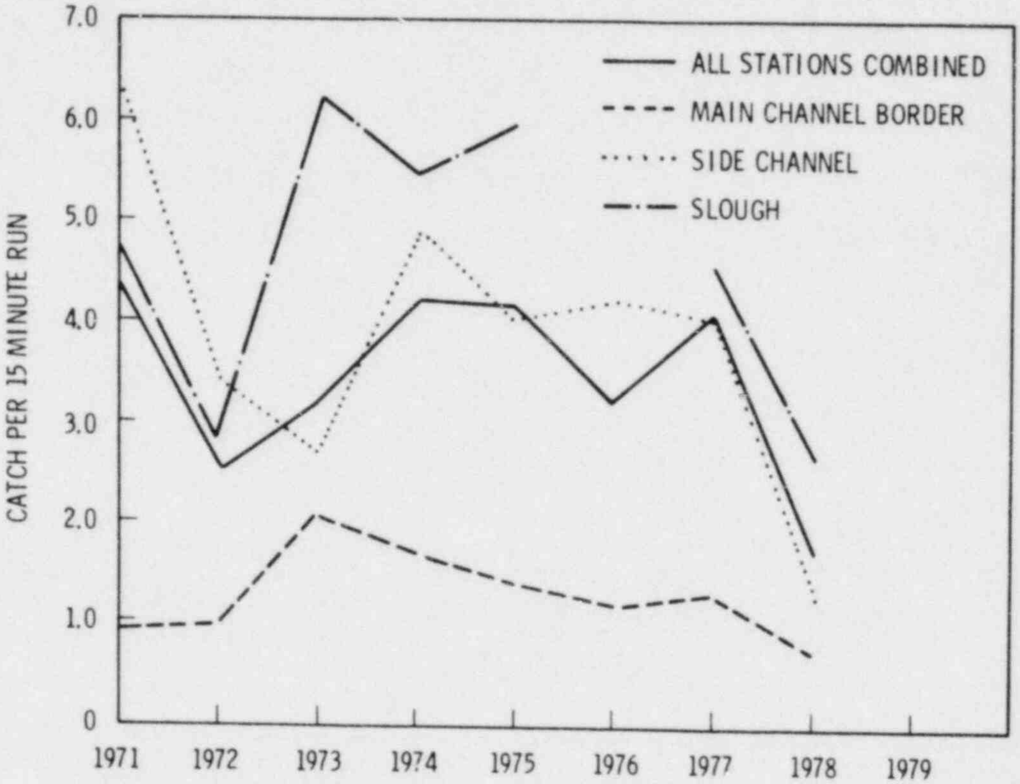

Figure 9. Average Yearly Electrofishing CPUE for Carp from Three Habitats at Quad Cities.

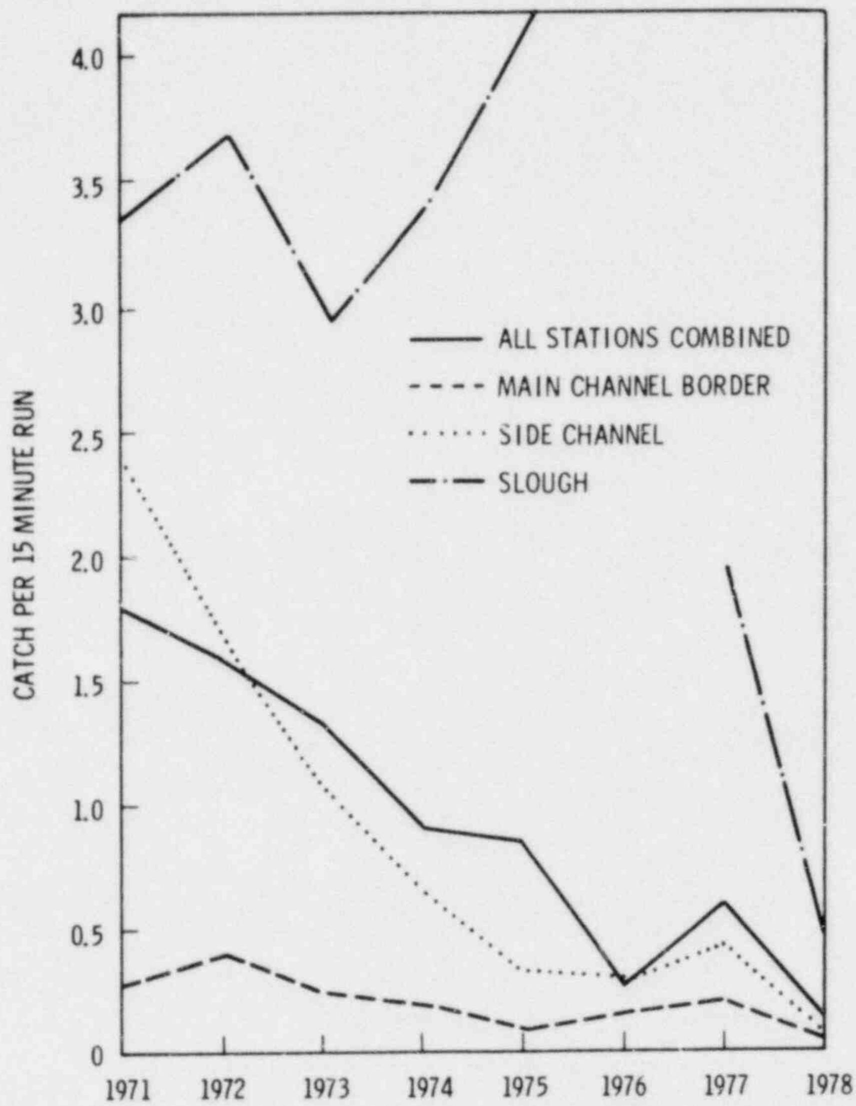

Figure 10. Average Yearly Electrofishing CPUE for White Crappie from Three Habitats at Quad Cities.

for all groups combined. This result is probably high since the number of habitat groups that were combined varied from two to six with the better correlations occurring for the smaller sample sizes. The lack of correspondence of yearly CPUE trends between habitats may have been caused by the same factors that seemed to alter habitat selection. Results suggest that no objective criteria can be developed for selecting a single habitat that will provide an adequate index of species abundance for any of the species in this study.

The CV computed for the sampling methods using habitat groups instead of all stations combined was also variable and inconsistent between methods, sites and species (Tables 7 and 8). Of the approximately 60 monthly data points from electrofishing and trapnetting and the 20 data points from trawling, the proportions of CV for all stations combined which exceeded the range of CV for the individual habitat groups for that year were 54% (electrofishing), 40% (trapnetting) and 59% (trawling). Many of the combined CV's were rather large (up to 1.90 greater than the individual groups); however, the inconsistencies between years, the need to sample all of the habitats, and the reduction in sample sizes which would result from computing each habitat separately would seem to nullify any advantages to analyzing individual habitat groups instead of combined totals for these methods.

Results from seine surveys were more consistent, with 88% of the combined CV exceeding the ranges of the individual habitat group CV. Many of these differences were large, indicating a potential for decreasing the variability of the seine CPUE results by using habitat groups instead of combined totals even though the sample sizes for the individual habitats would be reduced.

Sampling Method--Habitat Interactions

Each fish sampling method is designed for a particular habitat such as shorelines, shallow areas, or midchannel bottoms. There are obvious problems with applicability and effectiveness if the methods are used in other areas; i.e., if electrofishing is used in the middle of a deep river. There are also differences in the effectiveness of the methods within the broad habitat categories for which they were designed.

Table 7. Average Yearly Coefficients of Variation for Bluegill from Electrofishing and Trapnetting in Five Habitats at Prairie Island.

	1973		1974		1975		1976		1977	
	Trap.	Electro	Trap.	Electro	Trap.	Electro	Trap.	Electro	Trap.	Electro
All stations combined	2.19	1.12	2.35	2.44	2.23	2.22	2.73	2.21	1.92	2.32
Range of individual habitat values	1.41-1.73	.75-1.17	1.10-2.24	.80-1.92	1.15-2.49	.34-1.95	1.73-2.98	.99-2.15	1.02-1.85	1.19-1.87
Slough (North lake)	1.73	.94	2.24	1.48	1.93	1.95	1.96	1.50	1.85	1.87
River-lake	--	1.00	1.30	1.92	2.49	1.56	2.98	1.60	1.52	1.70
Main channel - silt, sand	1.51	--	1.10	1.84	1.26	1.97	1.95	2.15	1.02	1.65
Main channel - riprap	1.41		1.77	1.25	1.15	.91	1.73	1.01	1.06	1.41
Tailwaters	1.57	.75	--	1.24	1.28	.63	2.00	.99	--	1.19

Table 8. Average Yearly Coefficients of Variation for Walleye from Electrofishing and Trapnetting in Five Habitats at Prairie Island.

	1973		1974		1975		1976		1977	
	Trap.	Electro	Trap.	Electro	Trap.	Electro	Trap.	Electro	Trap.	Electro
All stations combined	1.66	1.67	2.01	1.79	2.41	1.40	2.25	1.80	1.91	2.35
Range of individual habitat values	1.39-2.64	1.00-2.69	1.37-2.24	1.36-2.16	.81-2.59	1.11-1.70	.80-1.73	.83-1.90	1.44-2.00	1.54-2.55
Slough (North lake)	1.41	1.66	1.37	1.84	2.07	1.32	1.54	1.80	2.00	2.55
River-lake	2.64	2.35	2.20	2.16	2.59	1.70	1.63	1.90	1.65	2.25
Main channel - silt, sand	--	1.00	1.87	2.05	2.65	1.24	1.38	1.63	1.72	2.35
Main channel-riprap	1.39	--	2.24	1.36	1.15	1.11	1.73	1.04	1.58	1.54
Tailwaters	1.57	2.69	1.73	1.44	.81	1.28	1.41	.83	1.44	1.60

Trapnetting and electrofishing are designed to sample similar habitats, so that habitat preferences detected for the various species should similar. However, the data showed no relation between the relative abundance of each species in the various habitat groups as sampled by the two methods (Tables 5 and 6). In three instances (carp at Susquehanna, bluegill at Prairie Island, and white crappie at Quad Cities) trapnet and electrofishing gave opposite results, with habitat groups with the greatest CPUE for trapnet having the least CPUE for electrofishing or vice versa depending on the species.

Even between the frame and oneida nets, which are variations of the same basic method, the relative efficiency changed between habitats such that the oneida net over coarse sand-pebble substrate at Susquehanna consistently produced a higher white crappie CPUE than for the framenet, while the framenet consistently had a larger CPUE over the fine-coarse sand substrates. The data for the other species were inconsistent and generally showed no habitat correspondence between the two methods, even though the total monthly CPUE trends corresponded very well for some of the species, especially bluegill.

These differences in CPUE indicate a high degree of method-habitat interaction and result from a number of factors such as sampling efficiency and changes in fish behavior related to habitat changes and sampling differences, probably caused by varying abiotic environmental factors.

Differences in the habitat of a sampling sites such as the presence or absence of a submerged brushpile, large rock or deep hole, can affect the efficiency of a sampling method. This is especially evident for the seine, which is most effective in a shallow, barren area, because any snags, large rocks, or unevenness on the river bottom may allow the fish to escape by going under or around the net. The presence of even minimal cover may also affect the efficiency of electrofishing in shallow water by providing escape cover for the fish until they can be stunned and collected. If there is no cover, a frightened fish may be likely to leave the area completely before coming within range of the electric field.

Differences in habitat may also cause differences in the behavior of some species. This is a possible explanation for the greater trapnet catches of bluegills and white crappies in barren habitats where the fish may actually perceive the nets as cover and enter them for protection. Another possibility is that fish are less mobile in areas of abundant cover so they are less vulnerable to capture by the nets than fish in the barren areas.

Other variables such as river level, turbidity and temperature probably affect the efficiency of all fish sampling methods, but they may affect each method differently. For example, river level, which is probably the most important variable in terms of sampling effectiveness, may cause either increased or decreased seining efficiency by changing the seinable area at various water levels. Small increases in river level may not affect trapnets, but they may decrease electroshocking efficiency because of increased current and water depth. River level may also affect efficiency by increasing the accessibility of various areas. Large increases in river level generally decrease the catches of both trapnetting and electrofishing because the fish disperse onto the flood plain.

Comparison of Sampling Methods

The ranges of annual CPUE and CV summarized by sampling method, species and site are shown in Table 9. As was generally expected, there were large differences in CPUE and CV among the various sampling methods. However, the differences were not consistent; no single sampling method produced the greatest CPUE or the smallest CV for all species at all sites. In general, carp, bluegill and walleye were most vulnerable to electrofishing at the three sites. Electrofishing also produced the smallest CV for catches of these three species. Channel catfish, especially young-of-the-year fish, were taken most effectively by trawling at both sites where the method was used. For white crappie, the most effective and least variable sampling method was electrofishing at Susquehanna, trawling at Prairie Island, and trapnetting at Quad Cities.

No consistency existed between the annual CPUE trends detected for the various species by the different sampling methods. There were a few instances where methods followed each other for short periods for certain species at a single site, or where one method such as seining or trawling which collected

Table 9. Range of Average Annual CPUE and Coefficients of Variation (in Parentheses) for Daytime Electrofishing (15 min run), Trapnetting (24 hr set), Trawling (7 min tow), and Seining (1 haul) at Susquehanna, Prairie Island and Quad Cities.

	Electrofishing			Trapnet			Seine			Trawl		
	Susq.	P.I.	Quad	Susq.	P.I.	Quad	Susq.	P.I.	Quad	Susq.	P.I.	Quad
Carp	2.41-5.09 (.89-1.57)	3.75-7.72 (.72-.94)	1.80-4.35 (.87-1.69)	.10-.41 (2.24-2.75)	3.44-6.04 (.80-1.12)	.04-.06 (2.93-3.01)	.00-.11 (3.32)	.13-.32 (2.37-3.01)	.00-.30 (1.63-2.84)		.64-3.24 (1.04-1.88)	.03-.20
Channel catfish	.00-.04 (2.24-2.90)	.00-.87 (2.94-3.79)	.32-.91 (2.38-3.73)	.00-.33 (2.48-3.10)	.06-.24 (2.16-6.25)	.04-.09 (3.43-3.62)	.00 (---)	.25-1.23 (2.55-3.14)	.00-1.36 (1.76-2.76)		.25-11.90 (1.28-3.22)	2.80-18.40
Bluegill sunfish	.67-1.82 (1.64-2.43)	2.59-7.43 (1.12-2.44)	.48-4.81 (1.74-2.34)	.47-4.46 (1.51-2.28)	.29-4.36 (1.92-2.73)	.22-.31 (3.07-3.38)	.64-4.57 (1.26-2.59)	.41-4.14 (1.62-2.48)	.37-5.55 (1.65-2.28)		.00-1.66 (1.16-3.49)	.00 (---)
White crappie	.00-4.41 (1.56-3.64)	.04-.69 (1.55-4.68)	.15-1.79 (1.38-3.88)	.16-3.61 (1.18-2.73)	.12-7.53 (1.54-3.14)	1.74-2.27 (1.34-1.77)	.00-.22 (2.00-3.32)	.37-2.09 (1.79-2.21)	.02-.79 (1.15-2.65)		.34-16.20 (1.20-1.75)	.00 (---)
Walleye	.09-.68 (1.65-2.82)	.38-1.38 (1.40-2.35)	.09-.82 (1.57-3.01)	.00-.15 (1.88-3.61)	.18-.47 (1.66-2.41)	.00 (---)	.00 (---)	.00-.45 (1.90-2.53)	.00-.21 (1.14-2.45)		.04-.58 (1.41-2.30)	.00-.03

young-of-the-year fish predicted the following year's results for electrofishing or trapnetting which collected adults, but these were rare. In general, the annual CPUE trends detected by the various sampling methods showed very little or no correspondence among gears and species. Two examples are shown in Figures 11 and 12.

The inconsistency of the CPUE and population trends between methods suggest that the various methods obtain different information about the same overall populations. This is not unexpected since, as Table 10 indicates, each method has a unique set of advantages and disadvantages and is most applicable in different situations. Because of this, the observed population indices may represent real differences in catchable populations of or the selectivity of each method. They may also represent apparent population differences caused by differing modes of capture or responses to environmental variables.

Although there do not seem to be consistent population differences within the habitat category which each method was designed to sample (i.e., shorelines, middepth, or midchannel bottom; see Table 10), the possibility of consistent population differences between the habitats sampled by the various gears is still great because of the large differences between these habitats. This would create real differences in the catchable populations available to the sampling methods, especially seining and trawling, which sample shallow shoreline and mid-channel bottom areas, respectively. Electrofishing and trapnetting comparisons should not be affected by this factor because the two methods sample roughly similar habitats.

Each of the sampling methods examined also exhibited a different size selectivity. The Prairie Island data, which is also representative of the other sites, is given in Table 11. In general, the trapnets caught adult fish over about 10 to 15 cm, while electrofishing gear captured young fish as well (minimum of 2 cm). However, susceptibility of fish to shocking is generally directly related to body length. Seines and trawls also caught fish over a large size range, but problems of gear avoidance by adult fish generally limited their usefulness to the capture of young-of-the-year and other small fish.

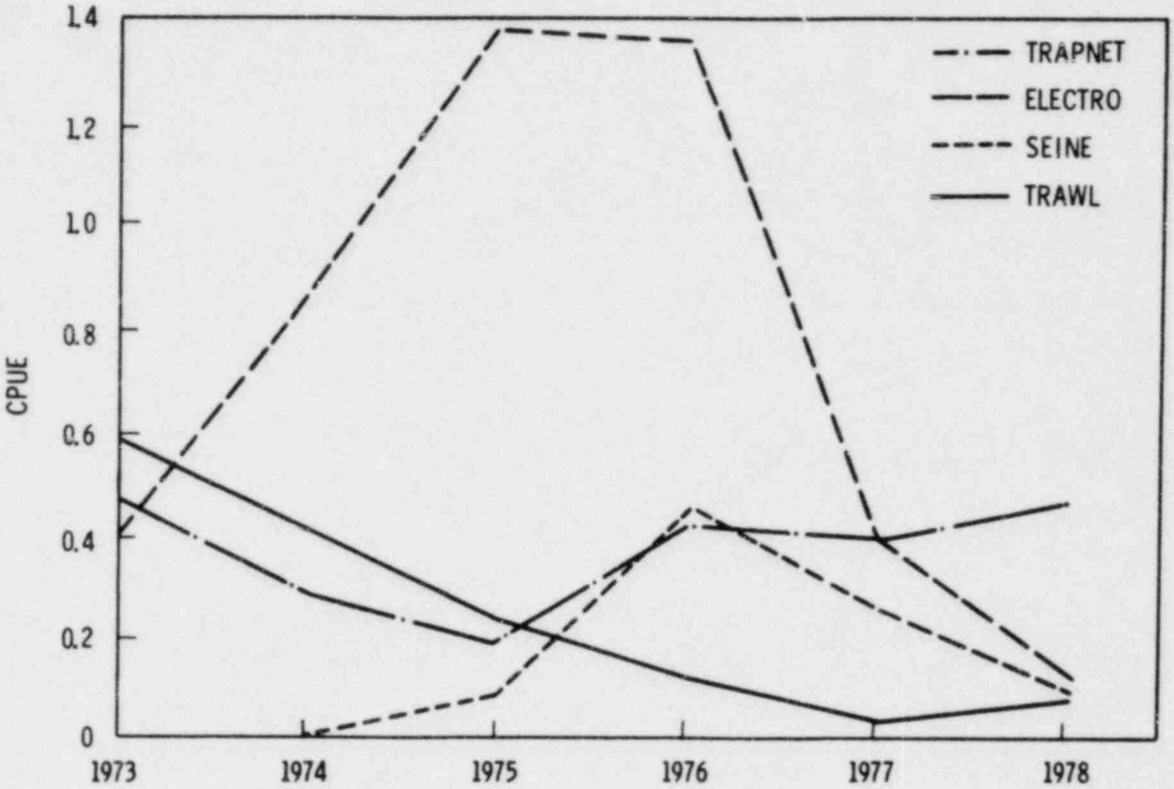

Figure 11. Average Yearly CPUE for Walleye at Prairie Island from A.C. Electrofishing (15 min run), Trapnetting (24 hr set), Seining (1 haul), and Trawling (7 min tow).

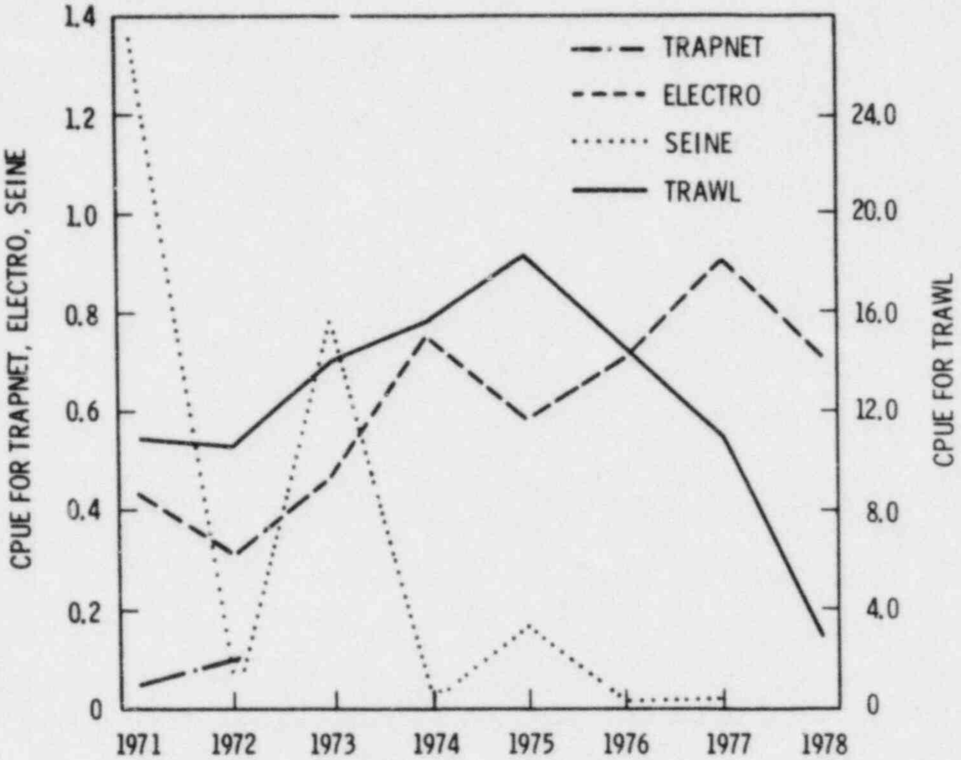

Figure 12. Average Yearly CPUE for Channel Catfish at Quad Cities from A.C. Electrofishing, Trapnetting, Seining, and Trawling.

Table 10. Summary of Juvenile and Adult Fish Sampling Methods for Riverine Sites.

Method	Advantages	Disadvantages	Applicability
A.C. Electro-fishing	Greatest range for given power (voltage) Non-destructive sampling	Difficult to dip stunned fish from bottom or cover, especially in turbid water Causes more tissue damage than D.C. Size selective for larger fish	Useful for sampling most adult fish in water up to 6 ft deep although turbidity and cover reduce its effectiveness Works well in shallow stump strewn or rocky areas
D.C. Electro-fishing	Causes forced swimming (galvanotaxis) of fish toward anode (+) so fish can be drawn from cover or bottom before they are stunned	Less range than A.C. Ineffective in highly conductive water Size selective for larger fish Some species selectivity by pulse rate	Useful for sampling most adult fish in water up to about 6 ft deep, especially in dense cover or high turbidity
Trapnet	Samples over time Non-destructive	Cannot be used in fast current Catch depends upon activity or movement of fish in addition to population High species selectivity Unknown area sampled Can be time-consuming to set and remove trap Smaller nets generally less effective than larger, more complicated nets	Samples many species of adult fish in water from 3-10 ft deep in slow to moderate currents
Trawl	Samples different habitat than other methods Quantitative technique - samples a known area	Cannot be used on most sites because of snags on the river bottom Obvious gear avoidance by adult fishes Often destructive sampling	Samples benthic fish in areas with clean, uniform bottoms Primarily used to sample young-of-the year fish
Seine	Samples smaller fish which escape through meshes of other gears Can sample shallow areas and shorelines which are inaccessible to other gears	Large gear avoidance problems Need shallow, snag-free sampling sites Sampling sites and sampling efficiency change with water level	Samples young-of-the year fish and minnows along shorelines

Table 11. Size Ranges (cm) of Fish Caught by Trapnet, Electrofishing Gear, Trawl and Seine at Prairie Island.

	Trapnet	Electrofishing	Trawl	Seine
Carp	16 - 80	2 - 80	2 - 70	2 - 65
Channel catfish	24 - 65	4 - 70	1 - 12	2 - 12
Bluegill sunfish	10 - 30	2 - 28	1 - 22	2 - 20
White crappie	10 - 34	6 - 34	1 - 30	2 - 26
Walleye	24 - 75	4 - 75	6 - 55	4 - 16

Size selectivity may also produce inconsistencies in the yearly CPUE trends between methods. The fish are collected by the gears at different sizes, and a successful spawning may yield an increase in CPUE for the seine or trawl, but it would not affect the trapnet catch during that year. Growth rates, mortality rates and migrations fluctuate annually, so that an adjustment for differences in recruitment time alone may not be sufficient for monitoring fish abundance.

Apparent rather than real population differences between the methods may be caused by the different modes of action of the sampling techniques. The CPUE of active sampling methods such as electrofishing, seining and trawling depends primarily on the catchable populations present. The catch of passive methods such as trapnetting, in which the fish must swim into the gear to be caught, depends not only on the catchable populations present, but also on the activity of the fish (Moyle, 1950). This can create inconsistencies between the results of various methods, as activity (and therefore catch) fluctuates in response to spawning behavior, water level or temperature. A large portion of the differences between electrofishing and trapnetting results might be explained by this factor.

3.3 COMPARISON OF TECHNIQUES AT MARINE AND LENTIC NUCLEAR POWER PLANTS

Methods

Site Description

Three sites representing marine, large lake and reservoir habitats were chosen to compare sampling differences related to site-specific environmental factors. For the marine location, Pilgrim NPP on Cape Cod Bay in Massachusetts was selected, Nine Mile Point NPP on Lake Ontario was selected to represent a large lake site, and Oconee NPP on Lake Keowee in South Carolina was selected as the reservoir site. Analyses will be presented in this report for all but the Oconee NPP.

Pilgrim NPP, operated by Boston Edison Company, is located on the western shore of Cape Cod Bay in the southeastern Massachusetts town of Plymouth. The bay is physically and ecologically a coastal area, with the biota being marine rather than estuarine in character. The plant reached 100% sustained power in December 1972. Marine ecological studies were started the same month and continued for five years. Otter trawl and lobster monitoring programs at Pilgrim met our criteria for duration of study and replication in sampling design.

Nine Mile Point NPP is located on Nine Mile promontory on the south shore of Lake Ontario. The Nine Mile Point and the James A. Fitzpatrick plants occupy a 365-hectare site near the town of Scriba, Oswego County, New York. The Nine Mile Point plant is operated by the Niagara Mohawk Power Corporation of Syracuse, New York, and has been operational since December, 1969. The Fitzpatrick plant was not operational during the period of these surveys (1973 through 1978). Preoperational ecological studies at the combined Nine Mile Point and Fitzpatrick sites began in 1963. In 1973, studies were started which included periodic sampling of fish populations. Three of the sampling programs based on CPUE methods met our criteria for duration of study and replication in sampling design. These were the otter trawl, gillnet and seine surveys. The primary circulation in the lake is counterclockwise, with the water flowing from west to east.

Sampling Methods

The fish communities in the vicinity of the Pilgrim NPP were sampled using an otter trawl. These otter trawl samples involved two replicate tows taken at each of three stations (Figure 13). Station 1 extended perpendicular from the shoreline, approximately 4 km northwest of the power plant. This station was considered the "control" and had a mean depth of 6 m mean low water (MLW). Stations 2 and 3 were positioned parallel to the shoreline, directly offshore from the plant outfall. Station 2 was located inside the thermal plume; Station 3 immediately outside it. Mean depths at these two stations are 9 and 12 m MLW, respectively. Sampling equipment consisted of a one-half Yankee 10.7 m (35 ft) otter trawl. Each tow lasted 20 minutes and covered approximately 1.4 km. All the fish from each tow were identified to species and enumerated. CPUE was computed as number of fish per 20 minute tow. Samples were taken biweekly throughout the year, weather permitting.

The lobster survey at Pilgrim NPP involved biweekly sampling of the total daily catch of two commercial lobstermen. Information collected from the lobstermen included the numbers of lobsters per pot per set, carapace length in millimeters, sex, reproductive state, location of each pot, and evidence of molting. The study area for the survey included inshore areas around the plant extending approximately 10 km into Cape Cod Bay. For purposes of the survey, the area was divided into 0.8 km^2 quadrats (Figure 14). The CPUE data on the lobster harvest was computed on a per-quadrat basis. Quadrats were treated as replicates in subsequent analyses.

The otter trawl, gillnet and seine surveys at the Nine Mile Point NPP were conducted at similar locations. The sampling locations for the three surveys were located along four transects, one each to the west and east of the plants, and one each at Nine Mile Point plant and James A. Fitzpatrick plant (Figure 15). Seine collections were made along the shore at the four transects. The collections were made biweekly from April to December except in 1973 when the first sampling date was in June. In 1973 a 30.5 x 2.4 x 2.4 m (100 x 8 x 8 ft) seine was used; in subsequent years a 15 x 2.4 m (50 x 8 ft) bag seine with 1.3 cm (0.5 in.) stretched mesh was utilized. Two 100 ft

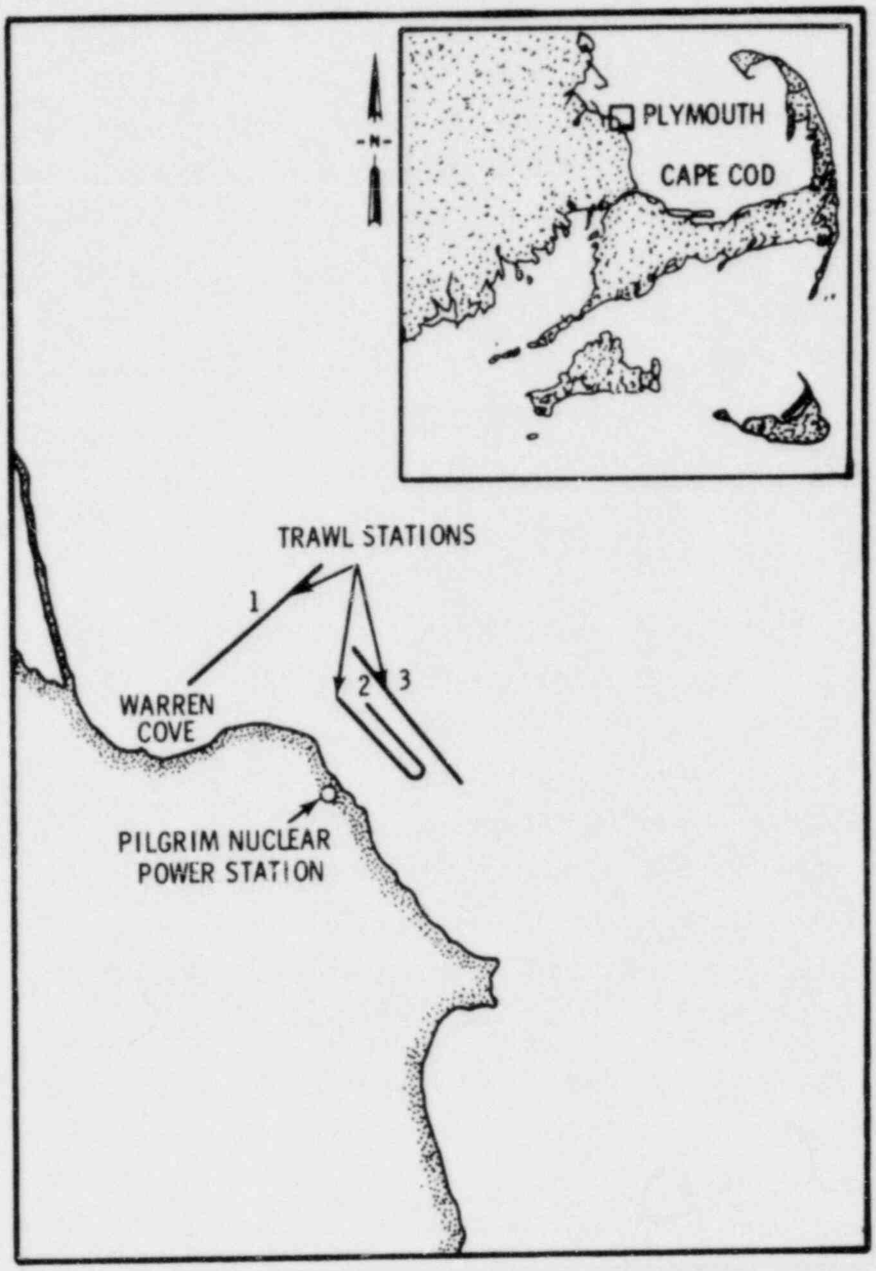

Figure 13. Sampling Stations for the Otter Trawl Near Pilgrim Nuclear Power Station (from Boston Edison Company, 1978).

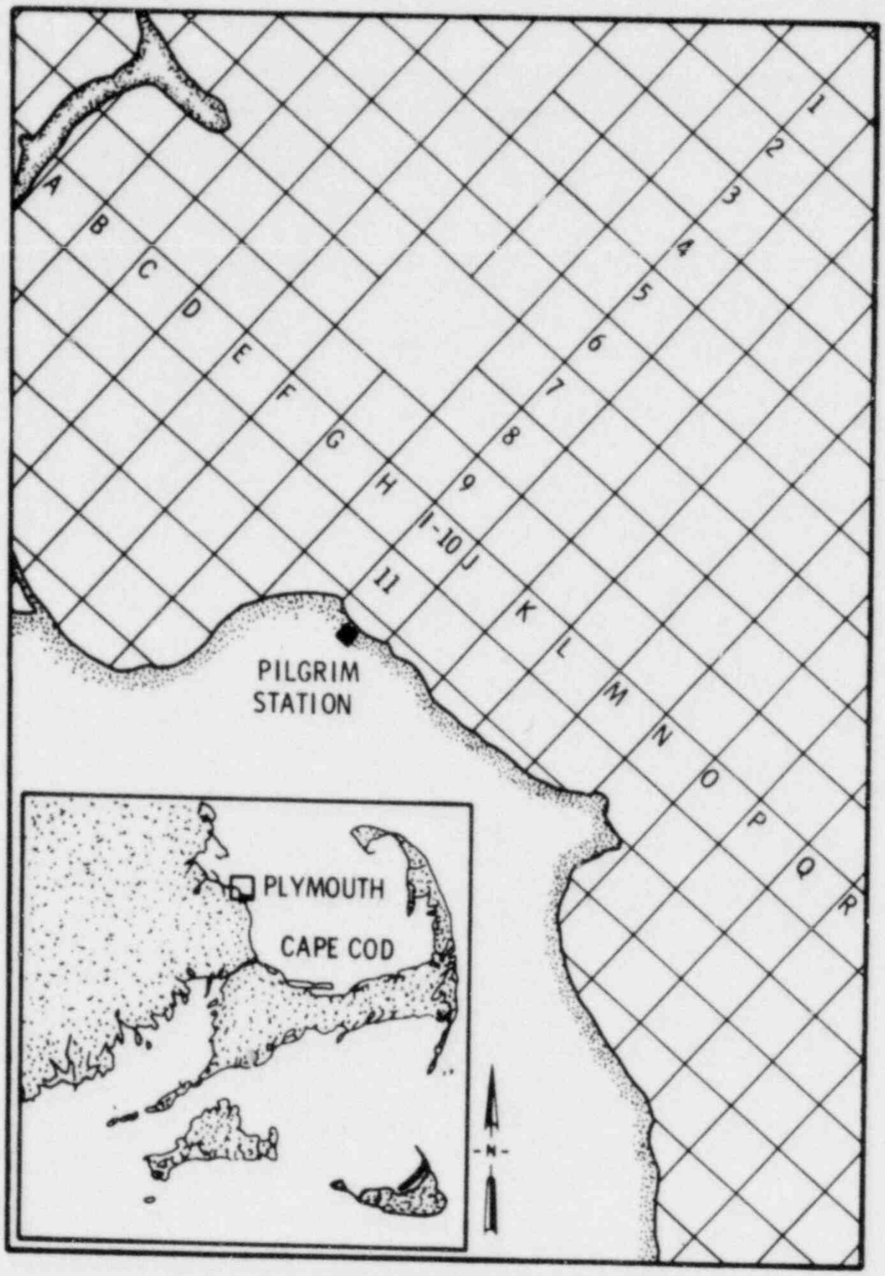

Figure 14. Sampling Quadrats for Lobster Near Pilgrim Nuclear Power Station (from Boston Edison Company, 1978).

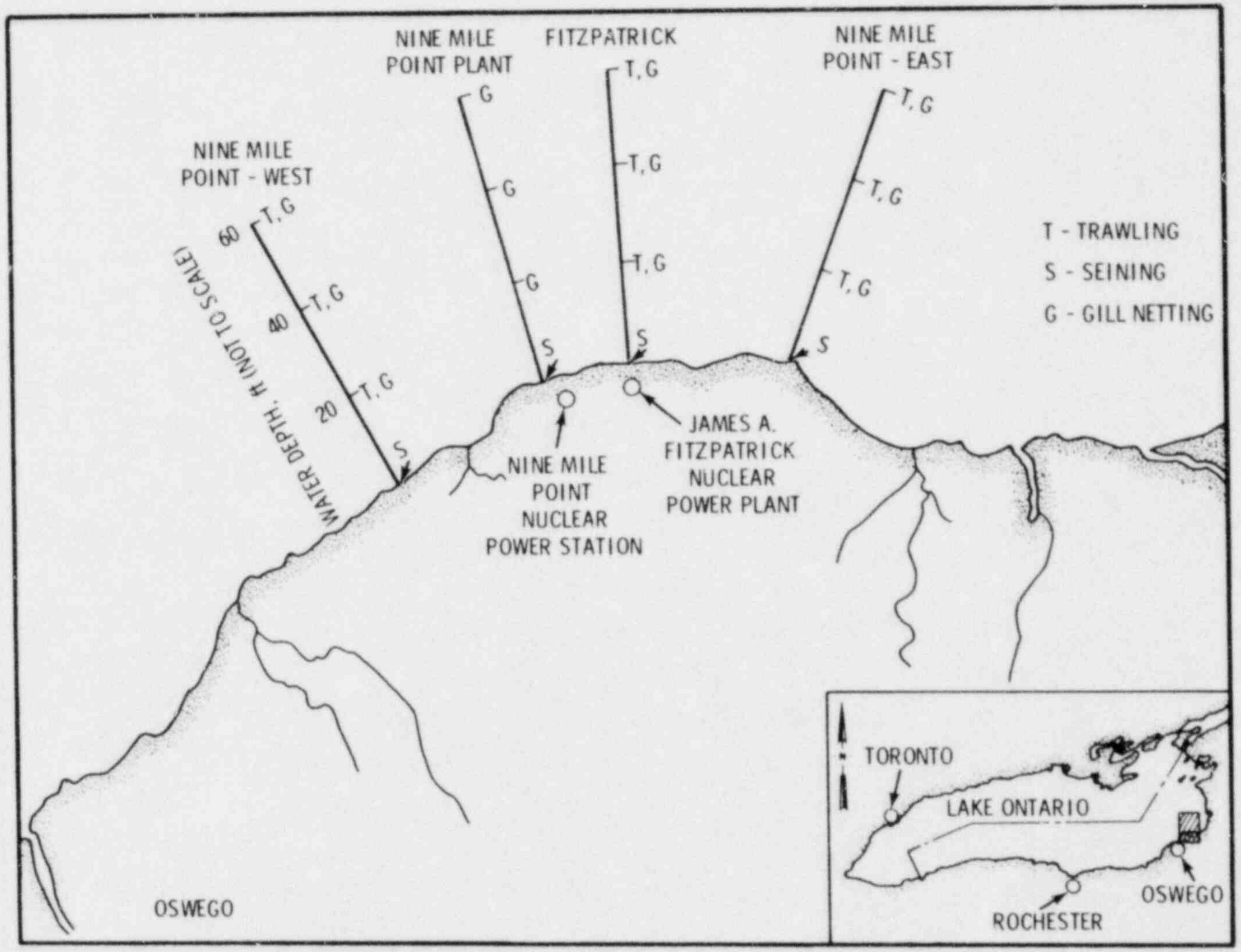

Figure 15. Sampling Locations for the Gill Net, Trawl and Seine Surveys Near the Nine Mile Point Nuclear Power Station (from Niagara Mohawk Power Corporation, 1975a).

(30.5 m) lines were attached to bridles at either end of the net; at each station one end of the line was held on shore while the other end was swept in an arc by a boat. The area sampled by each tow was between 30 and 45 m offshore.

The trawl survey at Nine Mile Point involved biweekly day and night samples along three transects. The tows were made east to west for 15 minutes at a constant speed. A single representative tow was taken for the Fitzpatrick and Nine Mile Point transects. At each transect, surface and bottom trawls were taken at three contour depths (20, 40 and 60 ft) in 1973 through 1975; for 1976 through 1978 only bottom trawls were taken at each contour depth. There was also a change in the trawl gear over the years of the study. In 1973 and 1974, a 9 m (30 ft) otter trawl was used; in 1975, the gear was a 7 m (23 ft) otter trawl. Both nets had 5 cm stretched mesh in the wings and a 1.3 cm stretched mesh-cod end liner.

Because of changes in sampling design and inconsistencies in reporting the data, only three years (1976 through 1978) of the gillnet survey at Nine Mile Point were analyzed. During these years, day and night samples were taken biweekly at five contours (15, 20, 30, 40 and 60 ft) located along the four transects (Figure 15). Two replicate nets were set at each sampling location and time between April and December.

The catch from each gear type was sorted by species and enumerated. CPUE was calculated for each species as the number of fish per unit of effort. For the seine, the unit of effort was a tow; for the trawl, a 15 minute tow and for the gillnet, a 12 hr set.

Species Selection

A large number of fish species were collected by the monitoring programs at Pilgrim and Nine Mile Point NPP. It was neither feasible nor warranted to analyze the sampling data for each species. The selection of species for analysis was influenced by several considerations. These considerations included abundance in the collection, commercial or ecological importance, and representation in the catches of other sampling gears.

Otter trawls at the Pilgrim NPP collected approximately forty fish species (Appendix B). Six species which represented over 90% of the total catch were selected for analysis: winter flounder (Pseudopleuronectes americanus), yellowtail flounder (Limanda ferruginea), windowpane (Scophthalmus squosus), ocean pout (Macrozoarces americanus), longhorn sculpin (Myoxoaphalus octodecemspinosus) and Raja spp., skates. The winter and yellowtail flounder are commercially important.

All six species studied at Pilgrim are bottom orientated, inhabiting the continental shelf. The winter flounder generally is found at depths between 2 and 40 m. They move to shallower waters in spring to spawn and to deeper waters in late fall (Leim and Scott, 1966). The habitat of the yellowtail flounder ranges from 10 to over 100 m but it is most abundant between 35 and 75 m. The windowpane is a shallow-water species rarely found at depths greater than 75 m. There is no evidence of extensive migration for this species. Because of its size, windowpane is not commercially fished. The ocean pout occurs from the intertidal zone to over 180 m. It migrates into deeper waters in the fall, returning to shallower waters in the spring. The longhorn sculpin is a coastal inhabitant occupying deeper waters in cold weather and returning to shallow water in the spring. The skates were not identified to species, but apparently at least four species are common to the area (Boston Edison Company, 1974a,b).

The other survey at Pilgrim involved the commercially important species, the American lobster (Homarus americanus). This species inhabits the east coast of Canada and the United States, from Labrador to North Carolina. It is found on rocky substrates from the shallow subtidal zone to over 300 m deep. In Cape Cod there is some evidence of a fall offshore migration.

Nearly sixty species of fish were collected by the three survey methods at Nine Mile Point (Appendix C). Species composition and abundance varied with gear. Catch data for 1974 (Table 12) is representative of the species composition of the total catch. Only the most abundant species of each gear

Table 12. Number of Fish Collected by Seine, Trawl and Gillnet at Nine Mile Point in 1974. Numbers in parentheses denote the relative contribution of the species in the fish catch.

Species	Seine	Trawl	Gill Net	Total	% Comp.
Alewife	3351 (1)	3193 (1)	68030 (1)	74526	74.60
Rainbow smelt	2	176 (2)	11524 (2)	11702	11.71
Spottail shiner	14 (4)	17 (5)	5427 (3)	5458	5.60
White perch	108 (2)	7 (6)	3123 (4)	3238	3.24
Yellow perch	1	0	1568 (5)	1569	1.50
Threespine stickleback	6 (6)	21 (4)	2	29	.03
Emerald shiner	77 (3)	30 (3)	2	109	.15
Smallmouth bass	7 (5)	0	264	271	.28
Gizzard shad	2	3	1000 (6)	1005	1.03
			Grand Total	99,917	

were used in the analysis. For the seine these were the alewife (Alosa pseudoharengus), spottail shiner (Notropis hudsonius), and white perch (Morone americana); for the trawl, alewife, rainbow smelt (Osmerus mordax), threespine stickleback (Gasterosteus aculeatus) and spottail shiner; for the gillnet, alewife, rainbow smelt, spottail shiner, and white perch.

The alewife is not commercially fished in Lake Ontario. Unlike its marine counterparts, the land-lock alewife is small and bony (Scott and Crossman, 1973) and therefore not considered commercially valuable. Alewife is an important forage fish and is noted for its large annual die-offs. The alewife is pelagic during most of the year, moving into shallower water to spawn in April and returning to deeper waters in August. There is also an inshore movement of alewife at night and a subsequent offshore movement during the day.

The spottail shiner is an important bait minnow as well as a forage fish. It spawns in the spring and early summer over sandy shoals and apparently is more susceptible to capture at night (Scott and Crossman, 1973). The rainbow smelt is a schooling pelagic fish which spawns in rivers and over shady shoals in spring. Smelt represent an important commercial and sport fishery. The white perch is similar to the alewife in being an important commercial species in the ocean. In lakes, however, its mature size is too small for commercial exploitation (Scott and Crossman, 1973). The perch spawns in the spring in shallow waters and exhibits horizontal as well as vertical diel movements. It moves offshore to deeper waters at night and returns to shallower inshore water during the day. The three-spine stickleback is a shallow-water species, best known for its contributions in studies of fish behavior. When abundant, it serves as an important forage species for larger species such as lake trout.

Statistical Analysis

Sampling methods were evaluated by statistical analysis of the fish catches expressed in terms of CPUE. Analysis was conducted on the total catches of fish and on a per species basis for the predominant and commercially important species. Plots of CPUE data served as a graphical aid in interpreting analytical results throughout the analysis. However, three statistical methods formed the cornerstone for the quantitative evaluation of sampling techniques. These were:

1. one-way analysis of variance for factorial treatment designs
2. analysis of variance for hierarchical (nested) data
3. correlation and regression analysis.

The purpose of this section is to discuss the role of these statistical procedures in the interpretation of CPUE data from fish monitoring programs. Due to the a posteriori nature of applying these techniques, evaluation of their appropriateness to the actual design cannot be made, although they seem reasonable.

An assumption of the analysis of variance is that the CPUE data are normally distributed with constant variance. Plots of the catch data suggest that CPUE is approximately lognormally distributed in most cases; hence, all subsequent analysis used natural logarithmic (ln) transformed data.

In carefully structured monitoring programs, the spatial and temporal components of the sampling design can be evaluated by an analysis of variance for factorial treatment designs. The factors included in the design are dependent upon the sampling program at the power plant. For each factor determined to be important in the design, two or more levels of treatment, reflecting differences in potential influence on fish abundance, need to be identified. The factorial treatment design is then constructed by forming all possible combinations among the different factors at their various levels.

The factorial array is conceptualized as being in a completely randomized design for the analysis of variance. No interaction term of order three or greater was included is the model equations. This assumes that higher order interaction terms are unimportant and can be included in the error term. The factors affecting CPUE are assumed to be fixed. Treating these factors as fixed effects, inference could be made only to the factors and their levels used in the monitoring programs.

To help illustrate the nature of a factorial treatment design, consider the gillnet catches at Nine Mile Point NPP (Figure 15). The factors and their levels of treatment can be summarized as:

A. Years of data analyzed: a = 1, 2

B. Date of samples collected each year: b = 1, . . ., 13

C. Day/night samples: c = 1, 2

D. Sampling station (transects): d = 1, . . ., 4

E. Depth contours: e = 1, . . ., 4

For this example at Nine Mile Point, the difference factors at their various levels define 832 (2x13x2x4x4) distinct treatment combinations in the factorial treatment design. The multiplicative model describing the CPUE data can be written as:

$$Y_{abcde} = \mu \cdot A_a \cdot B_b \cdot C_c \cdot D_d \cdot E_e \cdot (AB)_{ab} \cdot (AC)_{ac} \cdot (AD)_{ad} \cdot (AE)_{ae}$$
$$\cdot (BC)_{bc} \cdot (BD)_{bd} \cdot (BE)_{be} \cdot (CD)_{cd} \cdot (CE)_{ce} \cdot (DE)_{de} \cdot \varepsilon_{abcde}$$

where Y_{abcde} = CPUE for the spatial-temporal sample described by factors A,B,C,D,E at appropriate levels.

μ = overall mean effect

A_a = main effect of factor A (years) at level a = 1, 2

$(AB)_{ab}$ = two factor interaction effect (years x dates), a = 1, 2 and b = 1, . . ., 13

ε_{abcde} = multiplicative error term.

The logarithmic transformation of the model results in the linearized model used in the analysis:

$$\begin{aligned} ln Y_{abcde} = & \; ln + ln A_a + ln B_b + ln C_c + ln D_d + ln E_e \\ & + ln(AB)_{ab} + ln(AC)_{ac} + ln(AD)_{ad} + ln(AE)_{ae} \\ & + ln(BC)_{bc} + ln(BD)_{bd} + ln(BE)_{be} + ln(CD)_{cd} \\ & + ln(CE)_{ce} + ln(DE)_{de} + ln\varepsilon_{abcde} \end{aligned} \tag{1}$$

where $ln Y_{abcde}$ = ln(CPUE)

ln = overall mean of the transformed data

$ln\varepsilon_{abcde}$ = additive error term.

From the analysis of model (1) the spatial-temporal homogeneity of the fish community at Nine Mile Point can be investigated. Further, the analysis of variance can provide information on the merits of sampling during both day and night. With large factorial treatment designs characteristic of monitoring programs, lack of balance and/or orthogonality can produce results that are uninterpretable. For this reason only subsets of the data which were both balanced and orthogonal were used in this analysis of sampling methods. More detailed analysis of catch data was often indicated when significant second order interactions were identified in the above model.

To compare the relative efficiency of alternate sampling methods, estimates of the sampling error, $\hat{\sigma}^2$, are necessary for each technique. A second variance component which estimates the normal variability in CPUE from year to year, $\hat{\sigma}_y^2$, provides a means to interpret the "noise to signal" ratio of the sampling technique. As the ratio $\hat{\sigma}^2/\hat{\sigma}_y^2$ increases, the ability of a sampling method to detect a change in yearly CPUE decreases. This ratio forms an intuitively appealing criteria to evaluate sampling techniques. Further, these variance components form the basis upon which future monitoring designs can be based.

Estimates of CPUE sampling error, $\hat{\sigma}^2$, and yearly variance, $\hat{\sigma}_y^2$, were computed from an analysis of hierarchical (nested) data. Hierarchical data is generated by a process of repeated sampling and subsampling. In monitoring, this occurs by sampling selected years, days within the years and stations within the day. Under a random-effects model, these variance components can be estimated from the analysis of the model:

$$Y_{abc} = \mu \cdot A_a \cdot B_{ab} \cdot \varepsilon_{abc}$$

where μ = overall mean

A_a = effect of the year, a = 1, . . .k

B_{ab} = effect of the bth day within the ath year, b = 1, . . .n_b

ε_{abc} = multiplicative error term for the cth sample (c = 1,...,m) collected on the bth day of the ath year.

Using the ln-transformation, the linearized model for the sampling program becomes:

$$ln Y_{abc} = ln \mu + ln A_a + ln B_{ab} + ln \varepsilon_{abk} \quad (2)$$

where it is assumed

$$ln A_a = N(0, \sigma_y^2)$$
$$ln B_{ab} = N(0, \sigma_{days}^2)$$
$$ln \varepsilon_{abk} = N(0, \sigma^2)$$

The assumptions of the random-effects model (2) can never be fully realized by a monitoring program; hence, the variance estimates possess a bias of an indeterminant nature. In order to estimate the variance in yearly CPUE, the model assumes that the specific years for monitoring are randomly selected. By the nature of monitoring programs, sampling occurs systematically for a number of consecutive years; therefore, it is not a random sample through time. However, this systematic sample of years can still yield an unbiased estimate of $\hat{\sigma}_y^2$ if yearly abundance is a stochastic process. Comparable assumptions would be necessary with any alternative analysis if estimates of $\hat{\sigma}_y^2$ are to be derived.

In similar fashion, model (2) assumes that daily CPUE samples are independent and randomly distributed in the vicinity of the power plants. Only in the case of the lobster pot samples at Pilgrim is this assumption approximated. Typically, sampling occurred at fixed and specified sampling stations; the effect of this systematic sampling on the bias of $\hat{\sigma}^2$ is indeterminant. Again if the spatial abundance of fish can be assumed random, systematic sampling will not bias $\hat{\sigma}^2$.

Variance components were estimated by analysis of variance using the observed values for mean squares (MS) and expressions for their expected values (E(MS)). For illustration, only balanced data sets will be considered; assume $n_a = n$ for all a and $m_{ab} = m$ for all a and b, then an ANOVA table can be written as:

Source	Degrees of Freedom	MS	E (MS)
Total$_{\text{corrected}}$	knm-1	$\sum_{a=1}^{k}\sum_{b=1}^{n}\sum_{c=1}^{m}(Y_{abc}-Y_{...})^2/(knm-1)$	
Years	k-1	$\sum_{a=1}^{k} nm(\bar{Y}_{a..}-\bar{Y}_{...})^2/(k-1)$	$\sigma^2+m\sigma^2_{days}+nm\sigma^2_y$

Days w/in Years	k(n-1)	$\sum_{a=1}^{k}\sum_{b=1}^{n} m(\bar{Y}_{ab\cdot}-\bar{Y}_{a\cdot\cdot})^2/(kn-k)$	$\sigma^2+m\sigma^2_{days}$
Samples w/in Days	kn(m-1)	$\sum_{a=1}^{k}\sum_{b=1}^{n}\sum_{c=1}^{m} (\bar{Y}_{abc}-\bar{Y}_{ab\cdot})^2/(knm-kn)$	σ^2

It is important to note that σ^2 is not the yearly variation in CPUE, but rather the variation in the yearly effects estimated for model 2.

Values of σ^2 derived from the analysis of variance are conservative estimates of sampling error for a CPUE technique. Only if fish abundance was homogeneous about the power plant would replicate samples provide a true estimate of sampling error. Rather, the estimate of σ^2 is composed of two components: pure sampling error (measurement error) and the variability in the spatial abundance and catchability of fish. Let n be the number of fish caught in a sample; then it is readily seen.

$$Var(n) = \underset{N}{E}[Var(n|N)] + \underset{N}{Var}[E(n|N)]$$

$$Var(n) = \underset{N}{E}[pqN] + \underset{N}{Var}[pN]$$

$$Var(n) = pq\mu_N + p^2\sigma^2_N$$

where p = 1 - q = catch rate

N = abundance of fish

and μ_N and σ^2_N are the mean and variance in fish abundance.

The underlying models for the analysis of variance for the factorial treatment design and the hierarchical data are dissimilar. Principally, the factors in the factorial treatment design take into account both temporal and spatial effects which are considered fixed, while the hierarchical design considers only temporal effects assumed to be random. Since the mean square error (MSE) from the analysis of the factorial treatment designs is also an estimate of σ^2, comparison of the variance estimates by these two procedures should provide a rather robust estimate for the magnitude of σ^2.

Sampling gear for fish differ not only in their potential efficiency, but also in their selectiveness for fish species. Some gear and sampling methods are more likely to catch particular species than other methods. Correlation analysis of the catch data was performed to provide an indication of how comparable alternative sampling methods are for specific fish populations. Ideally, among comparable sampling methods revealed by the correlation analysis, the technique with minimum variance would be preferred, given equal costs of data acquisition.

Results and Discussion

Seasonal Trends in CPUE

Seasonal trends in CPUE were evaluated by plotting ln-transformed CPUE for total and individual species catch versus sampling date. The possible effects of the sampling location and time of day were not included in this analysis.

At Pilgrim NPP, seasonal trends in CPUE were evident in both the otter trawl (Figure 16) and the lobster pot surveys (Figure 17). For the otter trawl, total catch CPUE was lowest in winter with a peak value observed in late summer. Within the period when commercial lobster harvesting occurred, seasonal patterns in lobster CPUE were observed. The lobster CPUE generally increased from a low in early summer to a high in fall (Figure 17). The patterns in CPUE for both the otter trawl and lobster survey appeared consistent for the five years of the study (1973 through 1977).

The observed pattern in otter trawl catches at Pilgrim appears to be related to the migratory behavior of the flounders and skates. The seasonal pattern of catch for the winter flounder was particularly pronounced and this species accounts for 30 to 50% of the total catch. The winter flounder migrates to deeper waters in November, returning in spring to shallow waters

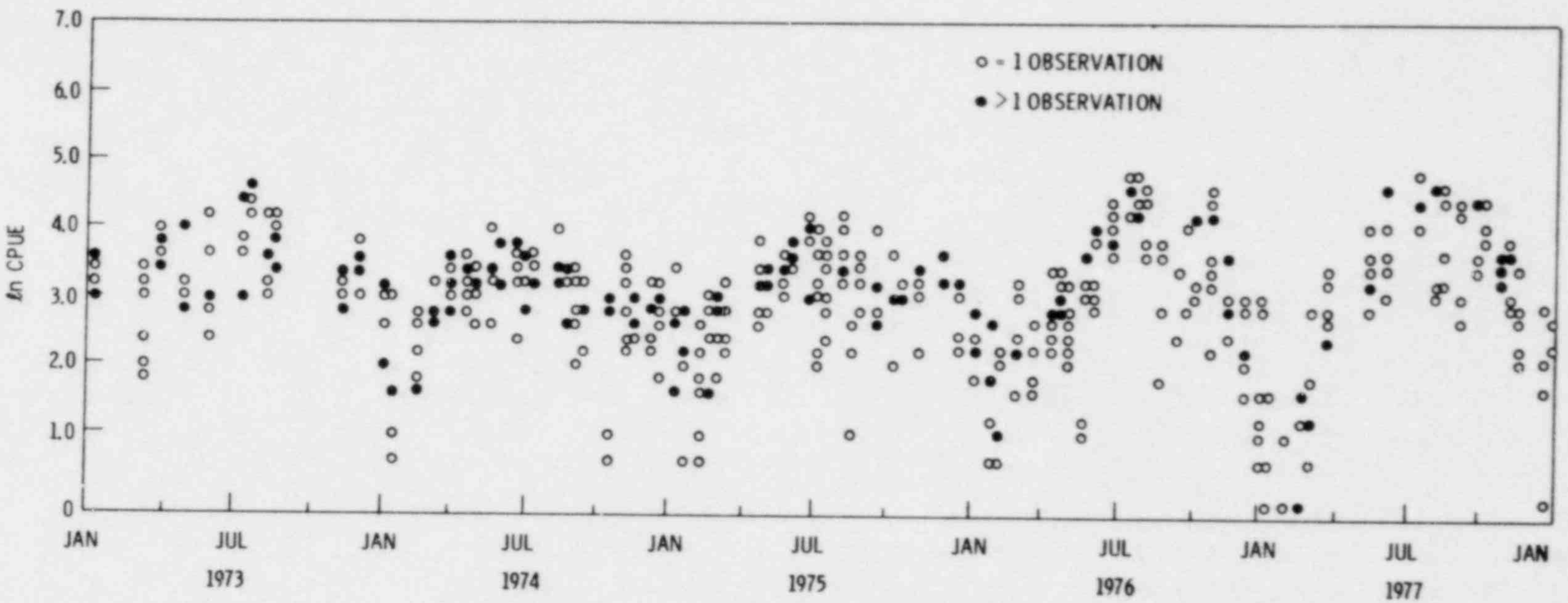

Figure 16. Seasonal Trend in CPUE for the Otter Trawl Samples Near Pilgrim Nuclear Power Station for 1973 through 1977. Points represent total CPUE for each sampling date; data were ln-transformed.

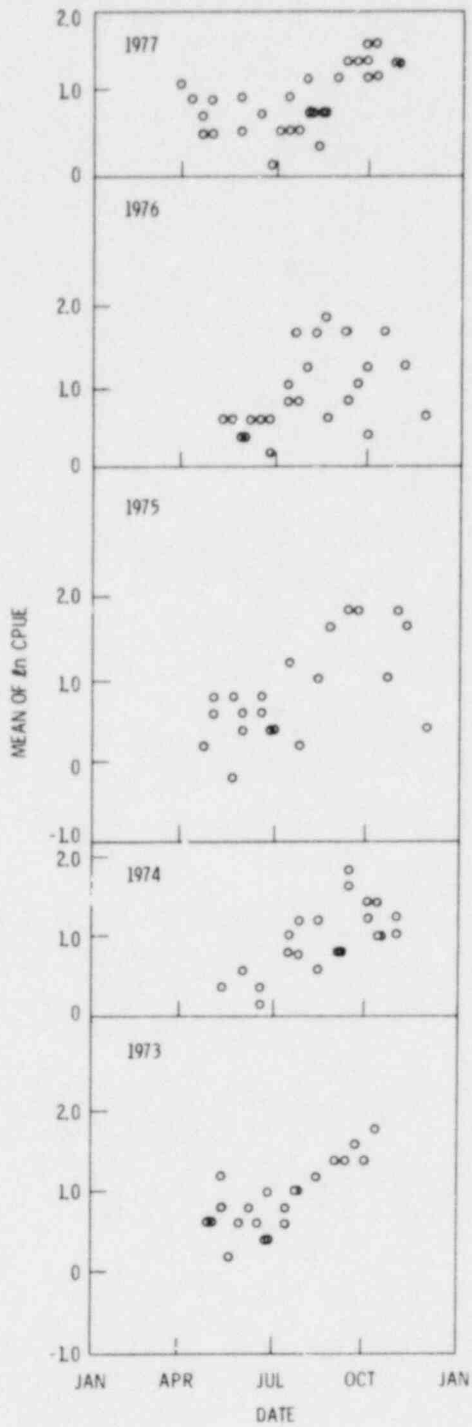

Figure 17. Seasonal Trend in Lobster CPUE near Pilgrim Nuclear Power Station for 1973 through 1977. Points represent means of the CPUE for each sampling date. Data were ln-transformed. ln CPUE = -0.098 + 0.015 Date; r^2 = 0.20.

to spawn. Several of the skate species exhibit similar migration patterns. Regression analysis was used to describe the seasonal trends in CPUE. Starting with 1 February when total fish CPUE values were annually the lowest, the pattern in CPUE could be described by a quadratic equation where the independent variable was day of the year (1, 2, . . ., 365) (Figure 18). The regression equation accounted for 40% of the observed variation in total fish CPUE. Regression analysis indicated a significant linear trend in lobster CPUE with time and accounted for 20% of the observed variation.

At Nine Mile Point Nuclear Power Plant, seasonal trends were not apparent in total CPUE from surveys conducted by gillnet, trawl or seine. The plot of the *ln*-transformed CPUE for the seine survey versus calendar dates (Figure 19) is representative of the lack of seasonal pattern also observed for gillnet and trawl catches. The life histories of several of the species chosen for analysis sugest that some seasonality in abundance should be observed. However, plots of the *ln*-transformed CPUE versus data for two of the species, alewife (Figure 20) and spottail shiner (Figure 21), do not reveal any consistent patterns in seasonal abundance either among years or gear types. For example, in two of the three years of gillnet data examined, alewife abundance declined between August and October. For the same periods, alweife abundance increased in the trawl surveys. This suggests that factors other than seasonal abundance, such as station location, time of sampling, or catchability, have obscured any seasonal trends.

Sampling Variance of Fisheries Techniques

Analysis of variance procedures were employed to estimate the sampling error (variance) associated with the monitoring of fish communities in the vicinity of power plants. Sampling programs using trawl, gillnet and seines at Nine Mile Point NPP and trawl and lobster pots at Pilgrim NPP were analyzed. The analysis of hierarchical data formed the basis for this investigation.

Assuming a random effects model, the components of variance for between years, $\hat{\sigma}_y^2$, and between replicate samples, $\hat{\sigma}^2$, could be estimated. The variance, $\hat{\sigma}_y^2$, estimates the variability in CPUE from year to year. The

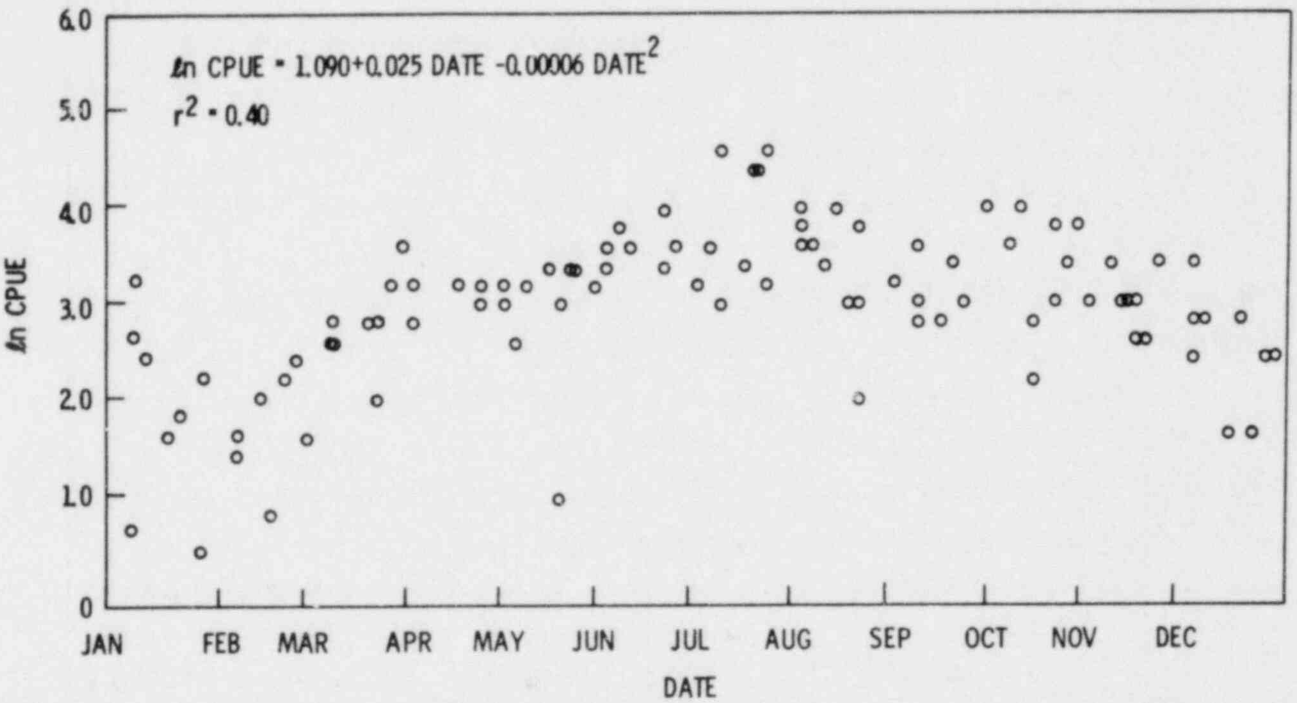

Figure 18. Seasonal Trend in Otter Trawl CPUE for the Total Catch Near Pilgrim Nuclear Power Stations. All years are plotted together with each point representing the mean CPUE for a sampling date. Data were *ln*-transformed.

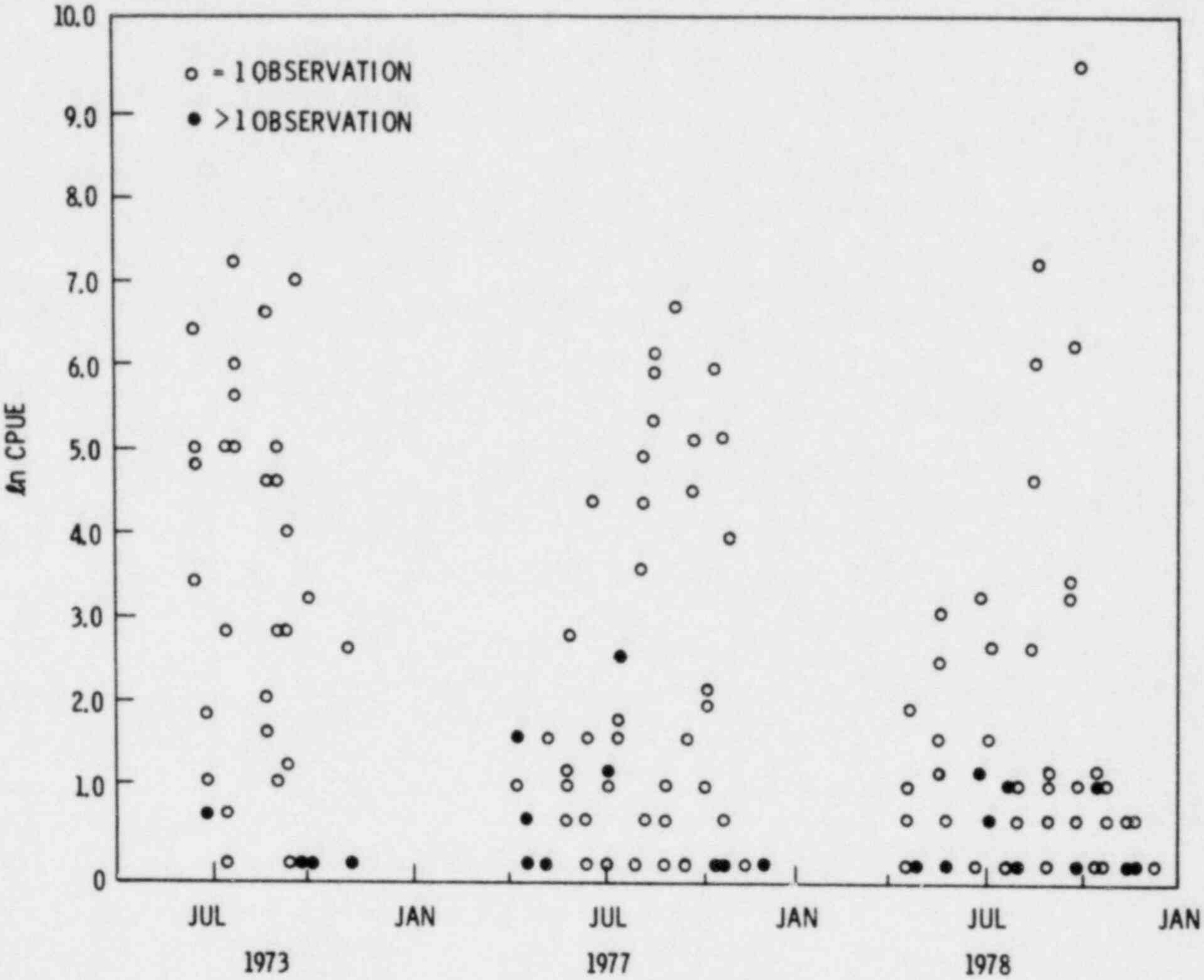

Figure 19. Seasonal Trend in CPUE for the Seine Survey at Nine Mile Point Nuclear Power Station, 1973, 1977 and 1978. Points represent CPUE for total catch; data were ln-transformed.

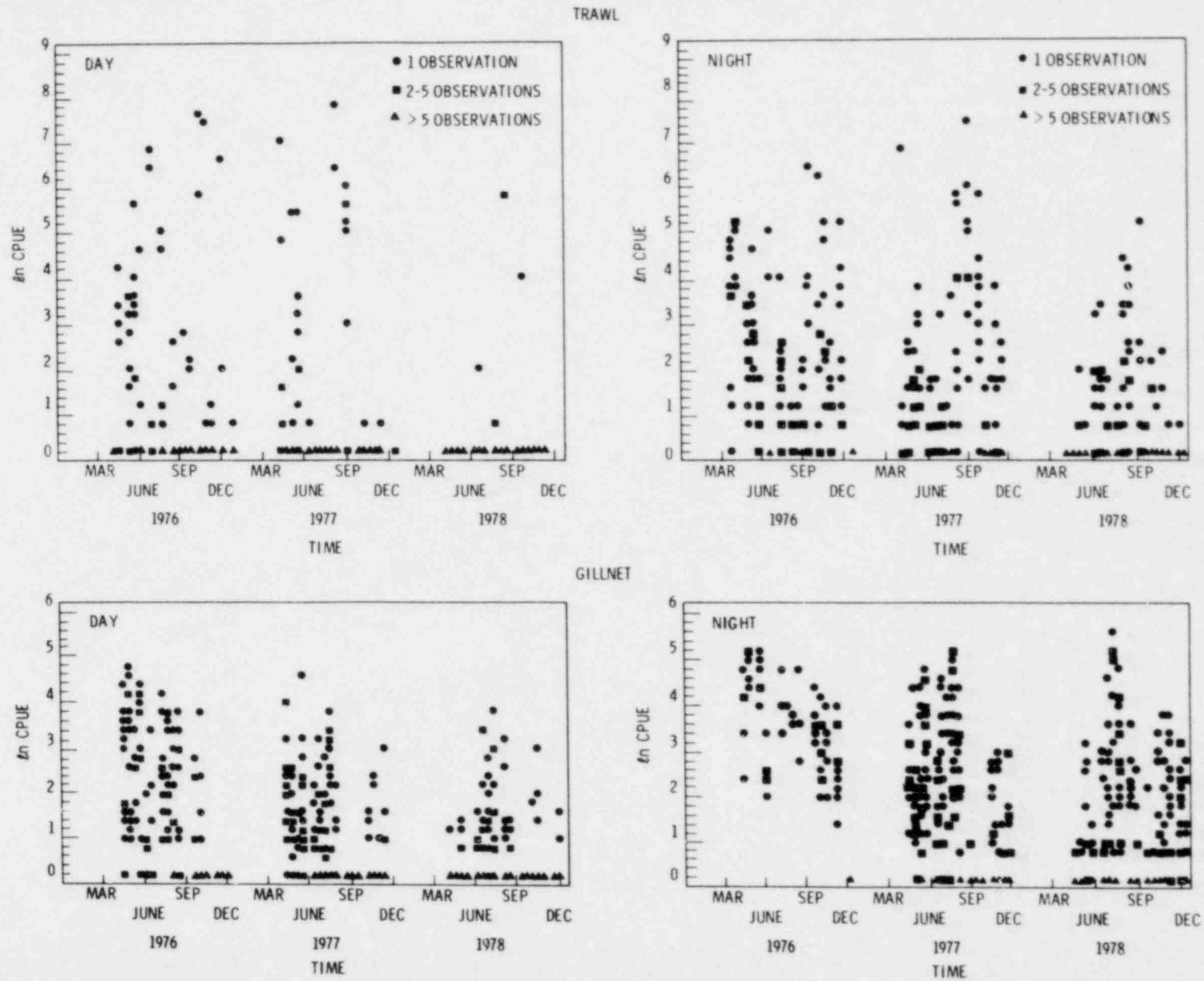

Figure 20. Seasonal Trend in Alewife for Gillnet and Trawl at Nine Mile Point Nuclear Power Station, 1976, 1977 and 1978. Data were *ln*-transformed.

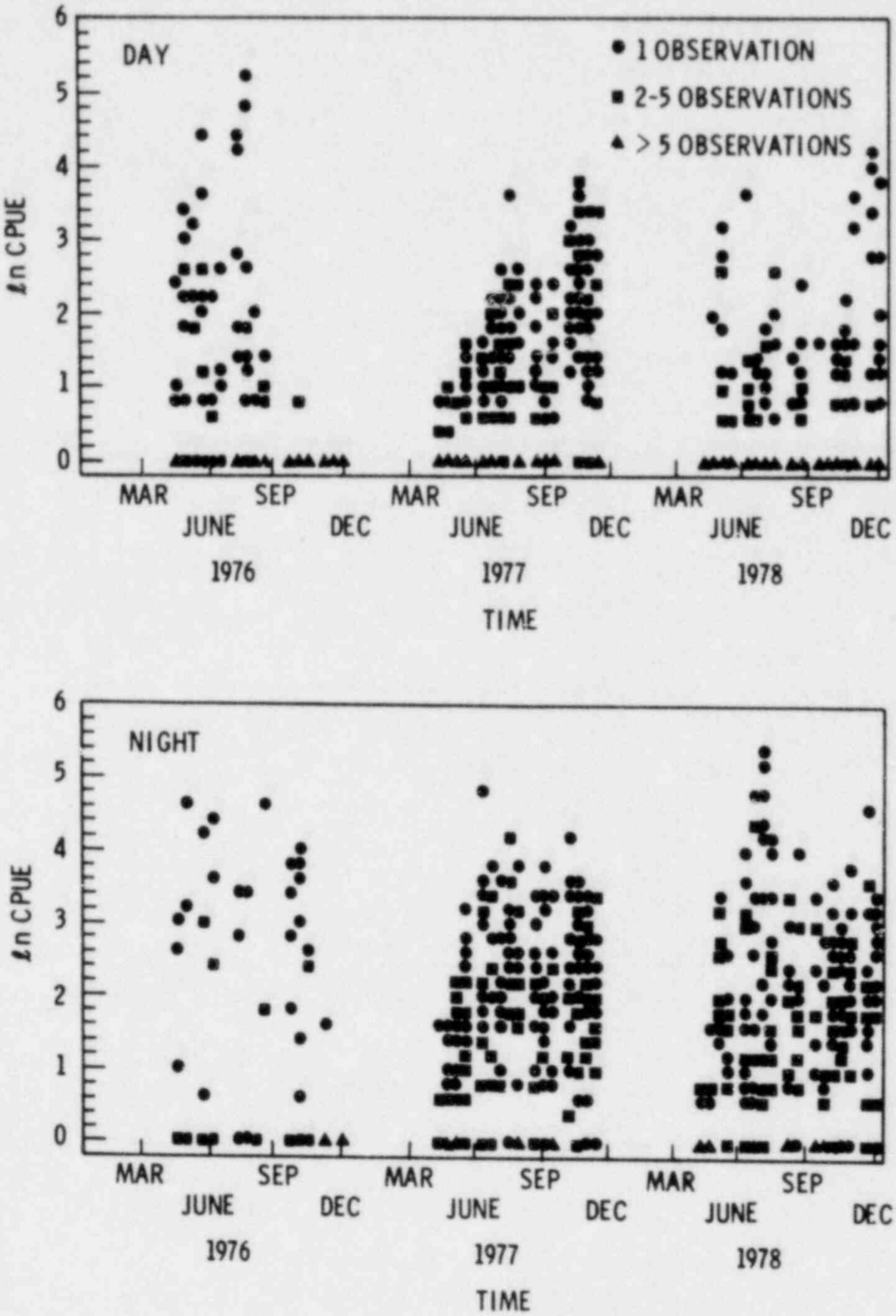

Figure 21. Seasonal Trend in Spottail Shiner for Gillnet at Nine Mile Point Nuclear Power Station, 1976, 1977 and 1978. Data were *ℓn*-transformed.

variance component, $\hat{\sigma}^2$, is an estimate of the sampling error associated with the monitoring technique. A major objective of a monitoring program is to observe the year-to-year changes in fish abundance. By forming the ratio $\hat{\sigma}^2/\hat{\sigma}_y^2$, an intuitive measure for the variability of the monitoring technique relative to normal changes in fish abundance is possible. As the ratio increases in value, the ability of a sampling method to detect a change in yearly CPUE decreases. Table 13 summarizes the results of this investigation of sampling error.

In general, the sampling error was at least one order of magnitude greater than the normal year-to-year variance in CPUE from Pilgrim and Nine Mile Point NPP's . The large values of $\hat{\sigma}^2/\hat{\sigma}_y^2$ indicate the difficulty of monitoring techniques using CPUE to detect changes in fish abundance. Further, the ratios suggest that relatively large changes in CPUE will occur before the monitoring techniques will demonstrate impacts on fish communities.

Alewife are an abundant fish in the vicinity of Nine Mile Point NPP. Results of the analysis indicate that monitoring programs (using gillnet, trawl and seine) would be more likely to detect changes in alewife CPUE than less prolific species or the total fish CPUE. The large range in variance estimates observed at Nine Mile Point NPP (Table 13) among species suggests that monitoring programs should be designed, if possible, for specific species of economic or ecological value. No single monitoring program can be designed to sample each species optimally in the vicinity of the power plants when sampling error varies from species to species.

With respect to the magnitude of the sampling error, the analysis at Nine Mile Point NPP indicates no preferred sampling method among trawl, gillnet and seine. However, the ratio $\hat{\sigma}^2/\hat{\sigma}_y^2$ appears somewhat lower for seine catches.

The variance estimates derived from the analysis of the factorial treatment designs of the monitoring programs serve as an indication of the robustness of $\hat{\sigma}^2$. These variance estimates are also included in Table 13. These estimates of sampling error will be smaller when factors such as station location and time of sampling have an effect on fish catches. If including such factors reduces the error variance, this implies that true replicate

Table 13. Estimates of Sampling Error ($\hat{\sigma}^2$), Between Year Variance in Abundance ($\hat{\sigma}_y^2$) and Associated Degrees of Freedom (D.F.) From the Analysis of Hierarchical Data and Factorial Treatment Designs. Analysis is based on ln-Transformed values of CPUE data from Nine Mile Point and Pilgrim Nuclear Power Plants.

Nuclear Power Plant	Data Set	Hierachical $\hat{\sigma}^2$	D.F.	$\hat{\sigma}_y^2$	D.F.	$\hat{\sigma}^2/\hat{\sigma}_y^2$	Factorial $\hat{\sigma}^2$	D.F.	$\hat{\sigma}^2/\hat{\sigma}_y^2$
Nine Mile Point									
	<u>Gill Net Catches</u>								
	1. All species	1.387	2507	0.067	2	20.7	0.438	693	6.5
	a. day samples only	0.932	1300	0.114	2	8.2			
	b. night samples only	0.996	1158	0.077	2	12.9			
	2. Alewife	0.956	2507	0.150	2	6.4			
	3. Spottail shiner	1.128	2507	0.023	2	49.0			
	4. Rainbow smelt	0.565	2507	0.008	2	70.6			
	5. White perch	0.639	2507	0.019	2	33.6			
	<u>Trawl Catches</u>								
	1. All species	2.199	1308	0.060	4	36.7	1.929	580	32.2
	2. Alewife	1.516	1308	0.081	4	18.7			
	3. Spottail shiner	0.213	1308	0.009	4	23.7			
	4. Rainbow smelt	1.058	1308	0.035	4	30.2			
	5. Threespine stickleback	0.141	1308	0.0003	4	470.0			
	<u>Seine Catches</u>								
	1. All species	2.527	128	0.240	2	10.6	6.028	127	25.1
	2. Alewife	2.727	179	0.474	3	5.8			
	3. Spottail shiner	0.516	179	0.046	3	11.2			
	4. White perch	0.784	179	0.012	3	65.3			
Pilgrim	<u>Trawl Catches</u>								
	1. All species	0.192	382	0.017	4	11.3	0.128	44	7.5
	2. Three flounders and one skate	0.203	382	-0.002*	4	----	0.189	44	----
	Lobster Pot Catches	0.147	668	0.009	4	16.3			

*A negative variance component can be regarded as a value of zero (Johnson and Leone, 1964).

samples were not taken, increasing the size of σ^2 for the hierarchical approach. Variance estimates using the hierarchical analysis of variance should be considered as conservative. When day and night catches by gillnet were analyzed separately, the estimate of sampling error was reduced (see Table 13). Monitoring designs will need to take into account this temporal-spatial heterogeneity in fish CPUE.

Deployment of Effort

Generally, the fish of primary interest monitored in aquatic impact studies are mobile, wide-ranging species. This mobility precludes the use of control/non-impacted stations and treatment/impacted stations in the design of monitoring programs. Usually, a resident population does not exist, but rather what is monitored is a transitory subset of a larger population whose range extends beyond the immediate vicinity of a power plant. The purpose of sampling techniques which use CPUE is to monitor the relative abundance of this extended population.

The ability of CPUE to serve as an index of population size is based on a number of assumptions. Perhaps the most important of these assumptions is that the probability of capture (e.g., catchability) remains constant through time. If this assumption of constant catchability is true, observed changes in CPUE can be used to infer changes in fish abundance. A difference in yearly CPUE must be judged, however, with respect to the normal variability in CPUE, e.g., the sampling error.

When designing a monitoring program, it is important to know whether the fish populations are dispersed homogeneously in the vicinity of the power plant or whether variations in the microhabitats (spatial heterogenity) need to be considered. Species of fish usually have preferred habitats. The purpose of this discussion is to evaluate whether the monitoring programs were sampling one wide-ranging population or reflecting a series of microhabitat variations.

In analyzing the otter trawl survey at Pilgrim NPP, it was initially assumed that the fish populations were spatially homogeneous; that is, there were no differences in mean population density among sampling stations. To test this assumption an analysis of variance of factorial designs was performed with sampling stations as one factor. A subset of the otter trawl CPUE data which was both balanced and orthogonal was used in the analysis. This data set consisted of three years (1974 through 1976) of sampling. Results of the analysis (Table 14) indicated a significant interaction between sampling station and sampling date. The interaction suggested that the difference in seasonal trends in CPUE noted for the other trawl survey was not the same at each station.

To investigate the differences in catch at the sampling stations further, mean CPUE of the *ln*-transformed data for each species was plotted against station (Figure 22). The CPUE for several species appear related to the location of the sampling stations. For example, the yellowtail flounder and longhorn sculpin had the largest CPUE at Station 3, the ocean pout CPUE was largest at Station 2 and the winter flounder and windowpane CPUE greatest at Station 1. Species CPUE may be related to the preferred depths for these species. The CPUE for the yellowtail flounder, which prefers depths of 35 to 110 m, increased from the shallowest station (1) to the deepest station (3). The winter flounder and windowpane, on the other hand, are shallow water species and had their largest CPUE at Station 1.

At Pilgrim NPP, Station 1 was designated the control station (Boston Edison Company, 1978). Unfortunately, it was the shallowest of the three stations, and given the distinct depth preference of the local species, could not be considered a true control for the treatment Stations 2 and 3. If sampling stations are to serve as true replicates (in a statistical sense) or controls it will be necessary to match the parameters, such as depth, of the various microhabitats.

An analysis of variance of factorial designs was used to investigate the possible effects of station location, depth contour and time of sampling (i.e., day or night) on the CPUE at Nine Mile Point NPP. A balanced and orthogonal subset of the original data for seine, trawl and gillnets was analyzed. The analysis was performed on the *ln*-transformed total CPUE for each method.

Table 14. Results of a Factorial Design Analysis of Variance, Testing the Effects of Year Sampling Date and Station on the Total CPUE (*ln*-Transformed) of the Pilgrim Nuclear Power Station Otter Trawl Survey.

Source of Variation	D.F.	F	Significance of F
Main Effects	15	19.054	0.001
Station	2	4.917	0.012
Year	2	9.388*	0.001
Date	11	23.390*	0.001
Two-Way Interactions	48	2.677	0.001
Station Year	4	0.698	0.598
Station Date	22	3.712*	0.001
Year Date	22	2.002*	0.025

* indicates significance at the 5% level.

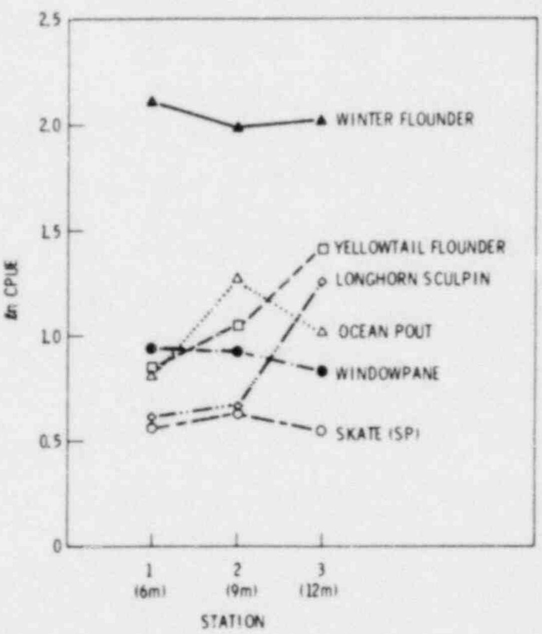

Figure 22. CPUE for the Most Abundant Fish Species in the Otter Trawl Survey at Pilgrim Nuclear Power Station. Depth at each station was determined at mean low water (MLW); data were *ln*-transformed.

Factors in the analysis of the seine data were station location, years (1976 through 1978), and date of collection. Results of the analysis (Table 15) indicated no effect of station location on total CPUE. The effect of station location on the CPUE of individual species was investigated by plotting the mean CPUE (*ln*-transformed) for each species versus station (Figure 23). White perch and spottail shiner appear to be slightly more abundant at the Nine Mile Point plant station, while alewife abundance declined at the Nine Mile East station. No information was found which could explain the apparent distribution of these three species at the sampling stations.

Analysis of the trawl CPUE data at Nine Mile Point involved the following factors: station location, depth contours, day/night sampling, date and year (1976 through 1978). Initial analysis identified a number of significant ($\alpha < 0.05$) interactions (Table 16), necessitating separate analyses of each depth contour. Results of the analysis of separate depth contours revealed a possible relationship between abiotic factors and catch which had a significant effect on total CPUE. At the shallowest contour (20 ft) the factors which had a significant effect on CPUE were sampling time and date. There were also significant ($\alpha < 0.05$) interactions between date and year and date and time. At the intermediate depth contour (40 ft), station location was a significant ($\alpha < 0.05$) factor; there was also a significant ($\alpha < 0.05$) interaction between station and year. At this contour, sampling date and time still had a significant ($\alpha < 0.05$) effect on total CPUE. At the deepest sampled contour (60 ft), station location and sampling time were the only significant ($\alpha < 0.05$) factors influencing CPUE. The station by year interaction was the sole significant ($\alpha < 0.05$) interaction.

These results indicate that station location was a significant influence on CPUE at deeper contours, while sampling date was more important at shallower contours. The relation between CPUE, station, and contour suggest that the shallowest contour (20 ft) was representative of a single habitat type, while at deeper contours factors such as current and substrate may be creating different habitats at each of the three stations.

Table 15. Results of a Factorial Design Analysis of Variance, Testing the Effects of Year, Sampling Date and Station on the Total CPUE (*ln*-Transformed) of the Nine Mile Point Seine Survey.

Source of Variation	D.F.	F	Significance of F
Main Effects	17	7.772	.001
Year	2	20.357*	.001
Station	3	1.179	.324
Date	12	7.323*	.001
Two-Way Interactions	66	1.169	.259
Year Station	6	.480	.821
Year Date	24	1.920*	.018
Station Date	36	.783	.788

* indicates significance at the 5% level.

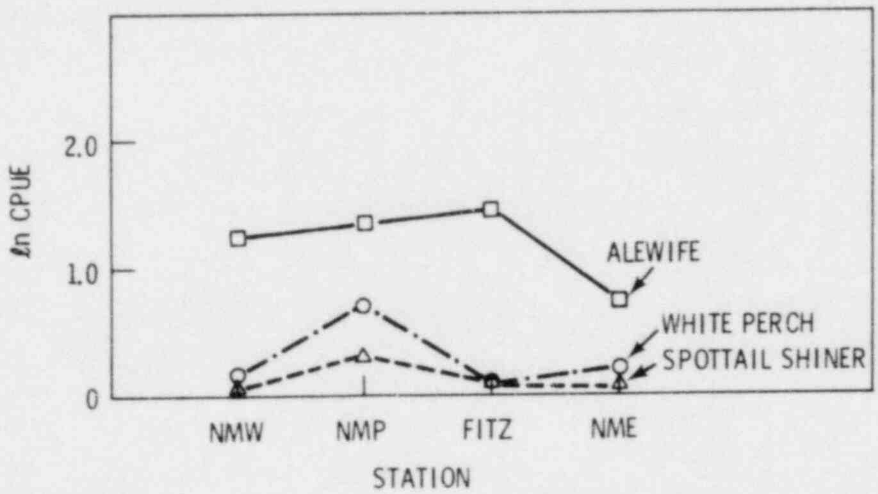

Figure 23. CPUE for Several Fish Species from the Seine Survey at Nine Mile Point Nuclear Power Station. Data were *ln*-transformed. (NMW = Nine Mile-West; NMD = Nine Mile-Plant; FITZ = Fitzpatrick Plant; NME = Nine Mile-East).

Table 16. Results of a Factorial Design Analysis of Variance, Testing the Effects of Year, Sampling Date, Sampling Time, Station and Contour on the Total CPUE (*ln*-Transformed) from the Nine Mile Point Trawl Survey.

Source of Variation		D.F.	F	Significance of F
Main Effects		19	10.708	.001
Year		2	12.404	.001
Station		2	10.836	.001
Contour		2	6.307	.002
Date		12	6.546	.001
Time		1	65.795	.001
Two-Way Interactions		102	3.190	.001
Year	Station	4	17.175*	.001
Year	Contour	4	.912	.456
Year	Date	24	5.670*	.001
Year	Time	2	3.821*	.022
Station	Contour	4	2.659*	.032
Station	Date	24	1.119	.317
Station	Time	2	3.047*	.048
Contour	Date	24	1.650*	.027
Contour	Time	2	1.539	.215
Date	Time	12	1.918*	.030

* indicates significance at the 5% level.

Figure 24 presents plots of the mean CPUE of alewife and spottail shiner for the trawl surveys at Nine Mile Point NPP on the basis of depth contour, station location and day/night sampling. The plots indicate an appreciable effect of day and night sampling on the CPUE. Alewife, the most abundant species caught by the trawls, shows a definite increase in CPUE in the night samples. Also, CPUE of alewife increased with depth at night, an apparent contradiction to the reported inshore nocturnal migration of the species. Only at one of the three stations did alewife CPUE increase at the greater depth contours during the day as anticipated according to their life history.

Station location, depth contours (15, 30, 40 and 60 ft) and day/night sampling were investigated for the gillnet survey at Nine Mile Point NPP .

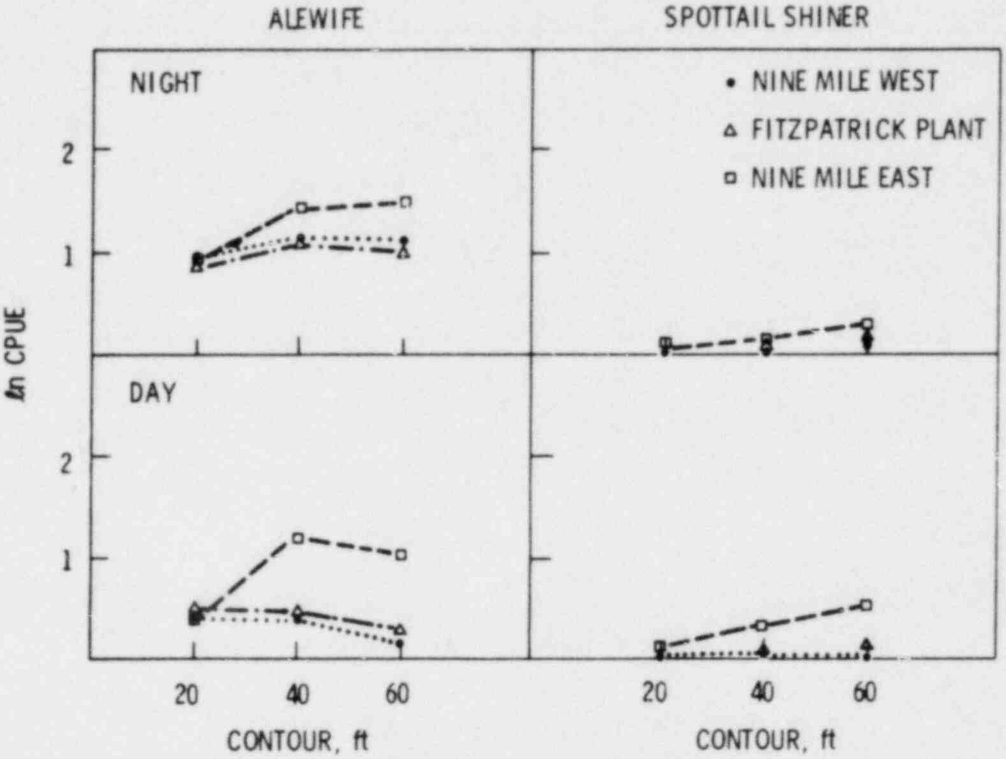

Figure 24. CPUE for Alewife and Spottail Shiner from the Trawl Survey at Nine Mile Point Nuclear Power Station. Data were *ln*-transformed.

Again, the overall analysis of variance for the factorial treatment design exhibited numerous first-order interactions among the factors necessitating further analysis (Table 17). Data from each depth contour was analyzed separately to assess the effects of station location on CPUE trends. Analysis of the data collected at each contour indicated that station location had a significant ($\alpha < 0.05$) effect on CPUE at all but the shallowest contour. These results are similar to the findings for the seine and trawl surveys. However, for the gillnet surveys, there was no significant ($\alpha < 0.05$) interaction between stations and the seasonal and yearly trends in CPUE. Day and night gillnet samples were different, as was the case for trawl sampling.

Table 17. Results of a Factorial Design Analysis of Variance, Testing the Effects of Year, Sampling Date, Sampling Time, Station and Contour on Total CPUE (*ln*-Transformed) from the Nine Mile Point Gill Net Survey.

Source of Variation	D.F.	F	Significance of F
Main Effects	20	53.425	.001
Station	3	11.022*	.001
Contour	3	46.730*	.001
Year	1	120.623*	.001
Time	1	584.370*	.001
Date	12	15.854*	.001
Two-Way Interactions	118	5.754	.001
Station Contour	9	3.475*	.001
Station Year	3	1.238	.295
Station Time	3	2.781*	.040
Station Date	36	1.687*	.008
Contour Year	3	2.001	.112
Contour Time	3	15.523*	.001
Contour Date	36	6.977*	.001
Year Time	1	14.016*	.001
Year Date	12	16.008*	.001
Time Date	12	5.422*	.001

* indicates significance at the 5% level.

Figure 25 presents plots of mean CPUE of gillnet catches of alewife and spottail shiner vs. depth contour and station location in day and night samples. There appears to be an appreciable effect of day and night sampling on the CPUE of both species. Catches at night were greater than the samples collected during the day. In the samples collected at night, CPUE increased with decreasing depth for both species. This pattern in CPUE corresponds to the reported nocturnal inshore migration for both species. In samples collected during daylight hours, alewife remained more abundant at shallower contours, while the spottail shiners were apparently more abundant at deeper contours offshore. The results for the spottail shiner are again in agreement with their reported migrations. No consistent patterns in CPUE among the four stations were evident.

We cannot determine from the results of this analysis, however, whether apparent differences in CPUE associated with day/night sampling, station location and depth contour are due to changes in fish abundance or changes in catchability. Diel movements of fish may simply make the fish species more vulnerable to capture, resulting in an apparent change in abundance. With the present constant effort techniques used to monitor fish abundance using CPUE, changes in abundance and catchability are indeterminant.

This analysis suggests one important guideline in the monitoring of fish communities. The temporal-spatial heterogeneity of CPUE in the vicinity of nuclear power plants requires that monitoring designs remain fixed once the program has been initiated. Changes in sampling locations could invariably introduce changes in CPUE related to the microhabital variations in the aquatic environment. These changes in CPUE would be confounded with any observed annual trends in fish abundance or changes related to the operation of the nuclear power plant.

Correlation Between Gears

Only the monitoring program at the Nine Mile Point plant permitted a comparison of the gears used to collect CPUE data. It was not possible to compare the two surveys at Pilgrim because comparisons of lobster and fish CPUE data would have been unwarranted. For the data at Nine Mile Point, a

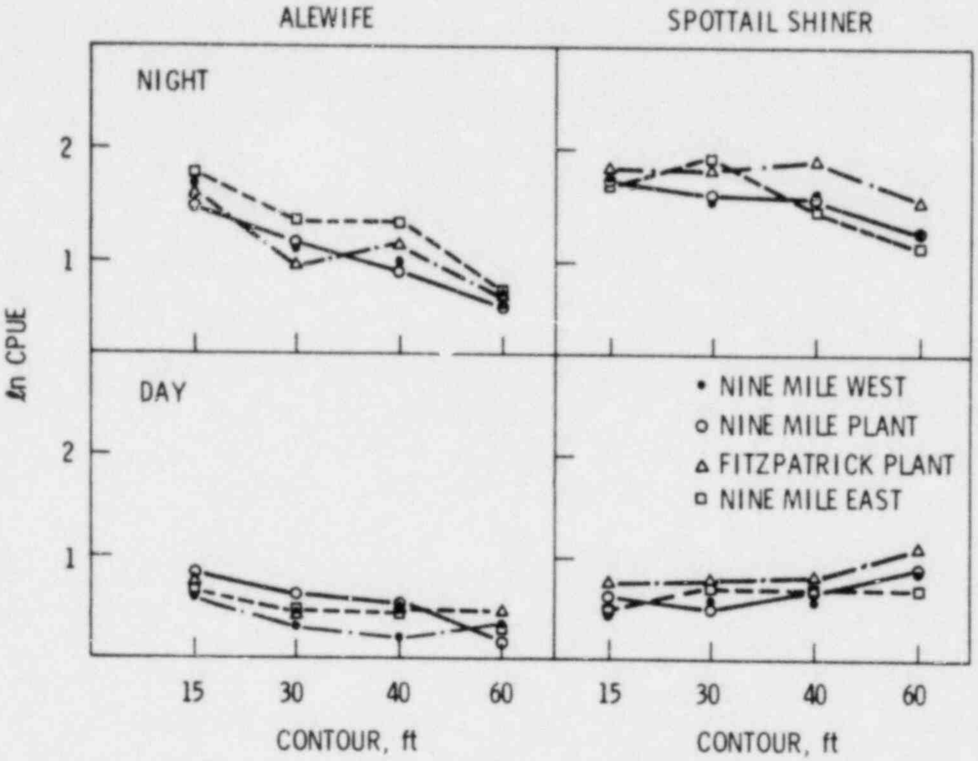

Figure 25. CPUE for Alewife and Spottail Shiner from the Gillnet Survey at Nine Mile Point Nuclear Power Station. Data were ln-transformed.

correlation analysis was used to determine if samples collected on corresponding days by each gear were similar either in total catch or in the catch of individual species. Results of the analysis indicated that no significant correlation ($\alpha < 0.10$) existed between the catches of the three gears. Restricting the data to individual contours and sampling times did not improve the correlations.

When the CPUE for individual species was plotted against sampling date, we found that the seasonal pattern for each gear type was different. Alewife CPUE for seine samples, for example, increased through the spring and early summer, reaching a maximum in late summer, then declining. Catch data for alewife from the gillnet survey revealed a peak abundance in early summer to midsummer, followed by a second, smaller increase in October. The trawl catch data for alewife had the highest CPUE in late summer; this peak was sometimes preceded by a smaller peak in late spring. Within one year, 1976, alewife CPUE in the seine samples peaked toward the end of July. In the trawl sample, the peak occurred in the beginning of October, while the gillnet data indicated a May peak.

Similar results were noted in comparing the catch results for the spottail shiner. The shiner appeared in the seine samples only between June and September, with the month of peak CPUE varying yearly. Trawl and gillnet surveys collected spottail shiners throughout the sampling period (April through November), with peak CPUE occurring in the latter part of the summer. As with the alewife, there was a spread of several months between the peak CPUE of spottail shiner in the gillnet, trawl and seine surveys.

The temporal and spatial patterns of CPUE noted for the three gear types at Nine Mile Point are indicative of more than just species abundance. These patterns are also indicative of factors relating to gear selectivity, including fish behavior and life history. All gears are selective for particular size classes of fish. Very small fish will generally pass through the nets, while larger fish may be able to avoid capture. It is possible that the various peaks in CPUE noted for alewife and spottail shiner are related to sampling of different age or size classes. For example, alewife, which reportedly spawns in shallow water in spring, has a peak CPUE in the trawl samples in the latter part of the summer. This peak may represent the maturing offspring from the spring spawning. A similar explanation could account for the pattern of spottail shiner abundance seen between the three gears.

It is also apparent in Figures 23, 24 and 25 and Table 12 that the three types of gear at Nine Mile Point differ in the species they catch. For example, in 1974 over 90% of the trawl and seine catches were alewife, compared to less than 75% for the gillnet. Spottail shiner, which rarely comprised more than 10% of the catch of either trawl or seine, sometimes surpassed alewife in the gillnet catches. Appendix C reveals further differences in species composition between the three gear types.

4.0 CONCLUSIONS

Through an examination of aquatic monitoring programs as currently implemented at Nuclear Power Plant Sites, evidence is available to provide guidelines for evaluating the use of CPUE indices. The assumptions underlying the applications of CPUE indices can be summarized as:

- CPUE is proportional to population abundance.
- CPUE data and sampling designs are sufficient to detect population abundance changes.
- Power plant-induced changes can be assessed through CPUE measurement.

The CPUE data from the selected monitoring programs do not provide evidence to support these assumptions.

The ability to equate changes in CPUE to changes in population abundance is dependent upon the assumed proportional relationship remaining constant. This is equivalent to requiring that the coefficient of catchability, or gear selectivity, remain constant. Although no quantitative evidence was encountered to evaluate the catchability coefficient, several lines of qualitative evidence were developed. A constant catchability coefficient would be expected to result in CPUE data bases characterized by relatively consistent interrelationships among replicate samples, sampling stations and fishing gears. Presumably, samples collected within a short time period should be proportional to the same population abundance. In general, this was not supported by the data. Large differences were observed between replicate CPUE samples and CPUE by stations and gears and did not reflect a constant proportionality in CPUE between stations or gears. In addition, the majority of the species did not have consistent daily or seasonal patterns that were supported by their general life history patterns. The coastal monitoring program did possess some consistency between these two lines of evidence. In addition, a constant proportionality would be expected to produce relatively consistent CV values. The general lack of quantitative or qualitative support for these intuitive expectations suggests that changes in the coefficient of catchability may be as important as changes in population abundance. This also produces a condition in which no objective criteria can be proposed for selecting sampling gear, sites and times or for evaluating the existence of population change based on CPUE indices.

Because the seasonal population patterns detected by the four fish sampling techniques were inconsistent between sites and species and the actual populations were unknown, it is uncertain which of the sampling methods, if any, detected the correct population fluctuations. However, in the riverine systems, electrofishing seemed to be the most satisfactory sampling method because it generally provided an adequate CPUE and a low variance for all species except channel catfish. Electrofishing also collected the best size distribution of any technique, capturing both small young-of-the-year and large adult fish. Although most of the sampling in these studies was done with A.C. equipment during the day, there are strong indications that the effectiveness can be further increased and the variability decreased by using properly designed D.C. electrofishing gear and by sampling at night.

Trawling was also a useful technique where it could be applied. Unfortunately, the applicability of this method is greatly limited by the need for relatively smooth, unobstructed substrate, so trawling cannot be used at all sites.

Seining is a more or less qualitative technique and is not as useful as electrofishing or trawling. The major difficulty lies in quantifying the effort, because the width of the haul and its effectiveness change radically with water depth. The length of a seine haul also varies from sample to sample in many programs. The seine samples in the three riverine studies exhibited generally low CPUE with a high variance, making the detection of population changes difficult.

Of the four sampling techniques used in the riverine studies, trapnetting seems to be the least useful in programs of this type. It essentially samples the same habitat as electrofishing, but it generally has a lower CPUE and a higher variance. Part of this may be caused by the trapnet's dependence on fish activity as well as population size to determine CPUE. In addition, trapnetting is less effective in sampling small fish than electrofishing.

The assumption that current aquatic monitoring programs can detect reasonable changes in CPUE indices does not appear to be well supported. The intuitive evidence based on the estimate of an order of magnitude for the "signal to noise ratio" suggests that relatively large changes may be undetectable. Addition evidence was found in the large CV values estimated from CPUE data. This implies that separation of power plant-induced changes in abundance from normal variability will be very difficult.

A second problem in evaluating changes in CPUE indices was reflected in the different evidence provided by each gear, station and gear-station combination. Lack of consistent evidence from these sources suggests that assessment of change of population abundance will be difficult. Objective criteria for combining this evidence is needed if a single hypothesis of no impact is to be tested. Another implication for monitoring programs that is suggested by this evidence is that sampling station and gears must be consistent throughout the monitoring program.

While identification of power plant-induced changes was not an objective of this research, information relevant to that objective was developed. A qualitative discussion of the concept of a "control" for fish and shellfish populations indicated some of the difficulties in establishing a control station. The data analysis in this report indicated that comparisons with the "designated" control were confounded by spatial differences in addition to the temporal, power plant and other effects.

This leads to the conclusion that current aquatic monitoring programs are providing CPUE indices for which reliable objective criteria upon which to base an evaluation of the existence or magnitude of power plant impacts are unavailable. Utilization of CPUE indices to detect changes in population abundance appears dependent upon development of sampling programs and statistical methodology capable of coping with changes in catchability and variability within and between years. Research on improved sampling programs should focus on ways to estimate catchability or reduce the sensitivity of CPUE indices to this variable. Statistical approaches that can reduce the magnitude of the error variance or increase the ability to detect between year changes is needed. The evaluation of population changes and cause and effect relationships will likely remain a qualitative process and include evidence drawn from ecological experience, CPUE indices and simulation modeling.

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APPENDIX A

Table A. Checklist of Common Fishes at Two or More Sampling Sites (A = abundant, P = present, R = rare).

Species		Susquehanna	Quad Cities	Prairie Island
Lepisosteidae				
Lepisosteus osseus	- Longnose gar		P	P
L. platostomus	- Shortnose gar		P	P
Clupicidae				
Dorosoma cepedianum	- Gizzard shad		A	A
Esoscidae				
Esox lucius	- Northern pike	P	P	P
Cyprinidae				
Cyprinus carpio	- Carp	A	A	A
Hybopsis aestivalis	- Speckled chub		P	R
H. storeriana	- Silver chub		A	P
Notemigonus crysoleucas	- Golden shiner	P	P	
Notropis anterinoides	- Emerald shiner		A	A
N. blennins	- River shiner		A	P
N. hudsonins	- Spottail shiner	A	P	A
N. spilopterus	- Spotfin shiner	A	A	A
Pimephales notatus	- Bluntnose minnow	P	P	P
P. vigilax	- Bullhead minnow		P	P
Catostomidae				
Carpoides carpio	- River carpsucker		A	P
C. cyprinus	- Quillback	A	P	P
Catostomus commersoni	- White sucker	A	P	P
Hypentelium nigricans	- Northern hogsucker	P		R
Ictiobus bubalus	- Smallmouth buffalo		P	P
I. cyprinellus	- Largemouth buffalo		A	P
Minytrema melanops	- Spotted sucker		P	P
Moxostoma anisuras	- Silver redhorse		P	P
M. macrolepidotum	- Shorthead redhorse	A	A	A
Ictaluridae				
Ictalurus melas	- Black bullhead		P	P
I. natalis	- Yellow bullhead	P	P	P
I. nebulosus	- Brown bullhead	A		P
I. punctatus	- Channel catfish	P	A	A
Pylodictis olivaris	- Flathead catfish		P	P
Percichthyidae				
Morone crysops	- White bass		P	A

Table A. (continued)

Centrarchidae				
Ambloplites rupestris	- Rock bass	P	P	P
Lepomis cyanellus	- Green sunfish	P	P	P
L. gibbosus	- Pumpkinseed	P	P	P
L. macrochirus	- Bluegill	A	A	A
Micropterus dolomieui	- Smallmouth bass	P		P
M. salmoides	- Largemouth bass	A	P	P
Pomoxis annularis	- White crappie	A	A	P
P. nigromaculatus	- Black crappie	A	P	A
Percidae				
Etheostoma nigrum	- Johnny darter		P	P
Perca flavescens	- Yellow perch	P	P	P
Percina caprodes	- Logperch		P	P
Stizostedion canadense	- Sauger		P	P
S. vitreum vitreum	- Walleye	A	P	P
Sciaenidae				
Aplodinotus grunniens	- Freshwater drum		A	A

APPENDIX B

Table B. Numerical Rank of Finfish Species Collected at All Stations in the Offsite Waters of Pilgrim Station by Otter Trawl, January 1970-December 1976 (from Boston Edison Company, 1978).

	Species	Totals	% Total
1.	Winter flounder	20,295	46.7
2.	Ocean pout	5,374	12.4
3.	Yellowtail flounder	5,322	12.2
4.	Longhorn sculpin	3,758	8.6
5.	Windowpane	2,533	5.8
6.	Skate[a]	2,472	5.7
7.	Rainbow smelt	622	1.4
8.	Atlantic cod	499	1.1
9.	Hake[a]	487	1.1
10.	Atlantic silverside	390	0.9
11.	Butterfish	249	0.6
12.	Scup	245	0.6
13.	Atlantic herring	224	0.5
14.	Spiny dogfish	199	0.5
15.	Goosefish	147	0.3
16.	Silver hake	98	0.2
17.	Seasnail	84	0.2
18.	Northern searobin	76	0.2
19.	Fourspot flounder	72	0.2
20.	Alewife	61	0.1
21.	Northern pipefish	47	0.1
22.	Cunner	45	0.1
23.	Grubby	36)	
24.	Sea raven	33)	
25.	Rock gunnel	26)	
26.	Planehead filefish	20)	
27.	Atlantic tomcod	19)	
28.	Blueback herring	12)	
29.	Tautog	10)	
30.	Summer flounder	8)	
31.	Black sea bass	7)	0.5
32.	Lumpfish	6)	
33.	American shad	5)	
	Atlantic menhaden	5)	
34.	Northern puffer	4)	
	Pollock	4)	
	Striped searobin	4)	
35.	Atlantic halibut	1)	
	Bluefish	1)	
	Lookdown	1)	
	Northern kingfish	1)	
		43,502	

(a) Not separated by species.

APPENDIX C

Table C. Species Inventory of Fish Collected in the Nine Mile Point Vicinity of Lake Ontario in 1973 through 1975 (from Niagara Mohawk Power Corporation, 1974, 1976).

Family	Scientific Name	Common Name	1973	1974	1975
Petromyzontidae	Petromyzon marinus	Sea lamprey	x	x	x
Lepisosteida	Lepisosteus osseus	Longnose gar	x	x	x
Anguillidae	Anguilla rostrata	American eel	x	x	x
Clupeidae	Alosa psuedoharengus	Alewife	x	x	x
	Dorosoma cepedianum	Gizzard shad	x	x	x
Salmonidae	Salmo gairdneri	Rainbow trout	o	x	x
	S. trutta	Brown trout	x	x	x
	Oncorhynchus kisutch	Coho salmon	o	x	x
	Oncorhynchus tshawytscha	Chinook salmon	x	x	x
	Coregonus artedii	Cisco or Lake herring	x	x	x
	Salvelinus namaycush	Lake trout	o	x	x
	Salvelinus fontinalis	Brook trout	o	o	x
	* S. namaycush fontinalis	Splake trout	o	o	x
Osmeridae	Osmerus mordax	Rainbow smelt	x	x	x
Esocidae	Esox americanus	Refin pickerel	o	x	x
	Esox lucius	Northern pike	x	x	x
Cyprinidae	Cyprinus carpio	Carp	x	x	x
	Notemigonus crysoleucas	Golden shiner	x	x	x
	Rhinichthys cataractae	Longnose dace	x	x	x
	Notropis atherinoides	Emerald shiner	x	x	x
	N. cornutus	Common shiner	x	x	o
	N. hudsonius	Spottail shiner	x	x	x
	Couesius plumbeus	Lake chub	x	x	x
	Carassius auratus	Goldfish	o	o	x
	Pimephales promelas	Fathead minnow	o	o	x
	Hybognathus nuchalis	Silvery minnow	o	o	x
	N. bifrenatus	Bridle shiner	o	o	x
Catostomidae	Catostomus commersoni	White sucker	x	x	x
	Hypentelium nigricans	Northern hogsucker	o	x	x
	Catostomus catostomus nannonyzon	Dwarf longnose sucker	o	o	x
	Erimyzon sucetta	Lake chubsucker	o	o	x
Ictaluridae	Ictalurus melas	Black bullhead	x	o	o
	I. nebulosus	Brown bullhead	x	x	x
	I. punctatus	Channel catfish	o	x	x
	Noturus flavus	Stonecat	x	x	x
	N. gyrinus	Tadpole madtom	o	o	x
Percopsidae	Percopsis omiscomaycus	Trout perch	x	x	x
Gadidae	Lota lota	Burbot	x	x	x
Atherinidae	Labidesthes sicculus	Brook silverside	o	x	o

Table C. (continued)

Cyprinodontidae	Fundulus diaphanus	Banded killifish	x	o	x
Gasterosteidae	Gasterosteus aculeatus	Threespine stickleback	x	x	x
	Culaea inconstans	Brook stickleback	o	o	x
Cottidae	Cottus bairdii	Mottled sculpin	x	x	x
Percichthyidae	Morone americana	White perch	x	x	x
	M. chrysops	White bass	x	x	x
	M. mississippiensis	Yellow bass	x	x	o
Centrarchidae	Ambloplites rupestris	Rock bass	x	x	x
	Lepomis gibbosus	Pumpkinseed	x	x	x
	L. macrochirus	Bluegill sunfish	x	o	x
	Micropterus dolomieui	Smallmouth bass	x	x	x
	Promoxis nigromaculatus	Black crappie	x	x	x
	M. salmoides	Largemouth bass	o	o	x
Percidae	Etheostoma nigrum	Johnny darter	x	x	x
	Perca flavescens	Yellow perch	x	x	x
	Stizostedion vitreum	Walleye	x	x	x
	Percina caprodes	Logperch			x
Sciaenidae	Aplodinotus grunniens	Freshwater drum	x	x	x
Amiidae	Amia calva	Bowfin	o	x	x

* Splake is a hybrid form; not a true species.
x Collected
o Not collected

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16. ABSTRACT (200 words or less)

Catch-per-unit-effort (CPUE) indices have been used as a fisheries management tool and in monitoring programs at nuclear power plants. An examination of CPUE techniques was conducted with the purpose of developing guidelines for evaluating monitoring programs and interpreting the resulting information. Data bases were selected for analysis from power plant monitoring programs which: (1) had an extensive data base; (2) made use of several fish sampling methods; and (3) had monitoring designs which incorporated replicate samples. At riverine sites, the emphasis centered on applied biological and field sampling; quantitative aspects were evaluated with graphics and coefficients of variation. At the remaining sites, emphasis was placed on statistics and a posteriori sampling designs and hypotheses. Data analyzed from selected programs do not provide evidence to support basic assumptions of CPUE such as proportionality of CPUE to population abundance, sufficiency of CPUE to detect changes of reasonable magnitude, and capability to assess power plant-induced change through CPUE measurement. The findings indicate that CPUE indices cannot be relied on as the sole bases for assessing population changes. Future approaches should be based on a realistic framework that integrates qualitative and quantitative components and recognizes the shortcomings of CPUE as a monitoring tool.

17. KEY WORDS AND DOCUMENT ANALYSIS

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