Canadian Technical Report of

Fisheries and Aquatic Sciences 2580

2005

EVALUATION OF ALTERNATE ANALYTICAL PROCEDURES AND VARIANCE COMPONENTS FOR STRAIT OF GEORGIA CREEL CENSUS CATCH AND EFFORT DATA

by

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Cat. No. Fs 97-6/2580E ISSN 0706-6457

Correct citation for this publication:

Korman, J., Nagtegaal, D.A., and Hein, K. 2005. Evaluation of alternate analytical procedures and variance components for Strait of Georgia creel census catch and effort data. Can. Tech. Rep. Fish. Aquat. Sci. 2580: 54p.

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A representative creel survey for the Strait of Georgia (SOG), extending from Victoria to Campbell River, has been conducted since 1980 and provides statistics on catch and effort based on data from angler interviews and aerial overflights. A number of improvements to the sampling design and analytical procedures have been suggested over time. These include more explicit specification of the error structure in Catch-Per-Effort (CPE) and effort statistics, improvements to methods used to estimate effort, and characterization of potential biases and variance components in catch and effort data.

In this analysis, we compare the utility of negative binomial, poisson, and normal probability models to describe the error structure in the SOG CPE data. The analysis is repeated across a large number of strata to provide robust conclusions concerning the error structure of these data. We compare the within-day variation in CPE data with the across-day variation within a month to comment on the allocation of interview effort within strata. We use a Monte Carlo analysis to define the relationship between variance in the average CPE within strata and interview sampling effort. We evaluate the utility of estimating the activity proportion at the time of the overflight by fitting a beta distribution model to all activity data within a stratum to account for the temporal dependence among observations. We compare the variance estimates derived from this approach (beta-method) with those estimated by using only the activity proportion at the time of the overflight (point-method). We also compare the variance associated with the activity proportion to variance in the average boat count from aerial overflights. We compare daily activity patterns across statistical areas and over time to evaluate the possibility of using activity patterns from adequately sampled strata to increase the precision for poorly sampled strata within a Bayesian framework. Finally, we examine temporal trends in the proportion of angling effort targeted at salmon to evaluate the possibility of revising the current trip-based method for quantifying effort.

A total of 560 strata had over 10 interviews over and were included in our CPE meta-analysis dataset. The mean catch/trip and coefficient of variation (CV) was 0.25 and 3.0 for chinook and 1.1 and 2.2 for coho, respectively. The average variance-to-mean ratio was 1.5 for Chinook and 2.7 for coho. The variance-to-mean ratio was almost always above 1 for both coho (86% of strata) and chinook (97%). Variance-to-mean ratios exceeding 2 were relatively rare for Chinook (16%) but were quite common for coho (66%). These variance-to-mean statistics warrant the application of the negative binomial distribution for both species, but especially coho. The negative binomial distribution provided the best fit to the CPE data based on a goodness-of-fit statistics, but, in general, had little effect on confidence limits except when sample size was small or the variance-to-mean ratio was very high.

Within-day variation in catch/trip was much higher than the across-day variation in mean catch rates over a month. The average ratio of within- to across-day variation in catch/trip was 6.0 for chinook and 3.3 for coho. 11% and 17% of the strata had within- to across-day variation ratios less than 1 for coho and chinook, respectively. This suggests there is no need to reallocate sampling effort to conduct fewer interviews per day over more days in a month.

As expected from the negative binomial model, the simulation analysis demonstrated that precision of CPE was affected by both average catch rate and the variance-to-mean ratio. Increasing the number of interviews reduced variance in the average catch/trip estimate with the majority of variance reduction accomplished with 30-40 interviews. There was almost no reduction in variance at sample sizes > 80 interviews. Obtaining hundreds of interviews for strata that contain large and busy landing sites therefore provides little if any improvement in precision in catch and effort estimates.. There are, however, bio-sampling objectives that will require minimum levels of interview effort to collect the desired biological data.

The beta distribution model had sufficient flexibility to capture the variety of activity profiles seen across strata. The benefits of using the beta-method for predicting the proportion of daily fishing effort at the time of the overflight relative to the point-method were highly variable and depended on a number of factors including sample size, the absolute values of maximum likelihood estimates of the activity proportion, and the extent of variation in daily boat counts. In general, the beta-method only provided significant reductions in uncertainty in the active daily proportion of fishing effort when both sample size and the activity proportion were low. There were a substantial number of strata in the meta-dataset with low sample size or low activity proportions, however the occurrence where both of these conditions occurred in the same strata was less common. Out of 712 strata used in this analysis, 134 or 19% had samples sizes less than 30 and MLE activity proportions of 0.3 or less and the beta-method substantially improved estimates of the activity proportion for these cases. There did not appear to be enough consistency in inter-annual patterns in activity profiles to use information from other years in a Bayesian framework to improve precision for poorly sampled strata. The coefficient of variation associated with the average daily boat counts were generally much larger than that associated with the activity proportion. CV of boat counts in our meta-dataset averaged 67% compared to 30% for the activity proportion. Approximately 60% of the strata in the dataset had CV's for activity proportion that were less than ½ the value of the boat CV's. This implies that the most effect way of reducing the total variance in effort statistics will be to increase the number of aerial overflights or collect additional counts from other sources.

The proportion of effort targeted at salmon generally showed slight to moderate declines from the late 1990's to the present in a limited number of statistical areas. In some of the more important statistical areas such as 13 and 28, there was little evidence of a change in the proportion of effort targeted at salmon during the summer when the majority of catch is obtained. It is unclear whether incorporating species or salmon-specific effort proportions would provide a more accurate assessment of the total effort.

RESUME

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Depuis 1980, une étude de la pêche sportive dans le détroit de Georgia, qui s'étend de Victoria à Campbell River, fournit des données de captures et d'effort de pêche estimées à partir des données d'entrevues auprès des pêcheurs à la ligne et de relevés aériens. Un certain nombre d'améliorations au modèle d'échantillonnage et aux procédures d'analyse ont été proposées au fil du temps, notamment une caractérisation plus explicite de la structure d'erreur dans les statistiques d'effort et de captures par unité d'effort, l'amélioration des méthodes utilisées pour estimer l'effort et la caractérisation des composantes de biais et de variance possibles dans les données sur les captures et l'effort de pêche.

Dans cette analyse, nous comparons l'utilité de différents types de modèles de probabilité (distributions binomiale négative, de Poisson et normale) pour décrire la structure d'erreur dans les données de captures par unité d'effort dans le détroit de Georgia. L'analyse est répétée pour un grand nombre de strates afin de tirer des conclusions solides à propos de cette structure d'erreur. Nous comparons la variation des données sur les captures par unité d'effort au cours d'une même journée à la variation d'une journée à l'autre au cours d'une période d'un mois afin de formuler des commentaires sur la répartition de l'effort d'enquête entre les strates. Nous employons une analyse de Monte Carlo pour définir la relation entre la variance de la moyenne des captures par unité d'effort à l'intérieur de chaque strate et l'effort d'enquête. Nous évaluons l'utilité de l'estimation du taux d'activité au moment du relevé aérien en ajustant un modèle de distribution bêta à toutes les données d'activité dans une strate afin de tenir compte de la dépendance temporelle des données. Nous comparons les estimations de la variance effectuées à l'aide du modèle de distribution bêta avec les estimations effectuées uniquement à partir du taux d'activité au moment du relevé aérien (méthode par point). Nous comparons également la variance liée au taux d'activité à la variance du nombre moyen de bateaux, observés par les relevés aériens. Nous comparons les profils d'activité quotidiens dans l'ensemble des secteurs statistiques et au fil du temps afin d'évaluer la possibilité d'utiliser les profils d'activité dans les strates échantillonnées de façon adéquate pour accroître la précision des données pour les strates moins bien échantillonnées dans un cadre bayesien. Finalement, nous examinons les tendances au fil du temps de la proportion de l'effort de pêche à la ligne consacrée au saumon afin d'évaluer la possibilité d'améliorer la méthode actuelle de quantification de l'effort fondée sur les sorties de pêche.

Au total, plus de 10 entrevues ont été menées dans 560 strates, et les données recueillies ont été intégrées dans notre jeu de métadonnées de captures par unité d'effort. Le nombre moyen de captures par sortie et son coefficient de variation (CV) étaient respectivement de 0,25 et 3,0 pour le saumon quinnat et de 1,1 et 2,2 pour le saumon coho. Le rapport moyen entre la variance et la moyenne était de 1,5 pour le saumon quinnat et de 2,7 pour le saumon coho. Le rapport entre la variance et la moyenne était presque toujours supérieur à 1 pour le saumon coho (86 % des strates) et le saumon quinnat (97 % des strates). Des rapports supérieurs à 2,0 étaient relativement rares pour le saumon quinnat (16 %), mais assez fréquents pour le saumon coho (66 %). Ces valeurs justifient l'utilisation de la distribution binomiale négative pour les deux espèces, particulièrement pour le saumon coho. La distribution binomiale négative est celle qui correspond le mieux aux données de captures par unité d'effort, d'après des données sur la qualité de l'ajustement. En général, cette distribution avait cependant peut d'effet sur les limites de confiance, sauf lorsque la taille des échantillons était petite ou lorsque le rapport entre la variance et la moyenne était très élevé.

Le nombre de captures par sortie variait beaucoup plus au cours d'une même journée que d'une journée à l'autre sur une période d'un mois. Le rapport moyen entre la variation du nombre de captures par sortie au cours d'une même journée et la variation d'une journée à l'autre était de 6,0 pour le saumon quinnat et de 3,3 pour le saumon coho. Le rapport des variations était inférieur à 1 pour le saumon coho et le saumon quinnat dans, respectivement, 11 % et 17 % des strates. Ces résultats suggèrent qu'il est inutile de répartir l'effort d'échantillonnage différemment de manière à réaliser moins d'entrevues par jour, mais durant plus de jours par mois.

Comme le modèle de distribution binomiale négative permettait de le prévoir, l'analyse de simulation a montré que la précision des données de captures par unité d'effort varie selon le taux de capture moyen et le rapport entre la variance et la moyenne. Une hausse du nombre d'entrevues entraîne une réduction de la variance de l'estimation du nombre moyen de captures par sortie, la plus grande réduction de la variance étant obtenue pour 30 à 40 entrevues. Lorsque le nombre d'entrevues dépasse 80, la variance ne diminue presque plus. Ainsi, la tenue de centaines d'entrevues pour les strates qui contiennent d'importants sites de débarquements achalandés permet, au mieux, d'améliorer très légèrement la précision des estimations des captures et de l'effort. Il existe cependant des objectifs d'échantillonnage biologique qui, pour être atteints, nécessitent relativement peu d'entrevues pour recueillir les données biologiques souhaitées.

Le modèle de distribution bêta était suffisamment souple pour rendre compte de la gamme de profils d'activité observés dans les strates. Les avantages liés à l'utilisation de cette méthode (plutôt que la méthode par point) pour prévoir la proportion de l'effort de pêche quotidien au moment du relevé aérien étaient très variables et dépendaient d'un certain nombre de facteurs, y compris la taille des échantillons, les valeurs absolues des estimations de vraisemblance maximale du taux d'activité et l'ampleur de la variation du nombre quotidien de bateaux. En général, la méthode de distribution bêta a permis de réduire de façon importante l'incertitude relative au taux d'effort de pêche quotidien seulement lorsque la taille de l'échantillon était petite et que le taux d'activité était faible. La taille des échantillons était petite ou le taux d'activité était faible dans un nombre important des strates, mais la présence de ces deux conditions dans la même strate était moins fréquente. Dans 134 des 712 strates utilisées dans cette analyse (19 %), la taille de l'échantillon était inférieure à 30, les estimations de vraisemblance maximale du taux d'activité étaient inférieures ou égales à 0,3, et la méthode de distribution bêta améliorait considérablement les estimations du taux d'activité. L'uniformité des tendances d'une année à l'autre dans les profils d'activité semblait insuffisante pour rendre possible l'utilisation des données d'autres années dans un cadre bayesien afin d'améliorer la précision des données pour les strates où l'échantillon était de taille insuffisante. Le CV du nombre quotidien moyen de bateaux était généralement beaucoup plus élevé que celui du taux d'activité : le CV du nombre de bateaux se chiffrait en moyenne à 67 %, comparativement à 30 % pour le CV du taux d'activité. Le CV du taux d'activité était inférieur à 50 % du CV du nombre de bateaux pour environ 60 % des strates dans le jeu de données. Par conséquent, la façon la plus efficace de réduire la variance totale des données d'effort de pêche sera d'augmenter le nombre de relevés aériens ou de recueillir des données de dénombrement d'autres sources.

De manière générale, depuis la fin des années 1990, la proportion de l'effort consacrée au saumon a connu des baisses faibles à modérées dans un nombre limité de secteurs statistiques. Dans certains des secteurs statistiques les plus importants (p. ex. les secteurs 13 et 28), rien n'indique un changement de la proportion de l'effort consacrée au saumon au cours de l'été, période où la plupart des captures sont effectuées. Il n'est pas clair que l'analyse des proportions de l'effort pour chaque espèce permettrait d'évaluer avec plus d'exactitude l'effort total.

1.0 Introduction

The Strait of Georgia (SOG) sport fishery is one of the most valuable recreational fisheries in British Columbia. A representative creel survey of the Strait, extending from Victoria to Campbell River, has been conducted since 1980. The creel survey provides statistics on catch and effort based on data from angler interviews and aerial overflights. The angler interviews provide information on Catch-Per-Effort (CPE) and daily activity patterns. The overflights provide estimates of total sport fishing effort (boat counts) in an area at the time the airplane passes through it. These data are combined to provide monthly estimates of total sport fishing effort, CPE, and total catch and releases of salmon and groundfish in the sport fishery (Hardie et al. 2002).

The analysis of catch and effort data from the SOG creel program is stratified across time (year, month, and weekend or weekday day type) and space (DFO creel sub-area). Within any stratum, the average catch/trip is computed from the total number of interviews. The activity profile obtained from the interview data, that is, the proportion of the total trips fishing during 1-hr. time blocks over the day, is used to expand the average number of boats from the overflights to a daily count. Formulas for computing the average and variance of catch and effort statistics are provided in Hardie et al. (2002).

A number of improvements and modifications to the analytical procedures for SOG creel data have been suggested since the inception of the program. In 1986, an initial review of the creel survey design was conducted on the 1980-83 creel data (English et al. 1986) and a summary of existing statistics to evaluate recent changes in sport fishery regulations was completed. A Georgia Strait creel survey workshop was held in 2000 and an external survey design and methods review was conducted (Sturhahn and Nagtegaal 2001). The workshop recommended that a framework be developed for establishing acceptable levels of precision and a review of the analytical process for generating catch estimates. A further review was completed (English et al. 2002) documenting a new approach to generating catch estimates that was much more robust to changes in fishing patterns and the distribution of survey effort.

The second part to the initial recommendation from the workshop in 2000 was to address aspects associated with estimation of effort and uncertainty in catch and effort estimates. In particular, further review needed to include more explicit specification of the error structure in CPE and effort statistics, improvements to methods used to estimate effort, and characterization of potential biases and variance components in catch and effort data. The intent of this paper is to summarize the analysis and outcomes of the review of these current issues.

Catch data are typically highly skewed with many occurrences of zero catch and few occurrences of very large catches. While the average catch/trip and its variance within a stratum are independent of the assumed error structure, computation of confidence bounds and other parameter of interest to managers (e.g. bag limits) are not. Assuming the data follow a normal distribution when they don't could lead to severe biases in these parameters. Precision objectives for the SOG creel survey are based on meeting target confidence levels (e.g. 95% confidence intervals of +/- 5% or 20%) and are therefore subject to errors associated with incorrect assumptions about error structure. In an assessment of the effects of changes in sampling intensity on precision of catch estimates, English et al. (2002) assumed that CPE data followed a normal distribution. English et al. (1986) found that CPE data could be well described by a negative binomial distribution, however their analysis was only applied to a limited number of strata and they did not attempt to fit alternate probability distributions to the data. In this analysis, we compare the utility of negative binomial, poisson, and normal probability models to describe the error structure in the SOG CPE data. The analysis is repeated across a large number of strata to provide robust conclusions concerning the error structure and range of parameters. With a reliable estimate of the form and parameters of the error structure in CPE data, we then use a Monte Carlo analysis to define the relationship between variance in CPE (within-strata) and sampling effort (number of interviews).

The distribution of interview effort among- and within-strata determine the precision of catch and effort estimates. The optimal allocation will depend on how catch and effort are distributed over time and space and the variance components of these statistics. English et al. (1986) used a Monte Carlo approach to understand the relative contributions of activity proportion, CPE, overflight boat counts, and the timing of boat counts on the total error in catch statistics within a stratum. They also examined factors affecting the allocation of effort among strata. One component not addressed in their analysis was a comparison of variation in CPE from interviews collected within a day with the variation in daily average CPE across days within a month. If across-day variation is a larger variance component compared to within-day variation, more reliable catch statistics would be obtained by conducting fewer interviews per day spread out over more days within a month, rather than collecting many interviews per day over a more limited number of days as is currently done in some areas. In this analysis we compare these two sources of variation.

Accounting for the temporal structure in the daily activity profile would likely reduce error in the estimate of total effort within a stratum. Currently, the average proportion of the interviewees that were actively fishing during one of 16 time blocks when the overflights occurred is used to expand the average overflight boat count. The flaw in this approach is that it ignores information from adjacent time blocks on the likely activity proportion during the overflight. Due to typical daily wind and human activity patterns, it is very likely that the distribution of effort over the course of a day has a pattern to it (e.g. Fig. 12 of English et al. 1986; Appendix C of English et al. 2002). The activity proportion in one time block will therefore be correlated with those in adjacent blocks. By assuming independence among these observations, the current methodology is statistically inefficient and results in higher variance in effort estimates. In this analysis, we evaluate the utility of estimating the activity proportion at the time of the overflight by fitting a temporal model to all activity observations within a stratum. We compare the variance estimates derived from this approach with those estimated by using only the activity proportion at the time of the overflight. Precisions gains in the estimate of the activity proportion during the overflight will not necessarily translate into increased precision in effort if the error in boat counts overwhelms the error in the activity proportion. We therefore compare the variance associated with the activity proportion with the variance in boat counts from overflights and use a maximum likelihood method to combine the error from both sources to estimate the precision in effort.

The effort term of CPE statistics generated from SOG creel data is simply the number of boat trips within a stratum. Effort statistics do not incorporate more detailed information such as number of lines, gear type, or the amount of effort targeted at different species groups (e.g. salmon vs. groundfish) that is collected during the interviews. Historical decreases in salmon abundance in the SOG and more restrictive sport fishing regulations (e.g. 1998 non-retention of coho and creation of no-fishing red zones) could have potentially reduced the proportion of effort targeted at salmon or particular salmon species. A shift in effort away from salmon would result in CPE estimates from more recent years being biased low relative to estimates from earlier years. This would occur if one argues that effort is now being overestimated because it is quantified as the number of boat trips, rather than the number of hours targeted at salmon or particular salmon species. In this analysis, we examine temporal trends in the proportion of effort targeted at particular species and species groups to determine the significance of this issue.

2.0 Methods

2.1 Catch-Per-Effort

The DFO creel survey database (Hein et al. 2002) was queried to provide all interview records from statistical sub-areas in the SOG for the period 1992-2001. The majority of catch and fishing effort occurs during the spring and summer so we only used interviews collected between April and September. Due to a decline in sampling effort over the 1990's, the earliest years in the database provide the most robust set for defining the correct error structure. Mean catch rates of salmon declined substantially in the mid to late 1990's, however there were still many strata in the early 1990's where the majority of trips had zero catch, an important characteristic for defining the appropriate error structure. Based on these considerations, we only used data from 1992-1993 for the analysis of CPE data.

2.1.1Evaluation of Error Structure

The frequency in number of coho and chinook retained for groups stratified by year, month, day type (weekend or weekday), and creel sub-area was calculated. Strata with less than 10 interviews were excluded from the analysis. Poisson, negative binomial (NB), and normal error models were fit to the frequency data by computing the mean (m) and variance (σ^2) of the data from each stratum.

The normal model,

(1) $$P(x) = \frac{1}{\sqrt{2\pi}} \exp(\frac{-(x-m)^2}{2\sigma^2})$$

predicts the probability of a catching x fish ($p(x)$) given a mean catch rate m and variance σ^2.

The poisson model,

(2) $$P(x) = \frac{\exp(-m)m^x}{m!}$$

predicts the probability of catching x fish given a mean catch rate of m. Note for the poisson model the variance-to-mean ratio must equal 1 as σ is assumed to equal m. If the data are truly poisson-distributed, the poisson model is statistically more efficient than the normal model as only one parameter needs to be estimated.

The negative binomial model,

(3) $$P(x) = \frac{\Gamma(k+x)}{\Gamma(k)x!}\left(\frac{k}{k+m}\right)^k\left(\frac{m}{m+k}\right)^x$$

predicts the probability of catching x fish given a mean catch rate m and overdispersion parameter k. The overdispersion parameter was estimated from the data using the method of moments (Hilborn and Mangel 1997) where,

(4) $$k = \frac{m^2}{\sigma^2 - m}$$

From eqn. 4 we can see that k will be negative if the mean exceeds the variances yet k must greater than zero (eqn. 3). The variance must therefore exceed the mean for a negative binomial distribution to apply. A small value of k is indicative of the variance greatly exceeding the mean (i.e., a large variance-to-mean ratio) resulting in a long right-hand tail to the distribution. Also note that as $\sigma^2 \rightarrow m$, $k \rightarrow \infty$ and the negative binomial distribution is approximated by the poisson. When applying the negative binomial model to the CPE data, k was set to a very large value in cases where $\sigma^2 < m$.

Confidence limits for the poisson, negative binomial, and normal distributions were computed using the likelihood ratio test or G-test method (Sokal and Rolf 1981). The log-likelihood for each error model was derived. For any strata, we cycled through a range of possible catch rates (retained fish per trip) and summed the log-likelihood values across all interviews for each rate. Two times the difference between this sum and the sum of likelihood's based on the most likely estimate (MLE) of the mean catch rate (m), termed the G-statistic, was computed. Statistical theory shows that the G-statistic is Chi-Square distributed with 1 degree of freedom ($\chi^2_{\alpha[1]}$). The probability of the G-statistics for each catch rate being evaluated was determined from the Chi-Square distribution. Linear interpolation was used to estimate the catch rates that corresponded to a probability of 0.8 (Type I error rate $\alpha = 0.2$). Note that for the normal error model, confidence limits were computed from,

(5) $$CL_{\alpha} = m \pm t_{\alpha[n-1]} \sigma$$

where $t_{\alpha[n-1]}$ is the value of the t-distribution at α and n-1, with n being the sample size. We verified that the confidence limits derived by the normal likelihood profiling method matched those derived from eqn. 5.

We evaluated the goodness-of-fit of the normal, poisson, and negative binomial distributions to the CPE data using a single classification G-test (Box 17.2, Sokal and Rolf 1982),

(6) $$G = 2\sum_{i=1}^{a} n_i \ln(\frac{n_i}{\hat{n}_i})$$

where n_i is the observed number of interviews where i fish were caught, $\hat{n}_i$ is the predicted number of interviews by the distribution, and a is the number of categories of i fish being evaluated. G is chi-squared distributed with a-2 degrees of freedom for the poisson model and a-3 degrees of freedom for the negative binomial and normal models. Note that with increasing goodness-of-fit for any catch category, $n_i \rightarrow \hat{n}_i$ and $G \rightarrow 0$. In such cases G will likely be less than $\chi^2_{\alpha[DF]}$, and the null hypothesis, that the distribution is normally-, poisson-, or negative binomially-distributed, is accepted at a probability of 1 - α.

The utility of the single classification G-test to determine the best error model for the CPE data was somewhat limited. In many cases we observed that none of the error models were statistically accepted even though, based on a visual inspection of the data, one model often provided a much better fit relative to the other two. An averaged goodness-of-fit statistic,

$$MG = \frac{\sum_{i=1}^{a} n_i \ln(\frac{n_i}{\hat{n}_i})}{a} \tag{7}$$

was used to index model fit. This statistic is similar to the G-statistic of eqn. 6 but is comparable across strata as it is standardized by the number of catch categories a.

2.1.2 Determination of Effects of Interview Sample Size on Estimation of CPE

A Monte Carlo analysis was used to evaluate the effect of interview sample size on the precision of average CPE estimates within a stratum. The rejection method (Press et al. 1982) was used to simulate the number of fish caught per trip across a pre-determined number of interviews assuming a negative binomial distribution. 100 trials were conducted for samples size ranging from 5 to 100 interviews under alternate assumptions about the mean and variation in catch/trip (m and k in eqn.. 3). The parameters were selected to represent the range in these statistics seen in the coho and chinook data based on the meta-analysis described in Section 2.1.1. Plots of the coefficient of variation as a function of interview sample size were used to describe the trade-off between precision and sampling intensity.

2.1.3 Variance Components of CPE Data

We compared the within-day variation in catch rates to the across-day variation. Such a comparison is of interest for allocating sampling effort in the SOG creel survey. High across-day variation would indicate that it is important to collect interviews on as many days as possible to minimize the overall variance. In contrast, if the overall variance is dominated by within-day variability, collection of many interviews over a few days per month would capture the majority of variation and likely be more cost-effective. The data used in the analysis of section 2.1.1 were pooled across day type and then stratified by interview date. For each date, we computed the mean and variance in catch rates. The variance in the mean daily catch rates within a year-month-sub-area strata were computed and termed the across-day variation. The average of the within-day variation in catch rates over all interviews in a stratum were also computed and termed the within-day variation. Frequency distributions of the ratio of the within-day variation to across-day variation in catch rates were used to quantify the components of variation for chinook and coho. Strata with less than 10 separate interview dates per month were excluded from the analysis as estimates of the across-day variance for such cases would be unreliable.

2.2 Error in Effort Statistics

In the current SOG creel methodology, total fishing effort within a strata is computed based on,

(8)
$$E = \frac{\overline{B}}{P_t} Ndays$$

where, E is effort in boat-days, $\overline{B}$ is the mean boat count for the strata based on a series of overflights, P_t is the proportion of the daily fishing effort active during the time block of the aerial survey, t, and $Ndays$ is the number of days in the month for the day type (weekday or weekend). As an alternate approach to estimate the active proportion of fishing effort at the time of the overflight, the beta distribution,

(9)
$$B_t \propto \int_0^t \theta_t^{(\alpha-1)} (1-\theta_t)^{(\beta-1)} dt$$

was used to generate a number between 0 and 1 for each particular time block t (B_t) based on parameters α and β, and the independent variable θ_t, which is the relative time associated with each time block (e.g. 1/16 for time block 1 and 16/16 for time block 16). The product of two independent Beta functions and a scalar (S),

(10)
$$P_t = S * B_{1,t} * B_{2,t}$$

was used to predict P_t, the active proportion of the daily effort for each time block t. The time block associated with the aerial overflight for each strata was used to determine which P_t value to use in eqn. 8 to compute total fishing effort.

The five parameters of the activity profile model (S, 2 α's and 2 β's) were fit to the 16 observations of the active proportion of fishing effort for each time block from the interview data assuming a binomial error structure,

(11)
$$P(P_t = q_t) = \left(\frac{N}{k_t^1} \right) q_t^{k} * (1-q_t)^{N-k_t^1}$$

where $P(P_t{=}q_t)$ is the probability that the active proportion of fishing effort during time block t is q_t, N is the total number of interviews of fisherman collected for the strata, and k_t^1 is the number of interviews where fishing occurred during time block t. The binomial error model is applicable to samples of any size from populations in which objects occur independently in only two classes (i.e., fishing or not fishing during time block t). For the binomial model note that the expected value for any P_t is simply $q_t N$ and the relative variance, CV, is $\frac{\sqrt{1-q_t}}{Nq}$. Thus the relative variation will decrease with increases in sample size or increases in the proportion of boats fishing during the hour of the overflight.

Using a function to model the 16 P_t values over a day has the implicit assumption that values among time blocks are not independent. The best-fit, or maximum likelihood estimate (MLE) activity profile was determined by minimizing the sum of the negative log-likelihood of eqn. 11 across all 16 time blocks using an iterative non-linear search procedure (Solver.dll in MS Excel). MLE daily activity patterns were compared among sub-areas within a year, and across years within sub-areas. The analysis was conducted to determine whether information from adjacent years or sub-areas could be used to increase precision in years or sub-areas with inadequate sample size within a Bayesian framework.

Confidence limits on the active proportion at the time of the overflight for each strata were determined using the *G*-test likelihood profile method. P_t was varied from 0 to 1 in even increments. Eqn. 10 was rearranged so that the scalar S was predicted based on the parameters of the beta distributions and current value of P_t being evaluated. A non-linear search procedure was used to find parameters of the beta distributions that provided the best fit to the current value of P_t being evaluated. Two times the difference between the negative log-likelihood of this value and the negative log-likelihood associated with the best-fit activity profile model was used to determine the probability associated with P_t using a Chi Square distribution with one degree of freedom. P_t MLE values and confidence limits derived by this approach are hereafter referred to as 'beta-estimates'.

The binomial error model was also used to derive confidence limits for the active proportion of the fishing effort at the time of the overflight assuming complete independence in activity proportions over time. In this situation, only the time block at the time of the overflight was considered. The activity proportion for this time block was varied systematically from 0 to 1 and the negative log-likelihood of each value given N and k_t^1 was determined. The *G*-test method was used to compute the probability associated with each value of P_t. MLE values and confidence limits derived by this approach are hereafter referred to as 'point-estimates'. Note that these MLE and variance estimates are consistent with the ones used in the current SOG creel analysis.

The uncertainty in total fishing effort for each strata was computed based on the product of the probability profiles for the activity proportions and probability profiles of the mean boat count. The latter profiles were determined assuming a normal error structure (eqn. 5). There were not a sufficient number of overflights per strata to evaluate alternate error models. The analysis was performed on individual strata defined by year, month, and, day type. Strata for winter months (October through March) and with less than 10 interviews were excluded from the analysis. We examined results for 1992, 1994, and 1996 to ensure we captured the full range of fishing effort and sampling intensity.

Inter-annual trends in the proportion of fishing effort within trips targeted at salmon (all species), groundfish (halibut, ling cod, rockfish) were plotted by statistical area and month. The objective of this analysis was to evaluate whether the amount of effort targeting salmon, and specifically coho, and chinook, has changed over time in response to reduced salmon abundance and increasingly restrictive regulations. Large shifts in targeted effort would warrant the use of an effort statistic that accounts for species or species-group targeted effort within a trip.

3.0 Results

3.1 Catch-Per-Effort

3.1.1 Error Structure of CPE Data

A total of 560 strata had over 10 interviews over and were included in our CPE meta-analysis. A large number of strata that were excluded from the analysis (Table 1). Example frequency distributions for best-fit poisson, negative binomial, and normal error models for two of the 560 strata (Fig. 1) show some of the common characteristics seen across the full dataset: a large number of zero-catch occurrences; superior fit of the negative binomial model; and narrower confidence limits associated with the poisson model. For sub-area 13A none of the probability models provided a statistically reliable fit to the data at a Type I error level of α=0.2 although the negative binomial model provided the best fit (Table 2). The effect of the 8 fish coho limit was very apparent. For sub-area 17E, only the negative binomial model provided a statistically significant fit. Variance-to-mean ratios for both sub-areas were ca. 3 and explain why the negative binomial model provided the best fit to the data in both cases. The average catch rate for sub-area 13A was very well determined (ratio of the upper confidence limit to the mean ca. 1) and there was more uncertainty in the catch rate for 17E, especially under the negative binomial model. When the average catch rate was high, the percentage of the catch distribution > 2 fish was sensitive to the error model selected (e.g. 13A). However when the average catch was low, differences in this statistic among error models were very small (e.g. 17E).

A comparison of mean and variance statistics derived from the 560 strata for coho and chinook catches show much higher catches and reduced relative variation for coho (Fig. 2). The mean catch/trip and coefficient of variation in catch/trip for was 0.25 and 3.0 for chinook and 1.1 and 2.2 for coho, respectively. The average variance-to-mean ratio was 1.5 for chinook and 2.7 for coho. The variance-to-mean ratio was almost always above 1 for both coho (86% of strata) and chinook (97%). Variance-to-mean ratios exceeding 2 were relatively rare for chinook (16%) but were quite common for coho (66%). These variance-to-mean statistics warrant the application of the negative binomial distribution for both species, but especially for coho. Examination of the frequency distribution of goodness-of-fit statistics (eqn. 7) confirms the applicability of the negative binomial distribution to these data (Fig. 3). Model fit was generally poorer for coho than for chinook. However, because of the higher variance-to-mean ratio for coho catch data, the relative performance of the negative binomial model compared to the other distributions was better. The poisson model outperformed the normal model but was still substantially worse than the negative binomial for chinook and especially for coho.

The negative binomial distribution provided the best fit to the CPE data but, in general, had little effect on the estimates of confidence limits. The poisson model had lowest upper confidence limits compared to the other models while the negative binomial model produced the highest limits (Fig. 4). The negative binomial model would also occasionally produce much larger upper confidence bounds in catch/trip relative to the other models in situations where sample size was small. The average ratio of the upper confidence limit to the mean for chinook was 1.5, 1.7, and 1.5 for poisson, negative binomial, and normal error models, respectively while the ratio for coho was 1.3, 1.5, and 1.2.

Imposition of more stringent bag limits, such as the 2 fish limit imposed for coho in 1994, has the potential to reduce harvest rates only if it effects a significant component of the angling population. The predicted percentage of interviews where more than two fish were caught in our meta-analysis dataset was very low because the average catch/trip was low. The assumed error model had little effect (Fig. 5). For chinook, the average percentages across the full dataset were 1.0, 2.0 and 1.8 for poisson, negative binomial, and normal error models, and 16.0, 14.6, and 18.3 for coho.

3.1.2 Interview Sample Size Effects on CPE Variation

Simulations used to represent CPE for chinook were based on an average catch/trip of 0.25 and a variance-to-mean ratio ranging from 1.25-3 based on statistics computed between April and September from 1992-1993 (Fig. 2). For coho, average catch and variance-to-mean ratios were simulated using values of 1 and 1.25-5, respectively. Precision of CPE was affected by both average catch rate and the variance-to-mean ratio. (Fig. 6). For example, the coefficient of variation (CV) dropped from 0.3 to 0.15 as the average catch/trip was increased from 0.25 to 1.0 assuming 40 interviews and a variance-to-mean ratio of 1.25. A slightly more than two-fold increase in the variance-to-mean ratio from 1.25 to 3 coupled with an average catch/trip of 0.25 resulted in an increase in CV from 0.3 to 0.5. Increasing the number of interviews reduced variance in the average catch/trip estimate with the majority of variance reduction accomplished with 30-40 interviews.

3.1.3 Variance Components of CPE Data

There were 213 strata where interviews were conducted on at least 10 separate days per month. This provided a sizeable dataset to compare the within-day variation in catch/trip with the across-day variation. Within-day variation in catch/trip was much higher than the across-day variation in mean catch rates over a month (Fig. 7). The average ratio of within- to across-day variation in catch/trip was 6.0 for chinook and 3.3 for coho. 11% and 17% of the strata had within- to across-day variation ratios less than 1 for coho and chinook, respectively.

3.2 Error in Effort Statistics

The beta distribution model had sufficient flexibility to capture the variety of activity profiles seen across strata (Fig. 8). These profiles were either uni- or bi-modal exhibiting early-morning, mid-day, and/or early-evening peaks depending on the sub-area, time of year, and day type. The benefits of using the beta-method for predicting the proportion of daily fishing effort at the time of the overflight relative to the point-method was highly variable and depended on a number of factors including sample size, the absolute values of maximum likelihood estimates of the activity proportion during the overflights, and the extent of variation in daily boat counts. When sample size was low the beta-method often provided a less-biased and more precise estimate of the activity proportion. For example, for strata 1992-6-0-16A (year-month-day type-sub-area) the activity proportion during the overflights was just over 0.2 with a total sample size of 42 interviews (Fig. 9). Note that in this case there were only nine interviews to represent the time block for the overflight. The beta-method provided a more robust estimate of the activity proportion at this time and had narrower confidence intervals relative to the activity proportion derived from the point-method. While the variability in the average boat count was reasonably high (CV=73%) compared to that associated with the activity proportion (26% for Beta-method, 30% for point-method), the reduced variance in the activity profile and higher MLE associated with the beta-method had a noticeable effect on the probability profile of total effort. This occurred because the point-method produced reasonable probabilities for very low activity proportions (e.g. a 20% probability of having an activity proportion of ca. 0.1) that caused large expansions of the average daily boat count and resulted in the long right-hand tail of the total effort probability profile. By using information from adjacent time blocks, the beta-method was able to reduce this uncertainty leading to a narrower probability profile for total effort.

Strata 1992-4-1-13A provided an interesting contrast to the result for 1992-6-0-16A (Fig. 10). Here the sample size (N=50) was similar to 1992-6-0-16A (N=42), but the activity proportion at the time of the overflight was much higher (0.52). This resulted in a more certain point-estimate of the activity proportion for 13A and smaller differences in the confidence limits based on point- and beta-methods. The effect of the differences in uncertainty in the activity proportion between the point- and beta-methods for 13A was not discernable on the total effort profile. This occurred because small absolute differences in the relative large activity proportion have little effect on total effort. For example, a change in the activity proportion from 0.1 to 0.2 (1992-6-0-16A) has a much bigger effect on total effort than a change from 0.4 to 0.6 (1992-4-1-13A).

Another common type of data situation we observed was a large interview sample size coupled with a low activity proportion at the time of the overflight (Fig. 11). MLE and probability profiles based on point- and beta-method were quite similar in these circumstances because the point-estimate of the activity proportion was well determined due to the large sample size (N=111, MLE=0.29, CV=0.16 for both methods). Uncertainty in the activity profile had little effect on the uncertainty in total effort, which was mostly determined by the large uncertainty in the average boat count (CV = 1.0).

In general, the beta-method only provided significant reductions in uncertainty in the active daily proportion of fishing effort when sample size and the activity proportion were low. There were a substantial number of strata in the meta-dataset with low sample size or low activity proportions (Fig. 12). However, the occurrence where both of these conditions occurred in the same strata was less common (Fig. 13). Out of 712 strata used in this analysis (1992, 1994, 1996, weekends and weekdays, April – September, N>10), 134 or 19% had samples sizes less than 30 and MLE activity proportions of 0.3 or less. The beta-method would substantially improve estimates of the activity proportion for these cases.

To assess the extent of the reduction in uncertainty associated with the beta-method we computed likelihood profiles for all 712 strata in our effort meta-dataset. We indexed uncertainty using the ratio of the 80% upper confidence limit to the maximum likelihood estimate of the activity proportion. A frequency distribution of this statistic (Fig. 14) showed that the beta-method had a higher proportion of strata where the ratio was very close to one (low uncertainty) and a lower proportion of cases where the ratio was very high (large uncertainty). While there were some noticeable differences between the beta- and point-distributions, the differences were not very large. This reflects the large number of strata with large sample sizes and/or high activity proportions at the time of the overflights.

The coefficient of variation associated with the average daily boat counts were generally much larger than that associated with the activity proportion (Fig. 15). CV of boat counts in our meta-dataset averaged 67% compared to 30% for the activity proportion. Approximately 60% of the strata in the dataset had CV's for activity proportion that were less than ½ the value of the boat CV's. It is likely that the larger variation associated with the average boat counts is the result of inadequate sample size given the true daily variation in effort or high measurement error. On average, only 3 overflights were conducted per strata in our meta-analysis, and for many strata, no overflights were conducted (Table 3).

Inter-annual differences in the daily activity pattern were highly variable among months and statistical areas (Fig. 16). There were some cases (e.g. 13A–weekend) where the activity profiles were very consistent from year-to-year in both spring and summer months. In other areas there was moderate year-to-year consistency in summer months only (e.g. 14C-weekday, 13A-weekday, 17E-weekday) and there were a few cases where inter-annual variation was high in all months (16B-weekend, 28A-weekend). In the five statistical sub-areas that we examined, the timing of overflights generally coincided with the peak or near-peak of the activity profile. The only exception to this was sub-area 14C that exhibited morning and evening peaks in effort but had mid-day overflights. In general, there was little correspondence in activity patterns among statistical sub-areas within a year, month and day-type (Fig. 17). If a similarity among sub-areas was observed in one time stratum, (e.g. 1992-April-weekday) it tended to not hold in other time strata.

The proportion of fishing effort targeting salmon and groundfish showed some evidence of an inter-annual trend, but the extent depended on location and month (Fig. 18). One common trend was a generally increasing amount of effort targeted at coho from the early- to mid-1990's, followed by an almost complete cessation of effort after 1998 when the non-retention regulation was implemented. It appears that effort targeted at chinook increased after 1998, likely in response to the coho regulation change. In general the decline in the amount of effort targeted at salmon (all species combined) has been small. Declining trends were observed for statistical areas 13 (April-June), 14 (April), 16 (April), and 17 (all months). In most of these cases the proportion of effort targeted at salmon dropped from approximately 80% to 60%. Increases in the proportion of effort targeted at groundfish were often observed in cases when effort targeted at salmon declined.

4.0 Conclusions

The negative binomial distribution was clearly the most appropriate probability model to represent the error structure of CPE data from the SOG creel survey. Use of a normal probability model to represent these data will result in an underestimate in the upper confidence limit of catch rates. The extent of this potential bias did not appear to be severe in most of the cases we examined. Underestimates in the upper confidence limit due to incorrect error structure were worst for strata with low sample sizes and high variance in CPE. Current precision estimates of SOG statistics still assume a normal distribution in CPE (e.g. English et al. 2002, Hardie et al. 2002). The analysis of English et al. (1986) identified that negative binomial model was the more appropriate distribution for CPE data. Their analysis was limited by the fact that they did not test alternate distributions using a large number of strata and did not provide an analytical method to use the negative binomial distribution to compute confidence limits. This analysis has addressed these deficiencies and therefore we recommend that the negative binomial distribution replace the current use of a normal probability model to describe the error associated with CPE data.

Within-day variation in CPE was considerably higher than across-day variation within a month. This suggests there is no need to reallocate sampling effort to conduct fewer interviews per day over more days in a month. Monte Carlo simulations based on a negative binomial error structure were used to describe the relationship between variation in average CPE estimates and interview sample size. Increasing the number of interviews reduced variance in average catch/trip estimates with the majority of variance reduction occurring at a sample size of 30-40 interviews. Very little reduction in variance occurred at sample sizes > 80 interviews. Based on this result, the benefit of obtaining hundreds of interviews for intensively sampled sub-areas is likely of marginal value for improving catch estimates. There are, however, bio-sampling objectives that will require minimum levels of interview effort to collect the desired biological data.

In general, the beta-method only provided significant reductions in uncertainty in the active daily proportion of fishing effort when both sample size and the activity proportion at the time of the overflight were low. About 20% of 720 strata from our dataset had samples sizes less than 30 and MLE activity proportions of 0.3 or less. The beta-method would substantially improve estimates of the activity proportion for these cases. CV of boat counts in our meta-dataset was two-fold higher than the CV for the activity proportion. This implies that the most effective way of reducing the total variance in effort statistics will be to increase the number of overflights or collect additional effort counts from other sources.

There did not appear to be enough consistency in inter-annual patterns in activity profiles to use information from other years in a Bayesian framework to improve precision for poorly sampled strata. There was also little correlation in activity patterns among statistical areas within years, so a Bayesian methodology which borrows information from adjacent areas to improve precision of a poorly sampled sub-area will likely also be of limited utility.

The proportion of effort targeted at salmon has declined from slight to moderate amounts in the late 1990's for some statistical areas. In other areas, especially some of the more important ones such as 13 and 28, there was little evidence of a change in the proportion of effort targeted at salmon during the summer when the majority of catch is obtained. It is unclear whether incorporating species or salmon-specific effort proportions would provide a more accurate assessment of the total effort. First, targeted effort at one species or species group (such as salmon) does not exclude catching other species or species group. If such 'by-catch' is significant, than using species or species-group specific effort will underestimate the actual effort. Second, even if by-catch is minimal, there will likely be greater bias and uncertainty in the species or group-specific effort estimates obtained from the interviews.

The variance in boat counts from overflights was at least two-fold higher than the variance associated with estimates of activity proportion. Assuming a fixed or declining total budget for the SOG creel survey in subsequent years, sampling effort for sub-areas where hundreds of interviews are conducted should be reduced and put towards funding additional overflights during summer months. If catch and effort were equally distributed among strata this analysis could be used as a guide to help re-distribute sampling effort. However, this analysis is limited by the fact that strata-specific estimates of CPE and effort were not combined to provide SOG-wide estimates. The gains in precision to the SOG-wide estimates from increasing sampling effort in sub-areas which produce less catch and effort could be smaller than the losses in precision that occur by reducing sampling intensity at more heavily used areas. This analysis is therefore useful for defining minimum sample size requirements but has limited utility for decisions on allocation of survey effort among strata.

5.0 Acknowledgements

This project was supported by a contract from the Department of Fisheries and Oceans to Ecometric Research. Thanks to Kris Hein for providing the data used in this analysis. Thanks to Carl Walters for comments on some of the statistical aspects of this work.

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Table 1. Number of sub-areas with low numbers (0-10) or no interviews by year, month, and day type. The SOG creel survey area is comprised of 114 sub-areas in total.

Day Type	**Weekday**						**Weekend**					
Month	**4**	**5**	**6**	**7**	**8**	**9**	**4**	**5**	**6**	**7**	**8**	**9**
# of Sub-Areas with <10 Interviews												
1992	66	59	48	47	45	60	59	48	46	43	46	57
1993	71	57	52	50	49	51	65	51	49	44	50	54
1994	73	59	53	49	48	60	63	48	47	45	49	54
1995	70	61	54	55	51	65	60	54	51	50	51	53
1996	75	67	59	55	51	60	64	61	49	48	48	58
1997	72	66	60	62	58	67	63	59	56	51	52	62
1998	67	72	62	61	60	65	71	62	57	62	55	63
1999	70	74	62	60	59	62	67	60	59	53	54	58
2000	71	65	59	52	49	58	66	60	52	47	47	53
2001	73	65	58	50	49	58	65	62	60	51	53	60
2002	75	65	62	60	58	68	64	64	56	60	53	61
# of Sub-Areas with No Interviews												
1992	47	38	25	25	26	38	45	31	26	23	23	35
1993	51	32	33	26	30	32	47	31	27	24	31	33
1994	46	35	29	32	30	43	39	29	26	24	28	37
1995	48	34	33	32	31	42	39	33	37	27	32	33
1996	54	40	37	28	33	42	48	41	32	27	27	43
1997	46	36	42	34	36	50	40	33	33	29	30	43
1998	46	44	41	40	37	49	47	34	33	35	31	44
1999	51	44	34	36	36	44	47	35	34	29	35	42
2000	54	38	29	26	23	31	40	35	19	24	29	26
2001	49	38	33	28	24	44	32	33	25	21	26	38
2002	51	34	37	34	33	43	45	32	31	30	30	38

Table 2. Statistics of catch per effort for coho during weekdays in June 1992 in sub-areas 13A and 17E. 80% lower (Lcl) and upper (Ucl) confidence limits, the ratio of the upper confidence limit to the mean (Ucl/Average), the percentage of the distributions exceeding 2 fish/trip (%>2 fish), and the average deviation of the expected and observed frequencies (MG) for 3 alternate error models are shown. The null hypothesis is that the distribution conforms to Poisson, Negative Binomial, or Normal error models.

		13A			17E	
Number of Interviews		839			84	
Average Catch/Trip		4.2			0.7	
Variance in Catch/Trip		12.2			2.0	
Variance-to-Mean Ratio		2.9			3.0	
Coefficient of Variation		0.8			2.1	
	Poisson	Negative Binomial	Normal	Poisson	Negative Binomial	Normal
Lcl	4.1	4.0	4.0	0.6	0.5	0.5
Ucl	4.2	4.3	4.3	0.8	0.9	0.9
Ucl/Average	1.02	1.04	1.04	1.18	1.35	1.3
% > 2 Fish	78.4	61.3	68.3	3.0	8.4	9.2
MG	27.3	5.6	12.5	3.5	0.2	7.7
Null	Reject	Reject	Reject	Reject	Accept	Reject

Table 3. Number of sub-areas with no aerial overflights to determine mean boat count. The SOG creel survey area is comprised of 114 sub-areas in total.

Day Type	Weekday						Weekend					
Month	**4**	**5**	**6**	**7**	**8**	**9**	**4**	**5**	**6**	**7**	**8**	**9**
1992	68	58	58	58	58	58	68	58	58	58	58	58
1993	68	58	58	58	58	68	58	58	58	58	0	0
1994	68	58	58	58	58	58	68	58	58	58	58	58
1995	68	58	58	58	58	58	68	58	58	58	58	58
1996	6	6	6	6	6	6	6	6	6	6	6	6
1997	6	6	6	6	6	6	6	6	6	6	6	6
1998	59	59	59	59	59	59	60	59	59	59	59	59
1999	60	60	64	59	59	59	60	60	64	59	59	59
2000	59	59	54	54	54	58	59	59	57	54	54	58
2001	58	58	58	55	54	58	58	58	58	55	55	58
2002	58	58	58	58	58	58	58	58	58	58	58	58

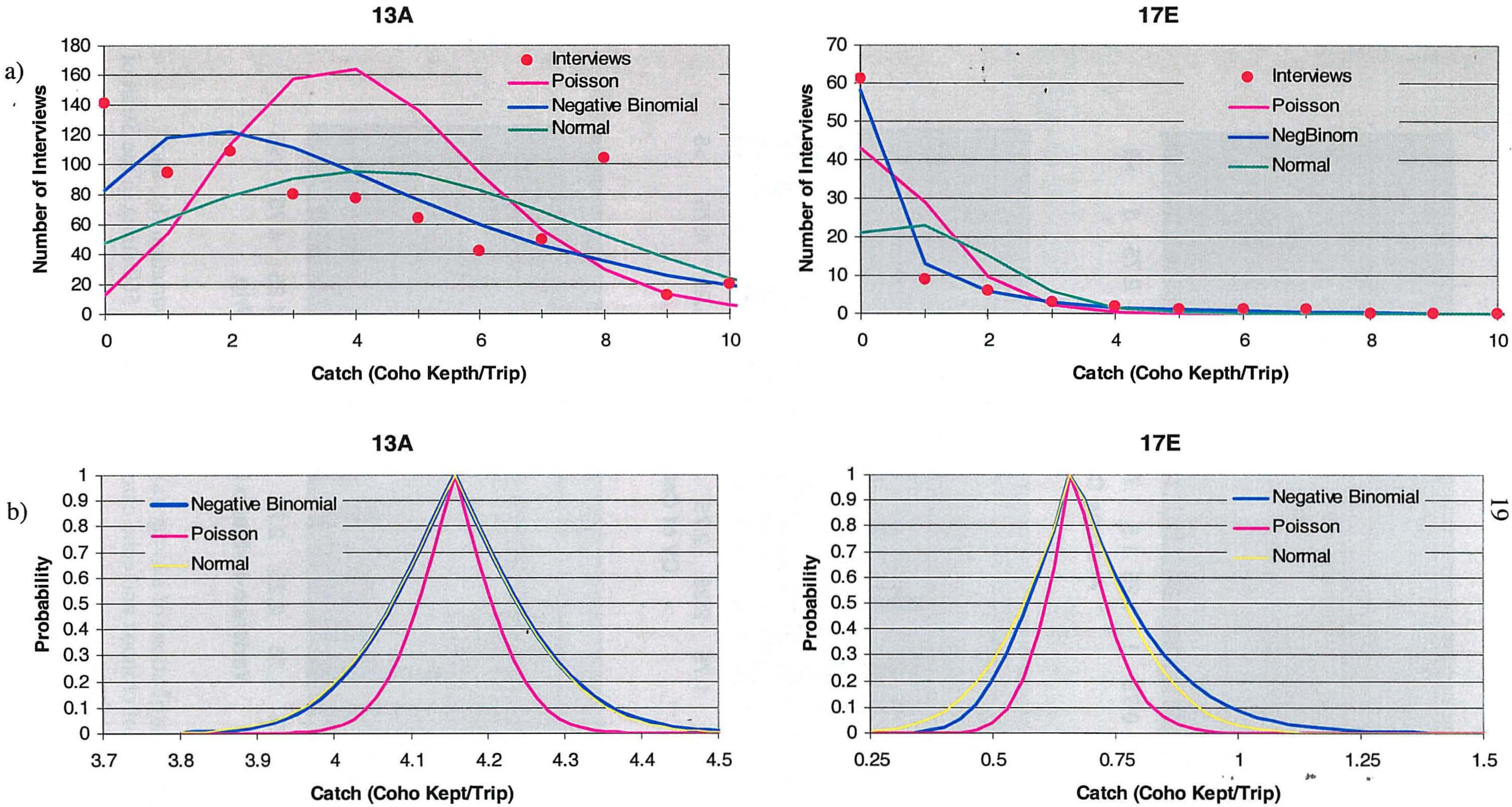


Figure 1. Observed and best-fit distributions of catch-per-trip (CPE) for coho in statistical sub-areas 13A and 17E on weekdays in June 1992 (a) and probability profiles (b). Confidence limits can be determined from the probability profiles by finding the x-axis values that correspond to a probability of 1-α (e.g., 0.8 limits occur at a probability of 0.2).

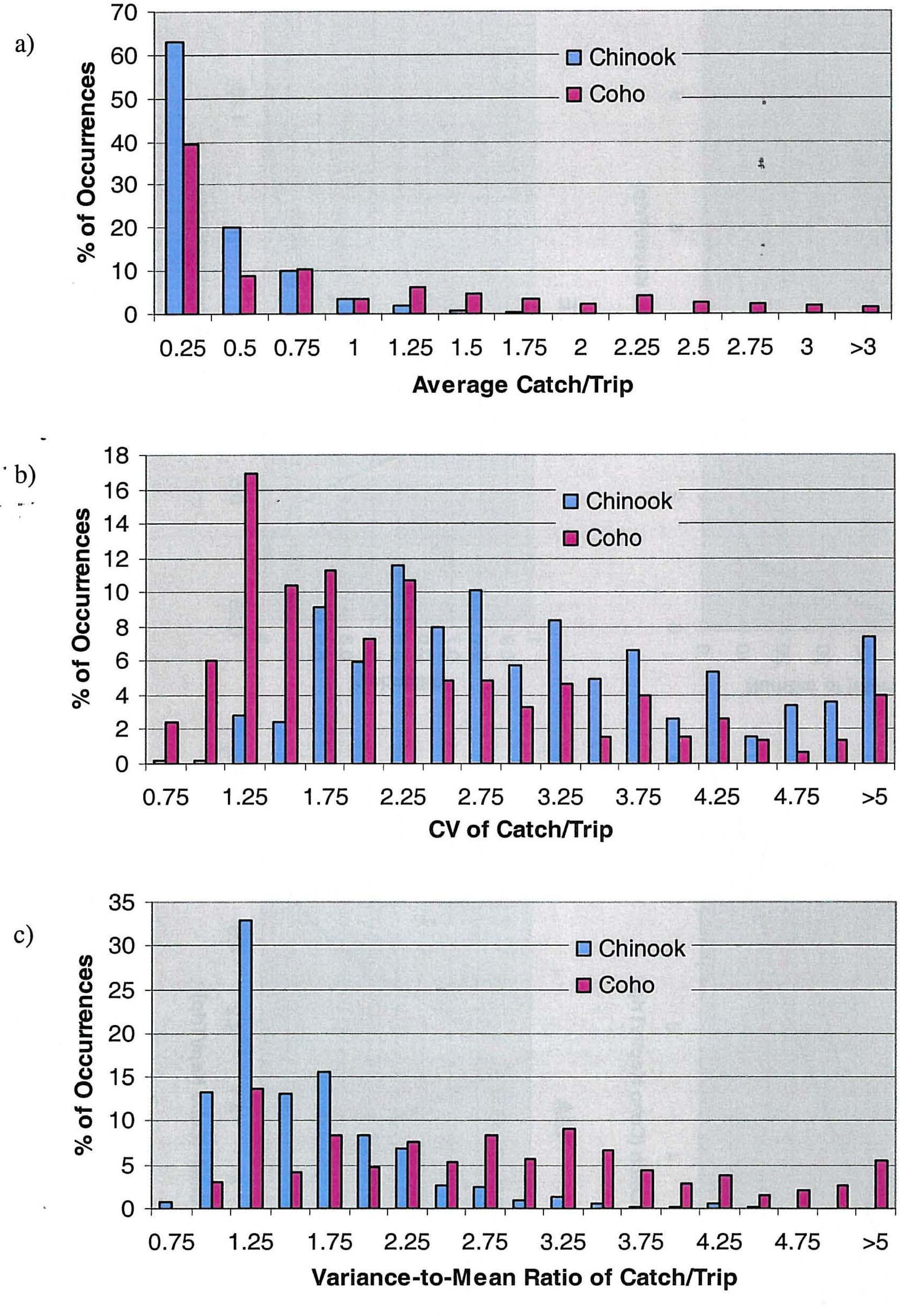
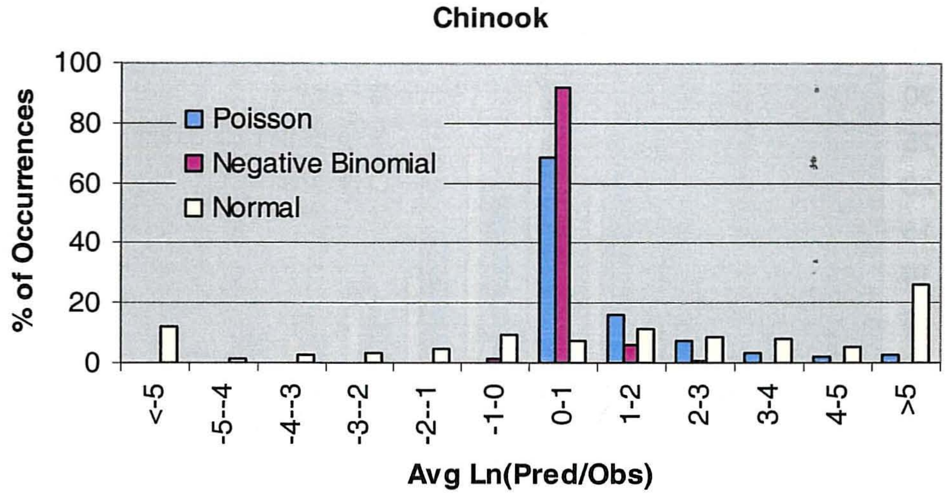


Figure 2. Frequency distributions of average (a), coefficient of variation (b), and variance-to-mean ratio of chinook and coho catch per trip across 560 strata in the Strait of Georgia creel survey database.

a)



b)

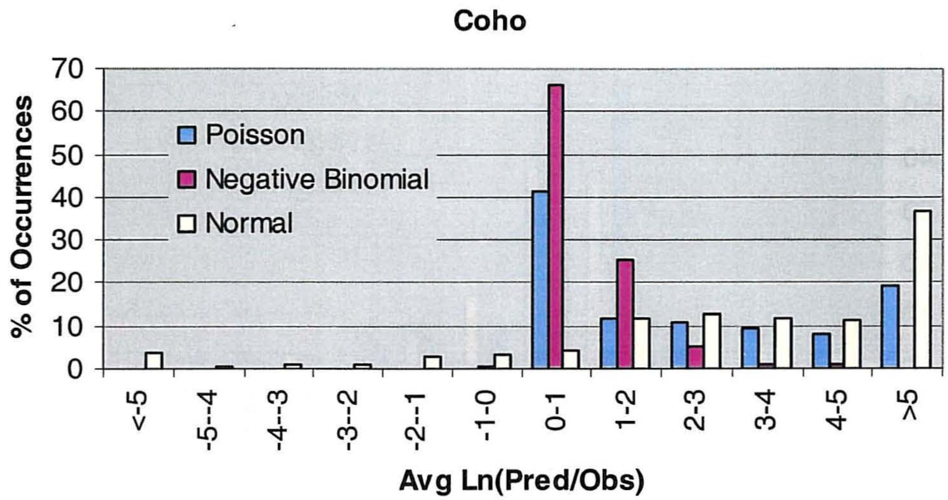
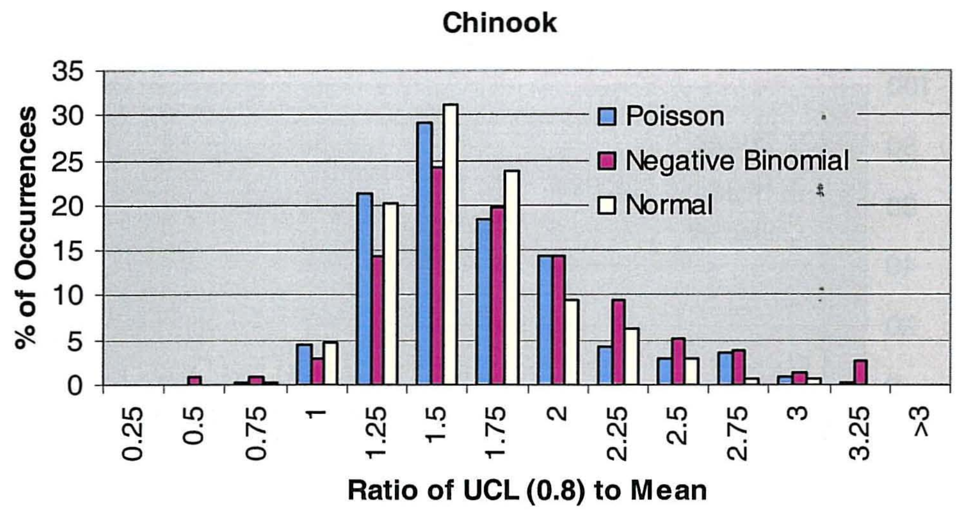


Figure 3. Frequency distributions of the goodness-of-fit of poisson, negative binomial, and normal error models to the catch/trip data across 560 strata in the Strait of Georgia creel survey database for chinook (a) and coho (b). The goodness-of-fit statistics (MG) is defined in Eqn. 7.

a)



b)

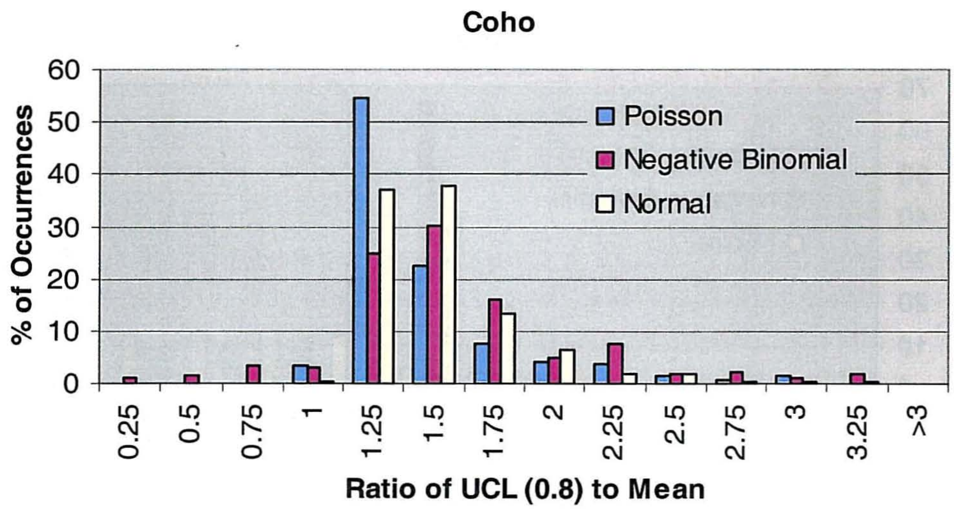


Figure 4. Frequency distributions of the ratio of the upper confidence limit (probability = 0.8) to the mean as an index of uncertainty in catch/trip estimates for chinook (a) and coho (b) for 3 error models.

a)

b)

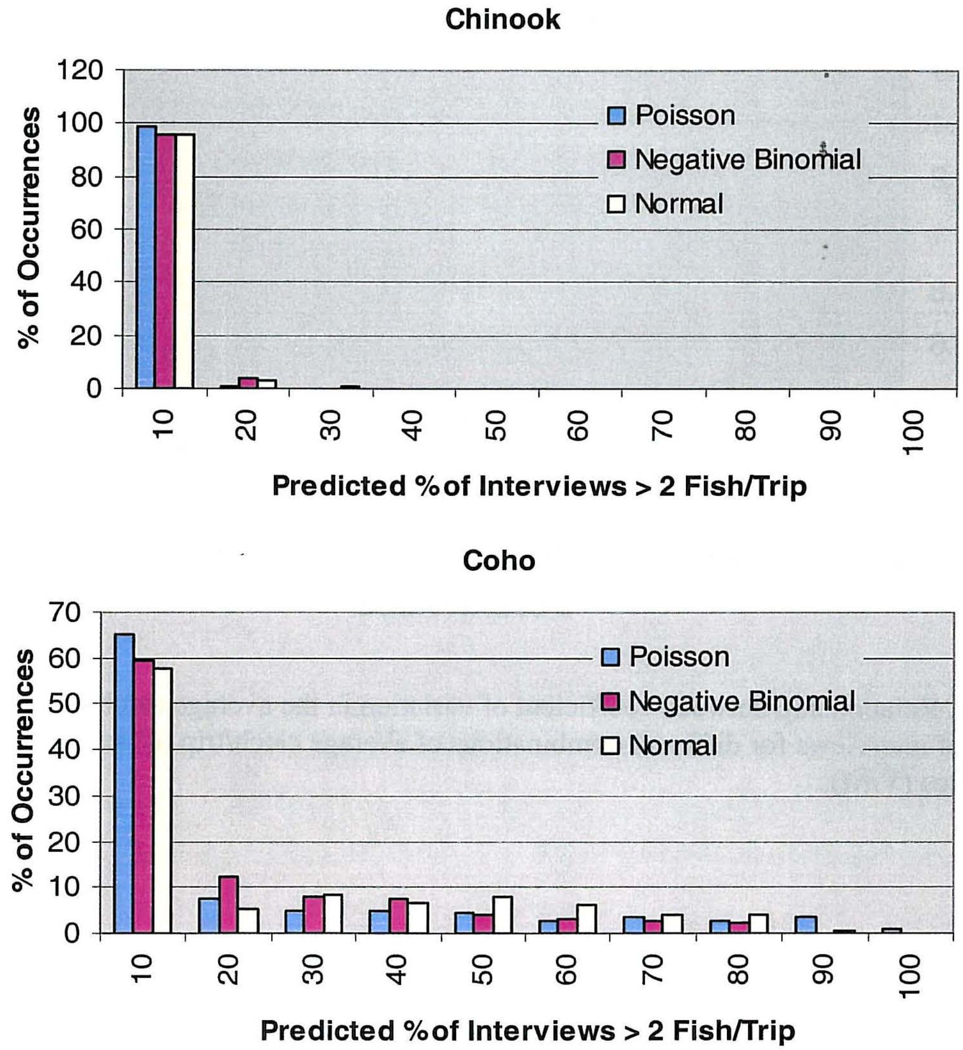


Figure 5. Frequency distributions of the predicted % of interviews where the catch/trip exceeds 2 fish for chinook (a) and coho (b) based on 3 error models.

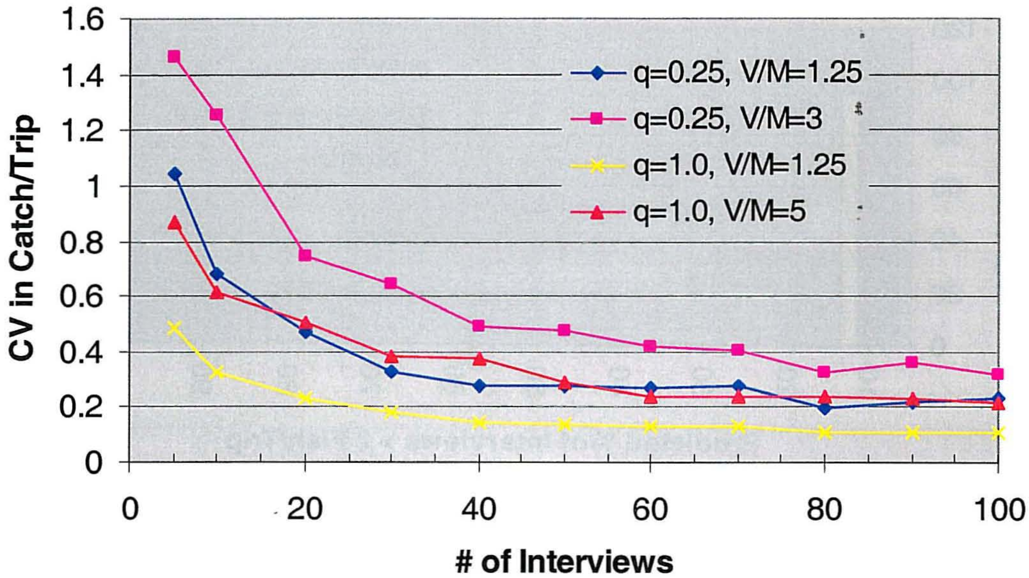


Figure 6. Relationship between coefficient of variation in the average catch/trip and the number of interviews for different combinations of average catch/trip (q) and variance-to-mean ratios (V/M).

a)

b)

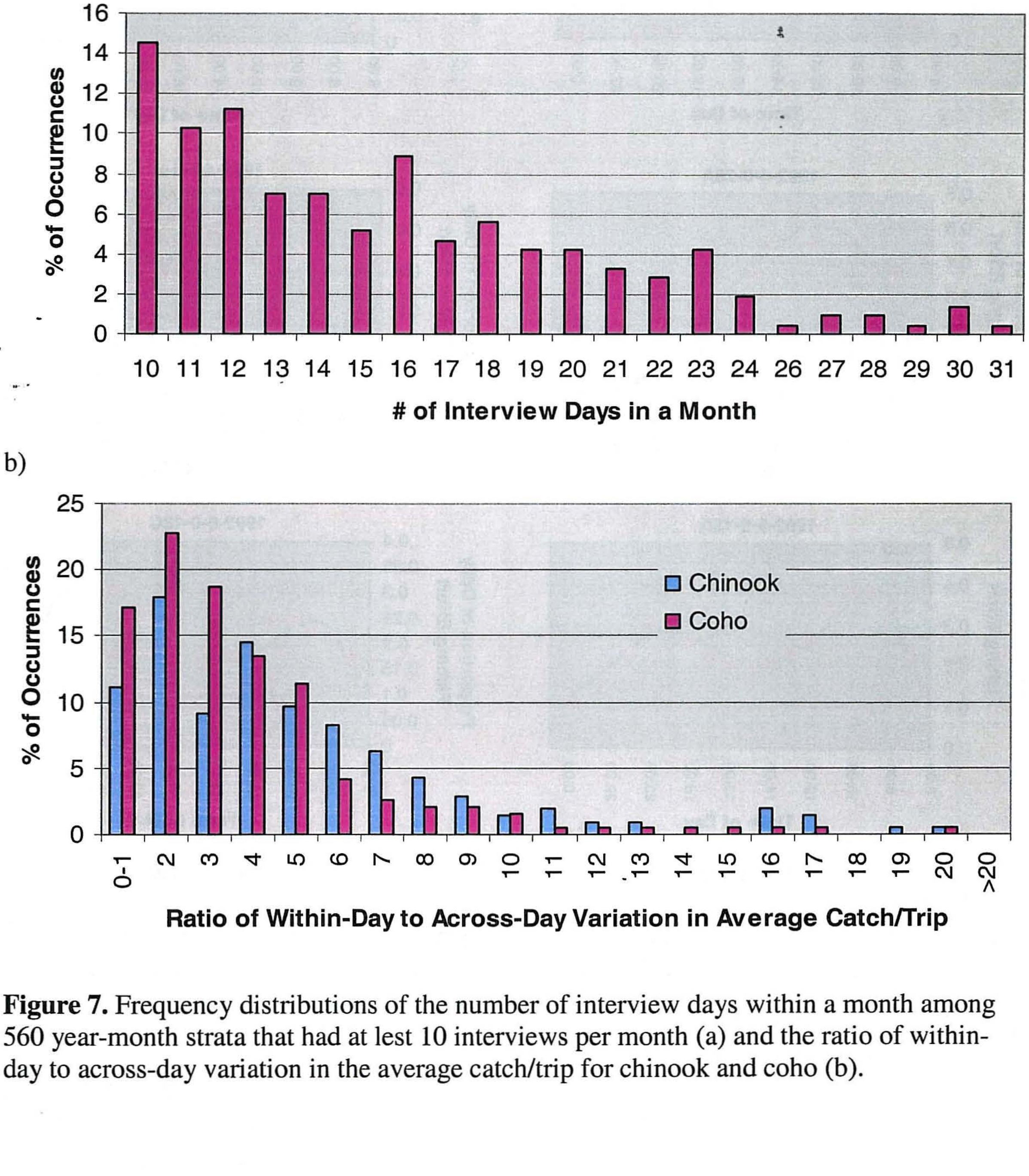


Figure 7. Frequency distributions of the number of interview days within a month among 560 year-month strata that had at lest 10 interviews per month (a) and the ratio of within-day to across-day variation in the average catch/trip for chinook and coho (b).

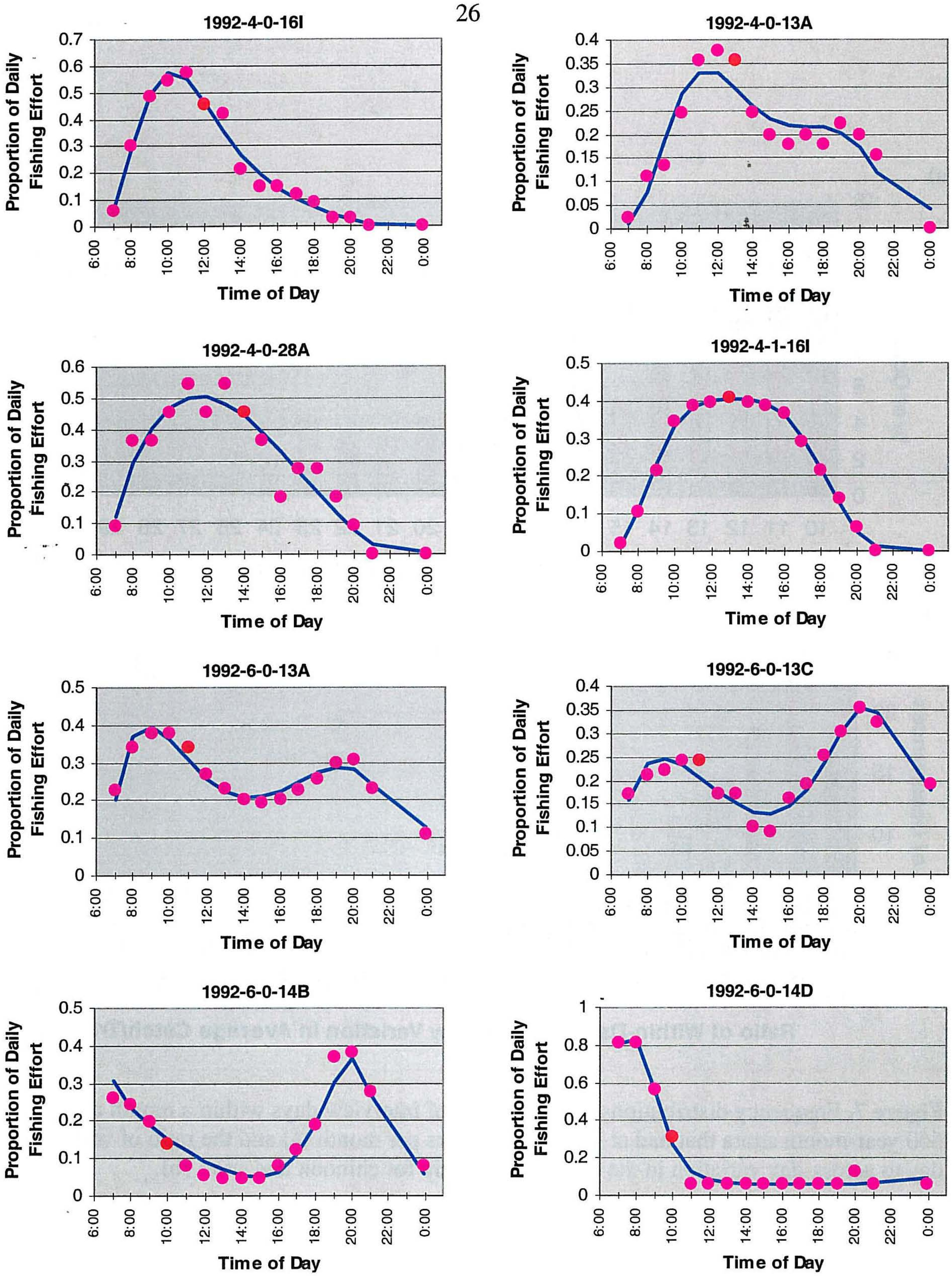


Figure 8. Plots of observed (magenta dots) and predicted (blue lines) proportion of daily fishing effort for different strata (year-month-day type-sub-area). The red dot denotes the time of the overflight boat count for the strata. The weekday and weekends are denoted as day type = 0 and 1, respectively.

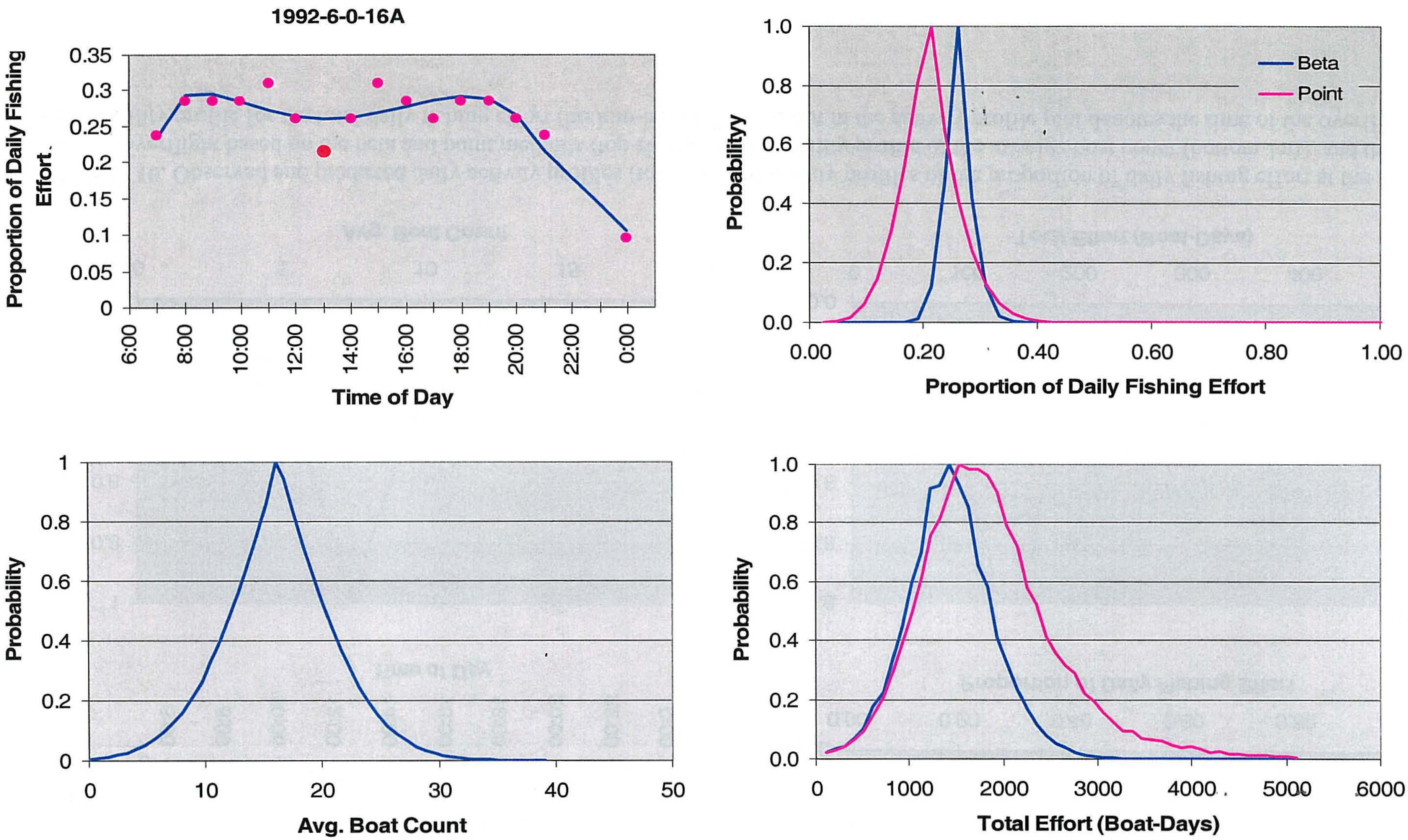


Figure 9. Observed and predicted daily activity profiles (top-left), probability profiles of the proportion of daily fishing effort at the time of the overflight based on the beta and point methods (top-right), the probability profile of the average boat count (bottom-left), and the probability profile for the total daily fishing effort (bottom-right). The red dot in the activity profile plot denotes the time of the overflight.

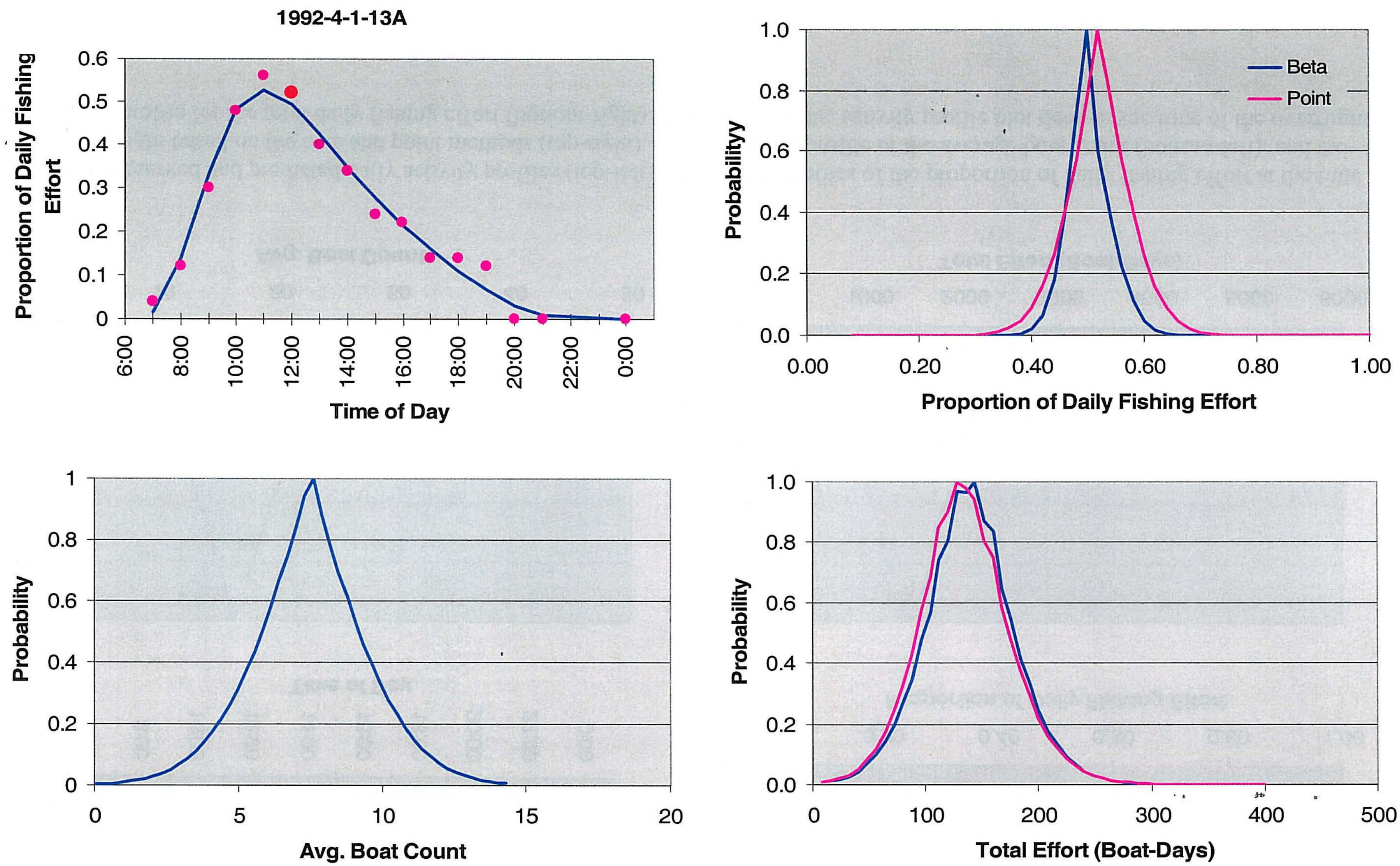


Figure 10. Observed and predicted daily activity profiles (top-left), probability profiles of the proportion of daily fishing effort at the time of the overflight based on the beta and point methods (top-right), the probability profile of the average boat count (bottom-left), and the probability profile for the total daily fishing effort (bottom-right). The red dot in the activity profile plot denotes the time of the overflight.

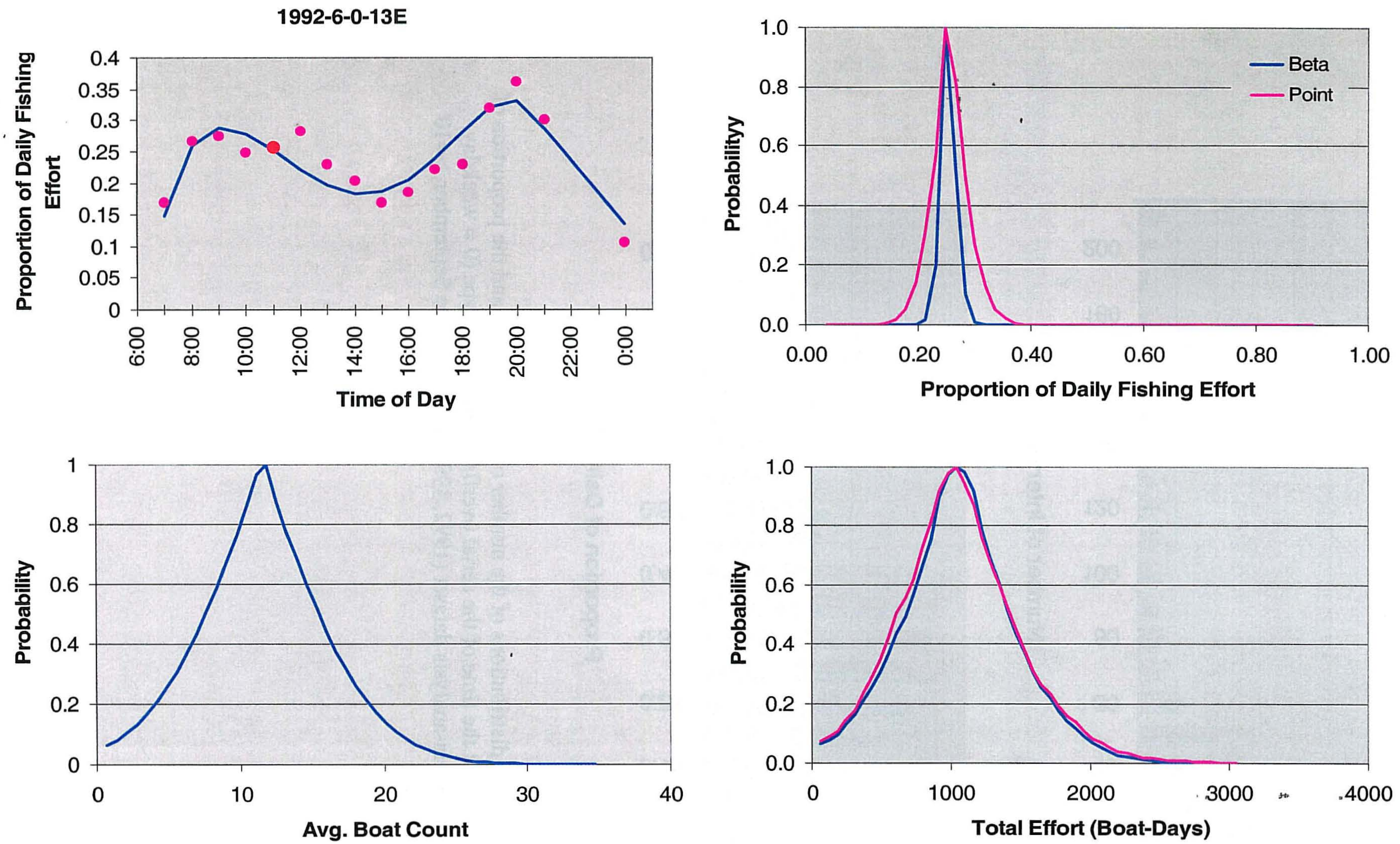
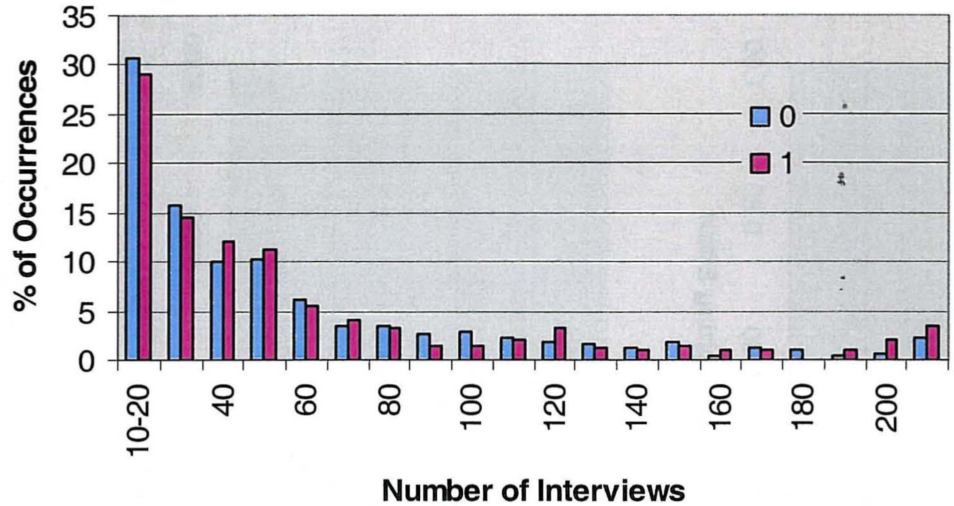


Figure 11. Observed and predicted daily activity profiles (top-left), probability profiles of the proportion of daily fishing effort at the time of the overflight based on the beta and point methods (top-right), the probability profile of the average boat count (bottom-left), and the probability profile for the total daily fishing effort (bottom-right). The red dot in the activity profile plot denotes the time of the overflight.

a)



b)

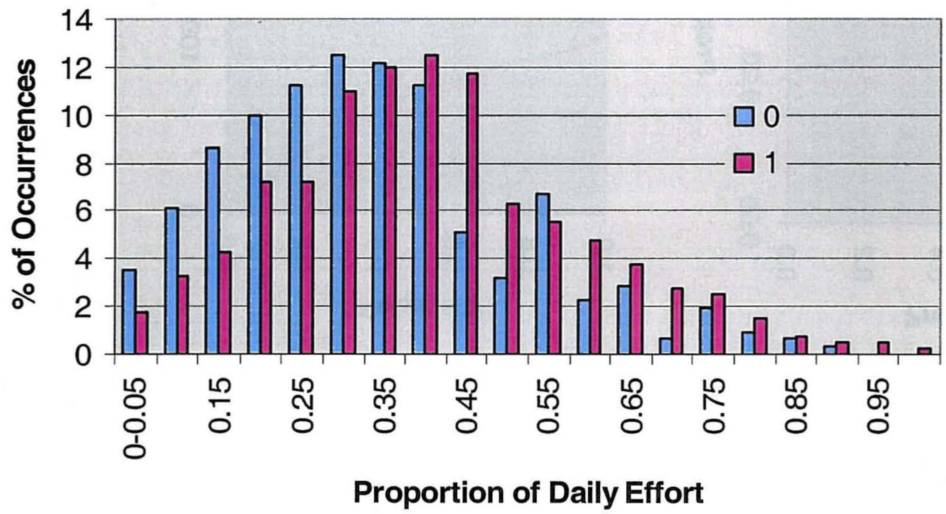


Figure 12. Frequency distributions of the number of interviews (a) and the proportion of daily fishing activity at the time of the aerial overflight (b) by day type (0 = weekday, 1=weekend) in the meta-analysis dataset (1992, 1994, 1996, April to September, >=10 interviews per strata).

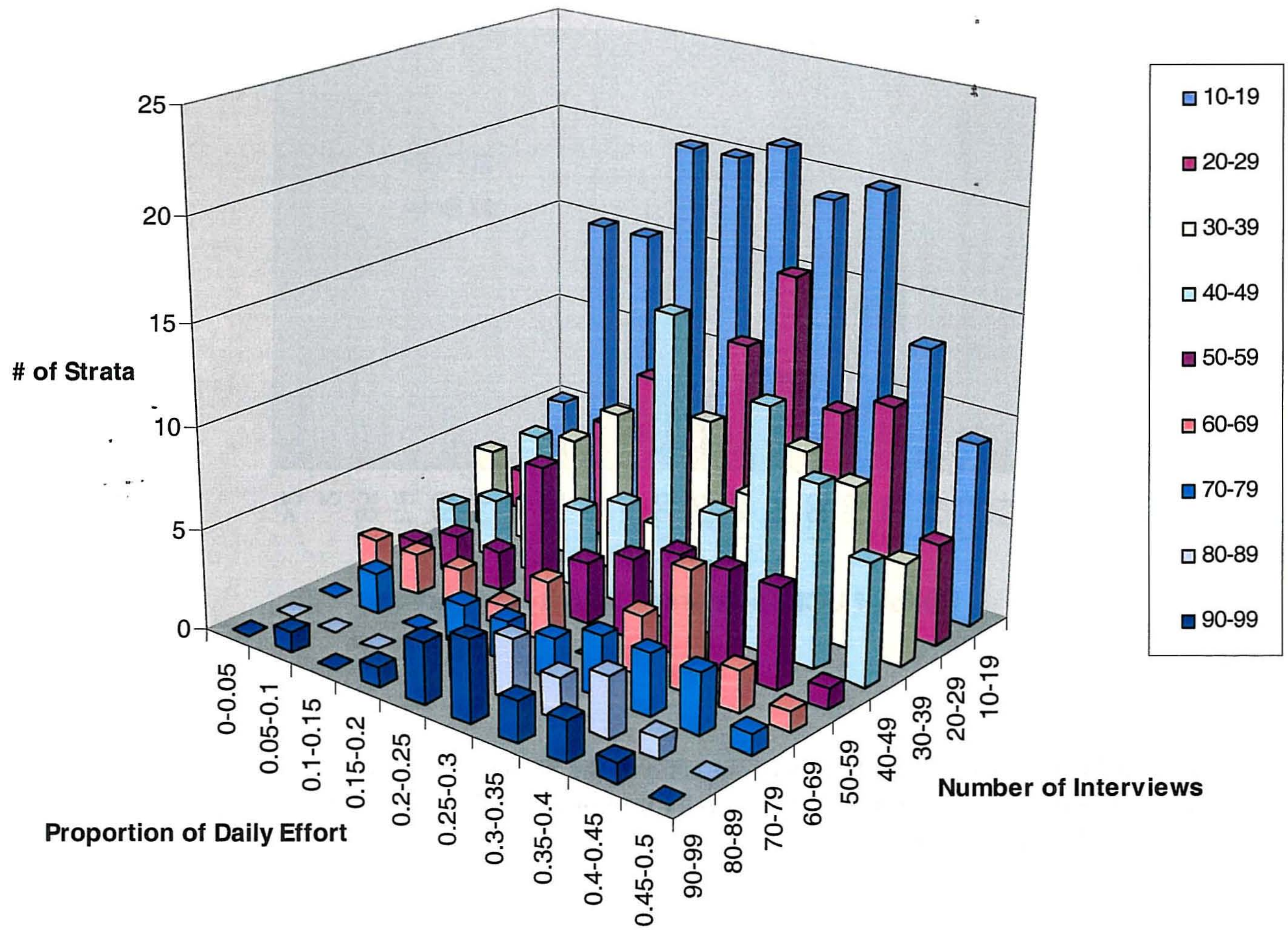


Figure 13. Frequency distribution of the number of strata in different categories of the number of interviews and the proportion of daily effort at the time of overflights in the meta-analysis dataset. Note the frequency distribution excludes strata with <10 or >100 interviews or where the activity proportion >0.5.

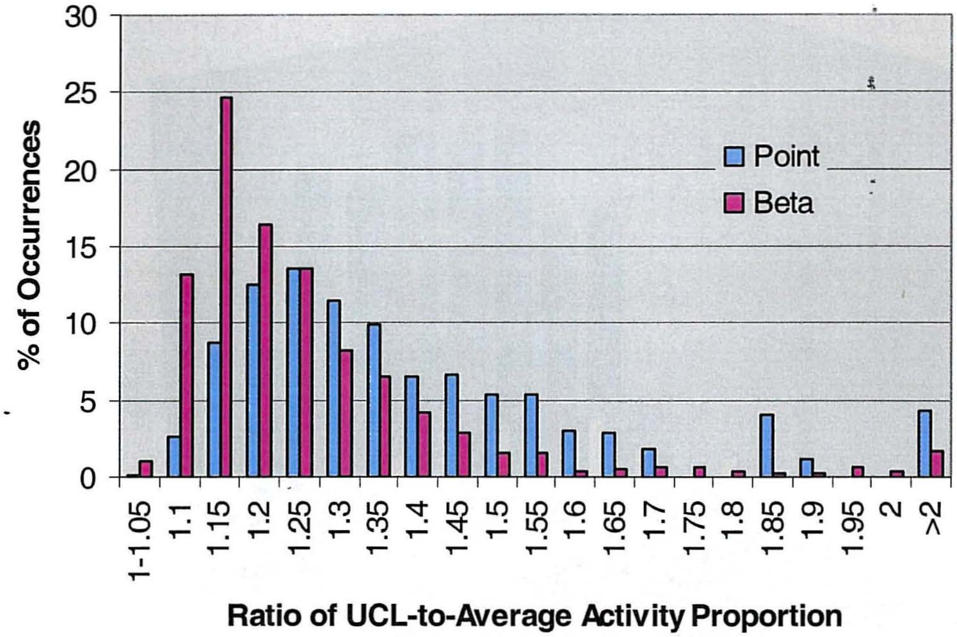
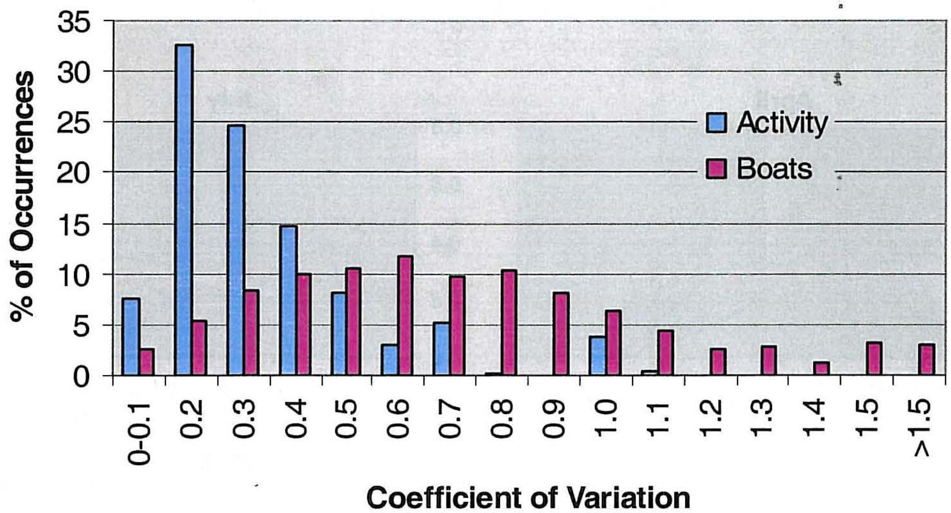


Figure 14. Frequency distribution of the ratio of the 80% upper confidence limit to the maximum likelihood estimate of the activity proportion at the time of the overflights for point- and beta-methods.

a)



b)

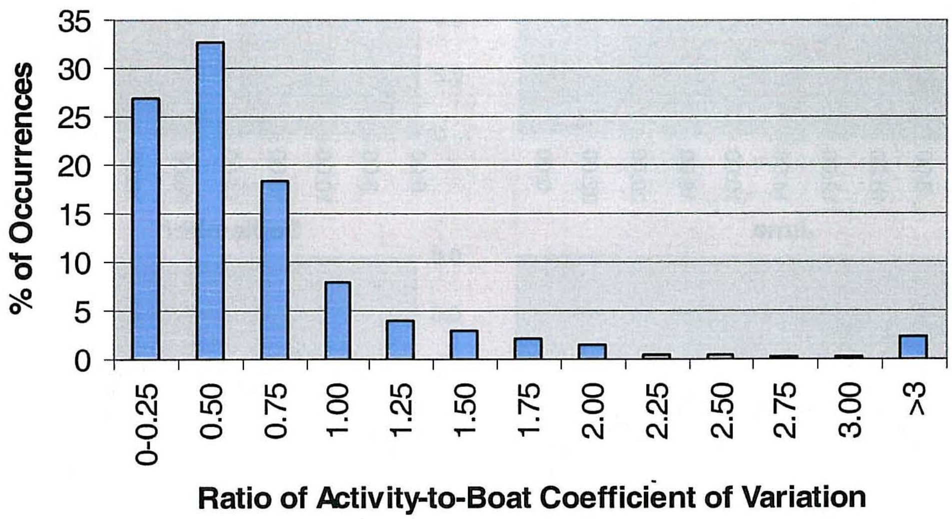


Figure 15. Frequency distributions of the coefficient of variation for the proportion of daily fishing effort active at the time of the overflights and for the average boat count (a) and the ratio of these CV's (b).

13A-Weekday

Overflight Time Block: 11:00 – 12:00

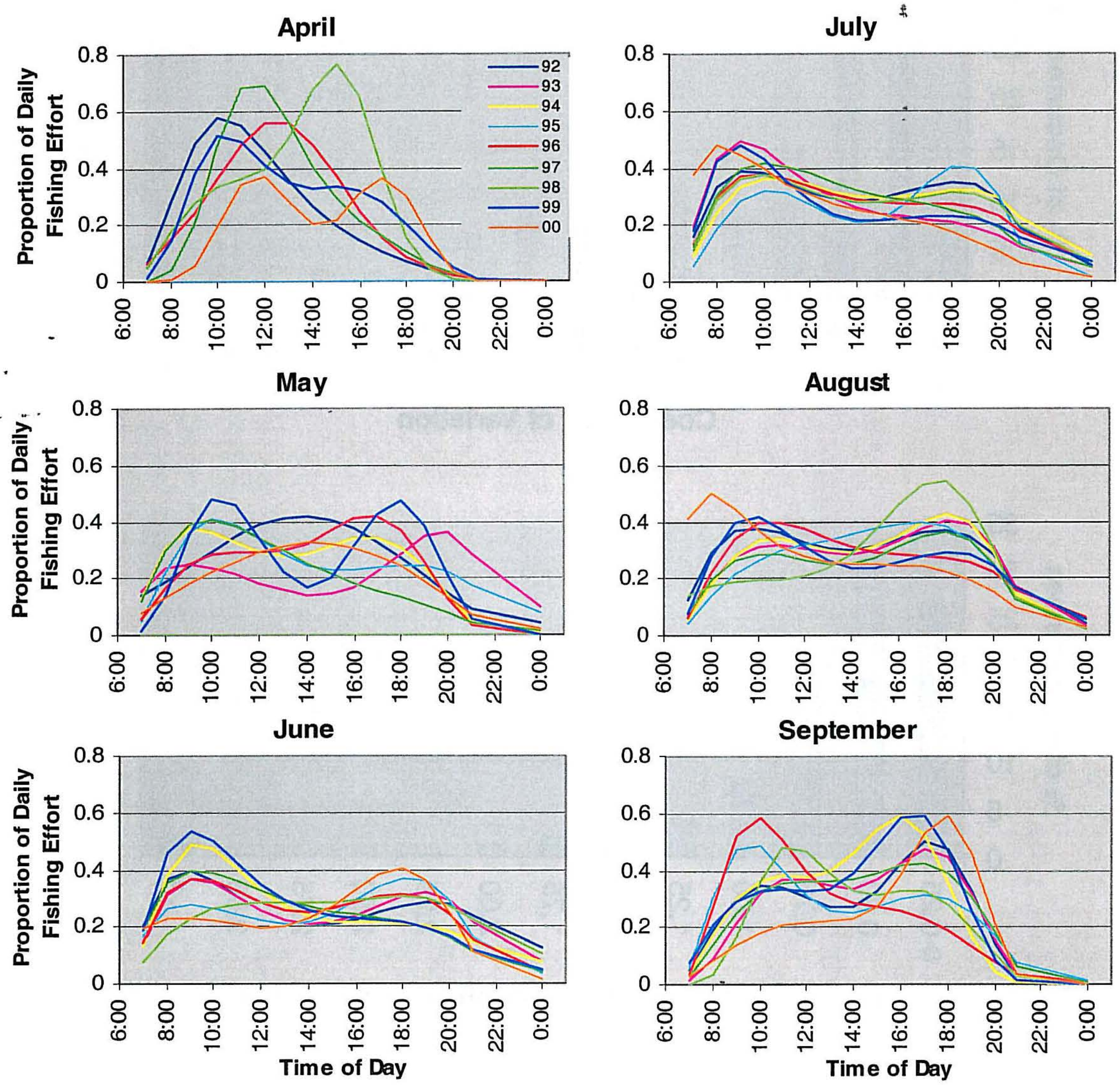


Figure 16. Inter-annual variation in daily activity patterns for statistical sub-areas 13A, 14C, 16B, 17E, and 28A by month and day type.

13A-Weekend

Overflight Time Block: 11:00 – 12:00

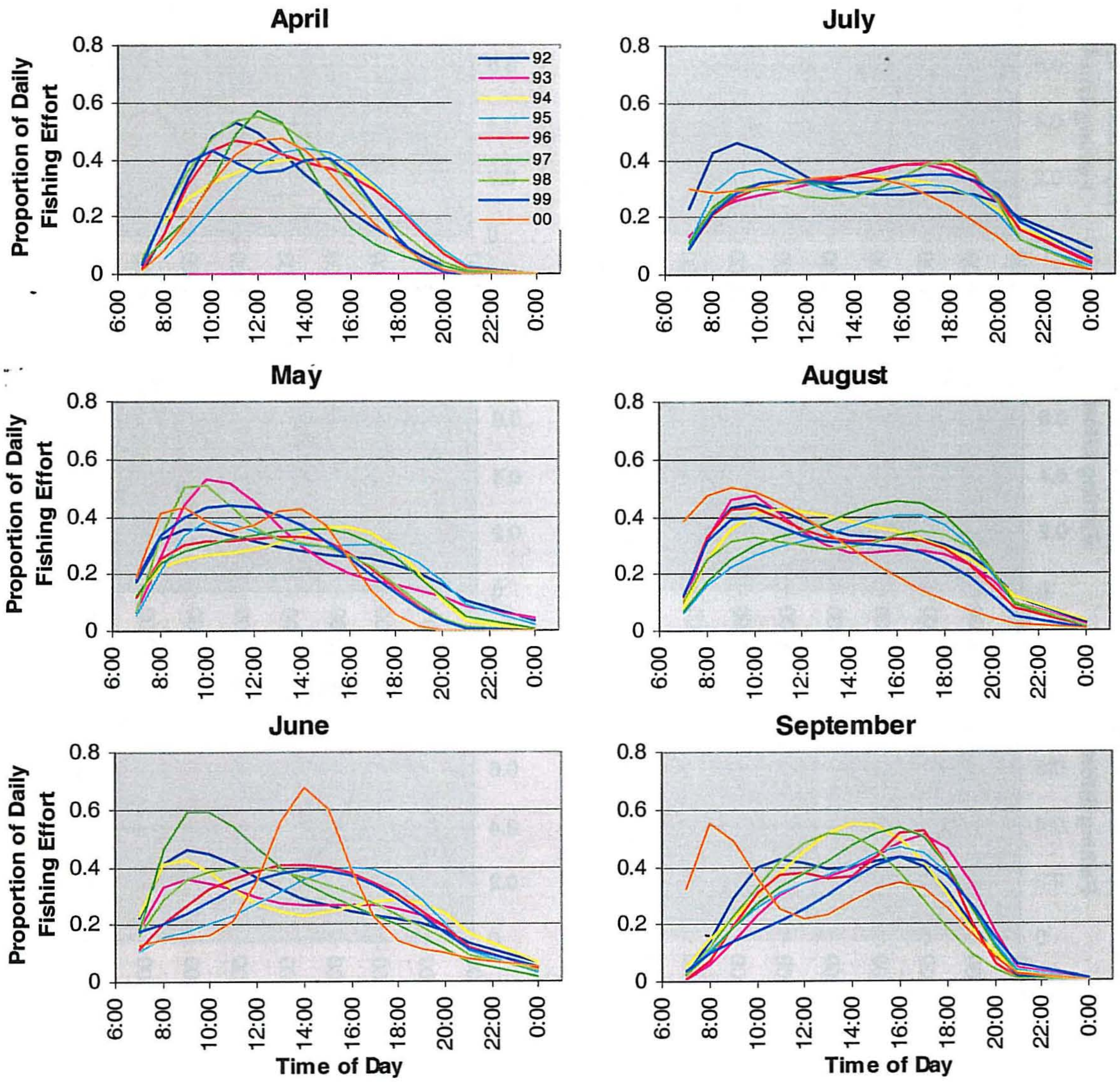


Figure 16. Con't.

14C-Weekday

Overflight Time Block: 11:00 – 12:00

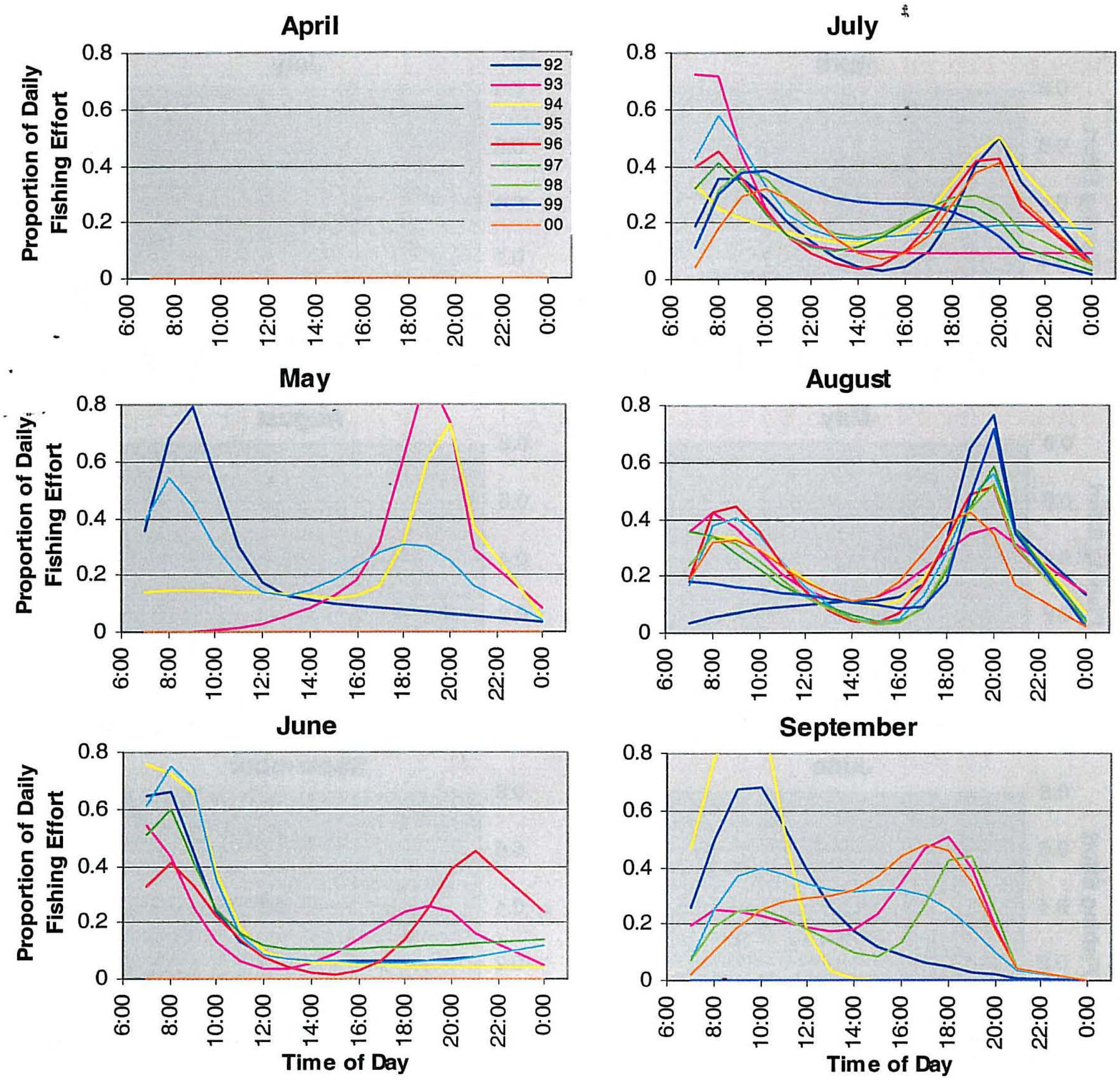


Figure 16. Con't.

14C-Weekend

Overflight Time Block: 11:00 – 12:00

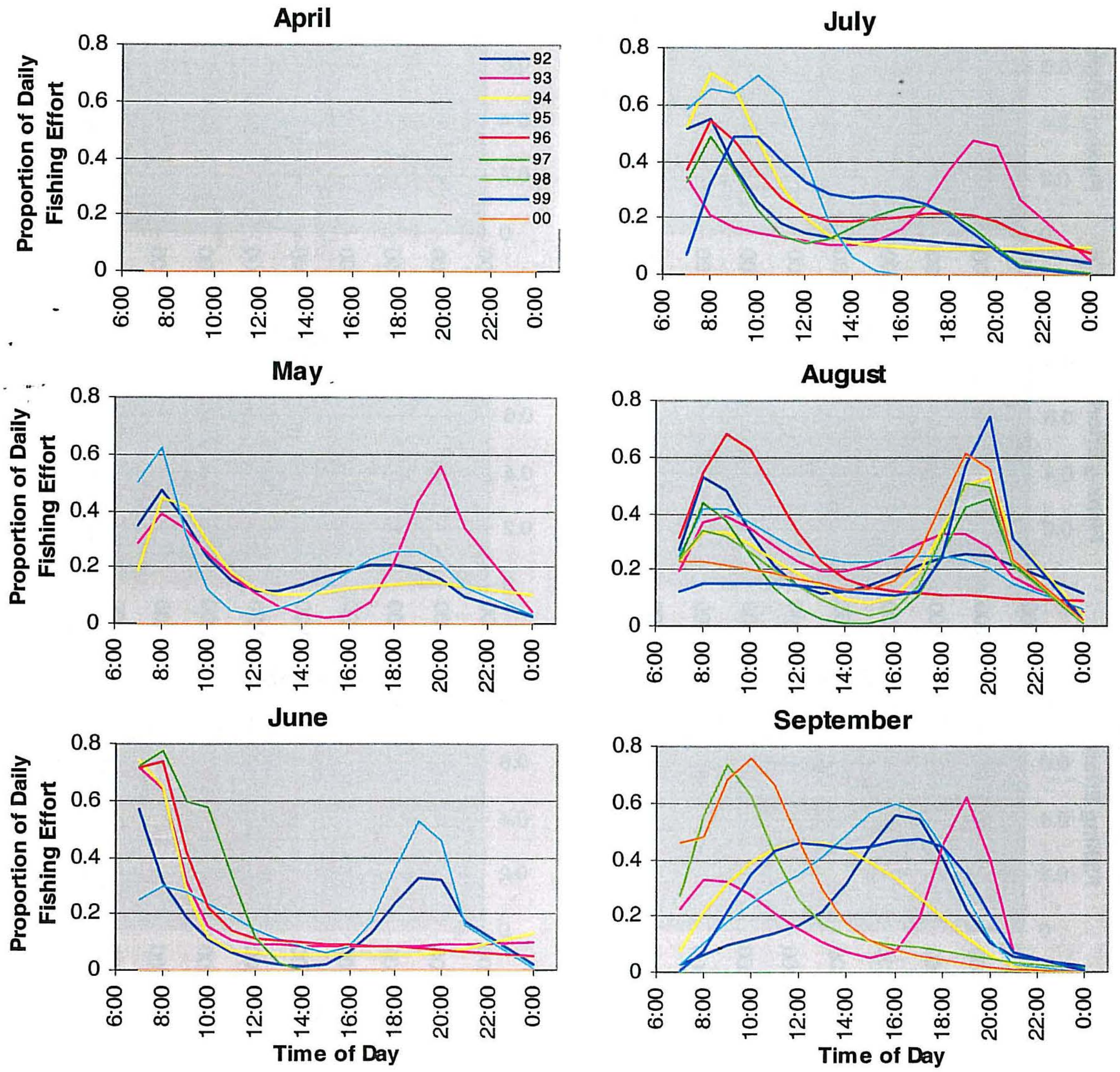


Figure 16. Con't.

16B-Weekday

Overflight Time Block: 14:00 – 15:00

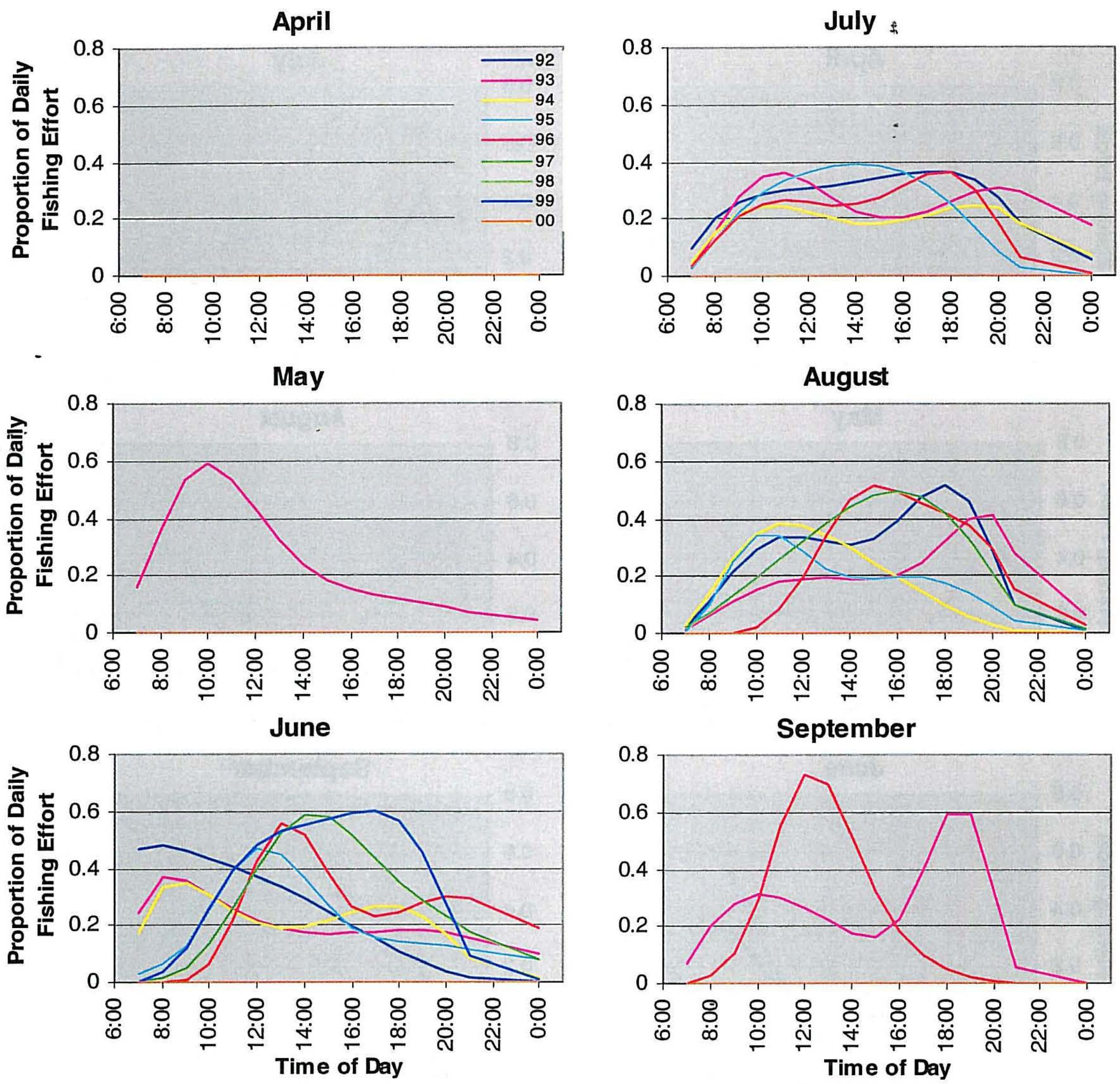


Figure 16. Con't.

16B-Weekend

Overflight Time Block: 14:00 – 15:00

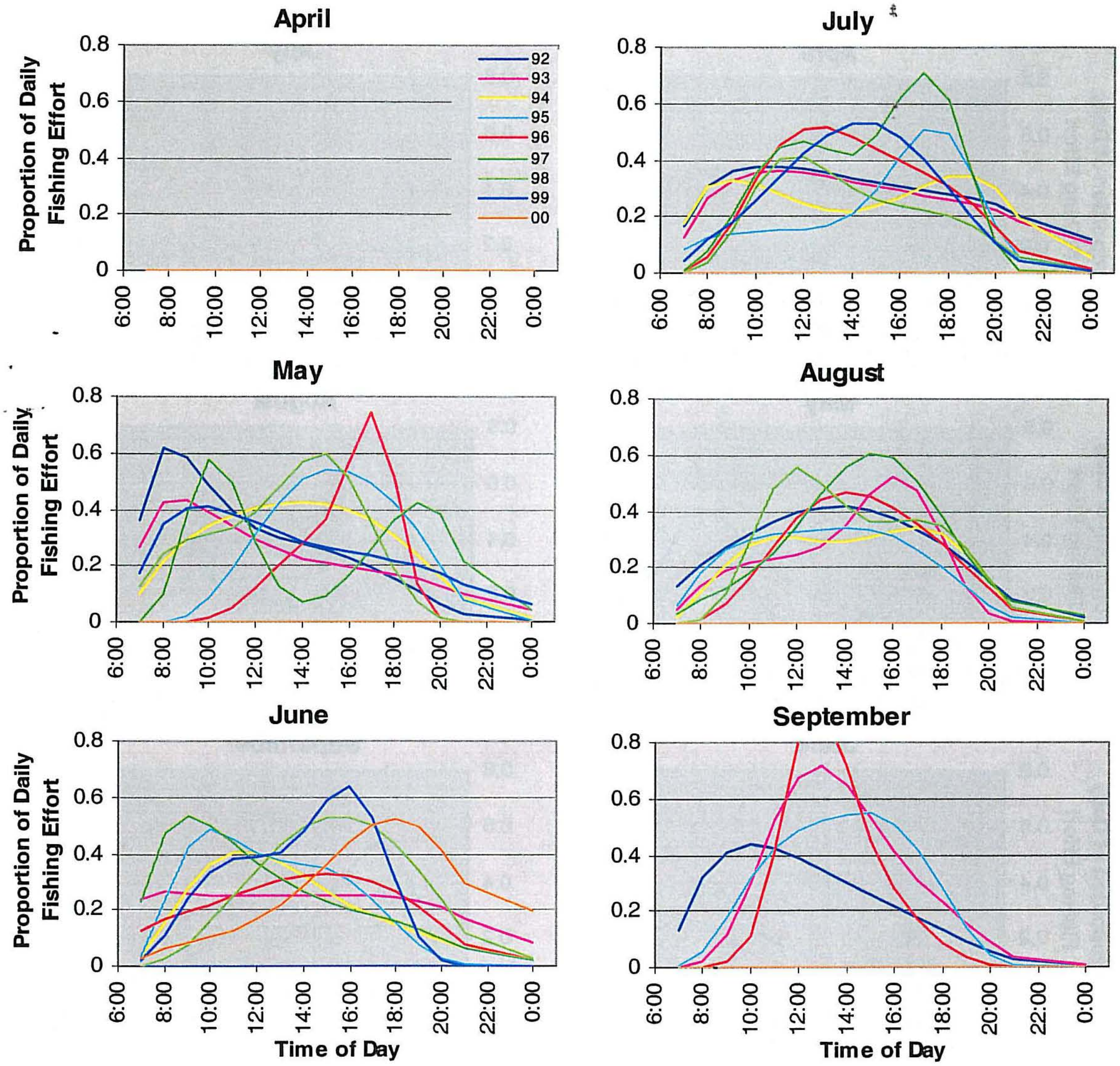


Figure 16. Con't.

17E-Weekday

Overflight Time Block: 11:00 – 12:00

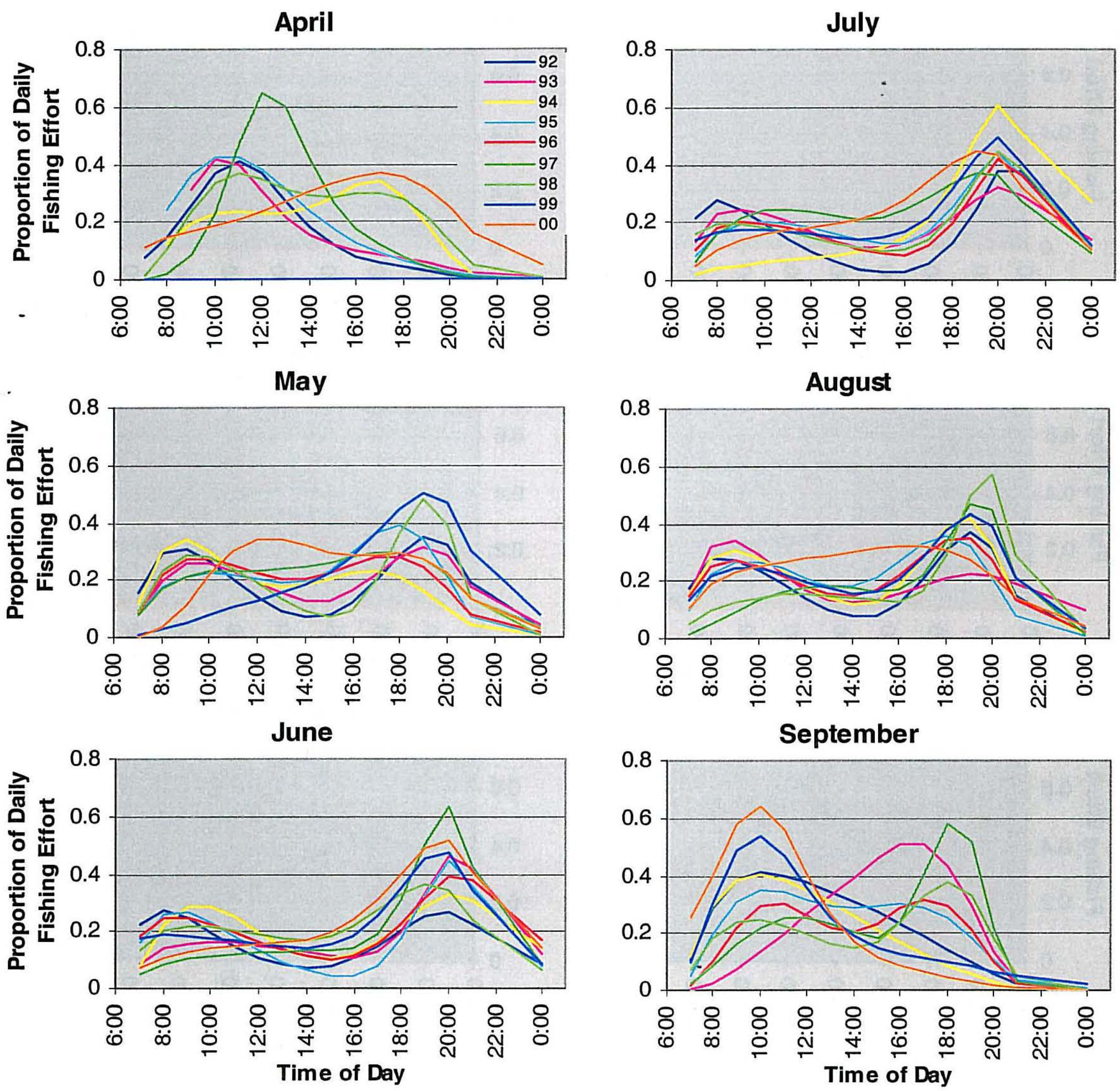


Figure 16. Con't.

17E-Weekend

Overflight Time Block: 11:00 – 12:00

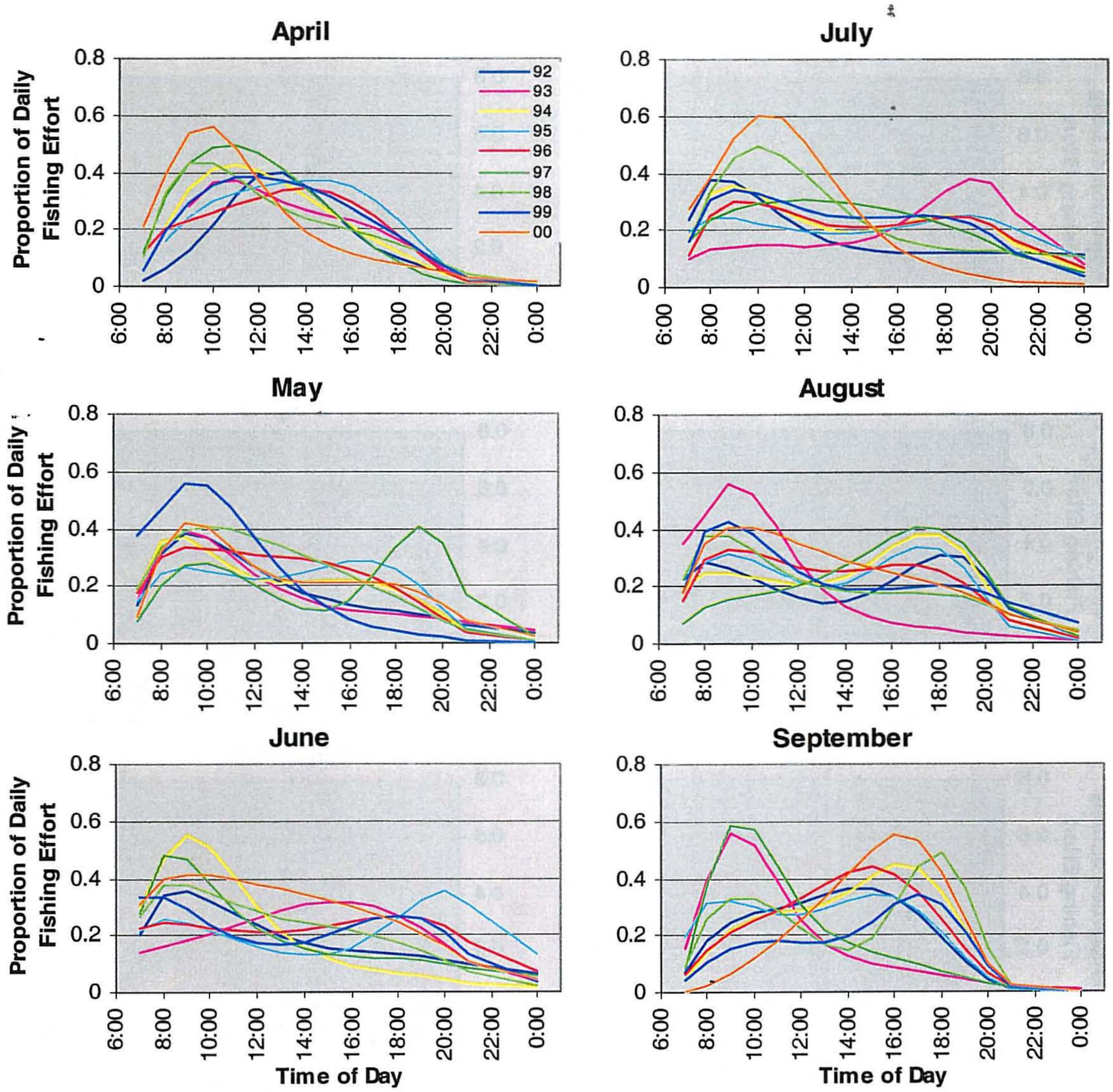


Figure 16. Con't.

28A-Weekday

Overflight Time Block: 8:00 – 9:00

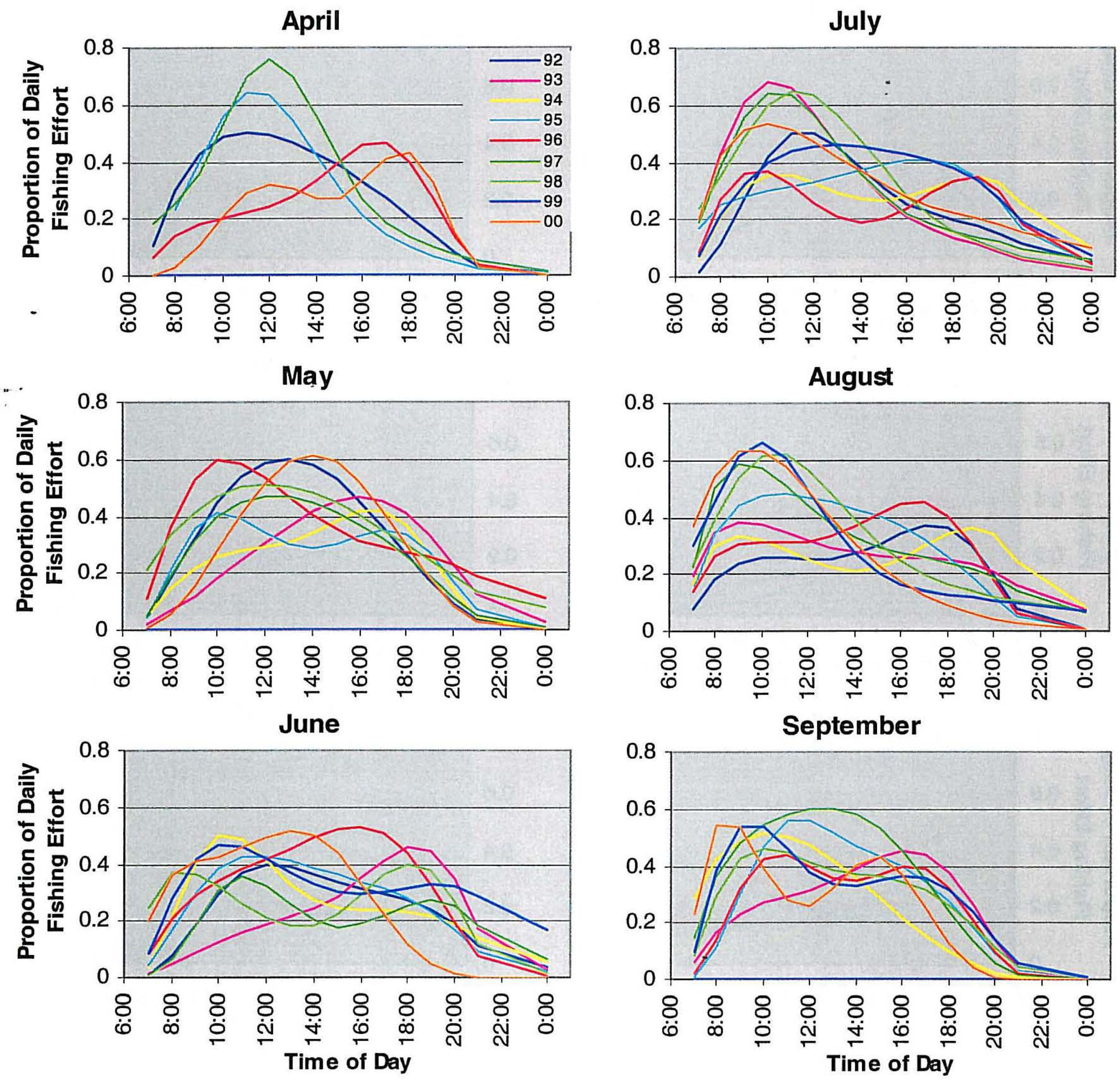


Figure 16. Con't.

28A-Weekend

Overflight Time Block: 8:00 – 9:00

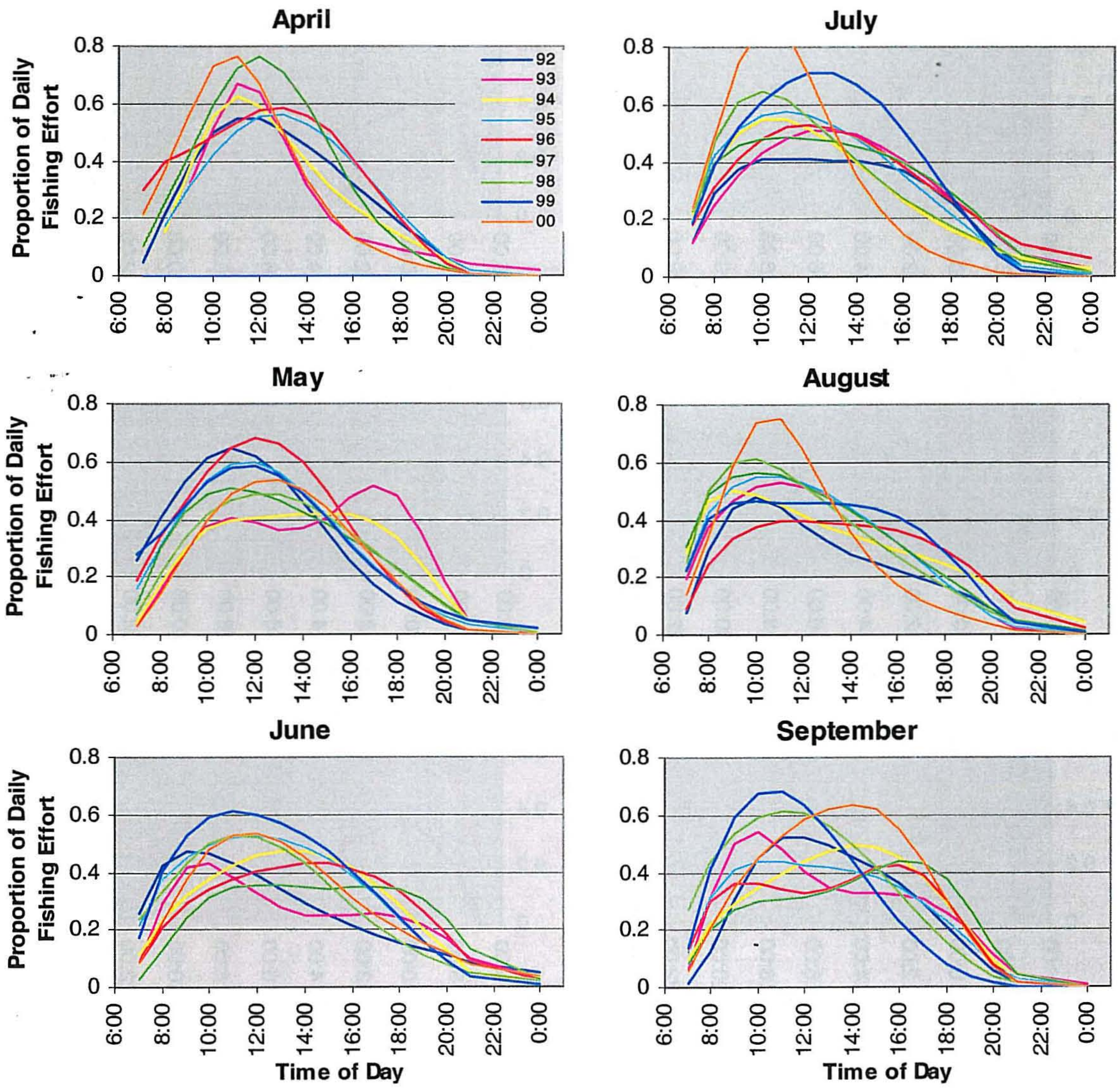


Figure 16. Con't.

1992 – Weekday

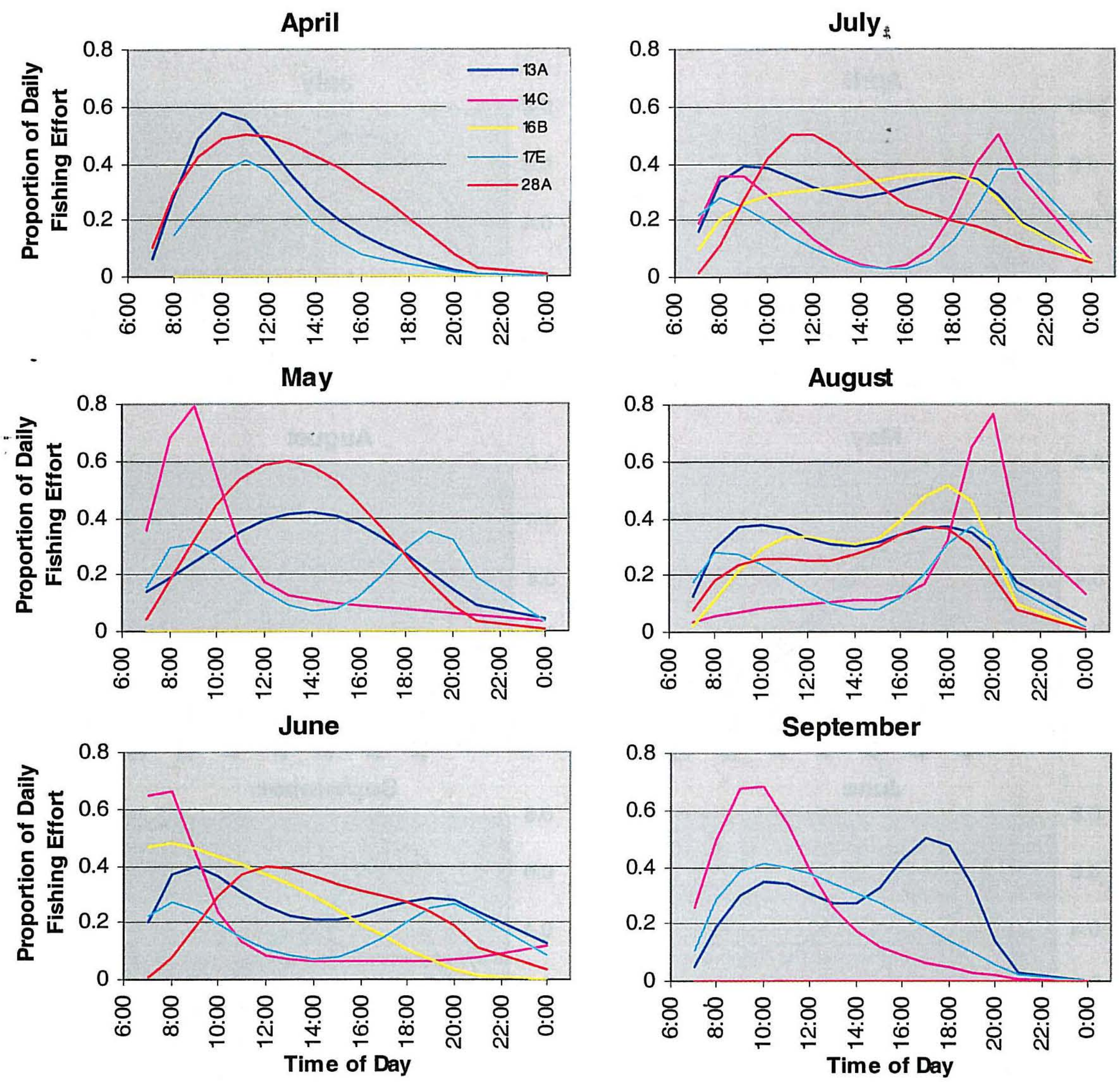


Figure 17. Comparison of daily activity profiles among areas by month, year, and day type.

1992 – Weekend

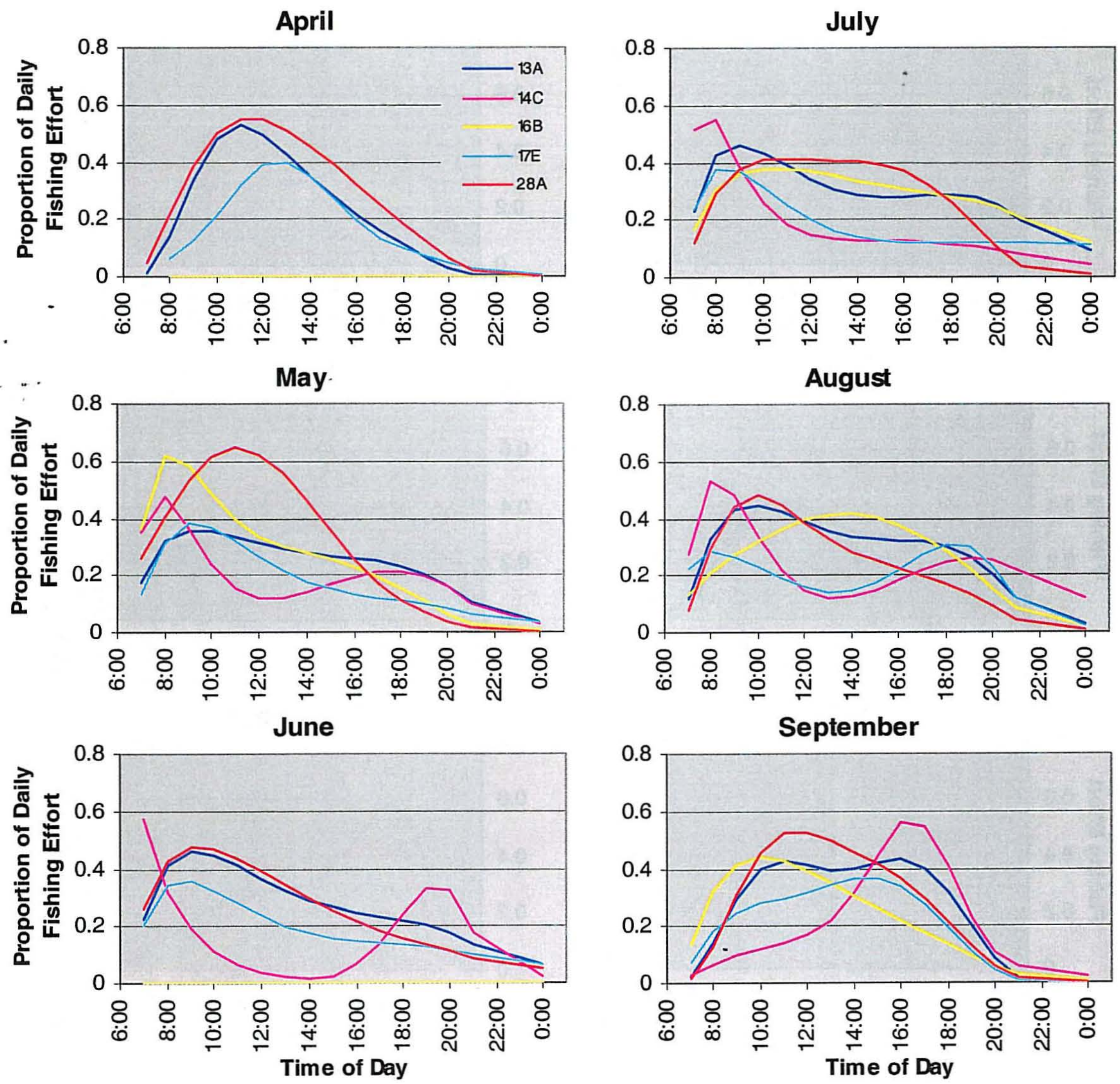


Figure 17. Con't.

1996 – Weekday

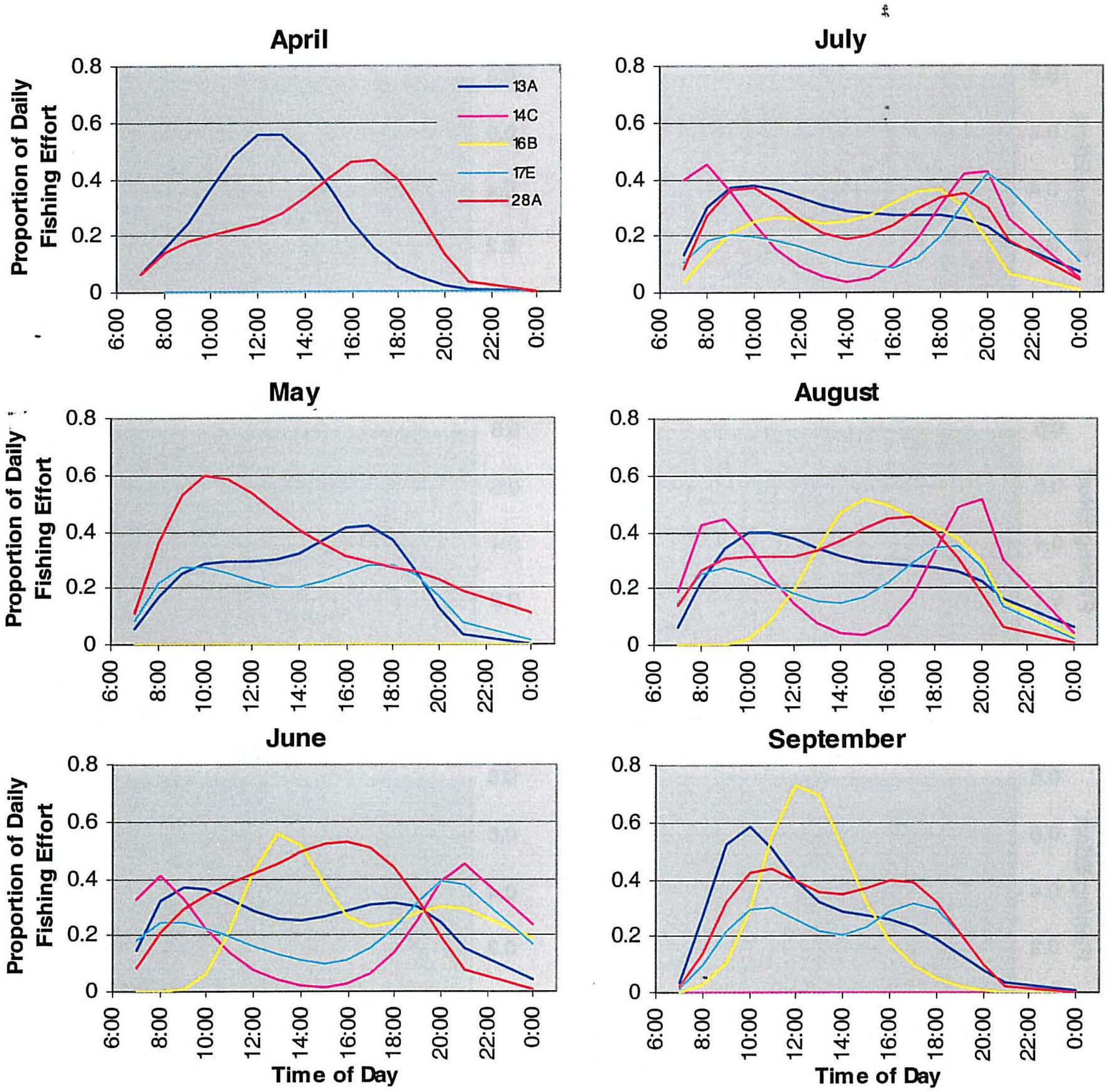


Figure 17. Con't.

1996 – Weekday

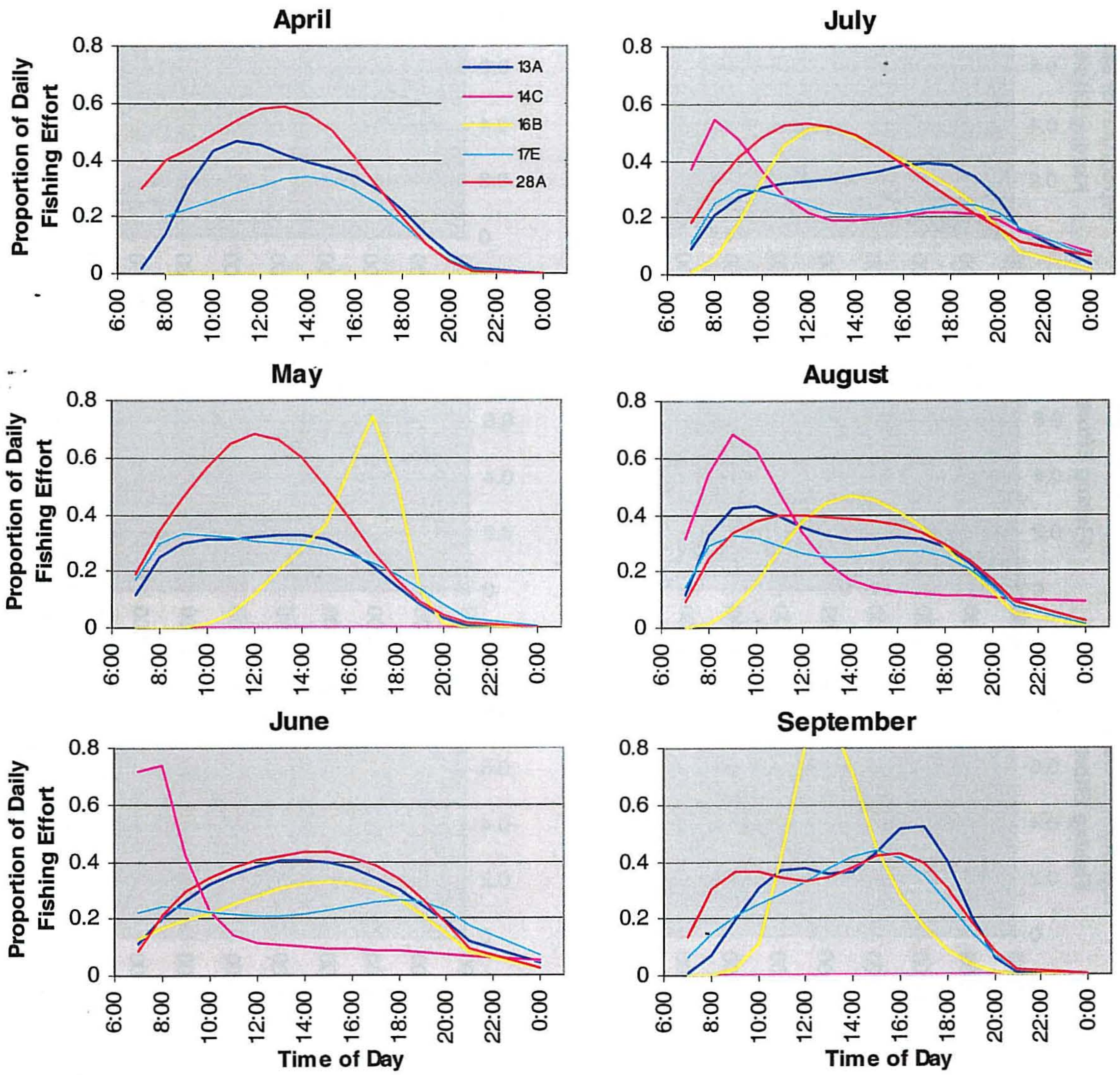


Figure 17. Con't.

2000 – Weekday

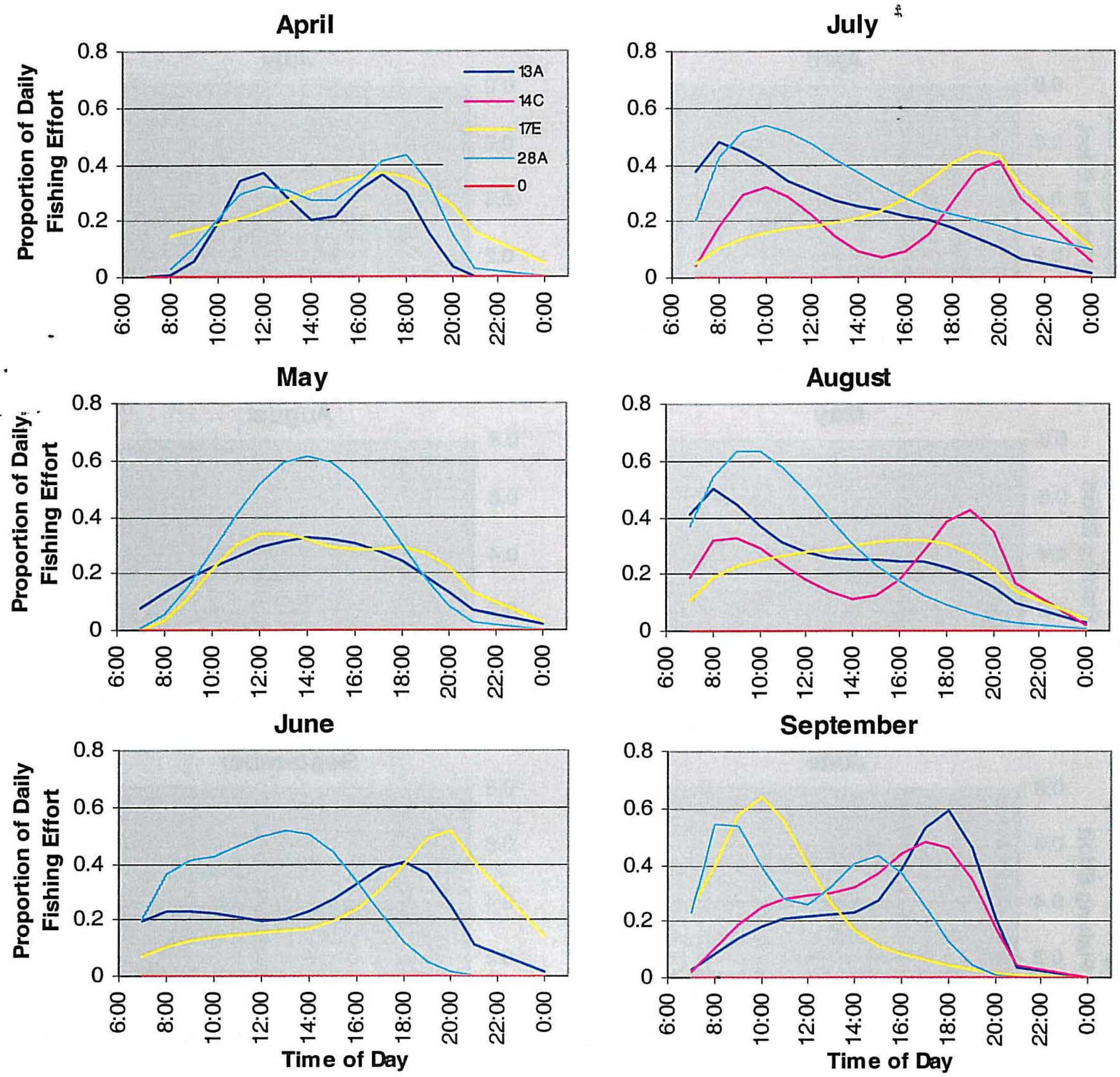


Figure 17. Con't.

2000 – Weekend

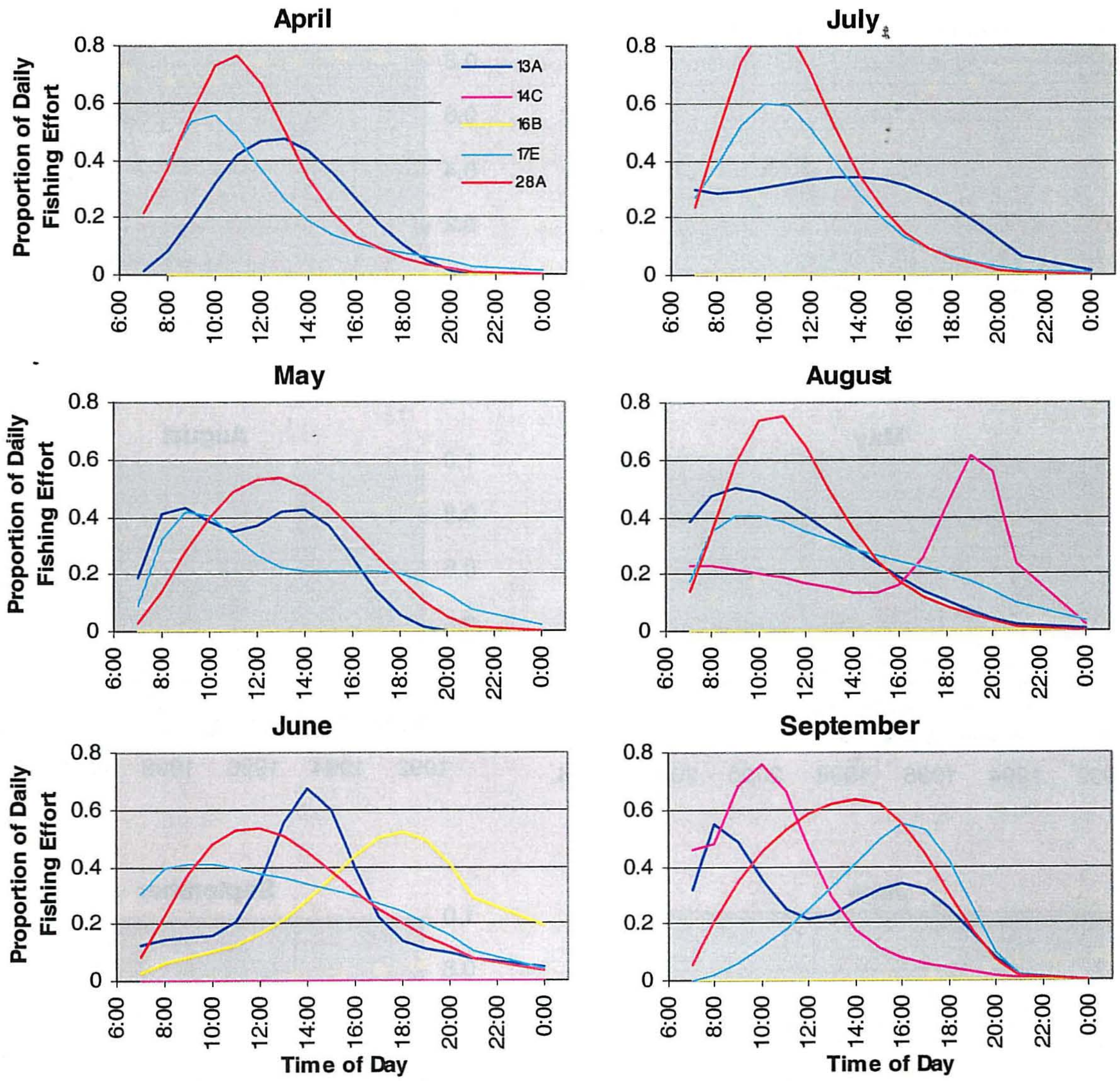


Figure 17. Con't.

Statistical Area 13

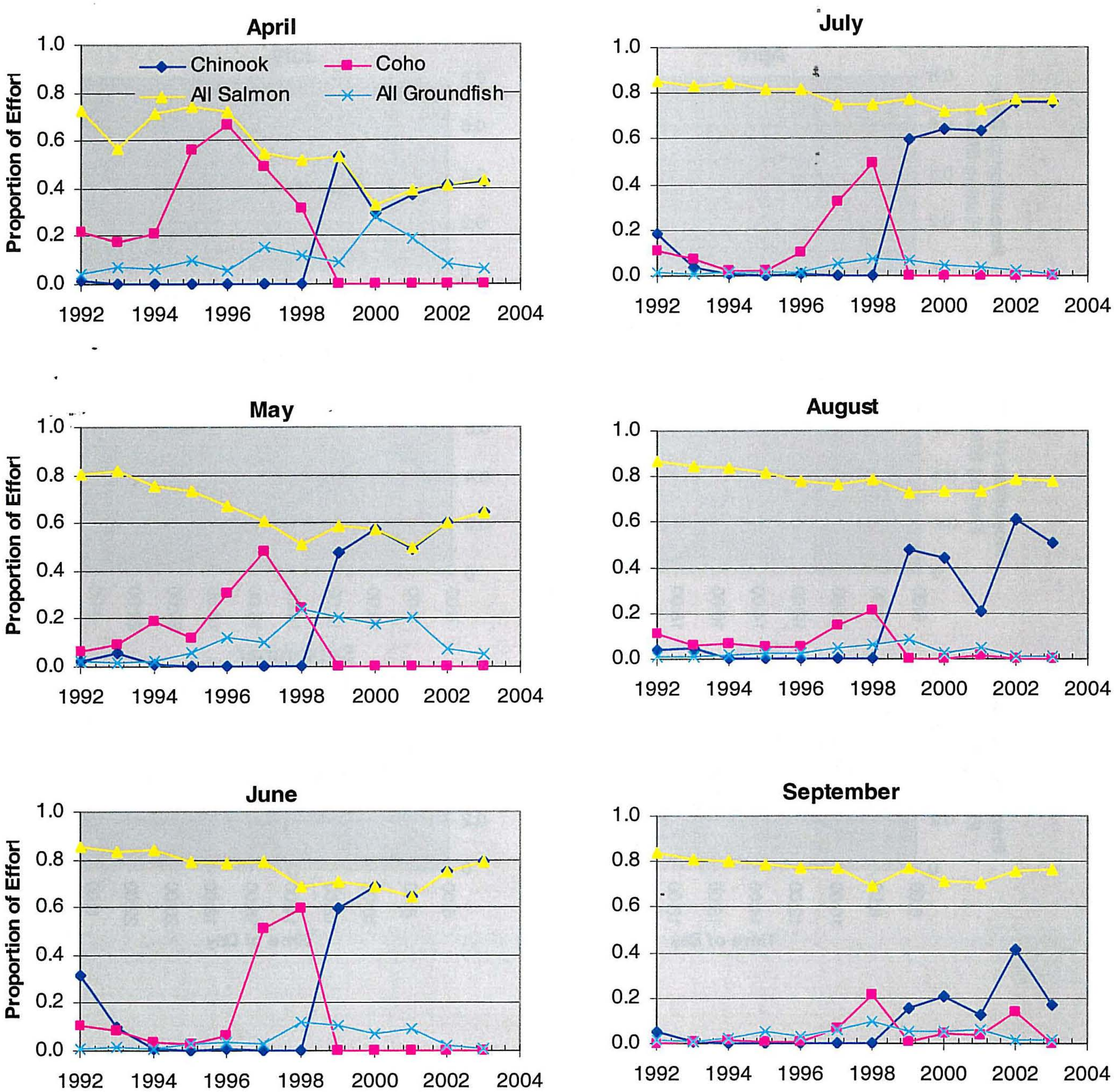


Figure 18. Temporal trends in the proportion of fishing effort targeted at chinook, coho, all salmon, and all groundfish (including lingcod, halibut and rockfish) for statistical areas 13, 14, 16, 17, and 28 by month.

Statistical Area 14

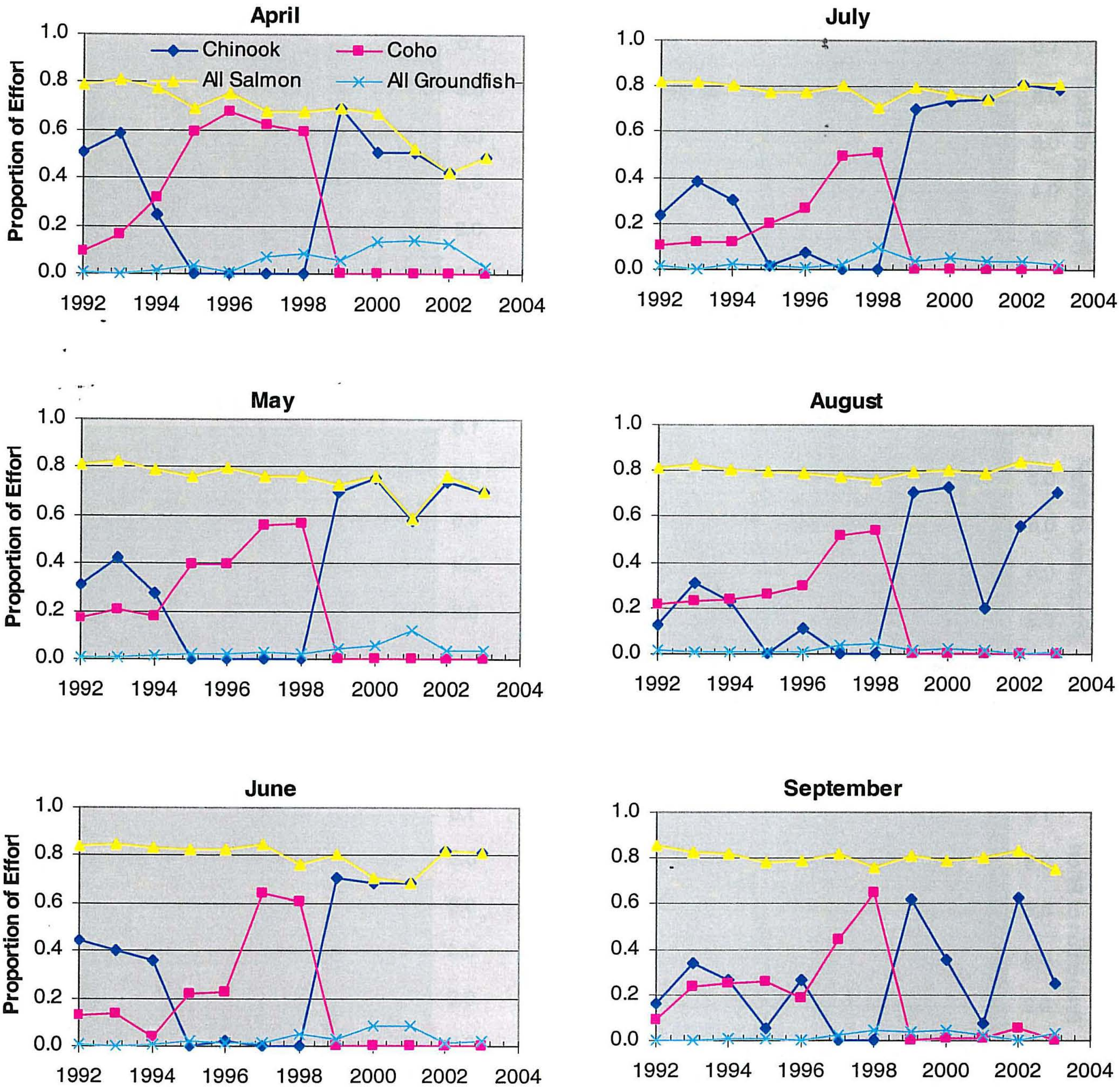


Figure 18. Con't.

Statistical Area 16

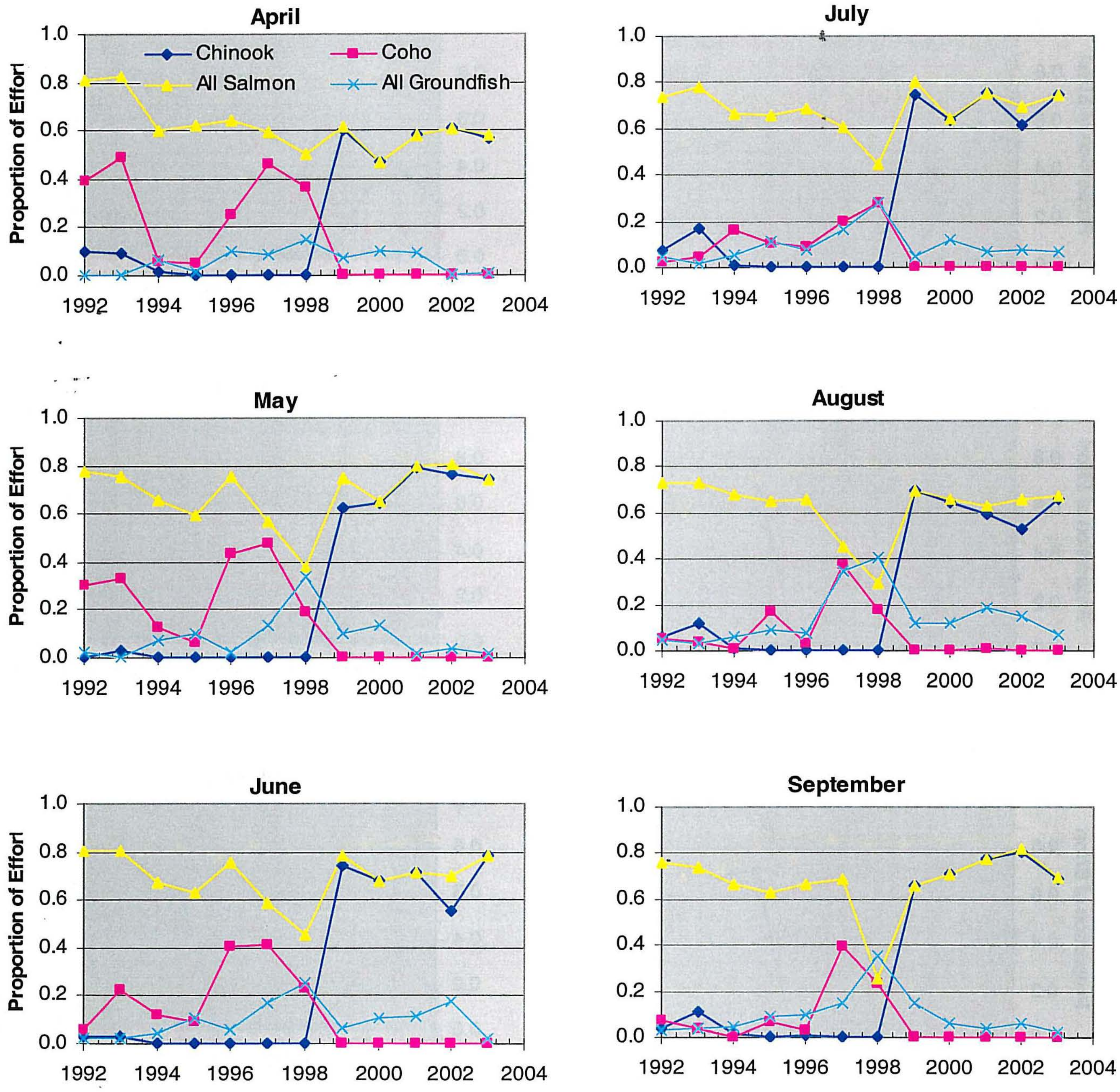


Figure 18. Con't.

Statistical Area 17

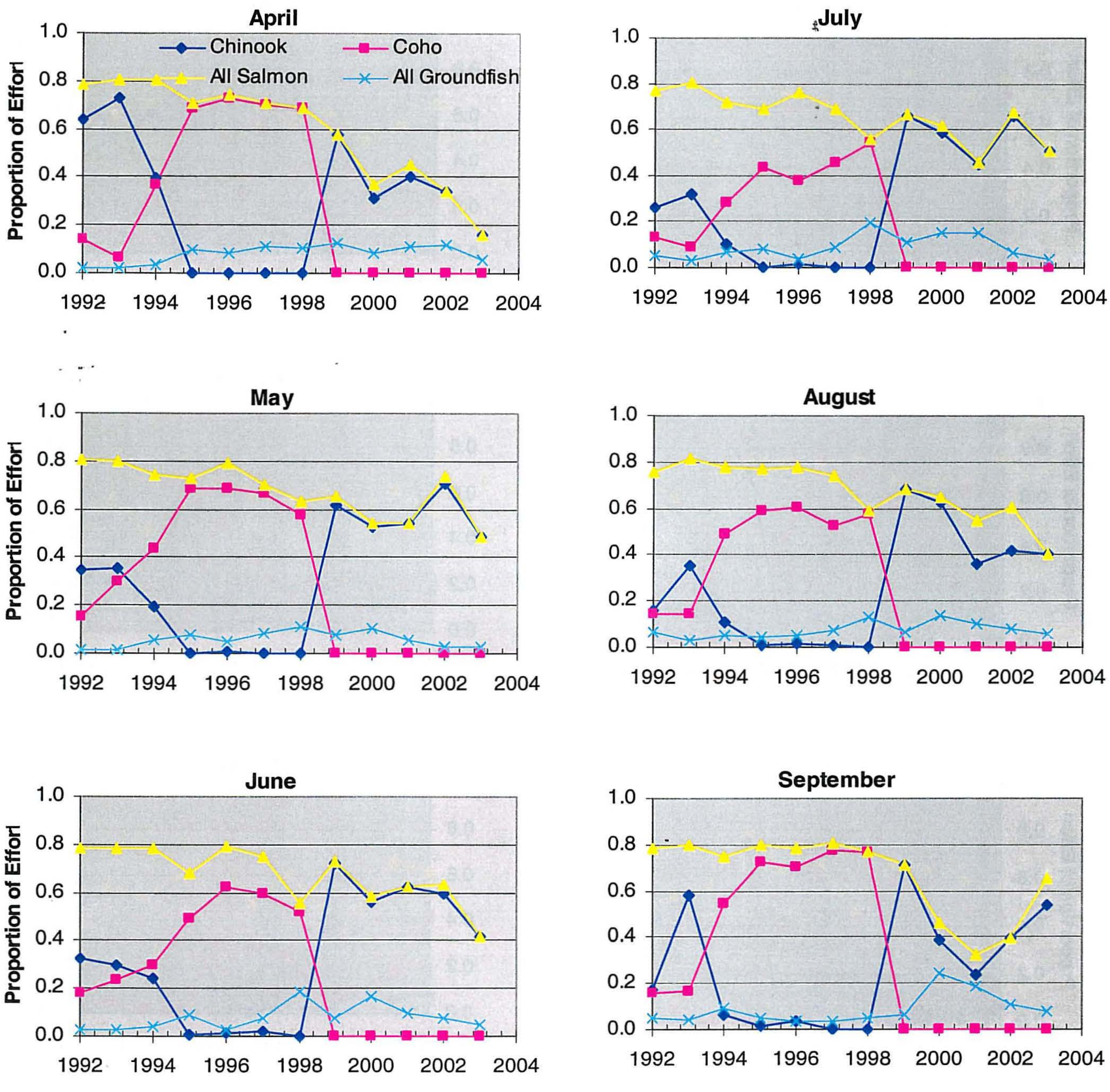


Figure 18. Con't.

Statistical Area 28

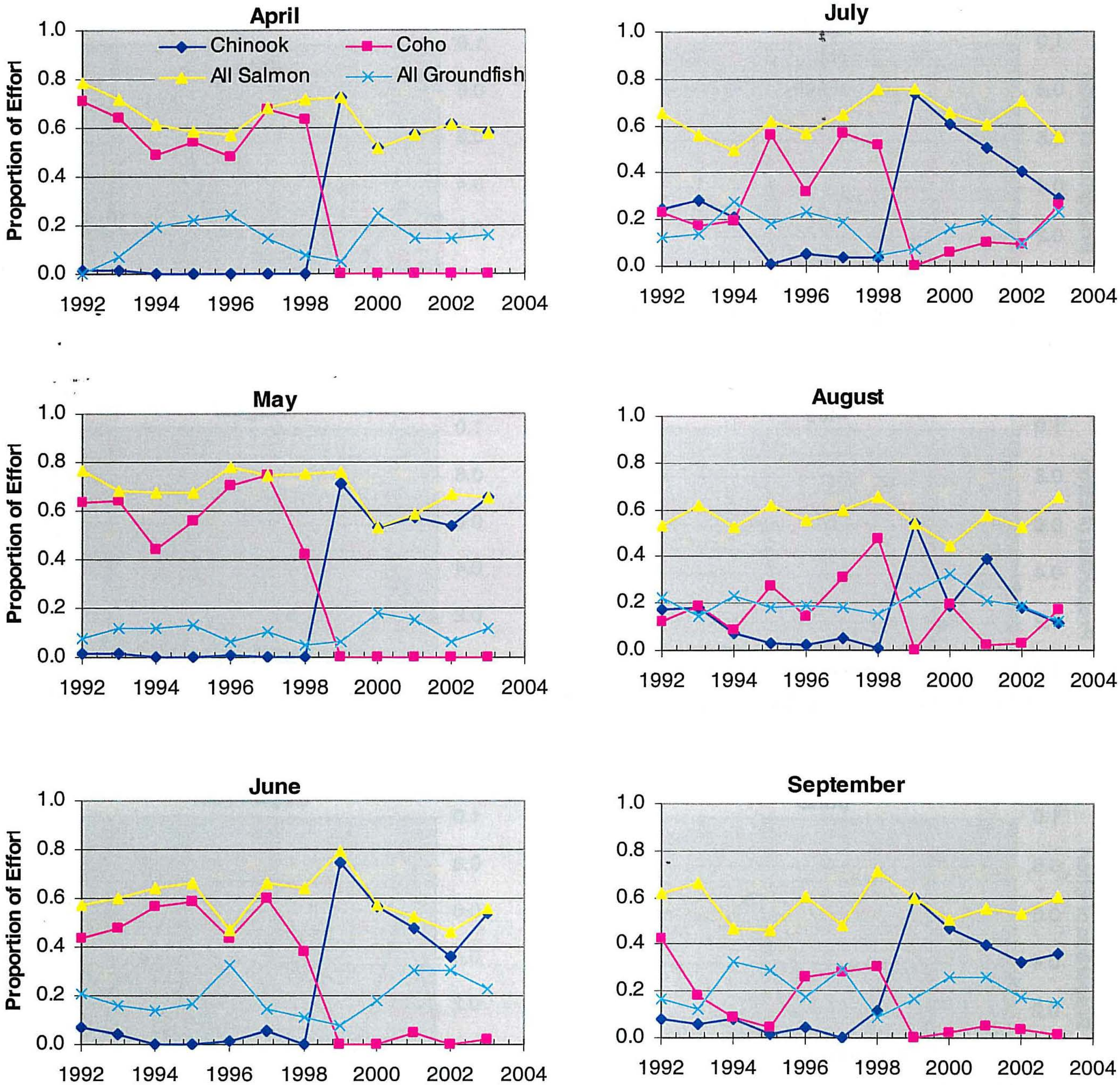


Figure 18. Con't.