AN ANALYSIS OF THREE COMMERCIAL HARVEST ESTIMATION PROCEDURES USED IN THE OKLAHOMA COMMERCIAL FISHERY

BY

MICHAEL LARRY PARRACK

Bachelor of Science

Oklahoma State University

Stillwater, Oklahoma

1965

Submitted to the Faculty of the Graduate College
of the Oklahoma State University
in partial fulfillment of the requirements
for the Degree of
MASTER OF SCIENCE
May, 1970

AN ANALYSIS OF THREE COMMERCIAL HARVEST

ESTIMATION PROCEDURES USED IN THE

OKLAHOMA COMMERCIAL FISHERY

Thesis Approved:

Robert C. Summerfelt
Thesis Adviser

Roy W. Jones

P. Larry Claypool

N. Durham
Dean of the Graduate College

PREFACE

This study was made in order to develop and evaluate methods of estimating inland commercial fisheries harvest and to describe the current Oklahoma commercial fishery. The field work was conducted from July, 1967 through June, 1968 by the Oklahoma Department of Wildlife Conservation under the supervision of Gary Mensinger.

I wish to express appreciation to Dr. Robert C. Summerfelt, Advisory Committee Chairman, and to Drs. Roy W. Jones and Larry P. Claypool, Advisory Committee Members, who reviewed the manuscript and gave advice and helpful criticism. Thanks are given to Dr. Carl E. Marshall for initial statistical counseling and to Dr. David Bee for advisement during analysis of the data. Special thanks are given to Dr. Bradford E. Brown for continuous advisement and direction throughout the entire study. I would like to express appreciation to my wife, Lenora, whose encouragement and understanding made this study possible.

The project was supported by the U. S. Bureau of Commercial Fisheries under Public Law 88-309, Project No. 4-25-D.

TABLE OF CONTENTS

LIST OF TABLES

CHAPTER I

INTRODUCTION

Estimates of commercial fisheries catch are needed to provide precise determination of the annual harvest and economic value of inland commercial fisheries. Harvest and catch statistics are useful in estimating rates of exploitation, size of harvestable stock, and relative population composition. Accurate and precise harvest estimation procedures are therefore valuable tools for fisheries resource management.

In Oklahoma, all past commercial harvest data were obtained from mandatory reports by commercial fishermen of their annual harvest (Jones, 1961; Elkin, 1959; and Houser, 1957). Houser (1957) fished commercial gear experimentally while studying the Lake Texoma fishery. His experimental fishing yielded catch rates similar to those reported by the commercial fishermen.

Workers in other inland commercial fisheries have used variations of the questionnaire method to determine total harvest. In Kentucky, Renaker and Carter (1967) obtained yearly catch figures by mailing questionnaires to commercial license holders. They interviewed five percent of the nonrespondents and expanded the catch of the interviewed sample of nonrespondents to obtain the total catch of the nonrespondents. They added the two figures together to obtain annual harvest figures. Carter (1961) interviewed 20 percent of the licensed Kentucky commercial fishermen and expanded the interview data to obtain an estimate of 1959 harvest. Lambou (1965) estimated the annual commercial harvest in the Atchafalaya Basin Floodway in Louisiana by expanding interview data. Eighteen and six tenths of the commercial license holders were systematically sampled by interview methods. The licensed commercial fishermen's landings were then estimated using a simple expansion estimate as described by Cochran (1963:165). Lambou (1965) interviewed 1.4 percent of the nonlicensed commercial fishermen who had a commercial fishing boat license, and estimated their catch by the same technique as for the licensed fishermen. Estimates of commercial harvest of fishermen without either a commercial fishing boat license or a commercial fishing license were attained by assuming that the average catches of licensed and unlicensed fishermen were equal. These estimates were checked by sampling systematically with questionnaire methods 24.6 percent of the wholesale fish dealers from the parishes in the vicinity of the Atchafalaya Basin Floodway. The total pounds of fish they bought from commercial fishermen were then estimated as before. Bryan and White (1959) obtained catch figures of the commercial fishery of the T. V. A. Lakes of Alabama by personal contacts with fishermen. Most of the information given by fishermen was from memory, and only in a few cases were records used.

In some state fisheries, complete harvest figures are obtained by direct census. Hill (1968) reports that commercial fishermen in North Dakota reservoirs keep complete harvest records of all landings, and no fish are shipped to market until checked by the state commercial fishery supervisor. Sullivan and Warnick (1968) report that in South Dakota the fishery is operated on a contract basis. The state employs a limited number of commercial fishermen to operate on a reservoir and guarantees a specified price for their landings so that accurate records of harvest are kept.

Freshwater commercial fisheries catch figures have therefore usually been obtained by questionnaire methods rather than from extrapolations of sampling data derived from direct observation of the fishermen's catch. The accuracy of catch statistics derived from fishermen's reports will depend upon the accuracy of the fishermen's records and the willingness of the fishermen to cooperate.

Questionnaire surveys do not sample actual harvest, only the reported harvest. An inexpensive, accurate statistical method based on samples of the actual harvest could be used to verify the estimates based on questionnaire data, and to make independent initial estimates. Three such estimates and a questionnaire census were used to estimate the commercial fisheries catch in Oklahoma from July, 1967, through June, 1968. The purpose of this study was to determine which of these estimators is the best usable estimator in situations as existed in the Oklahoma commercial fishery.

Samples of the Oklahoma commercial fishery harvest during the project year were taken on the four large Oklahoma impoundments from which 80 percent of the state's commercial harvest is landed. The sampling universe consisted of four populations. Each population was the commercial harvest of a lake. The four lakes were stratified by month in order to make monthly estimates and to increase the precision of the estimates. The three estimates used include two ratio estimators (Raj, 1968:85-98; Cochran, 1963:154-186) which used fishing effort as auxiliary information, and a simple expansion estimator (Cochran, 1963:165) based on average catch per fisherman trip.

In order to determine the best estimator of the total annual catch in this fishery, it was necessary to analyze the mean square error, as described by Cochran (1963:15) and Raj (1968:29,89) of the three estimates. The mean square error of the estimator $\hat{\phi}$, which estimates the parameter ϕ, is defined (Cochran, 1963:15) as the variance of $\hat{\phi}$ plus the square of the bias; that is,

$$\begin{aligned} \text{M.S.E.}\ (\phi) &= E\ (\phi - \hat{\phi})^2 \\ &= E\ [\phi - E(\hat{\phi})]^2 + [E(\phi) - \phi]^2 \\ &= (\text{variance of } \hat{\phi}) + (\text{bias})^2, \end{aligned}$$

where $E(\hat{\phi})$ means the expected value of $\hat{\phi}$. Therefore, the mean square error is a measure of precision and accuracy.

Accuracy is measured by the bias in that it is a measure of the size of the deviations from the value one wants to estimate. In this case this is the actual total catch, a paramenter or a fixed characteristic of the harvest during the sampling year. Precision refers to the size of deviations from the value that is really being estimated. The estimated total catch would vary from sample to sample if more than one sample of the complete population were taken at a given time interval. In this case precision, therefore, refers to the variance of the estimated total catch.

The precision will be estimated by procedures given by Cochran (1963:89-173) for estimating the variances of the estimators used. The accuracy of the estimates will be determined by comparison with the questionnaire census, by estimating the approximate bias of the ratio estimates, and by using various empirical information obtained during the study such as the relative accuracy of the auxiliary information used in the two ratio estimates.

Determination of sampling procedure and allocation of sample size are important when designing an estimation procedure. The sampling procedure used, including stratification of the populations and the allocations of sample size, will be described and analyzed in order to determine which methods are practical enough to use and still achieve a reduction in variance thus increasing the precision of the estimate. The estimated catch, as determined by the estimators described above, will be used to describe the current Oklahoma commercial fishery.

CHAPTER II

METHODS

General Procedures

All data for the project were collected by Oklahoma Department of Wildlife Conservation biologists. The identity of all commercial fishermen fishing on a given lake was obtained from commercial fishing license records since commercial fishermen are required by Oklahoma law to state the name of the lake they will fish when obtaining the license. Field biologists contacted each fisherman personally at the end of each month and obtained a report of the amount of effort each fisherman expended during the proceeding month. At this time the field biologist also took a questionnaire census of each of the fishermen's catches. Sometimes the fishermen mailed in their catch and effort reports but usually this information was obtained by interviews with the fishermen.

A random sample of fishermen was chosen and arrangements were made to meet these fishermen on sampling days. The field biologist met and accompanied the fisherman while he harvested his catch. As the fisherman picked fish from the net the field biologist measured and weighed each fish and recorded these data. During windy weather, wave action made the weighing of fish impractical so only length data were taken. In every strata, however, at least 30 individuals of each species were weighed so that weights could be calculated for unweighed fish. The field biologist also recorded the number of feet of net used and the number of days that the net had been fished since fish were last removed from it.

The field data were then turned over to the Oklahoma Cooperative Fishery Unit for analysis. All sampled data and reported effort data were coded and transferred to computer cards. Fortran computer programs were written to estimate the total harvest and harvest per effort by three different methods. Other programs were prepared to estimate the harvest of each species, the variation of the catch between and within strata, and the weights of fish of known lengths that were not weighed. IBM 7040 and System/360 Model 50 computers at the Oklahoma State University Computer Center were utilized to make the necessary computations.

Weight Estimation of Individual Fish

When windy weather made weighing of individual fish impossible in the field only length measurements were taken. In every strata at least 30 individuals of each species were weighed and measured so that accurate weights could be calculated for the unweighed individuals. In order to estimate weights the relation $W = c\ L^b$ was assumed where W = weight, b and c are constants, and L = length. The method of least squares (Steele and Torrie, 1960:167-162) was used for estimating the linear regression of log W on log L (in terms of natural logarithms) for each species based on the thirty or more individuals for which both weight and length were recorded. The estimated slope and the antilog of the estimated intercept were the estimates of the constants b and c, respectively, for the given species.

Fortran IV programs were written to estimate the above variables and to calculate the weight for all possible lengths in one tenth inch increments. Coding personnel then obtained weights from computer output for fish that were not weighed. The information was then punched on the data cards that were used to estimate harvest parameters.

Sampling Procedure

The populations sampled were the commercial fisheries catches on Texoma, Grand, Eufaula, and Fort Gibson reservoirs (Table I). These reservoirs were chosen because 83.7 percent of the total commercial harvest, as determined by a 1966 questionnaire census, came from these reservoirs. The remaining harvest came from nine other Oklahoma reservoirs, most of which were small private bodies of water such as city water supply reservoirs. Lake Texoma was included in sampling because it was estimated that over 50 percent of the total Oklahoma commercial fishery harvest came from this impoundment (Jones, 1961). Eufaula was included because the second largest group of fishermen (thirteen) were concentrated on this lake. Lakes Grand and Fort Gibson were sampled because these lakes historically contributed significantly to Oklahoma's commercial fishery harvest (Elkin, 1959; Jones, 1961).

A stratified random sampling procedure was used to estimate the catch on each reservoir. A simple random sample was taken separately for each reservoir within each of 12 nonoverlapping monthly strata. Before purchasing a commercial fishing license each fisherman was required to specify on what lake he planned to fish. All fishermen who could legally contribute landings to a given stratum within a population were known. These fishermen were contacted and asked if they

TABLE I

CHARACTERISTICS OF OKLAHOMA RESERVOIRS WITH A MAJOR COMMERCIAL FISHERY

Lake	Years Old in 1967	Surface Acres	Miles Shore Line	Location	Volume Acre Feet	Rivers Dammed
Texoma	23	93,080	580	S. Central Oklahoma	3,024,900	Red, Washita
Eufaula	2	102,500	600	E. Central Oklahoma	2,378,000	Deepfork, Canadian
Grand	26	46,400	1,300	N. E. Oklahoma	1,643,000	Neosho
Fort Gibson	14	19,100	225	N. E. Oklahoma	365,000	Neosho

would be fishing during the coming month. A sample of the required size was then chosen from the list of fishermen on each reservoir by use of a random numbers table. The chosen fishermen were contacted to arrange a mutually convenient day for the fishermen and the field personnel to go out together. The fisherman trip was the sampled unit. Pounds harvested and effort expended as net length and time fished were the measurements made.

Nonconformaties did occur. Occasionally a fisherman would say he would not be fishing and would fish, or one would say that he would be fishing in a given month and would not fish. Sometimes the fisherman and field biologist would agree upon a sampling date within the month but the fisherman, due to illness, personal reasons, or bad weather, would not show up on the arranged day and place. In such a case the field biologist tried to find another fisherman going out that day or returned without sampling. On days when two persons were available and were using the same transportation, two fishermen were sampled on the same day. In general, the procedure was for field biologists to meet with the fisherman, go out in the fisherman's boat with him, and record the length and weight of each fish as the commercial fisherman removed the catch from the net.

This sampling procedure therefore sampled fishermen trips in that the complete monthly catch of a sampled fisherman was not measured, only the complete catch of a single fisherman day or trip or raise was sampled. However, fishermen trips were not chosen randomly, only fishermen. In order to have chosen fishermen trips randomly, each fisherman on each lake would have to have known a month in advance each day he would fish in the coming month. The investigator feels, however, that chosing the fishermen randomly and the more or less arbitrary selection of the sampling day upon agreement between the field biologist and fishermen resulted in a sufficient random selection of fishermen trips.

The randomization procedure was further violated on Lake Texoma due to a noncooperative group of four to six fishermen who would not agree to letting their catch be sampled. Such fishermen were thus excluded from the samples.

Allocation of Sample Size

The total number of samples taken during the project year was determined by available resources. In order to achieve optimum allocation of samples to strata (Cochran, 1963:95-97) a reasonable idea of the values of the intrastratum variance must be known. No previous studies of the fishery included sampling the actual catch so that no reasonable idea of these quantities was available. Past numbers of fishermen, effort expended, and reported harvest were known and found by inspection to be positively related. However, as described previously, the numbers of fishermen fishing on a stratum were known in advance so that sample size was then allocated proportional to numbers of fishermen. Cochran (1963:102) believes that on a practical basis the precision gained by optimum allocation may not be worth the expense, and that the simplicity and self weighting features of proportional allocation are worth a 10 to 20 percent increase in variance. The investigator therefore felt that allocation of sample size proportional to fishermen numbers, which was known to be related to effort and harvest in past studies, was a usable procedure.

Allocation proportional to fishermen numbers was not strictly followed because of field difficulties. No samples were taken on Lake Texoma during January because field personnel were not available. Grand Lake was closed to commercial fishing during April by an act of the state legislature. During windy months fewer samples were taken than allocated because rough water made the prediction of possible fishing days impossible. During some months extra help was available so that more samples were taken than were allocated.

Analysis of numbers of fishermen trips actually sampled (Table II) show that on Lake Texoma sampling fractions for the various strata ranged from two to seven percent and that three percent of the total number of fishermen trips during the project year were sampled. On Lake Eufaula four percent of the total fishermen trips fished were sampled with the sampling fraction of the separate strata ranging from two to 13 percent. Thirteen percent of the fishermen trips were sampled on Lake Fort Gibson with sampling fractions ranging from four percent to 40 percent. Ten percent of the fishermen trips were sampled on Lake Grand with sampling fractions on the various strata ranging from five percent to 17 percent.

Measures of Effort

Measures of effort were developed to obtain estimates of the total harvest and to describe certain parameters of the fishery. The two measures used were fishermen trips or "raises" and net nights.

A fisherman trip refers to the effort expended by a fisherman during the period he harvests fish from his nets. This measure may also be referred to as a raise or net raise. Catch per raise or catch per

TABLE II

SAMPLING FRACTIONS, NEYMAN SAMPLE SIZE, AND ACTUAL SAMPLE SIZE OF FISHERMEN TRIPS SAMPLED

	Lake Texoma			Lake Eufaula			Lake Fort Gibson			Lake Grand		
	Sample	Allocation		Sample	Allocation		Sample	Allocation		Sample	Allocation	
Stratum	Fraction	Neyman	Actual	Fraction	Neyman	Actual	Fraction	Neyman	Actual	Fraction	Neyman	Actual
1	----	--	--	.031	1	2	.200	3	4	.118	1	4
2	.026	10	8	.068	1	5	.087	2	2	.056	1	2
3	.033	16	10	.076	4	6	.040	4	2	.174	4	4
4	.021	27	12	.133	6	6	.400	4	4	----	--	--
5	.027	32	16	.019	5	4	.097	0	1	.174	4	3
6	.030	12	10	.035	3	5	.053	0	1	.132	2	4
7	.077	3	12	.046	1	5	.167	5	4	.075	3	3
8	.056	1	12	.154	7	6	.075	5	3	.125	2	5
9	.040	6	14	.026	11	6	.104	10	6	.087	15	6
10	.030	2	8	.045	4	7	.294	12	9	.082	9	8
11	.026	4	6	.034	14	6	.125	2	4	.075	5	6
12	.033	4	8	.039	5	4	.136	1	3	.125	5	4

fisherman trip was therefore the total number of pounds harvested by a given fisherman when he went fishing. The length of net and period the net was fished are two sources of variation which are unaccounted for in this measure.

A net night is one foot of net fished for a 24 hour period so that net length and fishing period is adjusted for in the measure. Harvest per net night is the number of pounds caught per 24 hours per hundred feet of net. All nets were approximately the same width (six feet).

Effort figures were obtained by interviewing fishermen. Each fisherman fishing on a given stratum was contacted at the end of each month and was asked the number of nights and length of net he fished during the preceeding month. These figures were then added together within each stratum to obtain the total net nights fished on each stratum. Net nights expended to obtain the sampled catch were determined by the sampler by observing the length of net sampled and asking the fishermen how long the net had been fished.

Effort as raises were obtained in much the same way. At the end of each month each fisherman fishing in a stratum was contacted and asked how many times he went fishing, i. e., removed fish from his nets, during the preceeding month. Raises were easily measured on the samples because each sample was a fisherman trip or raise.

Estimation Procedures

Four estimates were made of the commercial harvest on each lake. One method of estimation was a questionnaire census. Two ratio estimates were made using net nights fished as a concomitant variable. One ratio estimate was adjusted for differences in fishermen catch efficiency and the other was adjusted for variation in daily catch. A simple expansion estimate was also used which expanded the mean catch per fisherman trip by the total number of fisherman trips. Notation and symbolism used to describe these estimators follow Cochran (1963).

As shown in the formulas given, all total estimates were made by using the separate estimation procedure (Cochran, 1963:167) so that stratum parameters were estimated and added together to obtain the total. This method was used because the ratio of catch to effort (R_h) varied significantly from stratum to stratum. Also the X_h were known thus making the method possible. Cochran (1963:98) states that unless the R_h are constant from stratum to stratum the use of a separate ratio estimate is likely to be more precise than a combined ratio estimate.

Questionnaire Census

The questionnaire census was based on the monthly fishermen catch reports required by Oklahoma state laws. During the year the study was conducted the field personnel contacted the fishermen personally every month and gathered this information as effort information was collected.

Estimate I

The first ratio estimate of the total harvest in pounds is of the general form given by Cochran (1963:154) and Raj (1968:85-86) as

$$1:1 \quad \hat{Y}_{Rst} = \sum_{h=1}^{L} \frac{\sum_{i=1}^{n_h} y_{hi}}{\sum_{i=1}^{n_h} x_{hi}} X_h$$

where n_h = the number of fishermen sampled in stratum h,

L = the total number of strata in a given population,

y_{hi} = the total catch of the i^{th} fisherman sampled in stratum h,

x_{hi} = the total net nights expended by the i^{th} fisherman sampled in stratum h, and

X_h = the total net nights expended by all fishermen in stratum h.

In order to know the y_{hi}, the i^{th} fisherman would have had to have his catch weighed and his effort determined each time he fished in the stratum. This was not feasible. The catch of the i^{th} fisherman therefore was estimated from a sample using a ratio estimator. The estimate was usually made from one sample so that the variance about this random variable, and thus the variance about the estimate of it, could not be estimated. On a few occasions a fisherman was sampled twice in a strata. In these few instances both samples were combined and treated in the analysis as one. The y_{hi} were then estimated by

$$1{:}2 \quad \hat{y}_{hi} = \frac{\sum_{j=1}^{n_{hi}} y_{hij}}{\sum_{J=1}^{n_{hi}} x_{hij}} x_{hi}$$

where n_{hi} = the number of samples taken of the i^{th} fisherman's catch in stratum h (one in most cases),

x_{hi} = the net nights fished by the i^{th} fisherman on stratum h,

x_{hij} = the catch of the i^{th} fisherman on the j^{th} sample in stratum h, and

x_{hij} = the net nights fished by the i^{th} fisherman on the j^{th} sample in stratum h.

The estimate of the approximate variance of the ratio estimate of the total catch was estimated following Cochran (1963:168) by calculating

$$1.3 \quad v(\hat{Y}_{Rs}) = \sum_{h=1}^{L} \frac{N_h(1-\frac{n_h}{N_h})}{n_h} (s_{yh}^2 + \hat{R}_h^2 s_{xh}^2 - 2 \hat{R}_h s_{xyh})$$

where
$$s_{yh}^2 = \sum_{i=1}^{n_h} (y_{hi} - \bar{y}_h)^2 / (n_h - 1),$$

$$s_{xh}^2 = \sum_{i=1}^{n_h} (x_{hi} - \bar{x}_h)^2 / (n_h - 1),$$

$$s_{xyh} = \sum_{i=1}^{n_h} (y_{hi} - \bar{y}_h)(x_{hi} - \bar{x}_h) / (n_h - 1), \text{ and}$$

$$R_h = \frac{\sum_{i=1}^{n_h} y_{hi}}{\sum_{i=1}^{n_h} x_{hi}} .$$

The y_{hi}, x_{hi}, and n_h are as explained in formula 1.1, N_h is the total number of fishermen, $\bar{y}_h$ is the average harvest per fishermen, and $\bar{x}_h$ is the average net nights fished per fisherman fishing in stratum h. These latter two values are estimated from samples.

The use of this formula in the present situation differs from that given by Cochran (1963:155) because it did not take into account the fact that the y_{hi} values were estimated and not known. It is apparent from the formula that the estimated approximate variance was calculated as zero if all fishermen fishing in a stratum were sampled at least once. It is important to note that the variance about the estimated y_{hi} was not included. If it had been possible to measure the y_{hi} directly instead of estimating it, or if a sampled fishermen's catch could have been sampled sufficiently so that the variance of the y_{hi} could have been estimated this above procedure would have be sufficient. If the y_{hi} could have been estimated from two or more samples the variance of these estimates could have been included in the variance of the total estimate. Since this situation did not exist this formula estimates only an unknown portion of the variance of estimate I.

The approximate bias of the ratio estimate was estimated using the formula (Cochran, 1963:160-163):

$$1.4 \quad E(\hat{R} - R) = \sum_{h=1}^{L} \frac{1 - \frac{n_h}{N_h}}{n_h (X_h/N_h)^2} (R_h S_{xh}^2 - S_{xyh}).$$

The R_h, S_{xh}^2, and S_{xyh}^2 are estimated by $\hat{R}_h$, s_{xh}^2, and s_{xyh}^2 which are explained in formula 1.3. The values n_h, N_h, and X_h are as explained in formula 1.1.

This estimate does not measure possible bias resulting from estimation of the y_{hi} (formula 1.2) because in most cases only one sample of a chosen fisherman's catch was taken. Therefore, this estimation method does not account for the total bias of the estimate as formula 1.3 did not account for the total variance of $\hat{Y}_{Rse}$. Therefore, it was assumed that the y_{hi} were known, not estimated with a possible bias, so that if all fishermen were sampled in a given strata the estimated bias is zero.

This estimator was used because it was based on the catch per fisherman and fishermen were the units that were randomly chosen to be sampled. The estimator therefore accounted for variability in the fishermen's catch efficiencies and would have been a good estimate if it had been possible to adequately estimate or measure the chosen fishermen's complete catches. Instead only a very small portion of each sampled fisherman's catch was measured.

Estimate II

The second ratio estimator of the total harvest is exactly as described by Cochran (1963:155) and is computed as

$$2.1 \qquad \hat{Y}_{Rst} = \sum_{h=1}^{L} \frac{\sum_{j=1}^{n_h} y_{hj}}{\sum_{j=1}^{n_h} x_{hj}}$$

where n_h = the total number of raises sampled in stratum h,

L = the total number of strata in a given population,

y_{hj} = the total pounds caught on the j^{th} raised sampled in stratum h,

x_{hj} = the total net nights fished to obtain the catch of the j^{th} sampled raise in stratum h, and

x_h = the total net nights fished by all fishermen fishing in stratum h.

This is a conventional ratio estimator using net nights as the concomitant variable. This resulting estimate was based on the assumption that fishermen trips or raises were the sampled units instead of fishermen so that the estimate accounts for catch efficiency differences from sample to sample. The ratio of pounds harvested per net night expended on the samples was expanded by the total number of net nights fished to obtain the estimated total catch for a given stratum. The approximate variance of the estimator was estimated as

$$2.2 \qquad v(\hat{Y}_{Rs}) = \sum_{h=1}^{L} \frac{N_h(1 - \frac{n_h}{N_h})}{n_h} (s_{yh}^2 + \hat{R}_h^2 s_{xh}^2 - 2 \hat{R}_h s_{xyh})$$

where

$$s_{yh}^2 = \sum_{j=1}^{n_h} (y_{hj} - \bar{y}_h)^2 / (n_h - 1),$$

$$s_{xh}^2 = \sum_{j=1}^{n_h} (x_{hj} - \bar{x}_h)^2 / (n_h - 1),$$

$$s_{xyh} = \sum_{j=1}^{n_h} (x_{hj} - \bar{x})(y_{hj} - \bar{y}) / (n_h - 1), \text{ and}$$

$$\hat{R}_h = \frac{\sum_{j=1}^{n_h} y_{hj}}{\sum_{j=1}^{n_h} x_{hj}} .$$

The x_{hj}, x_{hj}, and n_h are as explained in formula 2.1. N_h was the total number of raises fished by all fishermen in stratum h. The $\bar{x}_h$ and $\bar{y}_h$ are the average number of net nights fished and average pounds caught per raise in stratum h as estimated from samples.

Cochran (1963:163) states that this estimates the approximate variance of Y_{Rst}. Therefore, the variance of the estimated ratio, R, is equal to the reciprocal of X_h^2 times the variance of Y_{Rst}. Raj (1968: 88-91) states that the expected value of $(\hat{R} - R)^2$, i.e., the mean square error of $\hat{R}$, which is the variance plus the bias, is equal to the reciprocal of the concomittant variable squared times the variance of the estimated total. Therefore, the formula for the variance of the ratio estimator listed above estimates the bias plus the variance according to Raj and the variance only according to Cochran.

The approximate bias was estimated using formula 1.4 where R_h, S_{xh}^2, and S_{xyh}^2 are estimated by $\hat{R}_h$, s_{xh}^2, and s_{xyh}^2 as defined in formula 2.2 as in N_h. The X_h and n_h are explained in formula 2.1.

Estimate III

A simple expansion estimator (Cochran, 1963:21) based on the average catch per fisherman trip was also used. This estimator is of the form:

$$3.1 \quad \hat{Y}_{se} = \sum_{h=1}^{L} N_h \bar{y}_h .$$

The N_h and $\bar{y}_h$ are defined in formula 2.2. The total catch for a given stratum was therefore estimated by estimating the average catch per fisherman trip from samples and expanding the estimated mean by the total number of fishermen trips made by all fishermen on that stratum. Although the estimator did not account for catch efficiency differences due to length of net or the period the net was fished, it was valuable because of its simplicity and unbiased property.

The variance was estimated using the formula given by Cochran (1963:23)

$$3.2 \quad v(\hat{Y}_{se}) = \sum_{h=1}^{L} \frac{N_h^2 s_h^2}{n_h} \left(1 - \frac{n_h}{N_h}\right)$$

where $$s_h^2 = \sum_{j=1}^{n_h} (y_{hj} - \bar{y})^2 / (n_h - 1),$$

N_h and $\bar{y}_h$ are as defined in formula 2.2, and n_h and y_{hj} are as defined in formula 2.1.

CHAPTER III

RESULTS

Evaluation of Allocation of Samples

One of the major reasons for not attempting Neyman allocation (Neyman, 1934) of samples to the various strata to obtain minimum variance of the estimated catch was that the intrastratum variances were not known. No reasonable idea of such values were available. However, after sampling, it was possible to estimate these variances unbiasedly by calculating

$$S_h^2 = \frac{(y_{hi} - \bar{y}_h)^2}{n_h - 1} .$$

It was then possible to compute Neyman allocation by the formula given by Cochran (1963:97)

$$n_h = \frac{N_h \ S_h}{\sum_{h=1}^{L} N_h \ S_h} n$$

where n_h = the number of fishermen trips sampled in stratum h,

N_h = the total number of fishermen trips fished in stratum h,

y_{hi} = the pounds caught on the i^{th} fisherman trip in stratum h, and

$\bar{y}_h$ = the mean pounds caught per fisherman trip in stratum h.

In order to appraise the method of allocation used, Neyman allocation was calculated and compared with actual allocation for all strata (Table II). Although actual and Neyman allocation differed as may be expected, there was a positive correlation between the two in all populations. The nonparametric Spearmen Rank Correlation Coefficients (Siegel, 1956:202-213) are Lake Texoma, .53; Lake Grand, .64; Lake Eufaula, .45; Lake Fort Gibson, .79. This correlation measure assumes only ordinal data, not normality, and values range from zero to unity. Although these correlation coefficients are not large, they do indicate that the actual allocation was a usable procedure although it did not approach optimum.

Evaluation of Stratification by Months

Stratification is expected to give a more precise estimate than a simple random sample of the same size (Cochran, 1963:98). However, this occurs only if such stratification results in an intrastratum mean square which is smaller than the interstratum mean square. Greater precision results because the variance between strata is, in effect, eliminated. If the reverse is true, i.e., if the within stratum variance is larger than the between stratum variance, precision is lost so that a simple random sample would be better.

Estimation of Mean Squares

In order to estimate intrastrata mean squares for the populations, by finding a weighted average of the individual mean squares within each strata as given by Steel and Torrie (1960:73), the assumption of equality of intrastrata variances must be made. Although Bartlett's chi-square test for homogeneity of variances (Bartlett, 1937) indicated that unless a one in twenty chance occurred the variances were unequal, the method of pooling mean squares was used because it is a weighted average and is the only way to estimate the intrastratum variance. The within mean squares for each separate stratum (Table III) were computed according to Cochran (1963:93).

The variances between strata for each reservoir (Table III) were computed according to Cochran (1963:99-100). These figures are estimated by calculating the variances between monthly mean catch per raise values within the populations.

Reduction of Variance by Stratification

Viewed as an analysis of variance, the breakdown of variance for a given population is: The total between all raises, between strata, and within strata. It then follows that the resulting interstrata and intrastrata mean squares could be tested for equality by use of the F distribution as given by Steel and Torrie (1960:82-83). Therefore, F values were calculated (Table III) and tests for equality of variances were made.

As determined by these F tests the within and between stratum mean squares are unequal unless a one in 200 chance has occurred and an unrepresentative sample has been chosen. The interstratum variance was from 15 to 99 times the intrastratum variance so that from 98.9 percent to 94.1 percent of the total variance was removed by stratification (Table III). Thus, precision was gained by dividing the populations into monthly strata.

TABLE III

INTRASTRATUM AND INTERSTRATUM MEAN SQUARES AND THE PERCENT VARIATION REMOVED BY STRATIFICATION

Population	Interstratum Mean Squares	Intrastratum Mean Squares	F Ratio Between Mean Squares	Interstratum Percent of Total Mean Square
Lake Texoma	396814.0	45638.5	86.95	98.86
Lake Eufaula	357253.0	20882.6	17.11	94.48
Lake Grand	771024.6	45832.6	16.82	94.39
Lake Fort Gibson	62838.5	3920.5	16.03	94.13

Evaluation of Measures of Effort

Effort was measured as the number of feet of net fished per 24 hours and the number of fishing trips made. The latter did not account for net footage fished and time fished.

Although total effort figures were obtained in much the same way, that is by asking the fishermen how much they fished, the accuracy of the information obtained for the two methods was not equal. Fishermen kept no records of the amount of effort expended during the month so that these effort figures were given from memory. A fisherman may well remember how many times he went fishing in the preceeding month with reasonable accuracy. Accurately remembering the number of feet of net fished and the period each net was fished was impossible because lengths of net were continuously pulled and cleaned, repaired, or re-located. Whenever the field biologist was unable to locate and inter-view all fishermen fishing in a given stratum, the field personnel estimated the effort expended by these fishermen. This situation oc-curred frequently although the majority of total effort figures were given by fishermen. These estimates were facilitated by knowledge of the fishermen's gear and the amounts that individual fishermen usually fished. The field personnel then considered the weather during the preceeding month to determine the period the nets were fished thus es-timating the net nights expended by these fishermen. These estimates may have been less than accurate. The field biologist, however, could estimate quite accurately the effort in raises by counting the days that weather conditions allowed the fishermen to fish.

Although net nights as a measure of effort account for variability due to period of fishing and amount of gear fished it was not desirable because accurate measurement of total net nights fished was not possible. Fishermen trips or raises were more accurately measured because of the simplicity of the measurement and therefore proved to be a more valuable figure even though period of fishing and amount of gear were unaccounted for as a source of variation between catches.

Evaluation of Estimators

It is necessary to consider both the accuracy and precision of an estimator in order to appraise it. These two characteristics can be measured by estimating the bias and variance of each estimator. The total harvests, biases, standard errors, and coefficients of variations were therefore compared (Tables IV, V, and VI).

Questionnaire Census

A census of the commercial catch was obtained by requiring fishermen to submit monthly catch reports. Commercial fishermen did not accurately report nonsalable species. Game fish were turned loose after they were picked from the net and other fish that could not be sold were disposed of. Fishermen did not record or accurately remember that portion of the harvest.

Many fishermen did not keep exact records of their catch. Those who kept accurate records took their catch reports from bills of sale while many others kept accurate daily records of their catch. Most fishermen, however, reported what they remembered so that short reporting intervals increased accuracy of reported figures. Weekly reports, therefore, would have yielded more accurate catch figures than the monthly reports did. It was evident that if reporting dates were further apart, say one year on four months, the fishermen's ability to remember their catches correctly would have been reduced so that the accuracy of the questionnaire census would have been reduced. It was also found that occasional sampling of the catch served as a check against gross errors thus improving the accuracy of the reported figures.

Estimate I

The accuracy of estimate I was analyzed by computing the estimated approximate bias (formula 1.4) and by comparing it with other estimates and the questionnaire census.

Although biases were estimated (Tables IV and V), additional bias existed because the y_{hi}'s were estimated. And this bias could not be estimated and included with the first bias because of insufficient samples as explained previously. By excluding the latter unestimated bias, the total bias of estimate I for all populations was 0.03 pounds. Separate strata values ranged from -0.0067 to 0.0344 pounds. This is an extremely small value as compared to the total catch estimate of 2,345,696 pounds.

The ratio estimate is unbiased if $E(y/x) = b\ x$ where b is the slope of the regression of y and x (Cochran, 1963:161). In this application the regression of net nights fished and pounds caught is a straight line through the origin. This gives an unbiased ratio estimate of R.

This estimate, therefore, is not biased as a result of a biased estimate of R. Fishermen kept no records of total monthly effort as net nights expended so that the X_h were inaccurately guessed at by the fishermen which biased the estimate of the total catch. This may be corroborated by comparing estimate I with estimate III and the questionnaire census. The total harvest estimated by estimate I is twice the magnitude of the other two so that the fishermen probably tended to over estimate the total monthly net nights they fished. This occurred probably because fishermen did not account for net sections that were being repaired or cleaned and not fished for intervals of several days. Instead, they reported the total length of gear they could have operated if all gear had been fished continuously.

The precision of an estimate is measured by the variance. The approximate variance of estimate I was therefore estimated by formula 1.3 (Table IV). The combined standard error of estimate I for the four populations is 468,917 pounds and the coefficient of variation is 20 percent. It is important to note that this estimated variance does not include the variance of the estimated y_{hi} as explained in the methods section.

The mean square error is the criterion for comparing estimates and is defined as the variance plus the squared bias (Cochran, 1963:15-16). Because the estimated bias values are extremely small, the variance is essentially equal to the mean square error in this situation.

Estimate II

The bias was estimated according to formula 4.1 where the components are as described in formula 2.2. Unlike estimator I, all bias in the estimator was accounted for in this estimate. The results of the calculations were extremely small. Bias values ranged from -0.001 to

TABLE IV

TOTAL HARVEST, STANDARD ERROR, COEFFICIENT OF VARIATION, AND BIAS AS ESTIMATED BY ESTIMATOR I

Lake	Point Estimate in Pounds	Estimated Bias in Pounds	Estimated Standard Error in Pounds	Coefficient of Variation
Texoma	1,687,418	-0.0137	375,602	22.3
Eufaula	347,000	0.0452	80,426	23.2
Grand	216,253	-0.0452	4,323	2.0
Fort Gibson	95,025	0.0008	8,566	9.0
Total	2,345,696	0.0303	468,917	20.0

TABLE V

TOTAL HARVEST, STANDARD ERROR, COEFFICIENT OF VARIATION, AND BIAS AS ESTIMATED BY ESTIMATOR II

Lake	Point Estimate in Pounds	Estimated Bias in Pounds	Estimated Standard Error in Pounds	Coefficient of Variation
Texoma	1,304,405	0.0030	202,614	15.5
Eufaula	336,379	0.0052	39,528	11.8
Grand	207,217	-0.0005	17,874	8.6
Fort Gibson	86,689	0.0026	9,696	11.2
Total	1,934,690	0.0103	269,712	13.9

0.002 pounds for individual strata. The total bias for all populations was 0.01 pounds as compared to the total estimate of 1,934,690 pounds. The estimate of R was therefore unbiased in this situation.

This estimate, as estimate I, does not agree with the questionnaire census or estimate II so that the estimated total may not be accurate. As in estimate I, this was probably the result of inaccurate total expended effort information, as net nights fished, taken from fishermen interviews. Therefore, although R was estimated without bias, the inaccurate X_h resulted in an inaccurate total estimate.

The variance of estimate II was estimated by formula 2.2. These estimated variances (Table IV), unlike the estimated variances of method I, account for the total variance of the estimator. The total standard error for the combined populations was estimated to be 269,712 pounds so that the coefficient of variation of the estimated total by estimate II is 13.9 percent. Because the bias is negligible, the mean square error is therefore equal to the variance as for estimate I.

Estimate III

The questionnaire census and the simple expansion estimate of the total catch agree closely (Table VI). The questionnaire census is 100,000 pounds lower, which may be a result of a partial lack of reporting of nonsalable species. Estimate III is believed to be the most accurate because it agrees closely with the questionnaire census, it is unbiased by nature, and the total effort information incorporated in it, i.e., total fishermen trips, is believed to have been accurately measured.

TABLE VI

TOTAL HARVEST, STANDARD ERROR, AND COEFFICIENT OF VARIATION BY ESTIMATE III AND TOTAL HARVEST BY THE QUESTIONNAIRE CENSUS

Lake	Estimate III Point Estimate in Pounds	Estimate III Standard Error in Pounds	Estimate III Coefficient of Variation	Questionnaire Census
Texoma	834,915	203,907	24.4	602,355
Eufaula	141,258	5,845	4.1	173,484
Grand	94,895	25,319	26.7	172,504
Fort Gibson	55,468	5,338	9.6	64,003
Total	1,126,536	240,409	21.3	1,012,355

The precision of estimator III was estimated by formula 3.2. This estimated variance (Table VI) is large as compared to the estimated total so that the resulting coefficient of variation is 21.3 percent for the combined populations. This estimate was then the least precise of the three statistical estimates. The resulting mean square error as estimated from the data is equal to the variance due to the unbiased nature of the estimator.

Comparison of Estimators

As described above, estimates I and II were biased not because of biased estimates of $\hat{R}$ (this bias was negligible), but because the X_h were inaccurately reported. These estimates are therefore unacceptable unless the investigator can be sure of accurately obtaining total effort values. If total effort values are known, then estimates I and II are good methods because in this situation $\hat{R}$ is unbiased for all practical purposes and the estimators are precise as shown by their small coefficients of variation which were lowest of all estimates used.

The variance of estimate I was greater than the variance of estimate II as shown by the standard errors (Tables IV and V). This may have occurred because the variation of the fishermen's total catches, as estimated from one sample, was greater than the variation of the catch between fishermen trips.

Estimate I, which accounted for differences in fishermen catch efficiency, length of net fished, and period net was fished, was not satisfactory in this study. Because of inaccurately reported total effort figures and insufficient sampling, which resulted in an unestimated monthly harvest of individual fishermen, this estimator is not applicable. This procedure could be useful where sufficient sampling and correct measurement of total expended effort is possible.

Although estimate II has the smallest mean square error it was biased because of inaccurate measurement of the total effort as in estimate I. Estimates of bias do not account for this source of error, this value is assumed known, so that this inaccuracy was not incorporated in the mean square error term. This estimator is useful when the X_h can be measured accurately because it does account for differences between fishermen trips, feet of net fished, and length of time nets were fished.

While estimators I and II were invalid in this study, it is felt that estimator II is a potentially useful tool in estimating the total harvest. Its effectiveness, and hence usefulness, depends upon accurate records of total net nights fished. Records of each trip, such as length of net and time fished to the nearest hour for each net, would validate estimator II if gained from each commercial fisherman. There is very little hope for validating estimator I, since it is not practical to observe each trip made by each fisherman in the sample for an entire month.

The simple expansion estimate (estimate III) was the best estimate of the total annual harvest not because of the precision of the estimate, but because the expansion term (fishermen trips) was accurately measured. The estimate was the least precise of the estimates used. This resulted in a large coefficient of variation. However, because of the unbiasness of the estimator and the possibility of accurately obtaining total effort information, this estimator is best in situations as existed during the study.

Estimate III and the questionnaire census compare closely (Table VI). The estimated total catch by estimate III of salable species (1,018,147 pounds) was 61,437 pounds more than the total by the questionnaire census of salable species (956,672 pounds). This discrepancy is not meaningful when compared to the standard error of estimate III. It is probably, in part, the result of small errors in the reporting of salable species by the fishermen. If the unsalable species are included in the estimate, the difference, in total harvest between the two methods is 114,001 pounds which is almost double the above figure indicating that the questionnaire census method is less accurate if nonsalable species are included.

The commercial fisheries catch in Oklahoma, as determined from fishermen reports, has increased since 1958 although the number of fishermen has remained relatively constant. It is probable that increasing personal contact by the Oklahoma Department of Wildlife Conservation personnel has resulted in greater accuracy in these reports.

The accuracy of the questionnaire census may have been improved during the study by continual personal contact with the fishermen. Sampling the catch served as a check against gross errors. The accuracy was also improved by short reporting intervals because the majority of fishermen did not keep records of daily catches and catch reports were made from memory.

These findings indicate that the questionnaire census method, as used by Jones (1961), Elkin (1959), Houser (1957), Renaker and Carter (1957), Carter (1961), Lambou (1965), Bryan and White (1959) and other workers for estimating inland commercial harvest, may be inaccurate.

This method is most accurate if reporting intervals are short, intense personal contact and occasional sampling of the catch is made, and the estimate includes only salable species.

CHAPTER IV

DESCRIPTION OF THE FISHERY

Oklahoma's commercial fishery consisted of approximately 80 fishermen who fished singly or in pairs from small boats using gill and trammel nets. The nets were set and fished continuously throughout the season and were removed only when necessary for repairs or cleaning, or when shifted to other areas.

Oklahoma Commercial Fishing Laws

By statue, nets must be three inch bar mesh or larger, must be located four feet below the water's surface, and must be at least 100 yards from the bank. Nets must be removed each Friday and kept out until Monday from June 1, to September 7, so that no nets can be in the water through the weekend. This results in a four day fishing week in the summer. In addition, the spring season on some lakes has been closed to commercial fishing by the Oklahoma Legislature. In 1965, all lakes except Texoma were closed to commercial fishing from March 21 through May 21. In the spring of 1968, Grand Lake was closed during April.

Species Composition

Buffalo spp., flathead catfish, carp, freshwater drum, river carpsucker, and gar spp. are the major commercial species landed in

Oklahoma. The species composition (Table VII) was obtained by estimating the pounds caught of each species by the simple expansion estimate based on average catch per raise (Estimate III) and finding the percent of the total that each species contributed to the catch. Fishermen on the eastern reservoirs (Eufaula, Grand, and Fort Gibson) depended upon flathead catfish much more than fishermen on Lake Texoma. The Lake Texoma catch was 65.3 percent buffalo and carp, carpsucker, and gar comprised 30.6 percent of the catch. Catch compositions on Lakes Grand and Fort Gibson were similar. Salable species landed on these lakes in order of importance were buffalo, carp, flathead catfish, and paddlefish. Lake Eufaula was unique in that the largest single contribution to the catch was flathead catfish rather than buffalo. Lakes Eufaula and Fort Gibson were similar in that channel catfish, a game species which had to be released, made up a significant percentage of the catch. Of this, 3.6 percent is channel catfish (Table VII).

Buffalo and flathead catfish contributed most towards the fishermen's income with other species being of secondary importance. Although a large portion of the harvest was carp, this species contributed very little to the income of the fishermen because of its low market value.

Numbers of Commercial Fishermen

Commercial fishermen in Oklahoma are required to purchase a yearly license which cost $50.00 in 1967 and 1968. On the application for the license the fisherman was required to state a preference for the lake or lakes he desired to fish. In 1967 there were 82 fishermen fishing 13 lakes. In 1968, these figures were 82 and eight respectively.

TABLE VII

PERCENT SPECIES COMPOSITION OF THE CATCH

Species	Total	Lake Texoma	Lake Grand	Lake Eufaula	Lake Gibson
Buffalo spp.	55.9	65.3	36.8	24.8	38.3
Flathead catfish	10.4	2.4	13.3	50.8	13.9
Carp	15.6	17.9	15.9	3.7	16.1
Drum	1.4	0.8	5.8	0.9	2.5
River carpsucker	5.4	6.9	2.4	0.6	2.6
Gar spp.**	5.4	5.8	5.4	4.0	2.9
Paddlefish	1.4	---	12.6	---	4.1
Whitebass	0.3	0.2	1.1	0.1	0.7
Shad**	0.1	0.2	+0.0	+0.0	+0.0
Blue catfish*	0.1	0.1	---	---	---
Channel catfish*	3.6	0.3	5.7	14.9	18.1
Crappie spp.*	0.3	0.3	0.5	0.1	0.5
Others	0.1	---	0.3	---	0.3

*Game Species

**Unmarketable species

+0.0 Less than 0.05 percent

--- None

About half of the fishermen fished on Lake Texoma (Table VIII). Lakes Grand, Eufaula, and Fort Gibson accounted for 33 percent.

Fishing Effort

Fishermen fished nine million net nights on Lake Texoma which was the greatest amount of effort expended on any one lake (Table IX). Lake Eufaula fishermen expended five million net nights followed by those on Lake Grand who fished two million net nights and Lake Fort Gibson fishermen with one million net nights. On a seasonal basis, most of the effort was expended in the fall and spring quarters.

Both gill and trammel nets were used in these fisheries but the proportion differed markedly from lake to lake (Table IX). Trammel nets were most frequently used on Lake Eufaula, which was also the lake with the most intensive flathead catfish fishery although increased harvest of flathead catfish is not necessarily a result of the use of trammel nets. Most of the fishing was done with nets from three to three and one half inch bar mesh. On Lakes Grand and Fort Gibson, fishermen used larger mesh in the spring to catch paddlefish which was important on those lakes. On Lake Eufaula, four inch mesh was the usual size but five inch mesh was not uncommon.

Catch Rates

Fishermen harvested 193 pounds per fishing trip or 4.42 pounds per net night (Table X). The averages over all lakes were obtained by weighing the average for each lake by the pounds harvested on that lake.

TABLE VIII

NUMBER OF ACTIVE COMMERCIAL FISHERMEN BY LAKE AND MONTH

Month	Year	Lake Texoma	Lake Grand	Lake Fort Gibson	Lake Eufaula
July	1967	17	4	3	6
August	"	16	4	3	9
September	"	19	5	3	11
October	"	17	5	3	11
November	"	21	5	3	10
December	"	22	5	4	10
January	1968	22	4	3	10
February	"	27	4	4	10
March	"	30	4	4	10
April	"	29	-	3	10
May	"	28	3	4	13
June	"	24	4	4	12

TABLE IX

PERCENT OF FISHING EFFORT EXPENDED WITH VARIOUS GEAR

Lake	Percent of Effort by Mesh Size in Inches								Percent Gill Net	Percent Trammel Net	Total Net Nights Fished
	3.00	3.25	3.50	4.00	4.5	5.0	5.5	6.0			
Eufaula	24.6	11.5	25.5	27.3	6.1	4.3	0.3	---	57.2	42.7	5,222,484
Fort Gibson	63.8	2.9	21.6	9.5	---	2.0	---	---	69.1	30.8	976,698
Grand	53.8	4.7	27.7	---	9.1	3.7	---	0.7	95.2	4.7	2,378,622
Texoma	24.4	9.0	50.0	4.1	2.0	9.5	---	0.5	98.7	1.2	9,129,300

TABLE X

ANNUAL HARVEST RATES

Lake	Average Catch Per Raise	Average Catch Per 24 Hours Per 100 Feet of Net
Eufaula	96 pounds	3.57 pounds
Gibson	157 pounds	2.14 pounds
Grand	225 pounds	3.14 pounds
Texoma	208 pounds	5.03 pounds
Weighted Average	193 pounds	4.42 pounds

Catch rates varied drastically from month to month (Table XI). Catch rates were highest in the spring, moderate in the fall, and low in the summer and winter. Catch rates on Lake Eufaula were very low throughout the year but they did follow the same seasonal trend as the other lakes. Catch per 24 hours per 100 feet of net ranged from 1.7 pounds during August on Lake Eufaula to 8.7 pounds during June on Lake Texoma. Harvest per raise ranged from 23.9 pounds per raise on Lake Eufaula during July to 643.3 pounds per raise on Lake Grand during March.

Average Size of Fish Caught

The average lengths in tenths of inches and weights in tenths of pounds of the various species were computed separately for each lake for each quarter to compare seasonal trends in sizes captured. No seasonal trends were found.

Mean length of buffalo captured ranged from 18 to 22 inches and 3.3 to 7.4 pounds. The larger fish (20 to 22 inches in average length) were from Lake Texoma. Buffalo mean lengths were 19 inches on other lakes. The larger size flathead catfish (24 to 26 inches) were captured in Lakes Texoma and Eufaula. Flathead catfish from Lakes Grand and Fort Gibson had mean lengths of from 22 to 23 inches. Average weights ranged from six to 17 pounds. Blue catfish in Lake Texoma ranged from 25 to 29 inches in average length. The average weights ranged from 6.8 to 14.9 pounds. Gar ranged from 28 to 42 inches and from three to 15 pounds in average size. Paddlefish ranged between 46 to 59 inches in average length and from 14 to 29 pounds in average weight. The overall

TABLE XI

MONTHLY CATCH RATES BY LAKES

Month	Lake Eufaula		Lake Gibson		Lake Grand		Lake Texoma	
	Pounds Caught Per Raise	Pounds Caught Per Net Night	Pounds Caught Per Raise	Pounds Caught Per Net Night	Pounds Caught Per Raise	Pounds Caught Per Net Night	Pounds Caught Per Raise	Pounds Caught Per Net Night
July	23,9	1.1	144.7	3.1	145.6	4.2	84.0	2.7
August	38.5	0.7	115.9	3.5	179.7	3.7	66.1	2.1
September	57.8	0.8	146.3	2.5	190.1	3.5	170.8	5.0
October	202.9	2.6	145.6	2.5	142.1	3.1	98.4	4.0
November	119.5	2.1	90.1	1.9	111.6	1.9	208.6	6.3
December	55.1	1.2	174.6	1.4	152.4	2.0	157.8	2.8
January	42.6	1.2	76.4	2.1	204.5	1.0	---	---
February	122.0	2.2	160.0	3.6	137.8	4.8	238.3	2.5
March	116.1	2.1	245.1	1.9	643.3	3.2	447.2	7.0
April	165.9	2.8	222.0	4.3	---	---	333.9	6.9
May	115.1	5.1	179.3	6.6	461.9	7.7	284.7	7.3
June	82.2	3.5	210.0	4.2	108.2	4.1	192.3	8.7

average size was 56 inches and 26 pounds. White bass were smallest (13.2 inches and 0.8 pounds average) in Lake Texoma. The sizes on Lakes Grand and Fort Gibson (15.0 and 15.6 inches and 2.2 and 2.1 pounds) were very similar. Average size of channel catfish was slightly greater on Lake Eufaula than in the other lakes (mean length 23.8 inches; mean weight 6.6 pounds).

Yield Per Acre

Total annual commercial harvest was expressed in terms of pounds per acre (Table XII). Lake Texoma, which had 59 percent of the fishermen surveyed, had an annual yield of 8.96 pounds per acre as estimated by the simple expansion estimate (estimate III). Lake Texoma is also possibly more productive because of a larger growing season due to its more southerly location. On the average, Oklahoma waters may be said to yield 5.4 pounds per acre of commercial fish, but consideration must be given to the location of the lake in question if the figures are to be used specifically. The eastern Oklahoma lakes yielded approximately three pounds per acre while Texoma yielded approximately nine pounds per acre during the period of this study.

Jenkins (1967) reported that the standing crops of fishes, other than clupeids, on Lakes Grand, Fort Gibson, and Texoma were 236, 124, and 145 pounds per acre respectively. The commercial harvest on those lakes, as found by the simple expansion estimate, was 2, 3, and 9 pounds per acre respectively so that at most only approximately six percent of the standing crop (excluding clupeids) was harvested commercially.

TABLE XII

COMMERCIAL HARVEST IN POUNDS PER ACRE

Lake	Estimate III	Questionnaire Census
Eufaula	2.93	3.61
Fort Gibson	2.90	3.35
Grand	2.04	3.71
Texoma	8.96	8.99
Average	5.44	6.03

Total Harvest

The total commercial harvest and corresponding standard error on the Oklahoma lakes studied (Texoma, Grand, Fort Gibson, and Eufaula) from July 1967 to July 1968 was estimated to be 1,126,536±240,409 pounds by estimate III, the simple expansion estimate. This figure agreed closely with the questionnaire census value of 1,012,355 pounds and with the ratio estimate II (which emphasized differences between samples rather than fishermen) of 1,934,690±269,712 pounds. Of the total Oklahoma harvest 83.7 percent was taken from the lakes sampled as determined from a 1966 questionnaire census. After expanding on this basis, the total Oklahoma harvest for the project year was 1,345,921 pounds by the simple expansion estimate.

The monthly distribution of the total catch was estimated by estimate III for all lakes combined (Table XIII). The peak harvest period occurred during the spring (March through May) although February and June were also important months. There was a lesser peak from September through November. Harvest in mid-summer and mid-winter was very low. The spring fishing season (February, March, April, May, and June) accounted for 67 percent of the catch and the fall season (September, October, and November) accounted for 22 percent of the catch.

Discussion

The freshwater commercial fishery in most other states in mid-America differs from that in Oklahoma in two ways. The first is the wider range of gear used and the second is the extensive use of river

TABLE XIII

MONTHLY DISTRIBUTION OF COMMERCIAL HARVEST AS ESTIMATED BY ESTIMATE III

Date	Estimated Harvest in Pounds	Percent of Total Estimated Harvest
July, 1967	25,035	2.2
August, 1967	31,568	2.8
September, 1967	93,508	8.3
October, 1967	73,093	6.5
November, 1967	81,060	7.2
December, 1967	52,581	4.7
January, 1968	11,203	1.0
February, 1968	90,833	8.1
March, 1968	167,385	14.9
April, 1968	203,329	18.9
May, 1968	212,562	18.9
June, 1968	84,432	7.5

fisheries in other states. Rivers which are intensively fished commercially include the Mississippi, Arkansas, Missouri, Atchafalaya, Ohio, and Tennessee Rivers (Lyles, 1968).

Renaker and Carter (1967) reported that in Kentucky such diverse gear as hoop, wing, trammel, and gill nets, drag and bait lines, seines, cast nets, shad dippers, and even rod and reel are used. Basket traps are utilized in the Illinois portion of the Mississippi River (Starrett and Barnickol, 1955) and haul seines in the Iowa section (Carlander, 1954). Louisiana allows seines and hoop nets of one inch bar mesh to be used in the commercial fishery (Lambou, 1965). Both North Dakota (Hill, 1968) and South Dakota (Sullivan and Warnick, 1968) have hoop net fisheries. These differences in gear must be kept in mind when comparing Oklahoma's commercial fisheries with those of other states.

Even where a gill and trammel net fishery is operating, comparisons are difficult because of the differences in mesh size. Byrd (1956) reported that tidal streams in Alabama were fished with trammel nets with 1-1/2 and 1-5/8 inch bar mesh. North Dakota (Hill, 1968) laws are even more restrictive than Oklahoma laws as the minimum bar mesh size is three and one fourth inches. Of the studies reviewed from the literature only Lambou (1965), on the Atchafalaya Basin Floodway in Louisiana, reported gear types and mesh sizes similar to those used in Oklahoma.

Oklahoma ranks low in total harvest as compared to other states in the Mississippi River drainage fisheries. Lyles (1968) reported the 1966 Wisconsin catch as 12 million pounds, the Illinois and Arkansas catch as 5 million pounds each, and the Louisiana and Tennessee harvest as being 4 million pounds each. The 1967-68 Oklahoma catch of 1.1

million pounds compared closely with the 1966 Texas harvest of 1.3 million pounds (Lyles, 1968). In 1966, Oklahoma ranked thirteenth in commercial landings of the 25 states in the Mississippi River Drainage.

In Oklahoma 5.4 pounds per acre were harvested; this was slightly below the average weighted mean from 46 reservoirs of 7.0 pounds per acre given by Jenkins (1967). It was far below the 21.7 pounds per surface acre reported by Bryan and White (1959) for T. V. A. lakes in Alabama. Lambou (1965) reported 12.2 pounds per surface acre on the Atchafalaya Basin of Louisiana while 19.2 pounds per surface acre was reported as harvested on the Mobile Delta (Spencer, Swingle, and Scott, 1966). The Oklahoma figure was larger than the 1.4 pounds per acre reported for Oahe Reservoir in South Dakota (Sullivan and Warnick, 1968).

Average catch rates were 4.4 pounds per 24 hours per 100 feet of net and 193 pounds per fishermen trip on the lakes studied in Oklahoma. These catch rates are larger than the 61 pounds per fishermen trip reported for Oklahoma in 1957 by Elkin (1959) and the 56 pounds per fishermen trip reported for Oahe Reservoir in South Dakota (Sullivan and Warnick, 1968). During the project year, buffalo, flathead catfish, and carp accounted for the bulk of the commercial catch in Oklahoma. Lyles (1968) reported similar catch compositions in other Mississippi River drainage fisheries. The Kentucky harvest is made up of catfish, gizzard shad, buffalo, and carp in order of importance (Renaker and Carter, 1967). Buffalo, carp, and catfish also comprise the bulk of the mainstream fishery on the Mississippi River (Barnickol and Starrett, 1951). In South Dakota, Sullivan and Warnick (1968) found that buffalo, carp, and goldeye comprise the bulk of the catch.

In Louisiana the major commercial species are catfish, buffalo, and drum (Lambou, 1965). Most of the states in the Mississippi drainage allow the commercial harvest of catfish other than flathead catfish while Oklahoma allows only flathead catfish to be harvested commercially.

Tarzwell and Bryan (1944) reported that an extensive snagline paddlefish fishery existed on the lower Tennessee River with 740,000 pounds harvested between November 1942 and September 1943. Bryan and White (1959) found that paddlefish comprise approximately five percent of the catch in T. V. A. lakes. Ten percent of the catch on some lakes in North Dakota is paddlefish (Hill, 1968). In Oklahoma, paddlefish comprise 1.4 percent of the total catch, but are seasonally important on Grand Lake composing as much as 42 percent of the monthly catch in the spring and 12 percent of the annual catch.

Only four percent of the total annual harvest on the study lakes, as estimated by estimate III, was gamefish. Of this 3.6 percent was channel catfish, 0.1 percent was blue catfish, and 0.3 percent was crappie. White and Jaco (1961) reported that 0.5 percent of the commercial catch on Guntersville Lake was gamefish and White (1956) found that 1.2 percent of the commercial catch on T. V. A. lakes was gamefish. If channel catfish were a commercial species in Oklahoma as in other states such as Alabama, Kentucky, and Louisiana, only 0.3 percent of the catch would have been gamefish.

The average weights of commercial species in Oklahoma were larger than those reported elsewhere. During the project year the average weight of buffalo harvested from Oklahoma reservoirs studied was 5.3 pounds. The average weights of these fish harvested from T. V. A.

lakes was 3.9 pounds (White, 1956) and from the Mississippi River was 1.7 pounds (Barnickol and Starrett, 1951). Byrd (1956) reported the average weight of buffalo harvested from the tidal streams of Alabama was 8.9 pounds. The average weight of carp taken from the reservoirs studied was five pounds which is larger than the 2.6 pound fish caught in the Mississippi River fishery (Barnickol and Starrett, 1951) and the 4.5 pound fish landed from T. V. A. lakes in Alabama (White, 1956). Barnickol and Starrett (1951) reported that the average weight of flathead in the Mississippi River fishery was 3.1 pounds and White (1956) reported that the average weight of catfish of all species taken from the T. V. A. lakes to be 3.8 pounds as compared to the 7.5 pound average weight of flathead catfish caught in Oklahoma during this study. Paddlefish also followed this trend. The average weight of paddlefish harvested on the study lakes was 26.4 pounds as compared to the T. V. A. lakes where the average weight harvested was 10.0 pounds (White, 1956).

There were 80 fishermen during the project year in the total Oklahoma fishery, many who were part-time fishermen. Bryan and White (1959) reported that on T. V. A. lakes in Alabama there were 372 licensed commercial fishermen. Seventy percent of the licensed individuals depended on commercial fishing for 50 to 100 percent of their income and 169 of the 70 percent depended entirely on the commercial fishing industry. Lambou (1965) reported that in the Atchafalaya Basin fishery in Louisiana 602 persons were involved in the fishing operation; 419 of these were licensed commercial fishermen. Of these, 220 depended on commercial fishing as a main source of income. He found that 2,128 persons depended on that fishery as a source of income to a greater or commercial fishermen in Kentucky in 1965, and Carlander (1954) reported 5,807 fishermen working the upper Mississippi River in 1949. The number of Oklahoma commercial fishermen was quite small when compared to the number of fishermen in other states in the Mississippi River Drainage.

In Oklahoma approximately 13,700 pounds were landed per commercial license during the project year. On T. V. A. lakes in Alabama 10,515 pounds were landed per commercial license (Bryan and White, 1959). The Atchafalaya Basin Floodway fishery in Louisiana produced 10,378 pounds of fish per commercial license (Lambou, 1965). In Kentucky during 1965, 588 pounds were landed per commercial fishing license (Renaker and Carter, 1967). Therefore, in Oklahoma, even though the number of fishermen and the total landings are small, more fish were harvested per individual fisherman than in the other states studied.

CHAPTER V

SUMMARY

In order to appraise the present procedures used to estimate harvest and to describe the Oklahoma inland commercial fishery, the commercial harvest on four Oklahoma reservoirs was sampled and estimates of the total catch and other parameters were made. The major findings are as follows:

1. Buffalo spp., flathead catfish, and carp comprise 82 percent of the Oklahoma commercial landings.

2. Current Oklahoma laws restrict gear to gill and trammel nets of three inch mesh or larger and fishing to reservoirs.

3. The fishery is small with 80 full and part-time fishermen landing approximately one million pounds annually.

4. Oklahoma fishermen catch, on the average, 193 pounds per trip or 4.42 pounds per 24 hours per 100 feet of net fished.

5. Commercial fishermen harvested 5.4 pounds per acre or 6 percent of the estimated standing crop excluding clupeids in the reservoirs studied.

6. The average sizes of individual fish caught are larger than in many other states in the Mississippi River drainage.

7. Gamefish comprise a very small portion of the Oklahoma commercial catch. This figure is four percent if channel catfish are included and 0.4 percent if not included.

8. Stratification of populations of annual harvest into monthly strata removed 98.9 to 94.1 percent of the total variance between raises thus increased the precision of the estimates of the total catch tremendously.

9. The allocation of samples proportional to fishermen numbers was a useable procedure although it did not approach Neyman allocation.

10. The questionnaire census method of harvest estimation is accurate only if reporting intervals are short, intense personal contact is made with the fishermen including occasional sampling of the catch, and the census includes only salable species.

11. An unbiased estimate obtained by simple expansion of the mean catch per fishermen trip (estimator III) was the least precise estimate evaluated. It was a good estimate because the effort expansion factor was measured with accuracy. Estimator III, therefore, accurately estimated the total harvest.

12. The ratio of pounds caught to net nights fished can be estimated from samples with negligible bias with sampling procedures as used in this study.

13. The ratio estimators analyzed (estimators I and II) were unusable because the measure of total effort (net nights fished) were reported inaccurately.

14. The coefficient of variation of the ratio estimate which was adjusted for differences in catch efficiency between raises (estimate II) was smaller than the coefficient of variation of the ratio estimate which was adjusted for catch efficiency between fishermen (estimate I).

LITERATURE CITED

Barnickol, P. G. and W. C. Starrett. 1951. Commercial and sport fishes of the Mississippi River between Caruthersville, Missouri, and Dubuque, Iowa. Ill. Nat. Hist. Surv. Bull., 25(5):267-350.

Bartlett, M. S. 1937. Some examples of statistical methods of research and applied biology. Suppl. Jour. Roy. Stat. Soc., 4(2): 137-169.

Bryan, P. and C. E. White, Jr. 1959. An economic evaluation of the commercial fishing industry in the T. V. A. Lakes of Alabama during 1956. Proc. S. E. Assoc. Game and Fish Comm., 12:128-131.

Byrd, I. B. 1956. A report on commercial fishing studies conducted in tidal streams of Alabama. Proc. S. E. Assoc. Game and Fish Comm., 9:75-79.

Carter, J. P. 1961. A report on the commercial fish harvest in Kentucky for 1959. Kentucky Dept. Fish and Wildl. Res., Frankfort, Kentucky. 13 p.

Carlander, H. B. 1954. A history of fish and fishing in the upper Mississippi River. Upper Mississippi River Conservation Committee, 1954. 96 p.

Cochran, W. C. 1963. Sampling techniques. John Wiley and Sons, Inc., New York. 413 p.

Elkin, R. E. Jr. 1959. Commercial fisheries catch in Oklahoma, 1957. Proc. Okla. Acad. Sci., 39:183-190.

Hill, W. J. 1968. Management surveys of the Missouri River and its mainstem reservoirs in North Dakota. North Dakota State Game and Fish Dept. Rept. D. J. Proj. F-4-R-3., Job No. 1, 44 p.

Houser, A. 1957. A study of the commercial fishery of Lake Texoma. Okla. Fish. Res. Lab. Rept. No. 63. 32 p.

Jenkins, R. 1967. The influence of some environmental factors on standing crop and harvest of fishes in U. S. reservoirs, p. 298-321. In C. E. Lane, Jr. (chairman), Reservoir Fishery Resources Symposium. University of Georgia, Athens, Georgia.

Jones, L. 1961. Summary of commercial fisheries catch in Oklahoma for the years 1958-1960. Okla. Fish. Res. Lab. Rept. No. 83. 7 p.

Lambou, V. M. 1965. The commercial and sport fisheries of the Atchafalaya Basin Floodway. Proc. S. E. Assoc. Game and Fish Comm., 17:256-281.

Lyles, C. H. 1968. Fishery statistics of the United States, 1966. U. S. Dept. Int. Stat. Dig. No. 60. 679 p.

Neyman, J. 1934. On the two different aspects of the representative method: the method of stratified sampling and the method of purposive selection. Jour. Roy. Stat. Soc., 97:558-606.

Raj, Des. 1968. Sampling theory. McGraw-Hill Book Company, Inc., New York. 312 p.

Renaker, R. and B. T. Carter. 1967. The commercial fish harvest in Kentucky during 1965 and 1966. Kentucky Dept. Fish and Wildl. Res., Frankfort, Kentucky, 25 p.

Siegel, S. 1956. Nonparametric statistics. McGraw-Hill Book Co., Inc., New York. 312 p.

Spencer, S. L., W. E. Swingle, and T. M. Scott, Jr. 1966. Commercial fishing in the Mobile Delta, Alabama during the period of July 1, 1963 to June 30, 1964. Proc. S. E. Assoc. Game and Fish Comm., 19:432-483.

Starrett, W. C. and P. G. Barnickol. 1955. Efficiency and selectivity of commercial fishing devices used on the Mississippi River. Ill. Nat. Hist. Surv. Bull., 25(4):325-366.

Steel, R. G. and J. H. Torrie. 1960. Principles and procedures of statistics. McGraw-Hill Book Co., Inc., New York. 302 p.

Sullivan, J. K. and D. J. Warnick. 1968. Commercial fishing cost at Oahe Reservoir, South Dakota. Proc. S. E. Assoc. Game and Fish Comm., 21:391-395.

Tarzwell, C. M. and P. Bryan. 1944. Changes in the commercial fishery of the Tennessee River. Jour. Tenn. Acad. Sci., 20(1):49-54.

White, C. E., Jr., 1956. Fish catches with various types of commercial fishing gear used in T. V. A. lakes from June, 1954 through January, 1955. Proc. S. E. Assoc. Game and Fish Comm., 9:80-86.

White, C. E., Jr. and B. Jaco. 1961. Commercial and sport fishing on Gunterville Lake during the period of March 15-June 13, 1960. Proc. S. E. Assoc. Game and Fish Comm., 15:411-419.

VITA

2

Michael Larry Parrack

Candidate for the Degree of

Master of Science

Thesis: AN ANALYSIS OF THREE COMMERCIAL ESTIMATION PROCEDURES USED IN THE OKLAHOMA COMMERCIAL FISHERY

Major Field: Zoology

Biographical:

Personal Data: Born in Tulsa, Oklahoma, June 28, 1943, son of Neil A. and Margaret W. Parrack.

Education: Graduated from Edison Senior High School, Tulsa, Oklahoma, 1960; attended the University of Tulsa, Tulsa, Oklahoma, 1960-1961; received the Bachelor of Science Degree in Zoology, Oklahoma State University, Stillwater, Oklahoma, in 1965; completed requirements for the Master of Science Degree in May, 1970, at Oklahoma State University, Stillwater, Oklahoma.

Professional Experience: September, 1966, to February, 1970, Equipment Manager, Oklahoma State University, Stillwater, Oklahoma.

Membership: American Fisheries Society.