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Catch Assessment Survey Design for Monitoring the Upper Meta River Fishery, Colombia, South America

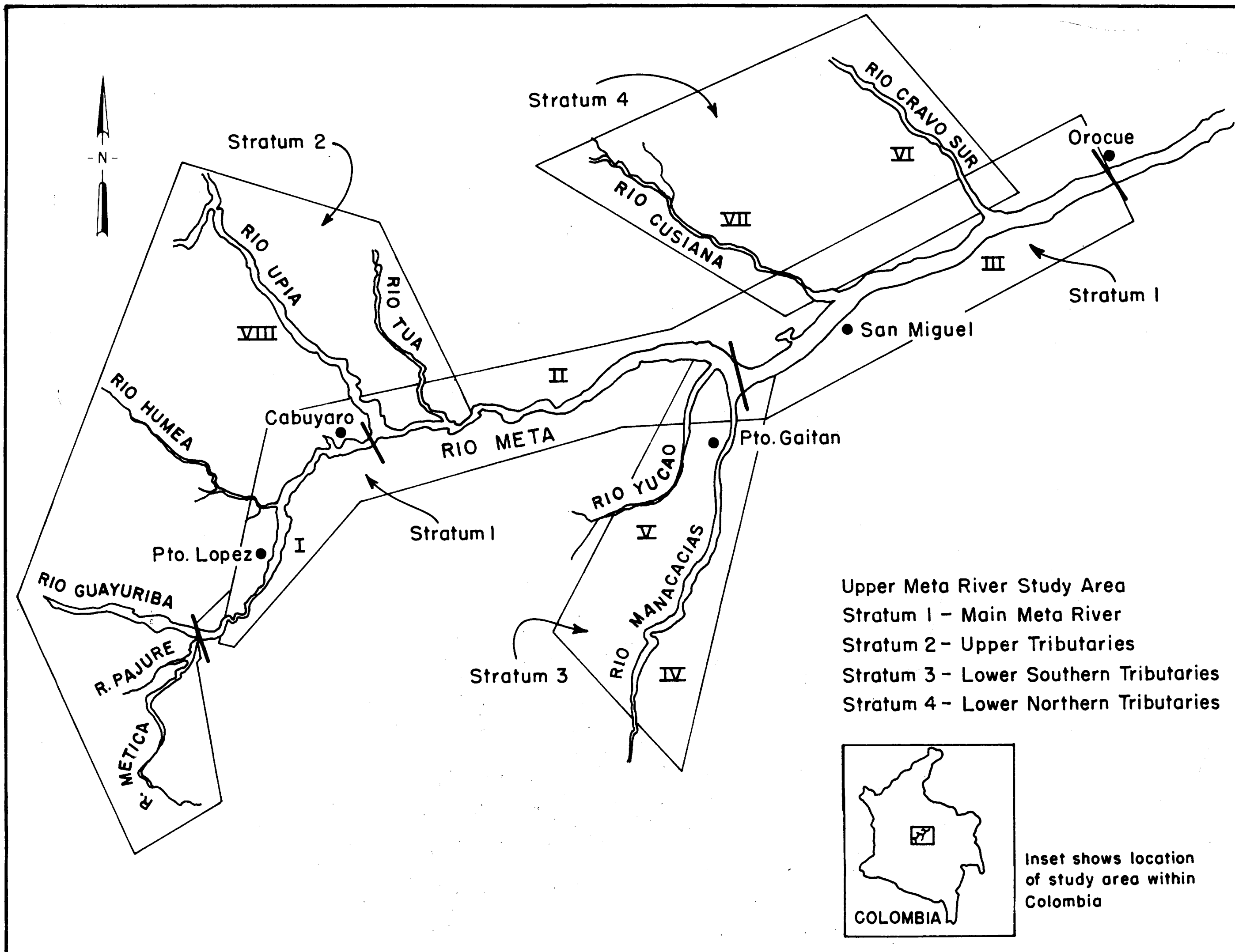

FIG. 1. The Upper Meta River area, showing the 10 zones of the 1977 frame survey (zones IX and X are lagoons to the north and south of the Meta River, respectively) and the four strata of the 1978 catch assessment survey.

SUMMARY

Catch and fishing effort in the Upper Meta River System for the hydrological year April 10, 1978 - April 9, 1979, were estimated using a statistically designed catch assessment survey (CAS). The design was based on CAS methods used at Auburn University and incorporated results from a frame survey conducted during the 1977 hydrological year on the Upper Meta River.

Total catch in 1978 was 1,071,366 kilograms from 126,334 Fishing Economic Unit (FEU)-days where 1 FEU-day was equivalent to 1.8 fisherman-days. Average catch per FEU-day was 8.1 kilograms. Ninety-one percent of the catch came from the main river and upper tributaries (70 percent and 21 percent, respectively). Similarly, 88 percent of fishing effort (FEU-days) was expended in the main river and upper tributaries (70 percent and 18 percent, respectively). Catch and fishing effort in lower tributaries, especially those on the southern side of the Meta River, were relatively insignificant.

The annual harvest was evenly distributed between the high and low water seasons. However, because the low water season was 71 percent as long as the high water season, daily catch was actually higher during low water. This was due primarily to increased daily fishing effort within the main river stratum during the low water period. Catch per unit effort changed only slightly from the high water season (7.9 kilograms per FEU-day) to the low water season (8.4 kilograms per FEU-day).

The relative standard error (RSE) for fishing effort (9.9 percent) indicated that samples were providing relatively precise estimates of this variable on an annual basis. Variation in fishing effort was inherently low because artisanal fishermen live near the river and their frequency of fishing changes little within seasons. Catch estimates were more variable, however, giving a RSE of 25.1 percent for the year; greatest variation was encountered in the low water season (RSE = 44.4 percent). Further seasonal stratification is recommended to reduce variation in catch estimates.

Future catch assessment surveys on the Upper Meta River are outlined and sampling schedules within time strata are defined. The number of time strata will be increased from two to four with the addition of one stratum for the rising and one stratum for the falling water season. It is recommended that six samples be taken within each time stratum; due to the logistics of sampling, two or three samples will be taken during a single field trip and trips will be systematically scheduled. The Upper Meta River will be divided into two geographical strata, one composed of all tributaries and the other composed of the main river only. Sample sections will be chosen with nonuniform probability, with twice as many samples coming from the main river stratum as from the tributary stratum (four samples and two samples, respectively).

Application of nonuniform probability sampling is recommended for initial surveys of all river fisheries within Colombia's Orinoco System. A pre-survey overflight will provide initial sampling probabilities based on number of canoes counted per section, and initial time strata will be the same as defined for the Upper Meta River. Strata definition and sampling probabilities for later surveys can be amended based on information gathered during the initial survey.

A 10-year CAS sampling program for Colombia's Orinoco System is proposed. Sampling will be conducted on the Upper Meta River in alternate years (from 1978). Six other Orinocian rivers will be sampled, one each year, during successive alternate years beginning in 1979. These other rivers have much less potential for immediate fisheries development than does the Upper Meta River and thus merit less sampling effort. After 1989, consolidation of sampling to include two or more river fisheries in 1 year may be feasible, thereby allowing completion of data collection necessary for a Schaefer surplus yield model in all fisheries of the Colombian Orinoco System within 15-20 years from 1978. Methods for obtaining estimates of maximum sustainable yield and optimum fishing effort at the community level based on the Schaefer surplus yield model are discussed.

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COVER PHOTO. INDERENA biologist interviews successful artisanal fisherman to acquire data on catch and fishing effort.

Catch Assessment Survey Design for Monitoring the Upper Meta River Fishery, Colombia, South America

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INTRODUCTION

THE INDERENA/USAID/AUBURN UNIVERSITY cooperative fisheries project in Colombia requested Dr. Stephen Malvestuto to consult in Colombia with the Llanos Orientales Fisheries Project during April 15-28, 1979. The specific purpose and expected outcomes of the visit were to bring an expert in survey analysis to Villavicencio to provide additional input into analysis of the accumulated 2 years of data from the Meta River fishery catch assessment survey (CAS). Special effort was employed in the estimation of catch and fishing effort from the food fish fishery. Specifically, assistance was given to:

1. Improve experimental design, i.e., develop methods to minimize variance estimates of catch, fishing effort, and catch per unit effort.
2. Plan and implement the analysis and presentation of project results.

BACKGROUND OF THE PROJECT

The principle project goal was to present a rational approach to fisheries management based on knowledge of fishing effort, catch per unit effort, and total catch from the fishery. Ultimately, the present data are to be incorporated into a surplus yield model *(6, Chapter 13)* to provide an estimate of maximum sustainable yield and optimum fishing effort. Catch statistics of length frequency by species, relative abundance of each species, and length frequency of the spawning populations have been recorded as further aids to future management decisions (7).

During the first 12 months of the program, data on catch and effort were collected via a frame survey where each of the 10 zones comprising the selected study area (the upper 316 navigable kilometers of the Meta River and its associated tributaries) was surveyed once during the high water phase (April 10-November 9), and again during the low water phase (November 10-April 9), figure 1. During the second 12-month period, ending April 9, 1979, the study area was divided into sampling strata according to the characteristics of (1) sample variation in catch per unit of fishing effort, (2) cost of sampling each stratum, and (3) intensity of fishing effort. Areas that had little need for study, or that returned little information in relation to sampling cost, were given little or no sampling effort.

This report suggests a more appropriate sample survey design which should be amenable to continued monitoring of the Upper Meta River System. Also, the design lends itself well to sampling of other fisheries in the Orinoco System. Details of these inputs are presented, along with a bibliography.

ANALYSIS OF RESULTS FROM THE 1978 CATCH ASSESSMENT SURVEY (CAS) ON THE UPPER META RIVER

The 1978 CAS on the Upper Meta River was based on stratification in time and space. Specifically, the hydrological year (April 10, 1978-April 9, 1979) was divided into two time strata (henceforth called time blocks) where Time Block A referred to the high water period (April 10, 1978-November 9, 1978) and Time Block B referred to the low water period (November 10, 1978-April 9, 1979). The river and its associated tributaries were divided into three geographical (area) strata where Stratum 1 encompassed the main Upper Meta River channel, Stratum 2 encompassed the upper tributaries, and Stratum 3 encompassed the lower southern tributaries, figure 1. The lower northern tributaries, the Rio Cusiana and Rio Cravo Sur (labeled as Stratum 4 in figure 1), were not included in the 1978 CAS because they contributed little to catch and effort in 1977 and were extremely difficult to sample during the low

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Isolated and meandering tributaries (left) and extensive sandbars (right) made access to, and travel on, the water difficult and time consuming.

TABLE 1. NUMBER OF SAMPLES TAKEN WITHIN EACH GEOGRAPHICAL STRATUM (1, 2, AND 3) DURING EACH TIME BLOCK (A AND B) DURING THE 1978 CAS

Time block	Number of samples taken: Stratum 1	Stratum 2	Stratum 3	Total
A	5	5	2	12
B	3	3	2	8
TOTAL	8	8	4	20

water period; however, 1978 catch and effort estimates were adjusted upward to include the expected contribution from these tributaries.

The main Meta River channel in Stratum 1 was divided into three sections, which were given equal probabilities (0.33) of being chosen for any given sample; likewise, the individual tributaries within Stratum 2 were given equal probabilities of being chosen (six tributaries with probability of 0.167 each), as were the individual tributaries in Stratum 3 (two tributaries with probability of 0.50 each). Table 1 gives the number of samples taken within each geographical stratum during time blocks A and B. Because of cost considerations, two main river sections or three tributaries were sampled during each survey trip.

Calculation of Total Fishing Effort

Within any sampled river section or tributary (henceforth referred to as sampling units = SU), a count of the total number of active fishing canoes (fishing economic units or FEU) provided an estimate of fishing effort. The steps involved in expanding this estimate of effort per SU to an estimate of total annual effort for the whole system are as follows:

(1) For each time block, expand the number of FEU counted within each SU (E_{su}) to a total daily number of FEU for the entire geographical stratum (E_{daily}) by dividing E_{su} by the sampling probability associated with the particular SU. Thus, for any given geographical stratum within any given time block, E_{daily} is calculated as

$$E_{daily} = E_{su}/P_{su}$$

where P_{su} = the probability associated with the particular SU. These calculations are shown in table 2.

(2) Calculate the average daily fishing effort per stratum ($\overline{E}_{daily}$) within each time block by averaging the sample totals (E_{daily}) calculated in table 2. Thus, for any given stratum within any given time block, $\overline{E}_{daily}$ is calculated as:

$$\overline{E}_{daily} = \frac{1}{n} \Sigma\, E_{daily}$$

where n = the number of SU sampled in the particular stratum within the particular time block. These calculations are shown in table 3.

(3) Calculate a variance for each $\overline{E}_{daily}$, i.e., a variance of the mean, as

$$V_{\overline{E}} = \frac{1}{n(n-1)} [\Sigma\, E^2_{daily} - (\Sigma\, E_{daily})^2/n]$$

Values of $V_{\overline{E}}$ (with intermediate sums) are also given in table 3.

(4) Calculate the total daily effort for each time block ($E_{daily\ total}$) by summing the $\overline{E}_{daily}$ for each geographical stratum. Thus,

$$E_{daily\ total} = \Sigma\, \overline{E}_{daily}.$$

For Time Block A:

$$E_{daily\ total} = 198.80 + 52.60 + 14.00 = 265.40 \text{ FEU}$$

TABLE 2. EXPANSION OF FISHING EFFORT PER SU (E_{SU}) TO AN ESTIMATE OF DAILY EFFORT FOR AN ENTIRE GEOGRAPHICAL STRATUM (E_{daily}) WITHIN EACH TIME BLOCK USING APPROPRIATE SAMPLING PROBABILITIES (P_{SU})

TIME BLOCK A: HIGH WATER

Stratum 1	Stratum 2	Stratum 3
$E_{SU} \div P_{SU} = E_{daily}$	E_{SU}* $\div P_{SU} = E_{daily}$	E_{SU}* $\div P_{SU} = E_{daily}$
76 ÷ 0.33 = 230	6.5 ÷ 0.167 = 39	8.7 ÷ 0.5 = 17
59 ÷ 0.33 = 179	19.1 ÷ 0.167 = 115	5.7 ÷ 0.5 = 11
62 ÷ 0.33 = 188	4.0 ÷ 0.167 = 24	
73 ÷ 0.33 = 221	0.8 ÷ 0.167 = 5	
58 ÷ 0.33 = 176	13.3 ÷ 0.167 = 80	

TIME BLOCK B: LOW WATER

Stratum 1	Stratum 2	Stratum 3
$E_{SU} \div P_{SU} = E_{daily}$	E_{SU}* $\div P_{SU} = E_{daily}$	E_{SU}* $\div P_{SU} = E_{daily}$
139 ÷ 0.33 = 421	6.9 ÷ 0.167 = 41	4.9 ÷ 0.5 = 10
106 ÷ 0.33 = 321	12.2 ÷ 0.167 = 73	3.1 ÷ 0.5 = 6
63 ÷ 0.33 = 191	13.9 ÷ 0.167 = 83	

*Decimal E_{SU} values were generated as a result of multiplying the total number of canoes counted by the proportion of canoes actively fishing on a daily basis; this proportion was estimated by questioning fishermen on canoe use. Larger E_{SU} values were rounded to the nearest whole number.

and for Time Block B:

$$E_{daily\ total} = 311.00 + 65.67 + 8.00 = 384.67 \text{ FEU}.$$

(5) Calculate the variance of $E_{daily\ total}$ for each time block ($V_{E\ daily\ total}$) by summing the $V_{\overline{E}}$ for each geographical stratum. Thus,

$$V_{E\ daily\ total} = \Sigma\, V_{\overline{E}}.$$

For Time Block A:

$$V_{E\ daily\ total} = 124.74 + 395.66 + 9.00 = 529.40 \text{ FEU}^2$$

and for Time Block B:

$$V_{E\ daily\ total} = 4{,}433.33 + 160.44 + 4.00 = 4{,}597.77 \text{ FEU}^2.$$

The square root of $V_{E\ daily\ total}$ for each time block is the standard error of $E_{daily\ total}$ ($SE_{E\ daily\ total}$). Thus, for Time Block A,

$$SE_{E\ daily\ total} = \sqrt{529.40} = 23.01 \text{ FEU}$$

and for Time Block B,

$$SE_{E\ daily\ total} = \sqrt{4{,}597.77} = 67.81 \text{ FEU}.$$

TABLE 3. CALCULATION OF MEAN DAILY FISHING EFFORT PER STRATUM ($\overline{E}_{daily}$) WITHIN EACH TIME BLOCK BY AVERAGING VALUES OF E_{daily} FROM TABLE 2 (VALUES OF $V_{\overline{E}}$ AND INTERMEDIATE CALCULATIONS ARE ALSO GIVEN)

TIME BLOCK A: HIGH WATER

Stratum 1	Stratum 2	Stratum 3
E_{daily} = 230 FEU	39 FEU	17 FEU
179	115	11
188	24	
221	5	
176	80	
$\overline{E}_{daily}$ = 198.80 FEU	$\overline{E}_{daily}$ = 52.60 FEU	$\overline{E}_{daily}$ = 14.00 FEU
$\Sigma\, E_{daily}$ = 994	$\Sigma\, E_{daily}$ = 263	$\Sigma\, E_{daily}$ = 28
$(\Sigma\, E_{daily})^2$ = 988,036	$(\Sigma\, E_{daily})^2$ = 69,169	$(\Sigma\, E_{daily})^2$ = 784
$\Sigma\, E^2_{daily}$ = 200,102	$\Sigma\, E^2_{daily}$ = 21,747	$\Sigma\, E^2_{daily}$ = 410
$V_{\overline{E}}$ = 124.74 FEU^2	$V_{\overline{E}}$ = 395.66 FEU^2	$V_{\overline{E}}$ = 9.00 FEU^2

TIME BLOCK B: LOW WATER

Stratum 1	Stratum 2	Stratum 3
E_{daily} = 421 FEU	41 FEU	10 FEU
321	73	6
191	83	
$\overline{E}_{daily}$ = 311.00 FEU	$\overline{E}_{daily}$ = 65.67 FEU	$\overline{E}_{daily}$ = 8.00 FEU
$\Sigma\, E_{daily}$ = 933	$\Sigma\, E_{daily}$ = 197	$\Sigma\, E_{daily}$ = 16
$(\Sigma\, E_{daily})^2$ = 870,489	$(\Sigma\, E_{daily})^2$ = 38,809	$(\Sigma\, E_{daily})^2$ = 256
$\Sigma\, E^2_{daily}$ = 316,763	$\Sigma\, E^2_{daily}$ = 13,899	$\Sigma\, E^2_{daily}$ = 136
$V_{\overline{E}}$ = 4,433.33 FEU^2	$V_{\overline{E}}$ = 160.44 FEU^2	$V_{\overline{E}}$ = 4.00 FEU^2

(6) Calculate total fishing effort within each time block (E_{block}) by multiplying each $E_{daily\ total}$ by the number of days within the time block. Time Block A contained 214 days and Time Block B contained 151 days. Thus, for Time Block A:

$$E_{block} = 265.40 \text{ FEU} \times 214 \text{ days} = 56{,}796 \text{ FEU-days}$$

and for Time Block B:

$$E_{block} = 384.67 \text{ FEU} \times 151 \text{ days} = 58{,}085 \text{ FEU-days.}$$

(7) The standard error of E_{block} for each time block (SE_{block}) equals $SE_{E\ daily\ total}$ multiplied by the number of days contained within each time block. Thus, for Time Block A:

$$SE_{block} = 23.01 \text{ FEU} \times 214 \text{ days} = 4{,}924 \text{ FEU-days}$$

and for Time Block B:

$$SE_{block} = 67.81 \text{ FEU} \times 151 \text{ days} = 10{,}239 \text{ FEU-days.}$$

The relative standard error of E_{block} (RSE_{block}) is defined as $(SE_{block}/E_{block}) \times 100$ and simply expresses the standard error of total effort as a percentage of total effort. Thus, for Time Block A:

$$RSE_{block} = (4{,}924 \text{ FEU-days}/56{,}796 \text{ FEU-days}) \times 100 = 8.7 \text{ percent}$$

and for Time Block B:

$$RSE_{block} = (10{,}239 \text{ FEU-days}/58{,}085 \text{ FEU-days}) \times 100 = 17.6 \text{ percent.}$$

(8) The daily total effort for the entire year ($E_{annual\ daily}$) is calculated by taking the weighted sum of $E_{daily\ total}$ for each time block. A time block weight (W) is defined for each time block as the number of days contained within the time block divided by the total number of days within the year. Thus, the weight for Time Block A (W_A) = 214/365 = 0.59 and the weight for Time Block B (W_B) = 151/365 = 0.41. Each $E_{daily\ total}$ is multiplied by its respective time block weight and the resulting values are added together. Thus,

$$E_{annual\ daily} = \Sigma\, WE_{daily\ total}.$$

In the present case,

$$E_{annual\ daily} = 0.59\ (265.40) + 0.41\ (384.67) = 314.30 \text{ FEU.}$$

Total annual effort (E) is then calculated by multiplying $E_{annual\ daily}$ by the number of days in the year. Thus,

$$E = 314.30 \text{ FEU} \times 365 \text{ days} = 114{,}720 \text{ FEU-days.}$$

It may be noted that E can also be estimated by simply adding the two time block totals (E_{block}). This gives E = 56,796 + 58,085 = 114,881 FEU-days. The procedure given above using time block weights allows the calculation of $E_{annual\ daily}$ which can be a useful summary statistic.

(9) The variance of $E_{annual\ daily}$ ($V_{E\ annual\ daily}$) is calculated as the weighted variance of the values of $V_{E\ daily\ total}$ so that

$$V_{E\ annual\ daily} = \Sigma\, W^2 V_{E\ daily\ total}.$$

Thus, in the present case,

$$V_{E\ annual\ daily} = (0.59)^2\ (529.40) + (0.41)^2 (4{,}597.77) = 957.17 \text{ FEU}^2.$$

The square root of $V_{E\ annual\ daily}$ equals the standard error of $E_{annual\ daily}$ ($SE_{E\ annual\ daily}$) so that, in the present case,

$$SE_{E\ annual\ daily} = \sqrt{957.17} = 30.94 \text{ FEU.}$$

The standard error of E (SE_E) is equal to $SE_{E\ annual\ daily}$ multiplied by the number of days within the year. Thus,

$$SE_E = 30.94 \text{ FEU} \times 365 \text{ days} = 11{,}292 \text{ FEU-days.}$$

The relative standard error of E (RSE) equals (SE/E) × 100 or (11,292 FEU-days/114,720 FEU-days) × 100 = 9.8 percent.

Calculation of Average Daily Catch per Unit Effort

For any given SU, an estimate of catch per unit effort per day or kilograms of fish caught per FEU per day is obtained from interviews. This value is calculated by dividing the total weight of fish harvested by the total number of FEU's interviewed and is taken to represent the catch per FEU for the **entire stratum** during the day of interview (U_{daily}). Thus, unlike estimating E_{daily}, the catch per unit effort measured within any given SU is **not** expanded by the probability associated with that particular SU to give a total for the entire stratum; the concern here is to obtain a representative estimate of daily harvest **per FEU.**

(1) Calculate a mean catch per FEU per day ($\overline{U}_{daily}$) by averaging the values of U_{daily} for each geographical stratum within each time block. Thus, $\overline{U}_{daily}$ for any given stratum within each time block is calculated as

$$\overline{U}_{daily} = \tfrac{1}{n}\, \Sigma\, U_{daily}.$$

Values of $\overline{U}_{daily}$ are given in Table 4.

(2) Calculate the variance of each $\overline{U}_{daily}$ as

$$V_{\overline{U}} = \frac{1}{n(n-1)}\ [\Sigma U^2_{daily} - (\Sigma U_{daily})^2/n]$$

This is a variance of the mean and is exactly analagous to the formula for $V_{\overline{E}}$ previously given. Values of $V_{\overline{U}}$ are also given in table 4.

(3) To calculate a mean U over strata within each time block, each $\overline{U}_{daily}$ is weighted by the relative amount of fishing

TABLE 4. CALCULATION OF $\overline{U}_{daily}$ BY AVERAGING VALUES OF U_{daily} FOR EACH GEOGRAPHICAL STRATUM WITHIN EACH TIME BLOCK: VALUES OF U_{daily} ARE ESTIMATES BASED ON CATCH AND EFFORT MEASURED THROUGH INTERVIEWS (VALUES OF $V_{\overline{U}}$ ARE ALSO GIVEN)

	Stratum 1	Stratum 2	Stratum 3
TIME BLOCK A: HIGH WATER			
U_{daily}=	11.39	7.39	3.75
	6.25	13.56	3.75*
	3.28	7.50	
	12.72	3.56	
	8.36	4.56	
$\overline{U}_{daily}$=	8.40 kg/FEU	7.31 kg/FEU	3.75 kg/FEU
$V_{\overline{U}}$=	2.92 (kg/FEU)^2	3.04 (kg/FEU)^2	0.00 (kg/FEU)^2
TIME BLOCK B: LOW WATER			
U_{daily}=	3.64	3.31	2.12
	16.04	1.50	2.12*
	4.75	26.35	
$\overline{U}_{daily}$=	8.14 kg/FEU	10.39 kg/FEU	2.12 kg/FEU
$V_{\overline{U}}$=	15.69 (kg/FEU)^2	63.98 (kg/FEU)^2	0.00 (kg/FEU)^2

*Assumed values based on first sample.

effort (relative number of FEU's) per stratum. On the average, 71 percent, 24 percent, and 5 percent of the fishing effort occurred in stratum 1, 2, and 3, respectively, giving stratum weights of 0.71 (W_1), 0.24 (W_2), and 0.05 (W_3). The weighted mean daily catch per unit effort ($\overline{U}_{daily\ weighted}$) is calculated as

$$\overline{U}_{daily\ weighted} = \Sigma\ W\overline{U}_{daily}.$$

Thus, for Time Block A:

$$\overline{U}_{daily\ weighted} = 0.71\ (8.40) + 0.24\ (7.31) + 0.05\ (3.75) = 7.91\ \text{kg/FEU},$$

and for Time Block B:

$$\overline{U}_{daily\ weighted} = 0.71\ (8.14) + 0.24\ (10.39) + 0.05\ (2.12) = 8.38\ \text{kg/FEU}.$$

(4) The variance of $\overline{U}_{daily\ weighted}$ is a weighted variance of the mean (V_W) and is calculated as

$$V_W = \Sigma\ W^2V_{\overline{U}}.$$

Thus, for Time Block A:

$$V_W = (0.71)^2(2.92) + (0.24)^2\ (3.04) + (0.05)^2\ (0.00) = 1.65(\text{kg/FEU})^2,$$

and for Time Block B:

$$V_W = (0.71)^2\ (15.69) + (0.24)^2\ (63.98) + (0.05)^2\ (0.00) = 11.59\ (\text{kg/FEU})^2.$$

The square root of V_W is the standard error of $\overline{U}_{daily\ weighted}$ (SE_W).

Thus, for Time Block A,

$$SE_W = \sqrt{1.65} = 1.28\ \text{kg/FEU/day},$$

and for Time Block B,

$$SE_W = \sqrt{11.59} = 3.40\ \text{kg/FEU/day}.$$

Relative standard errors for $\overline{U}_{daily\ weighted}$ ($RSE_{\overline{U}}$) are $(1.28/7.91) \times 100 = 16.2$ percent and $(3.40/8.38) \times 100 = 40.6$ percent for Time Block A and Time Block B, respectively.

(5) An annual estimate of $\overline{U}_{daily}$ over time blocks (U) is calculated by weighting each $\overline{U}_{daily\ weighted}$ by the time block weights previously defined as 0.59 and 0.41 for Time Blocks A and B, respectively. Thus, in the present case,

$$U = 0.59\ (7.91) + 0.41\ (8.38) = 8.10\ \text{kg/FEU/day}.$$

The variance of U (V_U) is the weighted sum of V_W and is calculated as

$$V_U = (0.59)^2\ (1.65) + (0.41)^2(11.59) = 2.52\ (\text{kg/FEU/day})^2.$$

The standard error of U (SE_U) = $\sqrt{V_U} = \sqrt{2.52} = 1.59$ kg/FEU/day. The RSE of U = $(1.59/8.10) \times 100 = 19.6$ percent.

Calculation of Total Annual Catch

The calculation of total annual catch follows the procedure given for calculating total annual effort. Estimates of total daily catch for each sampled stratum (C_{daily}) are calculated as the product of $E_{daily} \times U_{daily}$. These calculations are shown in table 5. Mean daily catch for each geographical stratum ($\overline{C}_{daily}$) and the variance of $\overline{C}_{daily}$ ($V_{\overline{C}}$) are calculated just as $\overline{E}_{daily}$ and $V_{\overline{E}}$ were calculated; calculation of $\overline{C}_{daily}$ and values of $V_{\overline{C}}$ are given in table 6.

TABLE 5. ESTIMATION OF C_{daily} AS THE PRODUCT OF E_{daily} AND U_{daily} FOR EACH GEOGRAPHICAL STRATUM

Stratum 1	Stratum 2	Stratum 3
TIME BLOCK A: HIGH WATER		
$E_{daily} \times U_{daily} = C_{daily}$	$E_{daily} \times U_{daily} = C_{daily}$	$E_{daily} \times U_{daily} = C_{daily}$
230 × 11.39 = 2,619	39 × 7.39 = 288	17 × 3.75 = 65
179 × 6.25 = 1,119	115 × 13.56 = 1,554	11 × 3.75 = 43
188 × 3.28 = 616	24 × 7.50 = 180	
221 × 12.72 = 2,810	5 × 3.56 = 17	
176 × 8.36 = 1,471	80 × 4.56 = 364	
TIME BLOCK B: LOW WATER		
$E_{daily} \times U_{daily} = C_{daily}$	$E_{daily} \times U_{daily} = C_{daily}$	$E_{daily} \times U_{daily} = C_{daily}$
421 × 3.64 = 1,533	41 × 3.31 = 137	10 × 2.12 = 21
321 × 16.04 = 5,152	73 × 1.50 = 110	6 × 2.12 = 13
191 × 4.75 = 907	83 × 26.35 = 2,192	

The total daily catch over all strata within each time block ($C_{daily\ total}$) is the sum of all $\overline{C}_{daily}$. For Time Block A:

$$C_{daily\ total} = 1{,}727.00 + 480.00 + 54.00 = 2{,}261.60\ \text{kg},$$

and for Time Block B:

$$C_{daily\ total} = 2{,}530.67 + 813.00 + 17.00 = 3{,}360.67\ \text{kg}.$$

The variance of $C_{daily\ total}$ ($V_{C\ daily\ total}$) is the sum of all $V_{\overline{C}}$. Thus, for Time Block A:

$$V_{C\ daily\ total} = 181{,}903.70 + 75{,}408.16 + 121.00 = 257{,}433\ \text{kg}^2,$$

and for Time Block B:

$$V_{C\ daily\ total} = 1{,}750{,}503.45 + 475{,}471.00 + 16.00 = 2{,}225{,}990\ \text{kg}^2.$$

Standard errors of $C_{daily\ total}$ are $\sqrt{257{,}433} = 507.38$ kg and $\sqrt{2{,}225{,}990} = 1{,}492$ kg,

for Time Block A and B, respectively.

Using analagous subscripts and calculations given for calculating total fishing effort (page 7), $C_{block} = 483{,}982$ kg for Time Block A and 507,461 kg for Time Block B. Respective values of SE_{block} are 108,579 kg and 225,292 kg, giving 22.4 percent and 44.4 percent for values of RSE_{block}.

An annual estimate of C_{daily} ($C_{annual\ daily}$) is calculated as the weighted sum of the $C_{daily\ total}$ values where the previous weighting factors of $W_A = 0.59$ and $W_B = 0.41$ are again used.

TABLE 6. CALCULATION OF $\overline{C}_{daily}$ BY AVERAGING VALUES OF C_{daily} FOR EACH GEOGRAPHICAL STRATUM WITHIN EACH TIME BLOCK (VALUES OF $V_{\overline{C}}$ ARE ALSO GIVEN)

	Stratum 1	Stratum 2	Stratum 3
TIME BLOCK A: HIGH WATER			
C_{daily} =	2,619	288	65
	1,119	1,554	43
	616	180	
	2,810	17	
	1,471	364	
$\overline{C}_{daily}$ =	1,727 kg	480.60 kg	54.00 kg
$V_{\overline{C}}$ =	181,903.70 kg²	75,408.16 kg²	121.00 kg²
TIME BLOCK B: LOW WATER			
C_{daily} =	1,533	137	21
	5,152	110	13
	907	2,192	
$\overline{C}_{daily}$ =	2,530.67 kg	813.00 kg	17.00 kg
$V_{\overline{C}}$ =	1,750,503.45 kg²	475,471.00 kg²	16.00 kg²

Thus, for the present data, $C_{annual\ daily} = (0.59)\ (2{,}261.60) + (0.41)\ (3{,}360.67) = 2{,}712.22$ kg.

Total annual catch (C) = $C_{annual\ daily} \times 365$ days = 989,960 kg. The variance of $C_{annual\ daily}$ ($V_{C\ annual\ daily}$) is calculated as the weighted sum of the values of $V_{\bar{c}}$ so that $V_{C\ annual\ daily} = (0.59)^2\ (257{,}433) + (0.41)^2\ (2{,}225{,}990) = 463{,}801\ kg^2$. The standard error of $C_{annual\ daily} = \sqrt{V_{C\ annual\ daily}} = \sqrt{463{,}801} = 681.03$ kg/day. The standard error of C = 681.03 kg/day × 365 days = 248,576 kg. The RSE for C is (248,576 kg/989,960 kg) × 100 = 25.1 percent.

Final Calculations of E and C for 1978

Because the two lower northern tributaries (Rio Cusiana and Rio Cravo Sur) were not sampled during the 1978 CAS, the estimates of E and C calculated above must be expanded to account for the missing rivers. The 1977 frame survey indicated that for Time Block A, these two tributaries contributed 13 percent of total effort and 10 percent of total catch; for Time Block B, these tributaries contributed 6 percent of total effort and 5 percent of total catch. When the time block estimates of catch and effort for 1978 are expanded upward by these percentages, estimates of total effort and total catch by time blocks are:

Time Block A: total effort = 64,541 FEU-days
total catch = 537,758 kg

Time Block B: total effort = 61,793 FEU-days
total catch = 533,608 kg

Summing the above estimates of catch and effort over time blocks gives the following adjusted values of total annual catch (C) and total annual effort (E):

C = 1,071,366 kg
E = 126,334 FEU-days

The standard errors associated with the 1978 estimates can be expanded upward by the same percentages so that the RSE's previously given remain the same. The annual estimate of U as previously calculated will be accepted as a representative value for the entire system. Table 7 gives the final estimated values of E, C, and U by time blocks and for the entire year.

Verification of Estimate of Annual Harvest (C)

Welcomme *(9)* found that when annual harvest (C) in metric tons from various African rivers was plotted against basin area (A) in square kilometers, the following exponential relationship was obtained by regression techniques:

$$C = 0.1326A^{0.8533}\ (r^2 = 90\%),$$

indicating that basin area is a good predictor of annual harvest. Welcomme assumed that the harvest estimates available to him were from river areas where fishing was "sufficiently intense to attract the attention of fisheries administrators and biologists," probably meaning main river channels.

The estimate of total annual harvest from the 1978 CAS on the Upper Meta River was approximately 1,071 metric tons; however, only about 751 metric tons were attributable to the main river channel (Stratum 1). Given that the watershed of the Upper Meta River is roughly 20,000 square kilometers, Welcomme's equation predicts an annual harvest of

$$C = 0.1326\ (20{,}000)^{0.8533} = 620 \text{ metric tons},$$

which is within 20 percent of the CAS estimate of 751 metric tons from the main river channel. Although the closeness of these two values does not necessarily verify the accuracy of our estimate in a true sense, it is reassuring to know that the survey design was providing reasonable estimates of harvest relative to other tropical river systems of similar size.

Precision Associated with Estimates of E, C, and U

It is apparent from table 7 that the precision of estimates of E, C, and U is significantly lower (RSE's are higher) during the low water period than during the high water period. RSE's less than 20 percent can be considered acceptable for catch assessment surveys on large aquatic systems *(5)*, although the smaller the RSE the better. A RSE of 20 percent implies that the 95 percent confidence interval will be approximately 40 percent of the mean, which is somewhat large; a RSE of 10 percent gives a 95 percent confidence interval of about 20 percent of the mean, which is more desirable. The RSE associated with the annual estimate of E is thus quite acceptable; RSE's for total annual values of C and U can hopefully be improved. The basic approach to improving the variability of estimates of C and U will be to further stratify the hydrological year into more homogeneous time blocks. Time blocks A and B, although called the high water and low water periods, respectively, also included periods of rising and falling water which tended to make these two time blocks more heterogeneous than desirable. The following section presents an improved CAS design for the Upper Meta River, which should improve the precision of estimates of C and U as well as of E.

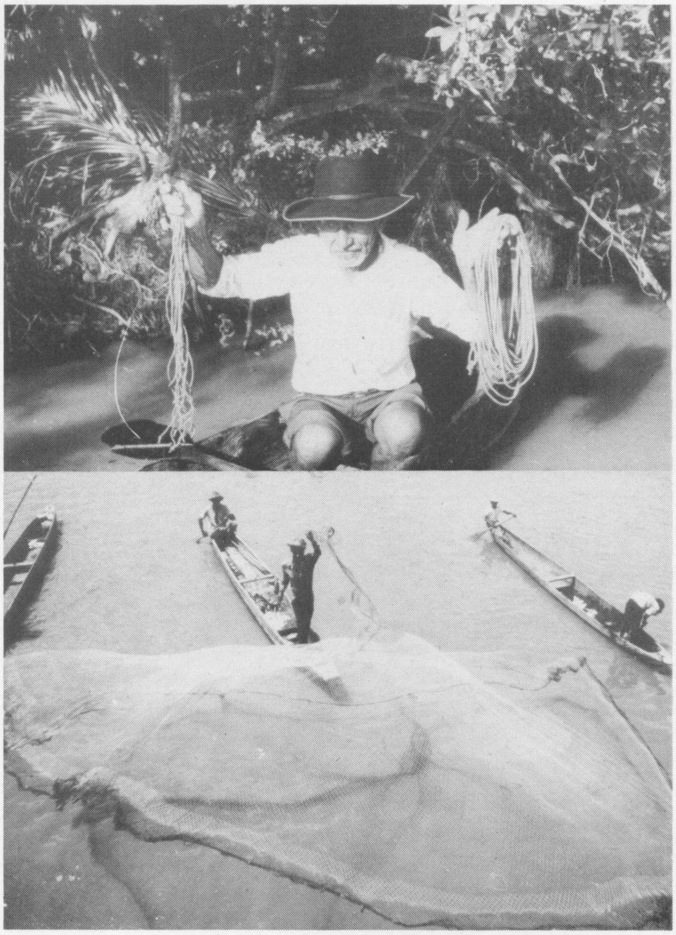
TABLE 7. ESTIMATES OF TOTAL EFFORT (E), TOTAL CATCH (C), AND CATCH PER UNIT OF EFFORT (U) BY TIME BLOCKS AND FOR THE ENTIRE SURVEY YEAR (1978) ON THE UPPER META RIVER (RELATIVE STANDARD ERRORS (RSE) ARE ALSO GIVEN)

Item	Time Block A	Time Block B	Annual
C (kg) =	537,758	533,608	1,071,366
(RSE)	(22.4%)	(44.4%)	(25.1%)
E (FEU-days) =	64,541	61,793	126,334
(RSE)	(8.7%)	(17.6%)	(9.8%)
U (kg/FEU/day) =	7.91	8.38	8.10
(RSE)	(16.2%)	(40.6%)	(19.6%)

CAS DESIGN FOR CONTINUED MONITORING OF THE UPPER META RIVER FISHERY

Sampling designs can vary from relatively simple to highly complex. The complexity of the design depends on the purpose to which the survey is directed. Catch assessment surveys (CAS) on natural aquatic systems are directed toward obtaining unbiased or accurate estimates of total catch (C), total effort (E), and catch per unit of effort (U) on an annual basis. The system may be composed of distinct components, i.e., habitat types, population groups, and different approaches to fishing, for which independent estimates of C, E, and U are desired.

Fishery managers are not only concerned with the accuracy of their estimates, but also with the precision or variability of their estimates. Highly variable estimates, i.e., estimates with relatively large standard errors, are of little value for management or research purposes. To provide relatively precise and thus useful estimates, the CAS design must take into account the natural variability within the system. Aquatic systems can be highly variable because of environmental fluctuations (seasonal changes for example) and the dynamics (growth, recruitment, and mortality) of the fish populations. Furthermore, the fishermen will respond to changes in the biological system as well as to social, economic, and cultural contingencies, thus adding another component of variability to the entire system



Fishermen on the Meta River employ a variety of fishing gear: top — elderly man displays 'hook-lines' from a small dugout canoe; bottom — fisherman hurls a 30-foot diameter cast net.

under study, i. e., the fishery. Thus, the CAS design may of necessity be relatively complex to account for, or statistically control, variability so that accurate and precise estimates of C, E, and U are forthcoming.

The gains, in terms of accuracy and precision, provided by an appropriately complex design may, in a real sense, be totally non-existent if the design necessitates resources (time, money, and manpower) that cannot reasonably be generated. In this sense, although gains may be sacrificed, the design should be practical in terms of government support capabilities; a workable survey which endeavors to monitor a fishery which is, or is expected to be, a valuable resource is certainly better than no assessment at all.

The primary consideration in this proposal, in terms of designing a CAS for continued monitoring of the Upper Meta River fishery, is that the design be appropriate relative to the support capabilities of INDERENA. Fortunately, this consideration does not appear to preclude the opportunity for obtaining estimates that are precise enough for management purposes as indicated by the relative standard errors associated with estimates of C, E, and U from the 1978 CAS (see section on "Precision Associated with Estimates of E, C, and U," page 9). The design presented here draws on the results of the 1978 CAS to stratify the system in a more efficient manner relative to the natural heterogeneity of the fishery in time and space. Although statistical terminology is highly developed, we have endeavored to present the design as simply as possible to facilitate its understandability and future application.

Division of the System into Time Blocks and Geographical Strata

Seasonal hydrological fluctuations in the river systems of Colombia have been well documented, especially on the Magdalena River *(1, 2, 3)*. These fluctuations are based on seasonal rainfall patterns which in turn determine biological patterns associated with the migratory behavior of the fish populations. Ultimately, the fishermen respond to these cyclical patterns so that estimates of C, E, and U tend to be highly variable during the hydrological year (defined here to be from April 1 to March 31). The survey design accounts for this seasonal variability by dividing the year into relatively homogeneous seasonal periods corresponding to the hydrological periods exhibited by the physical/biological system. Thus, on the Upper Meta River, the following seasonal strata or time blocks can be defined:

A: rising water (April 1 — May 31 = 61 days)
B: high water (June 1 — November 15 = 168 days)
C: falling water (November 16 — December 31 = 46 days)
D: low water (January 1 — March 31 = 90 days)

An indication of the changes which occur between these time blocks is given in figure 2, which shows seasonal fluctuations in river depth together with season fluctuations in daily weight (kilograms) of fish landed at Puerto Lopez (December 1977 — March 1979). It is apparent that in terms of weight of fish landed per day, the shorter periods of rising and falling water represent the most intensive periods of fishing success; the low and high water periods are of lesser importance, with the low water period producing slightly higher daily yields on the average than the high water period.

Variability within the fishery is not only apparent seasonally, but is also expected geographically as influenced by differing river habitats, especially with reference to the main river channel versus the tributaries. Unlike the Magdalena System, backwater lakes (cienegas) are not well developed on the Upper Meta River System and no fishing effort was observed in these

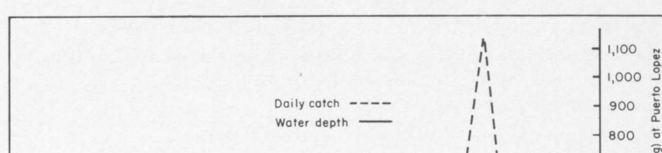


FIG. 2. Relation of Meta River water depth at Puerto Lopez to quantity of marketed fish, November 1977-April 1979. Proposed time blocks (A-D) for fishery surveys are defined.

'lagoons' during the 1977 frame survey. The current design thus calls for division of the Upper Meta System into only two geographical strata as follows:

I: Main Meta River
II: Tributaries

The advantages of stratification are two-fold. First, independent estimates of C, E, and U obtained from each stratum (time blocks and geographical) may help to characterize the system in more detail, thus providing a better understanding of how different components of the system develop and function relative to one another. Second, because the strata represent relatively homogeneous segments of the system, estimates independently obtained within the segments are expected to be more precise (less variable) than if the entire system were to be sampled as a whole *(4, Chapter 5).*

Sampling Within Time Blocks

The practicalities associated with sampling the Upper Meta River during 1977 and 1978 suggest that it is not reasonable to expect that more than six samples can be taken within any given time block. Additionally, the time, manpower, and cost associated with getting out on the river dictate that it is not feasible to take only one sample during any given trip, but rather that two or three samples be taken; that is, two or three sampling trips should be planned so that a total of six samples is taken within each time block. It is reasonable to suggest that during the smaller time blocks (A and C), two trips of three samples each be planned and during the larger time blocks (B and D), three trips of two samples each be planned.

Although the design calls for an equal number of samples within each time block, because the blocks are of different duration, sampling intensity actually differs from block to block. Specifically, sampling intensity on a daily basis is inversely proportional to the number of days within the time block. As an example, if the six samples were evenly spaced throughout each time block, samples would be taken as follows:

Block A: one sample every 10 days
Block B: one sample every 28 days
Block C: one sample every 9 days
Block D: one sample every 15 days

Thus, blocks A and C are being sampled most intensively, which is justified and desirable because daily fishing intensity is the greatest during these two periods (rising and falling water). Block D will be sampled at an intermediate level and Block B at the lowest level, which correspond to intermediate and low levels of fishing success as indicated by daily catch rates from the Puerto Lopez landing, figure 2. This scheme allows more sampling effort to be expended during the most important periods of the year relative to daily catch landed. This is logical in terms of one of the primary goals of the survey, which is to estimate catch as accurately and precisely as possible.

Theoretically, it is desirable that the sampling periods (the times during which sampling trips are made) should be randomly chosen within time blocks. However, past experience dictates that this is an unrealistic expectation since allocation of funds for field work will require an average of 3 to 4 weeks between survey trips. In lieu of randomization, then, it is suggested that sampling trips be as evenly spaced as possible within each time block. Because the exact dates of the annual hydrological periods will vary from year to year, it is further suggested that sampling trips within time blocks be scheduled according to observed changes in water level on the river rather than following preconceived fixed dates which may not be applicable in any given year.

Sampling Within Geographical Strata

There are two geographical strata, Main River (I) and Tributaries (II), within each time block. Thus, the six samples within any given time block must be allocated to Stratum I and Stratum II. Cochran *(4, p. 98)* gives three basic criteria for allocation of sampling effort: Within a given stratum take a larger sample if (1) the stratum is larger, (2) the stratum is more variable internally, and (3) sampling is cheaper in the stratum. These three criteria can be combined into a simple formula which basically says that relative sample size for a given stratum

$$= \frac{\text{relative stratum size} \times \text{relative variation}}{\sqrt{\text{relative cost}}}$$

Table 8 gives values of relative stratum size, relative variation, and relative cost associated with the main river and tributary strata as estimated from the 1978 CAS. The appropriate measure of relative stratum size is taken to be the fraction of the total annual catch provided by each stratum; relative variation is measured as the coefficient of variation (CV) of total estimated catch; and relative cost is the fraction of total cost attributable to sampling each stratum (on a per sample basis). It is evident from the table that internal variation (CV) and relative cost per sample (CS) are roughly the same for the two strata so that relative sample size (RS) becomes primarily a function of relative catch (CA). The values for relative sample size show that roughly twice as many samples should be taken in the main river stratum as in the tributary stratum ($0.23 \approx 2 \times 0.13$). Given that six samples are to be taken within each time block, the above information dictates that four samples should be taken from the main river stratum and two samples from the tributary stratum. This allocation of sampling effort is optimum in terms of relative size, variation, and cost per sample within the two respective strata.

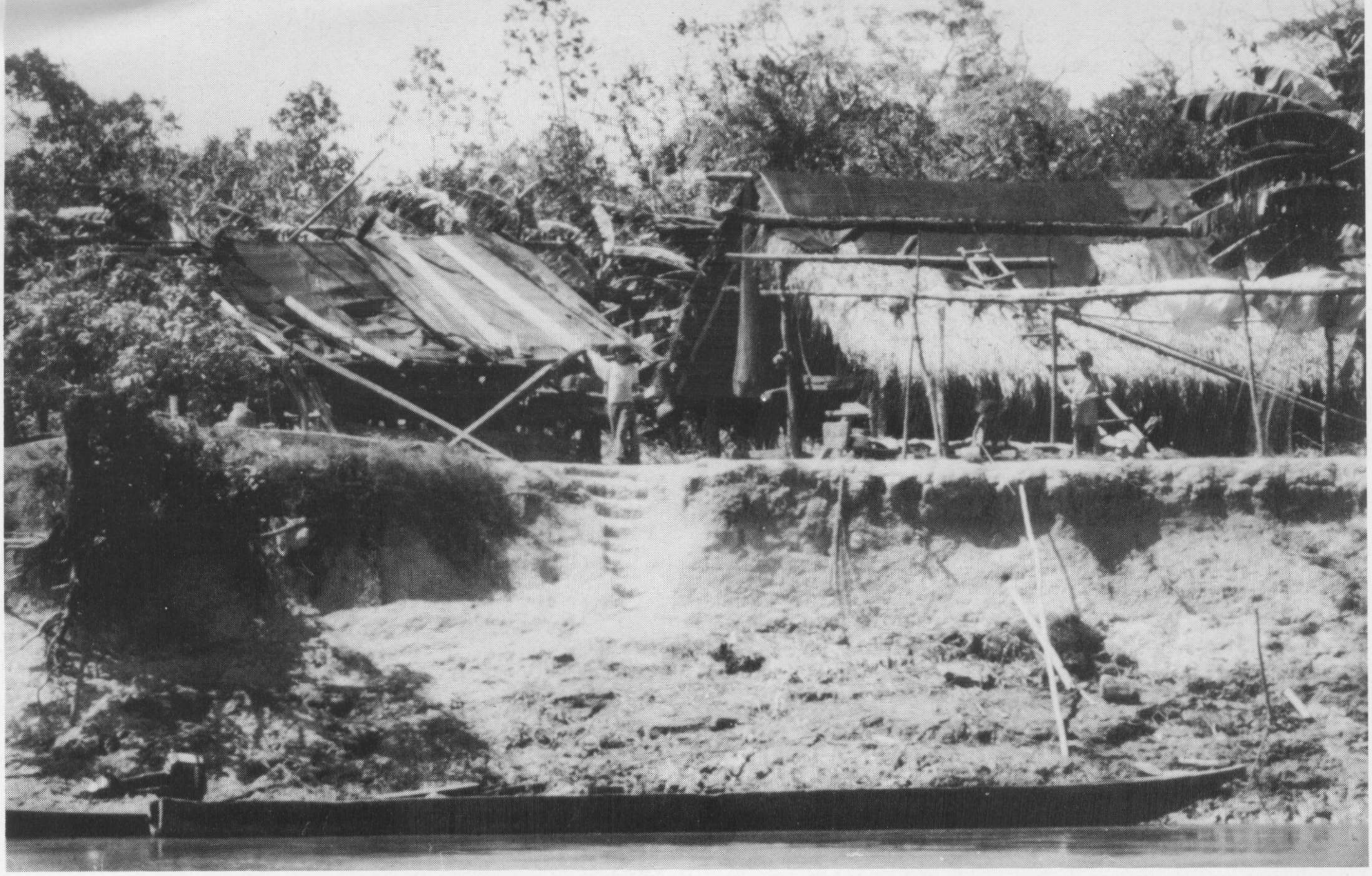
TABLE 8. VALUES OF RELATIVE CATCH (CA), RELATIVE VARIATION (CV), AND RELATIVE COST PER SAMPLE (CS) FOR THE MAIN RIVER AND TRIBUTARY STRATA (RELATIVE SAMPLE SIZE (RS) = $CA \times CV/\sqrt{CS}$)

Stratum	CA	CV	CS	RS*
I: main river	0.65	0.66	0.47	0.25
II: tributaries	.35	.70	.53	.13

*RS values can only be interpreted relative to one another, i.e., roughly twice as many samples should be taken in Stratum I relative to Stratum II.

Choosing River Sections and Tributaries for Sampling Purposes

Thus far, the sampling design calls for taking six samples within each time block, two of which will be tributary samples and four of which will be main river samples. Thus, within each time block, two tributaries and four river sections must be chosen. Statistical validity dictates that tributaries and river sections should be chosen at random. It is logical that the more important tributaries, and likewise the more important river sections, should have a greater chance or probability of being chosen than areas of lesser importance. It is also logical that these probabilities should be proportional to the intensity of fishing exhibited in these areas. The easiest measure of fishing intensity is fishing effort expressed as number of canoes (or number of fishing economic units). However, where the relative number and kinds of fishing gear per canoe differ within the system, the FEU as a unit of effort can be misleading. In this case, relative catch would be a better measure of relative fishing intensity



Riverside homes of fishermen are left high and dry during the low water season. During the high water season, these homes will frequently be inundated to depths of ½ meter or more.

where catch is a function of both number of canoes and the fishing power per canoe (as well as all other environmental factors which might cause differences in abundance or catchability of fishes between sampling units).

Catch data are available for the Upper Meta River and its tributaries from the 1977 and 1978 surveys. Sampling probabilities can thus be based on the relative catch, or percentage of total catch, contributed by each tributary within the tributary stratum and each section within the main river stratum. These probabilities are given in table 9. The Upper Meta River was divided into six sections which were each given an equal probability of being chosen for any given sample because the previous survey indicated that catch was fairly evenly distributed along the entire upper main river channel. Probabilities associated with individual tributaries vary considerably depending on their independent contributions to total catch. Table 9 also gives the random number ranges appropriate for the given probabilities. That is, when a tributary or main river section is being randomly chosen for sample, the random number chosen from a random number table (between 1 and 100) will necessarily fall into one of the ranges given in table 9; that particular range can then be associated with a particular tributary or river section using the table. Thus, for each time block, four random numbers will be chosen to give four river sections within Stratum I and two random numbers will be chosen to give two tributaries within Stratum II. This

TABLE 9. PROBABILITIES AND RANDOM NUMBER RANGES FOR RANDOMLY CHOOSING META RIVER SECTIONS (STRATUM I) AND INDIVIDUAL TRIBUTARIES (STRATUM II), BASED ON RELATIVE CATCH

River section or tributary	Probability	Random numbers
Stratum I		
1: Boca Guayuriba - Pto. Lopez	0.17	1-17
2: Pto. Lopez - Boca Upia	.17	18-34
3: Boca Upia - Pto. Guadalupe	.17	35-51
4: Pto. Guadalupe - Boca Manacacias	.17	52-68
5: Boca Manacacias - San Pedro	.17	69-85
6: San Pedro - Orocue	.17	86-00
Stratum II		
1: Humea	.09	1- 9
2: Tua	.47	10-56
3: Pajure	.01	57
4: Metica	.11	58-68
5: Guayuriba	.05	69-73
6: Upia	.08	74-81
7: Yucao	.03	82-84
8: Manacacias	.05	85-89
9: Cusiana	.06	90-95
10: Cravo Sur	.05	96-00

TABLE 10. THE 1980 SAMPLING SCHEDULE ON THE UPPER META RIVER (INDIVIDUAL RIVER SECTIONS AND TRIBUTARIES CHOSEN AT RANDOM USING THE PROBABILITIES GIVEN IN TABLE 9)

Time block	Stratum I: Meta River*	Stratum II: tributaries
A	1	Upia
	5	Tua
	1	
	5	
B	2	Cravo Sur
	6	Humea
	5	
	4	
C	4	Tua
	1	Tua
	4	
	6	
D	1	Manacacias
	3	Humea
	1	
	3	

*River section numbers correspond to those given in table 9.

random sampling procedure (nonuniform probability sampling) was conducted to give the sampling schedule on the Upper Meta River for 1980, which is shown in table 10.

PROPOSED METHOD OF CONDUCTING INITIAL SURVEYS OF OTHER MAJOR RIVERS IN LLANOS REGION

Initial Surveys

Nonuniform probability stratified random sampling can be applied to initial surveys of river systems other than the Upper Meta by the use of seasonal time blocks and geographical strata proposed in the previous section. Probabilities can be based on canoe (FEU) counts made during overflights of the proposed study areas prior to initiation of actual surveys. Time blocks can be defined based on Meta River information, assuming that similar hydrological cycles exist in all areas of the Llanos Orientales and that communities of fish and fishermen also respond in a similar manner. In new areas of study (the main Orinoco River or the Inirida River, for example) the initial year of sampling would entail allocating two-thirds of sampling effort to a main river stratum and one-third to a tributary stratum as proposed for the Upper Meta River.

A practical sampling unit (SU) within a main river stratum might be a 50-kilometer section of main river, and sampling units within the tributary stratum can be defined on an individual tributary basis. The probability of sampling any given SU within a stratum will be proportional to the number of canoes counted in the pre-survey overflight in relation to the total number of canoes in the entire stratum. Tentatively, four samples could be taken in a main river stratum and two samples in a tributary stratum as suggested for the proposed Upper Meta River survey (page 11). Resulting data can be analyzed using the detailed methods presented in the section beginning on page 6.

Follow-up Surveys

The decision to: (1) use a sampling fraction of two-thirds in a main river stratum and one-third in a tributary stratum, (2) use only the two strata described above, (3) use aerial canoe counts to determine sampling probabilities, and (4) use four seasonal time blocks as previously defined, are based on results of the Upper Meta River survey and on the feasibility of obtaining canoe counts from overflights. After the initial year of a CAS in a given study area, the creation of new sampling probabilities will probably be warranted for future surveys. These new probabilities and possibly new time and space strata will serve to increase the precision of the resulting estimates of catch, effort, and catch per unit effort. Thus, as more reliable information becomes available, this information should be used to improve the sample survey designs.

It is proposed that all major rivers of Colombia's Orinoco System other than the intensely sampled Upper Meta System be surveyed once in the next 10 years. We propose that catch assessment surveys be carried out in the following order:

1978 Upper Meta River (completed)
1979 Upper Guaviare River (in progress)
1980 Upper Meta River
1981 Lower Meta River
1982 Upper Meta River
1983 Lower Guaviare River

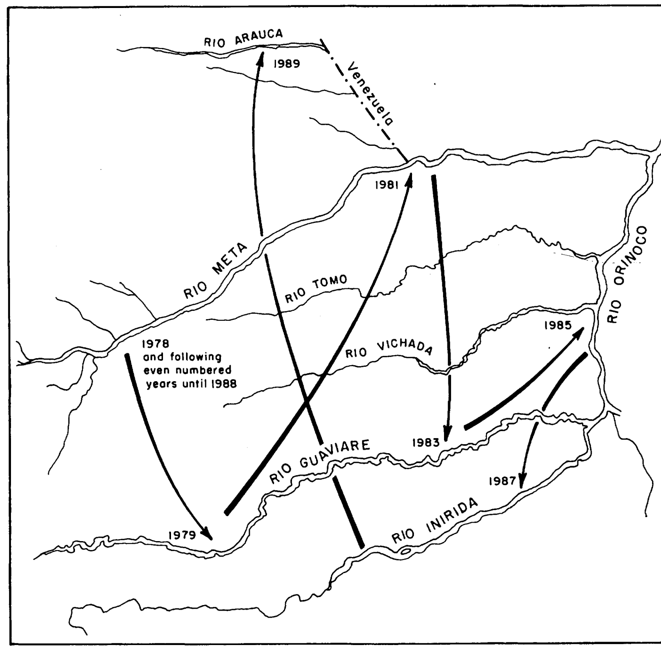


FIG. 3. The Colombian Orinoco River System showing proposed cycle of catch assessment surveys over the 10-year period, 1979-89.

1984 Upper Meta River
1985 Orinoco River and the tributaries Vichada and Tomo rivers
1986 Upper Meta River
1987 Inirida River
1988 Upper Meta River
1989 Arauca River

These river systems and proposed cycling of survey work are shown in figure 3. As can be seen by the above 10-year survey plan, the Upper Meta River will be sampled in alternate, even-numbered years and other systems during odd-numbered years. This schedule will provide continuing information on the Upper Meta River so that short-term changes in the development of the fishery can be monitored. The other river systems, which we assume to presently have less important fisheries than the Upper Meta, will be sampled much less frequently, but adequately, considering their assumed lower level of exploitation and slower rate of development.

It is hoped that after 1989, if sampling and administrative logistics improve, areas such as the Upper and Lower Meta, or the entire Guaviare and Inirida, can be incorporated into a single survey region so that the second round of surveys necessary for completion of surplus yield models (described in the following section) can be carried out more rapidly.

USE OF THE GRAHAM-SCHAEFER SURPLUS PRODUCTION MODEL FOR MANAGEMENT OF THE UPPER META RIVER FISHERY

Surplus yield models are particularly valuable in the early stages of a fishery investigation to make preliminary appraisals before more biological data are available. They are also important when biological data are scanty or nonexistent, but catch and effort data can be obtained. Their greatest advantage is that they require **only** catch and effort data for their

Substantial catch of large catfishes arriving at the Puerto Lopez municipal landing. The large fish being weighed is a valenton.

application. The other primary approaches to optimizing exploitation are the dynamic pool models, which attempt to describe an exploited population in terms of the basic parameters of recruitment, growth, and mortality. These parameters are typically difficult and expensive to measure and in certain situations may not be measurable at all, such as with age and growth relationships in tropical ecosystems.

The Graham-Schaefer surplus yield model postulates that recruitment, growth, and mortality are dependent on the fish population biomass (density dependent) such that these parameters can all be combined into a single common function. This function predicts the rate of population change based solely on the mean population size during a period of time when the population is stable or in equilibrium with the fishery, i.e., rates of growth and recruitment are exactly balanced by rates of natural and fishing mortality. Mean population size is, in turn, assumed to be a function of fishing pressure; thus, a given population size or biomass has associated with it a certain level of fishing effort. The population size and its associated level of fishing effort determine the amount of yield available to the fishery. In a biological sense, this yield is the biomass over and above that needed to exactly replace the population and is thus termed surplus yield or surplus production.

In theory, yield is taken to be a parabolic function of stock biomass as indicated in figure 4. The maximum stock biomass (B_{max}) is the carrying capacity of the environment, or the population size which can be supported prior to the advent of fishing. Fishing acts to reduce B_{max} to some lower biomass (B) and the population then responds by producing surplus biomass in an effort to return to B_{max}. This surplus biomass is available to the fishery as yield and if this surplus is harvested, the population biomass will remain stable at B. It is evident from the hypothetical curve in figure 4 that maximum surplus yield is attainable when the population biomass equals $B_{max}/2$ or 50 percent of the carrying capacity of the unfished system. When B is reduced below $B_{max}/2$ by fishing, the yield falls below the maximum sustainable yield (MSY), and if fishing pressure is not great enough so that B is greater than $B_{max}/2$, then yield again falls below MSY.

In terms of regulating a given fishery, it is obviously desirable to know $B_{max}/2$. More importantly, it is desirable to know the level of fishing effort associated with $B_{max}/2$. This level of fishing effort is the optimum level for the fishery (E_{OPT}) and, if maintained, will theoretically provide MSY. Fortunately, it has been shown mathematically *(6, section 13.3)* that E_{OPT} can easily be determined by simply obtaining values of catch per unit effort (kilograms of fish caught per fishing unit = U) and effort (E) during at least two periods when the fishery has stabilized, i.e., during at least two periods in which effort is constant, or changing only gradually. These periods should reasonably be at least 3 years in duration to ensure that the fish community under exploitation has come into biological equilibrium with the fishery. When the equilibrium values of U are regressed against the equilibrium values of E for the two (or more) equilibrium periods using the linear equation $U = a - bE$, then $E_{OPT} = a/2b$. That is, the optimum level of fishing effort simply equals the y-

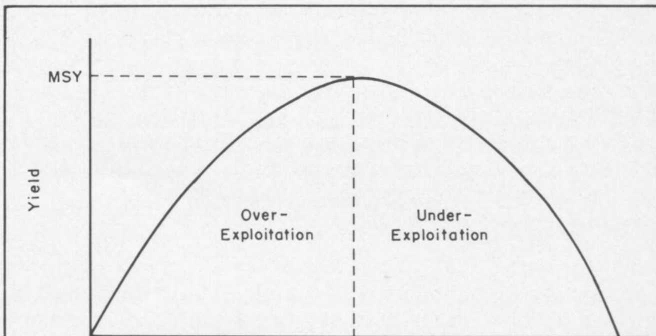


FIG. 4. Diagram depicting yield as a parabolic function of stock biomass. Maximum sustained yield (MSY) and optimum fishing effort (E_{opt}) are attained at $B_{max}/2$. See text for explanation.

Improvement of the road from Puerto Lopez to Villavicencio will increase accessibility of fish harvested from the Upper Meta River to population centers in Villavicencio and Bogota. As a result, fishing pressure will likely increase dramatically in the near future.

intercept (a) divided by 2 times the slope (b) where a and b are determined from the linear regression equation. Additionally, the maximum sustainable yield can be calculated as $MSY = a^2/4b$.

The general difficulty with using the above approach is that the development or expansion of the fishery may be so rapid that equilibrium periods, or periods when effort is relatively constant for a minimum of 3 years, may not be forthcoming. However, it appears that the commercial fishery on the Upper Meta River has remained stable over the past few years so that the estimates of E and U from the 1978 CAS can be used as the first set of equilibrium values. These values (rounded off), from table 7, are:

$$E = 126{,}300 \pm 12{,}400 \text{ FEU-days}$$

$$U = 8.10 \pm 1.60 \text{ kg/FEU/day}$$

It is likely that a second set of equilibrium values of E and U will be forthcoming in the near future with the paving of the road from Villavicencio to Puerto Lopez. Improvement of transportation systems stimulate increased supply and demand and eventually lead to increased exploitation of the fishery resource. When the road from Villavicencio to Puerto Lopez is paved, the ease with which fish can be transported to Villavicencio and Bogota will be greatly increased. The demand for fish is high in these areas and because fish prices increase as distance from the resource increases, fishermen will be encouraged to increase fish supply, i.e., to increase exploitation. The ultimate predicted result is that fishing effort will take a quantum leap on the Upper Meta River when the road is paved; the situation will then be ideal for obtaining another set of equilibrium values of E and U (assuming that the fishery again stabilizes). It thus appears that the current situation, in terms of future development plans in the Llanos Orientales, is ideal for use of the surplus yield model as a management tool.

It should be stressed that, given the present state of knowledge concerning the dynamics of the fish community in the Meta River, the surplus yield approach is the only method available for estimating an optimal level of fishing effort and its associated MSY. The method may be overly simplistic, but it has been applied to multi-species stocks in African lakes with promising results *(8)*.

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