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Overview of the Leslie Fishing Success Method as an Assessment Tool for Snow Crab Stocks

by

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ABSTRACT

The Leslie analysis of catch and effort data is often used to estimate the size of exploited snow crab (Chionoecetes opilio) stocks. The analysis is based on a least-squares regression of catch-per-unit-of-effort against cumulative catch at regular time intervals. Several sources of error in the method are discussed in respect to snow crab fisheries characteristics. In the best conditions, the Leslie analysis will provide a useful a posteriori stock size estimate for snow crab, but supplementary information on recruitment trend and growth rate is needed for accurate forecasting. Furthermore, given its several weaknesses, alternative methodologies to the Leslie analysis should be developped.

RÉSUMÉ

La taille des stocks exploités de crabe des neiges (Chionoecetes opilio) peut souvent être estimée par l'analyse de Leslie des données de capture et d'effort. Cette analyse consiste en une régression, par la méthode des moindres carrés, des prises-par-unité-d'effort sur les captures cumulatives à des intervalles de temps réguliers. Il faut cependant considérer diverses sources d'erreur dans son application à la pêche du crabe des neiges. Dans les conditions idéales, l'analyse de Leslie permet avantageusement d'estimer a posteriori la taille d'un stock de crabe des neiges. Cependant, il faut un supplément d'information sur les taux de recrutement et de croissance avant d'effectuer des prévisions justes. Enfin, considérant les faiblesses de l'analyse de Leslie, il faudrait recourir éventuellement à d'autres méthodes.

INTRODUCTION

The fishing success methods described by Leslie and Davis (1939) and by De Lury (1947) are simple mathematical analyses of catch and effort data. Their purpose is to estimate the size of the initial stock (in numbers or weight) present in the study area at the start of the fishery. In the case of a snow crab fishery, the data generally used are the catch and effort statistics in terms of catch weight and number of trap hauls respectively, as obtained from sales slips and logbooks. The study area is inevitably limited to the fishing grounds exploited by the fishermen.

Essentially, fishing success methods are based on the assumption that the catch per unit of effort (CPUE) is directly proportional to the stock size. Additionally,the fishery has to be intensive enough for CPUE to reduce as the stock is depleted. De Lury's method compares the reduction in CPUE to the cumulative summation of the fishing effort. Leslie and Davis's approach is to relate the reduction in the CPUE to the cumulative catch, itself inversely proportional to the remaining stock size. The latter approach is more suitable for snow crab fisheries as the catch statistics are generally more complete and accurate than the effort statistics. The initial stock size is estimated by extrapolating a linear regression of CPUE against cumulative catch to zero catch per unit of effort.

METHOD

(Development of mathematical expressions)

The initial stock, to be estimated by the analysis, is B_o, present at time = t_o. At a given time = t, after exploitation starts, the stock will be reduced by a given catch (K_t), which is the cumulative catch from t_o until time t, and will be equal to

$$B_t = B_o - K_t \qquad (1)$$

Assuming that the measurement of the fishing effort is reliable, each unit of effort should catch a constant fraction of the total stock, present at any given time. In other terms,

$$CPUE_t = q\ B_t \qquad (2)$$

where $CPUE_t$ is the catch per unit of effort at time = t and q is a constant fraction identified as the catchability coefficient. This is the classic catch equation for which an extensive discussion may be found in Paloheimo and Dickie (1964).

For example, a unit of effort might be a one-hour tow, at a given speed, with a given bottom trawl. This unit of effort will sweep a constant area of bottom which represents a small but constant fraction of the total fishing area. If the total area has an homogeneous density of fish on the bottom, and if the trawl catches all fish in its path, then a unit of effort will catch a constant fraction of the stock. This fraction is the catchability coefficient (q). In other words, the catch-per-unit-of-effort ($CPUE_t$) will be proportional to the stock size (B_t) by a fraction or catchability coefficient (q). In the snow crab fisheries, a trap haul of a given type of trap (preferably but not always corrected for soak time) is the unit of effort, and the same principle as for a bottom trawl applies.

Equations (1) and (2) can be combined:

$CPUE_t = q\ (B_o - K_t)$ or

$$CPUE_t = qB_o - qK_t \tag{3}$$

The latter equation represents a linear relationship between the variables $CPUE_t$ and K_t, with a slope of $-q$ and an intercept on the y-axis of qB_o. The parameters of the equation are estimated by least-squares regression. The initial biomass of the stock (B_o) can be obtained by solving the equation for $CPUE_t = 0$ (estimating the total cumulative catch equivalent to the total initial stock, which would be reached when nothing is left to catch).

The variables $CPUE_t$ and K_t are generally estimated from the fishing statistics for regular time intervals. Ideally, these time intervals should be infinitely small or instantaneous. In fact, they generally cover several days and the data used in the regression are expected to estimate the average situation during each time interval. In the initial Leslie method, K_t was the total cumulative catch made before the beginning of time interval t. Braaten (1969) suggested adding to this cumulative catch half of what is caught during the time interval t. This would represent more correctly the average stock corresponding to the average $CPUE_t$.

The confidence limits for the estimate of B_o can be calculated for any level of probability (De Lury 1951, Ricker 1975). These limits are not symmetrical as they are the intercepts on the x-axis of the confidence belts of the regression (Fig. 1). In some cases, where the correlation is weak, it might be impossible to find an upper limit of confidence for the estimate of B_o.

From the regression parameters, it is possible to estimate the average biomass (B_t) present at any time interval, using equation (2) and the average $CPUE_t$.

DISCUSSION
(Sources of error in the method)

A Leslie analysis will be most accurate if the following conditions are met:

1) There is a discrete stock with well defined boundaries,

2) The stock does not increase by immigration and growth or decrease by emigration and mortality, during the fishing season,

3) The individuals in the stock are constantly distributed randomly on the fishing grounds,

4) The fishing effort is distributed randomly over the fishing grounds,

5) Each unit of effort will catch a constant proportion of the stock (constant catchability),

6) Each fisherman will accurately report, for every trip, the total number of units of effort and the corresponding catch.

Among the snow crab stocks exploited in Atlantic Canada, few, if any, meet all of the conditions. In some cases, the situation is not at all suitable for Leslie analysis. In others, the departures from some conditions can be corrected for.

One basic assumption of the Leslie method is that stock size does not change during the fishing season, except for the removals made by the fishery. There must be no significant migration between the stock boundaries and adjacent areas. Of course, random movements of crabs within the fishing grounds would only be beneficial to the analysis, since they help to randomize their distribution. In Cape Breton zone 1, for instance, the fishing season is so short (few weeks) and access to other areas so limited that the assumption of no migration is probably valid. Furthermore, Watson (1970) demonstrated that large crabs generally travel less that 15 kilometers within a year.

By-catches to other fisheries and natural mortality of commercial crabs should be absent or sufficiently low during the fishing season to be negligible. Snow crab is a long-lived animal and adults are probably not vulnerable to predators except when soft-shelled. Thus natural mortality of males ≥ 95 mm CW is likely to be low and its effect is probably negligible within the duration of a fishing season. Indeed, a crude estimate for M of 0.065 was obtained from a tagging study in Cape Breton zone 1 (Bailey 1978). Crab catches by a different fishery during the crab season would bias the results of a Leslie analysis if they were caught on the same grounds and were not taken into account in the catch statistics. By-catches of snow crabs in the groundfishery off Cape Breton are reported to be high but they are made before and after the snow crab fishing season. Miller and Hoyles (1973) reported conflicts between the crab trap fishery and the cod gillnet fishery on the south and east coasts of Newfoundland.

Recruitment to the stock occurs when young male crabs molt above a legal minimum size (≥95 mm carapace width) and if migration of males ≥95 mm CW occurs from outside areas. This latter recruitment process, although a working hypothesis considered for some stocks, has not been demonstrated and is presumed not significant during the fishing season. However, molting generally occurs during the season and can seriously compromise the accuracy of the Leslie method. For a period following ecdysis, crabs may not be attracted to traps and when caught as softshells are often returned to the sea. This temporarily reduces catchability and catch rates. With ecdysis, large numbers of crabs may reach the legal size and substantially increase the fishable stock. There is evidence that such a phenomenon is occurring in the California Dungeness crab fisheries (Gotshall 1978, Methot and Botsford 1982). The influx of newly recruited crabs results in higher catch rates and destroys the linear relationship with cumulative catch because the requirement for a constant stock is violated. The problem can be solved if the molting period is identified and only the data collected before or after the period are used in the analysis. Care must be taken in the interpretation of the results since the estimated biomass corresponds to what was present at the beginning of the time series used for the analysis. This estimate would be different from what was there at the beginning of the fishing season if the data used concern the last part of the season and recruitment occurred during the first part. Furthermore, the total seasonal catch could be higher than the initial biomass estimated, if molting and subsequent recruitment occurred later in the season. (See Bailey 1978, for an example).

Miller (1975) suggested that adult snow crab males have a random distribution on the fishing grounds. If true, this pattern could be retained through the fishing season if fishing effort is also distributed randomly and if depleted areas are replenished by the random mobility of crabs (Watson 1970). However, Miller's evidence for a random distribution of crabs on the bottom is tenuous and it would still be reasonable to expect a certain amount of patchiness as is often the rule for other benthic marine organisms (Elliott 1977). In patchy conditions, the average CPUE can still give a reliable index of abundance for the stock if the total number of effort units is sufficiently high and if the distribution of effort is random over the fishing grounds.

Departures from a random distribution of effort could result in biased catch rates not reflecting the average abundance of crabs in the entire exploitable stock. The biomass estimated by the Leslie method is for the actual fishing grounds. Sometimes, the limits of the grounds are not the same as those of the total stock. For instance, areas of lower density of crabs, even if commercially interesting, might be neglected by fishermen in favor of areas of initially higher densities. Offshore grounds with high densities of commercial-size crabs might be neglected if fishermen are satisfied with returns from more accessible nearshore areas. Furthermore, it is conceivable in lightly fished stocks that patches of crabs within the fishing boundaries remain unaffected by the fishery if no traps are set in the vicinity. Such a biased fishing pattern would concentrate on only a segment of the total stock. Leslie analysis would estimate the biomass of the segment only. Of course, the estimated exploitation rate would be higher than the real exploitation rate on the total available stock. Biomass comparisons between years may be meaningless if the fishing grounds have changed substantially. Furthermore, if the fishing effort shifts from one segment of the stock to another during the season, it becomes impossible to use the catch and effort data for a Leslie analysis. Bias of this nature has been observed in some Newfoundland snow crab stocks (Taylor, pers. comm.) where fishermen fish the nearshore areas first, and expand progressively offshore as these first areas are fished down. A similar pattern exists in the California Dungeness crab fisheries where it creates problems with the Leslie analysis interpretation (Methot and Botsford 1982).

Consequently, it is important to know the geographical distribution of the fishery and to verify, if possible, to what extent it matches the distribution of the exploitable stock. For example, trap locations obtained from logbooks were used to map the approximate distribution of the fishery in northwest Cape Breton: the mapping shows that the fishing grounds have expanded between 1978 (Fig. 2) and 1982 (Fig. 3) but a close inspection of the intensity of fishing in each square for 1982 indicates that the fishery was mainly confined to the same area as in 1978. Nevertheless, high CPUE's are obtained outside the main fishing area which suggests that the fishery does not encompass the total exploitable stock of crabs.

The assumption of constant catchability should be tested against an independent method, such as a Leslie analysis of tagging data, as suggested by De Lury (1951). Bailey (1978) obtained relatively good compatibility between catchabilities from the total catch analysis and from the tag recaptures analysis. Furthermore, the study showed that a Petersen estimate of the total stock was similar to the estimate obtained with Leslie's method. This suggested that the linear shape of the catch-effort data was not fortuitous but related to a constant catchability during the weeks following the molting period. A similar confirmation of the Leslie analysis was achieved by Peterson et al. (1980) on an adult northern pike (Esox lucius) population. The Leslie estimate of total population was within 1% of that obtained from direct enumeration.

In lobster, Homarus americanus, catchability has been shown to vary with environmental conditions, such as temperature (Paloheimo 1963). Availability of food can also compete with the attractiveness of a baited trap and affect the catchability. Snow crab lives in a much more stable habitat (temperature, food supply) than lobster and should not exhibit as much variability in its catchability to baited traps. Nevertheless, the question of catchability requires further research.

Other factors having an impact on the estimation of catchability are those affecting the measurement of effort. The unit of effort should be a constant measure of fishing power. Factors such as soak time, bait quality and quantity, trap construction and fishermen's ability will affect the trap haul as a constant measure of effort. These should either be corrected for, or assumed constant overall so that they do not affect the end result. For instance, different fishermen might use different quantities of bait, but if they do so for the total season, their pooled effort will be relatively constant and their catch will be constantly proportional to the stock abundance.

One serious problem with the Leslie method concerns the reliability of the catch-effort statistics. Full reporting of the catch is a prerequisite to a meaningful Leslie analysis. The biomass estimate for a given stock will be underestimated in the same proportion the catch statistics are misreported if the error is constant, but might be completely out of range if the misreporting is not constant. Inaccurate effort reporting will yield wrong CPUE's which could seriously bias biomass estimates. For instance, reporting less trap hauls than actually made (which is tempting to some fishermen because of controls on the number of traps) will artificially inflate the CPUE. If the error is not constant, the results of the analysis will be aberrant. If the error is constant, the results may still be useful since the stock size and the exploitation level would be correctly estimated.

CONCLUSION

When the exploitation of a snow crab stock is randomly distributed over the fishing grounds, for the duration of the fishing season; when the stock is not modified by molting (unless this can be corrected for), migration or by other significant effects than direct exploitation; when the catch statistics are complete and the effort accurately documented; and when catchability can be assumed to be relatively constant, then a Leslie analysis of catch and effort data can give a reliable estimate of the stock size present on the fishing grounds during the season.

The Leslie estimate will be obtained after the fishery is over. It can be used for management decisions concerning the following season only if some assumptions are made concerning the stock recruitment and productivity. A time series obtained for Cape Breton Zone 1 (Elner 1982) indicates a stable production of approximately 1000 t for the 1978-1981 period. But in other areas, the production seems more variable, increasing in the southwestern Gulf and dropping in eastern Cape Breton. Until a better understanding of the recruitment process and of the growth rate is reached, assumptions that are made about the productivity of the stocks limit the usefulness, for catch prediction, of the stock estimates obtained with Leslie method.

Despite its possible usefulness, Leslie method should eventually be replaced or complemented by more reliable methods of stock assessment, such as tagging or bottom photography. Serious problems have been identified with a bottom trawl method tested on snow crab in Alaska and compared to the Leslie method (Colgate 1982). Furthermore, the results obtained with the later method were frequently erroneous. Thus, the possibility for many sources of error, the heavy reliance on accuracy of fishery statistics and the lack of direct control on the data collection, stress the need to develop alternative methodologies to the Leslie analysis.

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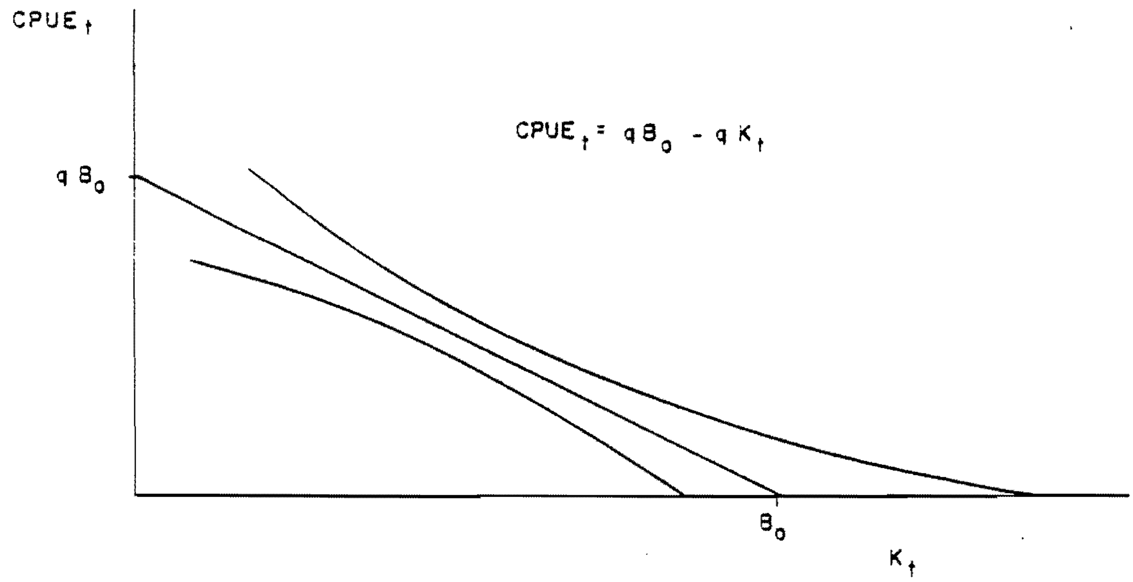

Figure 1. Leslie graph of catch per unit of effort ($CPUE_t$) versus cumulative catch (K_t).

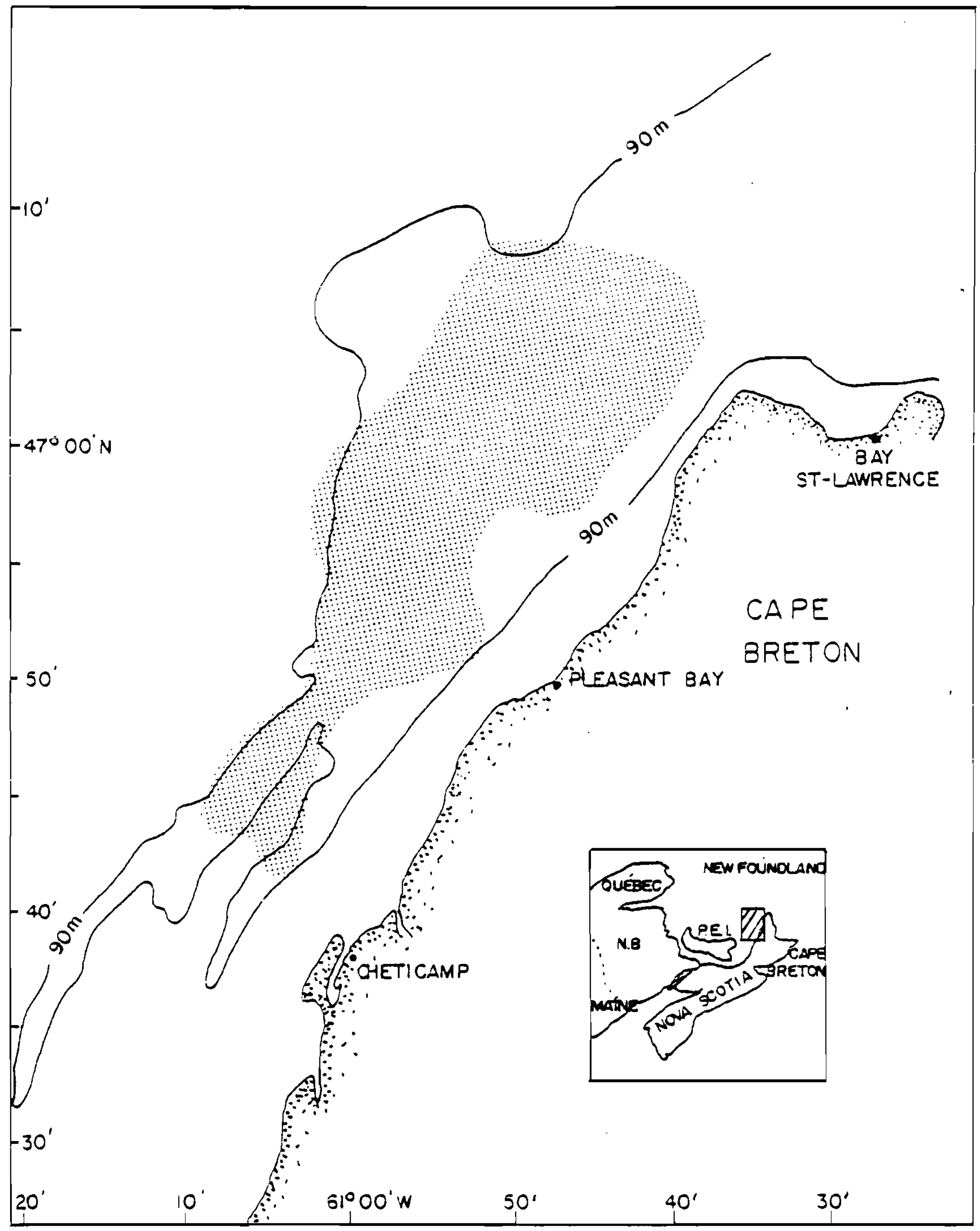

Figure 2. Distribution of fishing grounds (hatched area) in Cape Breton zone 1, for 1978, as determined from fishermen log books.

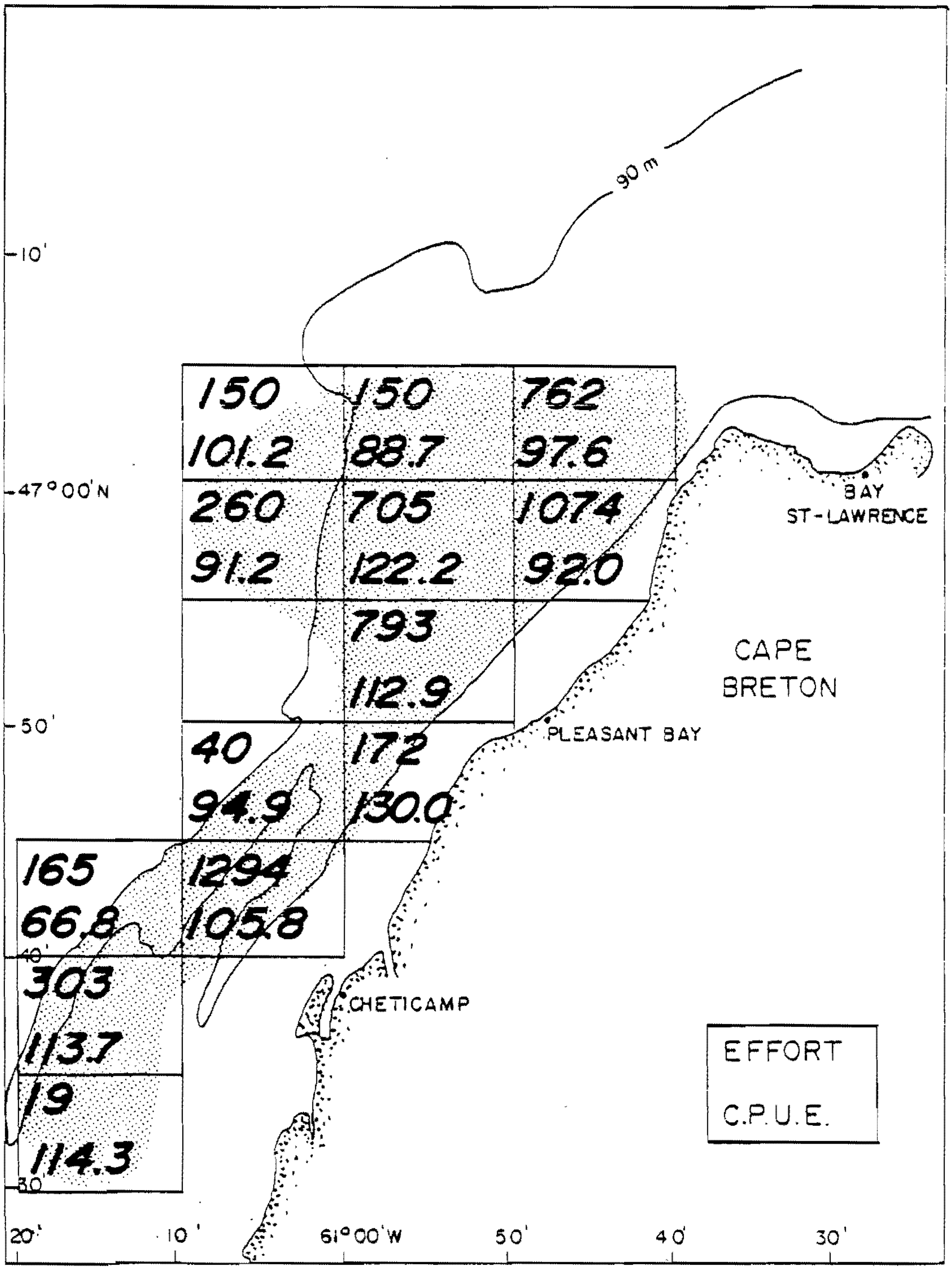

Figure 3. Distribution of fishing grounds, fishing effort and CPUE, in Cape Breton management zone 1, for 1982 as obtained from fishermen log books. Effort is expressed in trap hauls and CPUE in kg/trap haul.