STANDARD FORM NO. 64

Office Memorandum • UNITED STATES GOVERNMENT

TO : Chief, M.A.L.D.

DATE: 7? 6/2/58

FROM : Chairman, Edit. Comm.

SUBJECT: Oberacker ms

Attached you will find Edwards's and Wise's comments. I don't think that the manuscript could be put in publishable form without altering it so much that it would no longer be the same paper.

JOP

Art —

Re Aberackers ms.

I must agree with Wise's genl conclusion — tho not all his specific comments. There are several parts of the ms that need bucking up before publication is possible.

The discussion of his method and its implications seems to neglect the strong likelihood of seasonal movements affecting results. He puts aside the possibility with a few casual words. My conclusions based on P.S. fishery, indicate profound seasonal changes. It is noteworthy that the DeLury method has been successfully used only (as far as I know) in relatively closed systems such as lake.

over

His section on vessel relation to C_ξ is only barely enough discussed and could stand further work.

Bob

November 20, 1958

John P. Wise

Robert L. Edwards

Ms., "Population estimates of whiting (Merluccius bilinearis) stocks by the Delury regression technique," by D. Oberacker

Please review and comment.

Robert L. Edwards

Enclosure

STANDARD FORM NO. 64

Office Memorandum • UNITED STATES GOVERNMENT

TO : J.A. Posgay DATE: June 19, 1958

FROM : J.P. Wise

SUBJECT: Oberacker's ms. on estimation of whiting populations.

With regard to the inquiry in the memo of Clyde to the boss, dated June 16, I have examined the thesis and do not think that the material and conclusions are sufficiently sound to merit publication.

Some of the reasons are these:

1. The author admits that he cannot estimate the strength of the offshore population, and his estimate of the strength of the inshore population is roughly plus or minus fifty percent.

2. He discusses "catchable population" but does not define it. Nowhere is the point brought out that a good part of the population is partially catchable, and partially only, because of net selectivity.

3. In converting pounds of fish to numbers he uses samples which amount in total to about seven hundred fish, or, assuming half a pound per fish, to about three hundred and fifty pounds. This is <u>less than one-thousandth of one percent</u> of his estimate of the population. It does not seem to me that valid conclusions are likely to be drawn from so small a sample.

4. The method of calculating the numbers not catchable by otter trawl presented in Appendix F is not valid, since it does not take into account the selection curve.

5. The weakest part of the conversion of pounds to numbers is in the smaller part of the size range, and it is here that enormous errors can arise. An error of one hundred percent in pounds of fish of six centimeters is not serious, but since there are so many of the little beggars to the pound, it will be multiplied out of all proportion.

J.P. Wise

STANDARD FORM NO. 64

Office Memorandum • UNITED STATES GOVERNMENT

TO : Chief, NAFI

DATE: June 16, 1958

FROM : Ass't Chief

SUBJECT: Oberacker's Ms."A study of two populations of Merluccius bilinearis, etc."

I believe Oberacker's attached Master's thesis might well be published as a Special Scientific Report. I am therefore suggesting that it be put in the hands of our editorial committee for their opinions on the following questions:

1. Are the material and conclusions suffieiently sound to merit publication?

2. General comments on re-writing for a Sp. Sci. Rept.? (I think, for example, that many sections can be written more tersely, with deletion of some sections).

STANDARD FORM NO. 64

Office Memorandum • UNITED STATES GOVERNMENT

TO : Chief, NAFI DATE: July 21, 1958

FROM : Ass't Chief

SUBJECT: Oberacker's MS: "A study of two populations of M. bilinearis, etc."

I have just completed reviewing the comments of the Editorial Committee on the publishability of subject manuscript. I am disturbed by the lack of appreciation of the importance of this study and by the superficial treatment, as indicated by criticisms of the most trivial nature. These can only arise from a general lack of understanding of the subject, failure to examine the data carefully, especially the graphs, and perhaps that an approach to population problems other than one blessed by Beverton and Holt is to be regarded with due suspicion.

If the manuscript were badly written, so that its major points were obscured, one might expect the type of treatment given it. It is, however, unusually well-written.

The reasons offered for not accepting this manuscript vary, among the three editors, from none at all to more lengthy but completely untenable reasons. It is hardly worthwhile to discuss them here. I find only one point on which I agree the criticism is valid, but the point is trivial.

I suggest either that the manuscript be returned to the editorial board for a more thoughtful review or that we meet with the editorial board to discuss this matter.

C. C. T.

Bureau of Commercial Fisheries
Woods Hole, Massachusetts

July 30, 1958

Dr. D. B. De Lury
Ontario Research Foundation
43 Queens Park
Toronbo 5, Canada

Dear Dr. De Lury:

I am taking the liberty of sending you the enclosed manuscript by Donald P. Oberacker because I think you will find interesting the results of applying the "DeLury method" to a marine fishery situation and because I hope you may wish to comment on the general quality of the study, particularly with reference to its possible publication.

Mr. Oberacker began this study last summer at my suggestion and continued it at the University of Maryland during the past year. I am quite pleased by the indications of this study and am convinced that your method will prove useful to us in making general assessments of fisheries for which we have available catch and effort data only.

Sincerely yours,

Clyde C. Taylor
Assistant Chief
North Atlantic
Fishery Investigations

Enclosure

A STUDY OF TWO POPULATIONS OF *MERLUCCIUS BILINEARIS* (MITCHILL) BY THE USE OF THE DELURY REGRESSION METHOD OF ESTIMATING A POPULATION TOTAL

by

Donald Peters Oberacker

Thesis submitted to the Faculty of the Graduate School
of the University of Maryland in partial fulfillment
of the requirements for the degree of
Master of Science
1958

ACKNOWLEDGMENT

The author wishes to thank Dr. Howard Winn, Assistant Professor, Department of Zoology, and Dr. Vincent Schultz, Associate Professor, Agriculture Experiment Station, for their helpful counsel in the preparation of this manuscript.

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INTRODUCTION

An attempt is made in this paper to estimate the size of two populations of *Merluccius bilinearis* (Mitchill), principally by a method proposed by DeLury (1947) which utilizes catch-effort data.

Early in the twentieth century, *Merluccius bilinearis*, a marine fish commonly called "whiting," was used almost entirely as a fertilizer because the flesh deteriorates rapidly (Bigelow and Schroeder, 1953), and it was uneconomical to prevent spoilage in order to sell the fish as food. But with the improved techniques of freezing and preparing fish now available, both on ship and shore, the whiting has become an increasingly important table food fish. Most of the whiting now caught are used directly for human consumption and are an important constituent in the United States' economy (Ginsburg, 1954).

The majority of whiting now caught off the northeast coast of the United States come from two areas. One of these areas is an inshore area which lies along the coast of Massachusetts, and the other is an offshore area which lies approximately 30 miles east of the inshore area (Figure 1). Ever since whiting have been caught in the northwest Atlantic, its primary source has been the inshore area. Only since the recent increased demand for the whiting has the offshore area been utilized as a fishing ground.

It is desirable to have some idea of the size of the inshore and offshore whiting populations and the extent to which the populations are actually being exploited in order to properly manage the whiting fishery.

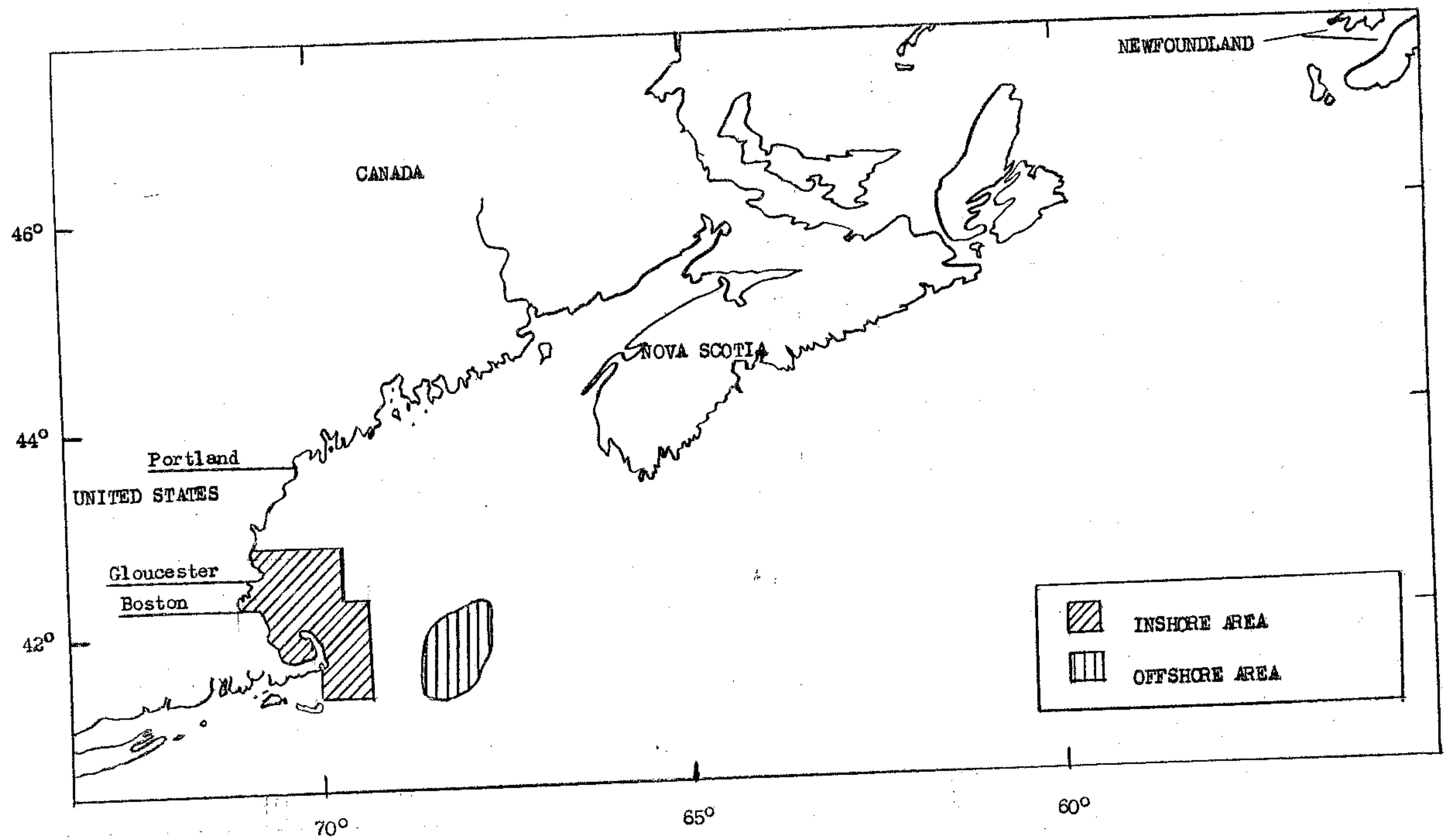

Figure 1. Map of the northwest Atlantic coastline showing the approximate location of the two study areas, inshore and offshore.

This paper is an attempt to fulfill the above needs by use of DeLury's procedure of population estimation from catch-effort data, a procedure which has been applied by various fisheries' biologists. Mottley (1949) used it on creel-census data to estimate a population size of rainbow trout, Salmo gairdnerii, in Paul Lake, British Columbia. The fish population sizes in three lakes in the Province of Ontario (O'Reilly Lake, Davern Lake and Little Lake) were studied by Omand (1951), who applied the procedure to data on catches of trap nets. He estimated the population sizes of the following species: black bass, Micropterus dolomieu; perch, Perca flavescens; bullhead, Ameiurus nebulosus; and sucker, Catostomus commersonnii. Ketchen (1953) used it in combination with an extensive tagging study to estimate the population size of a stock of lemon sole, Parophrys vetulus, on the fishing grounds of Hecate Straight, British Columbia. The size of a population of redear sunfish, Lepomis microlophus, was estimated by Gerking (1952), who used DeLury's procedure with data from trap catches of Cordy Lake, Indiana; the method was tested against other methods (Petersen and Schnabel) of estimating a population total. The agreement with these methods was good. Forney (1957) used it to estimate the population sizes of the following fish in 13 ponds in the State of New York: white sucker, Catostomus commersonnii; flathead minnow, Pimephales promelas; and silvery minnow, Hybognathus nuchalis regius. Forney obtained his data from successive seine hauls, and he found that the population size estimates by the DeLury method were generally lower than the true populations, which were determined by draining and counting.

The method proposed by DeLury depends upon the fact that the decrease in the catch per unit effort as the population becomes depleted bears a direct relationship to the extent of the depletion. The fishery must harvest a significant proportion of the population for the method to be applicable, as it depends on the ability to make a good estimate of the slope of the regression of catch per unit effort on accumulated catch. When a very small proportion of the population is taken by the fishery, the slope is nil or so slight that a small change in slope makes a tremendous difference in the point at which the projection of the regression line intercepts the x-axis; this intersection is the estimate of the total population size. The relationship between catch per unit effort and accumulated catch proposed by DeLury holds true only if the following assumptions are satisfied: (1) natural mortality, recruitment, and migration must be negligible during the period of study; (2) units of effort employed during the sampling periods must not compete with one another; and (3) the proportion of the population taken by a unit of effort should remain constant (Rounsefell and Everhart, 1953).

THE DELURY PROCEDURE FOR ESTIMATING POPULATION TOTALS

The method of estimating a population size as suggested by DeLury (1947) requires data by time periods of the number of individuals caught and the amount of "effort" expended in capturing them. DeLury (1947) states:

> "It will be assumed, then, that catch and effort records are available for a series of consecutive time intervals. The catch for a given time interval, specified by t, will be denoted by c(t) and the corresponding effort by e(t). The catch per unit effort for the time interval t is then C(t) = c(t)/e(t). Now, as a population becomes depleted, the value of C(t) ordinarily decreases, and the amount by which C(t) is diminished reflects the extent of the depletion which, in turn, depends on the total catch and the total effort. This qualitative statement may be made quantitative under suitable assumptions."

The following assumptions are made: (1) the population remains closed, that is, effects of migration and natural mortality are negligible; (2) units of effort employed during interval t do not compete with one another; and (3) the proportion, k, of the population captured during the time interval t by one unit of effort remains constant (DeLury, 1947).

If we designate the population size at the beginning of the study just before the first catch is made by N(o), then the catch per unit effort, C(t), at the time just before the first catch is made is kN(o), i.e., C(t) = kN(o).

If we let K(t) represent the number of individuals removed from the population up to time t, then the population at any time is N(o) - K(t). In a like manner, we may also represent the catch per unit effort, C(t), at any time as $C(t) = k\left[N(o) - K(t)\right]$, which may be written:

$$C(t) = kN(o) - kK(t). \qquad (1)$$

If values of C(t) are plotted against K(t) and the relationship between C(t) and K(t) is reasonably straight, estimates of k and N(o) follow at once by fitting a straight-line regression of C(t) on K(t) to the data and using it to estimate k, the slope, and N(o), the intercept divided by k. DeLury (1947) presents the complete mathematical derivation of formula (1).

It is possible to compute approximate confidence limits for the population estimate, N(o), by a formula presented by DeLury (1951).

It was decided that the above method might be used to estimate the two populations of whiting for the following reasons: (1) catch-effort data were available from the two areas by time periods, and (2) tagging studies made by Mr. R. L. Fritz of the U. S. Fish and Wildlife Service at Woods Hole, Massachusetts gave no indication that migration occurred during the months of July, August and September of 1957, thus apparently satisfying one of the assumptions for a closed population.

AREAS AND PERIOD OF STUDY

Boundaries for the two study areas were determined from commercial landing data on whiting. It was found that the bulk of the whiting landed from the Gulf of Maine came from the two areas we shall call "inshore" and "offshore" (Figure 1). Bigelow and Schroeder (1953) stated that the southwestern part of the Gulf of Maine, which is within the inshore area, was the chief center of abundance for whiting. Commercial landing records showed that it has only been in the last several years that the offshore area has been fished to any great extent. Currently the offshore area contributes almost as much to the total whiting catch each year as the much larger inshore area.

The eastern boundary for the inshore population is approximately 50 miles off the coast line, and the north to south length of the area is approximately 100 miles. No significant catches are recorded between the two areas, a distance of about 30 miles. The depths of the water in the two study areas are approximately the same (20 to 40 fathoms). The water depth between the two study areas is about 70 to 90 fathoms. The offshore area comprises approximately 2,400 square miles, as compared to approximately 5,000 square miles for the inshore area.

The period of this study is from July 1 to September 28, 1956. The year 1956 was selected because this was the year for which the latest data were available. The period was selected as it is during this time that the bulk of the whiting are landed from these two areas. Also, migration is apparently at a minimum during this period as the fish are on the spawning grounds. Bigelow and Schroeder (1953) stated that the whiting in the inshore area are a summer fish first appearing in catches in early spring and gradually disappearing in late fall. It is not known definitely where the whiting migrate to in late fall.

COLLECTION OF CATCH-EFFORT DATA

Catch-effort data were obtained from otter trawlers which fished for whiting in the study areas. With the otter trawl gear, which is designed for bottom fishing, the fishermen are quite proficient at catching the whiting because the whiting inhabit the bottom during the daytime (which is the time the whiting fishermen fish). Upon reaching port, the captain is interviewed by U. S. Fish and Wildlife Service personnel, who record the information on: (1) date fished, (2) number of hours fished, (3) location of catches, and (4) the total weight of the catch at port.

By visual inspection of the above interview data, it was apparent that each boat fished approximately once every three days. In order to insure comparable sampling periods consisting of adequate data, the study period was divided into three-day segments.

A cumulative total of the number of fish captured up to, but not including, each sampling period, K(t), must be recorded for each area when using DeLury's procedure. The interviewers do not obtain information on all the individual catches that are landed as some catches are landed on holidays or late at night when the interviewers do not work. However, the U. S. Fish and Wildlife Service does obtain information on total landings from data which are compiled from monthly records of plant owners (people who buy and sell whiting). They include all the whiting landed, except those used for animal food. By subtracting the interviewer totals from the plant owner totals, it was possible to obtain figures on the amount of fish not recorded by the interviewers.

These figures account for all the whiting caught in each study area except those utilized as animal food. The following procedure was used in completing the information on the total catches of whiting. Along with the above monthly total catch figures, a figure is available for the monthly total pounds of animal food fish caught, but this figure includes several species of fish. Information, from a study being conducted by Dr. R. L. Edwards of the U. S. Fish and Wildlife Service at Woods Hole, Massachusetts on the animal food fish industry, was obtained on the percent of whiting to the total amount of the animal food. This information was then used to complete the accumulated catch figures presented in Appendix A.

The catch information was subdivided into two categories: dressed whiting and round whiting. Round whiting includes the entire fish as it is taken from the water, and dressed whiting is that which has been eviscerated and beheaded. Because most of the fish were classified as round whiting, this category was used to describe the fish weighed, and the dressed whiting figures were converted into round whiting figures. The above conversion was possible because studies at Woods Hole, Massachusetts by the U. S. Fish and Wildlife Service showed that, on the average, the round weight of a whiting was 1.67 times as heavy as the dressed weight. Consequently, each dressed weight figure was multiplied by 1.67 to convert it to round pounds.

In most of the catches in the inshore area, more than one species of fish occurs. Simply by a selection of locality, type of bottom, depth, and by modifying the operation of the vessel's net, the experienced fisherman is capable of influencing the proportion of the various species in his catch. Only those catch records from the interviews in which at least

50 percent of the catch for the trip was composed of whiting were used to compute the catch per unit effort data. This decision on the handl of the mixed-catch problem was suggested from a study made by Ketchen (1953), where a similar situation occurred.

PROCEDURE AND RESULTS

A total catch figure for each three-day period, c(t), was calculated with the corresponding number of hours required to make the catch, e(t). Figures K(t), which represent all the whiting removed from the sampling area up to, but not including, the time of each of the three-day sample periods were recorded.

Inspection of the interview information revealed that the same vessels did not fish during each sampling period. By plotting the catch per hour of several vessels individually, each against the total accumulated catch for all vessels, it was seen that they differed considerably in their catch per hour (fishing power) for the same time periods and location (Figure 2). According to Gulland (1956), changes in the composition of the fleet will be reflected in changes in the average fishing power. Estimates of effort, and catch per unit effort, based on assumptions of constant fishing power, will therefore be distorted. Gulland also stated that the fishing power of trawlers is closely correlated with length of vessel, net tonnage of vessel, horse power of vessel, and gross tonnage of vessel. He adds that the power of engine fitted to a particular size of vessel is not likely to vary over a wide range so that, subject to caution, gross tonnage may be taken as a single index of power. The gross tonnage of a vessel is the internal cubic capacity of all space in and on the vessel which is permanently enclosed (100 cubic feet defined as one gross ton). The net tonnage of a vessel is the remainder after deducting

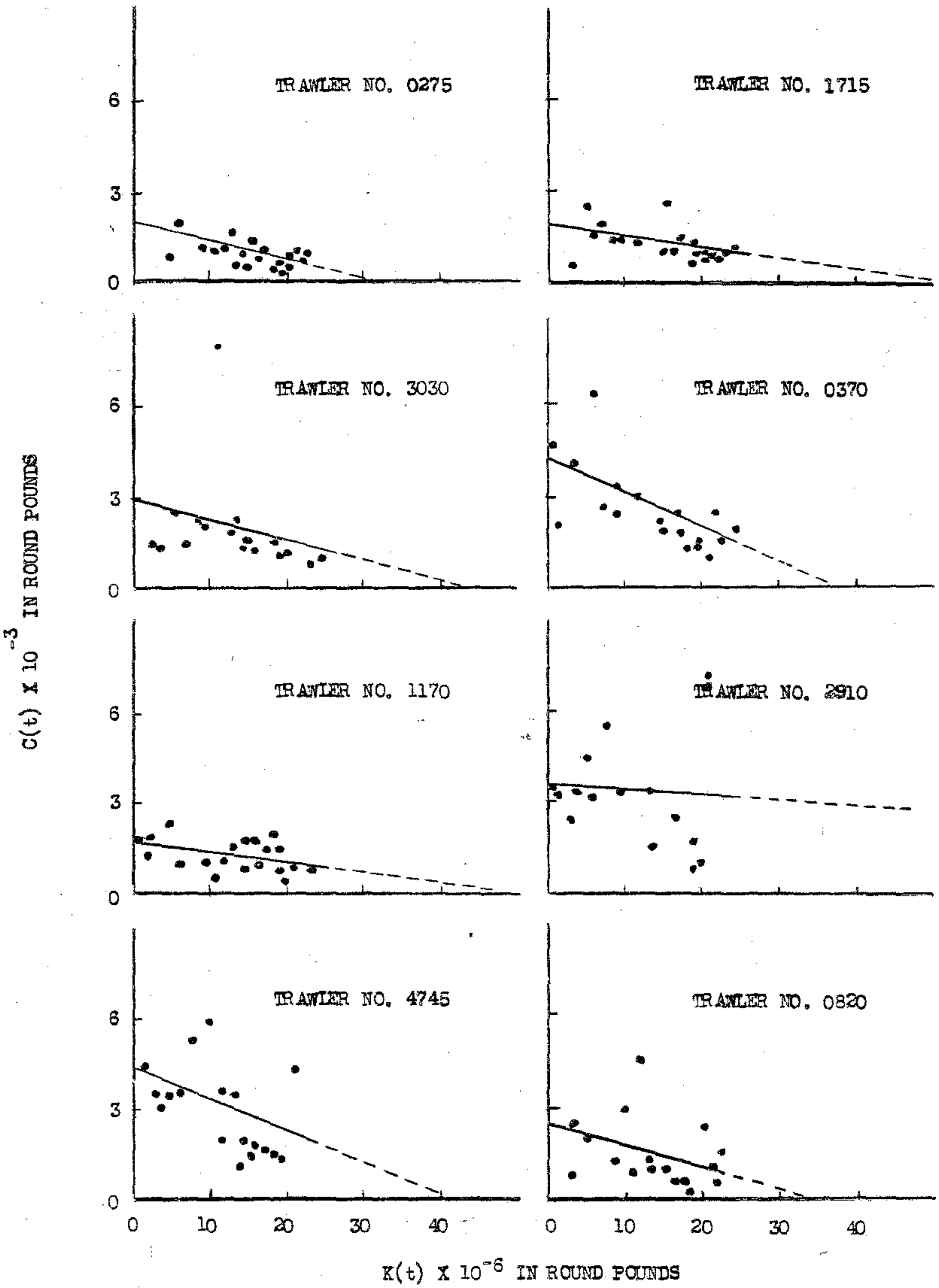

Figure 2. The relationship of catch per hour, $C(t) \times 10^{-3}$, to the total accumulated catch, $K(t) \times 10^{-6}$, for each of eight different otter trawlers in the inshore area during the period of July 1 to September 28, 1956.

from the gross tonnage of the vessel the tonnage of crew space, masters' accommodations, navigation space, allowance for propelling power, etc.

Data were obtained on horsepower, net tonnage and other characteristics of the trawlers (Anonymous, 1957), and it was found that gross tonnage was the best indicator of fishing power (Figure 3). The correlation coefficients for catch per hour and the various characteristics of a fishing vessel which might influence fishing power were computed. Net tonnage ($r = 0.82$) and gross tonnage ($r = 0.92$) were the only factors that exhibited an appreciable correlation with catch per hour (Appendix B).

The gross tonnage of each vessel was multiplied by its hours fished; these resulting figures were then sorted into three-day periods (by dates fished), and a total ton-hour figure was computed for each three-day period. Likewise, the catch figures in each three-day period were summed in order to arrive at corresponding three-day period catches. Catch per unit effort data, $C(t)$, expressed as catch per ton-hour in this study, were calculated by dividing each total three-day period effort figure into its corresponding total three-day period catch (Appendix A).

The catch per ton-hour data from the inshore area were then plotted against the accumulated catch data, resulting in a fairly good straight-line regression of catch per ton-hour on accumulated catch (Figure 4). Thus, it appeared that the data were suitable for use in a population size estimate of whiting from the inshore area by use of the formula suggested by DeLury (1947). It should be noted that a rough estimate of the population size may be obtained at this time by simply fitting a straight line by eye to the graphed data and extrapolating the line to the x-axis. The estimated population total is at the point of intersection where,

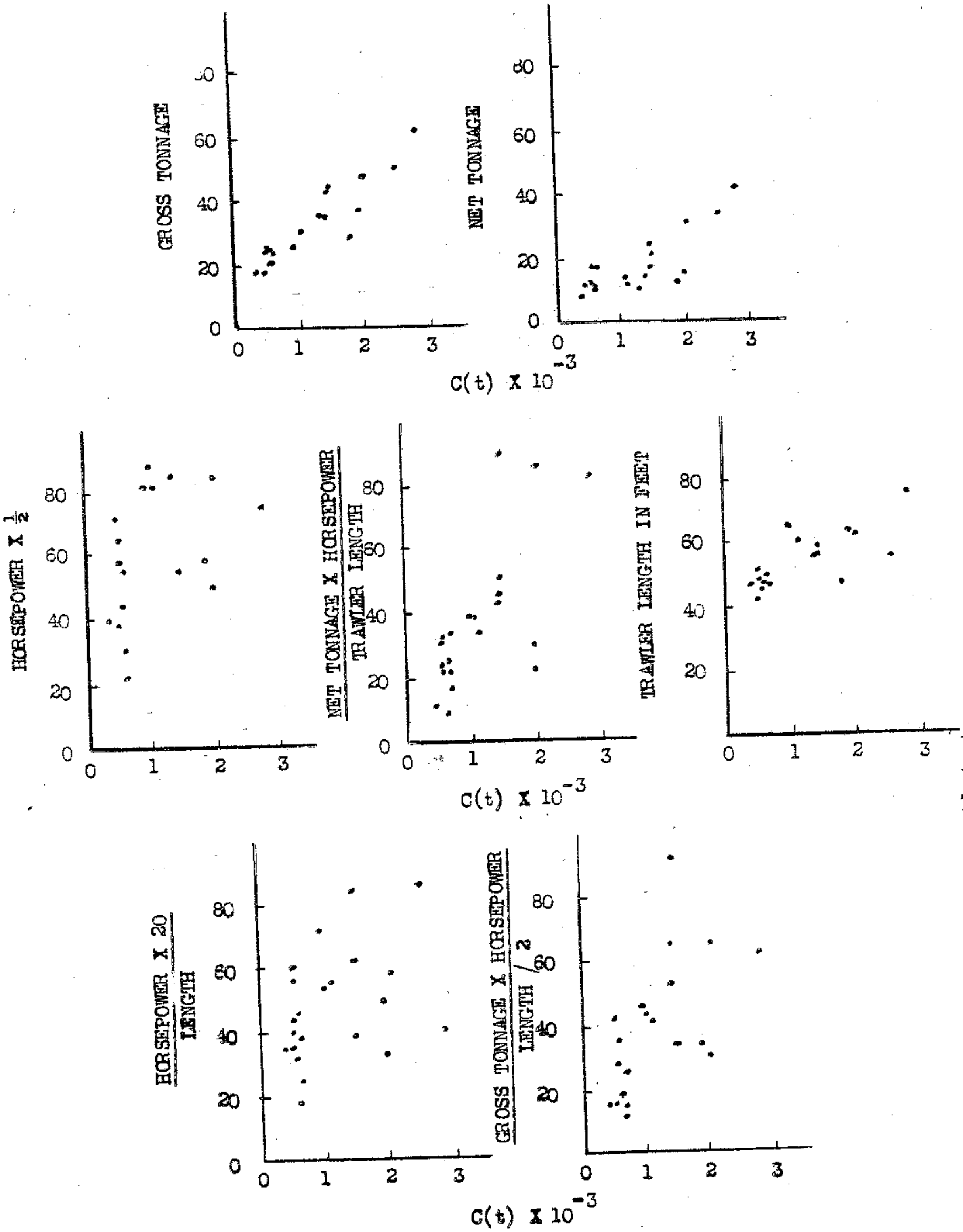

Figure 3. Characteristics of whiting trawlers in relation to catch per hour in round pounds, $C(t) \times 10^{-3}$.

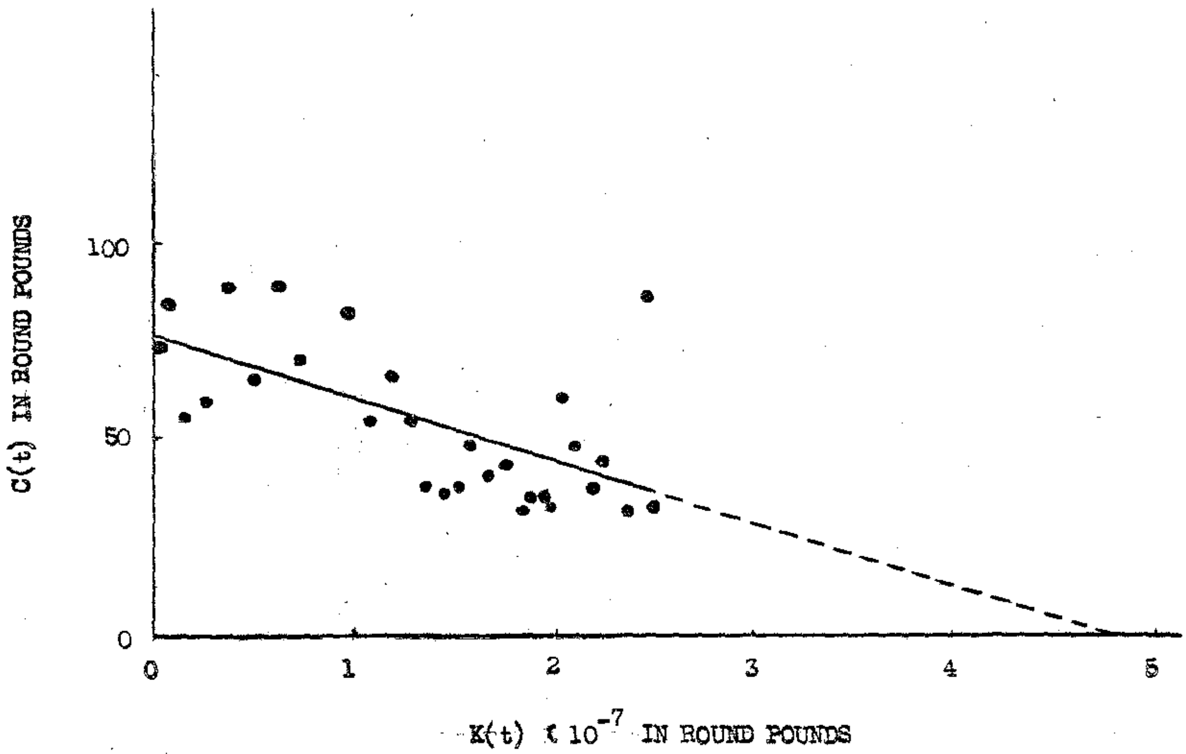

Figure 4. Relationship of catch per ton-hour, C(t), to the total accumulated catch, K(t) X 10^{-7}, of whiting for the inshore area during the period of July 1 to September 28, 1956.

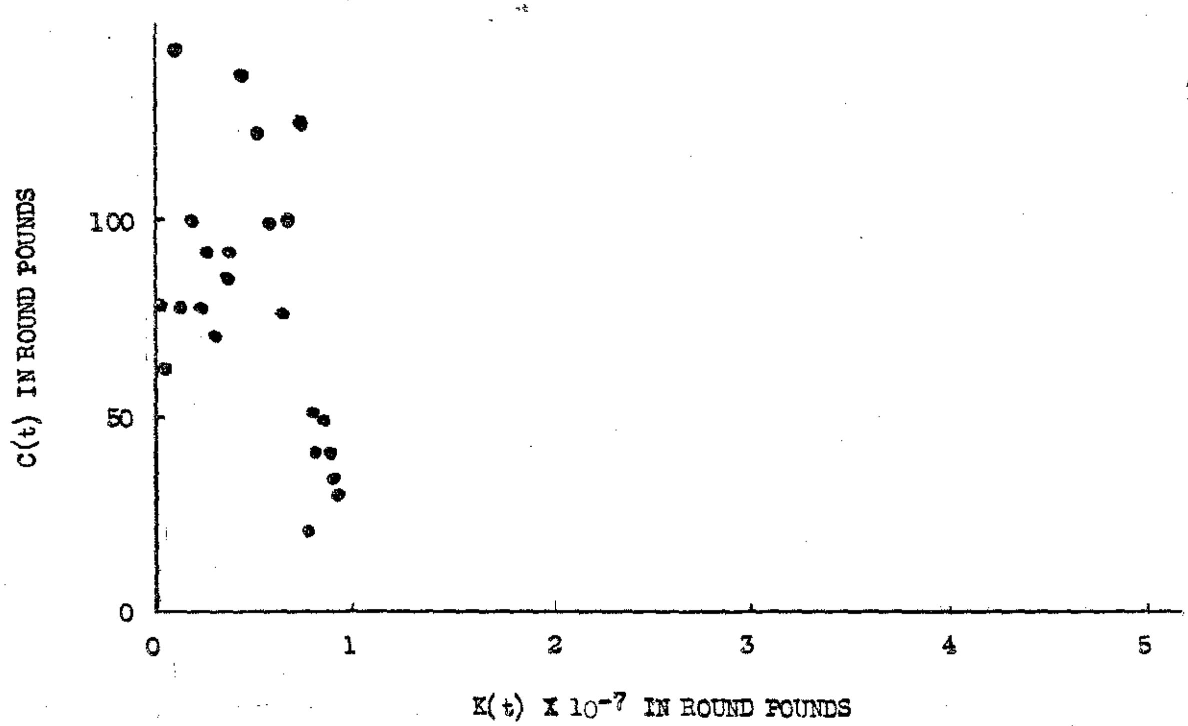

Figure 5. Relationship of catch per ton-hour, C(t), to the total accumulated catch, K(t) X 10^{-7}, of whiting for the offshore area during the period of July 1 to September 28, 1956.

theoretically, the entire population would have been caught. In other words, it is an estimate of the catchable population total of whiting in the inshore area at the time of the first sample (July 1, 1956).

A point estimate of the whiting population size in the inshore area was calculated to be 48,070,000 round pounds (Appendix C). The 95 percent confidence limits for the estimate of the population size is 34,500,000 to 84,770,000 round pounds. The confidence limits were calculated by a formula presented by DeLury (1951), which is presented in the Appendix D.

In order to convert these above figures into numbers of fish, length-weight relationship studies and length-frequency studies, which were made by U. S. Fish and Wildlife Service personnel at Woods Hole, Massachusetts, were utilized. These data were obtained from whiting taken during July of 1956 in the inshore area. The length-frequency data were converted to weight-frequency data by the use of these length-weight relationship data. The estimated population value was then proportioned into different weight classes on the basis of these data, assuming that the samples represented the population. Each figure, which represented the population of whiting in pounds of the various length classes of fish, was divided by the weight of an individual fish in its respective length class. This resulted in estimates of the number of individual whiting in each length class in the population. These were summed in order to obtain a figure which represented the total population estimate in numbers of fish. All the above figures are given in Appendix E. The population estimate and its confidence limits were then converted from round pound figures to numbers of fish. The point estimate of the population size was calculated to be 91,560,475 whiting and the 95 percent confidence limits as 65,710,000 to 161,460,000 fish. It must be noted that the above population estimates and confidence limits refer only to the population of fish catchable by otter trawl gear.

A study was made on the escapement of whiting through the "cod" end of 2.5 inch mesh otter trawl nets. This study was made from catches of the inshore area (Clark, 1954), and from this it was possible to estimate the percent of the population that is not caught by the nets. This study gives information on the escapement of whiting down to fish of 6 cm. in total length. By use of these data, the estimated population size was adjusted to include all fish except those smaller than 6 cm. total length (Appendix F). A population point estimate was then calculated to be 100,911,332 whiting, with a lower and an upper 95 percent confidence limit of 72,480,808 and 177,949,531 whiting, respectively.

Data were not available for use in this study on whiting caught in traps in the inshore area. The total trap catch amounted to 741,231 round pounds taken during the period of July 1, 1956 to September 28, 1956. This trap catch was not considered large enough to affect the population estimate calculations to any appreciable extent. As the traps contained a different mesh size net than that of the otter trawlers, to use the trap net data correctly would present a very complicated problem, as the traps are catching part of the trawler population and part of another that is not caught by the trawlers.

Catch per ton-hour data and accumulated catch data were also obtained for the offshore area (Appendix G). These data were plotted, and from inspection of the graph it was observed that there was no indication of a steady downward sloping linear regression trend as was present from the data of the inshore area (Figure 5). Thus, an estimate of the population size could not be attempted.

DISCUSSION

<u>Inshore area</u>: The decrease in the catch per ton-hour in the inshore area as the accumulated catch increases does not seem to be the result of a change in the number of fishing boats. A histogram of the number of vessels fishing during each time period indicates no correlation with that of the catch-effort data of the inshore area (Figure 6).

The downward regression of catch per unit effort on accumulated catch for the inshore area indicates that the mathematical model is adequate. If other factors than those considered in the derivation of the mathematical model are causing the phenomenon of a gradual decrease in the catch-effort figures as the accumulated catch increases, then the effect of these one or more factors must be fairly uniform. According to records of the U. S. Fish and Wildlife Service at Woods Hole, Massachusetts, on June 5, 1957 and September 18, 1957, 697 and 183 whiting, respectively, were tagged and released in the inshore area, and there was a 7.6 percent and a 0.5 percent tag return, respectively. All the tags were collected from the inshore area; thus, these data do not give any indication that the whiting move out of the area during the time of year that this study was conducted. The tags were returned during the months of June, July, August, and September of 1957. If migration, as well as fishermen, is reducing the population, the plotted regression line on the data would thus have a greater slope than it should have for a true population estimate using DeLury's procedure. In other words, the population size as of July 1, 1956 would be underestimated.

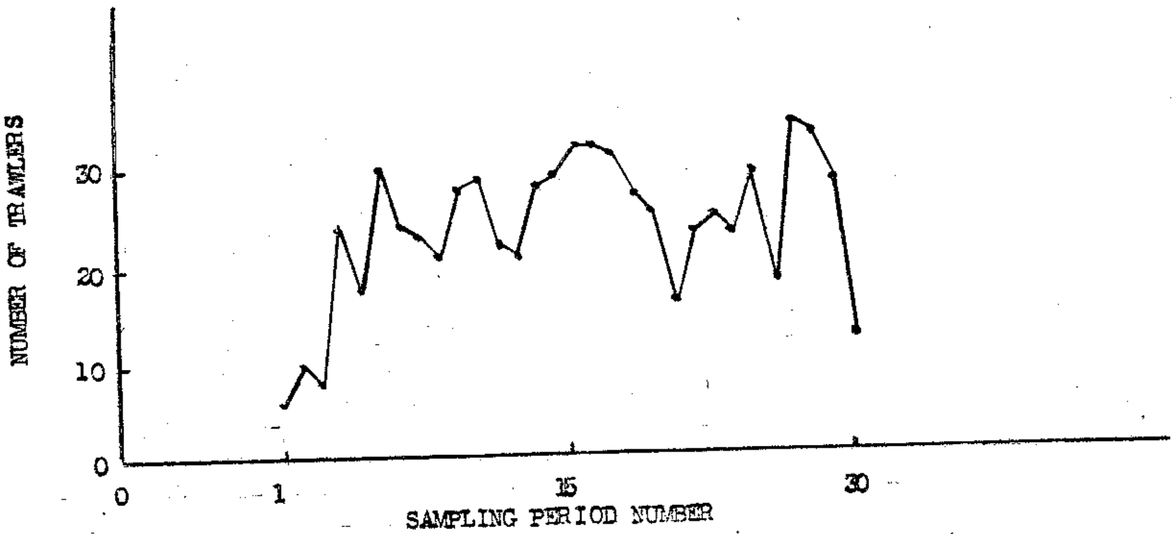

Figure 6. Number of whiting otter trawlers in the inshore area during each three-day sampling period from July 1 to September 23, 1956.

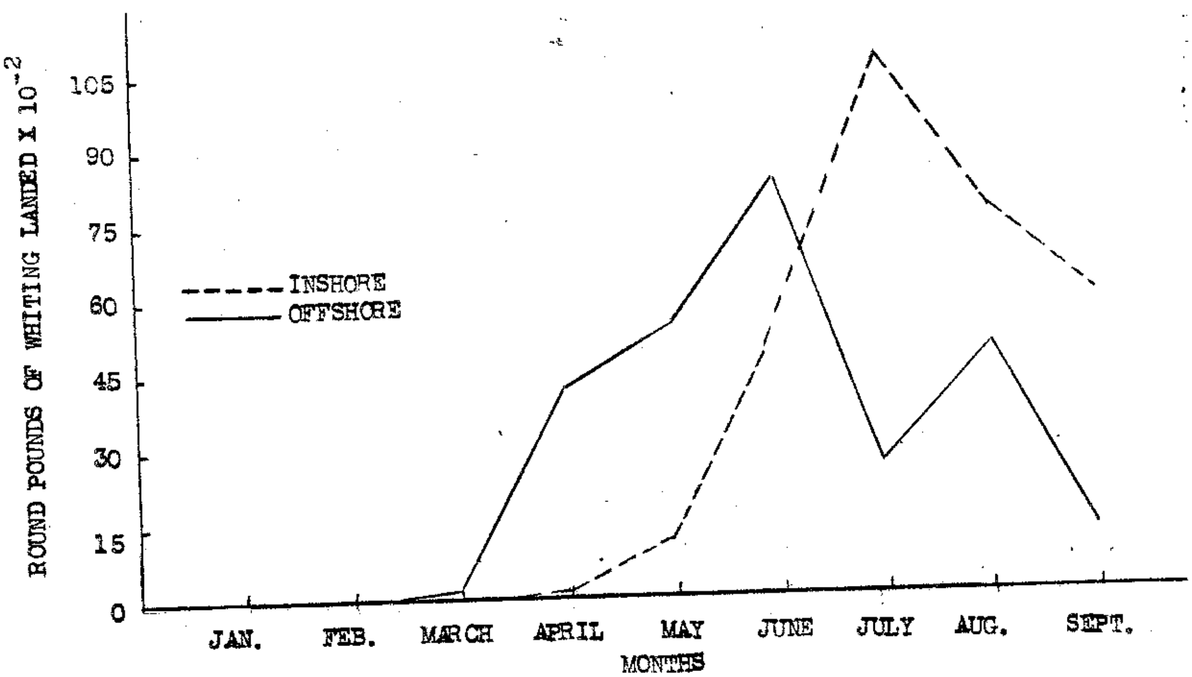

Figure 7. Comparison of monthly whiting catches from the inshore and offshore areas.

If whiting were emigrating according to a fixed percentage of the population size at all times, then the graph of the inshore data would indicate a population size smaller than that of the true population on June 1, 1956. That is, there would be two processes operating to reduce the number of whiting in the inshore area. If the amount of emigration is not occurring according to a fixed percentage of the number of whiting in the population at all times, but by some constant amount, then the regression line of catch per unit effort on accumulated catch would tend to be concave downwards. In the other case, if whiting were immigrating to the inshore area according to a fixed percentage of the population size at all times, then the graph of the inshore area (Figure 4) would result in an overestimate of the true population size. If immigration were not occurring according to some fixed percentage of the population size of whiting at all times, but at some constant amount, during the period of this study, then the graph of the inshore data would be curved upward. With both immigration and emigration occurring, the graph of the inshore data would show a regression line somewhere between that of the two extremes of migration discussed above, depending upon the ratios of immigration and emigration (Ketchen, 1953).

It should be noted that if the assumption of a closed population is not true, then only if immigration is continuously balanced by emigration would the catchability remain constant or equal the true catchability. But tagging returns indicate that migration into or out of the study areas is not occurring during the period of this study, although data for this are very inadequate at this time.

Absence of curvature in the inshore data (Figure 4) may be regarded as giving considerable support to the assumption that catchability is constant; although, the converse of this statement is not true. Curvature may arise from causes other than variation in catchability, like recruitment to the population. There is no way in this study to check the assumption that the catchability remains constant. At the present time, we know little about methods of insuring that catchability shall be constant (DeLury, 1954).

Offshore area: As for the analysis of the catch-effort data, the offshore population presents a different situation. It appears that the assumptions are not valid or that the catches are not being affected by preceding catches, which indicates that a very small proportion of the offshore population is being caught by the commercial fleet. If we can assume that there were no serious deviations from the assumptions, then it would seem that the offshore population must be larger than the inshore population, as the total catches from each area are fairly similar and the catches from the offshore area are not being affected by preceding catches. The main difference in the amount of whiting taken from each area is that most of the whiting from the inshore area were obtained during the months of July, August and September, whereas in the offshore area, the whiting were exploited at a more uniform rate from early spring into the fall (Figure 7).

On July 16, 1957, a total of 1,094 whiting were tagged and released in the offshore area by U. S. Fish and Wildlife Service personnel at Woods Hole, Massachusetts, and there was a 5.1 percent return of these tags. All the above tag returns came from within the offshore area during the months of July, August and September of 1957, where they were first released. Thus, this preliminary tagging information gives no indication of migration having taken place; however, the tagging study is very inadequate. Whatever interpretation is placed upon these data, it should be with great caution.

The constant catchability assumption made may not be valid as indicated by the data for the offshore area. Although no substantial data are available on the spawning season for the whiting in the offshore area, if it is similar to that in the inshore area, June to October with the peak in July and August, the graph of the offshore area (Figure 2) might be interpreted as follows. There is a gradual concentration of whiting from within the study area during the spawning season (which would make the fish more vulnerable to otter trawl nets), and then at the end of the spawning season a sudden dispersal takes place within the study area so that the fish would become more difficult to catch.

CONCLUSIONS

The data from the inshore area indicate that perhaps this population was fished heavily during 1956. For this reason, the inshore population should be studied for several years in order to determine whether or not there is overfishing.

The point estimate of the inshore population total catchable by otter trawl gear only for July 1, 1956 is 48,070,000 round pounds, with 95 percent confidence limits of 34,500,000 to 84,770,000 round pounds. With the above figures converted into numbers of fish, the point estimate of the inshore population total catchable by otter trawl gear only becomes 91,560,000 fish, with 95 percent confidence limits of 65,710,000 to 161,460,000 fish.

The point estimate of the whiting population total for the inshore area that includes all the fish in this population except those smaller than 6 cm. is 100,911,332 fish, with 95 percent confidence limits of 72,420,808 to 177,949,531 fish. All the above estimates as to population size are reliable only if the following assumptions were reasonably valid during the period of this study: (1) the populations were closed, (2) the units of effort did not compete with one another, (3) the proportion of the population captured during each sampling period remained constant, and (4) the data adjustments were reasonably valid. Further study of these assumptions is needed before we can be sure that the population size estimates are reliable. It must be realized that these estimates are probably minimum estimates at best.

If the assumptions have been reasonably met for the offshore population, one is led to the conclusion that this population must be larger than the inshore population, and that the commercial fleet is not harvesting as great a proportion of the offshore population total of whiting as they are of the inshore population total.

If migration can be safely eliminated as having an influential effect upon the catch-effort statistics, then the inshore fishermen, as far as whiting are concerned, took a large proportion (approximately 50 percent) of the population total catchable by otter trawl gear to market during July, August and September, 1956.

APPENDIX A

DATA USED IN ESTIMATING THE WHITING POPULATION TOTAL FOR THE INSHORE AREA.

Sampling Period	Catch per Hour	Catch per Ton-hour C(t)	Accumulated Catch K(t)
July 1-3	3346	74	0
	2618	84	739,840
	2398	57	1,607,810
	1672	60	2,406,701
	2920	88	3,501,801
	1770	65	4,893,441
	2740	89	6,007,206
	2317	70	7,199,594
	2048	67	8,544,464
	2634	81	9,524,511
	1676	56	10,910,547
	2162	66	11,860,764
	1651	55	12,943,627
	1189	38	13,648,488
	1092	38	14,422,022
	1199	38	15,114,958
	1506	48	15,850,953
	1186	41	16,713,573
	1239	43	17,407,744
	967	32	18,170,012
	1066	34	18,793,649
	1215	35	19,236,704
	1014	34	19,810,527
	1623	60	20,343,978
	1384	48	20,894,845
	1179	39	21,784,864
	1305	44	22,314,045
	922	31	23,187,681
	2462	87	24,620,436
Sept. 26-28	1012	33	24,849,926

APPENDIX B

DATA USED IN COMPUTING THE CORRELATIONS OF GROSS AND NET TONNAGE OF TRAWLERS TO CATCH PER HOUR.

Gross Tonnage	Net Tonnage	Catch per Hour
23	11	625
26	17	667
47	30	2022
34	14	1392
61	41	2792
28	12	1809
21	11	600
29	12	1113
25	11	500
25	17	667
27	11	500
37	14	1963
35	24	1484
43	21	1461
26	11	917
31	14	1083
18	7	267
25	11	583
50	34	2574
24	10	667
44	17	1461
18	12	500

APPENDIX C

FORMULAE USED IN CALCULATING AN ESTIMATE OF THE POPULATION TOTAL OF THE INSHORE AREA.

$$C(t) = kN(o) + kK(t)$$

where C(t) is the catch per unit effort; K(t) is the accumulated catch; N(o) is the population size at the time of the first sample; and k is the catchability constant.

$$\text{Since } k = \frac{\Sigma[K(t) - \text{average } K(t)]\,[C(t) - \text{average } C(t)]}{\Sigma|K(t) - \text{average } K(t)|^2},$$

$$kN(o) = \text{average } C(t) - k[\text{average } K(t)], \text{ and}$$

$$N(o) = \frac{\text{average } C(t) - k[\text{average } K(t)]}{k}$$

APPENDIX D

FORMULA FOR DETERMINING THE 95 PERCENT CONFIDENCE LIMITS ON THE INSHORE POPULATION TOTAL.

Confidence limits on $N(o)$ are given by the roots of the quadratic equation: $\lambda^2\left[K^2 - t^2s^2c_{22}\right] - 2\lambda\left[kN(o)k - t^2s^2c_{12}\right] + \left[\left(kN(o)\right)^2 - t^2s^2c_{11}\right] = 0$; where λ is the expected value of $- kN(o) / k$; t is the tabulated t value for the $1 - \alpha$ confidence level with $n - 2$ degrees of freedom; c_{22}, c_{12}, and c_{11} are elements of the inverse matrix; and the estimated variances of $kN(o)$ and k are s^2c_{11} and s^2c_{22}, respectively, with their estimated covariance of s^2c_{12}.

APPENDIX E. CALCULATIONS OF THE TRANSFER OF THE ESTIMATED POPULATION TOTAL FROM ROUND POUNDS INTO NUMBERS OF FISH.

Fish Total Length in cm.*	Frequency of Fish in Sample* (F_i)	Weight of Ind. Fish in Grams* (A_i)	Total Grams of Fish of Each Length ($F_iA_i = N_i$)	Percent of Total Sample ($\frac{N_i \times 100}{162,443} = T_i$)	Est. Pop. Total for Inshore Area Prop. as in N_i ($48,070,000\ T_i = Y_i$)	Weight of an Individual Fish in lbs. ($\frac{A_i}{453.592} = W_i$)	Est. Catch. No. Fish, Inshore Pop. Each Length ($48,070,000 T_i = Y_i$)
22	2	60	120	0.07	33,649	0.1322	254,531
23	3	69	207	0.13	62,491	0.1521	410,855
24	3	80	240	0.15	72,105	0.1763	408,990
25	2	87	174	0.11	52,877	0.1918	275,688
26	7	101	707	0.44	211,508	0.2226	950,171
27	2	115	230	0.14	67,298	0.2535	265,475
28	11	129	1,419	0.87	418,209	0.2843	1,471,013
29	25	145	3,625	2.23	1,071,961	0.3196	3,354,071
30	48	155	7,440	4.58	2,201,606	0.3417	6,443,096
31	72	175	12,600	7:76	3,730,232	0.3858	9,668,823
32	99	192	19,008	11.70	5,624,190	0.4232	13,289,674
33	88	210	18,480	11.38	5,470,366	0.4629	11,817,598
34	86	230	19,780	12.18	5,854,926	0.5070	11,548,178
35	67	253	16,951	10.43	5,013,701	0.5577	8,989,960
36	49	275	13,475	8.30	3,989,810	0.6062	6,581,673
37	33	300	9,900	6.09	2,927,463	0.6613	4,426,830
38	29	325	9,425	5.80	2,788,060	0.7165	3,891,221
39	13	355	4,615	2.84	1,365,188	0.7826	1,744,426
40	7	387	2,709	1.67	802,769	0.8531	941,002
41	7	419	2,933	1.80	865,260	0.9237	936,733
42	5	453	2,265	1.39	668,173	0.9986	669,110
43	1	490	490	0.30	144,210	1.0802	133,503
44	3	528	1,584	0.97	466,279	1.1640	400,583
45	3	563	1,689	1.04	499,928	1.2412	402,778

*Data from U. S. Fish and Wildlife Service, Woods Hole, Mass.

APPENDIX E. (continued)

Fish Total Length in cm.*	Frequency of Fish in Sample* (F_i)	Weight of Ind. Fish in Grams * (A_i)	Total Grams of Fish of Each Length $(F_iA_i = N_i)$	Percent of Total Sample $(\frac{N_i \times 100}{162,443} = T_i)$	Est. Pop. Total for Inshore Area Prop. as in N_i $(48,070,000\ T_i = Y_i)$	Weight of an Individual Fish in lbs. $(\frac{A_i}{453.592} = W_i)$	Est. Catch. No. Fish, Inshore Pop. Each Length $(48,070,000 T_i = Y_i)$
46	5	607	3,035	1.87	898,909	1.3382	671,730
47	5	650	3,250	2.00	961,400	1.4330	670,900
48	2	698	1,396	0.86	413,402	1.5388	268,652
49	0	-	0	0	0	---	0
50	0	-	0	0	0	---	0
51	0	-	0	0	0	---	0
52	2	883	1,766	1.09	523,963	1.9466	269,160
53	2	932	1,864	1.15	552,805	2.0547	269,044
54	0	-	0	0	317,262	---	0
55	1	1,066	1,066	0.66		2.3501	134,999

*Data from U. S. Fish and Wildlife Service, Woods Hole, Mass.

APPENDIX F

CALCULATIONS OF THE NUMBER OF WHITING NOT CATCHABLE BY OTTER TRAWL GEAR

The number of whiting not catchable by otter trawl gear, X, is equal to the following: 216 / 2,115 = X / 91,560,475, where, according to a study by Clark (1954), 216 / 2,115 is the ratio of uncatchable fish to catchable fish. The estimated population total of catchable fish for the inshore area is 91,560,475.

APPENDIX G

CATCH-EFFORT DATA FROM THE OFFSHORE POPULATION

Sampling Period	Catch per Ton-hour C(t)	Accumulated Catch K(t)
July 1-3	0	0
	80	0
	61	451,400
	144	868,840
	78	1,140,747
	100	1,757,742
	0	1,747,742
	78	2,172,328
	0	2,172,328
	91	2,381,328
	70	2,909,578
	85	3,167,358
	0	3,167,358
	93	3,589,858
	138	4,362,358
	122	5,172,090
	98	5,626,590
	78	6,254,490
	106	6,506,490
	126	7,417,990
	22	7,754,990
	51	7,980,990
	44	8,072,990
	50	8,382,823
	40	8,719,423
	35	8,898,973
	0	8,898,973
	32	9,033,973
	0	9,033,973
Sept. 26-28	0	9,033,973

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ABSTRACT

Title of Thesis: A Study of Two Populations of *Merluccius bilinearis* (Mitchill) by the Use of the DeLury Regression Method of Estimating a Population Total

Donald P. Oberacker, Master of Science, 1958

Thesis directed by: Dr. Howard E. Winn

By use of a procedure suggested by DeLury (1947), an attempt was made to estimate an "inshore" and an "offshore" whiting, *Merluccius bilinearis* (Mitchill), population total for July 1, 1956. The DeLury method was applied to commercial whiting catch-effort data from these two populations, and the assumptions for the method were discussed. A good estimate of the offshore population total by use of the DeLury procedure was not possible. The point estimate of the inshore population total (catchable by otter trawl gear) was estimated as 48,070,000 round pounds, with 95 percent confidence limits of 34,500,000 to 84,770,000 round pounds. The above estimate was converted to numbers of fish. By use of data from a study on escapement of whiting through otter trawl nets, the population total estimate above was expanded to include all whiting except those smaller than 6 cm. in total length.

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