AN INTRODUCTION TO SOME METHODS OF STOCK ASSESSMENT USED BY THE NORTHEAST FISHERIES CENTER AND ELSEWHERE

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M. P. Sissenwine

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National Marine Fisheries Service
Northeast Fisheries Center
Woods Hole Laboratory
Woods Hole, Massachusetts 02543
Laboratory Reference No. 79-32
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What is a stock assessment? It is an evaluation of the current status of a fishery and the outlook for the future. Stock assessment scientists are like detectives using clues to solve a mystery. The same logical ability is needed. There is the same need to consider all of the data, to use both exact scientific analyses and common sense. As the evidence accumulates, the scientist and the detective both become more certain of the solution to the mystery, but some uncertainty always remains.

What are the clues? The clues are scientific data, personal observations of scientists at sea on research vessels and/or commercial fishing vessels, and information obtained from individuals involved in the actual harvesting of fish or other knowledgable observers. This latter source of information is analogous to circumstantial evidence which is used by detectives and scientists alike to formulate hypotheses about the solution to the mystery, although circumstantial evidence in itself is not an adequate basis for proving the solution. Scientists must evaluate all of these clues using both their training and experience. There are two major sets of scientific data which are used as clues by scientists. These are fisheries data and research vessel data. The commercial fisheries data are collected at the fishing ports by port agents. The port agents collect data on what is caught, how much is caught, where it is caught, and how long it took to catch it. They also measure lengths of samples of fish from the catch and collect scales from the fish which are used to determine their age. In 1977, the age of approximately 47,000 fish was determined by the Northeast Fisheries Center (NEFC).

Research vessel data is collected aboard the ALBATROSS IV, the DELAWARE II, and several other vessels. Northeast Fisheries Center research vessel activities during a recent year are summarized in Table 1. During the year beginning March 1, 1977, 864 days were spent at sea. Cruises spanned from 2 to 26 days in duration. Four hundred forty one scientists were involved in a total of 5,309 man-days at sea.

The research vessel data most used in stock assessments are the results of randomized bottom trawl surveys. Using a random sampling design, when a large number of tows are made, the average catch per tow is proportional to the size of the population of fish which is being sampled by the trawl. The method of data analysis is similar to the methods used by professional pollsters to predict election results. More details on how the research vessel survey data is actually used will be given later.

A fundamental model used in the analysis of fish population dynamics is given in Figure 1. There are four forces affecting the biomass of an exploited fish population. These are growth and recruitment which tend to increase the size of the fishable population biomass and fishing and natural mortality which tend to decrease the size of the biomass. Fishing mortality corresponds to the catch. Natural mortality accounts for all deaths of fish other than those caused by fishing. Recruitment is the process by which eggs are laid, hatch, survive, and grow to the size at which they are vulnerable to fishing gear and therefore considered a part of the fishable population biomass. In this model, growth refers to the actual weight gained by fish in the population. The surplus production of the population is that catch which will generate a fishing mortality rate that equals the rate of recruitment plus growth minus natural mortality. If the catch is larger than the surplus production, the population biomass will decrease. If the catch is smaller than surplus

production, the population biomass will increase.

Recruitment is the major source of variability in surplus production. There are models that relate the rate of recruitment to the size of the spawning population that parents the recruits. Unfortunately, these models are seldom adequate to explain the observed variability in the data. Two examples of the relationship between recruitment and size of spawning stock are given in Figure 2. Note that most of the data points are far from the lines which correspond to hypothetical models describing the relationship between recruitment and spawning stock size. These deviations probably reflect environmental fluctuations.

Thus, from 1920-1950, management strategies were aimed at maximizing the yield per fish that recruit to the stock. Managers had conceded that they did not know how many fish would recruit to the fishable population, but at least they would manage the resource in order to get the greatest yield from each fish that recruits no matter how many of them there were.

Figure 3 describes a group of fish that all recruit to the fishable stock at the same time. Such groups of fish are usually referred to as cohorts or year-classes. In Part (a) of the figure, we note that the number of fish declines continuously over time. The number declines because some of the fish are dying; for now let's assume that they are only dying from natural mortality. At the same time as they are dying, the mean weight of those fish that live is increasing (Figure 3.b.). The total weight of the cohort of fish at any time is obtained by multiplying the number of fish by the mean weight. The result is shown in Figure 3.c. Here we see that the total weight of the cohort increases initially, reaches a peak, and then decreases.

The appropriate strategy to maximize the total yield from the cohort would be to allow them to grow until their total weight reached a peak and then to

catch them all at once. In order to do this, we would need an infinite number of fishing vessels standing idly by and wait for the fish to grow to a particular size or age and then pounce on them all at once. Since this is not feasible, the best strategy to maximize total yield per recruit is to begin fishing before the peak at a rate that will result in approximately the same number of fish being caught at an age younger than that corresponding to the peak as are caught at an age older than that corresponding to the peak. Thus, there are two factors that determine the yield from a particular cohort. These are the size or age at which the fish begin to be caught and the rate at which they are caught after that age. In Figure 4, the yield per recruit is given for all combinations of the age at entry to the fishery and the rate of fishing mortality. Note that in this example the maximum yield per recruit occurs when exploitation begins at about age 3½ and a high fishing mortality rate of greater than 0.9 is maintained. If exploitation begins at age 1, the maximum yield possible is lower than for age 3½, and this maximum yield occurs at a much lower fishing mortality rate (0.3). Note that the fishing mortality rates in this figure are expressed as instantaneous rates. Therefore, they may exceed 1.0. It is easy to visualize this by considering an example in which fish die at a rate of 0.1 per month (that is, 10% of the fish die each month). This mortality rate could also be expressed as 1.2 per year (by multiplying by 12 months). Nevertheless, the total number of fish that die during the year can never exceed the initial number of fish.

In some cases, there is no control over the age at which fish begin to be captured. For any particular age at first capture, there exists a graph which relates the yield per recruit to fishing mortality rate. Such a graph is given in Figure 5. Here the peak of the graph is labelled as F_{max}, or the fishing mortality rate that results in the maximum yield per recruit. Note

that as F approaches F_{max}, the additional yield resulting from each additional unit of fishing mortality is very small. Since fishing mortality corresponds to fishing effort (numbers of days fished or number of individuals involved in the fishery) and catch corresponds to income, the additional profit resulting from additional units of fishing effort as F approaches F_{max} is very low. In fact, total profit may be reduced as F approaches F_{max}. Thus, there is an economic basis for maintaining the fishing mortality rate below F_{max}. There are also biological considerations which indicate the desirability of maintaining fishing mortality rate below F_{max}, but these will not be discussed here. One such reference fishing mortality rate is $F_{0.1}$. $F_{0.1}$ is fishing mortality rate for which the slope (steepness) of the yield per recruit curve is one-tenth the slope of the curve for fishing mortality rate of 0. An example of $F_{0.1}$ is also given in Figure 5.

Thus, yield per recruit analysis provides guidance in the selection of a fishing mortality rate. But in order to determine the actual catch that corresponds to a particular fishing mortality rate, it is necessary to know the size of the population. An important tool of fisheries scientists, used to estimate the size of the populations, is called virtual population analysis (VPA).

Virtual population analysis is difficult to explain precisely, but is rather simply illustrated by an example. Virtual population analysis is applied to a single year-class, although the results for several year-classes may eventually be combined. In our example, let's consider the 1960 year-class which recruits to the fishery at age 1. In order to apply VPA, it is necessary to know the catch of the 1960 year-class by age. Illustrative data is provided in Table 2. In the first column, we list the year in which catch occurred, 1961-1970. In the second column, the age of fish of the

1960 year-class in each year is given. In the third column, the actual catch from the 1960 year-class in each of the years is given. In column 4, a minimum estimate of the size of the 1960 year-class in each of the years 1961-1970 is given. This minimum estimate of the size of the year-class is called the virtual population. If you look at the estimates beginning in 1961 running down the fourth column, you will probably have no idea how the estimates were calculated. But if you look at the estimate for 1970 and run up the column, it should be rather simple to understand the way the estimates are calculated. The minimum size of the 1960 year-class at the beginning of 1970 is ten fish. It is obvious that there must have been at least ten fish in 1970 since ten fish were caught. The minimum estimate in 1969 is 30 fish because since the beginning of 1969 a total of 30 fish were caught. The minimum estimate in 1968 is 80 fish, because since the beginning of 1968 a total of 80 fish were caught, and so on up column 4. Thus, the virtual population estimate for the cohort in the beginning of any year is the sum of the catch from the year-class that occurs after that date.

There are two sources of error that make the virtual population a minimum estimate of actual population size. The first source of error is that we have ignored natural mortality. That is, we have assumed that all of the fish are eventually caught. This is not the case; some of the fish die from natural causes. In column 5, we have corrected for natural mortality. Note that the estimates are larger than the minimum estimate in column 4. I will not go into the mathematical formulas necessary for making this correction. There is a second source of error that causes even column 5 to underestimate actual population size. This occurs because we have assumed that none of the fish survive beyond the end of 1970. That is, we are assuming that 100% of the population in 1970 is caught in that year. This corresponds to an infinitely

high fishing mortality rate. In fact, the fishing mortality rate in 1970 may not have been this high, and, therefore, some of the fish may have survived beyond the end of 1970. In column 6, we have made the assumption that only 50% of the fish available in 1970 are actually caught. Thus, in column 6, we are correcting for incomplete catch in the final year of the virtual population analysis. In order to run virtual population analysis, we must assume (or have an independent estimate) of the proportion of the fish which are caught in the final year of the analysis. This assumption concerning the proportion caught in the final year is often referred to as the assumption of "starting fishing mortality rates" (because these values are used to start the virtual population analysis) or "terminal fishing mortality rates" (because these values represent the final fishing mortality rates chronologically used in the analysis). In the final column of the table (column 7), we have calculated the percent difference between the population estimates in columns 5 and 6. Note that the further back in time we go, the smaller the difference between the two estimates. Thus, corrections for incomplete catch are most important in recent years and less important historically. This implies that the assumption or even guesses at "starting fishing mortality rates" in virtual population analysis are unimportant when considering estimates of population size historically (in this case, before about 1966 or 1965). Thus, virtual population analysis is a powerful tool for estimating the size of the populations historically, given accurate estimates of the catch of a year-class of fish and their natural mortality rate. The fishing mortality rate in the most recent year in which the year-class is caught is not particularly important for estimating population size historically.

Note that virtual population analysis may also be used to calculate the fishing mortality rates applied to the year-class of fish historically. Given

estimates of any three of catch, natural mortality, fishing mortality, and population size, an estimate of the fourth may be calculated. Also note that virtual population analysis may be applied to several cohort simultaneously, thus providing estimates of total population size in a given year.

I have now illustrated how virtual population analysis is applied to catch data in order to historically estimate the size of the fish population. How is the current size of a population assessed? This is accomplished by combining the results of virtual population analysis and research vessel survey data. Consider the illustration in Figure 6. Relative abundance indices from a survey (mean catch per tow, for example) are plotted for each year from 1966-1978. The results of virtual population analysis are plotted for each year from 1966-1976. The recent results from virtual population analysis are not given because these are too sensitive to assumptions about "starting fishing mortality rates." Note that the two curves in Figure 6 agree (in shape) rather closely during the period 1966-1976. Therefore, an empirical relationship may be established between the results of virtual population analysis and research vessel survey results. Then, this empirical relationship is used to estimate the size of the population in more recent years when virtual population analysis is not applicable.

I have now illustrated how fisheries data and research vessel data are used in concert to estimate the current status of a fish stock. Historical estimates of the size of the fish population may be obtained by applying virtual population analysis to the fisheries data. These results are then used to calibrate (correct for inefficiency in trawl gear) research vessel survey results. Once this calibration has been accomplished, research vessels survey data may be used to estimate current stock size. There are numerous modifications to this approach that are necessary when assessing the condition

of actual fish stocks. Nevertheless, the interdependence between fisheries data and research vessel data is fundamental to most stock assessments.

Table 1. VESSEL OPERATIONS AND TYPES OF RESEARCH BY NEFC FROM 1 MARCH 1977 THROUGH 28 FEBRUARY 1978

VESSEL (COUNTRY)	CRUISE NUMBER	DATES OF OPERATIONS	NUMBER OF SEA DAYS	TYPE OF OPERAION	NUMBER OF SCIENTISTS	NUMBER OF MAN DAYS	NUMBER OF STATIONS
WIECZNO (Poland)	77-01	01-07 Mar	7	Bottom Trawl, Plankton & Dredge Survey	4	28	49
GORLITZ (GDR)	77-01 (I)	03-15 Mar	13	Juvenile Herring-Plankton Survey	2	26	52
WIECZNO (Poland)	77-02	08-18 Mar	11	Juvenile Herring Survey	3	33	29
KELEZ (U.S. NOAA)	77-04	14-17 Apr	4	Current Meter Recovery and Deployment	5	20	12
ANTON DOHRN (FRG)	77-01	14-22 Mar	9	Juvenile Herring & Mackerel Survey	2	18	52
GORLITZ (GDR)	77-01 (II)	15 Mar-08 Apr	25	Juvenile Herring & Plankton Survey	2	50	57
ADVANCE II (U.S. Charter)	77-01	16 Mar-02 Apr	18	Ecosystems Biological Oceanography	8	144	35
ALBATROSS IV (U.S.-NOAA)	77-02 (II)	30 Apr-14 May	15	Bottom Trawl Survey	13	195	92
DELAWARE II (U.S.-NOAA)	77-05 (I)	03-13 May	11	Microdistribution Survey	4	44	91
NOGLIKI (USSR)	77-01 (II)	05-20 May	16	Tagging of Sea Herring	5	90	6
WHITEFOOT (U.S. Charter)	77-01	19-23 Apr	5	Current Meter Recovery and Deployment	5	25	1
DELAWARE II (U.S.-NOAA)	77-03	19 Mar-08 Apr	21	Bottom Trawl Survey	9	189	147
WIECZNO (Poland)	77-03	20 Mar-05 Apr	17	Long-line Survey for Sharks & Swordfish	4	68	19
DELAWARE II (U.S.-NOAA)	77-04	12-29 Apr	18	Plankton & Primary Productivity Survey	6	128	131
ALBATROSS IV (U.S.-NOAA)	77-02 (I)	13-27 Apr	15	Bottom Trawl Survey	13	195	111
NOGLIKI (USSR)	77-01 (I)	19 Apr-03 May	15	Tagging of Sea Herring	5	75	1
ANNANDALE (U.S. Charter)	77-01	12-17 May	6	Fish Egg Survey	9	55	33
ALBATROSS IV (U.S.-NOAA)	77-02 (III)	16-20 May	5	Bottom Trawl Survey	13	45	24
DELAWARE II (U.S.-NOAA)	77-05 (II)	17-27 May	11	Ichthyoplankton Survey	6	66	89
NOGLIKI (USSR)	77-02	22 May-06 Jun	16	Plankton-Oceanographic Survey	3	48	95
ALBATROSS IV (U.S.-NOAA)	77-03	24 May-03 Jun	11	Scallop Survey	11	121	163
DELAWARE II (U.S.-NOAA)	77-06 (I)	01-06 Jun	6	Environmental Assessment Survey	4	24	48
ALBATROSS IV (U.S.-NOAA)	77-04	07-16 Jun	10	Oceanographic Survey	13	130	27
DELAWARE II (U.S.-NOAA)	77-07	09-30 Jun	22	Ichthyoplankton Survey	7	154	134
ALBATROSS IV (U.S.-NOAA)	77-05	20 Jun-15 Jul	26	Primary Productivity Survey	10	260	32
PRINCE (Canada)	77-01	06-21 Jul	16	Scallop Survey	1	16	148
YUBILEINIY (USSR)	77-01	11-28 Jul	18	Larval Hake-Oceanographic Survey	1	18	120
DELAWARE II (U.S.-NOAA)	77-08	15-22 Jul	8	Environmental Assessment Survey	8	64	106
SUZUKA MARU (Japan)	77-01	19 Jul-08 Aug	21	Squid Survey	3	63	112
ALBATROSS IV (U.S.-NOAA)	77-06	20-29 Jul	10	Deep Water Dump Site Study	6	60	180
DELAWARE II (U.S.-NOAA)	77-09	27 Jul-06 Aug	11	Bottom Trawl Survey	8	88	115
YUBILEINIY (USSR)	77-02 (I)	30 Jul-15 Aug	17	Plankton-Oceanographic Survey	3	51	107
ALBATROSS IV (U.S.-NOAA)	77-07 (I)	01-05 Aug	5	Bottom Trawl Survey	13	45	40
ALBATROSS IV (U.S.-NOAA)	77-07 (II)	07-12 Aug	6	Hydroacoustic Survey	13	78	15
ALBATROSS IV (U.S.-NOAA)	77-07 (III)	16 Aug-01 Sep	17	Bottom Trawl Survey	13	221	149
DELAWARE II (U.S.-NOAA)	77-10	17-25 Aug	9	Dredge Testing Experiment	7	63	60
YUBILEINIY (USSR)	77-02 (II)	17 Aug-03 Sep	18	Plankton-Oceanographic Survey	2	36	83
YUBILEINIY (USSR)	77-03 (I)	05-16 Sep	12	Tagging of Sea Herring	2	24	1
DELAWARE II (U.S.-NOAA)	77-11 (I)	07-09 Sep	3	Gear Mensuration Study	5	15	8
DELAWARE II (U.S.-NOAA)	77-11 (II)	13-21 Sep	9	Gear Mensuration Study	5	45	153
YUBILEINIY (USSR)	77-03 (II)	16 Sep-04 Oct	19	Tagging of Sea Herring	2	38	7
WIECZNO (Poland)	77-05	17 Sep-03 Oct	17	Herring Predator-Prey Study	2	34	38
DELAWARE II (U.S.-NOAA)	77-12 (I)	26 Sep-07 Oct	12	Bottom Trawl Survey	8	96	137
WIECZNO (Poland)	77-06	04-24 Oct	21	Larval Herring Survey	5	105	117
ANTON DOHRN (FRG)	77-02	10-30 Oct	21	Herring Survey	10	210	78
DELAWARE II (U.S.-NOAA)	77-12 (II)	11-21 Oct	11	Bottom Trawl Survey	9	99	71
ARGUS (USSR)	77-01 (I)	15-25 Oct	11	Zooplankton, Oceanographic & Primary Productivity Sur.	6	66	72
ARGUS (USSR)	77-01 (II)	25 Oct-11 Nov	18	Zooplankton, Oceanographic & Primary Productivity Sur.	7	126	72
DELAWARE II (U.S.-NOAA)	77-12 (III)	25 Oct-07 Nov	14	Bottom Trawl Survey	8	112	138
DIANE MARIE (U.S.-Charter)	77-01	01-17 Nov	17	Long-line for Sharks & Swordfish	3	51	10
ANTON DOHRN (FRG)	77-03	01-18 Nov	18	Larval Herring Survey	9	72	117
MT. MITCHELL (U.S.-NOAA)	77-11	12-19 Nov	8	Ichthyoplankton, Oceanographic & Prim. Prod. Survey	5	45	37
ARGUS (USSR)	77-02	13-25 Nov	13	Squid Survey	3	39	41
KELEZ (U.S.-NOAA)	77-11/12	25 Nov-06 Dec	12	Ichthyoplankton, Oceanographic & Prim. Prod. Survey	7	84	38
DELAWARE II (U.S.-NOAA)	77-12 (IV)	28 Nov-06 Dec	9	Bottom Trawl Survey	7	63	72
KELEZ (U.S.-NOAA)	77-12	06-13 Dec	8	Ichthyoplankton, Oceanographic & Prim. Prod. Survey	5	40	17
DELAWARE II (U.S.-NOAA)	77-13	08-20 Dec	13	Larval Herring Survey	9	117	74
DELAWARE II (U.S.-NOAA)	78-01 (I)	05-13 Jan	9	Shellfish Resource Assessment Survey	8	72	107
DELAWARE II (U.S.-NOAA)	78-01 (II)	15-25 Jan	11	Shellfish Resource Assessment Survey	8	88	123
ALBATROSS IV (U.S.-NOAA)	78-01	18-27 Jan	10	Herring Survey	13	130	90
ARGUS (USSR)	78-01 (I)	28 Jan-13 Feb	17	Squid, Mackerel & Herring Survey	4	68	34
DELAWARE II (U.S.-NOAA)	78-01 (III)	30 Jan-11 Feb	13	Shellfish Resource Assessment Survey	8	104	121
ALBATROSS IV (U.S.-NOAA)	78-0x	31 Jan-06 Feb	7	Deep Water Dump Site Study	1	7	72
ALBATROSS IV (U.S.-NOAA)	78-02 (I)	14-22 Feb	9	Larval Fish Survey	9	81	140
ALBATROSS IV (U.S.-NOAA)	78-02 (II)	23 Feb-	6 +	Larval Fish Survey	11	66 +	41
DELAWARE II (U.S.-NOAA)	78-02 (I)	14-24 Feb	11	Ichthyoplankton Survey	7	108 +	60
ARGUS (USSR)	78-01 (II)	15 Feb-	14 +	Squid, Mackerel & Herring Survey	4	56 +	64
DELAWARE II (U.S.-NOAA)	78-02 (II)	27 Feb-	2 +	Ichthyoplankton Survey	7	14 +	20
			864		441	5,309	4,935

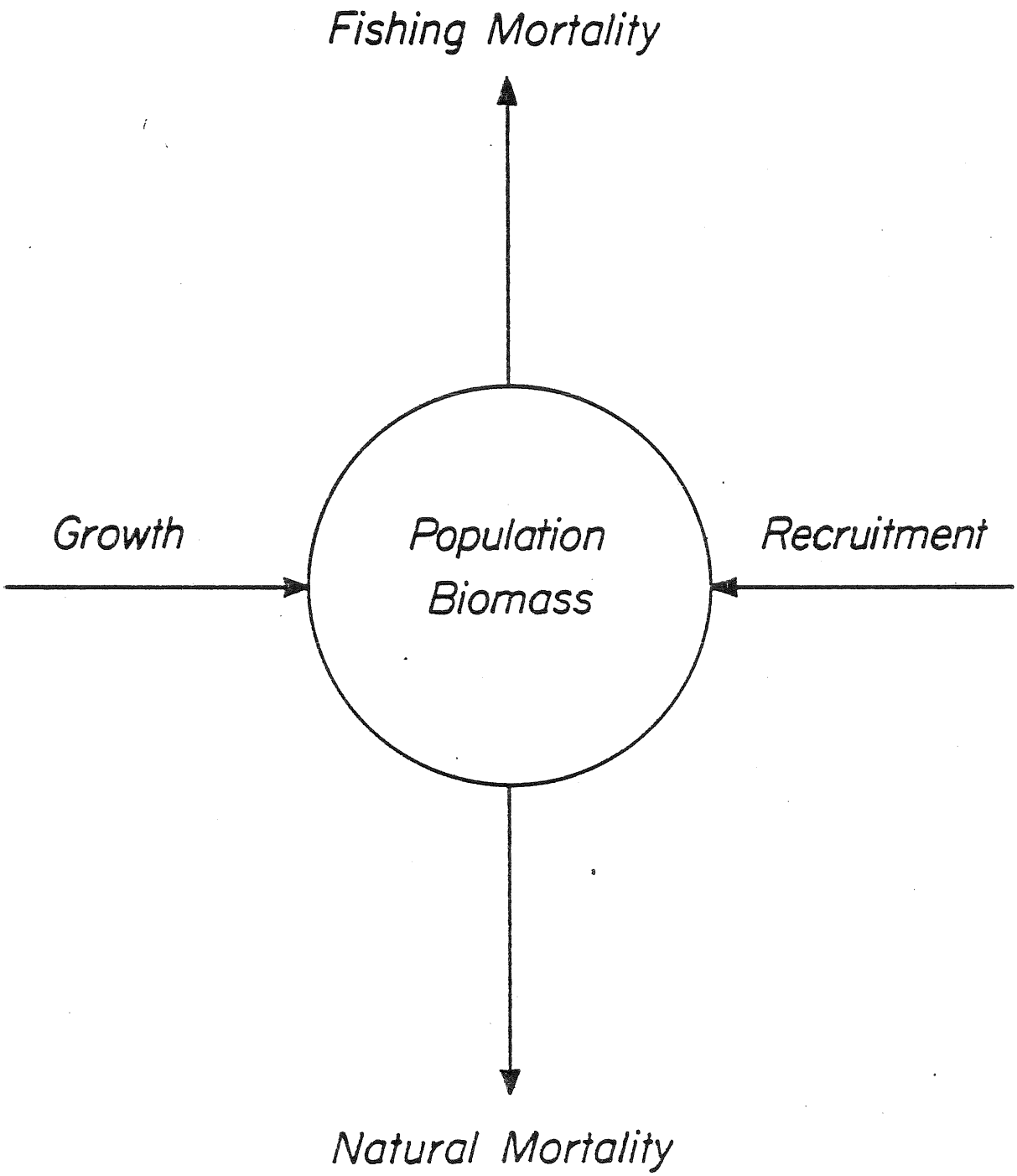
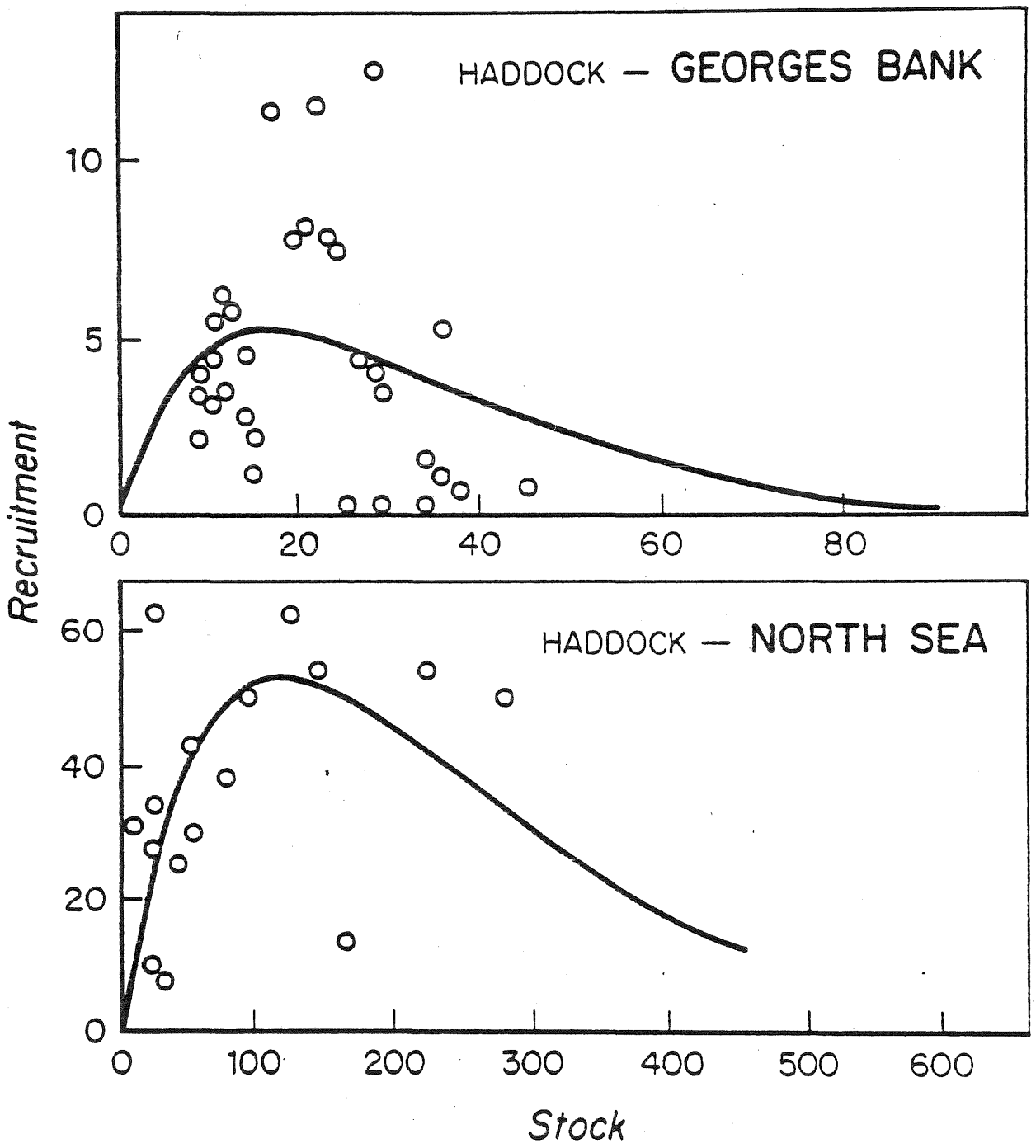

Fishing Mortality
Growth
Population
Biomass
Recruitment
Natural Mortality

Figure 1.


HADDOCK — GEORGES BANK
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Recruitment
HADDOCK — NORTH SEA
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100
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300
400
500
600
Stock

Figure 2.

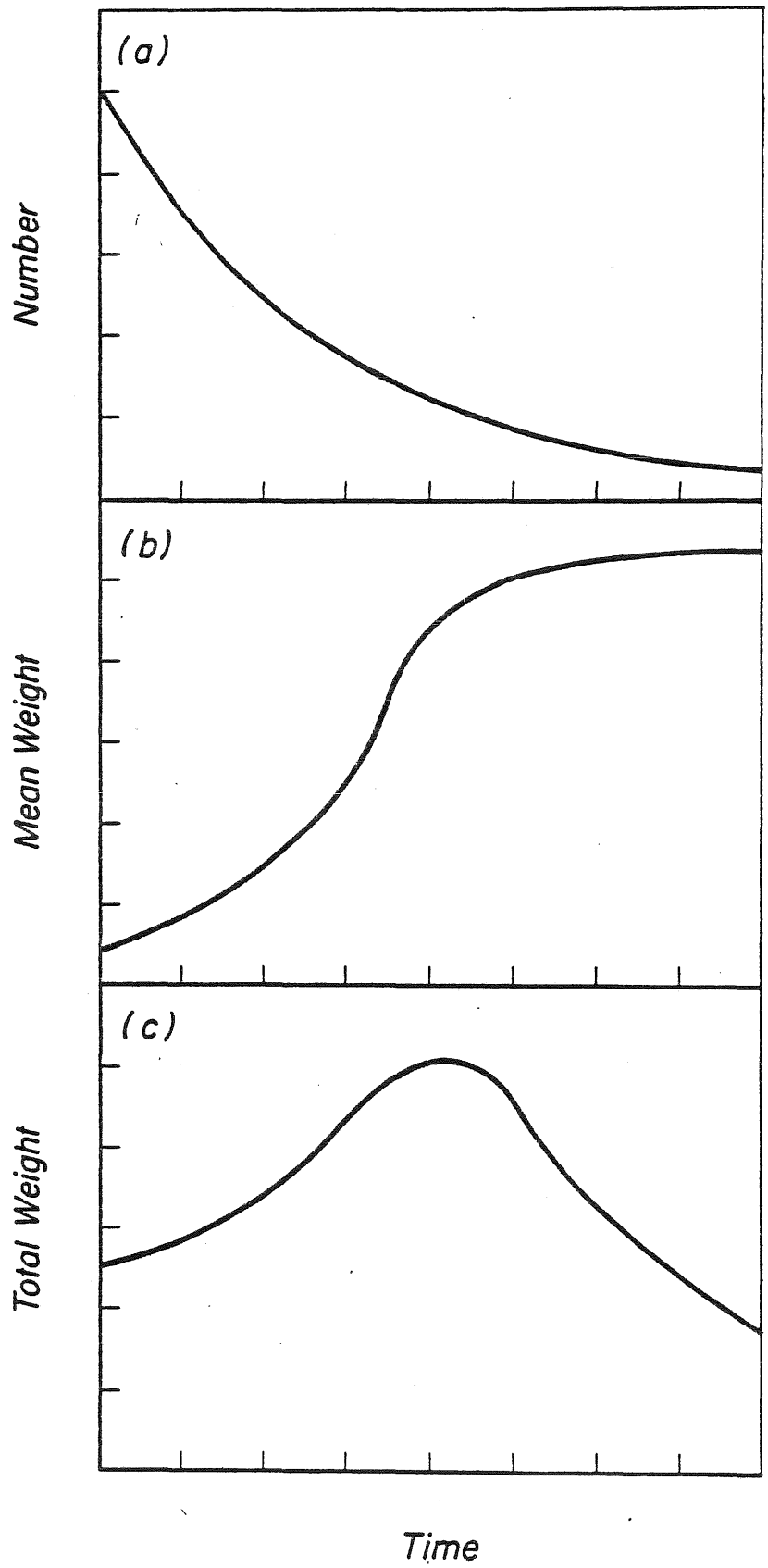
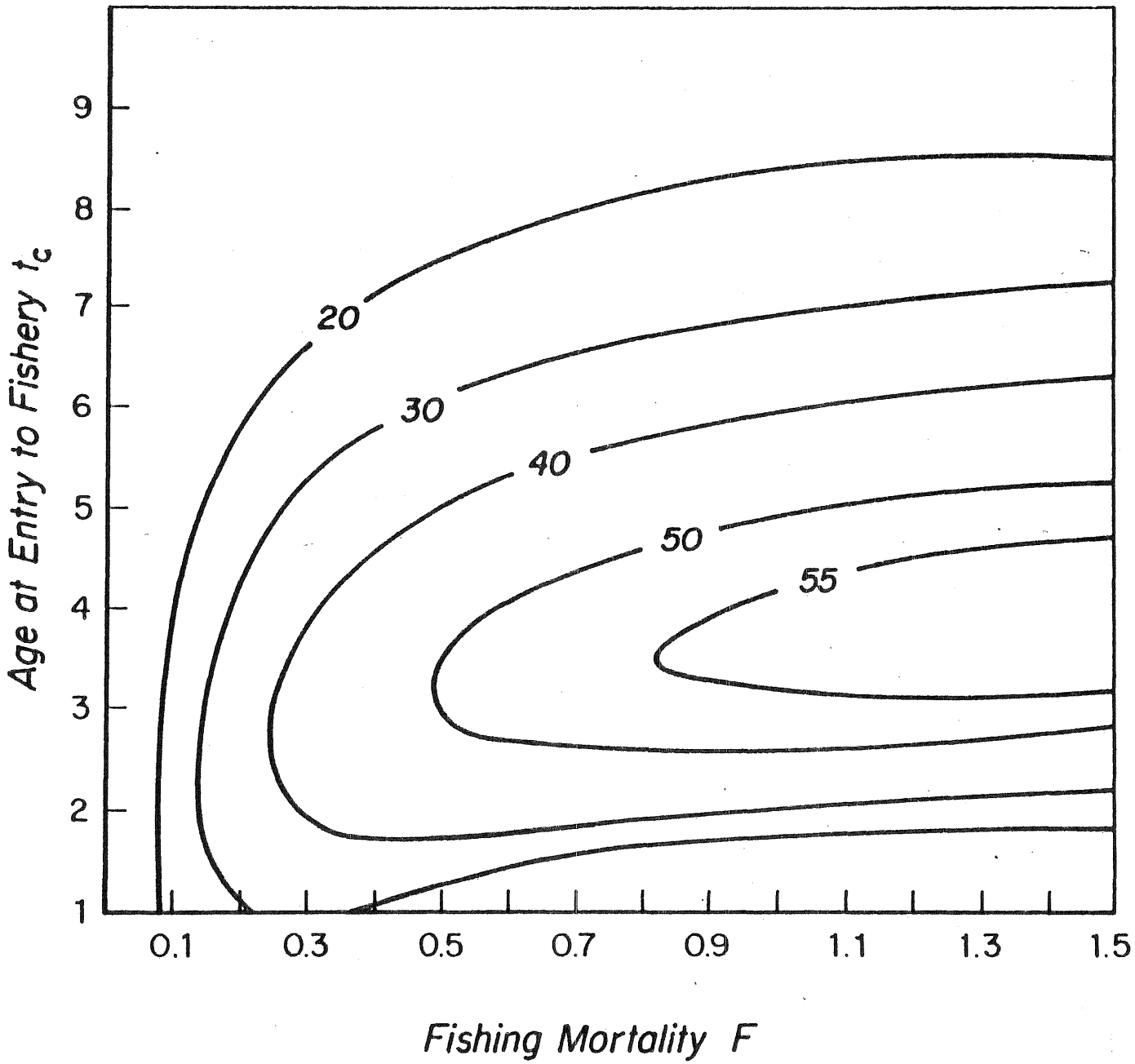


Figure 3.


Age at Entry to Fishery t_c
9
8
7
6
5
4
3
2
1
20
30
40
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0.7
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1.1
1.3
1.5
Fishing Mortality F

Figure 4.

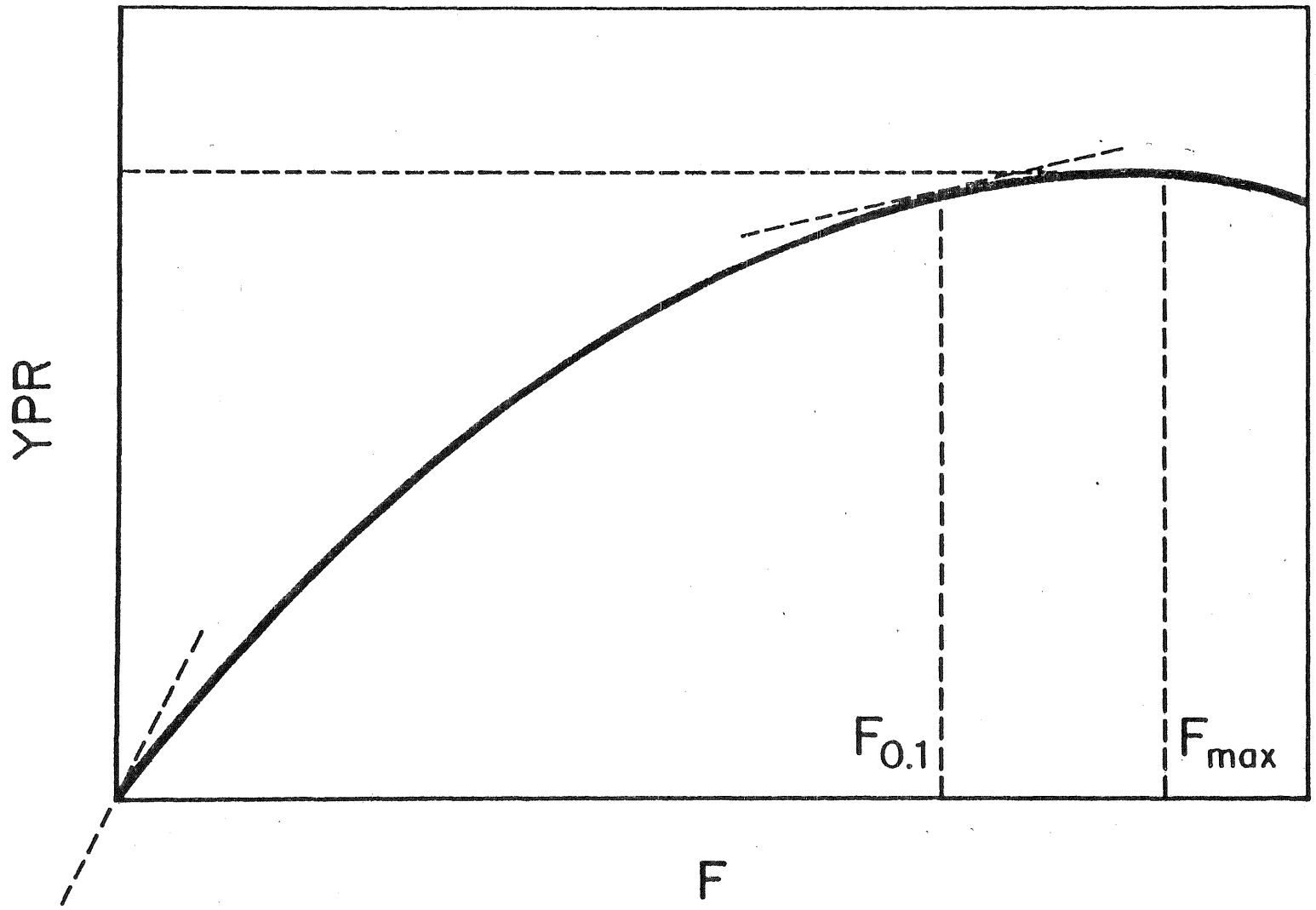

Figure 5.

Table 2. Virtual Population Analysis - 1960 YC.

Year	Age	Catch	Min. No. VP	Correction for M	Correction for Incompl. C	% Diff.
61	1	500	4,210	7,317	7,387	1%
62	2	1,500	3,710	5,538	5,596	1%
63	3	1,000	2,210	3,177	3,224	1%
64	4	600	1,210	1,696	1,735	2%
65	5	300	610	846	877	4%
66	6	140	310	421	447	6%
67	7	90	170	218	239	10%
68	8	50	80	97	115	19%
69	9	20	30	34	49	44%
70	10	10	10	10	22	120%
Proportion caught in 1970				100%	50%	

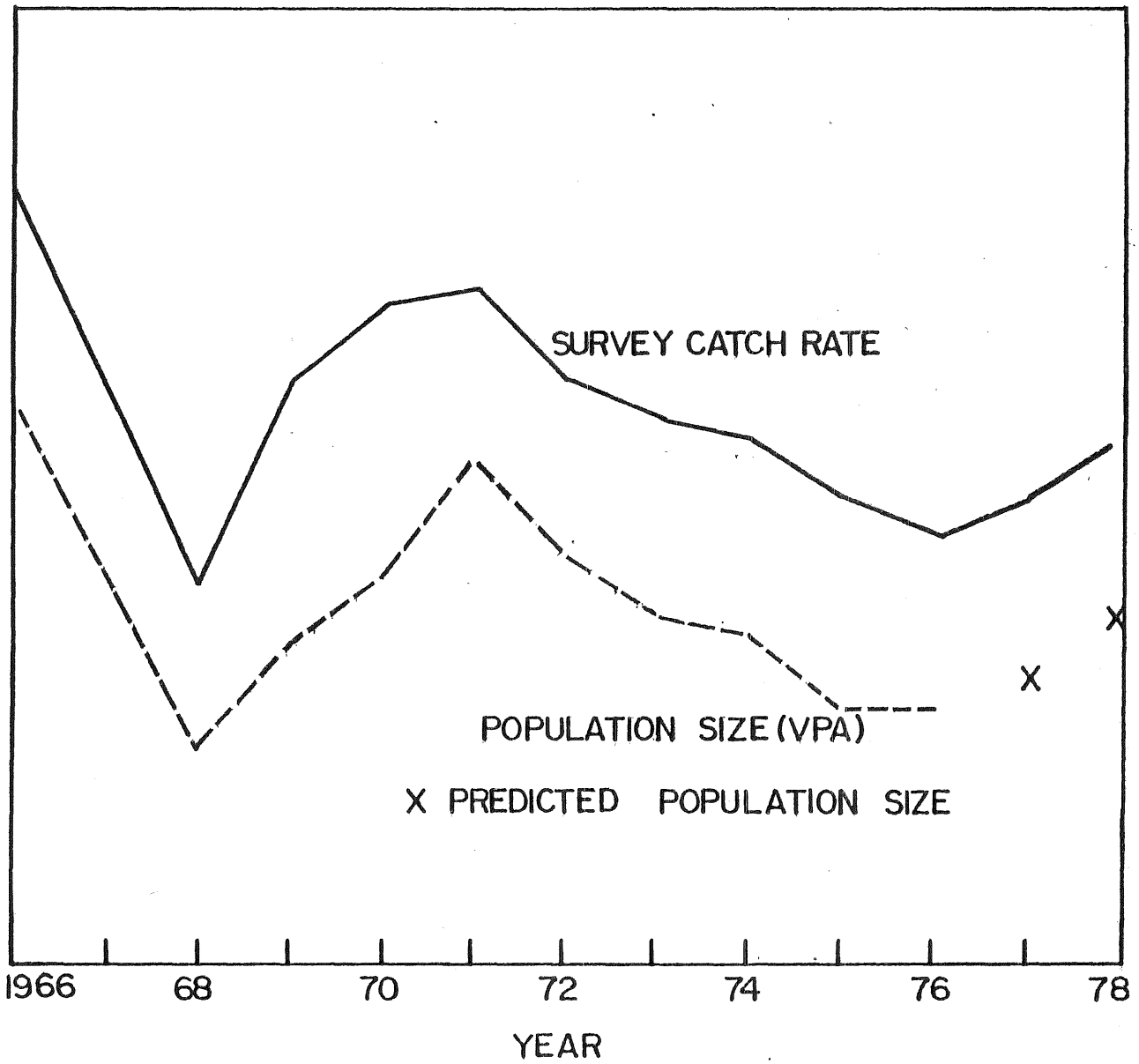
SURVEY CATCH RATE
POPULATION SIZE (VPA)
X PREDICTED POPULATION SIZE
1966
68
70
72
74
76
78
YEAR

Figure 6.