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Spawning Stock Biomass per Recruit Analyses for Seven Northwest Atlantic Demersal Finfish Species, Spring, 1984

by

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TABLE OF CONTENTS

	Page
SUMMARY	i
INTRODUCTION	1
THE SPAWNING STOCK BIOMASS PER RECRUIT ANALYSIS	1
YEAR CLASS REPLACEMENT OVER A LONG-TERM AVERAGE	3
METHODOLOGY	5
RESULTS AND DISCUSSION	8
ANTICIPATED FUTURE INVESTIGATIONS	10
LITERATURE CITED	12
TABLES	15
FIGURES	25

SUMMARY

Spawning stock biomass per recruit (SSB/R) analyses evaluate the effects of combinations of age at first capture and rate of fishing mortality on the opportunity of a cohort (year class) to spawn over its lifetime. A cohort's contribution to spawning stock biomass is diminished as a function of intensity and age of first application of fishing mortality. For a fished population to persist, a higher proportion of each spawner's offspring must survive to recruitment (relative to an unfished population), to compensate for decreased spawning opportunity. On average, the observed number of recruits per unit of spawning biomass must equal SSB/R.

Model assumptions and input data are described and isopleths of SSB/R (as a percentage of maximum SSB/R with no fishing) are presented for haddock, Atlantic cod, yellowtail flounder, winter flounder, American plaice, redfish and pollock. Assumptions (of no mortality before spawning, for example) and input data will be refined in future analyses.

INTRODUCTION

The New England Fishery Management Council identifies spawning stock biomass in association with minimum abundance levels as a major biological consideration in development of the multispecies Atlantic Demersal Finfish Fishery Management Plan. Their policy statement underlying the plan development defines a minimum abundance level of a stock as "that level of abundance below which there is an unacceptably high risk of recruitment failure (stock collapse)." The policy supports measures designed to prevent stocks from reaching those levels (NEFMC MS, 1984). From the objective, stocks are to be managed so that year classes in the spawning stock replace themselves on a long-term average basis. Where stocks are determined by the Council to be below minimum abundance levels, the objective becomes an increase in spawning potential.

At the request of the Council, we have prepared simple analyses of the relationship between fishing mortality, age at first capture and relative spawning stock biomass per recruit (relative to the situation where there is no fishing). The purpose of this document is to briefly review the analysis procedure and application in general, to document methodology and data sources and to summarize results for seven Northwest Atlantic species.

THE SPAWNING STOCK BIOMASS PER RECRUIT ANALYSIS

The spawning stock biomass per recruit (SSB/R) analysis evaluates the effects of fishing mortality and age at first capture on the spawning potential of a stock. It has traditionally been applied as an extension of yield per recruit analysis. Under natural conditions, the number of individuals in a year class (cohort) decreases with age due to natural mortality. At the same time, the weight of each individual survivor is increasing. As well, the proportion of the survivors that are sexually mature, and so contribute to the spawning portion

of the stock's biomass, is also increasing with age. The number alive at any age times the fraction mature at that age times the weight of an individual at that age represents the spawning stock biomass of the cohort for that age. The total contribution of a cohort to the spawning stock biomass (SSB) over its lifetime is found by summing the cohort's contributions at each age. This total value can then be scaled by the original number of recruits (R) starting out in the cohort, as SSB/R, to provide a general case regardless of the number of recruits.

The maximum spawning stock biomass per recruit is obtained with no fishing mortality in this analysis. Combinations of fishing mortality and the age at which it is first applied give rise to other lower levels of spawning stock biomass per recruit which can be expressed as percentages of the maximum. The analysis of spawning stock biomass per recruit is analogous to the more widely appled yield per recruit analysis, but the quantity of interest is potential biomass of spawners in a cohort rather than yield: the level of fishing mortality influences the rate of decline of cohort numbers over time, and hence the total number that can potentially spawn. If the age at first capture by a fishery were below the age of sexual maturity, some individuals that might normally survive to spawning age would not live to spawn even once. A cohort's contribution to the spawning stock biomass would be much greater if the same level of fishing mortality had been applied after most of the cohort had had the opportunity to spawn one or more times.

The same level of spawning stock biomass per recruit can be obtained from several different combinations of fishing mortality and age at first capture. For example, low levels of fishing mortality beginning at early ages can have the same effect on spawning stock biomass as higher levels

begun later. Contours of equal levels of SSB/R based on different combinations of fishing mortality and age at first capture can be plotted as isopleths.

This analysis assumes that the only factors influencing spawning stock biomass per recruit are the fishing mortality rates, natural mortality rates, age at first capture, growth rates and maturity rates. These age-specific rates are assumed to stay constant for each cohort in the standing stock, or at least fluctuate around some central values without trends. Variability in recruitment from year to year has no direct effect on the analysis, as the results are scaled on a "per recruit" basis. However, potential for density-dependent effects (e.g., effects of a very large year class) on any of those rates listed is not included in the analysis: growth rates, maturity schedules and fecundity are assumed to stay constant regardless of the level of spawning stock biomass. All units of spawning stock biomass are assumed to be equally effective at producing recruits: the ratio of eggs produced to grams of body weight is assumed constant over spawner size and age, and egg viability is also assumed to be independent of spawner age. The analysis does not identify or take into account depensatory dynamics (i.e., as stock sizes become low, recruitment becomes disproportionately low) or compensatory dynamics (as stock sizes become high, recruitment becomes disproportionately low).

YEAR CLASS REPLACEMENT OVER A LONG-TERM AVERAGE

What are the implications of a particular SSB/R level with respect to maintaining or restoring stock biomass? To maintain a population in balance, the number of reproducing adults dying must equal the number maturing; over their lifetimes, two parents must produce two offspring that live to reproduce. With no fishing, SSB/R is high. The "average" pair of recruits produces many offspring. Large numbers of those offspring could die before reaching reproductive age, but if only two out of the many lived to reproduce, the

stock would still persist. When SSB/R is reduced through fishing, the "average" pair of recruits produces fewer offspring. For the population to persist, a higher proportion of those offspring must survive than in the unfished case. For that population to increase, survival of offspring must be even higher.

Appropriate historical stock-recruitment data can be used to evaluate the likelihood of obtaining adequate survival to offset reduced SSB/R, while maintaining spawning stock biomass. We can calculate observed ratios of spawning stock biomass to recruits. These historical ratios can be compared with the ratio generated by the model for the fishing strategy of interest. If the long-term observed SSB/R values are lower than the SSB/R anticipated under a fishery strategy, the stock would be likely to increase under that fishery regime. (Historically, it had taken less spawning biomass to produce a surviving recruit.) If the two ratios were nearly equal, the stock would be likely to persist. These calculations can be approximated by simply superimposing SSB/R ratios (as slopes) in the stock (SSB)-recruitment (R) plots (Figure 1). If historical recruitment levels are usually above a proposed SSB/R line, the stock will likely increase under the associated fishing regime.

When a stock-recruitment relationship based on absolute abundance (e.g., from a virtual population analysis) is unavailable, it is possible to approximately evaluate the effects of reduced SSB/R, if estimates of fishing mortality, age at first capture and indices of abundance can be obtained. Although the evaluation is based on less information, it is at least suitable for qualitative judgements: given previous levels of fishing mortality and age at first capture, was the resulting fraction of maximum spawning stock biomass per recruit adequate to maintain stock levels, as reflected by stable

abundance indices? Alternatively, did the stock appear to decline or increase under such a regime? In cases where no estimates of previous levels of fishing mortality are available, effects of reduced SSB/R on other similar species or stocks can sometimes be observed.

METHODOLOGY

The calculations were performed using a Thompson-Bell type yield per recruit model. Input data for each age included in the analysis consisted of instantaneous rate of natural mortality (M), proportion sexually mature at age, individual weight at age and proportion recruited to the gear at age. No fishing or natural mortality was assumed to occur before spawning: all spawners alive 1 January were assumed to spawn. (The implications of this assumption are discussed in a following section.) In general, sources of input data were chosen on the basis of timely availability. Specific descriptions of input data are noted below, species by species.

Haddock. Mean weight at age was determined from an average of commercial weight at age in the U.S. catch from 1970 to 1982 (Table 1). Preportion mature was based on unpublished data (Overholtz, pers. comm). The first age included in the analysis corresponded to the age of recruitment in the stock-recruitment relationship (age 2). Instantaneous rate of natural mortality of 0.2 was obtained from Clark et al. (1982).

Atlantic Cod. Mean weight at age was calculated as $(W_t+W_{t+1})/2$, where W was the weight of an individual 1 January, based on an age-weight relationship from biological survey data (Serchuk et al., 1979)(Table 2). The maturity schedule was approximated as an average over a range of lengths at age for both sexes (Morse, 1979). Instantaneous rate of natural mortality of 0.2 was obtained from Serchuk et al. (1979).

Yellowtail Flounder. Individual weight (W) was based on length at age (Lux and Nichy, 1969) converted to weight at age, based on a January-December

length weight relationship (Lux, 1969) (Table 3). Mean weight at age was then calculated as $(W_t + W_{t+1})/2$, as for cod. The maturity schedule reflects age-specific maturity for females only (Royce et al., 1959). Instantaneous rate of natural mortality of 0.2 was obtained from Lux (1969).

Redfish. Individual weight was obtained from mean weight at age in the commercial catch, 1969-1980, (Mayo et al., 1983) (Table 4). Knife-edge maturity was assumed, as an approximation to the schedule for females of Perlmutter and Clark (1949). The first age included in the analysis corresponded to the age of first recruitment to the commercial fishery. Instantaneous rate of natural mortality of 0.05 was obtained from Mayo et al., 1983.

Pollock. Average weights at age were taken from the 1982 commercial fishery mean weights at age (Table 5). The data are averages of USA and Canadian sample data for gill nets and otter trawls, weighted by numbers landed by country and gear type (Mayo and Clark, MS 1984). The maturity ogive represents simple averages of male and female ogives, 1975-1979 (Beacham, 1983). Instantaneous rate of natural mortality of 0.2 was obtained from Mayo and Clark (MS 1984).

American Plaice. Weight at age was calculated as a simple average of male and female weights 1 January (from Sullivan, 1982) (Table 6). The proportion mature was estimated from female length at age and maturity at length, spring and fall combined (Sullivan, 1982). (Sullivan's (1982) maturity schedule is based only on samples from the Gulf of Maine.) Instantaneous rate of natural mortality of 0.2 was discussed by Sullivan (1982).

Winter Flounder. For each area (Gulf of Maine, Georges Bank, Southern New England) length at age was calculated using biological (samples from research vessel surveys) age-length relationships, averaged over sexes and

converted to weight at age, based on a length-weight relationship for sexes combined, January-December (Lux, 1969). Mean weight was then calculated as for cod. For maturity calculations, lengths at age of males and females were rounded down to the nearest whole centimeter, percentages mature at length were estimated (Morse, 1979), and an average maturity at age for sexes combined was calculated. For the Gulf of Maine, length at age could be evaluated only for females. Those age 1-2 values were based on combined estimates from a von Bertalanffy growth equation fitted to 1982 NEFC spring bottom trawl survey data and observations by Berry et al.(1965). Values for remaining ages were obtained from Howe and Coates (1975). For Georges Bank, length at age for males and females ages 1 and 2 was estimated as the mean of eastern and western Georges Bank observations for both sexes, which were then averaged (Lux, 1973). Values for remaining ages were calculated from von Bertalanffy equations for both sexes (Lux, 1973), and results averaged over sexes. For Southern New England, lengths at age for each sex were obtained from Berry et al. (1965) for ages 1-2 and from Howe and Coates (1975) for older ages and averaged between sexes. Instantaneous rate of natural mortality was assumed to be consistent with rates from tagging studies and rates for other flatfishes, 0.2 (Howe and Coates, 1976; Coates et al., 1970).

Mesh Size and Exploitation Rate. Mesh size effects were evaluated by multiplying a mesh size of interest by a species-specific selection factor (Table 8). The resulting fish size at 50% selection was converted to fish age at 50% selection through an age-length relationship.

Rate of exploitation (u) was added to isopleth figures as an alternative Y axis. The rate represents the proportion of fish that will die from fishing

mortality during a year (as opposed to the fraction dying from natural causes):

$$u = \frac{F}{F+M} (1-e^{-(F+M)})$$

where F = instantaneous rate of fishing mortality, original Y axis

and M = instantaneous rate of natural mortality.

RESULTS AND DISCUSSION

Haddock on Georges Bank are currently at approximately 25% of maximum SSB/R, based on described model structure, input data and current estimates of fishing mortality and estimated age at first capture (Figure 2). Current levels of fishing mortality (F) were estimated at about 0.6, based on the 1981 mean F from a virtual population analysis of data from 1982 (Overholtz et al., 1983). Partial recruitment begins at age 2, with full recruitment at age 3 (Overholtz et al., 1983). Age at 50% selection was estimated as 2.6 years for Georges Bank and 2.9 years for the Gulf of Maine (Clark et al., 1982).

Recruitment success of haddock in recent years at reduced stock sizes appeared insufficient to offset reduced SSB/R currently in force. Maximum spawning stock biomass per recruit (11.7 kg spawning stock biomass/1 recruit = 100%, as calculated in the analysis process) and fractions thereof were superimposed on a stock-recruitment plot as R/SSB (slope). Below spawning stock biomasses of 100,000 mt in recent years, recruitment survival was usually inadequate to sustain current SSB/R levels imposed by fishing practices: most recruitment levels were under the 25% line (Figure 3). Over a wide range of stock sizes (1931-1979, Figure 1), however, recruitment success has frequently appeared adequate to maintain an SSB/R level of 20-30% of the maximum.

Atlantic cod are at between 5-13% of maximum SSB/R (Figure 4). Most recent estimates of fishing mortality place current levels of F between

0.6-0.8 (Serchuk, pers. comm.). Cod are first captured at age 2 and fully recruited at age 3 (Serchuk et al., 1979). Some cod stocks have been observed to collapse under considerably higher levels of SSB/R (Serchuk, Pers. comm.). (A subsequent correction of input data changed results of this analysis less than 1% (Table 9).)

Yellowtail flounder currently are at approximately 12-18% of maximum SSB/R (Figure 5). Estimates of fishing mortality (F) for stocks on Georges Bank and southern New England average 1.0 and 0.6, respectively (McBride and Clark, 1983). Yellowtail flounder are first captured by the fishery at age 2 (McBride and Clark, 1983); age at 50% selection would occur somewhat later. Yellowtail appear to have sustained equally high fishing mortalities (F=0.92; Sissenwine, 1974) from 1960-1965; however, between 1962-1965, 12-24% of the catch was age 2, 25-50% was age 3 and 16-30% age 4; compared with 22-53% of the catch aged 2, 39-51% of the catch aged 3 and 5-20% of the catch aged 4, 1979-1982 (McBride and Clark, 1983). (A subsequent correction of input data changed results of this analysis less than 1% (Table 10).)

Redfish currently appear to be at levels of SSB/R of 10% or less than the maximum (Figure 6). Current level of fishing mortality is estimated at F=0.28, based on mean F for ages 9 and above in 1979 from a virtual population analysis begun in 1980 (Mayo et al., 1983). On average between 1969-1978, 50% of a cohort had recruited to the fishery by age 8; although in the case of the 1971 year class, 50% of the cohort had recruited to the fishery by age 6. Recent levels of recruitment (1969-1975 year classes) have usually been insufficient to sustain spawning stock biomass even if no fishing mortality occurred (Figure 7). In the case of the 1971 year class, a SSB/R ratio of 7% of the maximum was achieved. Thus, survival in recent years has been sufficient to sustain current fishery practices in only one of at least seven years. (Other recruitment indicators show no outstanding year classes from 1976 to present (Mayo et al., 1983).)

Pollock are between 45-55% of the maximum possible ratio of SSB/R, based on current estimates of fishing mortality (F=0.26, Mayo and Clark, 1984), and partial recruitment to the fishery at age (34% recruitment at age 3, 77% recruitment at age 4, and full recruitment at age 5; Mayo and Clark, 1984) (Figure 8). Recent assessments (Mayo and Clark, 1984) indicate the fishery could be maintained under current fishing practices based on indications of strong 1979 and 1982 year classes.

Expected level of SSB/R under prevailing fishing practices cannot be closely estimated for American plaice because current levels of fishing mortality rates are unknown (Figure 9.). Although abundance is high, landings are also high; and it is unlikely that fishing mortality rates are extremely low. American plaice are first captured at age 3, but age 5 fish contribute most of the catch (Sullivan, 1982).

Expected level of SSB/R under prevailing fishing practices cannot be closely estimated for winter flounder because current levels of fishing mortality rates are unknown (Figures 10,11,12). Landings, however, are at or near historical high levels for most of the stocks. Peaks of similar magnitudes in the late 1940's and again in the late 1960's both preceded significant declines. Winter flounder from the Gulf of Maine and southern New England are first landed at about age 2.5, and fish from Georges Bank first landed at age 2.1 (Foster et al., unpubl.)

ANTICIPATED FUTURE INVESTIGATIONS

These analyses can be substantially improved in terms of incorporating more realistic assumptions and input data. This model assumes no fishing or natural mortality occurs before spawning each year. This is clearly unrealistic; for example, spawners may be vulnerable to fisheries during period of pre-spawning aggregations, or may not spawn until midway through the year,

suffering both fishing and mortality until that point. The distribution of fishing (and natural) mortality before and after the spawning season would significantly affect the number of spawners surviving from the outset of the year to the spawning period: estimates of spawning stock biomass may be significantly reduced as a consequence.

Input data can also be refined from current approximations as more realistic or reliable estimates become available. Weight at age in the commercial catch is not equivalent to weight at age of a spawner; unless the commercial fishery coincides seasonally with spawning, and commercial fishing operations do not selectively remove larger individuals at age. Proportion mature at age may be based more realistically on female maturity schedules alone, if egg production rather than sperm production is assumed to limit recruitment. Mesh selection ogives are more realistic than assumptions of knife-edge recruitment to the fishery, and we plan to address this problem separately in future studies.

We anticipate future evolution of the technique. Significant or numerous adjustments of the types proposed above may lead to larger shifts in isopleths. Those shifts would change the evaluation of current levels of SSB/R, but would also have an effect on levels necessary to achieve replacement over a long-term average period (i.e., see "Year Class Replacement over a Long-Term Average"). We plan on continued refinement of the structure and input data of these analyses in the future.

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Table 1. Haddock: input data for SSB/R analysis

Age	Mean Weight (kg)[1]	Proportion Mature[1]
2	1.09	0.3
3	1.56	0.8
4	1.98	1.00
5	2.36	1.00
6	2.71	1.00
7	3.02	1.00
8	3.30	1.00
9	3.56	1.00
10	3.79	1.00
11	4.00	1.00
12	4.19	1.00
13	4.36	1.00
14	4.52	1.00
15	4.66	1.00
16	4.79	1.00

M = 0.2 all ages (Clark et al. 1982)

[1]Overholtz, pers. comm.

Table 2. Atlantic cod: input data for SSB/R analysis. More accurate values of proportion mature are included in parentheses. Change in results was less than 1%. See Table 9.

Age	Mean Weight (kg)[1]	Proportion Mature[2]
1	0.398	0.00
2	1.018	0.2
3	1.962	0.5
4	3.196	0.7
5	4.662	1.0
6	6.297	1.0
7	8.041	1.0
8	9.839	1.0
9	11.646	1.0
10	13.426	1.0
11	15.152	1.0
12	16.803	1.0
13	18.365	1.0
14	19.830	1.0
15	21.194	1.0
16	22.456	1.0
17	23.061	1.0

M = 0.2, all ages (Serchuk et al. 1979)

[1]Serchuk et al. 1979, combined sexes $(W_t + W_{t+1})/2$

[2]Morse, 1979; approximately averaged over range of lengths at age and sexes.

Table 3. Yellowtail flounder: input data for SSB/R analysis. Mean weight at age 3 reflects typographic error included in analysis. Correct value is displayed in parentheses. Change in results was less than 1%. See Table 10.

Age	Mean Weight (kg)[1]	Proportion Mature[2]
1	0.081	0.00
2	0.246	0.52
3	0.421	0.67
4	0.593	1.00
5	0.744	1.00
6	0.867	1.00
7	0.964	1.00
8	1.038	1.00
9	1.094	1.00
10	1.117	1.00
11	1.200	1.00
12	1.200	1.00
13	1.200	1.00
14	1.200	1.00
15	1.200	1.00

M = 0.2, all ages (Lux, 1969).

[1]Lux and Nichy, 1969; Lux, 1969

[2]Royce et al., 1959

Table 4. Redfish: input data for SSB/R analysis.

Age	Mean Weight (kg)[1]	Proportion Mature[2]
3	0.052	0.00
4	0.092	0.00
5	0.135	0.00
6	0.171	0.00
7	0.195	0.00
8	0.245	0.00
9	0.277	1.00
10	0.297	1.00
11	0.333	1.00
12	0.377	1.00
13	0.404	1.00
14	0.420	1.00
15	0.441	1.00
16	0.465	1.00
17	0.494	1.00
18	0.498	1.00
19	0.538	1.00
20	0.560	1.00
21	0.549	1.00
22	0.572	1.00
23	0.595	1.00
24	0.570	1.00
25	0.589	1.00
26-60	0.624	1.00

M = 0.05, all ages (Mayo et al., 1983)

[1]Mayo et al., 1983; mean weight at age in commercial catch

[2]Perlmutter and Clarke, 1949

Table 5. Pollock: input data for SSB/R analyses

Age	Mean Weight (kg)[1]	Proportion Mature[2]
1	.305	0.0
2	.663	0.40
3	1.311	0.42
4	2.379	0.76
5	3.467	0.95
6	3.896	0.98
7	4.350	1.00
8	5.341	1.00
9	6.214	1.00
10	7.050	1.00
11	7.752	1.00
12	8.802	1.00

M = 0.2, all ages (Mayo and Clark, MS 1984)

[1]Mayo and Clark, MS 1984; 1982 commercial fishery mean weights at age, from U.S. and Canadian sample data for gill nets and otter trawls, weighted by numbers landed by country and gear type.

[2]Beacham, 1983; simple averages of males and female data, 1975-1979.

Table 6. American plaice: input data for SSB/R analysis.

Age	Mean Weight (kg)[1]	Proportion Mature[2]
1	.004	0.00
2	.035	0.00
3	.110	0.20
4	.210	0.55
5	.36	0.74
6	.53	0.96
7	.71	1.00
8	.88	1.00
9	1.06	1.00
10	1.21	1.00
11	1.36	1.00
12	1.51	1.00
13	1.62	1.00
14	1.74	1.00
15	1.75	1.00

M = 0.2, all ages (discussed in Sullivan, 1982)

[1]Sullivan, 1982, age-length and length-weight calculations averaged between sexes.

[2]Sullivan, 1982; percent females mature at length.

Table 7. Winter flounder: input data for SSB/R analysis.

	Gulf of Maine		Georges Bank		Southern New England	
Age	Mean Weight (kg)[1]	Proportion Mature[2]	Mean Weight (kg)[3]	Proportion Mature[4]	Mean Weight (kg)[5]	Proportion Mature[4]
1	.058	.00	.082	.00	.061	.00
2	.202	.13	.421	.33	.176	.15
3	.409	.65	.890	.96	.347	.59
4	.603	.85	1.291	1.00	.536	.83
5	.772	.92	1.647	1.00	.718	.95
6	.909	1.00	1.943	1.00	.875	1.00
7	1.014	1.00	2.178	1.00	1.006	1.00
8	1.090	1.00	2.359	1.00	1.114	1.00
9	1.142	1.00	2.494	1.00	1.200	1.00
10	1.179	1.00	2.592	1.00	1.268	1.00
11	1.208	1.00	2.664	1.00	1.326	1.00
12	1.221	1.00	2.673	1.00	1.353	1.00

M = 0.20 (averaged, Howe and Coates, 1975 and Howe et al., 1970)

[1]Berry et al. (1965) and NEFC survey data (age 1), Howe and Coates (1975) (ages 2-12) (females), Lux (1969), and mean weight as $(w_t + w_{t+1})/2$.

[2]Morse (1979) (percent females mature at length at age).

[3]Lux (1973) (mean length at age 1, 2; averaged between sexes, 3-12); Lux (1969), mean weight as calculated above.

[4]Morse (1979) (percent mature at length at age, averaged between sexes).

[5]Berry et al. (1965) (ages 1 and 2); Howe and Coates (1975) (ages 3-12); averaged between sexes; Lux (1969), mean weight calculated as above.

Table 8. Mesh selection factors and age-length relationships used to relate mesh size to age at 50% selection.

Species	Mesh Selection Factor	Age-Length Relationship	
Haddock	3.4 (Mayo et al. 1981)	$l_t = 73.80\ (1-e^{-.3763(t-.1649)})$ Georges Bank	(Clark et al. 1981)
Atlantic Cod	3.6 (Smolowitz 1983)	$l_t = 148.1\ (1-e^{-.12(t+0.616)})$	(Pentilla and Gifford 1976)
Yellowtail Flounder	2.25 (Smolowitz 1983)	$l_t = 50.0\ (1-e^{-.335(t+0.26)})$	(Lux and Nichy 1969)
Redfish	2.5 (Mayo et al. 1981)	$l_t = 37.80(1-e^{-.1049(t+2.84)})$ Gulf of Maine, combined sexes	(Mayo 1980)
		$l_t = 39.84\ (1-e^{-.1029(t+2.27)})$(Ages >28; females only)	(Mayo 1980)
Pollock	3.3 (Mayo et al. 1981)	linear interpolation of mean length at age from commercial catch	(Mayo and Clark 1984)
American Plaice	2.35 (Smolowitz 1983)	$l_t = 61.981\ (1-e^{-.1701(t-.0463)})$ combined from single sex equations	(Sullivan 1982)
Winter Flounder	2.2 (Smolowitz 1983)	Gulf of Maine: linear interpolation of female lengths at age	(Howe and Coates 1975)
		Georges Bank: linear interpolation of lengths at age combined over sexes	(Lux 1969)
		Southern New England: linear interpolation of lengths at age combined over sexes	(Berry et al. 1965; Howe and Coates 1975)

Table 9. Percentage of maximum spawning stock biomass per recruit as a function of fishing mortality and age at 50% selection, Atlantic cod. Values in parentheses reflect correction of proportion mature at ages 3-4 from 0.5 and 0.7, respectively, to 0.6 and 0.85.

Level of F	Age at 50% Selection 1	2	3	4	5	6
1.0	1.%(1.)	3.%(3.)	7.%(7.)	13.%(14.)	21.%(22.)	30.%(31.)
.9	1. (1.)	3. (4.)	7. (8.)	14. (15.)	22. (23.)	31. (32.)
.8	2. (2.)	4. (4.)	8. (9.)	15. (16.)	23. (24.)	32. (33.)
.7	3. (3.)	5. (5.)	10. (10.)	16. (17.)	25. (26.)	34. (34.)
.6	4. (4.)	7. (7.)	11. (12.)	18. (19.)	27. (28.)	35. (36.)
.5	5. (5.)	9. (9.)	14. (15.)	21. (22.)	29. (30.)	38. (39.)
.4	8. (8.)	12. (13.)	18. (19.)	25. (26.)	33. (34.)	42. (43.)
.3	13. (14.)	18. (18.)	24. (25.)	31. (32.)	39. (40.)	48. (48.)
.2	23. (24.)	29. (29.)	35. (35.)	42. (42.)	49. (50.)	57. (57.)
.1	45. (46.)	50. (51.)	55. (56.)	61. (61.)	66. (67.)	72. (72.)

Table 10. Percentage of maximum spawning stock biomass per recruit as a function of fishing mortality and age at 50% selection, yellowtail flounder. Values in parentheses reflect correction of weight at age 3 from 0.521 kg to 0.421 kg.

Level of F	Age at 50% Selection 1	2	3	4	5
1.0	3.%(3.)	9.%(9)	19.%(17.)	30.%(29.)	41.%(41.)
.9	4. (4.)	10. (10.)	20. (19.)	31. (30.)	42. (42.)
.8	5. (5.)	12. (11.)	21. (20.)	33. (31.)	44. (43.)
.7	7. (6.)	13. (13.)	23. (22.)	34. (33.)	45. (44.)
.6	9. (8.)	16. (15.)	25. (24.)	37. (36.)	47. (46.)
.5	11. (11.)	19. (18.)	29. (28.)	40. (39.)	50. (49.)
.4	16. (15.)	23. (23.)	33. (32.)	44. (43.)	54. (53.)
.3	23. (22.)	31. (30.)	40. (39.)	50. (49.)	59. (58.)
.2	34. (34.)	42. (41.)	50. (50.)	59. (58.)	67. (66.)
.1	56. (56.)	62. (61.)	68. (67.)	74. (73.)	79. (79.)

Figure 1. Spawning stock biomass (000's tons) and subsequent recruitment (millions, age 2) for Georges Bank haddock, 1931-1979. The 1963 point (194,700 tons, 368.8 million recruits) has been omitted. Straight lines represent slopes (inverse) of SSB/R, as a percentage of maximum.

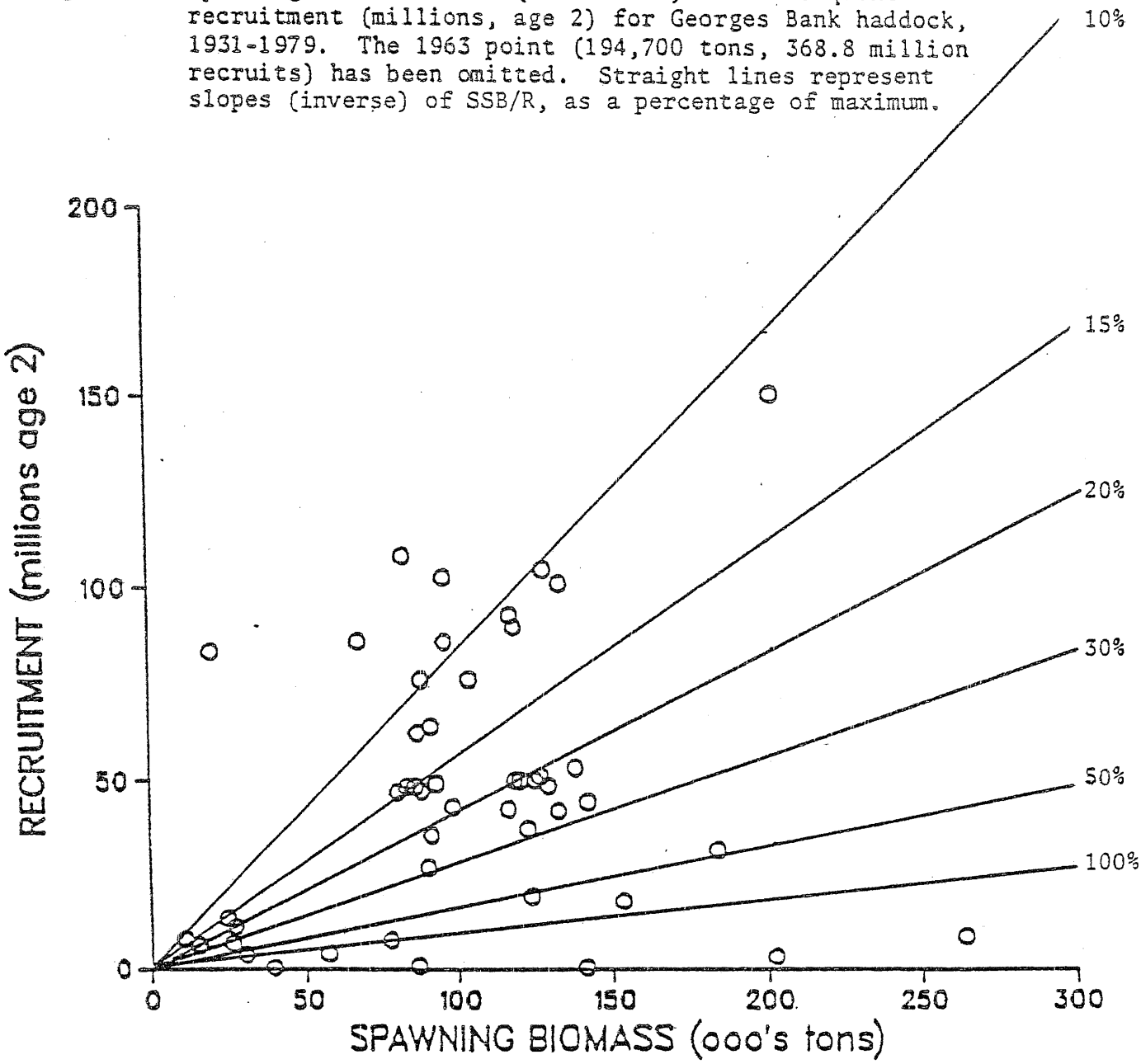
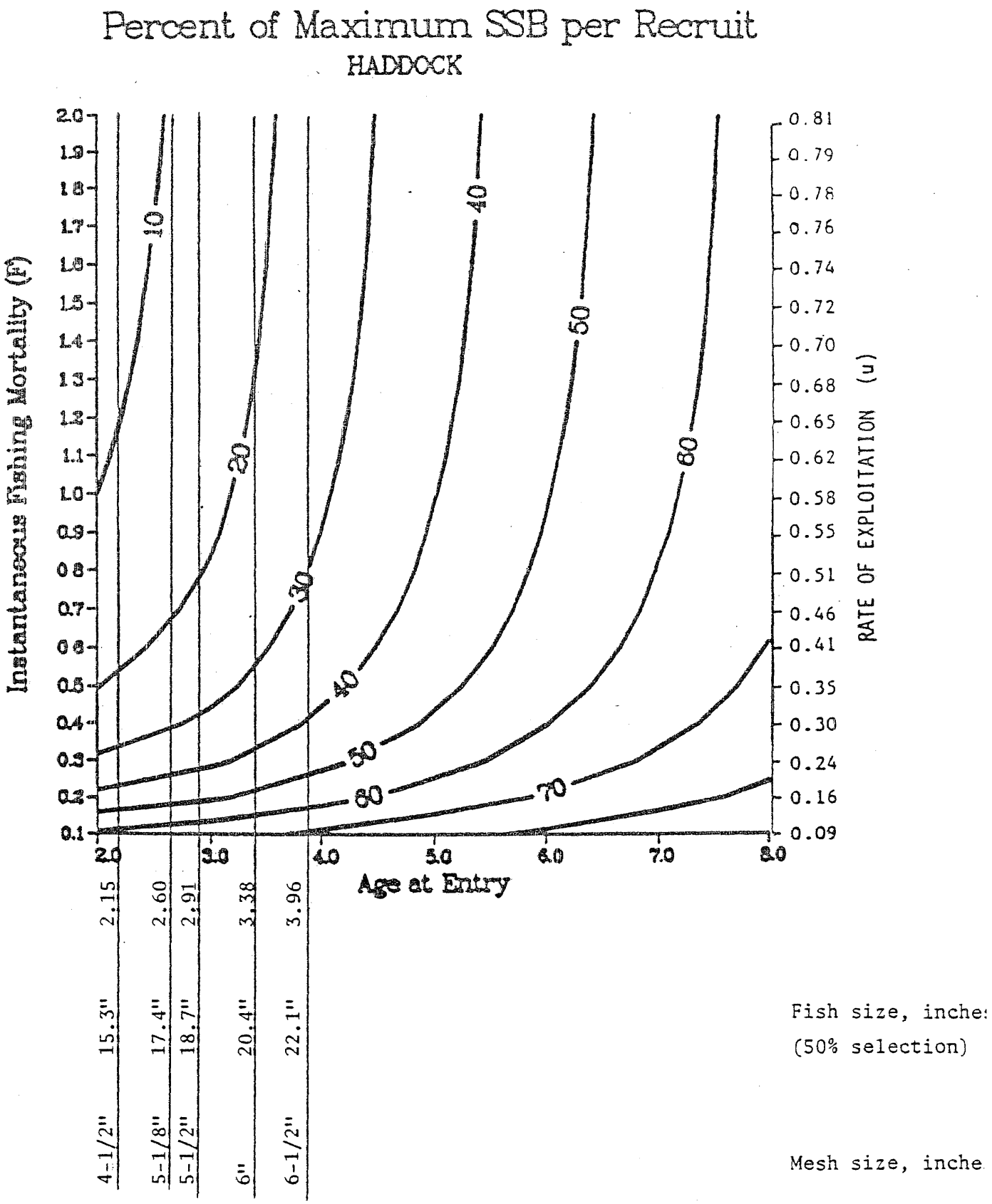


Figure 2. Isopleths of percentage of maximum spawning stock biomass per recruit, Georges Bank haddock.



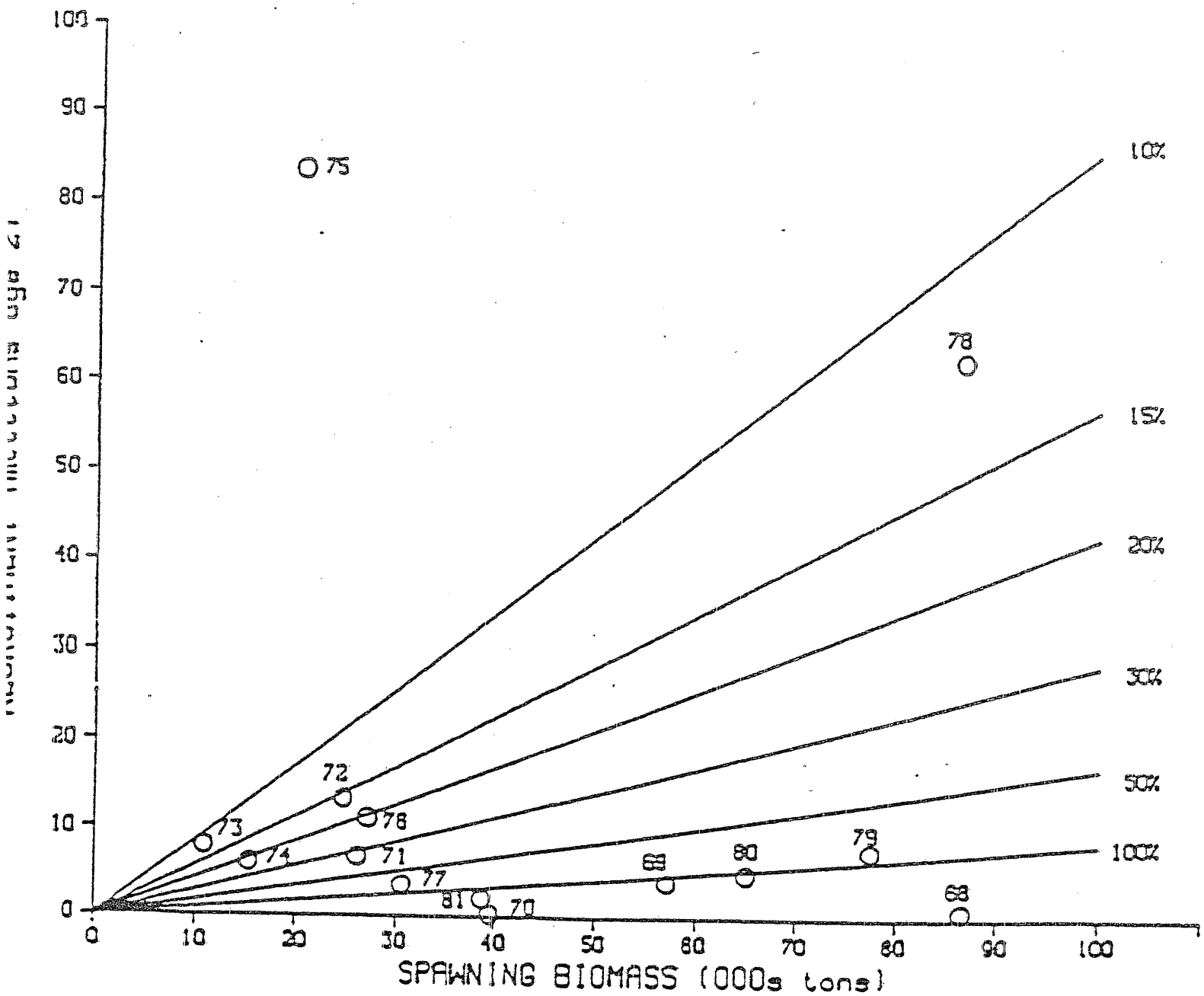


Figure 3. Spawning stock biomass (000's tons) and subsequent recruitment (millions, age 2) for Georges Bank haddock, 1968-1981, where spawning stock biomass is less than 100,000 mt. Straight lines represent slopes (inverse) of SSB/R as a percentage of maximum. Numbers next to points refer to year class.

Figure 4. Isopleths of percentage of maximum spawning stock biomass per recruit, Atlantic cod.

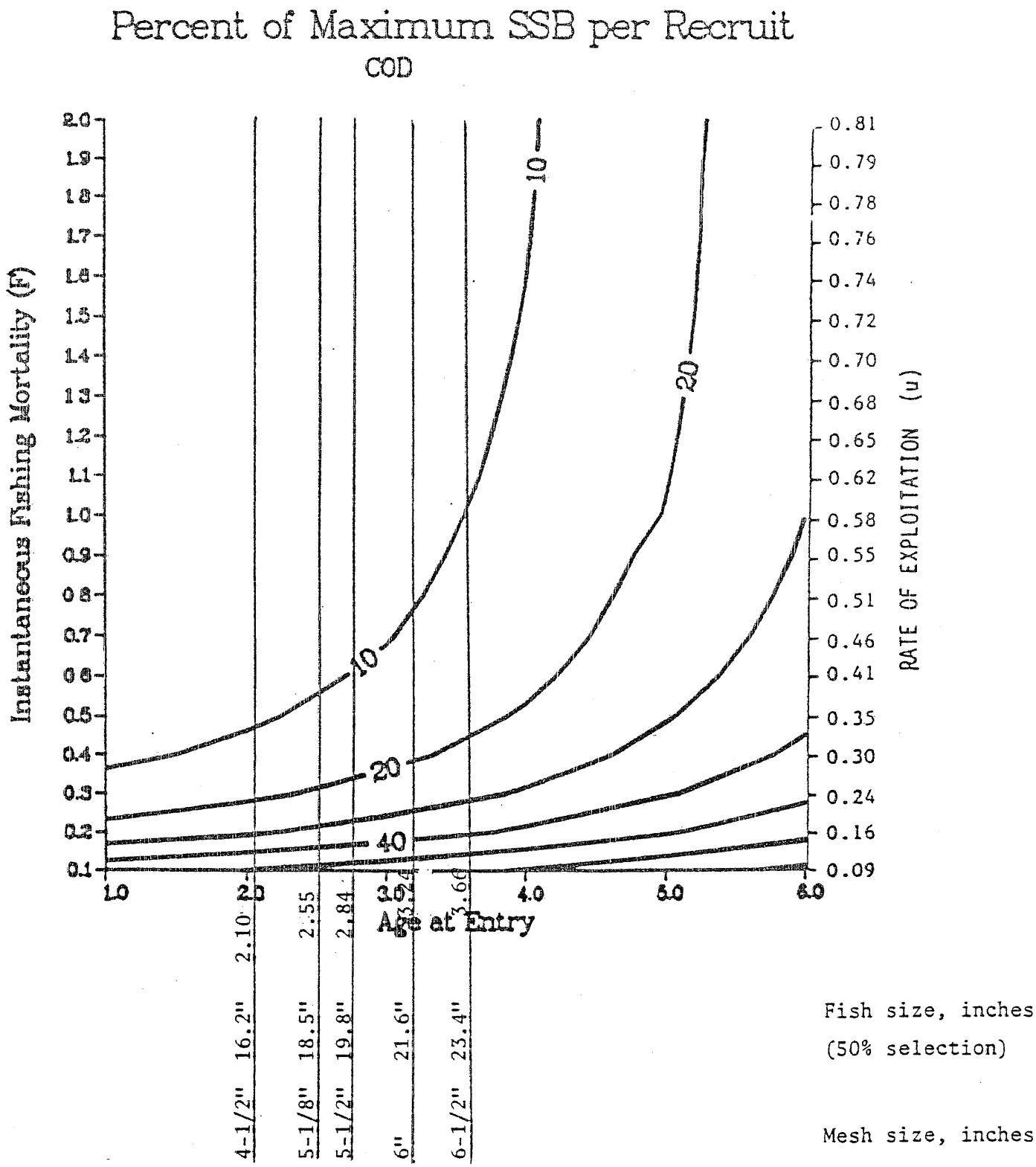


Figure 5. Isopleths of percentage of maximum spawning stock biomass per recruit, southern New England yellowtail flounder.

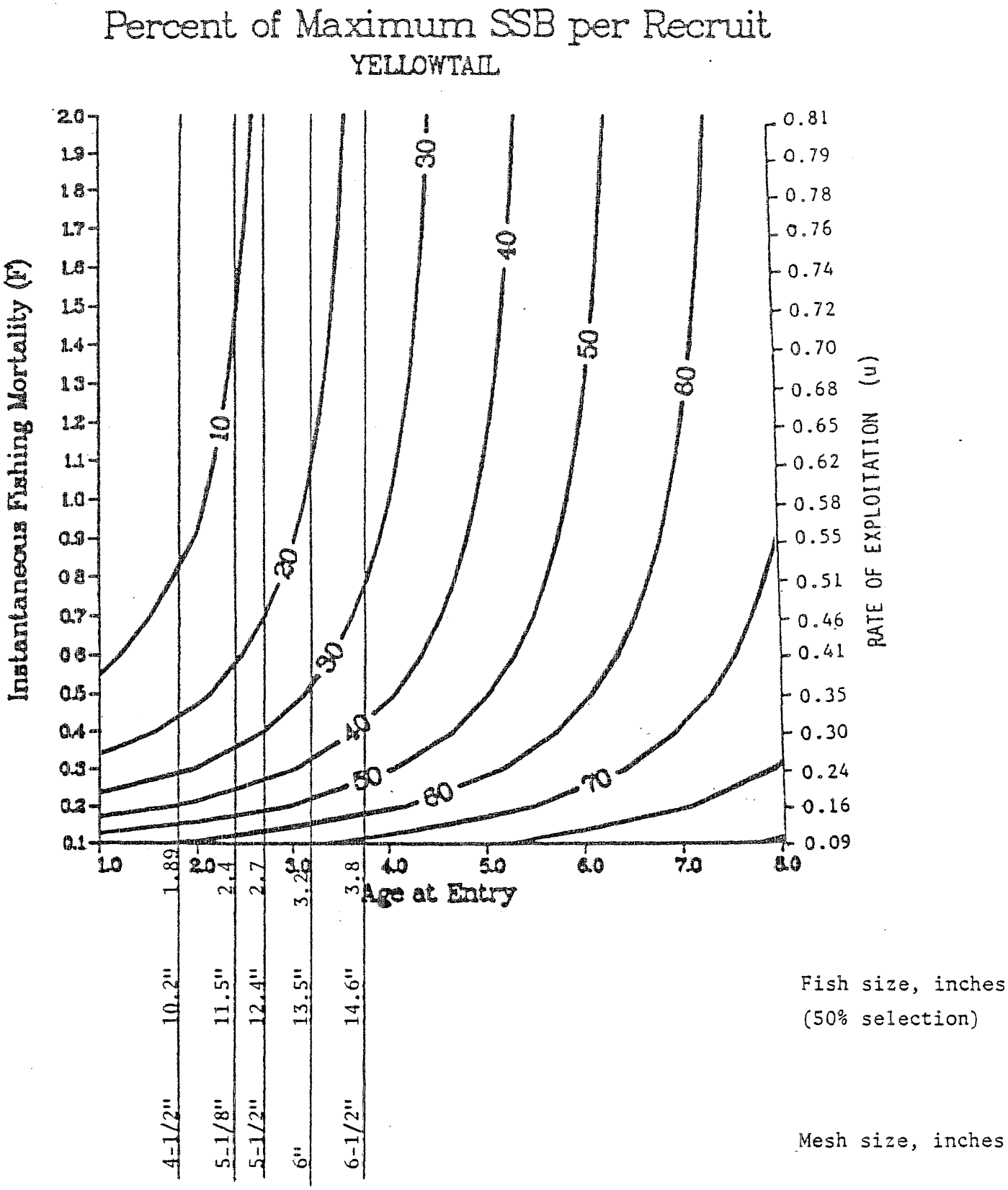


Figure 6. Isopleths of percentage of maximum spawning stock biomass per recruit, redfish.

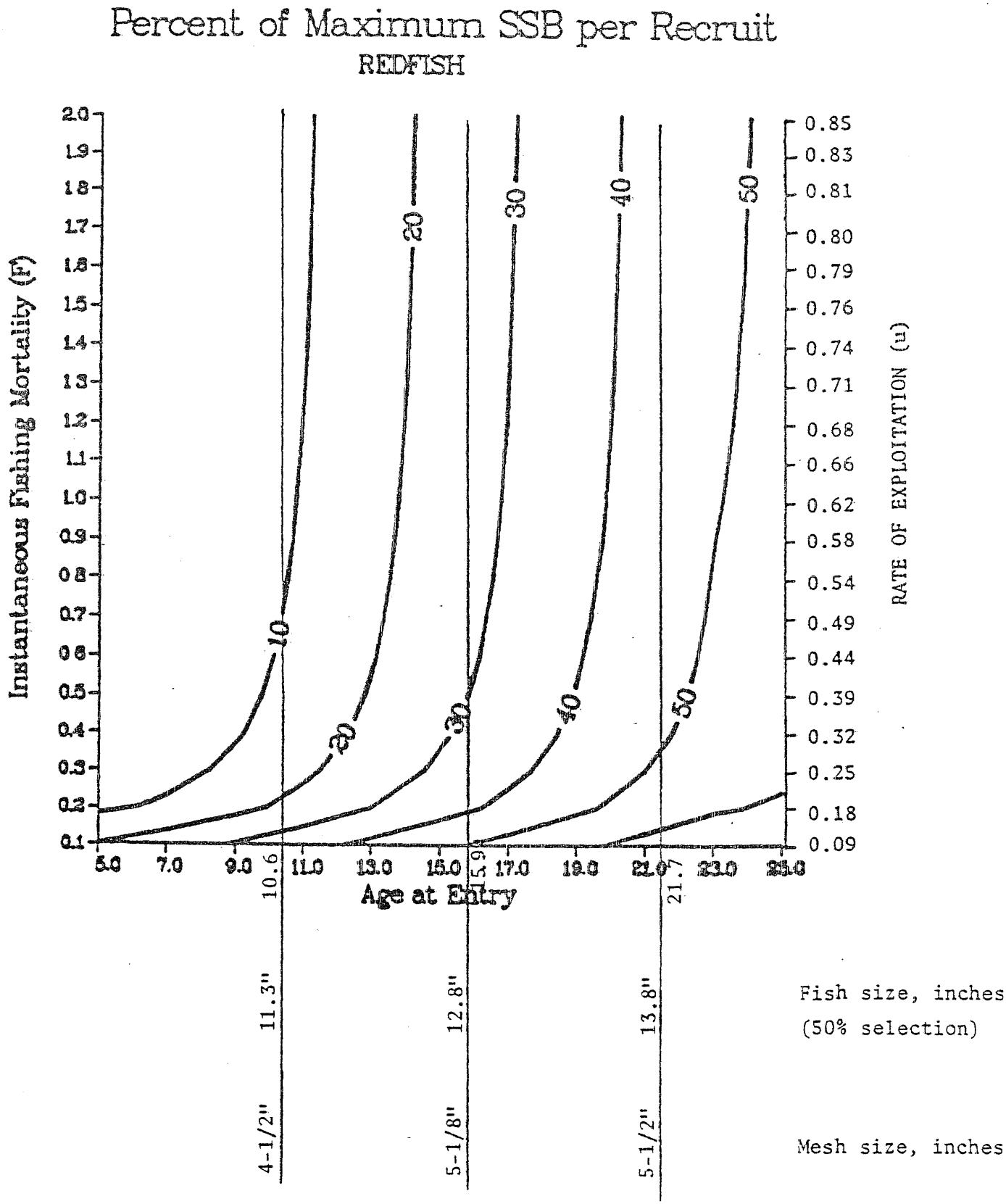


Figure 7. Spawning stock biomass (000's metric tons) and subsequent recruitment (millions, age 3) for redfish, 1969-1975. The 1971 point (104,000 tons, 212.1 million recruits) has been omitted.

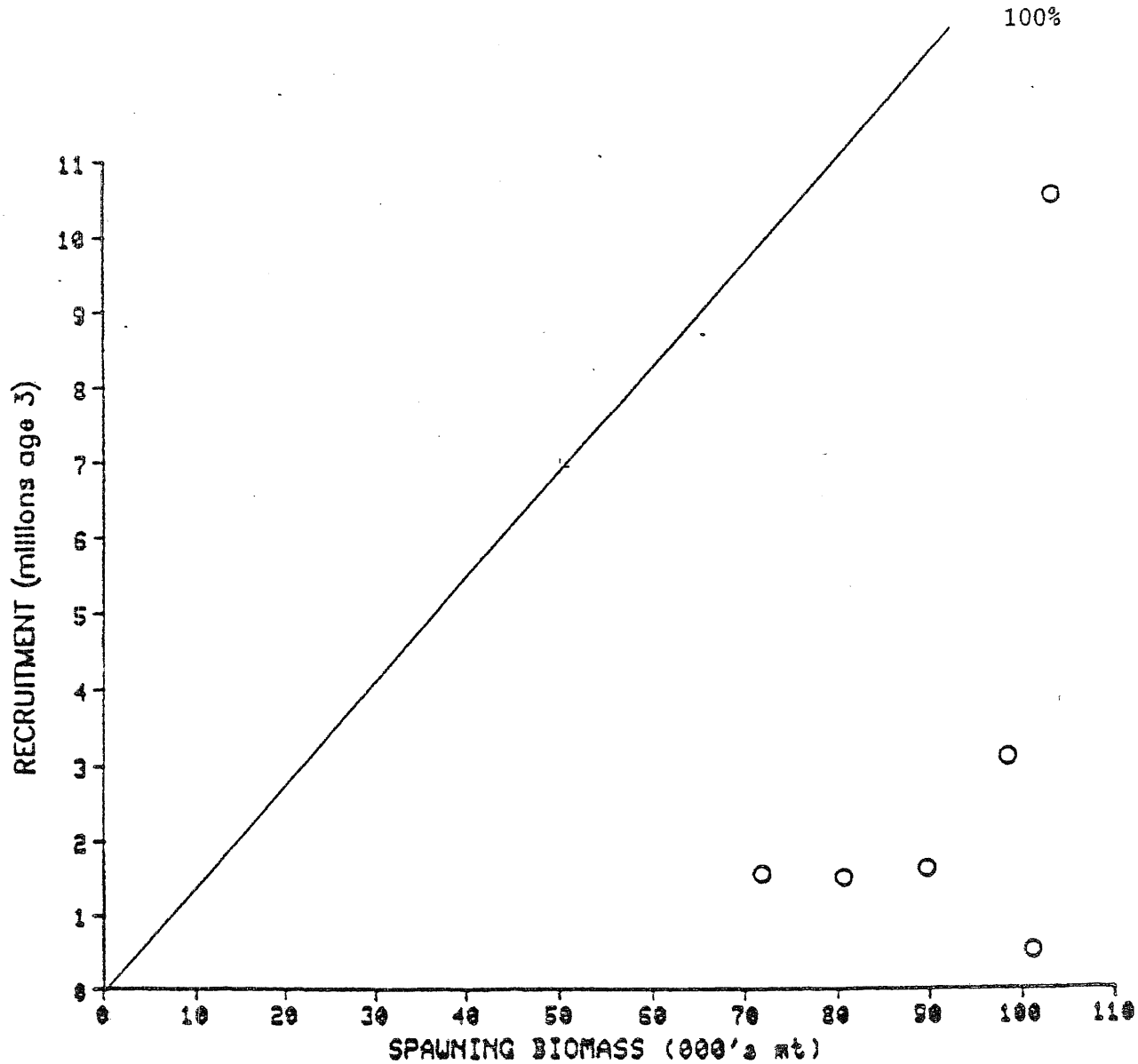


Figure 8. Isopleths of percentage of maximum spawning stock biomass per recruit, pollock.

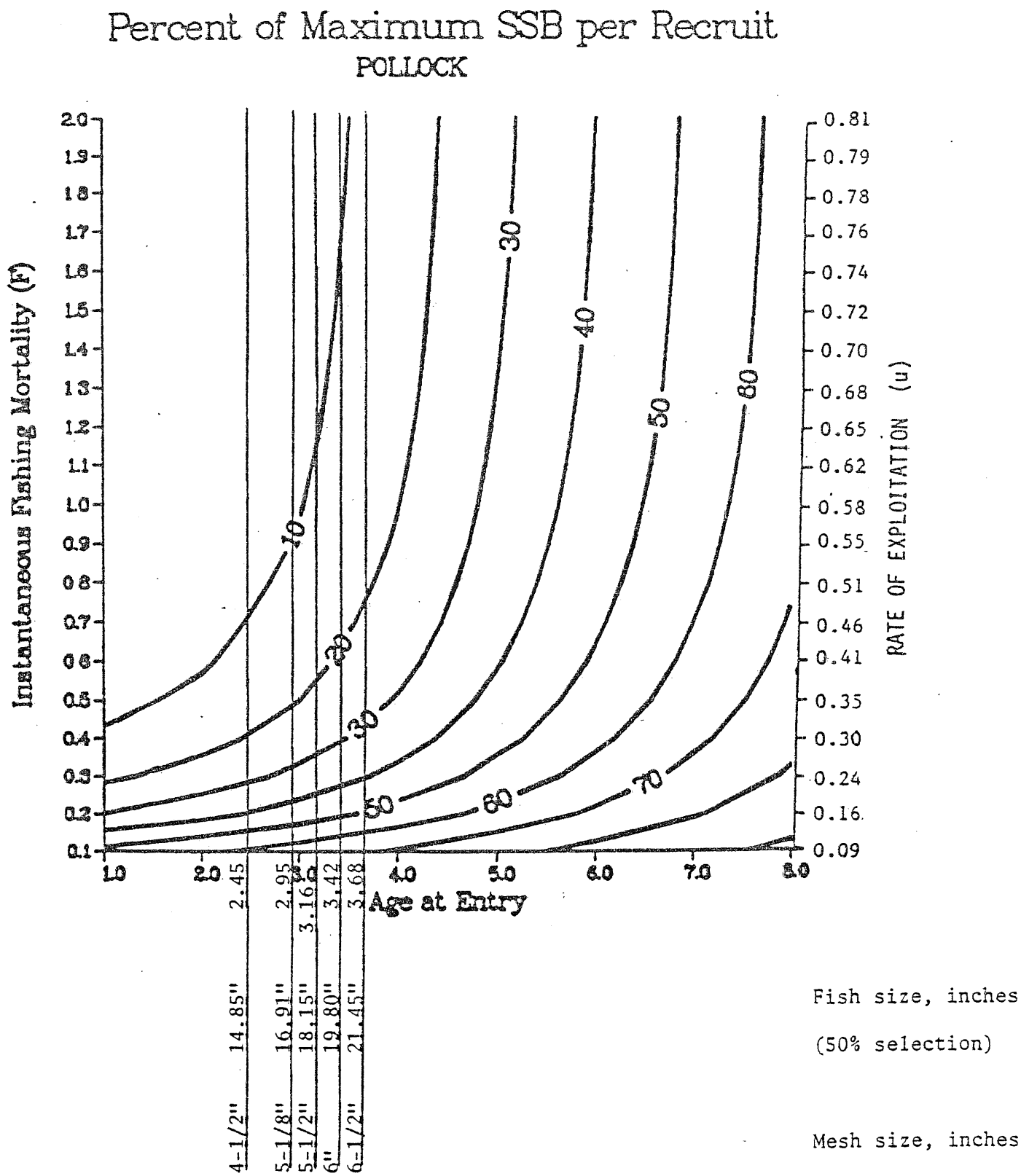


Figure 9. Isopleths of percentage of maximum spawning stock biomass per recruit, American plaice.

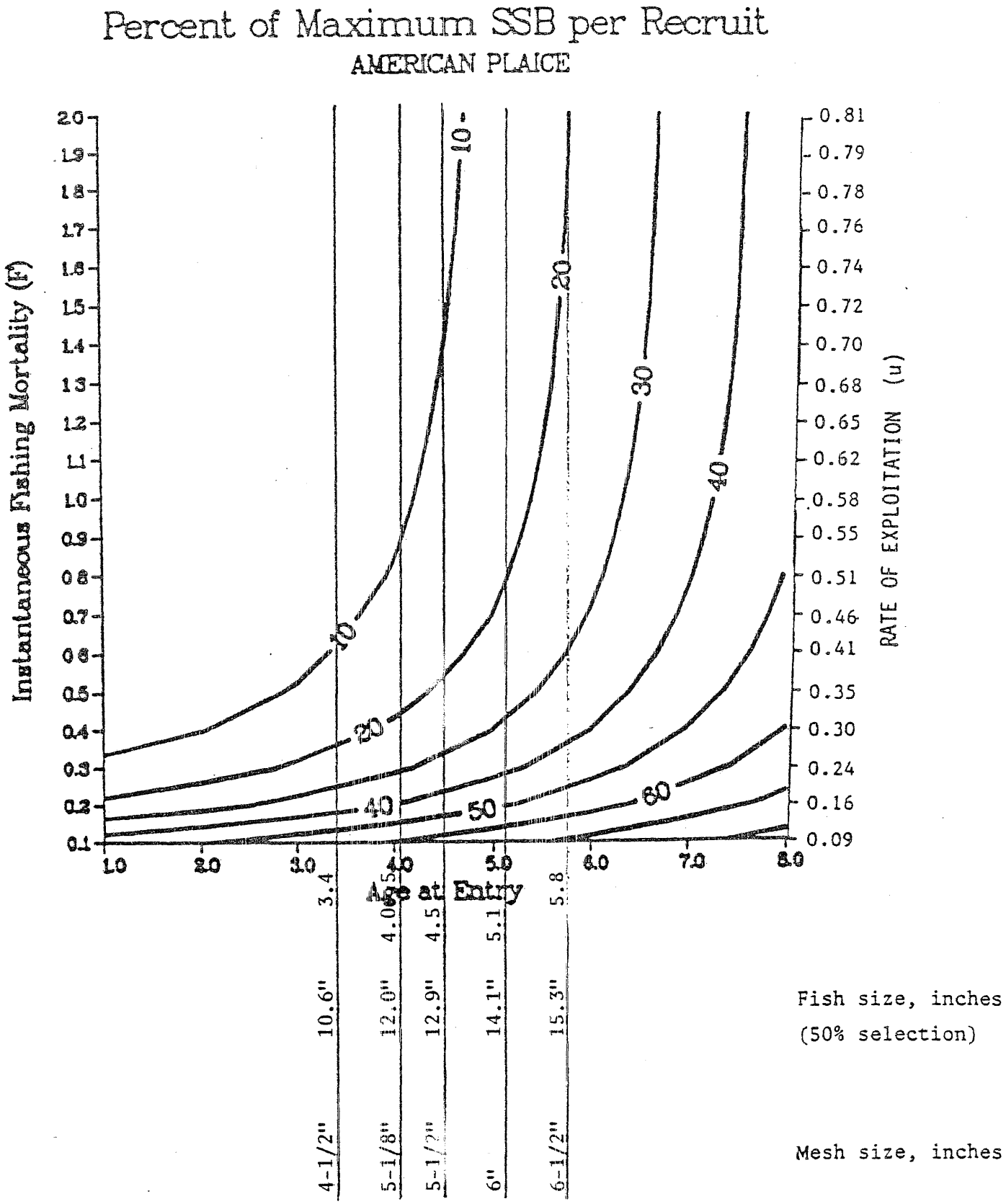


Figure 10. Isopleths of percentage of maximum spawning stock biomass per recruit, Gulf of Maine winter flounder.

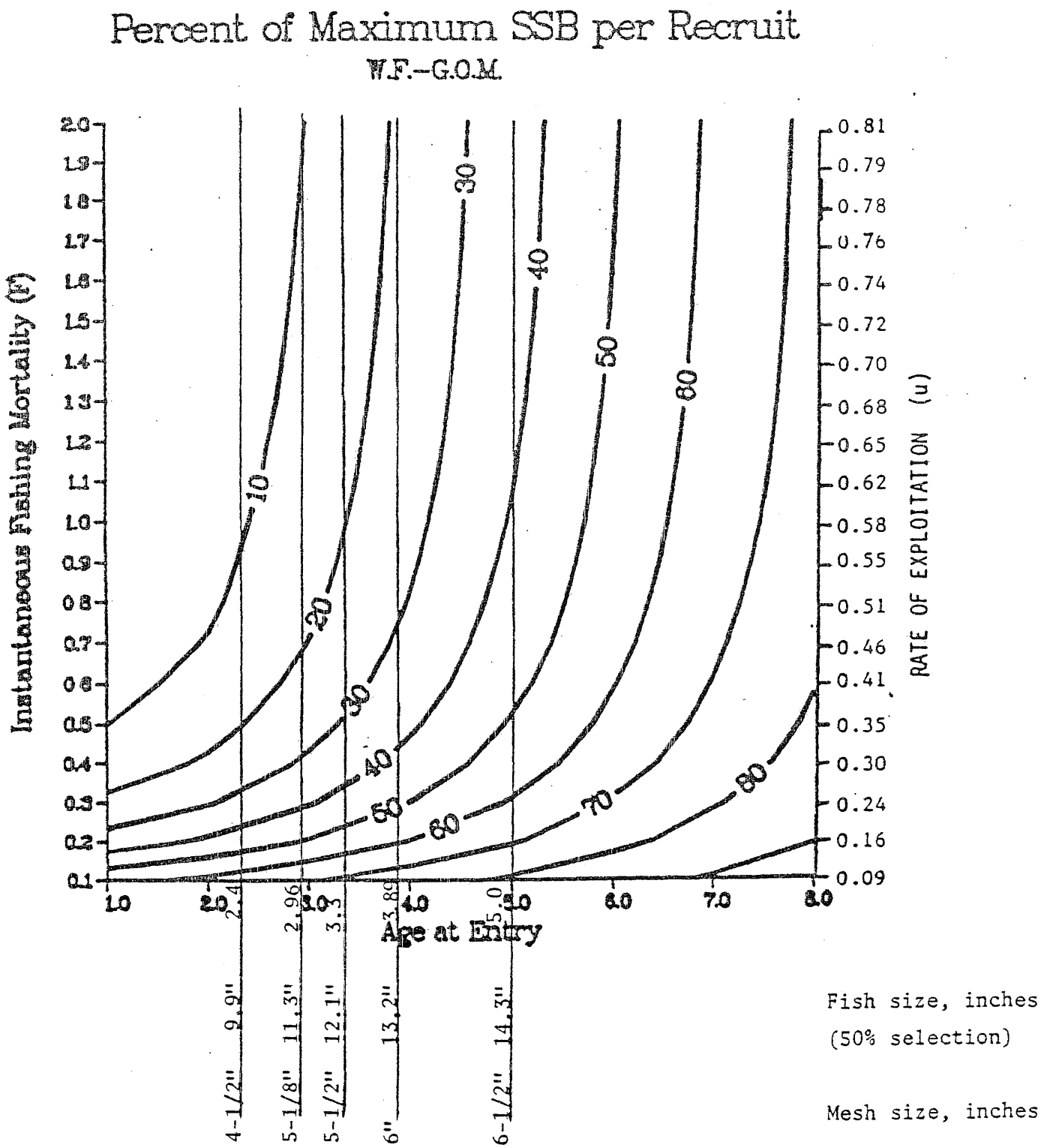


Figure 11. Isopleths of percentage of maximum spawning stock biomass per recruit, Georges Bank winter flounder.

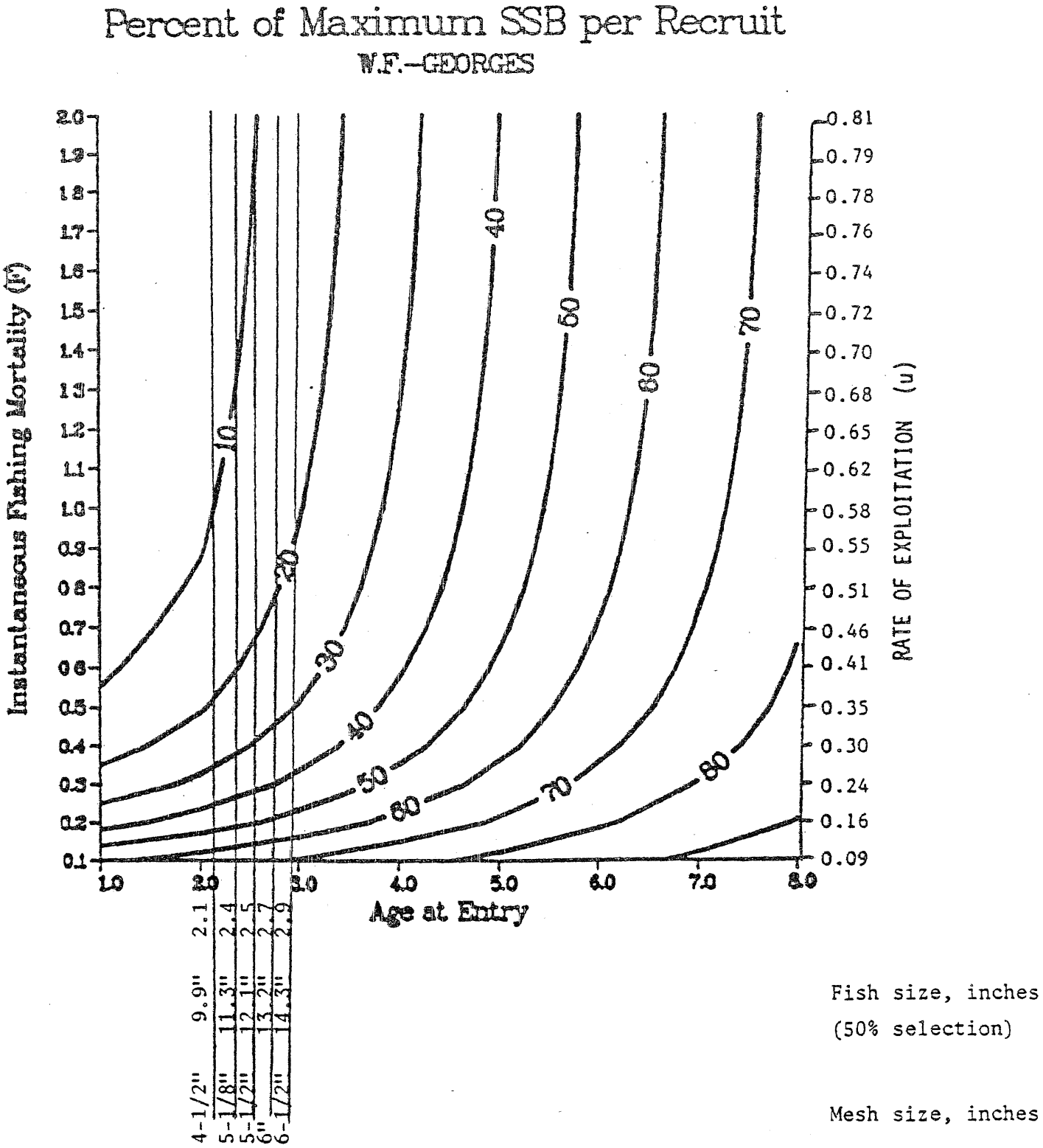
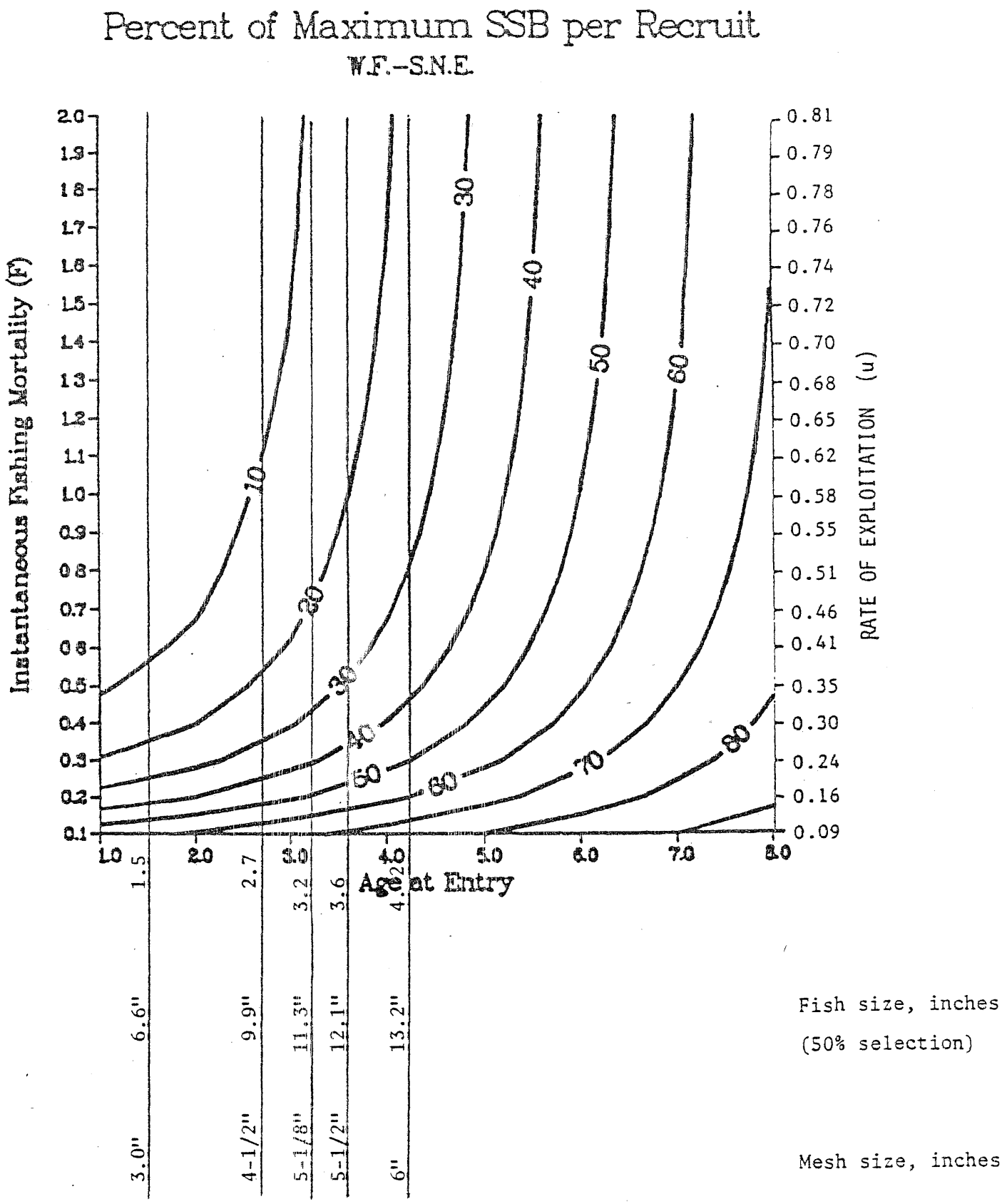



Figure 12. Isopleths of percentage of maximum spawning stock biomass per recruit, Southern New England winter flounder.