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Spawning Stock Biomass Per Recruit Analyses for Seven Northwest Atlantic Demersal Finfish Species

by

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SUMMARY

Spawning stock biomass per recruit analyses, previously presented in Gabriel et al. (1984), have been revised to incorporate pre-spawning mortality, partial recruitment, and more reliable weight and maturity at age data. The revised analyses provide lower estimates of historical and current levels of spawning stock biomass per recruit of seven species as a percentage of maximum and long-term replacement levels. Despite these changes, advice from the analyses are identical to those provided fisheries managers in the earlier study. General procedures and applications of spawning stock biomass per recruit analysis are discussed.

INTRODUCTION

Long-term management strategies that emphasize the size of a spawning biomass rather than yield are currently becoming more important. Under the Magnuson Fisheries Conservation and Management Act (MFCMA), social and economic concerns must be considered and may substantially modify yield-related objectives. The Northeast Multi-Species Fishery Management Plan, developed by the New England Fishery Management Council (NEMFC), has among its objectives the maintenance or increase of spawning stock biomass, to minimize the possibility of recruitment failure and stock collapse (NEFMC 1985). Traditional "biological reference points" such as F_{max} [level of instantaneous fishing mortality (F) that produces maximum yield per recruit (Y/R)] are no longer as relevant in these contexts, as spawning stock rather than yield becomes the primary object of interest.

Although the concept of spawning stock biomass per recruit (SSB/R) has been part of the study of the dynamics of exploited fish populations at least since Beverton and Holt (1957), its management application has been recent and not as well developed as its Y/R analog. In 1983, the Working Group on Methods of Fish Stock Assessments, of the International Council for the Exploration of the Sea (ICES) proposed new biological reference points, related to spawning and recruitment; for example, the designation of a level of F above which the chance of recruitment failure may be significant (Anon. 1984). The NEFMC's Multi-Species Management Plan is one of the first to utilize this approach.

Earlier SSB/R analysis for Northwest Atlantic demersal fishes was based on a relatively simple model structure, with data selected opportunistically (Gabriel et al. 1984). The objective of this paper is to review the SSB/R analysis procedure and application, in general, especially the case when the analysis is used to compare theoretical effects of alternate mesh sizes on SSB/R and to report results of the analyses incorporating improved analytic structures and biological data for seven demersal finfish species (Atlantic cod, haddock, yellowtail flounder, winter flounder, redfish, American plaice, pollock).

SPAWNING STOCK BIOMASS PER RECRUIT ANALYSIS

The SSB/R analysis is used for evaluating the effects of fishing mortality and age at first capture on spawning potential. It has traditionally been applied as an extension of Y/R analysis. Under natural conditions, the number of individuals in a year class (cohort) decreases with age due to instantaneous natural mortality (M). At the same time, the weight of each individual survivor is increasing. As well, the proportion of the survivors that are sexually mature, contributing to the spawning portion of the stock's biomass, is also increasing with age. At each age the number alive times the fraction mature times the weight of an individual 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 bescaled 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 (Figure 1).

Maximum SSB/R is obtained with no fishing mortality. Combinations of instantaneous fishing mortality (F) and the age at which entry to the fishery (t_c) give rise to lower levels of SSB/R which can be expressed as percentages of the maximum. An exploitable regime of higher fishing mortality or lower age at first capture will lead to SSB/R levels that are lower percentages of the maximum. The same level of SSB/R can be obtained from several different combinations of F and t_c. For example, low levels of F 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 (Figure 2).

YEAR CLASS REPLACEMENT OVER A LONG-TERM AVERAGE

What level of spawning stock biomass per recruit is necessary to conserve a fish population To maintain a population in balance, the number of reproducing adults dying must equal the number maturing; i.e., 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 has many opportunities to spawn. Large numbers of their offspring could die of natural causes 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 has fewer opportunities to produce offspring. For the population to persist, a higher proportion of the prerecruit offspring must survive than in the unfished case. For that population to increase, survival of prerecruit offspring must be even higher.

The likelihood of obtaining adequate survival to offset reduced SSB/R from fishing can be evaluated using appropriate historical stock-recruitment data. A management regime giving rise to few spawning opportunities (low SSB/R, as discussed in the previous paragraph) requires good survival (high observed R/SSB) to support it. We can calculate ratios of observed spawning stock biomass and subsequent number of surviving recruits. When survival is high, many recruits are produced per unit of spawning stock biomass; the ratio of SSB/R can be low and the population will still persist. When survival is low, few recruits are produced per unit of spawning stock biomass and the ratio of SSB/R must be higher; the spawning effort of a large amount of spawning biomass is required to produce a surviving recruit. If long-term average observed value of R/SSB equals the inverse of the SSB/R anticipated under a fishing strategy, the population should persist with fluctuations about some mean level. Of course, this assumes that historic patterns of fluctuations in R/SSB are repeated.

The comparison of observed levels of R/SSB and potential levels of SSB/R can be made using a standard stock-recruitment plot (e.g., Shepherd 1982). A potential level of SSB/R can be superimposed on the plot, as its reciprocal, R/SSB, which is in the same units as a slope. The level may be displayed as a percentage of the maximum SSB/R: 100% would correspond to SSB/R (and its reciprocal, R/SSB) with no F. Higher F would lead to lower SSB/R, lower percentages of the maximum SSB/R, higher R/SSB and steeper slope (Figure 3).

When deterministic stock-recruitment relationships can be defined from observed data, the intersection of the slope with the stock-recruitment curve indicates the level at which stock biomass and recruitment level would theoretically stabilize. That tendency toward equilibrium is the multiple-age analog to the equilibrium defined by Ricker (1954) for single-aged stocks. In reality, the equilibrium is likely to be obscured by effects of environmental fluctuations (Shepherd 1982). When deterministic stock-recruitment relationships are infeasible, location of the stock-recruitment points can be examined with respect to the slope. Points above that line represent years in which recruitment was more than adequate to maintain spawning stock biomass under the defined pattern of fishing mortality. In those cases, observed R/SSB was high (so observed SSB/R was low) and survival was more than adequate to offset reduced SSB/R under the associated regime of fishing mortality. Points below the line represent years in which observed recruitment was inadequate to maintain spawning stock biomass under the fishery conditions, leading to short-term stock decline. If points are equally distributed above and below that line, the stock is likely to persist over the long-term average. This slope can thus be evaluated as a "replacement" line: are losses due to mortality under the potential level of SSB/R replaced through historically observed recruitment, on average?

GENERALIZED FORMS OF INPUT DATA

The Thompson-Bell algorithm modified by the International Council for the Exploration of the Sea (ICES) (Almeida, ed. 1984) requires as input data estimates of instantaneous natural mortality (M), which can be age specific, the proportions of F and M that take place before spawning on an annual basis, the proportion sexually mature at age, the individual weight at age in the spawning stock and proportion recruited to the fishery at age (Figure 1).

To organize a standardized approach to SSB/R analysis, I have adopted some conventions for selection of input data for the Thompson-Bell model:

1. The youngest age to be included in the analysis corresponds to the first age of fish are present on the grounds [Beverton and Holt's t (1957)]. This allows theoretical comparison of the effects of the widest range of mesh sizes as well as full effects of partial recruitment on estimates of SSB/R. Slopes (as the inverse, R/SSB) can then be scaled to correspond with age at recruitment in the observed stock-recruitment index, if one is available. Age 1 is usually chosen as the youngest age in this analysis, as the first age that is generally vulnerable to trawl gear (although in some cases young of year may be vulnerable).

2. The total number of ages to be included corresponds to 3/M (Anthony 1982). Thus, a plus group would be included only if age-specific data for the oldest of the 3/M ages were unavailable (or if number of age classes exceeded the capacity of the computer program).

3. The proportion of sexually mature individuals at age is based on the fraction of females mature at time of spawning. This corresponds to assumptions that 1) recruitment is limited by egg production rather than sperm production at age, and 2) egg production and viability per unit of spawning biomass is independent of age/length of spawner.

4. The individual weight at age in the stock is based on an average of weights of males and females at the time of spawning. The average may be weighted by sex ratio if the ratio differs strongly from 1:1, however. This provides estimates of spawning stock biomass compatible with biomass estimates from virtual population analysis (VPA) which are usually not provided by sex). (Virtual population analysis allows estimates of absolute stock abundance and F by age over time; based on landings data, including total landings, length distribution of landings, age distribution of landings at length, and weight at length.)

The schedules of maturity, annual and within-year mortality and weight at spawning should correspond to those used to calculate spawning stock biomass from VPA. Traditional estimates of spawning stock biomass from VPA may have to be adjusted to account for maturation, growth, and mortality between 1 January and time of peak spawning.

INPUT DATA AND METHODS

Ideally, input data would consist of historical direct empirical observations of mean weight at age in the spawning stock and fraction mature at age. These data were approximated by estimating length at age from a von Bertalanffy growth curve for sexes combined, calculating weight at age from a length-weight relationship, and calculating fraction mature from a maturity ogive (curve showing fraction mature at length). Values were estimated as of

the month of peak spawning (as reported by Colton et al. 1979, unless otherwise noted). Table 1 notes special cases of this procedure and equation sources.

The proportions of F and M before spawning were calculated as the percentage of the year elapsing before peak spawning, implying that F and M are uniformly distributed over the year. In the case of F, these proportions generally fell within ranges observed for proportions of annual landings made in months before spawning, 1982-1984 (Table 2). In the case of the two exceptions, winter flounder (Southern New England) and American plaice (Gulf of Maine), the proportion of F taking place before spawning was based on the mean proportion of annual landings in months before spawning. Actual values input to analysis are displayed for each species in Tables 3 through 10.

For display in an isopleth diagram (Figure 2), SSB/R analyses were performed to evaluate effects of fishing mortality begun at successively later ages. In the knife edge case, recruitment to gear would be assumed 0% in ages before recruitment and 100% at and after age at recruitment. In the case of partial recruitment at age here, 50% of fishing mortality is effective at age of recruitment. Within that year, however, actual recruitment is less than 50% in the early part of the year and greater than 50% in the latter part. This was approximated by changing the location of the selection ogive so that 50% retention is obtained at a length halfway between lengths at successive 1 Januaries: partial recruitment at age was modelled as a series of step

functions approximating the selection ogive. As a result, degree of partial recruitment at any age was based on average length, halfway through that year (Tables 11-19).

Partial recruitment schedule from a specific mesh size is developed by locating the selection ogive so that 50% retention is obtained at the appropriate fish length associated with the mesh size (where length = selection factor X mesh size). Each age-specific rate can be obtained by applying that ogive to average length within age (Tables 11-19).

RESULTS

Ideally, results should be evaluated using current estimates of effective mesh size (or partial recruitment), F, and historic stock-recruitment data such as obtained from VPA. Effective mesh size together with F defines the current SSB/R regime operating in the fishery, while VPA data determine R/SSB levels the stock has historically produced. These data are complete for haddock and redfish. Except for pollock, current SSB/R regimes must otherwise be approximated based on F estimates and estimated ages at first and full recruitment, where they are available. Quantitative analysis of the adequacy of SSB/R levels for stock maintenance cannot be made without VPA type data. Except for haddock and redfish, if we want to determine whether current fishing practices will lead to stock decline, replacement or rebuilding, we are dependent on general descriptions of trends and conditions (e.g., Status of Fishery resources off the Northeastern United States, Anthony, ed. 1985). Results for haddock and redfish are described below. Results for other species are presented in Table 20 and Figures 4-9. Except for pollock,

current SSB/R levels have in recent years been below 15% of the maximum possible (when levels can be estimated) and stocks are declining.

Current F on haddock has been estimated at 0.6; partial recruitment has been approximately 0.0 at age 1, 0.6 at age 2, and 1.0 at age 3 (Overholtz et al. 1983). This is close to age at entry of 2.5 years in this analysis, where partial recruitment is 0.0 at age 1, 0.5 at age 2, and 0.93 at age 3 (Table 12). SSB/R at this combination of F and partial recruitment is about 14% of the maximum possible (Figure 2). Direct observations at sea (Overholtz, pers. comm.) indicate that recruitment may even be complete (1.0) at age 2, with appreciable partial recruitment at age 1. Thus, the 14% level should be considered an upper bound, and SSB/R may actually be even lower.

Alternative SSB/R regimes are displayed on a stock-recruitment plot (Figure 3). Spawning stock biomass was recalculated from VPA results (Clark et al. 1982; Overholtz et al. 1983) to include effects of mortality before spawning and changes in (commercial) first quarter mean weights at age over time. Maximum SSB/R (10.99 kg/age 2 recruit) was originally defined from the SSB/R analysis. Its reciprocal, R/SSB, was superimposed on the plot as a slope, representing 100% of the maximum SSB/R (no fishing mortality) (Figure 3). Alternative lower levels of SSB/R, representing higher levels of fishing mortality and lower percentages of the maximum, were also superimposed as steeper slopes (based on their reciprocals). (Individual points above a particular replacement line represent years in which survival to recruitment was adequate to maintain or increase spawning stock biomass under the affiliated SSB/R regime:

$R/SSB_{observed} > R/SSB_{calculated}$ or $SSB/R_{observed} < SSB/R_{calculated}$.)

The 14% level is too low to achieve replacement or rebuilding, given historical and recent patterns of recruitment. A regression of observed spawning stock biomass vs. recruitment, 1931-1981 (through the origin) yielded a slope of 0.44 age 2 recruits/kg spawning stock biomass or 2.28 kg SSB/R (Figure 10). This represents the observed long-term average survival of recruits as R/SSB from 1931-1981 and corresponds to 21% of the maximum. Although formal tests for lack of fit could not be applied, the regression appeared to systematically yield negative residual errors when stock biomass exceeded 150,000 mt with one exception (Figures 10, 11), consistent with compensatory density dependent recruitment at high stock size. When years in which spawning stock biomass exceeded 150,000 mt were excluded (1960-1966), the slope increased to 0.48 recruits/kg spawning stock biomass or 2.08 kg SSB/R, 19% of the maximum. Negative residuals were observed in 10 of the 13 years in which spawning stock biomass was below 80,000 mt, however; compared to 15 out of 31 years in which spawning stock biomass was between 80,000-150,000 mt (Figures 11, 12). Thus, depensatory recruitment at low stock size also appears possible. For most recent years (1970-1981), regression yielded a slope of only 0.33 age 2 recruits/kg spawning stock biomass, or 3.04 kg SSB/R, 28% of the maximum. Consequently, current fishery practices, providing only 14% or less of the maximum spawning opportunity, are not supported by the historical pattern, which indicates that on long-term average at least 19-21% of maximum potential is required. Over the past 50 years, recruitment would have been inadequate to achieve replacement if the current SSB/R regime were maintained as a long-term strategy (Figure 3). In only two of the past 10 years has recruitment been adequate to achieve replacement or rebuilding under the present fishing conditions (Figure 3). Given poorer survival patterns

observed in the last 10 years or so, 28% (or more) of maximum SSB/R would presently be necessary to achieve stock replacement.

The recent level of redfish SSB/R is approximately 5% of maximum, based on recent levels of F (0.28) and partial recruitment (0.1 at age 4, 0.25 at age 5, 0.5 at age 6, 0.75 at age 7, 0.85 at age 8, and 1.0 at ages 9 and above, based on the 1971 year class) (Mayo et al. 1983, Figure 13). For other year classes (1969-1978), 50% recruitment at age 8 still yields SSB/R levels under 10% of the maximum.

This level is too low to achieve replacement, given historical stock-recruitment information from VPA. Spawning stock biomass from 1969-1975 was recalculated from VPA results (Mayo et al. 1983) as for haddock. In 1971, approximately 2.1 age 3 recruits were produced per kg of spawning stock biomass (R/SSB) or 0.47 kg SSB/R, representing about 6% of the maximum spawning potential (7.94 kg SSB/R). In this year alone recruitment was close to levels for rebuilding or replacement given current fishing practices that provide 5-10% of maximum spawning potential, however. Under conditions of no fishing mortality, a kilogram of spawning stock biomass needs only produce an average 0.12 recruit to achieve replacement (0.12 R/SSB or 7.94 kg SSB/R). In years other than 1971, less than 0.10 recruit was produced per kg of spawning stock biomass. Hence, in those years, the stock would be unable to replace itself even with no fishing mortality. Individual points on a stock-recruitment plot, except for 1971, fall below the replacement line for conditions of no fishing mortality (100% of maximum spawning potential) (Figure 14). In addition to the short time series of VPA observations for Gulf of Maine redfish, showing inadequate SSB/R to sustain current fishing

practices, other recruitment indicators (research survey indices) show no outstanding year classes for 1976 to present (Mayo et al. 1983).

DISCUSSION

The overall effect of incorporation of within-year mortality before spawning, partial recruitment and improved life history data was to lower estimates of percentage of maximum SSB/R compared to earlier analysis (Gabriel et al. 1984) (Table 21). In many cases, original values were reduced by approximately the proportion of fishing and natural mortality before spawning. Consequently, differences between results of the two analyses were largest for later-spawning species. Discrepancies of more than 2% after this reduction can be traced to changes in other input parameters.

Estimates of long-term average replacement levels for haddock were also lower in this analysis. Because spawning biomass was estimated as of month of peak spawning, VPA estimates of SSB were lowered to reflect mortality before spawning. Although estimates of current levels of SSB/R for haddock declined from 25% in earlier analysis to 14%, estimates of historical levels of SSB also declined. Long-term average replacement levels were reduced from 20-30% of the maximum to 15-25%. A target level of 30% in the first analysis corresponds to a target of about 25% in this analysis; in both cases, such a target would be supported by 6" mesh at F=0.6.

In the case of species for which information is less complete, it generally appears that current levels of SSB/R are inadequate to maintain or improve spawning stock biomass. Georges Bank cod are now at 5-15% of maximum SSB/R, yet other cod stocks have been observed to collapse under considerably higher proportions of maximum SSB/R (Serchuk, pers. comm.). In the case of Southern New England yellowtail flounder, the stock appeared to have been able

to sustain itself at (current) levels of 8-11% from 1960-1965 (Sissenwine 1974). During that period, however, the catch was obtained from several age classes that were represented in the stock. Recently, the fishery has been operating primarily on each incoming year class, the stock contains few age classes, current age at entry is probably lower due to increased dependence on recruitment, and recent F levels appear to have increased (Clark et al. 1984). Consequently, the possibility of fishery collapse with a single year of poor recruitment is more likely than in 1960-1965.

For haddock, the SSB/R level defined for replacement of spawning stock biomass under recent conditions (28%) is consistent with those from simulation models by Overholtz et al. (In press). Those stochastic models incorporated effects of recent poor recruitment and low stock sizes and historical stock-recruitment information. At $F_{0.1} = 0.26$ and full recruitment at age 2 (age at recruitment 2.5 in this analysis), they found slow rebuilding toward a spawning stock size of 50,000 mt in 25 years. That combination of F and age at entry corresponds to SSB/R levels of 30-35% of the maximum. That 30-35% level was considered the minimum necessary to achieve any rebuilding, consistent with the 28% found here as the minimum to achieve replacement given present conditions.

There are some limitations to the use of SSB/R analysis in the development of long-range management strategies. The relationship between stock and recruitment is implicitly assumed to be linear. Mortality, growth, maturity, fecundity, and hence the output SSB/R is assumed constant, regardless of stock size: a kilogram of SSB will produce a particular average number of recruits. In fact, at very high stock sizes, recruitment (per unit SSB) may become disproportionately low if density dependent mechanisms are

operating (compensation). Likewise, recruitment may become disproportionately low at very low stock sizes (depensation). The distribution of observed SSB/R points with respect to replacement lines is likely to change depending on the range of SSB considered. This appears to be the case for haddock. Consequently, if long-term average replacement levels were defined from observations at intermediate stock sizes, they may be inadequate targets as stocks reach very high or low levels. Interim replacement levels may have to be defined based on data from periods of low stock abundance, for example.

Similarly, density-dependent mechanisms such as oceanographic conditions or predator abundance may also rapidly change levels of recruitment (per unit SSB). Long-term average replacement levels defined from periods of favorable environmental conditions or low predator (or high prey) abundance may then become unrealistic. Long-term management strategy must thus be flexible enough to incorporate potential environmental and interspecific effects not included in SSB/R analysis.

When management strategies deal specifically with mesh size options, several differences between theory and application must be noted. A partial recruitment vector in this analysis represents the operation of a single mesh size of a single gear type (otter trawl) in a fishery.

1. Comparisons of effects of alternate mesh sizes on SSB/R are based on theoretical schedules of partial recruitment from standardized controlled experiments. Actual partial recruitment obtained after adopting a particular mesh size cannot be predicted (assuming only a single mesh size is operating in the fishery). For example, a selection behavior of a single mesh size itself is highly variable. Rates of partial recruitment and mesh selection depend on individual net rigging practices and individual tow conditions.

Selectivity changes as meshes constrict when the cod end fills, or when clogging or gilling occurs. Effective partial recruitment at age to a given mesh size is thus likely to be higher than estimated by an unpredictable amount. Estimates of SSB/R levels predicted from analyses represent the "best case", and actual results are liable to fall short.

2. In reality, more than one mesh size may operate on a stock. An unknown fraction of fishing mortality may be applied by adjacent small mesh fisheries (e.g., the exempted fishery program in the Northeast Atlantic Multispecies Fishery Management Plan). Those effects are not incorporated in these projections or estimates. Additional partial recruitment options should be considered, as linear combinations of fishing mortality from small and large mesh fisheries.

3. Management strategies designed to achieve target SSB/R levels using mesh regulations or other measures to influence age at entry to the fishery depends on concurrent constant or decreasing F. In fact, if effort increases, effects of mesh size increases can be cancelled or negated.

4. Alternative gear types may provide selection patterns that are more compatible with goals of maintaining or improving SSB/R levels than otter trawls.

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Table 1. Equation sources for input values and special cases in calculation of input values.

Species	Age-length equation	Length-weight equation	Maturity ogive	Natural mortality	Notes
Atlantic cod	Penttila and Gifford, 1976	None	Morse, 1979	Serchuk et al.,1979	1
Haddock Georges Bank	Clark, pers. comm.	NEFC Survey unit, unpub.	None	Clark et al.,1982	2
Yellowtail flounder So. New England	Lux and Nichy (1969)	Lux, 1969b	Morse, 1979	Lux, 1969a	3
Winter flounder					
Georges Bank	Lux, 1973	Lux, 1969b	Morse, 1979	Coates et al., 1970	4,5,6
So. New England	Berry, et al., 1965				
	Howe and Coates, 1975	Lux, 1969b	Morse, 1979	Howe and Coates, 1975	7
Redfish	Mayo, 1980	Brown, 1963	Perlmutter & Clark,1949	Mayo et al., 1983	-
American plaice	Sullivan, 1982	Lux, 1969b	Morse, 1979	Sullivan, 1982	8
Pollock	Mayo, pers. comm.	NEFC Survey unit, unpub.	Beacham, 1983 (1975-1979 period)	Mayo and Clark, 1984	

1. Age-weight relationship developed by Serchuk et al. (1979).
2. Maturity rates based on weighted mean of 1968-1972 and 1973-1975 maturities at age (Overholtz, pers. comm.).
3. Length at age one from survey means (Lux and Nichy, 1969).
4. Lengths at age one, two from survey means (Lux, 1973).
5. Weights calculated separately for males and females then averaged (unweighted).
6. Mortality rate modified, incomplete mixing possible.
7. Lengths at ages one, two from Berry et al. (1965); above age two from Howe and Coates (1975) (Walford equation).
8. Weights calculated separately for males and females, then averaged (weighted by sex ratio) (Serchuk, pers. comm.)

Table 2. Proportion of fishing mortality that takes place before spawning, assuming 1) F distributed equally over year or 2) F distributed as landings in months before and after spawning.

Species	Proportion of F taking place before spawning		
	Distributed equally over year	Distributed as landings in months before and after spawning	
		Mean, 1982-1984	Range
Atlantic cod (Georges Bank)	0.167	0.14	0.08-0.21
Haddock (Georges Bank)	0.167	0.20	0.16-0.23
Yellowtail flounder (So. New England)	0.33	0.35	0.20-0.37
Winter flounder			
(Georges Bank)	0.25	0.22	0.20-0.25
(So. New England)	0.167	0.07	0.05-0.09
Redfish (Gulf of Maine-Georges Bank)	0.50	0.48	0.46-0.50
American plaice (Gulf of Maine)	0.25	0.21[1]	0.19-0.22
Pollock	0.00	0.00	0.00

[1] 1983-1984 only.

Table 3. Atlantic cod (Georges Bank): input data for SSB/R analyses.

Instantaneous rate of mortality (M): 0.2.
Month of peak spawning: March-April.
Proportion of fishing and natural mortality before spawning: 0.167 (1 March).

Age	Length (cm) Sexes combined	Percent mature Female	Weight in stock (kg) Sexes combined
1	28.5	0.00	0.224
2	42.0	0.25	0.732
3	54.0	0.63	1.575
4	64.7	0.86	2.725
5	74.1	1.00	4.129
6	82.5	1.00	5.723
7	89.9	1.00	7.444
8	96.5	1.00	9.235
9	102.3	1.00	11.049
10	107.5	1.00	12.845
11	112.1	1.00	14.595
12	116.1	1.00	16.274
13	119.8	1.00	17.869
14	123.0	1.00	19.368
15	125.8	1.00	20.766

Table 4. Haddock (Georges Bank): input data for SSB/R analyses.

Instantaneous rate of mortality (M): 0.2.
Month of peak spawnings: February-March.
Proportion of fishing and natural mortality before spawning: 0.167 (1 March)

Age	Length (cm) Sexes combined	Percent mature Female	Weight in stock (kg) Sexes combined
1	20.6	0.00	0.088
2	36.0	0.30	0.486
3	47.1	0.81	1.106
4	55.1	0.91	1.790
5	60.9	0.98	2.427
6	65.1	0.98	2.972
7	68.1	0.99	3.412
8	70.2	0.99	3.755
9	71.8	0.99	4.015
10	72.9	1.00	4.210
11	73.7	1.00	4.356
12	74.3	1.00	4.462
13	74.7	1.00	4.539
14	75.0	1.00	4.596
15	75.2	1.00	4.637

Table 5. Yellowtail flounder (Southern New England): input data for SSB/R analyses.

Instantaneous rate of mortality (M): 0.2.
Month of peak spawning: May.
Proportion of fishing and natural mortality before spawning: 0.33.

Age	Length (cm) Sexes combined	Percent mature Female	Weight in stock (kg) Sexes combined
1	11.6	0.000	.009
2	29.0	0.599	.213
3	35.0	0.876	.408
4	39.2	1.000	.603
5	42.3	1.000	.784
6	44.5	1.000	.934
7	46.1	1.000	1.055
8	47.2	1.000	1.145
9	48.0	1.000	1.213
10	48.6	1.000	1.266
11	49.0	1.000	1.303
12	49.3	1.000	1.330
13	49.5	1.000	1.349
14	49.6	1.000	1.359
15	49.7	1.000	1.368

Table 6. Winter flounder (Georges Bank): input data for SSB/R analyses.

Instantaneous rate of mortality (M): 0.2.
Month of peak spawning[1]: March-June.
Proportion of fishing and natural mortality before spawning: 0.25.

Age	Length (cm)		Percent mature	Weight in stock (kg)		
	Male	Female	Female	Male	Female	Mean
1	11.3	11.9	0.00	.016	.017	.017
2	26.7	27.3	0.56	.218	.244	.231
3	38.8	39.6	1.00	.687	.803	.745
4	43.8	45.9	1.00	.996	1.289	1.142
5	47.3	50.4	1.00	1.261	1.738	1.499
6	49.6	53.8	1.00	1.459	2.142	1.800
7	51.3	56.2	1.00	1.618	2.463	2.040
8	52.4	58.0	1.00	1.727	2.724	2.225
9	53.2	59.4	1.00	1.809	2.940	2.374
10	53.8	60.3	1.00	1.873	3.085	2.479
11	54.1	61.0	1.00	1.905	3.201	2.553
12	54.4	61.6	1.00	1.938	3.303	2.620
13	54.6	61.9	1.00	1.960	3.354	2.667
14	54.7	62.2	1.00	1.971	3.407	2.689
15	54.8	62.4	1.00	1.982	3.442	2.712

[1]Spawning season poorly defined (Colton et al., 1979).

Table 7. Winter flounder (Southern New England): input data for SSB/R analyses.

Instantaneous rate of mortality (M): 0.27.
Month of peak spawning[1]: March.
Proportion of natural mortality before spawning: 0.167.
Proportion of fishing mortality before spawning: 0.07.

Age	Length (cm)		Percent mature	Weight in stock (kg)		
	Male	Female	Female	Male	Female	Mean
1	13.5	14.8	0.00	.027	.034	.030
2	19.9	22.8	0.28	.088	.137	.112
3	26.0	30.3	0.72	.201	.341	.271
4	30.8	35.6	0.89	.338	.571	.454
5	34.5	39.4	1.00	.479	.791	.635
6	37.4	42.1	1.00	.613	.977	.795
7	39.7	44.0	1.00	.737	1.126	.931
8	41.4	45.4	1.00	.838	1.244	1.041
9	42.8	46.4	1.00	.928	1.334	1.131
10	43.9	47.1	1.00	1.003	1.399	1.201
11	44.7	47.6	1.00	1.060	1.448	1.254
12	45.4	47.9	1.00	1.112	1.477	1.294
13	45.9	48.1	1.00	1.150	1.497	1.323
14	46.3	48.3	1.00	1.181	1.517	1.349
15	46.6	48.4	1.00	1.205	1.527	1.366

[1]Klein-MacPhee, 1978.

Table 8. Redfish: input data for SSB/R analyses.

Instantaneous rate of mortality: 0.05.
Month of peak spawning: June-July.
Proportion of fishing and natural mortality before spawning: 0.5.

Age	Length (cm) Sexes combined	Percent mature Female	Weight in stock (kg) Sexes combined
1	13.9	0.00	.031
2	16.3	0.00	.051
3	18.4	0.00	.074
4	20.4	0.00	.103
5	22.1	0.00	.132
6	23.7	0.08	.164
7	25.1	0.35	.196
8	26.3	0.60	.228
9	27.5	0.83	.262
10	28.5	0.92	.293
11	29.4	0.95	.322
12	30.3	0.97	.354
13	31.0	0.99	.381
14	31.7	1.00	.408
15	32.3	1.00	.433
16	32.8	1.00	.454
17	33.3	1.00	.476
18	33.8	1.00	.499
19	34.2	1.00	.518
20	34.5	1.00	.532
21	34.9	1.00	.552
22	35.2	1.00	.567
23	35.4	1.00	.577
24	35.7	1.00	.592
25	35.9	1.00	.603
26	36.1	1.00	.613
27	36.2	1.00	.619
28	36.4	1.00	.630
29	36.5	1.00	.635
30	36.7	1.00	.646
31	36.8	1.00	.652
32	36.9	1.00	.657
33	37.0	1.00	.663
34	37.0	1.00	.663
35	37.1	1.00	.668
36	37.2	1.00	.674
37	37.2	1.00	.674
38	37.3	1.00	.680
39	37.3	1.00	.680
40	37.4	1.00	.685
41	37.4	1.00	.685
42	37.5	1.00	.691
43	37.5	1.00	.691
44	37.5	1.00	.691
45	37.6	1.00	.697
46	37.6	1.00	.697
47	37.6	1.00	.697
48	37.6	1.00	.697
49	37.6	1.00	.697
50	37.6	1.00	.697

Table 9. American plaice (Gulf of Maine): input data for SSB/R analyses.

Instantaneous rate of mortality (M): 0.2.
Month of peak spawning: March-April.
Proportion of natural mortality before spawning: 0.25 (1 April).
Proportion of fishing mortality before spawning: 0.21.

Age	Length (cm)		Percent mature	Weight in stock (kg)		
	Male	Female	Female	Male	Female	Mean[1]
1	11.8	11.2	0.00	.009	.008	.008
2	19.3	19.5	0.00	.049	.051	.050
3	25.6	26.5	0.09	.126	.141	.133
4	31.0	32.4	0.42	.239	.277	.258
5	35.5	37.3	0.72	.376	.444	.410
6	39.3	41.5	0.88	.529	.634	.599
7	42.5	45.1	0.95	.687	.838	.788
8	45.2	48.1	1.00	.844	1.039	1.000
9	47.5	50.6	1.00	.997	1.231	1.184
10	49.4	52.7	1.00	1.136	1.411	1.356
11	-	54.5	1.00	-	1.578	1.578
12	-	56.0	1.00	-	1.728	1.728
13	-	57.3	1.00	-	1.866	1.866
14	-	58.4	1.00	-	1.989	1.989
15	-	59.3	1.00	-	2.093	2.093

[1]Mean weight weighted by sex (F, Serchuk, pers. comm.)

Ages	Male	Female
1-5	50%	50%
6-7	33%	67%
8-10	20%	80%
>10	-	100%

Table 10. Pollock: input data for SSB/R analyses.

Instantaneous rate of mortality (M): 0.2.
Month of peak spawning: January.
Proportion of fishing and natural mortality before spawning: 0.00.

Age	Length (cm) Sexes combined	Percent Mature Female	Weight in stock (kg) Sexes combined
1	16.72	0.000	0.046
2	30.74	0.059	0.290
3	42.57	0.452	0.777
4	52.54	0.722	1.470
5	60.95	0.946	2.305
6	68.03	0.976	3.215
7	74.00	1.000	4.148
8	79.04	1.000	5.059
9	83.28	1.000	5.933
10	86.86	1.000	6.739
11	89.88	1.000	7.474
12	92.42	1.000	8.132
13	94.56	1.000	8.716
14	96.37	1.000	9.231
15	97.89	1.000	9.682

Table 11. Partial recruitment vectors for Atlantic cod (Georges Bank).

Age	Mean Length* (cm)	Age at Recruitment 1.5	2.5	3.5	4.5	5.5	6.5
1	33.0	0.50	0.05	0.00	0.00	0.00	0.00
2	46.0	0.98	0.50	0.08	0.00	0.00	0.00
3	57.5	1.00	0.95	0.50	0.10	0.00	0.00
4	67.8	-	1.00	0.92	0.50	0.15	0.00
5	76.8	-	-	1.00	0.90	0.50	0.18
6	84.9	-	-	-	1.00	0.90	0.50
7	92.0	-	-	-	-	1.00	0.90
8	98.0	-	-	-	-	-	0.98
9	-	-	-	-	-	-	1.00

$^{*}\frac{\ell_t + \ell_{t+1}}{2}$

Data Source: Smolowitz, 1983

Table 12. Partial recruitment vectors for haddock (Georges Bank).

Age	Mean Length* (cm)	Age at Recruitment 1.5	2.5	3.5	4.5	5.5
1	25.7	0.50	0.00	0.00	0.00	0.00
2	39.7	0.97	0.50	0.01	0.00	0.00
3	49.8	1.00	0.93	0.50	0.05	0.00
4	57.0	-	0.98	0.90	0.50	0.10
5	62.3	-	1.00	0.96	0.82	0.50
6	66.0	-	1.00	0.97	0.92	0.80
7	68.8	-	-	1.00	0.95	0.85
8	70.7	-	-	1.00	0.97	0.90
9	72.1	-	-	1.00	0.98	0.93
10	73.1	-	-	1.00	0.99	0.94
11	73.9	-	-	-	1.00	0.95
12	74.4	-	-	-	1.00	0.95
13	74.8	-	-	-	1.00	0.96
14	75.0	-	-	-	-	0.96
15	75.2	-	-	-	-	0.97

$^{*}\frac{\ell_t + \ell_{t+1}}{2}$

Data Source: Smolowitz, 1983

Table 13. Partial recruitment vectors for yellowtail flounder (Southern New England).

Age	Mean Length(cm)*	Age at Recruitment 1.5	2.5	3.5	4.5	5.5
1	16.7	0.50	0.01	0.00	0.00	0.00
2	29.8	1.00	0.50	0.20	0.05	0.01
3	35.6	-	0.97	0.50	0.20	0.10
4	39.7	-	1.00	0.95	0.50	0.32
5	42.6	-	-	1.00	0.80	0.50
6	44.7	-	-	-	0.95	0.72
7	46.4	-	-	-	1.00	0.90
8	-	-	-	-	-	1.00

$^{*}\frac{\ell_t+\ell_{t+1}}{2}$

Data Source: Smolowitz, 1983 Age 1: 102 mm covered.
Ages 2-5: 133 mm covered.

Table 14. Partial recruitment vectors for winter flounder (Gulf of Maine).

Age	Mean Length* (cm)	Age at Recruitment 1.5	2.5	3.5	4.5	5.5
1	15.0	0.50	0.10	0.00	0.00	0.00
2	21.7	0.97	0.50	0.10	0.02	0.00
3	27.6	1.00	0.97	0.50	0.12	0.05
4	32.7	-	1.00	0.85	0.50	0.15
5	37.2	-	-	0.95	0.82	0.50
6	41.0	-	-	1.00	0.95	0.85
7	44.4	-	-	-	1.00	0.92
8	-	-	-	-	-	≐1.00
9	-	-	-	-	-	≐1.00
10	-	-	-	-	-	≐1.00
11	-	-	-	-	-	≐1.00

$^{*}\frac{\ell_t + \ell_{t+1}}{2}$

Data Source: Smolowitz, 1983 Ages 1,2: 103 mm covered.
Ages ≥ 3 : 133 mm covered.

Table 15. Partial recruitment vectors for winter flounder (Georges Bank).

Age	Mean Length* (cm)	Age at Recruitment 1.5	2.5	3.5	4.5	5.5
1	15.6	0.50	0.00	0.00	0.00	0.00
2	30.4	1.00	0.50	0.04	0.00	0.00
3	40.5	-	0.95	0.50	0.12	0.07
4	45.7	-	1.00	0.85	0.50	0.19
5	49.4	-	-	0.95	0.80	0.50
6	52.2	-	-	0.98	0.90	0.72
7	54.1	-	-	1.00	0.93	0.83
8	55.5	-	-	-	0.98	0.90
9	56.5	-	-	-	0.99	0.92
10	57.2	-	-	-	1.00	0.93
11	57.7	-	-	-	-	0.93
12	58.0	-	-	-	-	0.94
13	58.3	-	-	-	-	0.94
14	58.5	-	-	-	-	0.95
15	58.6	-	-	-	-	0.95

$^{*}\frac{\ell_t + \ell_{t+1}}{2}$

Data Source: Smolowitz, 1983 Ages 1: 103 mm covered.
Ages $\geq$2: 133 mm covered.

Table 16. Partial recruitment vectors for winter flounder (Southern New England).

Age	Mean Length* (cm)	Age at Recruitment 1.5	2.5	3.5	4.5	5.5
1	16.5	0.50	0.08	0.00	0.00	0.00
2	23.7	1.00	0.50	0.10	0.01	0.00
3	29.9	-	0.95	0.50	0.12	0.08
4	34.6	-	1.00	0.85	0.50	0.20
5	37.9	-	-	0.92	0.72	0.50
6	40.5	-	-	0.98	0.90	0.70
7	42.3	-	-	1.00	0.92	0.85
8	43.7	-	-	-	0.95	0.90
9	44.7	-	-	-	0.98	0.92
10	45.5	-	-	-	1.00	0.94
11	46.2	-	-	-	-	0.94
12	46.7	-	-	-	-	0.95
13	47.0	-	-	-	-	0.96
14	47.3	-	-	-	-	0.97
15	47.5	-	-	-	-	0.98

$^{*}\frac{\ell_t + \ell_{t+1}}{2}$

Data Source: Smolowitz, 1983 Ages 1, 2: 103 mm covered.
Ages ≥ 3 133 mm covered.

Table 17. Partial recruitment vectors for redfish (Gulf of Maine).

Age (t)	Mean Length* (cm)	Age at Recruitment 3.5	6.5	9.5	12.5	15.5
1	13.9	0.09	0.08	0.00	0.00	0.00
2	16.3	0.30	0.17	0.03	0.02	0.00
3	18.4	0.50	0.23	0.10	0.03	0.02
4	20.3	0.75	0.32	0.18	0.06	0.04
5	22.1	0.91	0.41	0.23	0.09	0.05
6	23.6	0.98	0.50	0.30	0.13	0.09
7	25.0	1.00	0.60	0.38	0.20	0.11
8	26.3	-	0.67	0.42	0.23	0.15
9	27.4	-	0.75	0.50	0.30	0.20
10	28.5	-	0.82	0.55	0.38	0.25
11	29.4	-	0.88	0.61	0.40	0.30
12	30.3	-	0.91	0.68	0.50	0.39
13	31.0	-	0.93	0.72	0.55	0.40
14	31.7	-	0.95	0.78	0.60	0.42
15	32.3	-	0.97	0.82	0.70	0.50
16	32.8	-	0.98	0.85	0.72	0.52
17	33.3	-	0.99	0.87	0.80	0.57
18	33.8	-	1.00	0.90	0.83	0.62
19	34.2	-	-	0.91	0.87	0.68
20	34.5	-	-	0.93	0.90	0.70
21	34.8	-	-	0.95	0.93	0.78
22	35.1	-	-	0.97	0.95	0.79
23	34.4	-	-	0.99	0.96	0.80
24	35.6	-	-	1.00	0.97	0.82
25	35.9	-	-	-	0.99	0.84
26	36.1	-	-	-	1.00	0.85
27	36.2	-	-	-	-	0.86
28	36.4	-	-	-	-	0.87
29	36.5	-	-	-	-	0.87
30-31	36.6	-	-	-	-	0.88
32-33	36.8	-	-	-	-	0.89
34-37	37.0	-	-	-	-	0.90
38-40	37.3	-	-	-	-	0.91
41-50	37.6	-	-	-	-	0.92

$$*\frac{\ell_t + \ell_{t+1}}{2}$$

Data Source: Clark, 1963 Age 3: 80 mm.
Age 6: 109 mm.
Ages 9-15: 132 mm.

Table 18. Partial recruitment vectors for American plaice (Gulf of Maine).

Age	Mean Length (cm)*	Age at Recruitment 1.5	2.5	3.5	4.5	5.5	6.5
1	13.32	0.50	0.10	0.02	0.00	0.00	0.00
2	20.85	1.00	0.50	0.10	0.03	0.00	0.00
3	27.35	-	1.00	0.50	0.15	0.08	0.04
4	32.55	-	-	1.00	0.50	0.21	0.05
5	37.23	-	-	-	0.95	0.50	0.21
6	41.26	-	-	-	1.00	0.95	0.50
7	44.67	-	-	-	-	1.00	0.80
8	47.62	-	-	-	-	-	1.00

*$\frac{\ell_t + \ell_{t+1}}{2}$

Data Source: Smolowitz, 1983

Table 19. Partial recruitment vectors for pollock.

Age	Mean Length*(cm)	Age at Recruitment 1.5	2.5	3.5	4.5	5.5
1	23.7	0.50	0.00	0.00	0.00	0.00
2	36.6	1.00	0.50	0.00	0.00	0.00
3	47.5	-	1.00	0.50	0.00	0.00
4	56.7	-	-	0.98	0.50	0.00
5	64.5	-	-	1.00	0.90	0.50
6	71.0	-	-	-	1.00	0.85
7	76.5	-	-	-	-	1.00

$^{*}\frac{\ell_t+\ell_{t+1}}{2}$

Data Source: Smolowitz, 1983.

Table 20. Results of SSB/R analyses where data are incomplete.

Species	Current SSB/R level (% of maximum)	F	Age at 50% recruitment	Status of stock[1]
Atlantic cod	5-15%	0.6-0.8 (Serchuk, pers. comm.)	First captured: 1 (Serchuk, pers. comm.) Fully recruited: 3 (Serchuk et al. 1979)	Declining
Yellowtail flounder				
Georges Bank	$\leq$11%	$\geq$0.8	Assumed 1.9[2]	Declining
Southern New England	$\leq$ 8%	$\sim$1.0 (Clark et al., 1984)	(Age at 50% recruitment to 5 1/8" mesh)	
American plaice	Unknown	Unknown	First captured: 3 Most of catch: 5 (Sullivan, 1982)	Declining
Winter flounder				
Georges bank	Unknown	Unknown	First landed: 2	Declining
Southern New England	Unknown	Unknown	First landed: 2 (Foster, pers. comm.)	Declining
Pollock	35%	0.26 (Mayo and Clark, 1984)	Partial recruitment vectors[3]	Stable

[1] Anthony, ed., 1985.

[2] Corresponds to 2.4 in knife-edge recruitment analysis (In this analysis, 1.9 marks the beginning of a one-year interval. Halfway through that interval, fish are 50% recruited. See Appendix I.)

[3] Partial recruitment: age 2, 5%; age 3, 34%; age 4, 77%; age 5, 100%) (Mayo and Clark, 1984).

Table 21. Comparison of previous and current results of SSB/R analysis for selected mesh sizes and fishing mortality, percent maximum SSB/R (±1%).

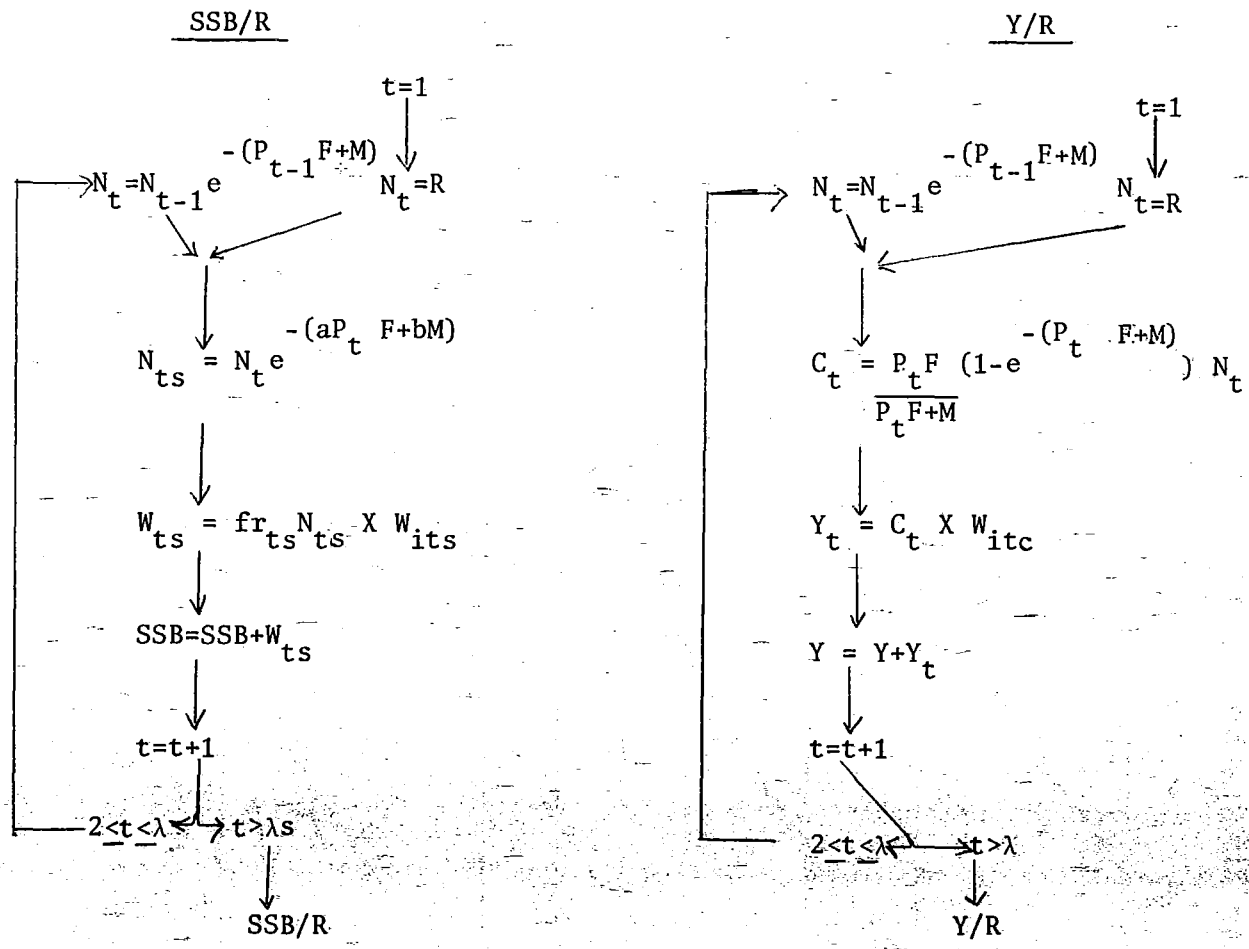
Species	Mesh Size	F	Gabriel et al., 1984	This analysis	Proportion of fishing and natural mortality before spawning
Atlantic cod	6"	0.6	14%	13%	0.167
Haddock	5½"	0.6	24%	21%	0.167
	6"	0.6	29%	26%	
Yellowtail flounder	5-1/8"	0.8	15%	11%	0.33
	6"	0.8	23%	16%	
Redfish	5-1/8"	0.3	35%	17%	0.50
Pollock	5½"	0.26	40%	33%	0.00
American plaice	5½"	0.4	27%	19%	0.25[2]
Winter flounder					
Georges Bank	5½"	0.4	30%	25%	0.25
So. New England	5½"	0.4	37%	40%	0.167[3]

[1]Visually estimated from isopleths.

[2]Proportion of fishing mortality before spawning = 0.21.

[3]Proportion of fishing mortality before spawning = 0.07.

Figure 1. Schematic diagram of calculation of SSB/R and Y/R using Thompson-Bell algorithm (without plus group).



Where R = initial number of recruits in cohort
N_t = number of cohort age t, 1 January.
N_{ts} = number in cohort age t, alive at spawning.
P_t = partial recruitment level at age t.
a = fraction of fishing mortality within year applied before spawning.
b = fraction of natural mortality within year before spawning.
W_{its} = weight of individual age t at month of spawning.
fr_{ts} = fraction mature at age t at month of spawning.
W_{ts} = weight of spawning segment of cohort age t at time of spawning.
SSB = total weight of spawning stock over lifetime of cohort.
λ_s = oldest age in spawning stock.

C_t = Catch in numbers of cohort at age t.
W_{itc} = Average weight of individual fish caught age t.

Y_t = Yield in weight of cohort at age t.
Y = Total yield of cohort over its lifetime.
λ = Oldest age in fishery

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

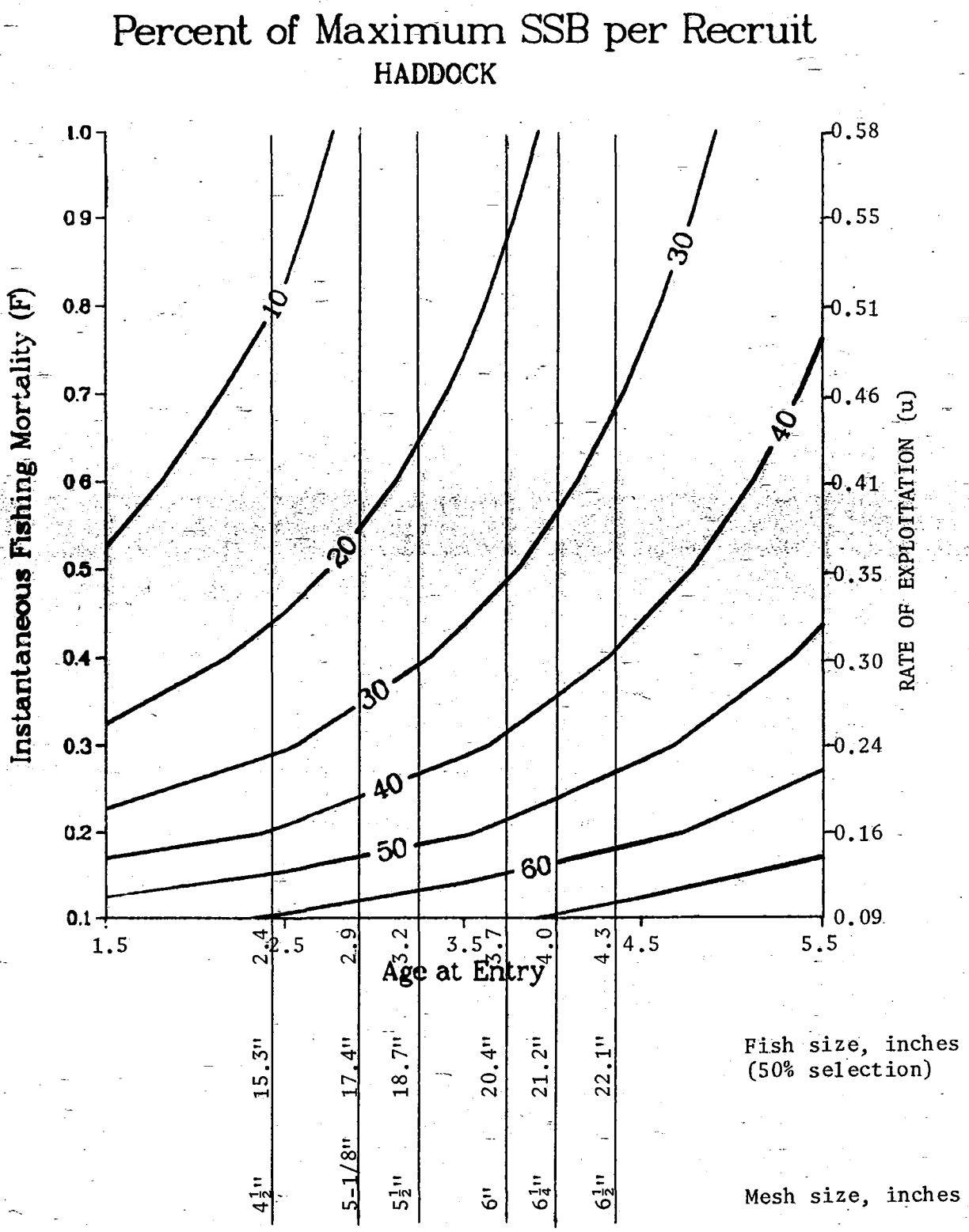


Figure 3. Spawning stock biomass (000's tons) and subsequent recruitment (millions, age 2) for Georges Bank haddock, 1931-1981. The 1963 point (178, 534 tons, 368.8 million recruits) has been omitted. Straight lines represent slopes (inverse) of SSB/R, as a percentage of maximum. Dashed line (14%) is close to current fishing regime of SSB/R. Filled points = 1970-1981.

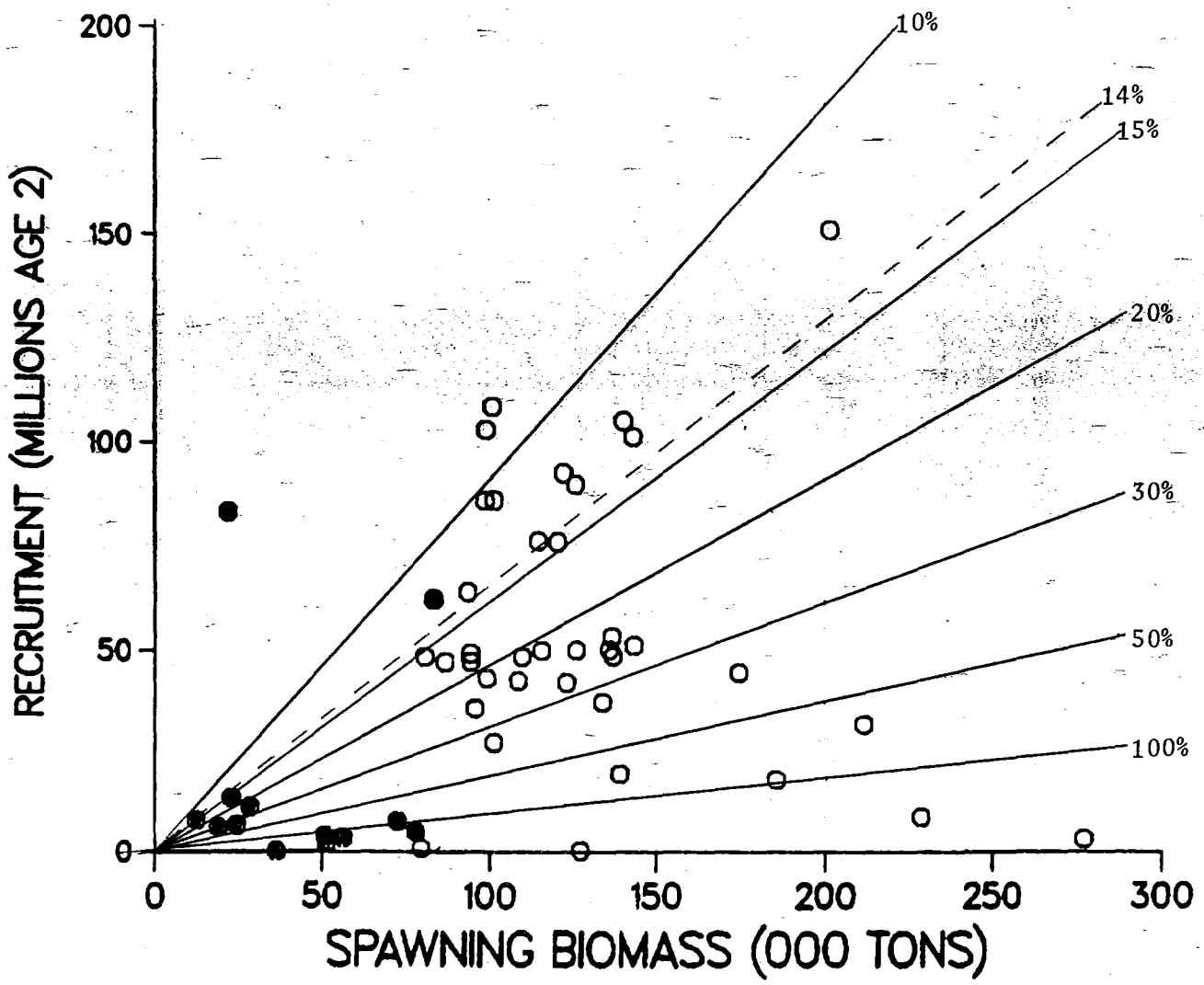


Figure 4. Isopleths of percentage of maximum spawning stock biomass per recruit, Atlantic cod (Georges Bank).

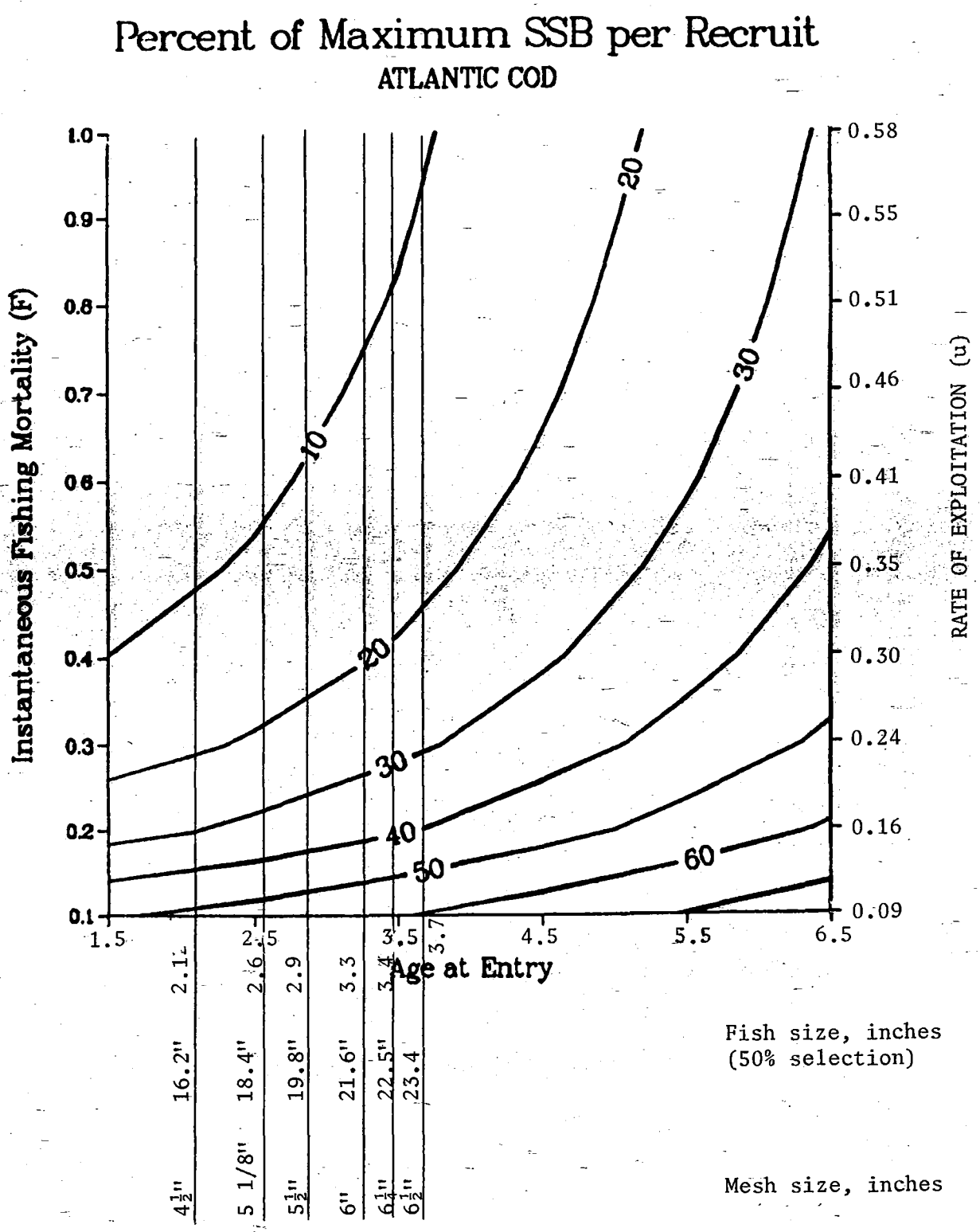


Figure 5. Isopleths of percentage of maximum spawning stock biomass per recruit, yellowtail flounder (Southern New England).

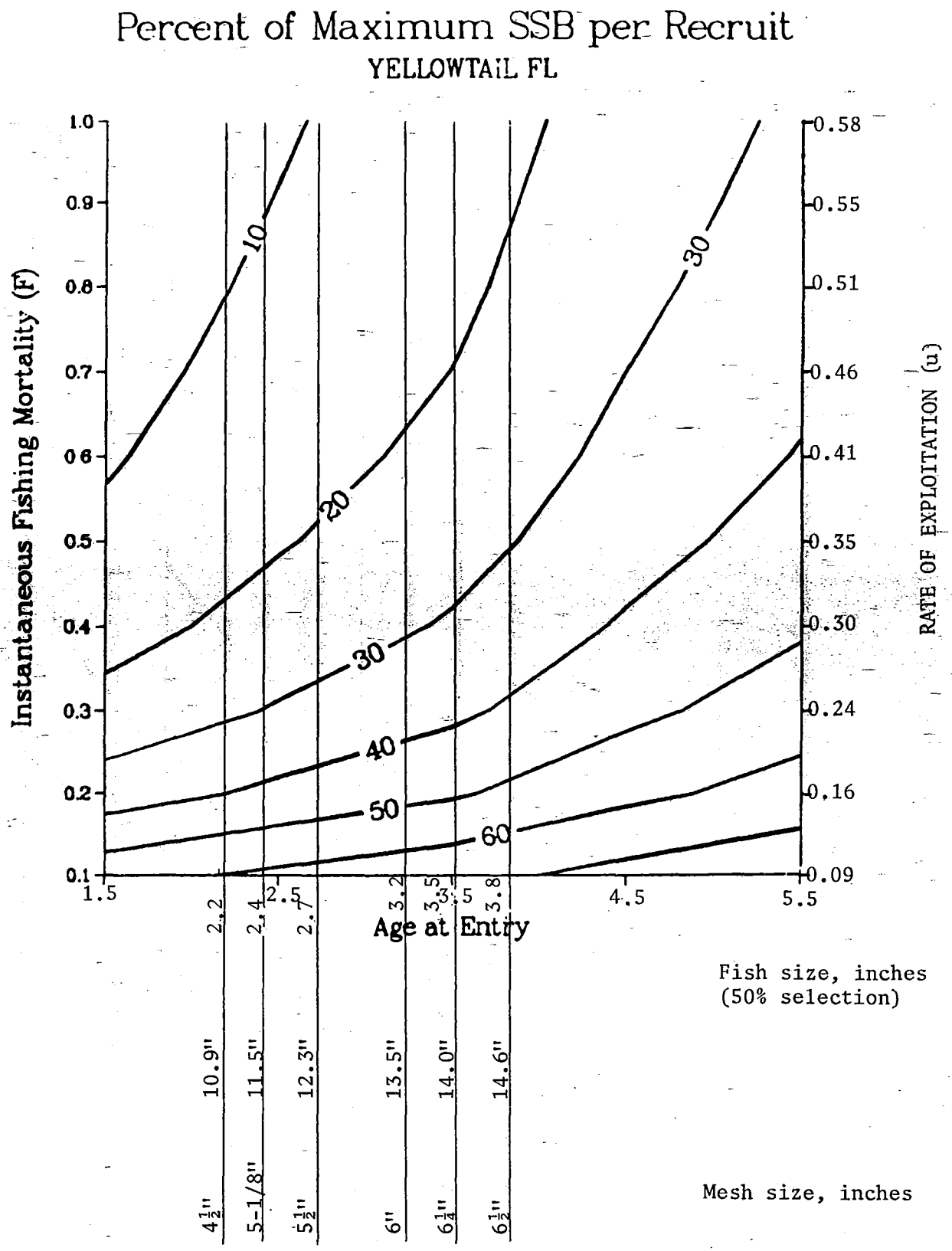


Figure 6. Isopleths of percentage of maximum spawning stock biomass per recruit, American plaice.

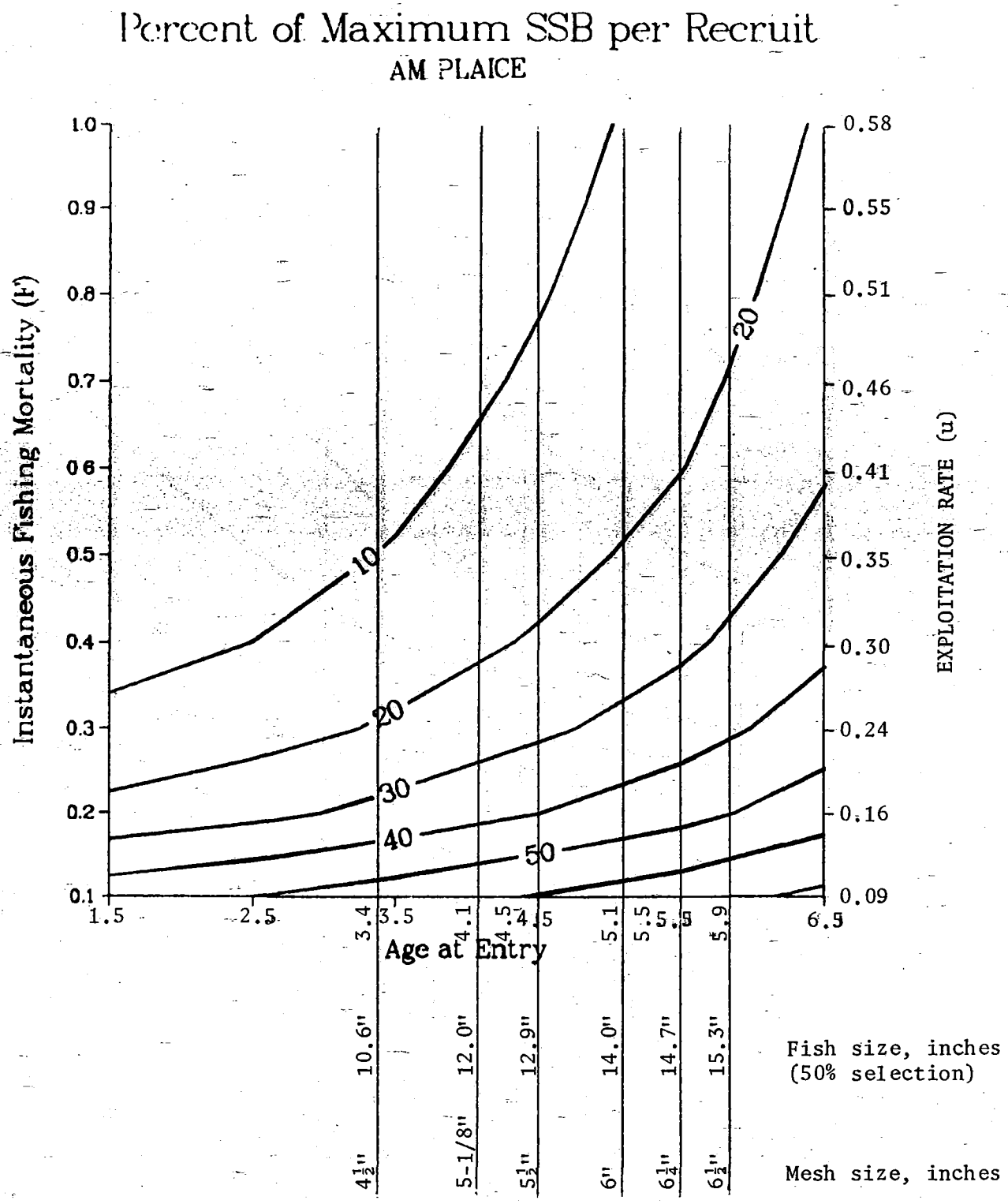


Figure 7. Isopleths of percentage of maximum spawning stock biomass per recruit, winter flounder (Georges Bank).

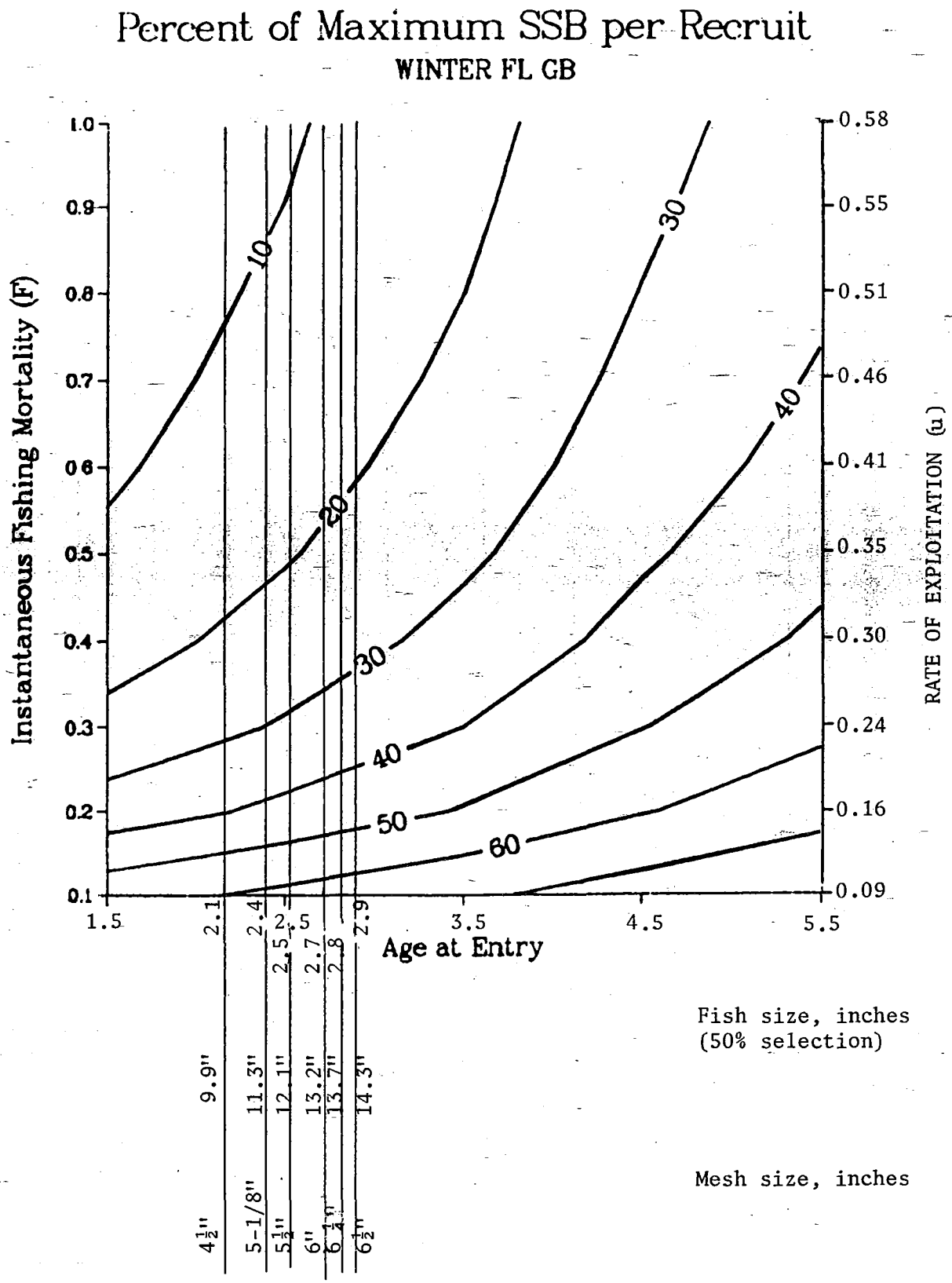


Figure 8. Isopleths of percentage of maximum spawning stock biomass per recruit, winter flounder (Southern New England).

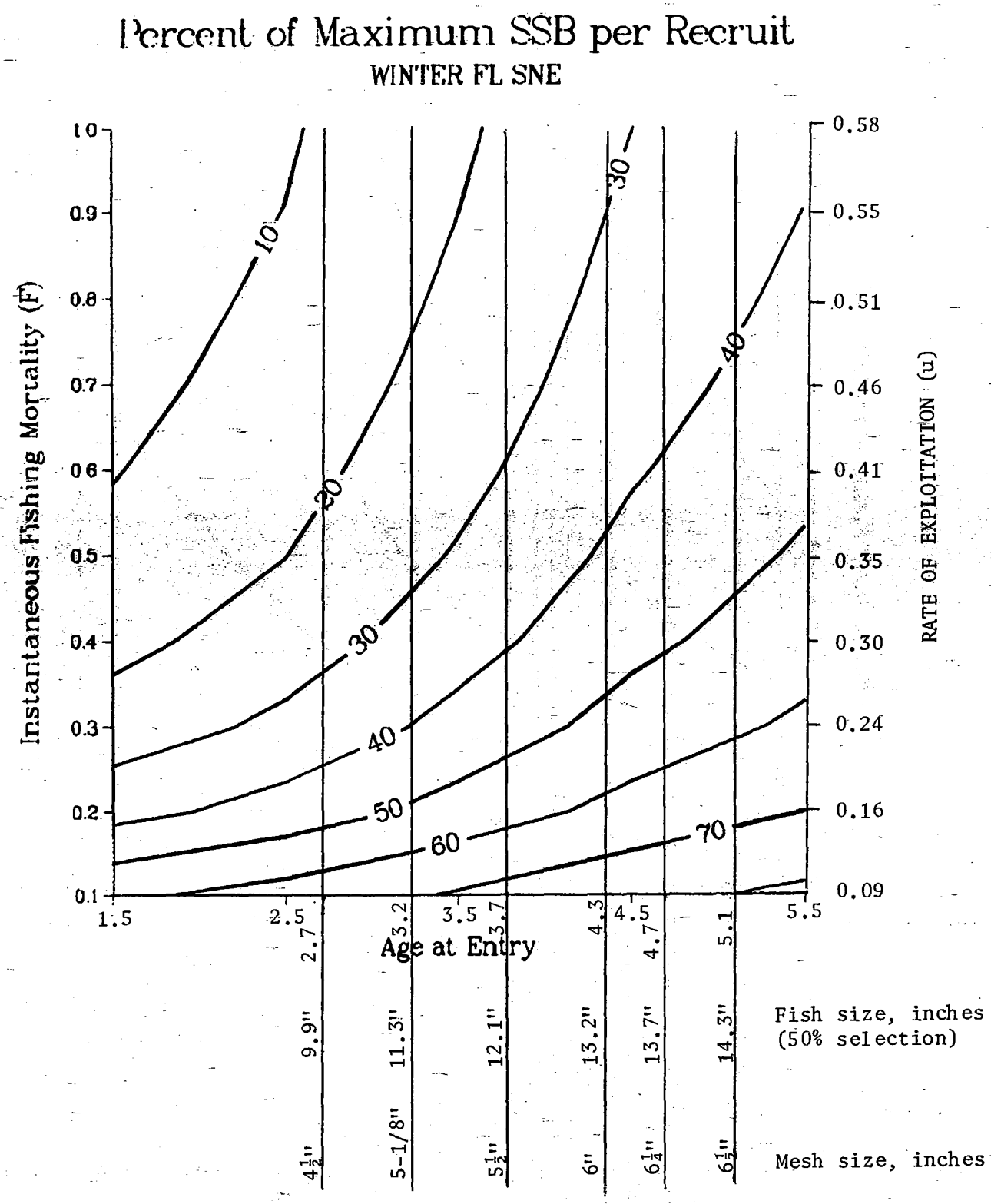


Figure 9. Isopleths of percentage of maximum spawning stock biomass per recruit, pollock.

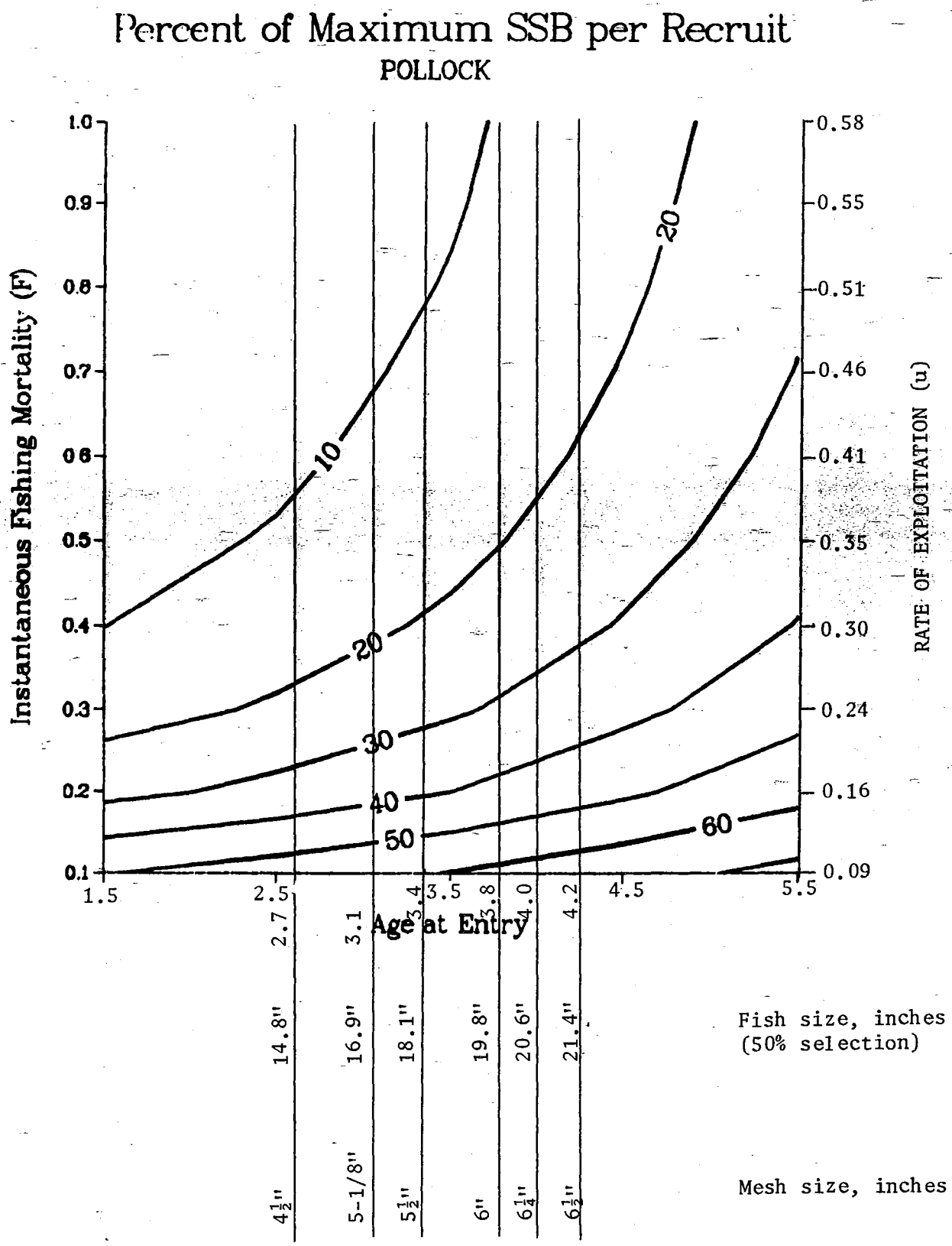


Figure 10. Spawning stock biomass (000's tons) and subsequent recruitment (millions age 2) for Georges Bank haddock, 1931-1981. The 1963 point (178,534 tons, 368.8 million recruits) has been omitted. Straight lines represent regressions of spawning stock biomass vs. recruitment for 1931-1981 (21%), 1931-1959, 1967-1981 (stock size below 150,000 mt) (19%) and 1970-1981 (filled points) (28%). Percentages were calculated as $(SSB/R_{observed}) / (SSB/R_{maximum}) \times 100$, where $SSB/R_{observed}$ = 1/slope of regression and $SSB/R_{maximum}$ = maximum calculated SSB/R with no fishing mortality.

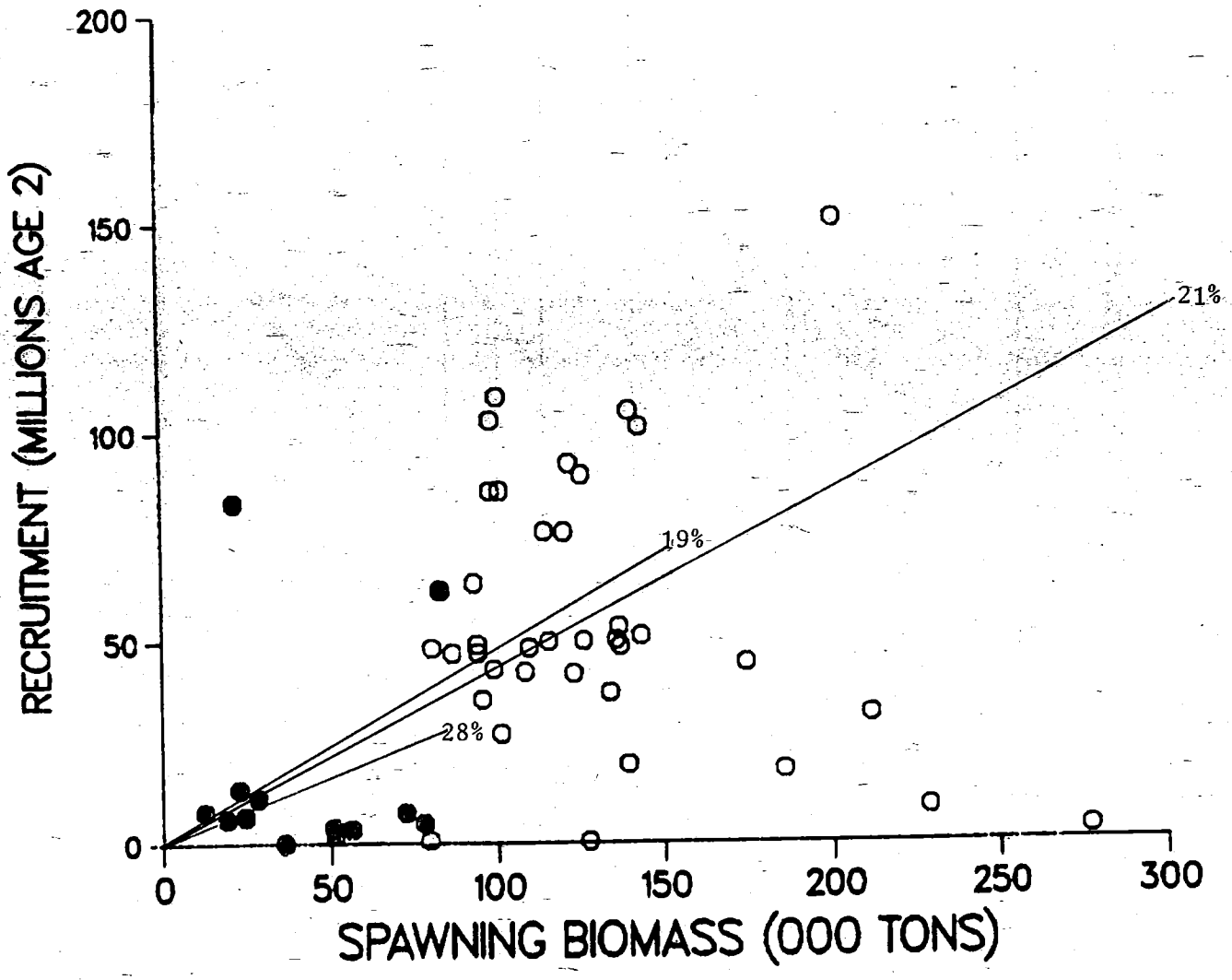


Figure 11. Residual plot for regression of observed spawning stock biomass vs. recruitment, 1931-1981 (R = 0.44 SSB). A residual of 290,589 at stock size of 178,534 mt has been omitted.

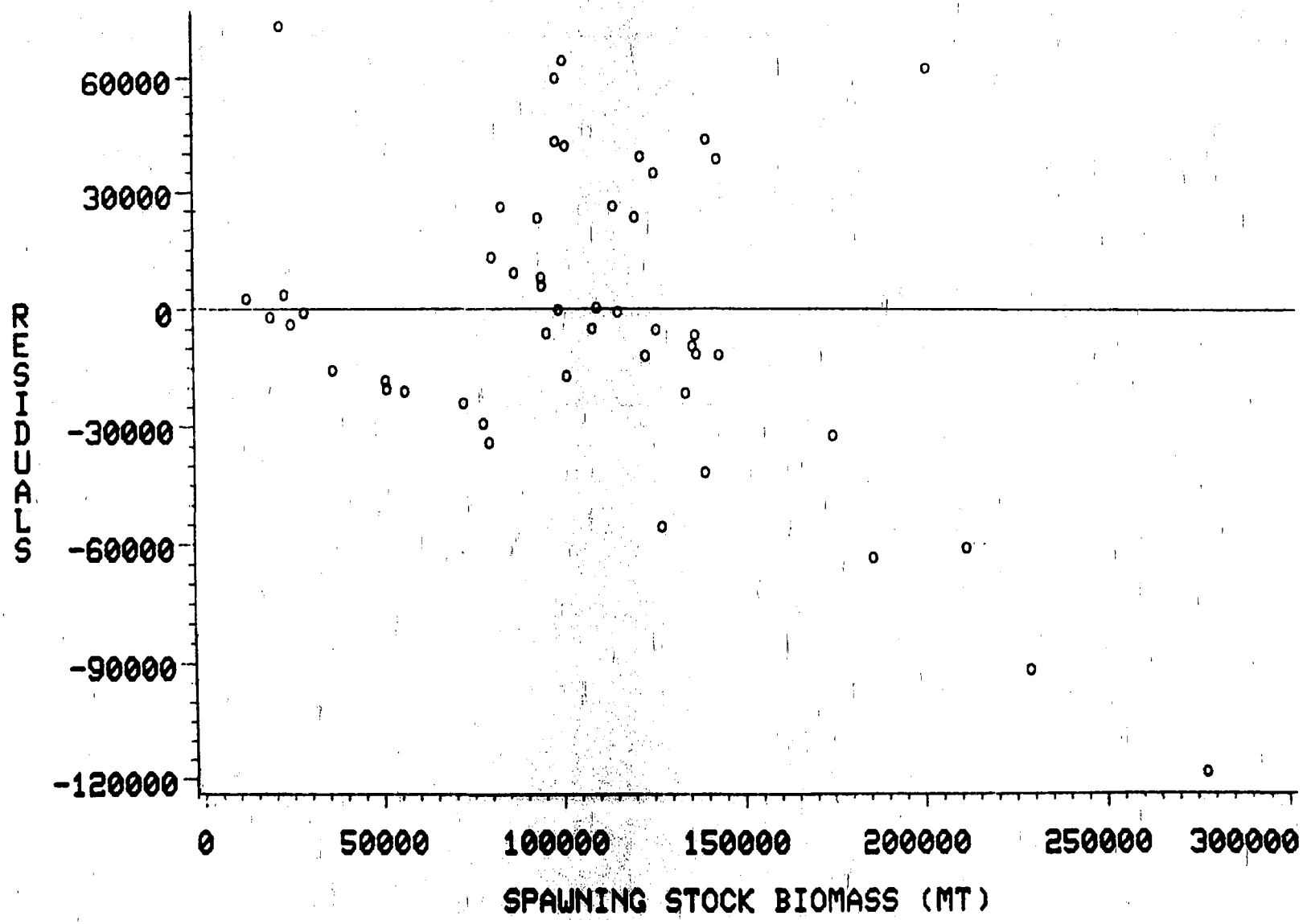


Figure 12. Residual plot for regression of observed spawning stock biomass vs. recruitment in years where stock biomass was less than 150,000 mt, 1931-1959, 1966-1981 (R = 0.48 SSB).

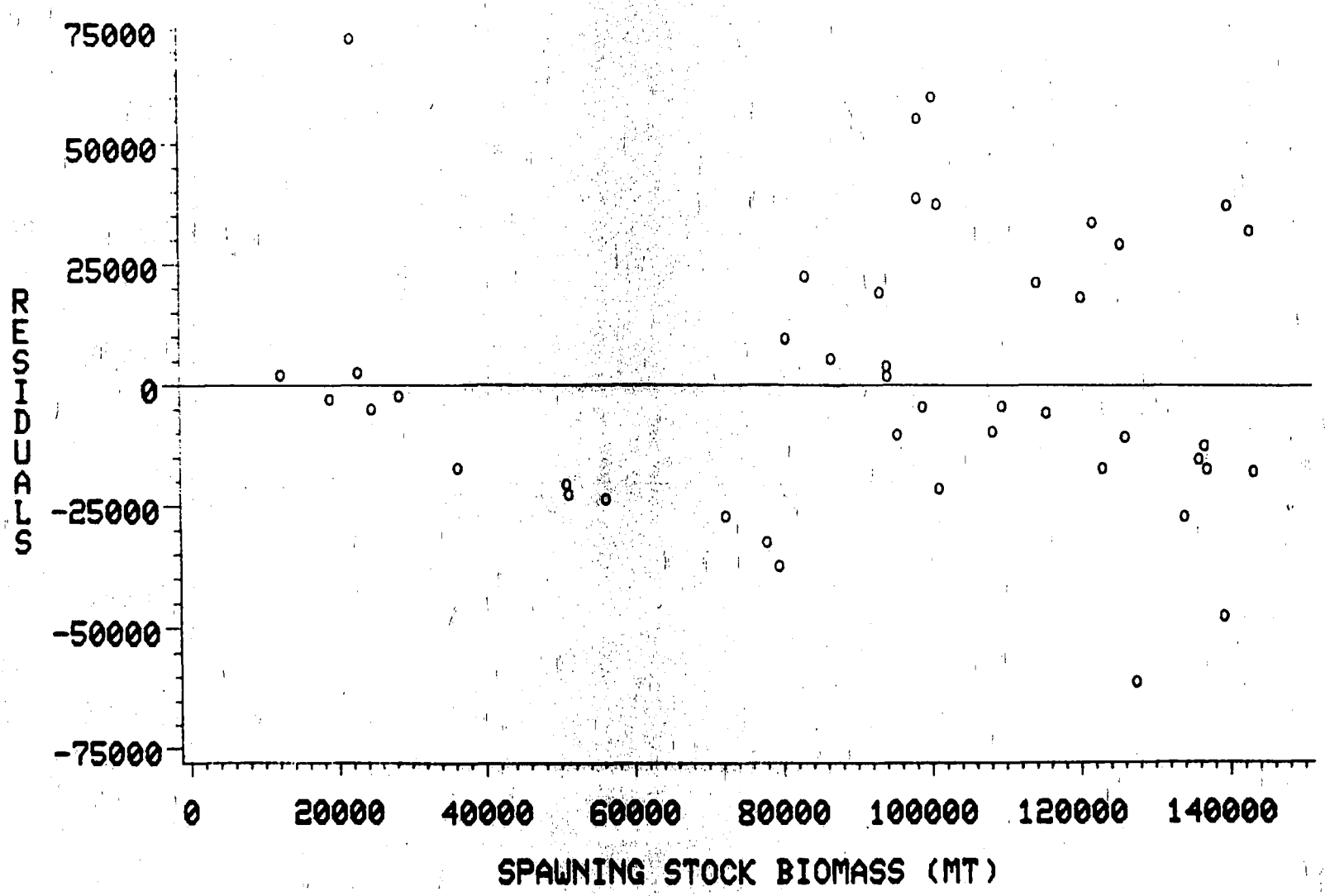


Figure 13. Isopleths of percentage of maximum spawning stock biomass per recruit, redfish (Gulf of Maine).

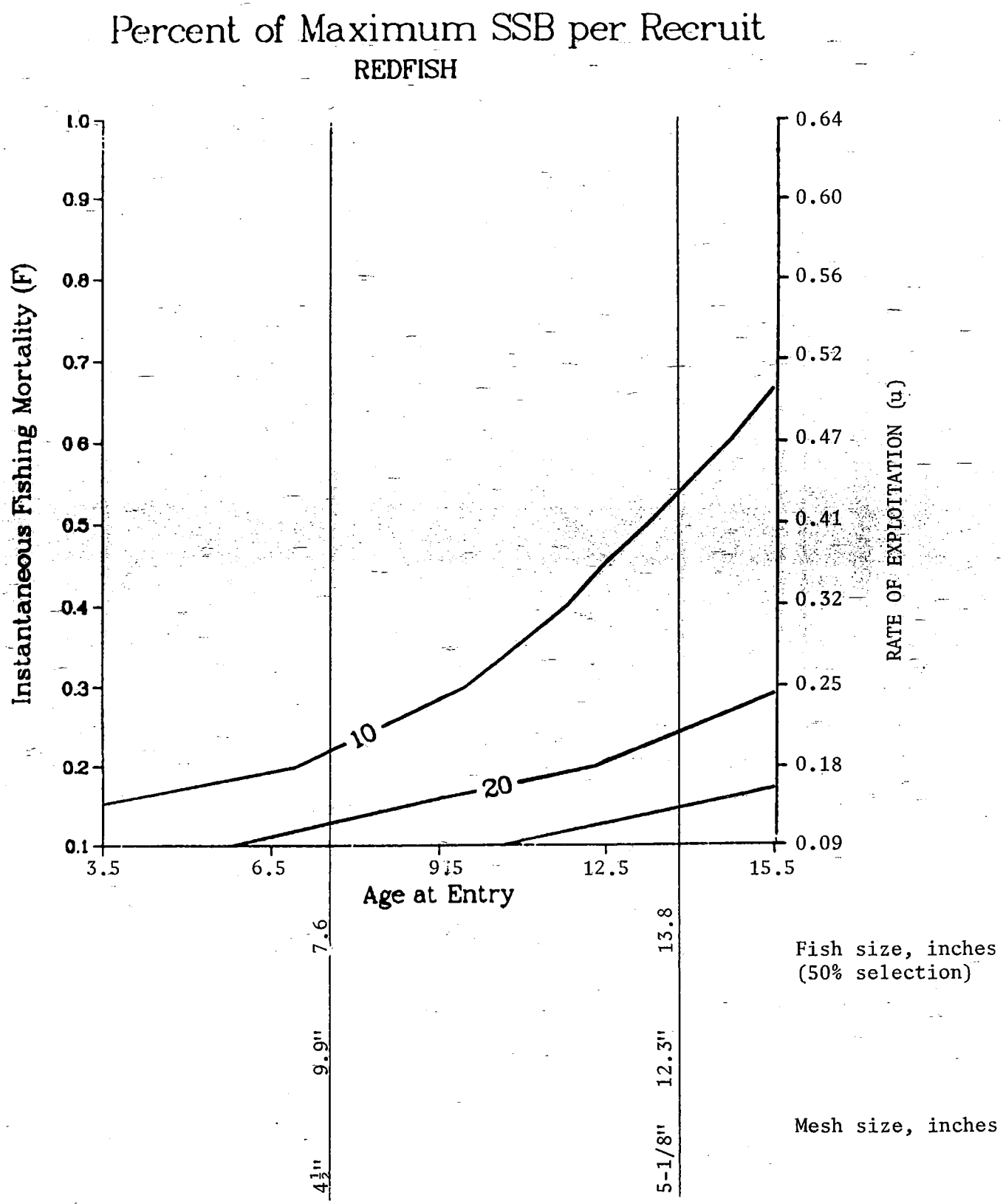
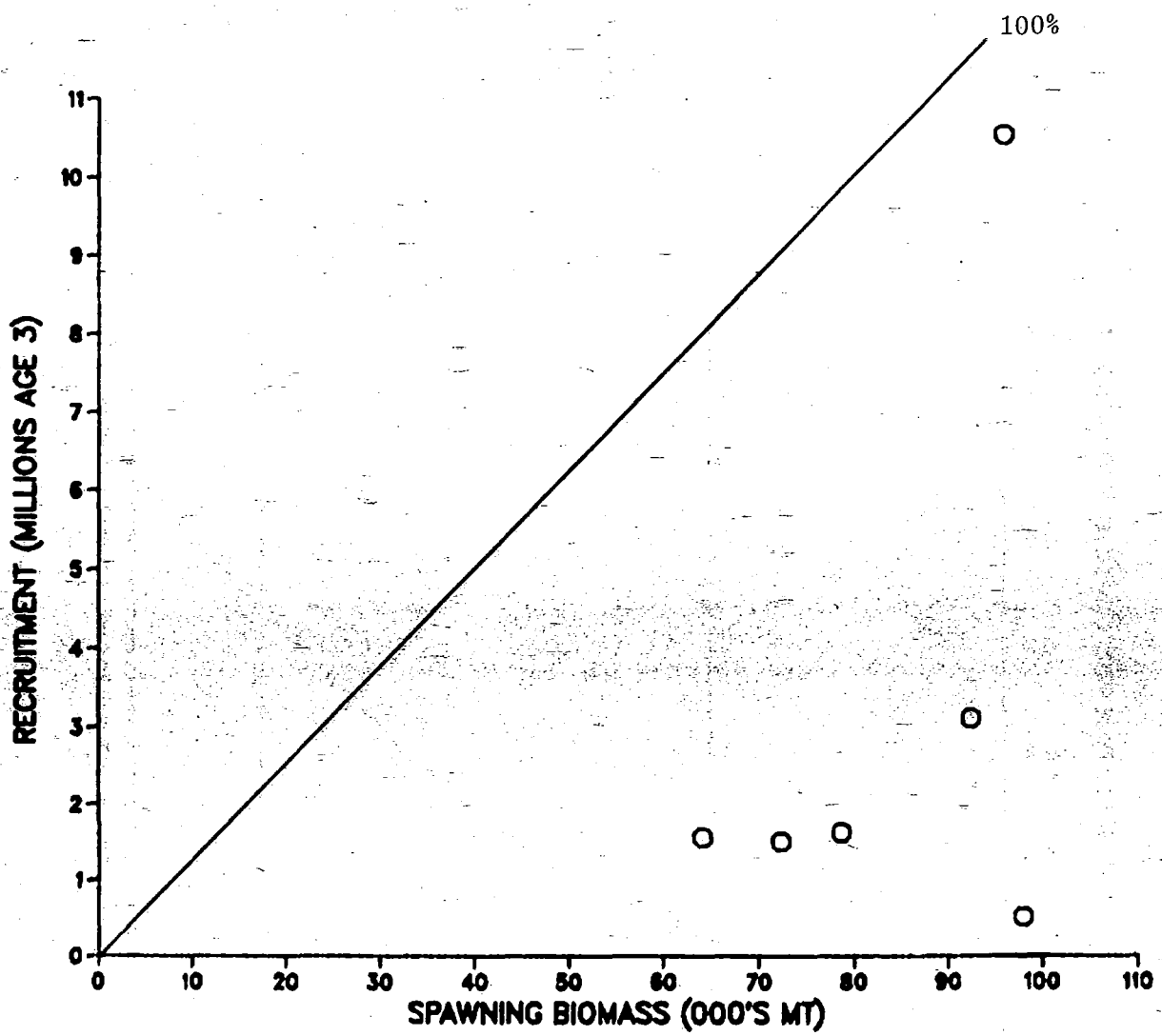



Figure 14. Spawning stock biomass (000's metric tons) and subsequent recruitment (millions, age 3) for redfish, 1969-1975. The 1971 point (100,710 mt, 212.1 million recruits) has been omitted.