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Total sustainable finfish yield from Subareas 5 and 6[1] based on yield per recruit and primary production consideration[2]

by

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Introduction

Present high yields of finfish (average 1969-1971, Subareas 5 and 6: 930 $\times10^3$ MT) from the continental shelf off northeastern United States have been developed by shifting high effort levels across species populations. This fishing strategy, coupled with the overlapping distribution patterns of the species, can result in continuously increasing exploitation rates for each species, fishing pressure being maintained through incidental catches when effort is shifted to other species. The consideration of total yield from the total stock of available species is, therefore, appropriate. The total species complex must be treated as a unit stock because the increasing effort necessary to take less available and less abundant species in effect generates increased probability of capture for the entire complex subject to exploitation. A yield per recruit (Beverton and Holt, 1957) approach to this concept and consideration based on primary productivity are discussed in this paper.

Yield Per Recruit

The parameters necessary for yield per recruit analysis using Beverton's (1963) modified form of the yield equation are tabulated (Table 1) for the major species: the gadoids, flounders, redfish, herring and mackerel. The values listed are estimates after taking into account the possible ranges of the various parameters. Available sources of data are cited. M/K ratios largely ranged between 0.75 and 3.50; L_c/L_∞ ratios ranged from 0.35 to 0.60.

Inspection of the yield per recruit functions in Beverton and Holt (1966) indicate that at least a 60% exploitation rate is necessary to obtain maximum sustainable yields per recruit for most species. This means that most species can be expected to be reduced to less than 25% of their initial abundance to achieve the maximum. The hakes seem to be a group without a relative maximum in yield per recruit due to their apparently high natural mortality.

Total Catch and Effort Data, Subareas 5 and 6

A curve of sustainable yield as a function of fishing effort is developed using the total catch and effort data from Subareas 5 and 6 and the yield per recruit function. Catch per effort may be expected to decrease at a decreasing rate as fishing effort increases (see, e.g. Gulland, 1961). MSY's should be at stock size less than one-half of maximum size as predicted by the constant parameter, yield per recruit model and also for total yield by many stock-recruitment relationships (Ricker, 1958).

Catch/effort data (Table 2) do not exhibit a consistent trend of decrease with effort, but rather a period of approximately constant catch/effort from 1961 to 1964, preceding the remaining years of declining catch/effort.

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[1] Stat. Area 6

[2] Revision of Sp.Mtg.Res.Doc. 73/10 presented to Special Commission Meeting, FAO, Rome, January 1973.

The level trend of the first period can be interpreted as due to "learning", development of technology, and the shifting of fishing effort to major species stocks that had previously been relatively unaffected by the overall fishery. It is highly unlikely that average biomass (proportional to catch/effort) remained the same during those years. Grosslein (1972) has presented evidence, based on groundfish surveys, of the overall decline of the stocks throughout the last decade. He shows that most of the major stocks had declined by 50% or more with some stocks such as herring and haddock declining by 90%. The decline in catch/effort beginning in 1965 is an indication that the entire complex of available species had by then become subject to substantial exploitation by a fully developed fishery technology. This decline is, therefore, taken as being a valid index of the reduction in stock size of the total species complex, treated as a unit stock. Though the 1971 catch/effort data point is relatively high considering that an earlier, larger increase in effort from 1968 to 1969 (relative to the increase from 1970 to 1971) did not produce as great a catch/effort value, it was still substantially less than the values of the mid 1960's; this may reflect the rapid growth of the mackerel fishery beginning in 1969, again involving the development of new fishery technology. Only catch/effort data after 1964 were used; i.e., considered as being proportional to total stock size.

Curves of relative stock size from the yield/recruit model (Beverton and Holt, 1966) were fitted by assuming that the average catch/effort for 1970 to 1971, about 6.5 MT/day, reflected a stock size that was one-third of the maximum stock size, a conservative estimate according to Grosslein's data. This assumption defines one point for fitting the curves; i.e., the catch/effort at maximum stock size. Fitting a curve is then essentially a matter of calibrating the effort scale so as to place the theoretical curve closely through the observed points. Two such curves (Figure 1), for $M/K = 0.5$, $c = .34$, and for $M/K = 4.0$, $c = .60$ to cover the species types expected, were constructed; they are similar in shape and indicate how the mean curve for the total species complex should pass through the data points. The fit was obtained by calibrating the effort scale such that $F/M = 1$ at 115 $\times 10^3$ days fished.

An average of the catch/effort values defined by the two curves was taken as defining the expected curve representing the species complex considered as a unit stock. This mean curve has the same general shape as the parent curves and affords a reasonable fit to the data. In general, the catch/effort in years during which effort had increased lie above this curve as would be expected since the values for those years are likely over-estimates of equilibrium.

The average values of catch/effort between the two fitted curves multiplied by the corresponding effort, gave a yield curve (Figure 2) that seems to approach asymptotically an MSY of about 950,000 MT. Assuming that to be the upper limit, it may be noted that 90% of this MSY, or 885,000 MT, is obtainable at approximately the 1968 level of fishing effort. These conclusions require that recruitment remains unaffected at the necessary levels of fishing effort. There is in fact a high probability of reduced recruitment, generated within individual species stocks, at the lower stock densities that would result from regulating fishing mortality to maximize yield per recruit. Such reduced recruitment would ultimately bring a decline in sustainable total yield.

MAXIMUM FISH PRODUCTION AND PRIMARY PRODUCTION

An estimate of maximum fish production, i.e., the MSY for the combined fish stocks, can also be obtained by extrapolating the primary productivity values for the waters of the Northwest Atlantic continental shelf. Charts based on the work of Steeman-Nielsen (1954) indicate primary productivity between 100 and 200 g C/m^2/year in the mid-Atlantic Bight and between 200 and 400 g C/m^2/year in the Gulf of Maine; an average of 250 g C/m^2/year, rather higher than the overall area-weighted average, is used in this paper. This is considerably greater than the 100 g C/m^2/year estimated by Ryther (1969) for average coastal productivity of the world ocean. Expanding that value over the area of Subareas 5 and 6, about 260 $\times 10^3$ km^2, and using a 10:1 protoplasm to carbon ratio, 650 x10^6 MT primary production was obtained. Although the major fish species of commercial importance here feed to a large extent upon invertebrates, this annual primary production must be taken through 2.5 to 3 trophic steps, (Ricker, 1969) in the conversion to fish production. He considered three steps necessary after accounting for within-trophic-level feeding, i.e., the larger zooplankton that feed carnivorously upon nannoplankton and the predation by larger fish upon fish larvae, juveniles and smaller fish species. He further estimated the transfer efficiency of production (P) between trophic levels (n), i.e., P_n/P_{n-1}, to be about .10 to the herbivore stage and about .15 between subsequent carnivore stages.

The small magnitude of the transfer efficiencies mean that large differences in predicted fish production will result from small changes in trophic steps. Thus, for example, estimates of annual fish production lie between 650 x10^6 MT x .10 x .15 x .15 = 1.5 x10^6 MT (3 steps) and 650 x10^6 MT x .10 x .15 x .387 = 3.8 x10^6 MT (2.5 steps). Rvther (1969) concluded that three trophic steps were involved in the food chain to fish production in coastal waters if herbivorous fish were excluded. Perhaps a mean of 2.75 steps would be more correct, but still likely conservative. Then annual fish production would be 650 x10^6 x .10 x .15 x .240 = 2.3 x10^6 MT.

Production at the fish level cannot all be harvested on a sustainable basis because of availability factors, natural mortality, and the necessity of maintaining a reproducing stock whose production through growth remains unimpaired. Dickie (1972) suggested that the ecotrophic coefficient, F/Z, would not exceed .50 in nature; Gulland (1970) also used that value to estimate sustainable yields for a variety of world fisheries. However, we may assume here that an efficient fishery should be able to harvest about 70% of the production as did Ricker (1969). It was mentioned above that yield per recruit considerations suggests that most stocks could be exploited at greater than the 60% level.

Multiplying then by 70%, we obtain between 1.0 x10^6 MT for 2.5 steps and 2.7 x10^6 MT for 3 steps to available production, with a mean of 1.6 x10^6 MT resulting from the 2.75 step conversion. The 2.7 x10^6 MT would seem too high, for to imply that present catches can be nearly tripled is not consistent with observations that stocks as a whole have declined about 60% (Grosslein, 1972), implying in turn that present catches are close to the MSY level. These extrapolations are tenuous but they again suggest that the catch from Subareas 5 and 6, over one million MT in 1971, is close to or beyond the upper limit of sustainable harvest.

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Table 1. Mean values, species population parameters.

Species	K	L_∞	M	M/K	L_c/L_∞	Data Source
Cod	.16	115	.20	1.25	.40	Brown and Heyerdahl (1972)
Pollock	.19	107	.25	1.32	.37	
Haddock	.28	73	.30	1.07	.52	Beverton (1965)
Silver hake	.12	72	.40	3.33	.35	Anderson (1972)
Red hake	.20	51	.70	3.50	.45	Richter (1972)
White hake	.20	<51	.70	3.50	.45	
Spotted hake	>.20	41	>.70	3.60	.56	
American plaice	.15	70	.20	1.33	.43	Pitt (1972)
Grey sole	.20	64	.20	1.33	>.43	
Yellowtail flounder	.34	50	.25	.74	.52	Lux and Nichy (1969)
Winter flounder	.40	44	.30	.75	.57	
Sand flounder	.40	43	>.30	.75	.57	
4-Spot flounder	>.40	33	>.30	.75	>.57	
Spiny dogfish	.15	124	.10	.49	.40	Holden (1968; Jensen (1966)
Redfish	.12	40	.20	1.67	.52	Kelly and Wolf (1959)
Sea herring	.35	34	.25	.70	.60	Anthony (1972); Beverton (1963)
Mackerel	.40	55	.20	2.25	.45	Anderson (1973)

Table 2. Total catch and catch per standardized effort, 1961-1971, ICNAF Subareas 5 and 6.

Year	Standardized Effort (days fished)	Catch (MT)	Catch/Effort
1961	43,710	342,998	7.85
1962	67,764	534,295	7.88
1963	78,121	585,952	7.50
1964	97,466	759,523	7.79
1965	103,550	919,443	8.88
1966	114,305	934,633	8.18
1967	95,845	723,027	7.54
1968	121,712	840,769	6.91
1969	163,938	942,244	5.75
1970	127,083	782,690	6.16
1971	154,415	1,065,713	6.90

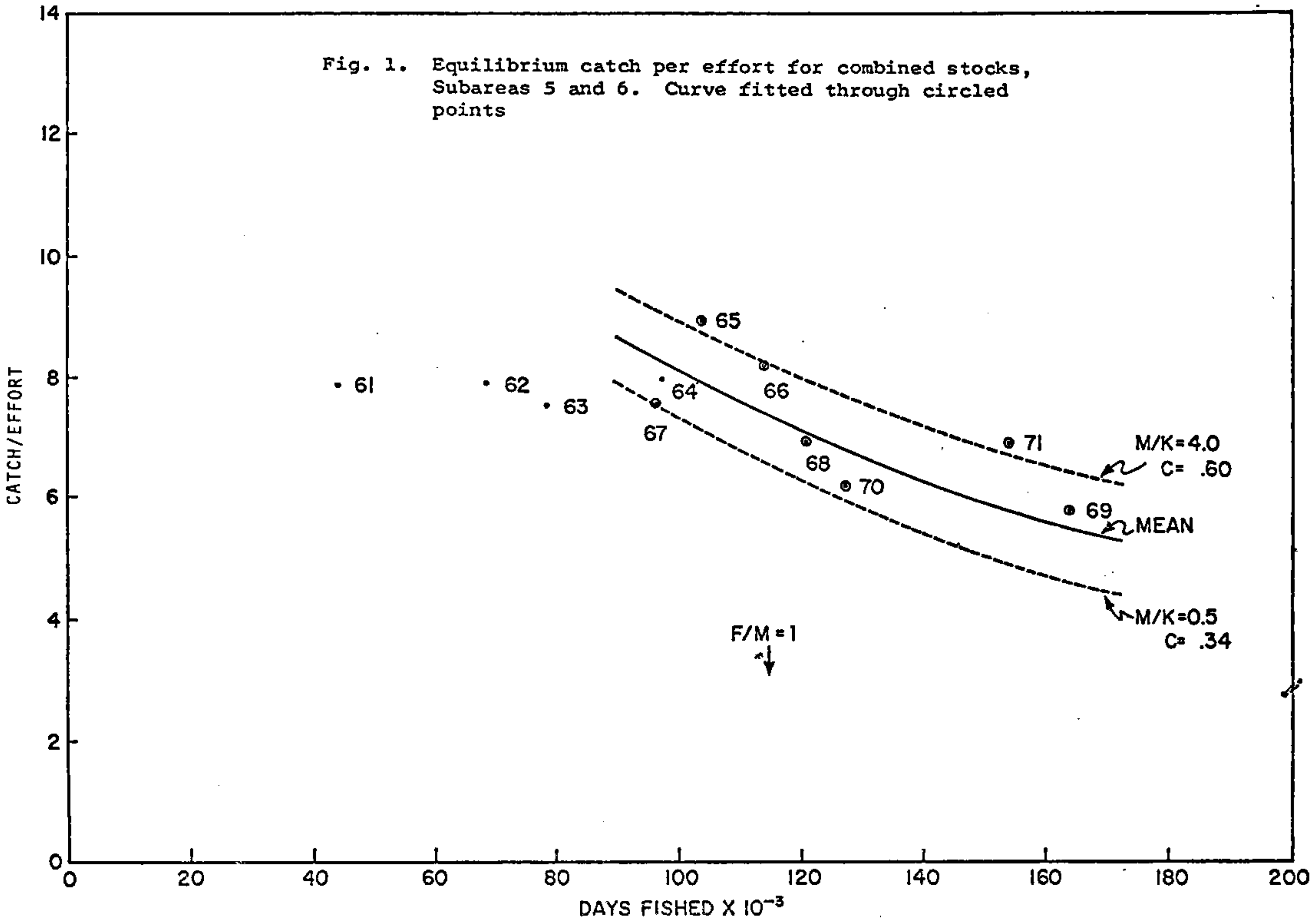

Fig. 1. Equilibrium catch per effort for combined stocks, Subareas 5 and 6. Curve fitted through circled points

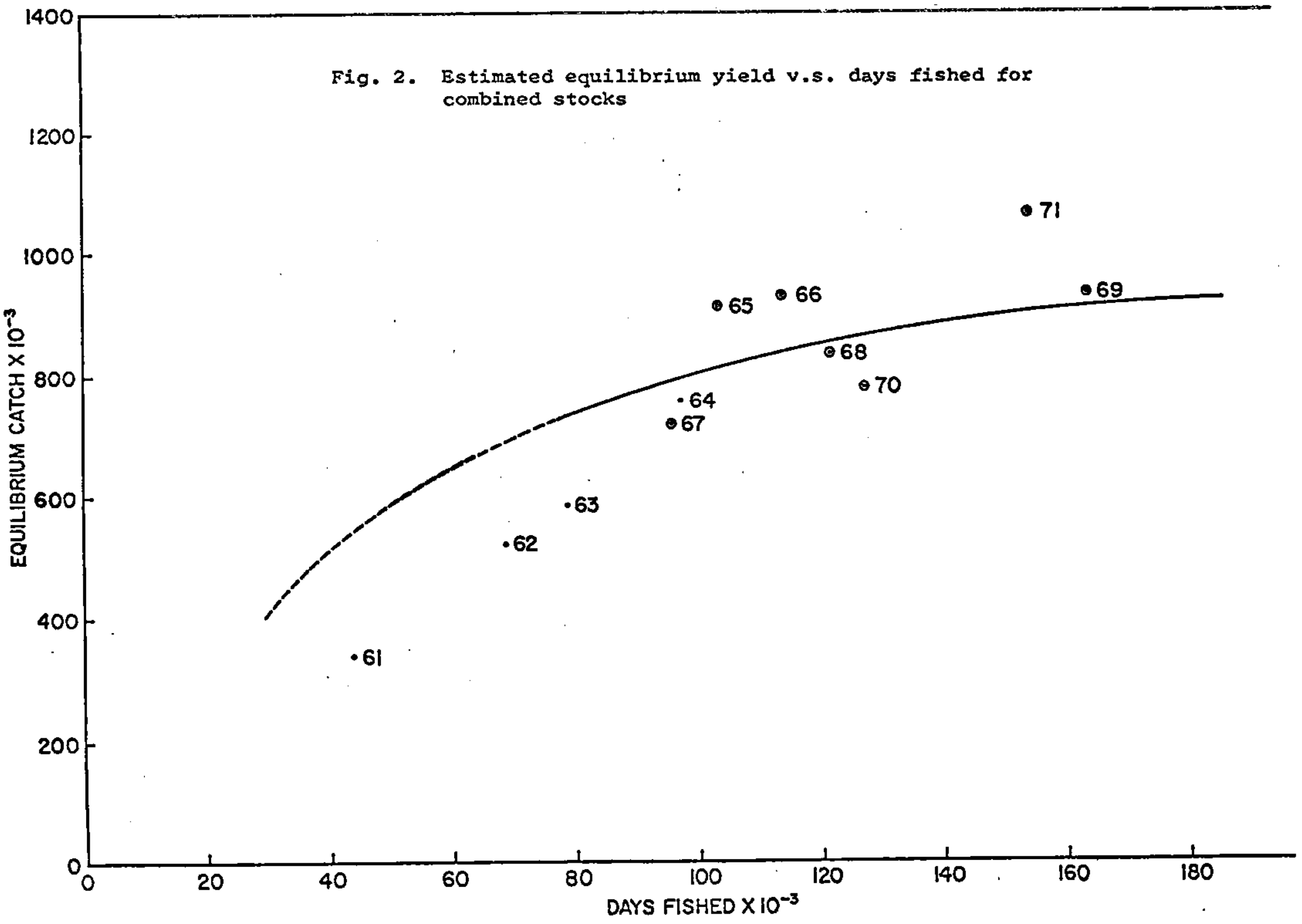

Fig. 2. Estimated equilibrium yield v.s. days fished for combined stocks