

International Commission for



the Northwest Atlantic Fisheries

Serial No. 3511
(D.c. 5)

ICNAF Res.Doc. 75/32

ANNUAL MEETING - JUNE 1975

A system simulation of the Atlantic mackerel fishery in ICNAF
Subareas 3, 4, and 5 and Statistical Area 6;
with special reference to stock management

by

P.F. Lett, W.T. Stobo, and W.G. Doubleday
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Introduction

The international commercial catch of Atlantic mackerel (*Scomber scombrus*) from ICNAF Subareas 3, 4, and 5 and Statistical Area 6 increased from 6,831 m.t. in 1961 to 419,306 m.t. in 1973 (Anderson MS 1975_a). The estimated value of F in 1973 was 0.60; the recommended level by the ICNAF ad hoc mackerel working group (Redbook 1973, Part 1).

A stock recruitment relationship was derived for Atlantic mackerel which spawn in the Gulf of St. Lawrence (Lett et al. MS 1975_b). Using the determined relationships, a system simulation was constructed to investigate the effects of different levels of fishing intensity on stock biomass, catch and recruitment. These effects are examined when temperature is held constant and treated as a stochastic variable.

It is anticipated that the validity of maximum sustainable yield being determined at a fishing mortality of 0.6 could also be investigated. Furthermore, a test is made of Ricker's (1963) hypothesis that small increases in effort beyond maximum sustainable yield cause rapid declines in stock biomass, recruitment, and catch.

Structure of the Model

The program is initialized by the number, mean weight, and selection at each age class between 2⁺ and 11⁺. Although numbers at age can remain arbitrary, mean weights and selection were adapted from the work of Anderson (MS 1975_a). The growth of the fish remained constant, not responding to either density dependence or temperature.

The catch equation:

$$(1) \quad Y_a = \frac{N_a \times \bar{W}_a \times [1 - \text{EXP}[-(F \times \psi_a + M)]] \times (F \times \psi_a)}{(F \times \psi_a) + M}$$

was used to determine catch at age (Beverton and Holt 1957). Y_a is the catch of fish of age a , N_a is the numbers at age a , \bar{W}_a is the mean weight, ψ_a is the selection, and F and M are fish and natural mortality rates, respectively. Natural mortality was assumed to be 0.3 (Redbook 1973, Part 1), while the level of F is the option of the user. The catch at each age was accumulated over the number of ages involved.

The number of individuals in each age class was determined at the end of each year by the following relationship,

$$(2) \quad {}_t N_a = {}_t N_a \times \text{EXP}(-F \times \psi_a + M)$$

where N_a was accumulated over all year classes to determine the final population size.

The biomass of individuals (B_a) in each age class was calculated by

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The biomass of the population was then used to determine an index of the egg production of the entire mackerel biomass of individual 2⁺ and over. In the simulation the total biomass, determined by Anderson (MS 1975_b) was assumed to spawn in the Gulf of St. Lawrence. However, preliminary analysis indicates that perhaps only 50-60% of the total biomass of the stock in ICNAF areas 3, 4, 5, and 6 actually spawn in the Gulf of St. Lawrence (P. F. Lett and R. G. Halliday

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unpublished data). This estimate is based on the fitting of the relationship among herring year class size, catch of herring larvae and the total pelagic biomass (Lett et al. MS 1975_p). When mackerel stock biomasses between 50-60% of the total biomass were used the best of the relationship was obtained.

The equation used to determine the catch of mackerel eggs/100,000 cu m of water strained (Eg) was

$$(4) \log(Eg+1) = 1.63 \times 10^{-2} B - 1.25 \times 10^{-5} B^2 \quad (\text{Lett et al. MS 1975}_p) \text{ where } B = 10^{-6} \times B_{TOT}.$$

The number of eggs was used to determine larval survival 30 days after deposition by the following equation:

$$(5) \log(L_R+1) = 0.412 \log(Eg+1) + 0.142 \quad (\text{Lett et al. MS 1975}_p) \text{ where } L_R \text{ is the catch of larvae/100,000 cu m of water strained.}$$

Larval survival interacted with temperature to determine the year class size of mackerel. The following equation was used to predict the recruitment of 1⁺ mackerel:

$$(6) \quad Y_R = 117.3 + 71.569 \times T_p \times \log(L_R+1)^2 \quad (\text{Lett et al. MS 1975}_p).$$

T_p is the maximum mean monthly temperature at Grande-Riviere on the western shore of the Gulf of St. Lawrence (Lauzier MS 1969) which is well correlated with temperatures in the Gulf (Lett et al. MS 1975_p). No trends were found in the maximum mean monthly temperature, therefore it was treated as a normally distributed random variable with mean 13.85 and standard deviation 1.26°C. The standard deviation was multiplied by the standard deviation determined from a standard normal function and added to the mean temperature.

The year class size was multiplied by 10⁶ lagged for two years and subject to an annual natural mortality of 0.3. At the end of each year the entire population was updated so that ${}_{t+1}N_{a+1} = {}_tN_a$. These fish returned to the start of the simulation to represent the subsequent population.

Results and Discussion

Variations in recruitment were most pronounced when there was no fishing (Fig. 1). These fluctuations, with a period of 6 years, were also present when temperature was

treated as a stochastic variable, although the magnitude of the peak year class of 1^+ fish at the end of the year varied considerably (Fig. 2). When there was no fishing effort, the stock biomass cycles around the right-hand side of the stock recruitment curve (Lett et al. MS 1975_b) producing the simulated wide variations in year class size.

Anderson (MS 1975_b) states that the fishery was made up of two strong year classes during the period 1968-72 when the total effort was expanding. This agrees with the observation that recruitment peaks are usually made up of two strong year classes when fishing intensity is low (Fig. 1, 2).

In accord with these findings, Ricker (1954, 1958) indicates that when B and C reproduction curves, skewed versions of the normally distributed mackerel reproduction curve, are used to predict recruitment the stability of catch also increases with fishing effort. However, the response of the variance in mackerel biomass to fishing is somewhat different from that noted for cod (Lett et al. MS 1975_a). Since the transition from cod larvae to juveniles shows a density dependent mechanism with a descending right-hand limb, declines in larval abundance due to reduction in stock biomass lead to greater fluctuations in biomass. The transition of mackerel larvae to juveniles is typical for a pelagic fish with a flat right-hand limb, thus reduction in biomass cause no improvement to year class size. Fish species which show increasing density dependence with higher larval abundance are less stable but more robust since movement down the left-hand side of the egg production curve can still lead to the production of stronger year classes. However, once the maximum of the juvenile, larvae relationship is reached, these stocks will also decline with a reduction in variance.

At an $F=0.3$ the recruitment pattern represents a damped harmonic oscillator, taking ≈ 20 years to reach equilibrium (Fig. 1). These oscillations are also present when temperature is treated as a stochastic variable. However, the

system never really reaches equilibrium, but fluctuates around a mean value. As the fishing mortality increases the level of recruitment also increases. This is achieved by an increase in egg production (Lett et al. MS 1975_b). Figure 2 also demonstrates the effect of reducing fishing mortality from 0.8 to 0.3. The recovery of the fishery takes = 25 years, with stability being achieved in 40 years. Furthermore, when F was reduced to 0.0 from 0.8, recovery took = 12 years.

At a fishing mortality of 0.6, recruitment was maximized at a value of 3×10^9 fish. This was approximately twice the recruitable year class size, of 1^+ fish at the end of the year when $F=0.0$. A recruitment failure occurred when $F=0.9$, the decline to a minimum value taking = 30 years.

The simulated patterns in mackerel recruitment and subsequent catch were quite similar. A 6-yr cycle in recruitment produced a 6-yr cycle in catch at $F=0.1$. As fishing mortality increased, the cyclic nature of catch was reduced (Fig. 3, 4). When temperature was held constant the cycle was completely removed; however, the cyclic nature remained when temperature was treated as a stochastic variable.

During the 19th century catches showed considerable variation (Sette and Needler 1934), similar to those noted for low fishing mortalities. The estimated fishing mortalities for this period would have varied between 0.03 and 0.10, if the carrying capacity of the system has not changed appreciably. These levels of mortality would indeed produce the observed fluctuations in catch. Lett et al. (MS 1975_a) postulate that the periodicity in stock size is approximately 3 times the mean age at first maturity. Mackerel mature at age 2^+ , and the observed periodicity is 6 years.

Small shifts in fishing effort have a dramatic effect on catch when fishing mortality is low, producing the observed spikes (Sette and Needler 1934). Taylor et al. (1957) relates these fluctuations in catch to temperature, however the smoothing of both temperature and catch by 5-yr moving averages, would automatically produce a correlation between the two variables. However their correlation coefficient was low (0.554), suggesting

that temperature may only explain 31% of the variation in catch, even after smoothing. In light of the simulated effects of stock biomass, and the methods used by Taylor et al. (1957) to determine the correlation, it is unlikely that temperature is responsible for any cycles in the mackerel fishery. The low levels of stock biomass observed in the early 60's (G. H. Winters personal communication) are more likely the result of a mass mortality of mackerel in the Gulf of St. Lawrence due (*Ichthyosporidium hoferi*) a fungus infection of marine fish (Sinderman 1958).

Maximum catch was obtained when F was equal to 0.7 and temperature was constant, however, when temperature was introduced as a stochastic variable catches at $F=0.6$ and 0.7 were approximately equal (Fig. 4) at 4.5×10^5 metric tons. At $F=0.8$ catches began to decline, however, the rate of decline was much greater when temperature was random. Eventually, catches at $F=0.8$ were equal to those for $F=0.9$ at a minimum level of 0.14×10^5 metric tons. Therefore, a 14% increase in effort after maximum sustainable yield is achieved results in a total collapse in the fishery (Fig. 6). This is the exact result predicted by Ricker (1963) for a pelagic recruitment mechanism.

Anderson (MS 1975_b) noted that increases in effort have resulted in substantial declines in stock abundance similar to those in figure 5. It would seem that the recruitment mechanism can be likened to a spring, allowing the population to partially respond to the effects of exploitation. However, also like a spring it will break when too much force is applied, this point being at the peak of the egg production curve. Recovery is possible, but only if fishing is stopped.

References

- Anderson, E. D. MS 1975. The effect of a combined assessment for mackerel in ICNAF Subareas 3, 4, and 5, and Statistical Area 6. Int. Comm. Northwest Atl. Fish. Doc. 75/14.
- MS 1975. Relative abundance of Atlantic mackerel off the northeastern coast of the United States. Int. Comm. Northwest Atl. Fish. Doc. 75/15.
- Beverton, R. J. H. and S. J. Holt. 1957. On the dynamics of exploited fish populations. Fish. Invest., Lond. Ser. 2, 19: 533 p.
- Lauzier, L. MS 1969. Variations of temperature and salinity in shallow waters of the southern Gulf of St. Lawrence. Fish. Res. Board Can. Tech. Rep. 150, 23 p.
- Lett, P. F., A. C. Kohler, and D. N. Fitzgerald. MS 1975. A model of the interaction of temperature with the recruitment mechanism for the Gulf of St. Lawrence cod stock. Int. Comm. Northwest Atl. Fish. Doc. 75/10.
- MS 1975. The influence of temperature on the interaction of the recruitment mechanisms of Atlantic herring and mackerel in the Gulf of St. Lawrence. Int. Comm. Northwest Atl. Fish. Working Paper.
- Redbook. 1973 Part 1. Annex 1 - Report of ad hoc mackerel working group. Int. Comm. Northwest Atl. Fish. Redbook 1973. Part 1.
- Ricker, W. E. 1954. Stock and Recruitment. J. Fish. Res. Board Can. 11: 559-623.
1958. Handbook of Computations of Biological Statistics of Fish Populations. Fish. Res. Board Can. Bull. 119, 300 p.
1963. Big effects from small causes: two examples from fish population dynamics. 20: 257-264.
- Sette, O. E. and A. W. H. Needler. 1934. Statistics of the mackerel fishery off the east coast of North America 1804 to 1930. U.S. Dept. Comm., Bureau Fish., Invest. Rep. 19: 48 p.
- Sinderman, Carl J. 1958. An epizootic in Gulf of St. Lawrence fishes. Transactions 23rd North American Wildlife Conference (March 1958), p. 349-360.
- Taylor, C. C., H. B. Bigelow, and H. W. Graham. 1957. Climatic trends and the distribution of marine animals in New England. U.S. Dept. Int. Fish. and Wildl. Ser. Fish. Bull. 115 Vol 57: 349-360

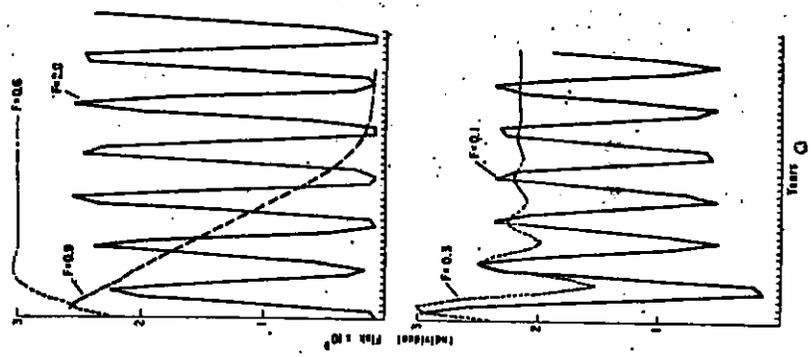


Fig. 1

The simulated recruitment pattern for age 1+ mackerel at different levels of fishing mortality. Temperature was held constant at 13.85°C, the mean monthly maximum for the Gulf of St. Lawrence.

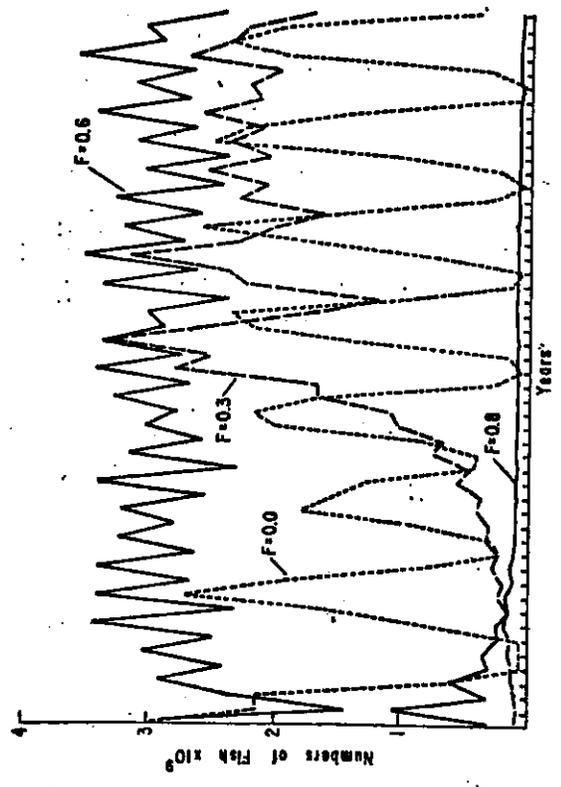


Fig. 2

The simulated recruitment pattern of age 1+ mackerel at different levels of fishing mortality. The mean monthly maximum temperature in the Gulf of St. Lawrence was treated as a normally distributed stochastic variable with mean 13.85 ± 1.28 SD. The curve at F=0.3 shows the initial effects of recovery from a former F=0.8.

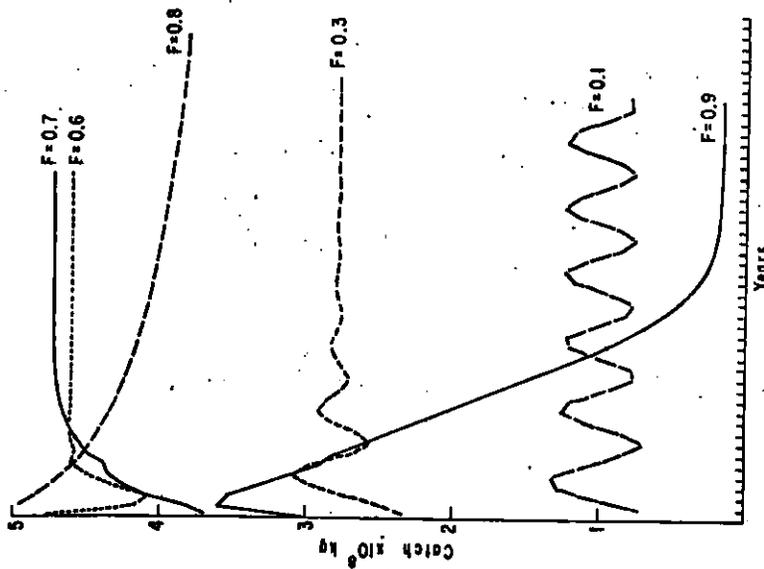


Fig. 3

Simulated catches of mackerel over time at different levels of fishing mortality. The length of time needed to reach equilibrium after shifting F is also illustrated. Temperature was held constant at 13.85°C , the mean monthly maximum in the Gulf of St. Lawrence.

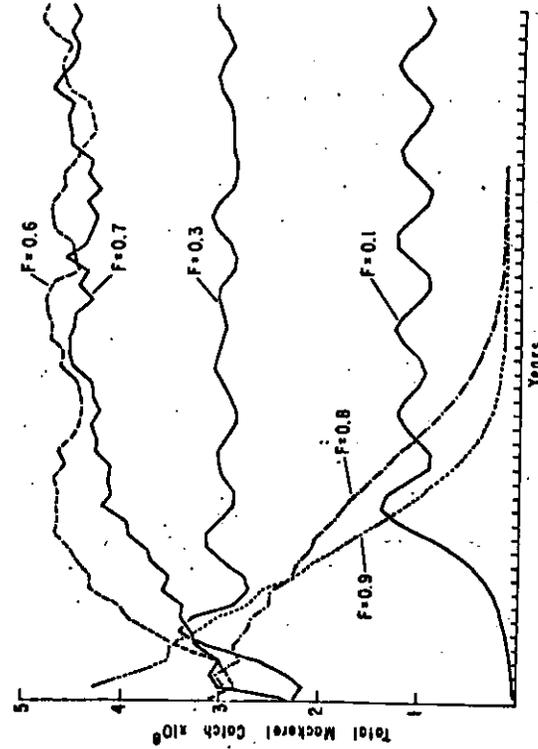


Fig. 4

Simulated catches of mackerel with the mean monthly maximum temperature in the Gulf of St. Lawrence being treated as a normally distributed stochastic variable, $13.85^{\circ}\text{C} \pm 1.28 \text{ SD}$. With temperature varying both $F=0.6$ and 0.7 produce similar catches with $F=0.8$ causing a rapid decline in the fishery.

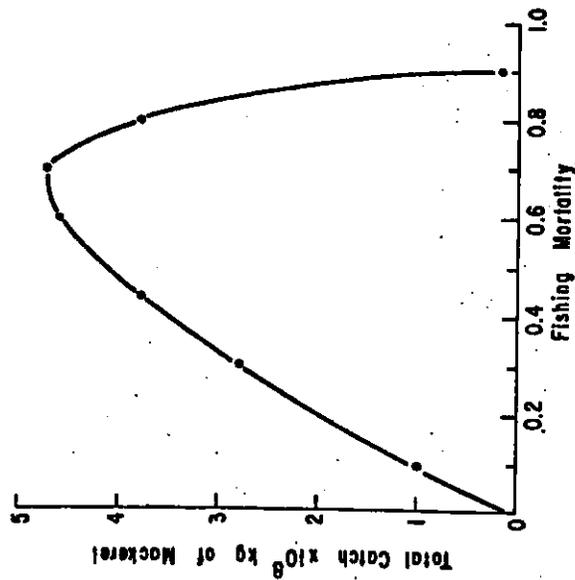


Fig. 6

Simulated relationship between equilibrium catch and fishing mortality for a constant monthly maximum temperature in the Gulf of St. Lawrence of 13.85°C. This curve fits the observed catch data presented by Anderson (MS 1975) with less than 5% error.

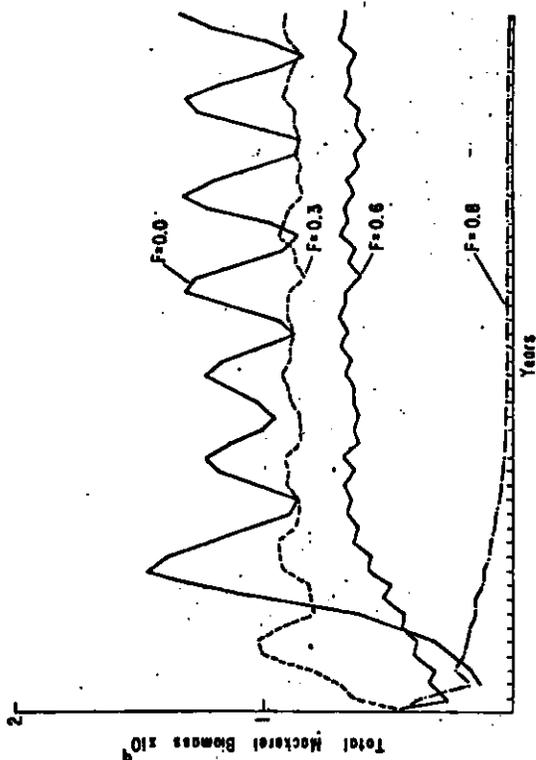


Fig. 5

Simulated response of stock biomass to different levels of fishing mortality over time. Temperature is treated as a normally distributed stochastic variable (13.85 ± 1.28°C SD). The greatest fluctuation in population biomass occur when fishing mortality is zero.