Developing a Management Strategy for the Flyingfish Fishery of the Eastern Caribbean

ROBIN MAHON
FAO Fishery Resources Officer
Bellairs Research Institute
St. James, Barbados

ABSTRACT

Los peces voladores-golondrinas, *Hirundichtys affinis*, son el componente mayor y mas importante de las pesquerías ocea anicas de las islas del sudeste del Caribe. Simulaciones hechas con la captura por unidad de esfuerzo (por 26 anos) en ela área de Barbados indican que hay una variabilidad considerable entre años referente a la abundancia de este pez. Trabajos recientes sugieren que parte de esta variabilidad puede ser relacionada a factores ambientales y que por lo tanto, puede ser predecible a corto plazo. Sin embargo, cualquier estratégia de manejo para esta especie debe tratar de tomar en cuenta la variabilidad impredecible para este caso. Si una población puede ser sometida a un modelo, las simulaciones a largo plazo son una forma de bregar con tal variabilidad. En el caso del pez volador, que es probablemente una especie anual, usamos un modelo de reclutamiento al "stock"con una variabilidad al azar. La magnitud de esta variabilidad esta basada en estudios históricos de años anteriores. Las simulaciones esta an siendo usadas para determinar el promedio del efecto al "stock"causado por varios niveles de mortalidad por pesca. Los criterios para establecer la estratégia de pesca son: capturas totales, capturas por unidad de esfuerzo, variabilidad entre años referente a la captura y el riesgo de que el abasto pesquero se colapse. Opciones de manejo a base de los términos expresados anteriormente deberían ser mas fáciles para entender por los administradores y pescadores que opciones basadas en el concepto de un rendimiento sostenido determinado (deterministic sustainable yield).

INTRODUCTION

Flyingfish (*Hirundichthys affinis*) are the most important component of the fisheries for pelagic species in the southeastern Caribbean (Mahon *et al.*, 1986). Total annual catch by all islands is estimated to be approximately 4,000—5,000 metric tons. Barbados, the major prosecutor of this fishery, has recently expanded its fleet, about doubling its catch (Jones and Oxenford, 1986). Other islands are developing their fisheries for pelagics in general, and for flyingfish in particular. Thus, the ability of the flyingfish stock in the eastern Caribbean to sustain increased exploitation is a matter of concern for all islands participating in the fishery.

Flyingfish are considered to be short-lived, probably living one year (Lewis *et al.*, 1962; Storey, 1983; Oxenford, 1986). Analysis of 26 years of catch per unit effort data from Barbados indicates a considerable amount of variability in annual recruitment. A significant proportion of this variability appears to be correlated with environmental factors (Mahon, 1986). In outlining a strategy for assessing the potential of the flyingfish stock, Mahon *et al.*,(1986) noted that attempts to determine appropriate exploitation rates should take the observed variability into account.

The problem of determining maximum yield from single age stocks in fluctuating environments was first addressed for salmon (Ricker, 1958; Larkin and Ricker, 1964; Tautz *et al.*, 1969). They considered two strategies, "constant effort" and "constant escapement [of spawners]", and concluded that the average catch at constant escapement is greater than that at constant effort, but that the variability in catch is greater. In subsequent analyses these properties consistently emerge, although Gatto and Rinaldi (1976) show that under certain circumstances, variability, if defined as extreme catches, may be similar under both strategies.

Under a constant effort policy, the proportion of the stock taken each year would be the same; that is, a constant exploitation rate. Consequently, assuming a linear relationship between abundance and catch per unit effort, the amount of catch would fluctuate with abundance. With constant escapement, the usual approach is to estimate the spawning stock which gives the maximum surplus recruitment and catch only the stock in excess of that spawning stock.

The above strategies can also be compared with the "constant catch" approach where MSY or some other catch quota is set and taken each year (Beddington and May, 1977; Ruppert *et al.*, 1985). In a completely deterministic stock recruitment situation, the constant catch and constant escapement situations are identical.

In addition to determining a strategy which would produce the maximum average long term catch, managers may want to consider the socioeconomic effects of catch variability, and the risks, for example of an extended collapse of the fishery, associated with various levels of fishing under the constant effort strategy. If, as in the case of flyingfish, there is some knowledge of the stock production system (stock-recruitment relationship) and of the uncertainty about this relationship, population simulation can be used to estimate the probability of occurrence of various events of concern to the manager (Walters, 1984).

In this study a simple stock-recruitment simulation model is used with random environmental perturbations based on the historical variability, to explore the response of the flyingfish population to various exploitation rates. The results of these simulations are used to evaluate various fishery characteristics which could be useful to fishery managers in establishing a harvesting policy.

THE FLYINGFISH POPULATION MODEL

The simulation uses the stock recruitment relationship described by Mahon (1986). This relationship is based on the catch per unit effort (CPUE) of flyingfish by launches fishing from Speightstown, Barbados. The time series is of the average monthly catch per trip from October to the following September (a fishing season, Mahon *et al.* 1982) and shows a steady increase in CPUE over the period 1958 to 1984. The launches are known to have increased in size and horsepower over this period, and since it is unlikely that the flyingfish population had increased steadily during this time, the changes in catch per unit effort were assumed to be due to increased fishing power of the launches. The trend in the time series of CPUE was estimated by a quadratic function, and the mean of the series plus the residuals around the trend used as the standardized CPUE (Figure 1). The possibility that there was a steady decrease in CPUE as the fishery developed, and that this was overcompensated for by the increase in fishing power per launch cannot be evaluated with these data.

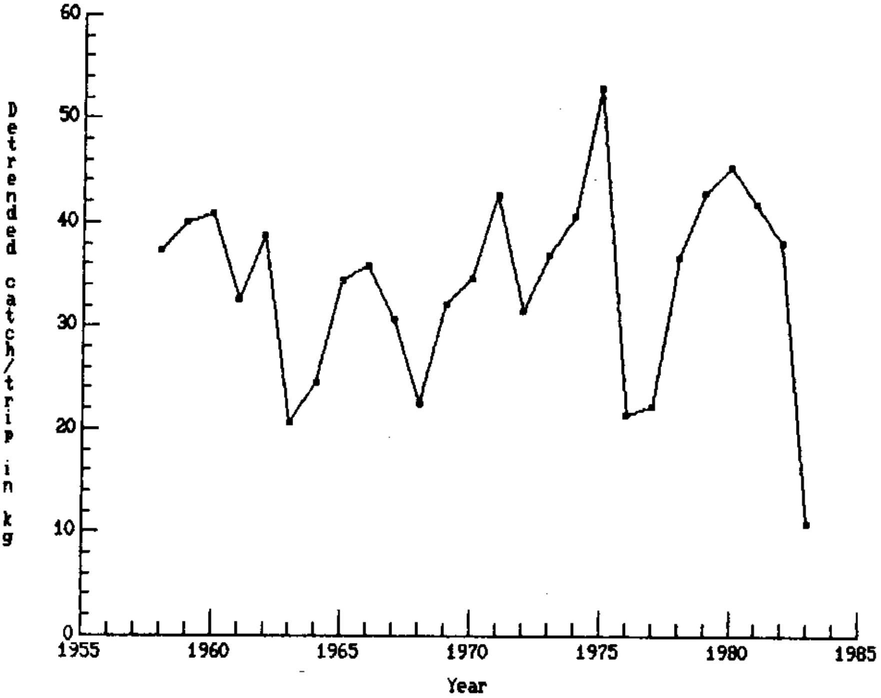


Figure 1. The time series of CPUE (catch/trip) for the flying fish fishery at Speightstown, Barbados.

Since flyingfish appear to be annual, the CPUE in each year is assumed to be the recruitment resulting from the population indicated by the CPUE in the previous year. Hence the same time series, lagged by one year, provides estimates of both stock and recruitment over 25 years. The plot of recruitment versus stock indicates that the former is independent of the latter over the range of stock sizes observed (Figure 2). Walters and Ludwig (1981) demonstrate the possible effects of measurement error on the stock-recruitment relationship; however, there was no means of detecting or quantifying these effects for the flyingfish data.

There is no information on the stock-recruitment relationship at stock sizes less than 20 units. However, given the obvious coincidence of zero stock and zero recruitment, a somewhat sharp decline in recruitment would be expected to the left of the observed data. A Ricker (1975) stock recruitment function indicates a relatively linear decline in the relationship from the leftmost cluster of points to the origin (Figure 2). Given that this cluster of points, at about 20 units, is lower than the main cluster, at about 35—40 units, it seems unlikely that there would be any compensatory increase in recruitment at stock levels lower than 20 units.

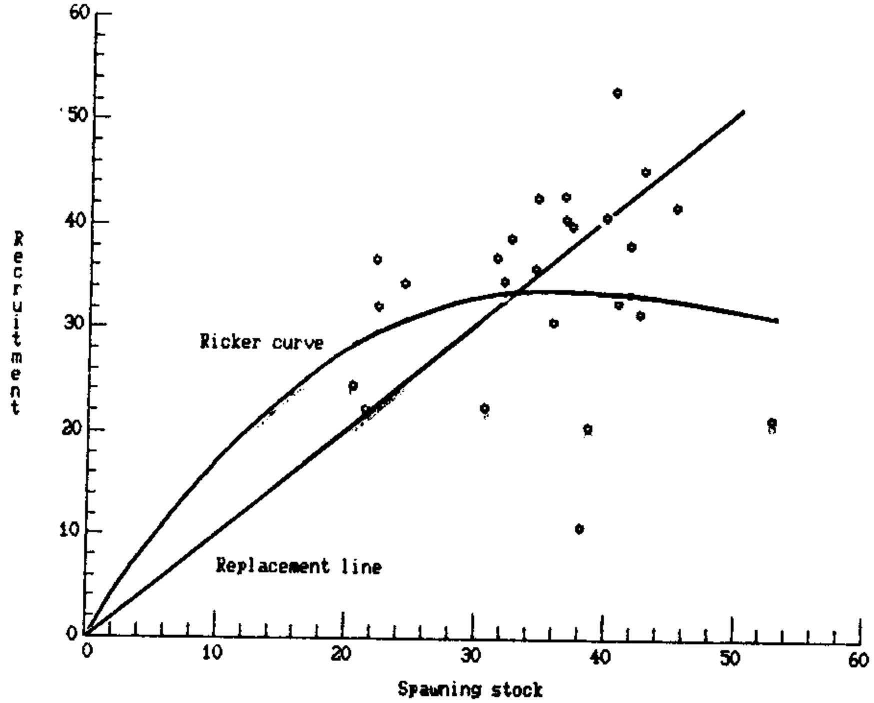


Figure 2. Recruitment versus stock for flyingfish.

For each year of the simulation, the fitted stock recruitment relationship was used to calculate an estimate of recruitment from the previous year's stock. This recruitment estimate was then increased or decreased by a random environmental effect based on the variability of the observed data about the stock recruitment line. The final recruitment estimate was taken as an estimate of the stock available to the fishery in the following year.

The environmental effect in each year was drawn at random from the vector of observed recruitment divided by the vector of estimated recruitment calculated from the stock recruitment relationship. The frequency distribution of these environmental effects is skewed towards poor recruitment (Figure 3). This is in contrast to the pattern usually observed for exploited stocks, where

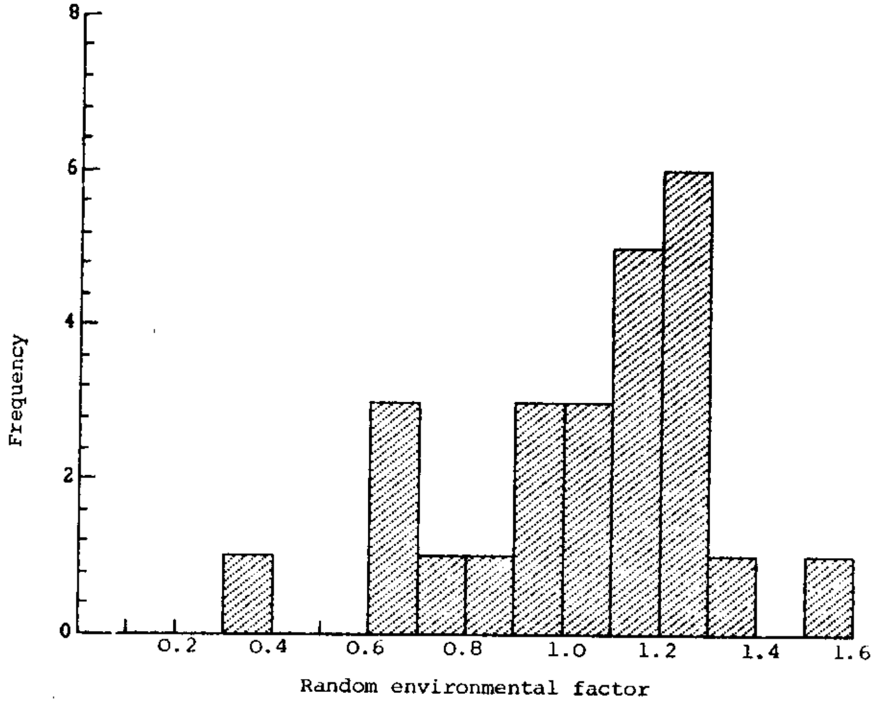


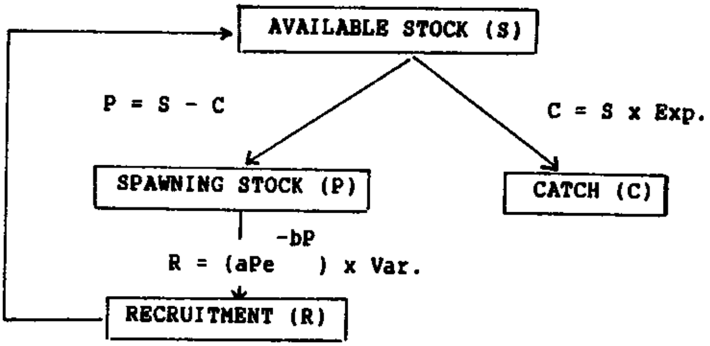
Figure 3. The frequency distribution of the historically observed environmental factor sampled at random for the simulations. The factor is the ratio of observed to estimated recruitment.

residuals are usually skewed towards good year classes (Garrod, 1983; Walters, 1984). Since there is no apparent relationship between the residuals and stock size, this study assumes that the environmental effects are independent of population size, as Garrod (1983) found for other species.

Although, fishing mortality and spawning are spread over most of the year with a peak about March, both were treated as if they occurred instantaneously in mid-season with fishing preceding spawning. The sequence of events in the simulation process is shown in Figure 4.

The simulations were started with a CPUE of 35 kg/trip and run for 1,010 years. The last 1,000 years output of catch, available stock and spawning stock were used to evaluate the performance of the fishery in each case.

In exploring the constant effort policy, the available stock was exploited at 14 levels of fishing, ranging from 0 to 65% (in increments of 5%) of the stock biomass removed before spawning. The remaining stock was then used as parent or spawning stock to estimate recruitment for the following year.



Exp. = exploitation rate,
a and b are parameters of the Ricker stock-recruitment function,
Var. observed variation drawn at random

Figure 4. The sequence of events in the simulation.

In exploring the constant escapement, catch was the difference between the required spawning stock and the available stock and the available stock was the greater of the two, and zero when it was less than or equal to required spawning stock. As above, spawning stock was available stock minus catch.

The constant catch policy was evaluated for a range of catches relative to the peak catch under the constant effort option; 0.2 to 1.6 times peak catch in increments of 0.2. The simulation was started with a population corresponding to CPUE of 35 kg/trip and each of 50 simulations attempted was allowed to run either for 1,000 years or until the stock went extinct. Extinction was considered to have occurred when catch exceeded available stock.

RESULTS OF THE SIMULATIONS

The behaviour of the index of available stock at various levels of fishing under the constant effort approach is shown in Figure 5. At an exploitation rate of 60 percent, the population in each of 10 trials declined to less than 0.5 kg/trip and stayed there.

The simulation representing the current status illustrates the considerable degree of interannual variability on a scale of 1—5 years (Figure 5a). It also shows that the level of abundance may change substantially for longer periods in the order of 5—15 years. For example, at about year 160, after a period of precipitous decline, abundance recovers rapidly to a relatively high level of about 40 kg/trip and holds that level for 10—20 years. In contrast, between years 380—400 the population remains at the relatively low level of about 22 kg/trip for an extended period.

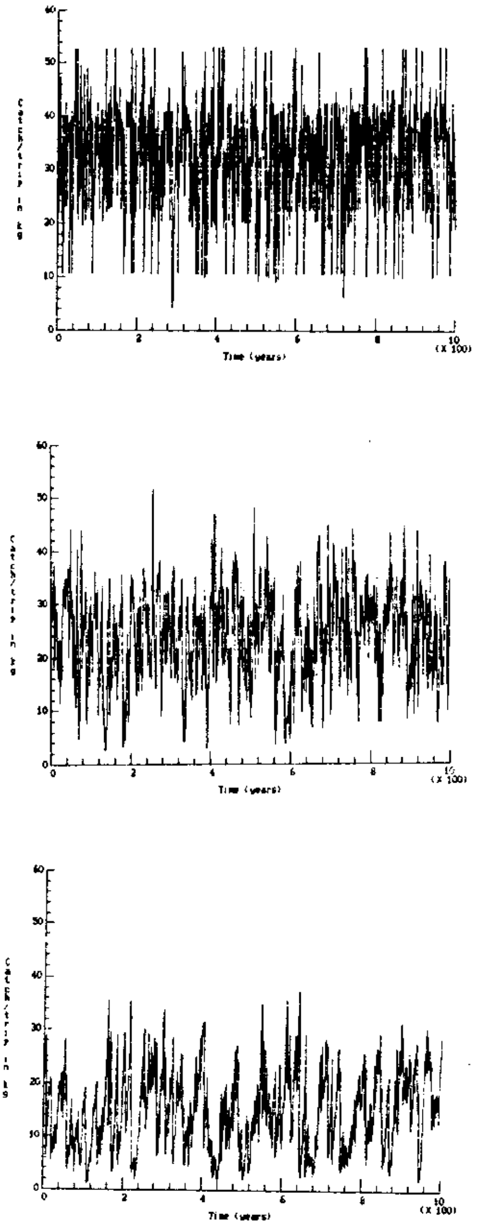


Figure 5. Simulated time series of CPUE for flyingfish. (A) current status, (B) optimum constant effort (exploitation rate of 40%), and (C) overexploitation at the constant exploioitation

At the estimated optimum exploitation rate of 40% , the variability results in longer cycles of low stock size than observed at the current status (Figure 5b). Overexploited at the rate of 55% , a large part of the variability becomes of a cyclical nature, as the stock is depressed and climbs back up the ascending limb of the stock recruitment curve (Figure 5c).

The particular fishery characteristics which will be of concern to a fishery manager will depend on the management objectives which have been set. Some characteristics of the flyingfish stock which are likely to be of interest in developing a management strategy are considered below and have been calculated from the output of the simulations at various levels of exploitation (Table 1). These characteristics have been summarized graphically (Figure 6).

The annual catch represents the total revenue from the fishery. Maximizing total annual catch is frequently an objective in fishery management. The values in Table 1, are averages over the 1,000 year period. The actual amount to be expected in any particular year is largely unpredictable. As would be expected, total annual catch increases with exploitation rate to a maximum, then drops off sharply as the stock moves onto the left hand limb of the stock recruitment curve.

Variation in total annual catch is of great concern to the fishing industry. Fluctuations in the supply of fish can create marketing problems, and translate into variable employment opportunities in the processing and fishing sectors. Strategies to damp out the effects of natural variability frequently observed in fish stocks may be part of a management plan. These may include storage facilities to spread out supply to processors and the marketplace, and insurance schemes to offset the impact of low catch years on fishermen. Alternatively, if high catch levels and high variability are related, the strategy may tradeoff catch for stability.

The historically observed variation about the stock recruitment curve results in a coefficient of variation (CV) of about 30% at the current status. This increases slowly up to an exploitation rate of about 40%, then rather more rapidly at higher exploitation rates (Table 1, Figure 6).

The absolute variation in catch may be of more interest than the relative variation indicated by the CV. The upper and lower quartiles show the range within which 50% of the total annual catches would be expected to fall (Figure 6). These indicate that the range of expected catches increases with exploitation rate.

The catch per unit effort (CPUE) will be of particular concern to fishermen, as this will determine the profitability of their individual operation and thence their income. In the flyingfish fishery CPUE would also vary unpredictably with the same coefficient of variation as that shown for total catch. Quartiles for CPUE are not shown.

Depending on the economics of the fishery, there may be some CPUE below which fishermen may not be able to meet their financial obligations, or may simply stop fishing the resource. The latter is particularly likely in the case of part time fishermen, or where alternative resources may be available. As mentioned, insurance schemes may help to offset the impact of such events, however, sustained critically low levels will generally lead to severe economic hardship in the fishing industry. Consequently, a management strategy should consider the frequency and duration of such critically low levels.

Table 1. Some characteristics of the flyingfish fishery at various exploitation rates under a constant effort policy, and under a constant escapement policy with an average spawning stock equivalent to that at the optimum exploitation rate of 40%. Catches are relative to the maximum long term (100 units), CV is the average percentage deviation of annual catch from the mean, CPUE is given in kg/trip.

Exploitation rate (%)	Average catch (range)	CV of catch	Average CPUE
Current	—	—	33
5	18 (3-28)	28	33
10	34 (6-55)	29	32
15	50 (8-83)	29	32
20	65 (9-110)	30	31
25	78 (10-138)	34	30
30	89 (11-159)	33	28
35	97 (7-180)	34	27
40	100 (11-215)	36	24
45	94 (10-204)	41	20
50	77 (5-196)	50	15
55	47 (1-145)	68	8
60	0	—	0
Constant escapement	110 (0-245)	56	24

For the purposes of this analysis a CPUE less than or equal to 10 kg/trip is considered to be the critical level. The percent of time spent below the critical level for periods of 1 to 10+ years is shown in Table 2. Taking critically low CPUE for four or more years as a collapse, the percent of time spent collapsed begins to increase rapidly at an exploitation rate of about 35—40%.

The constant escapement option was run with an escapement equal to the average spawning stock index (14.4 kg/trip) at the optimum constant effort (exploitation rate 40%) (Figure 7). The resulting fishery characteristics should be compared with those observed at the 40% exploitation rate. As expected, both the average annual catch and its variability were higher with the constant escapement option than with the constant effort option (Table 1). In contrast, the frequency and duration of critically low CPUE, as defined above, is considerably less for the constant escapement option (Table 2). However, CPUE was based on the index of available stock, which does not indicate the impacts of the fishery closures required to control escapement. Complete closure was necessary in 5% of the years.

As expected from previous theoretical studies, constant catch always resulted in extinction, except at very low catch levels (Table 3). Beddington and May (1977) have pointed out that extinction is certain under a constant catch policy, the question is, what time frame to use in estimating the probability of extinction. Using the 1,000 year time frame, extinction occurred in about 1—2% of simulation runs even at the lowest catch level tried.

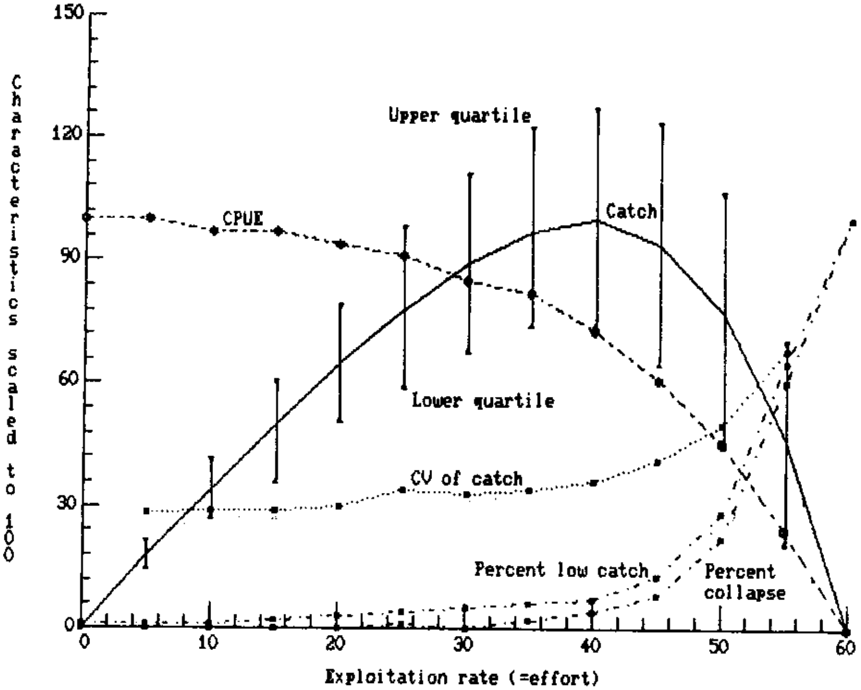


Figure 6. Summary of fishery characteristics at various levels of constant effort (exploitation rate). Catch, its upper and lower quartiles, its coefficient of variation (CV), and catch per unit effort (CPUE) are shown. Also shown are the percent of time the stock spends at critically low CPUE or in collapse as defined in the text.

COMPARISON OF OPTIONS AND PROBLEMS OF IMPLEMENTATION

The results of the simulations are consistent with the theoretical expectations. Although, as pointed out by Ricker (1958) the results are intuitive, they serve several useful purposes. Firstly, assuming the model is a reasonable representation of the flyingfish production system, they provide some idea of the magnitude of the tradeoffs under various harvesting policies. Secondly, they provide the data required for graphical representation of the various options. This is particularly useful in attempting to explain the options and their relative merits to non-technical fishery decision makers.

The constant escapement policy results in a long term average catch which is about 10% greater than that which would be obtained at the optimum constant effort. Year to year variation in catch is higher, but tendency for the stock to be reduced to and remain at unprofitably low levels is less, buffered by the closure of the fishery at low stock levels. Owing to the variability in recruitment, the constant catch option does not appear to be appropriate for flyingfish. This was the case even for menhaden, in which the available stock consisted of several age groups (Ruppert *et al.*, 1985).

Decisions on which policy to adopt will also have to consider the implications of implementation. The fact that flyingfish is a shared stock and will require regional management (FAO, 1986), must be kept in the forefront. Assuming the appropriate effort level can be estimated, constant effort could be achieved through a licensing system. Owing to the tendency for fishing power of vessels to increase under licensing systems, this parameter would require monitoring. Allocation of the total effort among participants would require intercalibration of vessels.

Estimating the amount of effort which would correspond to the optimum exploitation rate would require information on fishing mortality. Rough estimates of total catch and total stock size could give first approximations of fishing mortality (Mahon *et al.*, 1986). Even so, the fact that flyingfish are part

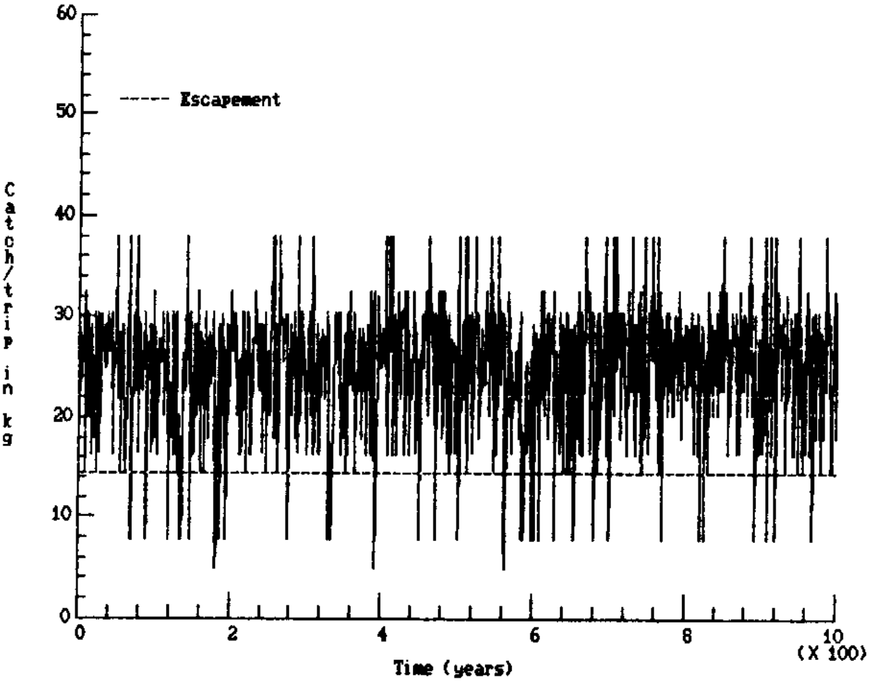


Figure 7. Simulated time series of CPUE for flyingfish under the constant escapement policy at the spawning stock size producing maximum surplus recruitment.

Table 2. The percentage of years spent in collapses (CPUE < 10 kg/trip) of 1 to 10+ years duration at various exploitation rates, and at constant escapement of a spawning stock equaling the average at the optimum exploitation rate of 40%.

Exploitation rate (%)	Duration of collapse (years) 1	2	3	4	5	6	7	8	9	10+
0	1									
5	1									
10	1	1								
15	2	1	1							
20	3	1	1							
25	4	2	1	1						
30	5	3	2							
35	6	3	2	2	1	1	1			
40	7	5	4	4	3	2	2	2	2	
45	13	11	9	8	6	3	3	2	2	
50	28	26	24	22	22	20	17	14	11	11
55	65	63	62	60	59	57	55	54	52	52
Constant Escape.	4	1								

Table 3. The time (years) to stock extinction at various levels of constant catch. Catch is shown as a proportion of maximum catch under the constant effort policy.

	Proportion of maximum catch 0.2	0.4	0.6	0.8	1.0	1.2	1.4
Average time to extinction	350*	42*	15	15	8	6	4
Maximum	>1000	>1000	156	89	51	23	20
Minimum	80	8	4	2	2	1	1

* Where the simulation ran for 1000 years, 1000 was used in the average.

of a multispecies pelagic fishery would make the estimation of the corresponding fishing effort rather imprecise. Depending on the availability of, and preference for, other species, the total effort directed at flyingfish could vary considerably from year to year. Intuitively, the effect of variable effort would be to increase the probability of stock depletion and collapse. However, this should be explored by further simulation exercises.

One frequently cited approach to "locating" the optimum fishing mortality (=effort) is to increase effort gradually until total catches begin to decline; thus experimentally revealing the peak (Evans, 1981). These simulations suggest that this approach would be particularly inappropriate for flyingfish. Owing to the variability which has been observed, several (probably as many as 20—30) years would be required to obtain a reasonable estimate of average catch at each increment of fishing effort. Gradual expansion of the fishery on this time scale would be unrealistic.

Given the asymmetry in the total catch curve and other fishery characteristics (Figure 6), rather dramatic undesirable effects can be expected at exploitation rates much in excess of the optimum. As pointed out by Evans (1981) a conservative approach, in which a somewhat less than optimal catch is taken, may be appropriate as a means of reducing the probability of collapse. Given the difficulty of estimating directed effort due to the multispecies nature of the fishery, this may be particularly advisable. Even so, a considerable amount of research and information will be required to ensure that the effort remains on the left hand side of the optimum (Figure 6).

Although it appears clear that the constant escapement option is more desirable than constant effort for flyingfish, implementation is even more difficult. Firstly, for the benefits to be realized, the fleet would have to have the capacity to take the occasional large catches which would result from this approach. Assuming a relatively large capacity, the fishery would have to be closed in most years when the surplus stock (stock in excess of required spawning stock) has been caught. Achieving this with any degree of precision would require accurate estimates of stock size, and of the amount of catch taken through the season.

Before fishery managers could commit the industry to a constant escapement policy, further studies should be conducted to determine the relative effects of imprecision on the two policies. The possibility exists that the advantages of the constant escapement approach may be lost unless it can be implemented precisely.

In conclusion, it is clear that attempts to optimize long term average flyingfish catches by implementing either of the two policies evaluated in this study will require a greater commitment to data collection and analysis by the participants in the fishery. Even with reasonably precise information on stock and catches, the observed variability and multispecies nature of the fishery does not argue well for precise optimization. Assuming that the eastern Caribbean islands could collectively exert sufficient effort to overfish the flyingfish stock, a strategy of "expand slowly and watch" will probably fail to locate an optimum fishing level. The likelihood of stockwide overfishing in the face of a no action policy will largely depend on the relative areas occupied by the stock and the fishery, and remains to be assessed (Mahon *et al.*, 1986).

ACKNOWLEDGMENTS

I am most grateful to Wayne Hunte and Hazel Oxenford for stimulating discussions, and to Susan Mahon, Hazel Oxenford and Stephen Willoughby for reviewing the manuscript.

REFERENCES CITED

Beddington, J.R. and R.M. May. 1977. Harvesting natural populations in a randomly fluctuating environment. *Science* **197**(4302):463-465.

----------, J.R., W.E. Arntz, R. Bailey, G.D. Brewer, M.H. Glantz, A.J.Y. Laurec, R.M. May, W.P. Nellen, V.S. Smetacek, F.R.M. Thurow, J.-P. Troadec, C.J. Walters. 1984. Management under uncertainty: Group report. pp. 227-244. In: R.M. May (ed.). *Exploitation of marine communities*. New York, Berlin, Heidelberg, Tokyo: Springer-Verlag.

Evans, G.T. 1981. The potential collapse of fish stocks in a developing fishery. *N. Amer. J. Fish. Manag.* 1:127-135.

FAO. 1986. Report of the Expert Consultation on shared fishery resources of the Lesser Antilles region. FAO Fishery Reports No. (In press).

Garrod, D.J. 1983. On the variability of year class strength. *J. Cons. int. Explor. Mer.* **41**: 63-66.

Gatto, M. and S. Rinaldi. 1976. Mean value and variability of fish catches in fluctuating environments. *J. Fish. Res. Board Can.* **33**: 189-193.

Jones, R. and H.A. Oxenford. 1986. Barbados. pp. 23-26. In: Mahon, R., H. Oxenford and W. Hunte [eds.] Development strategies for Flyingfish Fisheries of the Eastern Caribbean. International Development Research Agency, Ottawa, Canada, IDRC-MR128e.

Larken, P.A. and W. E. Ricker. 1964. Further information on sustained yields from fluctuating environments. *J. Fish. Res. Bd. Can.* **21**:1-7.

Lewis, J.B., J.K. Brundritt, and A.G. Fish. 1962. The biology of the flyingfish *Hirundichthys affinis* (Gunther). *Bull. Mar. Sci. Gulf. Caribb.* **12**: 73-94.

Mahon, R. 1986. Seasonal and interannual variability in abundance of flyingfish. pp. 89-130. In: Mahon, R., H. Oxenford and W. Hunte (eds.). Development Strategies for Flyingfish Fisheries of the Eastern Caribbean. International Development Research Agency, Ottawa, Canada IDRC-MR128e.

----------, R., H. Oxenford, and W. Hunte (eds.). 1986. Development strategies for flyingfish fisheries of the eastern Caribbean. International Development Research Agency, Ottawa, Canada , IDRC-MR128e: 148 pp.

----------, R., W. Hunte, H. Oxenford, K. Storey, and R.E. Hastings. 1982. Seasonality in the commercial marine fisheries of Barbados. *Proc. Gulf Carib. Fish. Inst.* **34**: 28-37.

Oxenford, H.A. 1986. Synopsis of the biological data on the four-winged flyingfish *Hirundichthys affinis* Gunther. pp. 51-88. In: Mahon, R., H. Oxenford, and W. Hunte (Eds.) Development strategies for Flyingfish Fisheries of the Eastern Caribbean. International Development Research Agency, Ottawa, Canada, IDRC-MR128e.

Ricker, W. E. 1958. Maximum sustained yields from fluctuating environments and mixed stocks. *J. Fish. Res. Bd. Can.* **15**: 991-1006.

----------, W.E. 1975. Computation and interpretation of biological statistics of fish populations. Bull. Fish. Res. Bd. Can. 191:382 pp.

Ruppert, D., R.L. Reish, R.B. Deriso, and R.J. Carroll. 1985. A stochastic population model for managing the Atlantic menhaden (*Brevoortia tyrannus*) fishery and assessing managerial risks. *Can. J. Fish. Aquat. Sci.* 42:1371-1379.

Storey, K.W. 1983. Aspects of the biology and fishery of the flyingfish, *Hirundichthys affinis*, at Barbados. M.Ph. Thesis, University of the West Indies, Barbados, 161 pp.

Tautz, A., P.A. Larkin, and W.E. Ricker. 1969. Some effects of simulated long-term environmental fluctuations on maximum sustainable yield. *J. Fish. Res. Bd. Can.* 26:2715-2726.

Walters, C.J. 1984. Managing fisheries under biological uncertainty. pp. 263-274. In: R.M. May (ed.). *Exploitation of marine communities*. New York, Berlin, Heidelberg, Tokyo: Springer-Verlag.
Walters, C.J. and D.A. Ludwig. 1981. Effects of measurement errors on the assessment of stock-recruitment relationships. *Can. J. Fish. Aquat. Sci.* 38:704-710.