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A study of the dynamics and management of the hairtail fishery, *Trichiurus haumela*, in the East China Sea

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Abstract

This study concerns the dynamics and management of the hairtail fishery (*Trichiurus haumela*) in the East China Sea. Virtual population analysis was used to assess the historical pattern of stock size and an age-structured production model was developed to simulate the historical and future changes of catch and stock of hairtail under different fishing strategies. The results show that the stock of hairtail has been declining in general since the beginning of the 1960s. In 1981, it was 275.10^3 metric tons, overfished but not very seriously. Subsequent management measures brought some positive effects to stock and catches and slowed down the decline, but they cannot change the status of overfishing of the stock. The current fishing regime will inevitably lead to more severe depletion of the stock and also decrease the catch in the end. To prevent further deterioration of the stock and maintain catches, any further expansion of fishing effort must be stopped. Alternatively, a longer closed season should be introduced or the age at first capture should be raised.

Keywords : Hairtail, *Trichiurus*, dynamics, management, production model.

Une étude de la dynamique et de la gestion des pêches de Trichiurus haumela, *dans l'est de la mer de Chine.*

Résumé

Cette étude porte sur la dynamique et l'aménagement des pêches du poisson-sabre, *Trichiurus haumela*, de l'est de la mer de Chine. L'analyse de population virtuelle a été utilisée pour établir l'historique du stock et un modèle de production en fonction de l'âge a été développé afin de simuler les changements historiques ou futurs des captures et du stock de ce poisson avec différentes stratégies de pêche. Les résultats montrent que le stock de *Trichiurus* était en régression depuis les années 1960. En 1981, les captures s'élevaient à 275.10^3 tonnes, surpêche mais non dramatique. Par la suite des mesures d'aménagement ont eu des effets sur le stock et les captures et ralentirent le déclin mais elles ne peuvent modifier l'état de surpêche du stock. Le régime habituel de pêche conduira inévitablement vers une diminution du stock et aussi vers une diminution des captures. Afin d'éviter une détérioration plus importante du stock et de maintenir les captures, toute augmentation de l'effort de pêche doit être stoppée. Alternativement, une saison interdite de pêche plus longue devrait être introduite ou bien l'âge de première capture devrait être plus élevé.

Mots-clés : *Trichiurus*, dynamique des populations, gestion des pêches, modèles de production.

INTRODUCTION

Hairtail, *Trichiurus haumela* (Forsskål, 1775) is a highly productive, demersal species believed to constitute a unit stock in the East China Sea (*fig.* 1), which is separate from the stock in Bo Hai and the Yellow Sea (Hu and Zu, 1986). In spring, the fish migrate onshore and from south to north to reproduce. The maturity age was 2 years old in 1960s. Due to the heavy fishing in recent years, the fish adapted itself

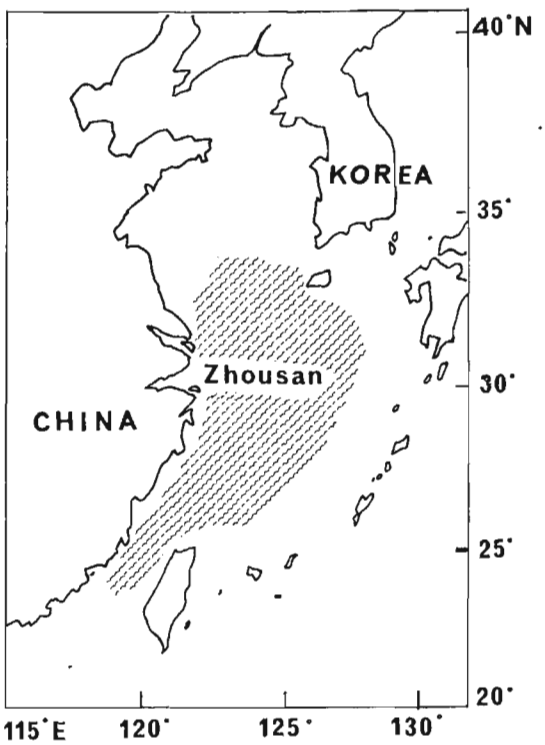

Figure 1. – Distribution of hairtail in the East China Sea.

to the pressure of fishing and nearly 95% of the one-year-old fish become mature (Luo, 1982, Hu and Zu, 1986, and Xu, 1988). The reproductive season is from March to October, with the peak between May and August. At the end of the autumn, hairtail migrate back to the south to over-winter. During migration, this species forms large schools offshore. Particularly in winter, hairtail support the major fishing season on the Zhousan fishing ground. They are exploited by Chinese, Japanese and South Korean fishermen. The main fishing gears are trawls, local purse-seines and longline. Reviews of various aspects of the hairtail fishery can be found in Gu (1980, 1981) and Xu (1988).

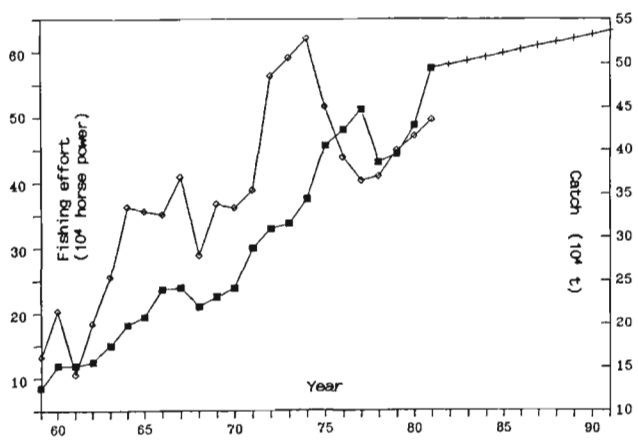

Figure 2. – Fishing effort (10^4 horse power) and catch (10^4 tons) over time (■ observed effort; + extrapolated effort; ◇ catch).

Fishing effort and catches are recorded from 1959-1981 (Zu, 1983 and Xu, 1988). Effort has expanded rapidly over this period and catches increased to a peak of 520.10^3 metric tons in 1974. Since then, the catch has declined (*fig.* 2) and the average size of individuals in the catch has decreased (*fig.* 3 *a*). To prevent the extinction of the stock, the Chinese government introduced some regulations in 1982, such as fishing licences and a three-month closed season, which kept yearly catches near 400.10^3 metric tons for some time. But in 1988, the catch of state-run fishing companies, which can represent the situation of this fishery, showed a decline trend according to the official publications.

The hairtail fishery is the largest fishery in China, having the highest yield of any individual species. The stock in the East China Sea supplies nearly 90% of the total catch (Zu, 1983). Therefore, it is of interest to fisheries biologists and managers to know the real state of the stock in the East China Sea and predict what effect the continuation of the current management regime will have upon the population and its potential yield and what management measures should be established to obtain the maximum sustainable yield. In this paper, we assess the historical stock sizes using virtual population analysis (VPA) tuned to fishing effort data (Gulland, 1965, Laurec and Shepherd, 1983) and explore the effects of different fishing regimes on the population and the catches. For this purpose, a simple age-structured production model is developed.

MATERIAL AND METHODS

The data used are fishing effort and catches from 1959 to 1981 (Zu, 1983) and age composition of catches from 1959 to 1966 and from 1972 to 1977 (Gu and You, 1979) (*table* 1).

Virtual population analysis

To assess the historic stocks, VPA tuned to the fishing effort was used. It is very important to have a successive series of data for VPA. So, we have to find a way to bridge the gap between 1966 and 1972. Using the age composition data, it is possible to find trends in the proportions of different age groups to total catch numbers. The proportion of young fish has increased (*fig.* 3), whereas the proportions of individuals older than one year have decreased over time (*fig.* 3). The average weights of individuals also declined gradually in years 1959-1977 (*fig.* 3 *a*). Regression models of the proportions of different age groups to total catches against time were fitted to interpolate proportions of catch at age for 1967-1971.

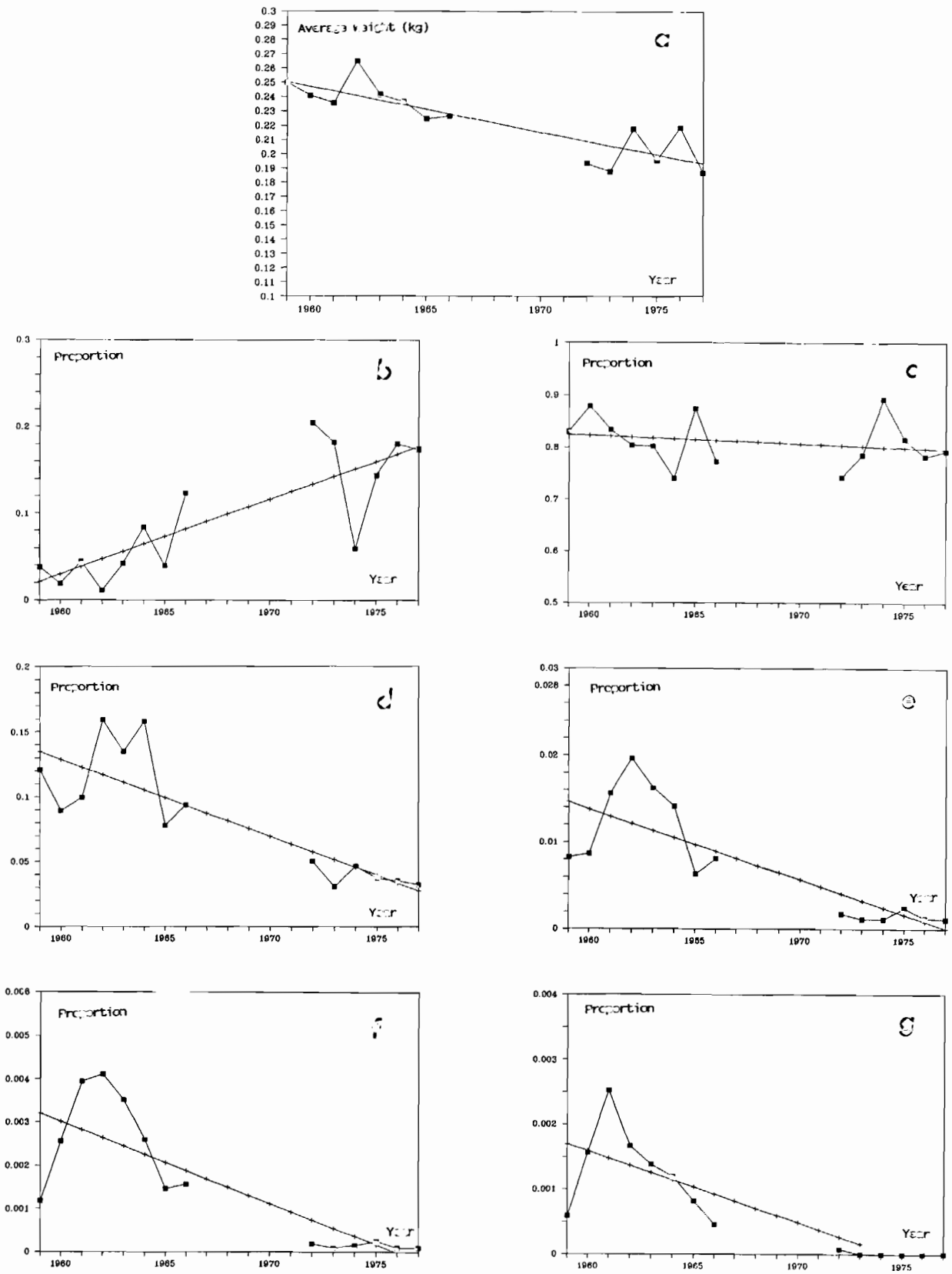

Figure 3. – Average individual weight (kg) of hairtail (a); Proportion of age group 0 (b), age group 1 (c), age group 2 (d), age group 3 (e), age group 4 (f) and age group 5 (g) to total catch number (○ observed; + calculated).

The growth equation of hairtail is as follows (Hu and Zu, 1986):

$$W_i = 2176[1 - \exp(-0.274(i + 0.87))]^3$$

where i is age, W_i is weight in grams at age i.

From the growth equation, the average weights of every age group can be derived. Considering the total catch in weight, total catch numbers from 1967-1971 can be calculated from the following equation:

$$C_w(t) = \sum_{i=0}^{5} W(i)\, p(t, i)\, C_n(t)$$

where $C_w(t)$ is total catch in weight at year t, $C_n(t)$ is total catch in number at year t, $W(i)$ is average weight of fish from age group i, $p(t, i)$ is proportion of catch number from age group i to total catch number at year t.

Then according to the interpolated proportions $p(t, i)$ of different age groups to total catch numbers, the catch numbers for the different ages from 1967-1971 were derived. The results are shown in *table* 1.

where lt stands for last year. The fishing mortalities of terminal age group for different years were then set equal to the averages of estimates of fishing mortalities of the last two age groups. Thus it was assumed that exploitation pattern was the same for the oldest two ages. Then, a VPA was rerun. This sequence was repeated until the $F(lt, i)$ and the terminal fishing mortalities for every cohort converged. The calculation schema is shown in *figure* 4. The age compositions of the stock and fishing mortalities for different ages in different years were obtained (*table* 2 and 3). Natural mortality was fixed at $M = 0.44\ \text{year}^{-1}$ (Hu and Zu, 1986). A sensitivity test shows that the uncertainty of M will affect the results; a 10% change in M, which was considered as the likely range of error, will cause a 1-7% change in estimated recruitment and fishing mortalities.

The average of the fishing mortalities of different age groups, from VPA, excluding age 0 and the terminal age, were taken as the average fishing mortality for that year. Relating fishing effort to fishing mortality for each year, we get the relationship:

Table 1. – Age composition of hairtail catch from 1959-1977. The unit is a hundred million.

YEAR\AGE	0	1	2	3	4	5
1959	0.257	5.627	0.818	0.056	0.008	0.004
1960	0.167	7.877	0.801	0.078	0.023	0.014
1961	0.282	5.279	0.630	0.099	0.025	0.016
1962	0.086	6.256	1.239	0.153	0.032	0.013
1963	0.456	8.659	1.455	0.176	0.038	0.015
1964	1.255	11.090	2.369	0.212	0.039	0.018
1965	0.620	13.706	1.219	0.099	0.023	0.013
1966	1.895	11.833	1.436	0.124	0.024	0.007
1967	**1.345**	**12.040**	**1.293**	**0.121**	**0.025**	**0.012**
1968	**1.131**	**9.200**	**0.924**	**0.083**	**0.017**	**0.008**
1969	**1.512**	**11.310**	**1.053**	**0.091**	**0.018**	**0.008**
1970	**1.639**	**11.320**	**0.973**	**0.080**	**0.016**	**0.007**
1971	**1.900**	**12.155**	**0.956**	**0.074**	**0.014**	**0.006**
1972	5.158	18.736	1.265	0.044	0.005	0.002
1973	5.315	22.877	0.904	0.033	0.003	0.000
1974	1.522	22.880	1.186	0.030	0.004	0.000
1975	3.426	19.331	0.879	0.058	0.006	0.000
1976	3.510	15.154	0.689	0.024	0.002	0.000
1977	3.480	15.818	0.646	0.022	0.002	0.000

Tuned VPA was applied to the estimated catch at age in numbers derived above. The essence of the tuning method (Laurec and Shepherd, 1983) consists of finding the log catchability coefficient

$$Q(t, i) = \ln[F(t, i)/E(t)]$$

where $F(t, i)$ is fishing mortality of age i at year t, $E(t)$ is effort at year t, for each age and year except the last year. The terminal fishing mortality rate for last year, $F(lt, i)$, was tuned by the fishing effort and $Q'(i)$, the mean value of $Q(t, i)$ of age group i over years:

$$F(lt, i) = E(lt)\exp[Q'(i)]$$

$$F = 0.064\,E \qquad (r^2 = 0.92)$$

where F is fishing mortality, E is fishing effort in 10^4 horse power-year, r is correlation coefficient (see *fig.* 5).

In this paper, we use horse power-year (HPY) as the measure of fishing effort. This is because most fishing gears in this fishery are very similar, but the fishing boats have quite a wide size range. According to the statistical data, the yearly catch of a vessel is proportional to the horsepower of its engine. Since we are concerned with relative units, the horse power-year can be used as the measure of fishing effort

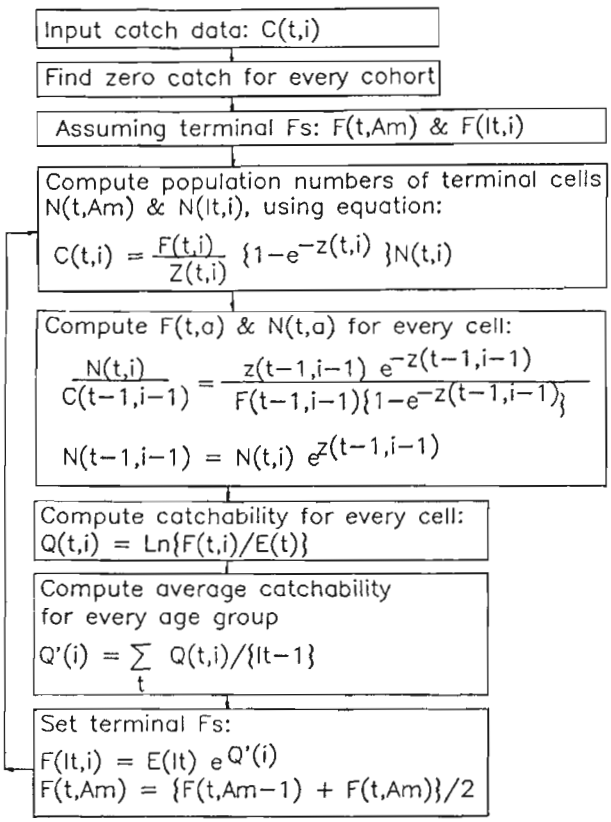

Figure 4. – Calculation schema of virtual population analysis (VPA).

(Gulland, 1983). Some completely different fishing gears which make up a small proportion of the total effort were standardised according to their catches.

A surplus production model for hairtail

For fisheries management, the most important thing is the knowledge of the population dynamics and its response to fishing and regulation measures of management. VPA *per se* is of no use in predicting into the future. It is essentially a method for reconstructing historical abundance (Beddington and Cooke, 1984), which is very helpful for understanding the population dynamics of stock. Here, the VPA results were used for a comparison and as basic data for our modified production model. Whereas general production models are quite useful for studying potential yield and predicting the future status of stock. For example, MSY is a useful reference quantity to know, because at the very least it provides some sort of scaling for catches. If current catches are greater than MSY, one can after all be reasonably sure that they are not sustainable. In the stock production method little attempt is usually made to separate the effects of recruitment, growth and natural mortality: one deals with net production. Changes of exploitation pattern lead to different results, and the inability of stock production methods to deal with such effects is simply because they are over-simplified in this respect (Shepherd, 1982, 1988). Here, a modification of production model presented by Schaefer (1957) was used, which takes into account changes of age composition of catch and makes it possible to study what combination of first capture age and fishing effort should be kept in order to obtain the maximum sustainable yield and what will happen to the stock in response to different strategies.

Schaefer assumed that the population follows a logistic growth and the yields from each year are proportional to the total stock biomass. The latter may not be true, because the unfishable population under first capture age has no direct influence on the year's catch. In this model the yield at time t is assumed to be proportional to the fishable stock size, which only consists of catchable individuals. So we have the following equations:

$$\frac{dX_t}{dt} = r X_t\left(1 - \frac{X_t}{K}\right) - \frac{dY_t}{dt}$$

$$\frac{dY_t}{dt} = q a_t E_t X_t \qquad (1)$$

$$a_t = \sum_{i=A_c}^{A_m} N_{t,i} W_{t,i} / \sum_{i=0}^{A_m} N_{t,i} W_{t,i}$$

where

X_t is total stock biomass at time t.

Y_t is catch at time t.

E_t is fishing effort at time t.

a_t is proportion coefficient of fishable stock to total stock at time t.

i is age.

$N_{t,i}$ is number of age i at time t.

$W_{t,i}$ is weight of age i at time t.

A_c is age at first capture.

A_m is maximum age of fish.

r is maximum rate of population growth.

K is carrying capacity.

q is catchability coefficient.

Under the assumption that the fishing effort and the coefficients of proportionality are constant within

Table 2. – Age composition of hairtail stock from 1959-1977 (VPA results). The unit is a hundred million.

YEAR\AGE	0	1	2	3	4	5
1959	17.773	8.849	1.434	0.293	0.114	0.024
1960	14.903	11.242	1.426	0.298	0.145	0.067
1961	17.244	9.465	1.316	0.305	0.131	0.075
1962	23.516	10.882	2.050	0.361	0.119	0.064
1963	25.005	15.077	2.229	0.377	0.114	0.052
1964	31.199	15.742	3.088	0.335	0.107	0.044
1965	26.420	19.096	1.811	0.232	0.055	0.038
1966	27.110	16.523	2.012	0.247	0.072	0.017
1967	21.717	15.956	1.761	0.221	0.063	0.028
1968	24.788	12.919	1.337	0.170	0.049	0.021
1969	24.936	15.066	1.418	0.166	0.045	0.019
1970	27.498	14.860	1.278	0.128	0.037	0.015
1971	37.833	16.408	1.184	0.100	0.022	0.012
1972	50.250	22.857	1.488	0.061	0.009	0.003
1973	49.501	28.277	1.109	0.049	0.006	0.000
1974	37.381	27.670	1.458	0.051	0.006	0.000
1975	32.457	22.865	1.043	0.071	0.010	0.000
1976	31.558	18.190	0.818	0.033	0.003	0.000
1977	29.092	17.545	0.718	0.028	0.003	0.000

time t or change in steps, we can integrate the differential equations **(1)** and get the following results:

$$X_t = \frac{(r - q E_t a_t) K}{r\{1 + [(r - q E_t a_t) K/(r X_0) - 1] \exp[-(r - q E_t a_t) t]\}}$$
$$Y_t = \frac{q E_t a_t K}{r} \mathrm{Ln}\left[\frac{r X_0 [\exp((r - q E_t a_t) t) - 1]}{(r - q E_t a_t) K} + 1\right] \quad (2)$$

where

X_0 is initial stock size, X_t is stock size at time t, Y_t is cumulative catch to time t.

If time t is fixed to one year, the stock size at the end of the year and the year's catch are as follows:

$$X_1 = \frac{(r - q E a) K}{r\{1 + [(r - q E a) K/(r X_0) - 1] \exp[-(r - q E a)]\}}$$
$$Y_1 = \frac{q E a K}{r} \mathrm{Ln}\left[\frac{r X_0 [\exp(r - q E a) - 1]}{(r - q E a) K} + 1\right]. \quad (3)$$

Where E and a are fishing effort and coefficient of proportionality respectively for that year. It is clear from the equations above that, given estimates of r, K, q and the initial population size, the stock size and catches of every year can be calculated step by step from the fishing effort data.

What is the effect of limiting fishing time on the stock? From equation **(2)**, if the closed period of the year is of length T, during which no fishing occurs, the stock after time T is:

$$X_T = \frac{K}{1 + (K/X_0 - 1) \exp(-r T)}. \quad (4)$$

After time T, effort E is exerted to the end of year and the stock at the end of year and the catch are as follows:

$$X_1 = \frac{(r - q E a) K}{r\{1 + [(r - q E a) K/(r X_T) - 1] \exp[-(r - q E a)(1 - T)]\}}$$
$$Y_1 = \frac{q E a K}{r} \mathrm{Ln}\left[\frac{r X_T [\exp((r - q E a)(1 - T)) - 1]}{(r - q E a) K} + 1\right]. \quad (5)$$

Using equations **(4)** and **(5)**, we can project the trajectories of stock size and catch under different scenarios of seasonal closures. Note that the stock will not be in equilibrium. The calculation of the catchable proportion coefficient (a) is difficult. But note that $a = f(E, A_c)$, which, if A_c is fixed, is very insensitive to changes of fishing effort when the fishing effort becomes large enough (*fig.* 6). So we can use the catchable proportion coefficient at steady state for a given fishing effort and age at first capture as an approximation.

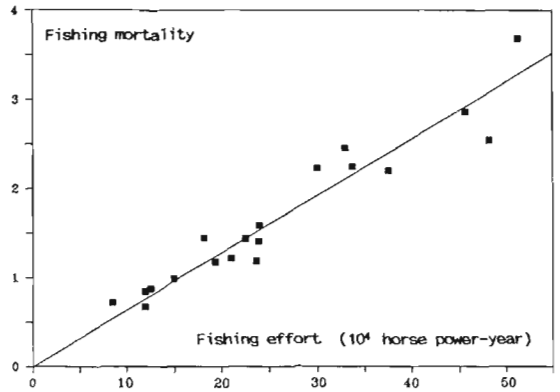

Figure 5. – Relationship between fishing mortality and effort (10^4 horse power per year).

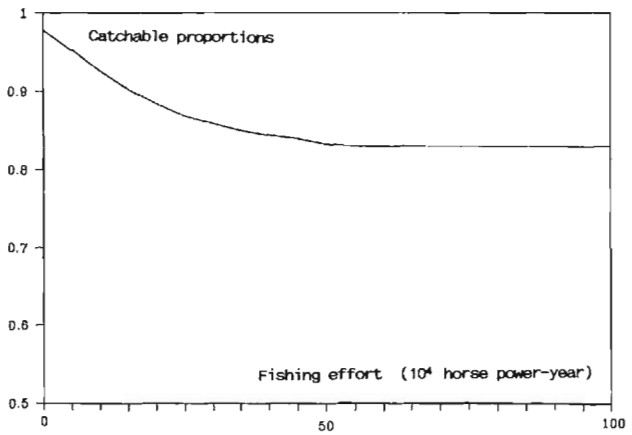

Figure 6. – Catchable proportion over fishing effort (10^4 horse power-year) under fixed age of first capture.

Determination of parameters

The basic framework is simply a mathematical expression for the application of a common statistical technique, least square, to examine the discrepancy between observations of catch and stock and the values of those estimated from production model in order to determine the most appropriate estimate of parameters, r, K and q. That is, we require to find

$$\text{minimise} \sum_t [(Y_t - Y'_t)^2 + (X_t - X'_t)^2] \qquad (6)$$

where Y_t, X_t is catch and stock calculated from production model at year t; Y'_t, X'_t is observed catch and stock from VPA at year t.

In theory, equation **(3)** can be used for the calculation of X_t and Y_t in equation **(6)**. However, the complexity of the function makes the minimisation very difficult. Here, rewriting the differential equations **(1)** into difference equations and setting $\Delta t = 1$, we have:

$$\Delta Y = q\,E\,a\,X$$
$$\Delta X = r\,X(1 - X/K) - \Delta Y$$

where ΔY is year's catch, ΔX is yearly growth in stock size. So, this is equal to:

$$Y_t = q\,E_t\,a_t\,X_t$$
$$X_{t+1} = X_t + r\,X_t(1 - X_t/K) - Y_t \qquad (7)$$

where t is time in years. Substituting equation **(7)** into equation **(6)**, we get the least-squares estimates for the parameters of **(6)**: $r = 2.5$, $K = 591.10^3$ metric tons and $q = 0.0175/10^4$ HPY.

Equilibrium yield

If the stock is at equilibrium, from equations **(1)**, we can obtain the equilibrium yields from different stock sizes:

$$Y_e = r\,X(1 - X/K). \qquad (8)$$

The greatest value of Y_e occurs when $X = K/2$ and is equal to:

$$MSY = r\,K/4.$$

Equation **(7)** can be rewritten in terms of fishing effort, E, by writing $X = K(1 - q\,E\,a/r)$:

$$Y_e = q\,E\,a\,K(1 - q\,E\,a/r). \qquad (9)$$

It is clear, $Y_e = f(E, A_c)$. At equilibrium, the catchable proportions are:

$$a = \frac{\exp(-MA_c)\left[\sum_{i=A_c}^{A_m} W_i \exp(-(F+M)(i-A_c))\right]}{\sum_{i=0}^{A_c-1} W_i \exp(-M\,i) + \exp[-MA_c]} \times \frac{1}{\left\{\sum_{i=A_c}^{A_m} W_i \exp[-(F+M)(i-A_c)]\right\}}. \qquad (3)$$

Combining equations **(9)**, **(10)** and $F = 0.064\,E$, we can get the isopleth of yields (*fig.* 7).

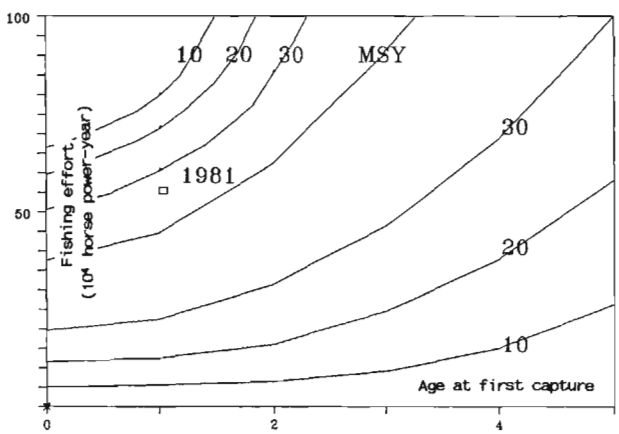

Figure 7. – Yield-isopleth diagram for hairtail; yield: 10^4 ton; fishing effort: 10^4 horse power per year; MSY: maximum sustainable yield).

RESULTS

Model comparison

After estimating all the parameters in equation (3) and the initial stock size in 1959, which was known from VPA, 240.10^3 metric tons, we can simulate the historic changes of stock and catches, based on the fishing effort data. The results are shown on *figures* 8

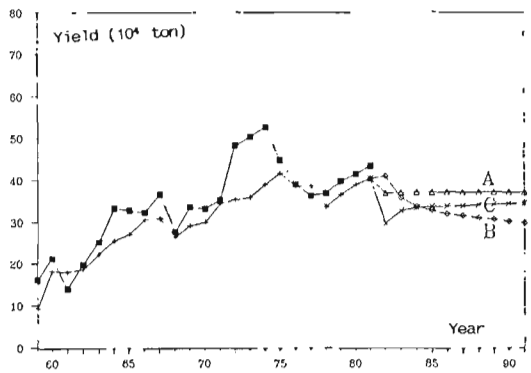

Figure 8. – Yields observed and predicted of hairtail (yield: 10^4 ton; ■ actual yield; + predicted yield; A, B and C expected yield).

and 9. The catches fit well, but stock sizes less so. During 1960-1962, the simulated stock sizes are much higher than the VPA results, but the stock was larger than simulated during 1970-1973.

Well known results for conventional VPA (Pope, 1972) demonstrated that the errors from arbitrarily setting the terminal fishing mortalities for every cohort decrease exponentially with increasing cumulative fishing mortality. If the terminal fishing mortality $F_{A\,m}$ was overestimated 100% for a year class and the cumulative fishing mortality from cell i to cell $A_m - 1$ was 2.0, then the percentage error in N_i would be at most -7% and the percentage error in F_i would be at most $+7\%$ (Pope, 1972). So, in general, it has been thought that VPA can obtain quite good estimates of fishing mortalities and population size for long-lives species. Shepherd (1988) points out that a few (say five) age classes are sufficient for most purposes, although a few more may sometimes be useful as an aid to determining fishing mortality, especially if it is low. Hairtail is not a long-lived species, six age groups, but it has quite a high fishing mortality for every age group. The big, sharply increasing cumulative fishing mortalities make the errors of estimates of fishing mortality and population number become quite small quickly. On the other hand, the population number beyond 3 years old is only a very small proportion of the total stock (*table* 1 and 3). This guarantees that even if there are some errors of estimates in the oldest age group, the estimates of total biomass for every year, which will be used in the age-structured production model later, will not suffer too much. The Xu assessed total biomass of hairtail stock in the East China Sea, on the basis of total catch data (Xu, 1988) gives results similar to our VPA (*fig.* 9).

The Laurec-Shepherd tuning method assumes that catchability is constant over time. If this assumption is untenable, the method should work well for tuning the fishing mortalities of the oldest age group in each year, but may result in errors in estimating fishing mortalities for every age group of the last data year. The hypothesis of constant catchability implies the catch in numbers per unit effort (CPUE) should be proportional to the population number for every age group. In *figure* 10, it can be seen that the CPUE has a trend very similar to the population number. For the age group of one year old, there are some

Table 3. – Fishing mortality of different ages in different years (VPA results).

YEAR\AGE	0	1	2	3	4	5
1959	0.018	1.386	1.132	0.267	0.090	0.232
1960	0.014	1.705	1.103	0.385	0.217	0.294
1961	0.020	1.090	0.853	0.502	0.267	0.302
1962	0.005	1.146	1.254	0.713	0.398	0.284
1963	0.023	1.146	1.456	0.823	0.518	0.438
1964	0.051	1.723	2.150	1.374	0.585	0.686
1965	0.029	1.811	1.553	0.724	0.709	0.532
1966	0.090	1.799	1.770	0.920	0.515	0.671
1967	0.079	2.039	1.898	1.058	0.648	0.732
1968	0.058	1.770	1.647	0.879	0.540	0.604
1969	0.078	2.027	1.963	1.058	0.650	0.734
1970	0.076	2.090	2.112	1.330	0.732	0.800
1971	0.064	1.960	2.524	1.977	1.409	0.975
1972	0.135	2.586	2.984	1.810	1.172	1.172
1973	0.142	2.525	2.638	1.588	1.106	0.000
1974	0.052	2.839	2.588	1.188	0.819	0.000
1975	0.139	2.890	3.024	2.676	1.343	0.000
1976	0.147	2.793	2.943	1.904	1.232	0.000
1977	0.159	4.386	4.333	2.363	1.396	0.000

differences in the first and last years, but a similar trend was kept from 1963 to 1971. This suggests that the catchability was higher in the first period and lower in the last few years than in the middle period. In the tuning process, a mean value of catchability is used, and even in this case the estimate of terminal F may not suffer too much.

The tuned VPA should be reliable in this case if the catch at age data is good. However, the simulated stock sizes are much higher than the VPA results during 1960-1962. This may be because the fishery was developing in this period (*fig.* 2) and did not cover the whole stock, which may be supported to some extent by Xu's assessment. Useful information on historic stock size can be obtained only when the level of exploitation is reasonably high (Shepherd, 1988). So, the estimates of stock size from such a data of catch at age must be under true values. The other significant point is that the stock is larger than simulated during 1970-1973. Obviously, it is because of the extra strong recruitment in this period (*table* 2). The production model is unable to consider the influence of recruitment on stock size. It deals only with net production. The major part of hairtail stock consists of one and two-year-old fish and the effect of recruitment on stock size is obvious. Therefore, what the production model can describe is the general situation of the stock. Any favourable environmental condition may result in an extra strong recruitment and will change the situation of stock.

Regulatory measures

From the isopleth of yield (*fig.* 7), it is clear that different ages at first capture will yield different levels of optimal fishing effort. For example, in the current fishing regime, the age at first capture is one year and the optimal fishing effort should be about 425.10^3 horse power-year (HPY) to obtain maximum equilibrium yield. If the first capture age is raised to two years old, a fishing effort of about 600.10^3 HPY should be maintained. In 1981, the fishing effort was 508.10^3 HPY, which was too large to get the maximum equilibrium yield. If this regime remained, yields would have been about 320.10^3 metric tons. In practice, owing to the introduction of closed fishing season from 1982, higher yields were obtained.

In figure 7, it can also be seen that the age at first capture should be kept between one and two. If it is beyond two, a great increase of fishing effort will be needed. Even though the average size of individuals in the catch is larger, this may not be worthwhile economically. If age at first capture is less than one, recruitment failure may result, because the age at maturity for hairtail is one year. Controlling the age at first capture by mesh size is possible, but not very precise. To protect the juveniles, it is probably necessary to restrict fishing activity on the nursery areas where there is a high proportion of juveniles.

DISCUSSION

The Chinese government introduced regularoty measures from 1982. The first was the issue of fishing licences for limiting the dramatic expansion of fishing effort. The second was a 3-month closed season. Under these management strategies what changes occurred to the stock and catches? With additional fishing effort data it is very easy to answer these questions using the equations above. However, the exact data are not available. It is known, however, that the fishing boats with 600.10^3 HP in 1986 were engaged in this fishery. Catches of recent years were always near 400.10^3 metric tons (Hu and Zu, 1986). We assume the fishing effort increased at the same rate every year from 1981 to 1986 and this trend has continued thereafter (*fig.* 2). Using equations **(4)** and **(5)**, the trajectories of catch and stock size were obtained (*fig.* 8 line A and *fig.* 9 line A).

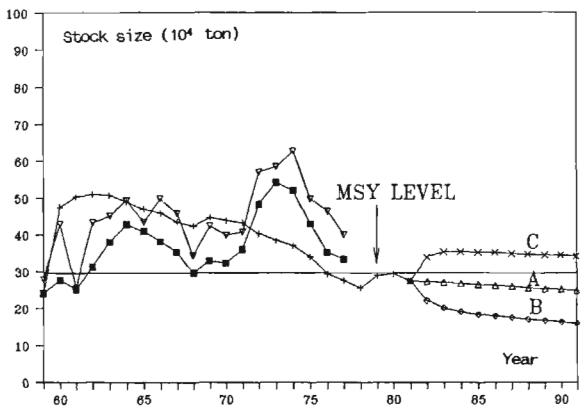

Figure 9. – Change process of the hairtail population size (stock size: 10^4 ton; ■ VPA results; + predicted; ▽ Xu's assessment; A, B and C expected results).

The stock size at the end of 1986 was 262.10^3 metric tons, about 89 per cent of the level under which the maximum equilibrium yield can be obtained. The catches were maintained at more than 372.10^3 metric tons, which fits in well with the yield levels noted above. Obviously, these catches were almost the same as the maximum sustainable yield, MSY (371.10^3 metric tons), but the stock is not at equilibrium. These catches were obtained by high fishing efforts and supported by the depletion of stock, which eventually must lead to a decline of the annual yield. The 1988 catch was in fact smaller than the previous years. If the fishing effort continues to increase, the stock will be depleted more heavily and the catches will decline gradually. Therefore, to arrest the further decline of stock and catch, it is most important to control the expansion of fishing effort. Although a fishing licence system was put into effect in 1982, the expansion of effort has not been stopped completely but has only been slowed down.

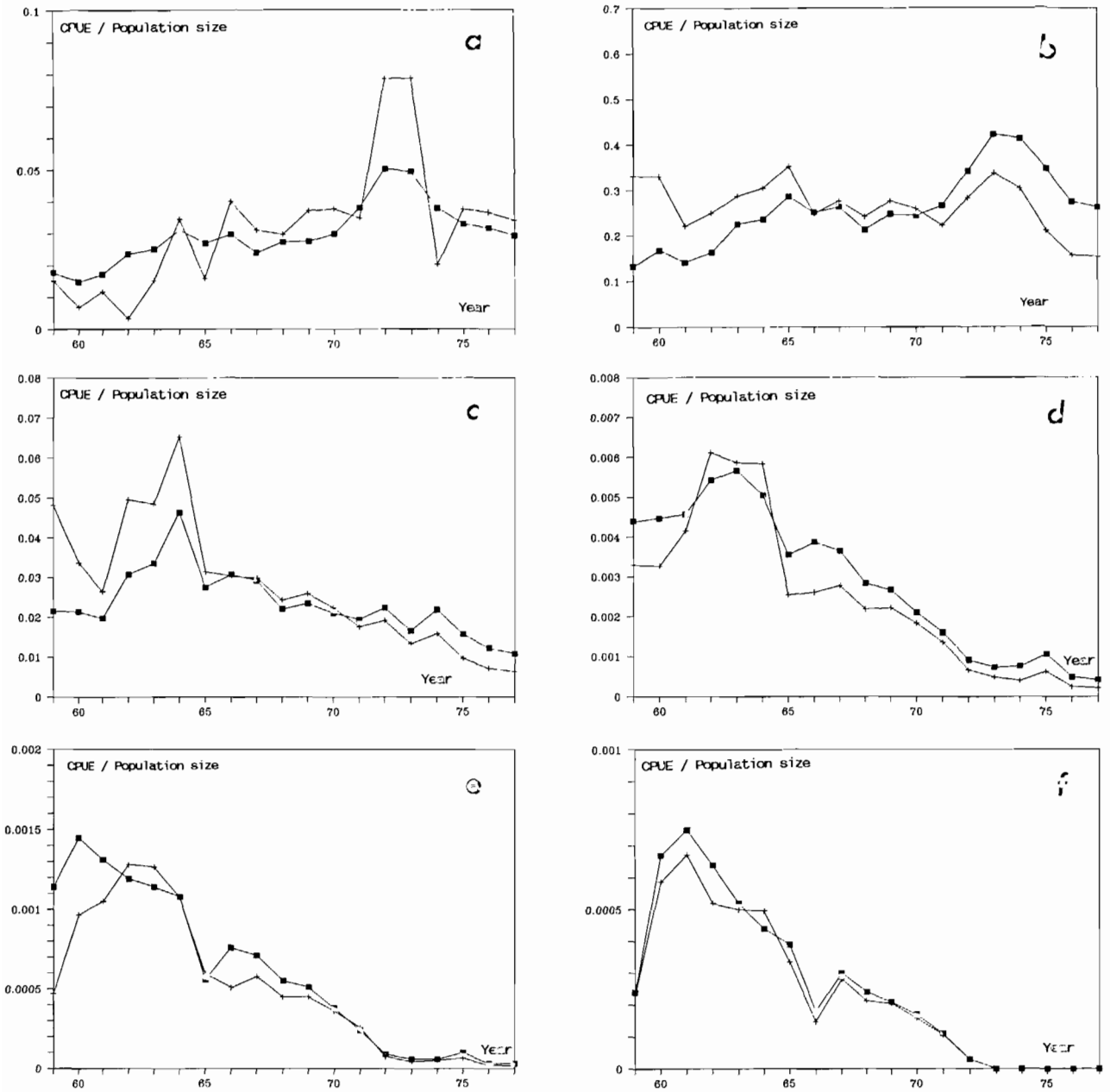

Figure 13. – Comparison between CPUE and population size; age group 0 (a); age group 1 (b); age group 2 (c); age group 3 (d); age group 4 (e); age group 5 (f); ∴ population size; + CPUE.

If the fishing effort had increased at the projected rate (*fig.* 2), but there was no closed season, the catch and stock size would have changed as in *figure* 8 line B and *figure* 9 line B. The stock would have been heavily overfished, 180.10^3 metric tons, only 61 per cent of MSY level, and catch would have declined sharply, 320.10^3 metric tons in 1986. So, the regulation measures put into effect from 1982 played a very important role in preserving the stock of hairtail by partially restricting fishing effort.

If, under the projected fishing regime (fishing effort increasing as in *figure* 2 and a 3-month closed season), the age at first capture also had been raised to two years old, the curves of change of catch and stock size would have been like *figure* 8 line C and *figure* 9 line C. The stock size remains larger than under situation A and situation B and that at which the maximum equilibrium yield can be taken, but the catches in the early years will be lower than under situation A and B. Some years later, the annual yield will approach the level of situation A gradually. Under this strategy (C), the stock will become more stable and can bear more serious natural disturbance and heavier fishing. The catch will consist of larger

individuals, which may lead to a higher income from the fishery. If management for this fishery attaches importance to the employment of fishermen, increasing the age at first capture may both conserve the resource and improve fishermen's income.

CONCLUSION

Simulation models similar to the one described in this paper have been applied extensively to fisheries problems (Larkin and Hourston, 1964; Sissenwine, 1977; Rivard, 1982). Their advantages are they can simulate both past and future populations and associated yields and examine the effect of different management strategies.

These simulation results suggest the stock of hairtail has been declining in general since the beginning of the 1960s, except the period from 1971-1973 when unusual strong recruitments occurred. At the beginning of 1981, the stock size was 275.10^3 metric tons, less than that under which the maximum equilibrium yield can be taken. At that time the stock was overfished but not seriously. The management strategies introduced afterwards brought some positive effects to stock size and catches by slowing down the decline, but they have not reversed the effects of overfishing of the stock. It is predicted that the current fishing regime will have the following effects. If fishing effort increases and the closed fishing season is fixed to three months, this will inevitably lead to heavier depletion of the hairtail stock. The catches will ultimately decrease. Therefore, in order to prevent the further deterioration of the stock and keep yield as high as possible, the further expansion of fishing effort must be stopped. Alternatively, a longer closed season should be introduced or the age at first capture should be raised.

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