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Biological and economic factors in the selection of cultured fish species and the development of a bio-economic model

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Abstract — *The selection of candidate species for mariculture is determined by a number of biological factors, e.g. foraging efficiency, growth efficiency, mortality, grow-out period and susceptibility to environmental fluctuations, disease and crowding, as well as economic factors e.g. the supply and price of fry, grow-out cost and price of adult. A computer model incorporating these major factors is being developed, to determine and compare the potential of different culture species. Results of environmental tolerance experiments on 16 marine fish species revealed that some species, e.g.* ***Mylio macrocephalus****, are euryhaline and may be cultured in areas with fluctuating salinities. Other species, e.g.,* ***Epinephelus tauvina*** *and* ***Lates calcarifer*** *are hypoxia tolerant and can be cultured in waters where oxygen depletions may occur. These two species are, however, particularly sensitive to cold and may have over-wintering problems. The application of environmental tolerance data in selecting appropriate candidate species to suit different hydrographic conditions at different culture sites is demonstrated.*

INTRODUCTION

Selection of appropriate species is one of the most important factors in determining the success of fish farming. The desirable economic and biological attributes of a cultured species are given in Table I. Economically, the price of fry and grow-out costs should be relatively low while adults should be well received by the market and fetch a high price. The supply of fry should be stable and non-limiting. Biologically, cultured species should be able to withstand prevailing environmental fluctuations, and have high growth and foraging efficiencies, low mortality, a short grow-out period, and low susceptibilities to crowding and pathological infections. The biology of the cultured species, especially with regard to nutritional requirements, disease diagnosis, prevention and treatment should be well known, although such data are generally not available for most farmed tropical species. This paper elaborates upon the rationale for species selection in Hong Kong, which is largely based on the fish environmental tolerances and comparisons of profit return, using a bio-economic model.

Tab. 1. — Desirable biological and economic attributes of cultured species

BIOLOGICAL ATTRIBUTES	
Foraging efficiency	High
Growth efficiency	High
Tolerance to environmental changes	High
Susceptibility to disease and crowding	Low
Grow-out mortality	Low
ECONOMIC ATTRIBUTES	
Supply of fry	Unlimited and steady
Price of fry	Low
Grow-out period	Short
Grow-out cost	Low
Price of adult	High

SPECIES SELECTION BASED ON ENVIRONMENTAL TOLERANCES

The first pre-requisite for a successful cultured species is the ability to withstand and grow under environmental conditions prevailing at the culture sites. This is particularly important in regions with marked seasonality and/or in estuaries, where cultured fish are often subjected to wide temporal and spatial environmental fluctuations. The paucity of data on environmental requirements and tolerances of marine fish, particularly warm water species, however, often leads to selection based on experience rather than scientific data.

In Hong Kong, all marine fish farming activities are carried out in 28 designated fish culture zones, amongst and within which, spatial and temporal variations in hydrography are large (Fig. 1). Fish culture zones in the western approaches, for example, may be subject to large annual fluctuations in salinity (30 ppt in winter and 7 ppt in summer when discharges from the Pearl River is maximal). Annual water temperature ranges from 12°C to 32°C in all fish culture zones, and fluctuations are particularly marked in waters less than 3 m deep (depths above the thermocline). Dissolved oxygen levels at the culture zones generally vary from 3 to 8 mg $O_2\,l^{-1}$, and in zones where waters are eutrophic or organically enriched, oxygen depletions ($<$ 1 mg $O_2\,l^{-1}$) caused by algal blooms and red tides may occasionally occur, leading to fish kills.

In view of the above problems, a series of environmental tolerance experiments have been carried out for 16 commonly cultured species (Woo & Wu, 1982; 1984; Wu & Woo, 1982, 1984; Wu, 1988), in order to provide a scientific basis for selecting species best suited to the particular environmental conditions at different sites.

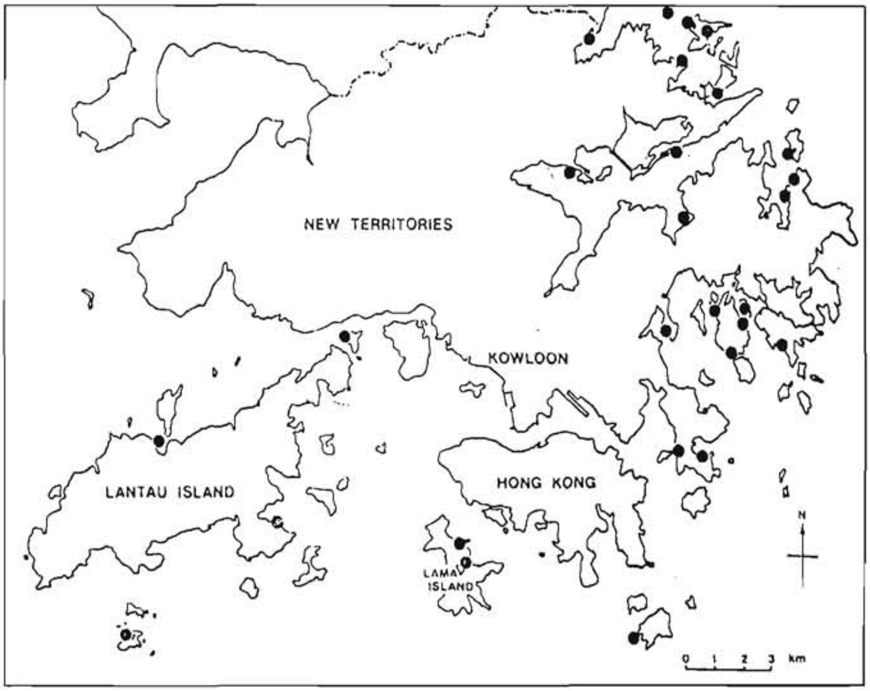


Figure 1. — A map showing the distribution of the 28 fish culture zones in Hong Kong and general hydrographic conditions.

The mortality, behavioural changes and physiological responses of nine species of marine fish under various levels of hypoxia were compared (Table 2). Large variations in tolerances between different species were found, and some species exhibited remarkable tolerances to hypoxic stress. For example, *Epinephelus tauvina* and *Lates calcarifer* survived without symptoms for 7 hours when subjected to 1 mg $O_2\,l^{-1}$, and only 10 % mortality was found for the former species at 0.5 mg $O_2\,l^{-1}$. In contrast, *Chrysophrys major* and *Rhabdosarga sarba* exhibited abnormal behaviour, followed by death, within minutes when subjected to the same level of hypoxic stress. The above laboratory findings are further supported by fish kill statistics in Hong Kong : *C. major* and *R. sarba* always suffering heavy losses in fish kills caused by hypoxia, while other species are normally affected to a lesser extent. Conversely, *L. calcarifer* and *E. tauvina* which have never been implicated in any fish kills due to oxygen depletions, showed a high tolerance to hypoxia in the laboratory (Wu, 1989).

Tab. 2. — Time (in min.) for 50 % of various experimental fish to show mortality (LT_{50}) and abnormal behaviours (BC_{50}). For mortality/behavioural changes ocurring in less than 50 % of the population throughout the experimental period, actual mortalities are shown in brackets (After Wu, 1989)

SPECIES	0.5 mg O_2 l^{-1}		1.0 mg O_2 l^{-1}	
	BC_{50}	LT_{50}	BC_{50}	LT_{50}
Chrysophrys major	TQC	TQC	20	60
Rhabdosarga sarba	TQC	TQC	130	225
Siganus oramin	TQC	7	10	177
Lutjanus ruselli	TQC	14	76	(30 %)
Epinephelus akaara	70	92	110	160
Mylio macrocephalus	30	100	NBC	NM
Epinephelus awoara	150	200	190	270
Lates calcarifer	373	393	NBC	NM
Epinephelus tauvina	(10 %)	(10 %)	NBC	NM

* TQC = Too quick to count NBC = No behavioral changes
NM = No mortality

Detailed biochemical studies on *Ephinephelus akaara* and *Mylio macrocephalus*, respectively exposed to hypoxic conditions of 4.0 to 2.5 mg O_2/l revealed no increases in serum and tissue lactate, and only slight changes in other tissue metabolites and electrolytes indicating that they obtain enough oxygen to prevent anaerobiosis under such regimes (Woo and Wu, 1984).

The overall results therefore suggest that hypoxia tolerant species such as *Lates calcarifer* and *M. macrocephalus* may be cultured in eutrophic waters where oxygen depletions are more likely to occur, while sensitive species such as *C. major* and *R. sarba*, should not be cultured in such environments.

Wu and Woo (1982) showed that ten out of thirteen tested species are euryhaline, and survived without abnormal behaviour and tissue hydration for more than two weeks in salinities > 10 ppt. Further experiments carried out upon *E. akaara* and *M. macrocephalus* showed only transient disturbance of various electrolytes and metabolites at salinities > 12 ppt, suggesting that physiological disturbance is unlikely to occur at salinities above this (Woo & Wu, 1982). It therefore appears that salinities above this regime would not normally limit culture most of these species.

Tolerances to cold (12°C) were compared for 8 species. Experimental results showed that *S. oramin*, *L. calcarifer* and *E. tauvina* are relatively sensitive to cold, while *E. akaara*, *E. awoara* and *M. macrocephalus* are more tolerant (Table 3).

The laboratory findings were clearly supported by fish kill statistics in Hong Kong : a high mortality of the former three species was found during cold spells when water temperatures fall below 15°C for a prolonged period (> 7 days). Contrarily, *Mylio macrocephalus*, *Epinephelus*

Tab. 3. — Time (in min.) for 50 % of experimental animals to exhibit abnormal behaviors (BC_{50}) at 12°C (n = 20). (After Wu, 1989)

Species	BC_{50} (%)	Mortality (%)
Siganus oramin	TQC	20
Lates calcarifer	1	—
Epinephelus tauvina	20	—
Rhabdosarga sarba	50	—
Chrysophyrs major	89	—
Epinephelus akaara	NBC	—
Epinephelus awoara	NBC	—
Mylio macrocephalus	NBC	—

* NBC = No behavioral changes, TQC = Too quick to count.

akaara and *Epinephelus awoara* which showed no abnormal behaviours at 12°C in the laboratory, have never been reported upon in fish kills caused by cold spells. The results therefore indicate over-wintering problems for *L. calcarifer* and *E. tauvina* in Hong Kong. Shortening of the grow-out period by, for example, importing larger fingerlings might minimize the risk of fish kills for these two species in a severe winter.

The upper lethal temperatures of *Chrysophrys major* and *Mylio macrocephalus* were found to be 32°C and 36°C respectively (Woo and Fung, 1980). The low tolerance of *C. major* to high water temperatures suggests that this species is less suitable for culture in shallow waters, i.e. < 3 m, the shallowest thermocline in the coastal waters of Hong Kong, where water may easily be heated up by solar radiation in the summer, to a temperature beyond the lethal limit for this species.

BIO-ECONOMIC MODEL

The ultimate success of fish farming is determined by the economic return which is, in turn, dependent upon a number of biological and economic factors, namely, food conversion ratio, grow-out period, age-specific mortality, price of fry and adult, grow-out cost (labour and feed), etc.... Each of these parameters varies with different species. For example, the price of *C. major* fry is $1 each and 80 % can be expected to grow to marketable adults in 12 months when the market price will be HK $40/kg. The price of fry for *E. tauvina* is much higher (HK $14 each), the grow-out period is longer (18 months) and only 62 % can be expected to grow to marketable adults, but their price is HK $94/kg. The price for *E. akaara* is HK $16 each, the grow-out period is the longest (24 months) and only 58 % can be expected to grow to market adults, but their price is very high (HK $ 135/Kg). The grow-out costs for these three species is also different because of differences in their daily feed ratio, grow-out period and age-specific mortality and growth (Table 4; Fig. 2).

Tab. 4. — Some biological and economic parameters of six common cultured species in Hong Kong

Species	Price of fry ($.no^{-1})	Price of 450g adult ($.kg^{-1})	Grow out period (M)	Survival rate (%)	Daily feed (% body wt)
Chrysophrys major	1	40	12	80	6
Epinephelus akaara	14	135	24	58	4
Epinephelus tauvina	12	94	18	62	5
Rhabdosarga sarba	3	44	18	?	?
Mylio macrocephalus	2	75	24	?	?
Lates calcarifer	3	58	12	?	?

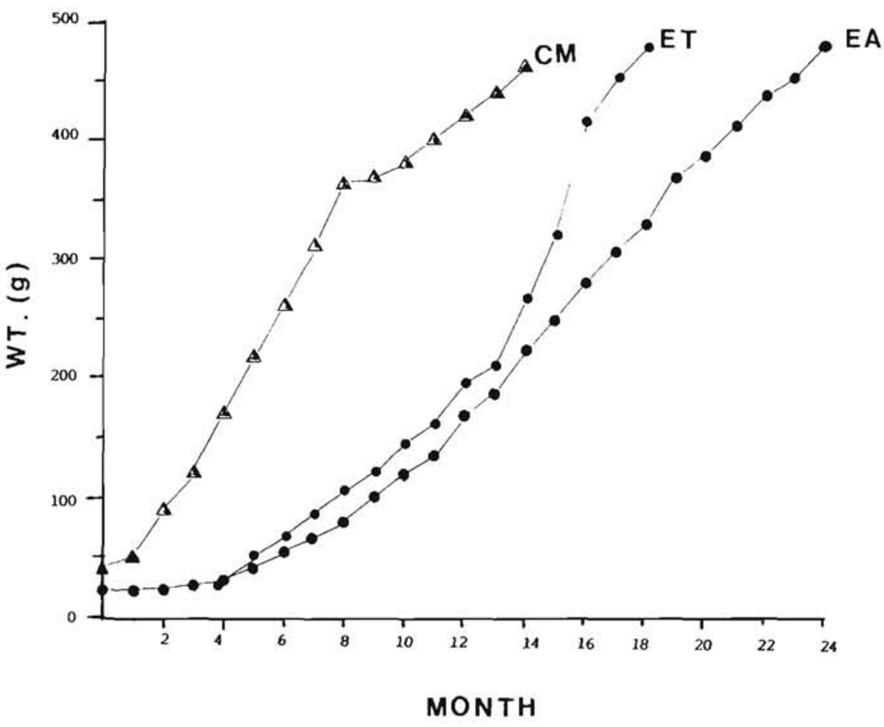
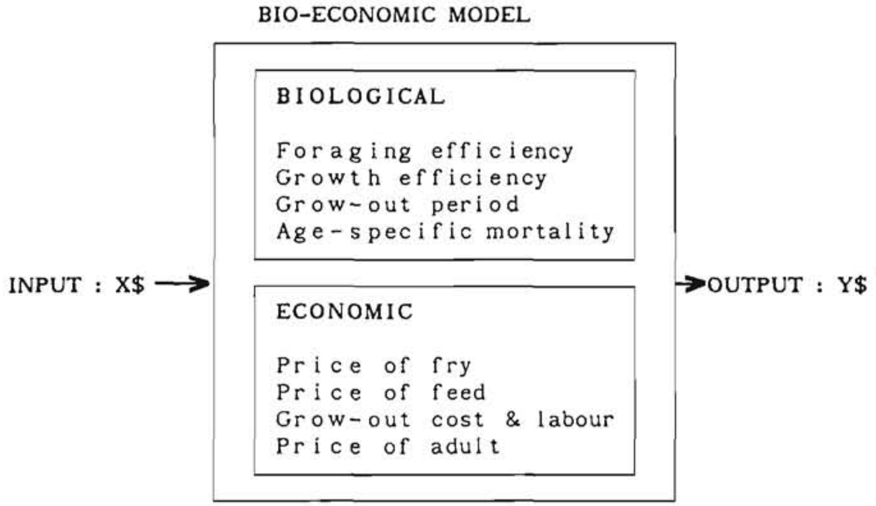


Figure 2. — Age specific growth curves for *Chryophrys major* (CM), *Epinephelus tauvina* (ET) and *Epinephelus akaara* (EA).

A computer model has been developed, in which the above biological and economic factors have been taken into consideration, for computing and comparing the profit return (profit per $ investment per unit time) of different cultured species under varying conditions (Fig. 3). Such an analysis provides a comparison of potential economic return for different species under different conditions, e.g. change in the price of feed, fry or adult, reduced grow-out mortality, etc... The most profitable candidate species under a particular suite of environmental and economic conditions can therefore be identified. By comparing the profit return of different species under varying conditions, the major limiting factor for culturing each species can also be identified and further research developed to solve the problem.



$$\text{PROFIT RETURN (\%/yr)} = \frac{12\ (Y-X)/X}{\text{GROW-OUT PERIOD (M)}} \times 100$$

Figure 3. — Bio-economic model for determing profit return of different cultured species.

At present, analyses have been carried out for *C. major*, *E. tauvina* and *E. akaara*. For the values of biological and economic parameters given in Table 2 and Figure 3, and for the present feed cost of HK $ 2 Kg, the calculated profit returns for the three species are : - 18.6 %, 33.0 % and 37.1 % per annum respectively. Assuming that the cost of feed (trash fish) increases from $ 2/kg to $ 3/kg, the profit return per annum of the three species will change to : -16.2 %, 12.2 % and 25.1 % respectively, giving a negative profit return for culturing *C. major*. Assuming that the price of *E. akaara* fry increases from $14 to $16 each, the profit return per annum for *E. akaara* will decrease to 29.4 %. In such case, culturing *E. akaara* would then be less attractive than *E. tauvina* because of the lower profit return. Further analyses are being carried out and extended to other species.

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