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ECONOMIC PROBLEMS OF MARINE FISH CULTURE
WITH SPECIAL REFERENCE TO BLUEFIN TUNA

by

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ABSTRACT

The culture of bluefin tuna has not yet reached a practical business stage in Japan and it is still only in the experimental stage. But, we do have a long history of yellow-tail *Seriola* and kuruma shrimp *Penaeus* culture. Therefore, we are able to consider the economic problems of bluefin tuna culture based on our experience with other mariculture.

This paper examines the most important factors affecting the economics of mariculture with special reference to bluefin tuna using the following formula:

$$A/B > a/b$$

A: selling price per kg of marketable fish
B: buying price per kg of feed
a: conversion ratio from feed to fish
b: weight of feed in total cost

PROBLEMES ECONOMIQUES DE L'ELEVAGE DES POISSONS MARINS,
AVEC REFERENCE PARTICULIERE AU THON ROUGE

L'élevage du thon rouge n'a pas atteint encore le niveau commercial au Japon. Il n'est encore qu'au stade expérimental. Mais, nous avons une longue habitude de l'élevage des sérioles et des pénéides. Donc, nous pouvons examiner les problèmes économiques du thon rouge, à la lumière de nos autres essais d'aquaculture.

Ce papier examine les facteurs les plus importants affectant l'économie de l'aquaculture, utilisant la formule :

$$A/B > a/b$$

A = Prix de marché du poisson
B = Prix d'achat de la nourriture
a = Taux de conversion alimentaire du poisson.
b = Part de la nourriture dans le prix total.

INTRODUCTION

The culture of bluefin tuna has not yet reached a practical business stage in Japan and it is still in the experimental stage. But we do have a long history of yellowtail (*Seriola*) and other fish culture. Therefore, we are able to consider the economice problems of bluefin tuna culture based on our experiences with other cultures. This paper examines the most important factors affecting the economics of fish culture with special reference to bluefin tuna.

I. THE RELATION BETWEEN PROFITABILITY AND THE PRICE OF FISH

Generally speaking in order to keep the fish culture profitable, it is necessary to maintain the following relation :

$$\frac{A}{B} > \frac{a}{b}$$

A = selling price of commercial size fish (per kg)
B = buying price (per kg) of feed
a = conversion ratio from feed to fish
b = weight of feed to total cost.

The present situation of seriola culture in Japan is as follows :

$$\frac{¥\ 1,200 = A}{¥\ 70 = B} > \frac{7 = a}{0,50 = b}$$

$$17.1 > 14.0 \qquad \frac{A/B}{a/b} = 1.22$$

This means that it is possible to make a profit from seriola culture. In the case of bluefin tuna, especially large size tuna, the selling price is very much higher than for seriola and we can get the following relation :

case I

$$\frac{¥\ 3,000}{¥\ 70} > \frac{g}{b}$$

$$42.8 > \frac{g}{b}$$

$$b > 0.21$$

case II

$$\frac{¥\ 3,000}{¥70} > \frac{a}{0.8}$$

$$42.8 > \frac{a}{0.8}$$

$$a < 34.2$$

The result of case I indicates that an increase in feed cost would not affect the profitability very much. The result of case II indicates that it would be possible to make some profit from bluefin tuna culture, because the conversion ratio of bluefin tuna is not higher than 34:1 (Fig. 1). Thus, we can easily understand the profitability of culture using this formula. Here I will name A/B the price balance of fish culture, and a/b the economic density of fish culture, and $\frac{A/B}{a/b}$ as the coefficient of fish culture security.

In order to clarify the relation between the price balance, the economic density, and the conversion ratio, I have made a table (Table 1). In Table 1, column I shows the relation between the selling price of commercial size fish and the buying price of feed, namely the price balance. It shows that when the selling price of fish per kg is ¥ 700 and the price of feed is ¥ 70 per kg, then the price balance is 700/70 = 10. Column II is the weight of feed cost to total cost, namely the economic density of fish culture. This weight is rather low when the number of fish in the pond or cage compared with the invested capital is small. If the price balance is 10:1 and the economic density is 0.10, then we can get the following relation in order to maintain profitability : $10 = \frac{a}{0.1} \qquad a = 1.$

The numbers given in Table 1 show the conversion ratios which will enable management to cover costs without any profit or loss. In the case of seriola culture, the conversion ratio in Japan is about from 6:1 to 8:1, and the price balance has been from 15:1 to 20:1 recently. It is rather difficult to rear seriola with a conversion ratio under 6:1, and an economic density over 0.60. Therefore, it can easily be understood from Table 1 that the area for profit from seriola culture is rather narrow. However, in the case of the bluefin tuna culture, the value of price balance is rather high, especially for large size tuna. This means that bluefin tuna culture can be even more profitable compared with seriola culture, even if the conversion ratio is higher than 10:1. Of course, we could not give a vast amount of feed to the fishes. But, if the mortality of tunas is very high, it results in a high conversion ratio. This means that tuna culture can be profitable not withstanding high mortality as compared with seriola culture.

II. ECONOMIC PROBLEMS IN SERIOLA CULTURE

I have explained that the relation between A/B and a/b is very important in fish culture. In the case of seriola culture in Japan, we can see this relation in practice. The value of A/B is very changeable from year to year, but over a long period there some gradual trends, and the culture methods and system have changed in accordance with these trends. (Fig. 2). Seriola culture in Japan started at the beginning of the 1960's, and at that time the main type of culture was the net enclosure type, which was rather more extensive than the cage type that developed later. At the beginning of seriola culture, the price balance was comparatively high, but it became low from 1960 to 1966 due to the increasing production of cultured seriola. This means that the economic condition of seriola culture became more difficult.

The cage type of seriola culture, which is rather more intensive than the net enclosure type, was developed around 1965. The merit of the net cage is as follows :

A. Mobility

When an emergency occurs, for example red water, it is very important to move the cages from the contaminated sea to another clean area to avoid mass mortality.

B. Adaptability

The areas suitable for net enclosure type culture are limited by the coastal topography, but net cages, especially the sinking cage type, are adaptable to sea areas having rough sea conditions.

C. Efficiency

Using net cages, culturists can raise a greater amount of seriola per m^3 than with the net enclosure type, and they are able to get a high return on their investment. More over, due to the high rate of return small scale fishermen can invest their money in seriola culture as a side work and can get some profit, even if they operate only one cage.

In 1974, the price balance deteriorated to a low level because of the oil crisis, but after that year it improved again. The reason that the price balance is now good because of the low price of low quality fishes, for which there is a diminishing demand as an edible fish. Nowaday, the intake of animal protein by people in Japan has reached the ceiling. They want to eat high quality fishes and various types of meat and they don't want low quality fishes.

During the first stage of the development of seriola culture, the shape of the cage was square and it was made with artificial fiber net due to the low cost of this material. After 1975, the circular wire net cage was developed and has been adopted because it saves labour and it is easy to manage, but the wire net is very expensive, about ten times as expensive as the fiber net. The last net enclosure type unit for seriola culture disappeared in 1974.

From an economic point of view, the cost of feed and seedlings is important because both make up a large part of the total cost (Table 2). The significant point is that the rate of increase in their prices is getting higher. (Fig. 3). This phenomena can be explained by basic economic theory.

Assume, for example, that there are unexploited resources such as feed and seedlings both of which fishermen can get only from the sea, and that there is not artificial hatching and breeding of seedlings. At first, there are only a few culturists so that the demand for feed and seedlings is still small. Owing to the existence of unexploited resources, the price of these items rather cheap and the only cost is that of catching, transporting and preserving them plus average profit. In the second stage, the situation is rather similar. Of course, the amount of unexploited resources is dwindling but there is still a reserve to some extent. In this case, the price maintains the same level as in the first stage theoretically (Fig. 4). Finally, in the last stage, there are no unexploited resources left. As soon as unexploited resources disappear, culturists have to compete with each other to get feed and seedlings, and then the prices start to rise surprisingly fast.

One of the main reasons for the change from fiber to wire netting is the saving of labour and another is to improve the rate of survival and the rate of growth of fishes, because water circulation is much better with wire netting than with fiber netting. As the price of seedlings has risen considerably the age composition of the total quantity of cultured seriola shipped to the market has undergone a marked change (Table 3).

III. ECONOMIC PROBLEMS IN BLUEFIN TUNA CULTURE

As bluefin tuna culture in Japan is just at the experimental stage, the mortality of cultured fish is very high. Of course, this high mortality will be reduced as the result of continuing research year by year. However from an economic point of view, there is a great advantage for bluefin tuna culture. This advantage is that the price of bluefin tuna in Japan is very much higher than that of seriola. Here I will go back to Table 1.

The same kind of feed can be used for bluefin tuna as for seriola. Therefore the value of the price balance is very high for bluefin tuna culture. I will make the assumption that the price balance is 60. This assumption means that the economic density of tuna culture is 15% for the break even point at which there is no profit but nos loss if the conversion ratio of bluefin tuna is taken to be about 9:1. In the case of seriola culture in Japan the economic density is from about 40% to 60%, which means that 15% is a very low figure. This indicates that bluefin tuna culture will have a broad area of economic density within which it will remain profitable, and will permit the adoption of many types of culture methods from extensive to intensive. This means that many types of bluefin tuna culture are possible according to the environmental conditions. But, the price balance of seriola culture fell from 22:1 to 12:1 in the 1960's, and as a result net enclosure type culture could not be maintained due to the extensive nature of this kind of culture.

We can say that bluefin tuna culture can continue to be very profitable even if the conversion ratio is rather high. However, the amount of feed used is limited to a certain level.

The feed which is in excess of the conversion ratio is wasteful for fish culture, because the fish cannot eat more than a certain amount. More over, the leftovers of feed will accumulate on the sea bottom, and the conditions in the culture area will deteriorate.

If there is a high mortality of fishes, especially of large size fishes, the conversion ratio will also, of course, go up. Supposing that just before shipment half of the fish die due to shortage of oxygen, this is sure to double the conversion ratio. Altough the conversion ratio of bluefin tuna differs somewhat according to the size of the fish, the average ratio of it is usually from 7:1 to 12:1. The conversion ratio of large size fish is certainly greater than for small size fish of the same species. This means that the economic density of bluefin tuna will be easily over the level of 60% due to the use of large amounts of feed. Calculating theoretically, before we fall below the break even point with a price balance of 60 and an economic density of 0.60, we need to use a very large amount of feed to produce a conversion ratio as high as 36:1. After several experiments of bluefin tuna culture, it has already become clear that bluefin tuna are very easily damaged by abrasions against the net, and the mortality of bluefin tuna is much higher than with seriola. It is possible to achieve a lower mortality in bluefin tuna culture. There is little need to worry about the weakness of bluefin tuna to abrasions because of the high price balance. The main problem for bluefin tuna culture is how to get or collect enough seedlings for culture. Here, I will try to examine the profitability of bluefin tuna culture using data which is derived from experience with seriola culture.

The bluefin tuna culture in Japan has two important advantages which are :

A. High growth rate

The growth rate of bluefin tuna is very high compared with seriola or other species (Fig. 5). At the end of the first year, young tuna fish reach a body weight of 6kg, and at the end of the second year, tuna reach 20kg. At the end of the third year tuna can grow to about 60 kg, although there are many differences in the body weight of individual fishes. The growth rate of bluefin tuna is more than five times higher than that of seriola.

B. High price

It is said that the taste of cultured seriola is rather fatty compared to those caught by fishing and that it is due to the artificial feeding of the fishes. Many people in Japan do not like the fatty cultured seriola and prefer the natural fishes. But in the case of bluefin culture, the situation is different. Japanese people are fond of eating bluefin tuna as raw fish for "Sashimi", and fatty bluefin tuna valued highly by consumers.

The following table made by Dr HARADA and KIGOSHIMA LABORATORY shows the high price of cultured bluefin tuna (Table 4).

Before I calculate the profitability of bluefin tuna culture some clarification is needed concerning the amount of feed according to body weight. Second year tuna need 4.7 times as much feed as first year fish and third year tuna need 20 times as much feed as third year seriola (Table 5).

In order to examine the profitability of bluefin culture, I have to introduce several assumptions due to the lack of actual data. My assumptions are as follows :

a. Producer price of the cultured fish

First year fish	1.200
Second year fish	3.000
Third year fish	4.000

The price of first year fish I have assumed is the same as for cultured seriola, because young fish do not taste good as "Sashimi". It is said that at the end of the second year with a body weight of 20kg the young fish begin to acquire the real taste of bluefin tuna.

b. Price of feed

I have assumed that the feed of bluefin tuna is the same as that of seriola and that the feed cost per kg is about 70, which was the average price in 1977.

c. Economic density of fish culture

First year fish	70%
Second year fish	80%
Third year fish	90%

We can take the actual cost composition for seriola culture and we can assume that the cost of each item is roughly the same, except for the amount of feed used in quantity and in value (Table 6).

Table 7 shows the price balance, the economic density of fish culture and the coefficient of fish culture security. According to calculation, tuna culture is profitable at all ages. However in my calculation the mortality of bluefin tuna has not been taken into consideration. With the presnt level of techniques some mortality of bluefin tuna is inevitable.

The culture of first year bluefin will be difficult to keep profitable. But, in the culture of the second and third year fish, the coefficient of fish security is very high, and therefore some profit can be expected from the culture of second and third year fish in spite of the high mortality of bluefin tuna. However, taking the high mortality into account, the culture of second year fish would be more profitable than third year fish or over. Moreover, as their size increases the fish need a larger area, especially in the case of large bluefin tuna which are very powerful swimmers.

d. The future prospects of bluefin tuna culture

I have considered the culture of the bluefin tuna based on net cage type culture. But, as already mentioned, many types of the bluefin tuna culture could co-exist owing to the high value of the price balance.

From the experiences of fish culture in Japan it is possible to summarize the merits of the enclosure type culture system compared to the net cage type as follows :

a. High growth rate,
b. Low conversion ratio,
c. Low mortality.

These merits stem from the extensive methods of this type of culture. In Japan, the available land is limited, and suitable areas for fish culture are few. As a result, the net cage type of culture was developed. This intensive method of fish culture needs a large outlay for equipment per m^3 of culture space and a large amount of feed and a high density of fish per m^3.

Using this intensive type of culture it is necessary to use sophisticated techniques for taking care of the fishes and it requires many working hours due to the high density of fish in the small net cage, the cultured fish are more likely to be affected by diseases, parasites, and the changes of the environment in the culture area.

At present the main effort in relation to bluefin tuna culture in Japan is directed at the development of a net cage type system.

The reason for this is to enable many private small scale fishermen to start net cage culture in the western part of Japan. In trying to adapt the net cage culture system for bluefin tuna culture, the greatest problem has been the high mortality from abrasions caused by rubbing the skin against the net.

Fortunately, there is a long history of fixed net fisheries in Japan. The techniques for setting up fixed nets in rather wild sea conditions have become highly developed. In the present circumstances of large type fixed net fisheries it is considered a good catch if 2,000-20,000 pieces of seriola get caught in the net in the course of the year. At the present time, no adult bluefin tuna but only young or small ones are caught in the large type of fixed nets. But it would be very easy to rear that number of bluefin tuna seedlings by using the fixed net.

When the seedlings of bluefin tuna are still small at the beginning of the culture, it would be better to make up a small type of fixed net. After the seedlings have grown a rather large type of net can be made up surrounding the small one and when the seedlings are in the large net, the small net can be removed. In this way, it would be possible to rear bluefin tuna without any abrasions from the net and with a much lower mortality.

In addition there are many good places suitable for bluefin tuna culture in the southern part of Japan.

There are many reefs around the islands and isles of Okiwana, and large enclosed ponds could be formed around there using the topography of the reefs. In addition to the low cost of construction this type of pond, the growth rate of bluefin tuna in the warmer area would be rather faster than in the more northern areas. But, there is one serious problem for fish culture in the tropical or semi-tropical areas, This is the shortage of the raw-fish for feed. I can say that large catches of low quality fish are limited in tropical or semi-tropical seas and it is rather difficult to transport and to store low quality fish to be used as feed. Therefore feed costs would be very high. For bluefin tuna culture in tropical or semi-tropical areas, it would be necessary to use artificial feed. In Japan as in the rest of the world, culturists of marine fish have not used much artificial feed because of its high cost. In order to develop fish culture in tropical areas using reefs, the development of cheap and easily stored artificial feed is very important. The use of artificial feed is also advantageous because it avoids water pollution and saves much hard work.

As I have already stressed, the natural resources available for feed are limited.

As a result, if the production of cultured fish increases the cost of the available feed will increase at a more rapid rate.

This would be a serious limitation for fish culture. But, with artificial feed the situation is different, it can be transported, stored and imported from foreign countries. Because of this the development of artificial feed is very important for the future development of fish culture.

PROOF OF HASEGAWA'S FORMULA

In order to manage fish cultures successfully, culture farms must be able to conform to the following simple relationship.

$$A \geqq \frac{N}{W} \text{ --------------- } 1)$$

Where A = selling price of commercial-size fish per Kg

N = total cost

W = total weight of production

From 1)

$$A \geqq \frac{N \cdot a}{W \cdot a} \text{ ----------- } 2)$$

Where a = conversion ratio from feed to fish

From 2)

$$\frac{A}{B} \geqq \frac{N \cdot a}{W \cdot a \cdot B} \text{ ------- } 3)$$

Where B = price per Kg of feed

Then, W.a.B is the total cost of feed used, and $\frac{W \cdot a \cdot B}{N}$ is the ratio of feed to total cost.

Next, to simplify formula 3), we take $\frac{W \cdot a \cdot B}{N}$ as b

Therefore $\frac{A}{B} \geqq \frac{a}{b}$

TABLE 1. CONVERSION RATIO TABLE BY PRICE BALANCE BY ECONOMIC DENSITY OF FISH CULTURE

II \ I	10	15	20	25	30	35	40	45	50	55	60
0.10	1	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0
0.15	1.5	2.3	3.0	3.8	4.5	5.3	6.0	6.8	7.5	8.3	9.0
0.20	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0
0.25	2.5	3.8	5.0	6.3	7.5	8.8	10.0	11.2	12.5	13.8	15.0
0.30	3.0	4.5	6.0	7.5	9.0	10.5	12.0	13.5	15.0	16.5	18.0
0.35	3.5	5.3	7.0	8.8	10.5	12.3	13.5	15.8	17.5	19.3	21.0
0.40	4.0	6.0	8.0	10.0	12.0	14.0	16.0	18.0	20.0	22.0	24.0
0.45	4.5	6.8	9.0	11.3	13.5	15.7	18.0	20.3	22.5	24.8	27.0
0.50	5.0	7.5	10.0	12.5	15.0	17.5	20.0	22.5	25.0	27.5	30.0
0.55	5.5	8.3	11.0	13.8	16.5	19.3	22.0	24.7	27.5	30.3	33.0
0.60	6.0	9.0	12.0	15.0	18.0	21.0	24.0	27.0	30.0	33.0	36.0

I = price balance

$$= \frac{\text{selling price}}{\text{feed price}} \text{ (per kg)} \quad \frac{A}{B}$$

II = economic density of fish culture

$$= \frac{\text{feed cost}}{\text{total cost}} \quad \frac{a}{b}$$

TABLE 2. SELLING PRICE AND COST OF SERIOLA PER PIECE

	one year fish	two year fish	three year fish
Producer price ¥	1.560	4.200	6.500
total coast ¥	1.390(100)	3.160(100)	4.730(100)
seedling ¥	300(21.6)	300(9.5)	300(6.3)
feed ¥	640(46.0)	1.960(62.0)	3.080(65.1)
wage ¥	220(14.4)	400(12.7)	600(12.7)
others ¥	250(18.0)	500(15.8)	750(15.9)
body weight(kg)	1.3	3.5	5.5

TABLE 3. PERCENTAGE OF SHIPPED FISH (SERIOLA) BY YEAR, SIZE

	1960-1969	1970-1975	1975-1977
total	100 %	100 %	100 %
this year fish	97	60	10
2 years old fish	3	30	80
3 years old fish	-	10	10

TABLE 4. SELLING PRICE OF CULTURED BLUEFIN TUNA

	AVERAGE BODY WEIGHT	AVERAGE (KG) SELLING PRICE	PRICES
Dr HARADA	50.6 kg	4.300 ¥	12
KOGOSHIMA'S LAB.	60.7	4.800 ¥	11

TABLE 5. AMOUNT OF FEED NEEDED BY SIZE (BLUEFIN TUNA)

	1 year fish (6kg)	2 years fish (20 kg)	3 years fish (60kg)
conversion ratio	7	11	15
amount of feed (kg)	6x7 = 42	(20-6)x 11 + 42 = 196	(60-20) x 15 +42+196 = 838
	1	4.7	19.9

TABLE 6. THE ESTIMATED PRICE AND COST OF CULTURED BLUEFIN TUNA PER PIECE

	one year fish (6 kg)	two years fish(20kg)	three years fish (60 kg)
producer price ¥(per kg)	1.200	3.000	4.000
producer price(per piece)	7.200	60.000	240.000
estimated total cost ¥	4.250(100)	15.650(100)	61.150(100)
seedling ¥	750(18)	750(48)	750(12)
feed ¥	2.900(68.2)	13.700(87.5)	58.600(95.8)
wage ¥	200(4.7)	400(2.6)	600(0.9)
others ¥	400(9.9)	800(5.1)	1.200(1.2)

TABLE 7. PRICE BALANCE, ECONOMIC DENSITY AND COEFFICIENT OF FISH CULTURE SECURITY

	one year fish (6kg)	two years fish (20kg)	three years fish (60 kg)
A ¥	1.200	3.000	4.000
B ¥	70	70	70
a	7	10	14
b %	70	80	90
(1) A/B	17.1	42.8	57.1
(2) a/b	10	12.5	15.5
(1)/(2)	4.7	3.4	3.7

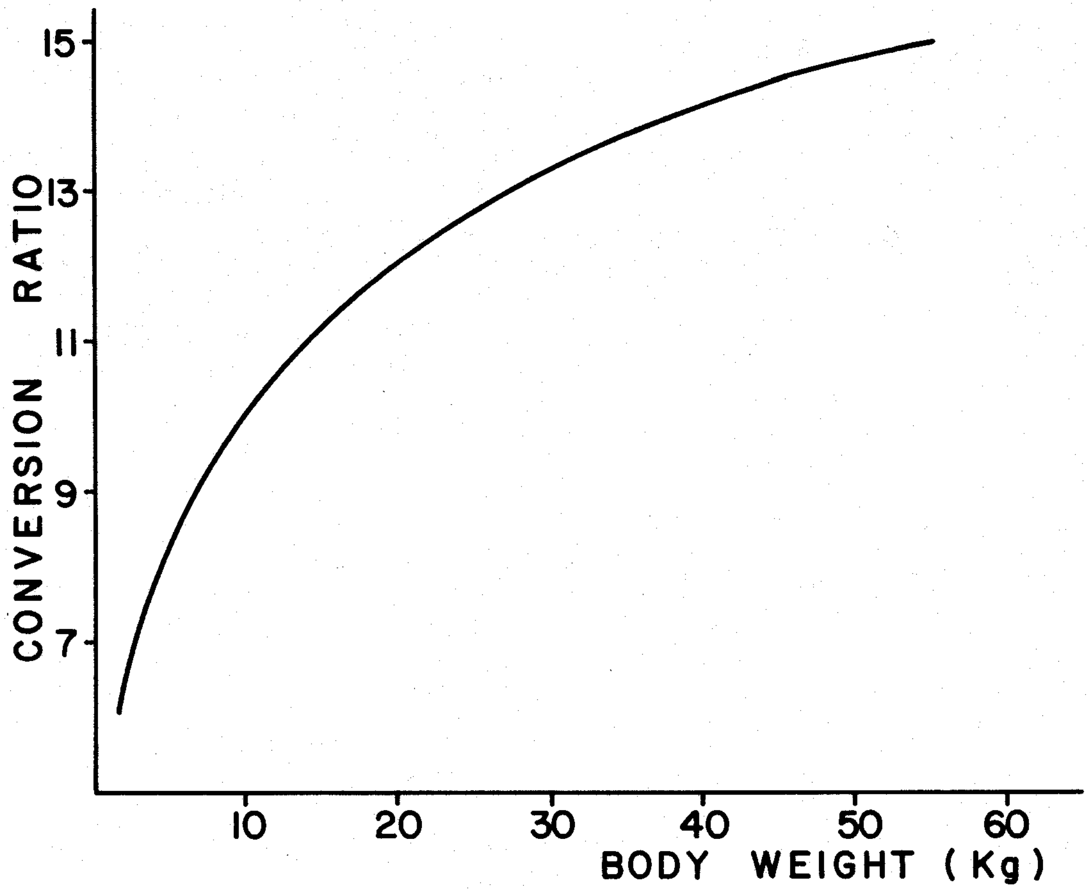

Figure I : Conversion ratio

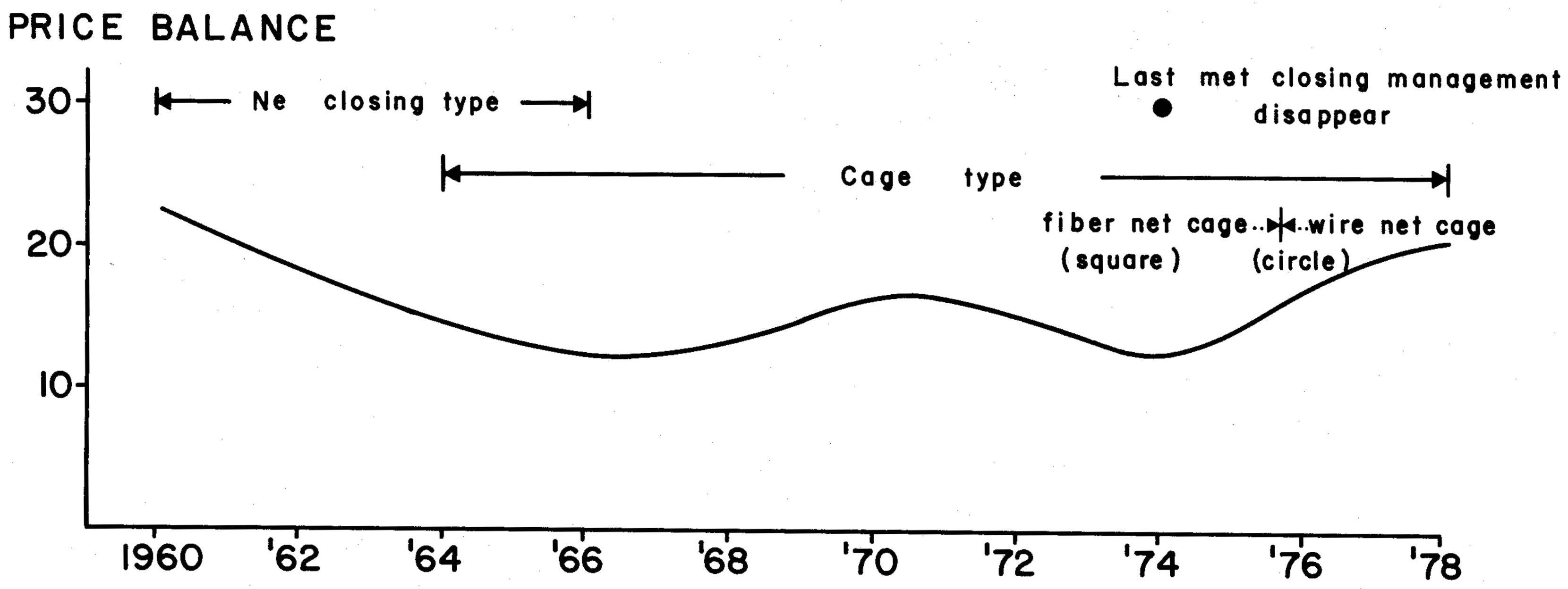

Figure 2 : A trend of the price balance and the change of culture method

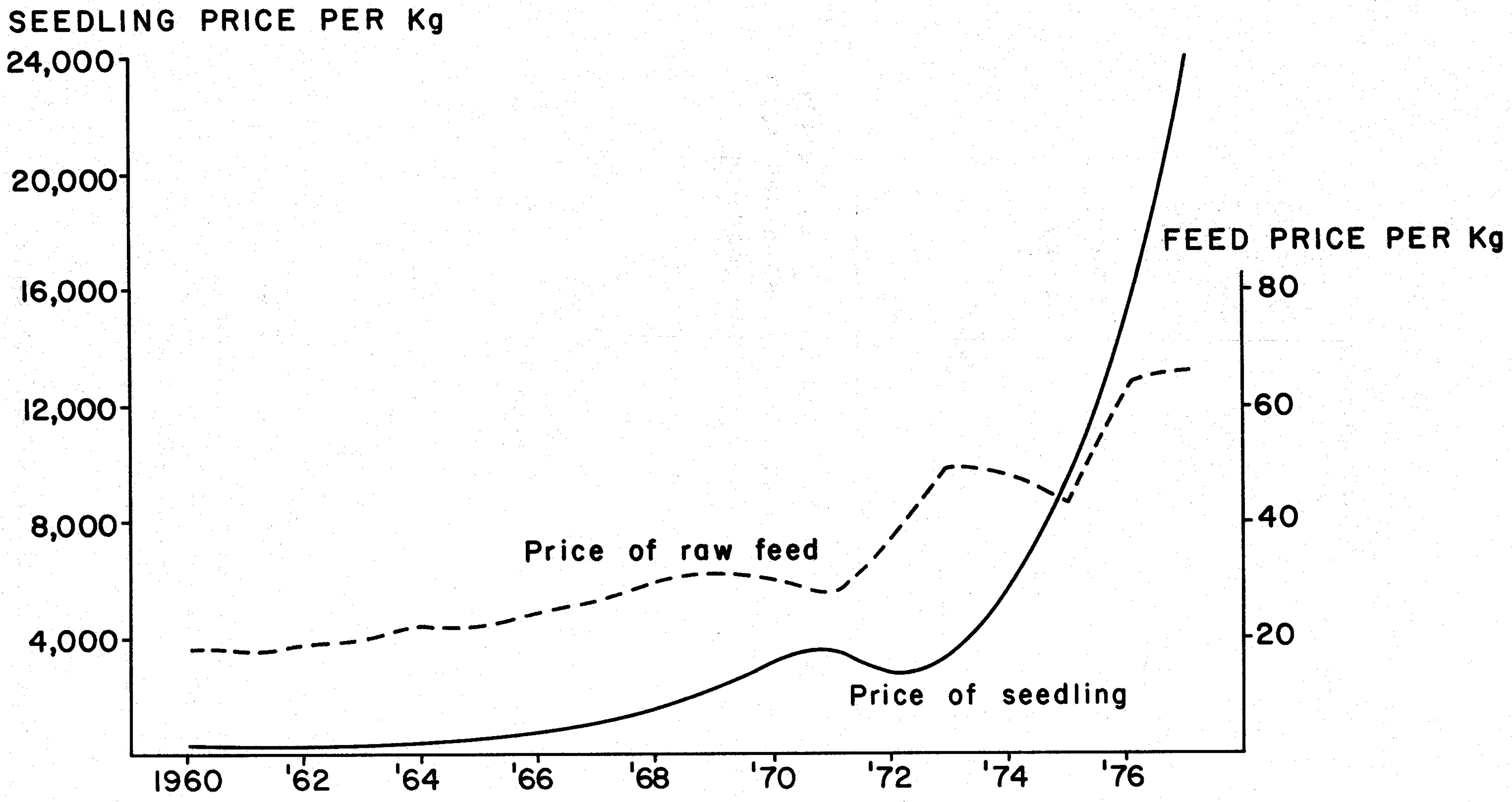

Figure 3 : Price trends of raw feed and seedling

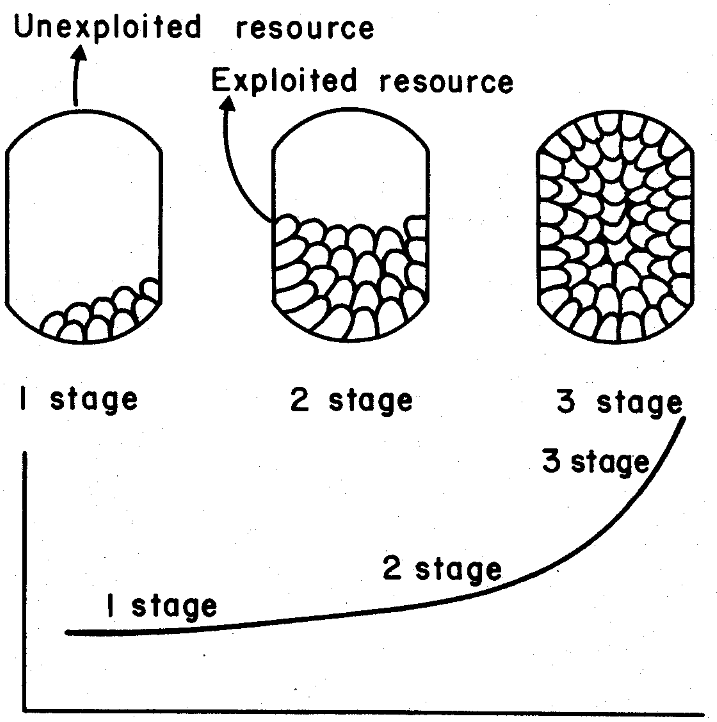

Figure 4 : Relation between price, supply and demand of resources such as raw feed and seedling.

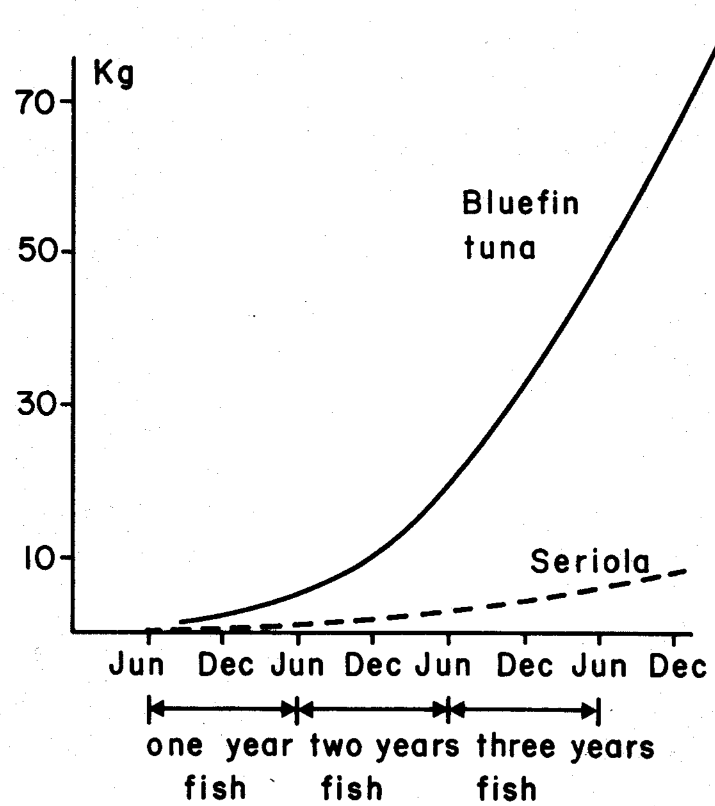

Figure 5 : Body weight by ages