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Present status and prospects of technical development of tuna sea-farming

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SUMMARY – Tuna is some of the most important species in the fisheries because of their large size, their excellent taste and their high market price. In particular, bluefin tuna which is the largest species of tunas, reaching more than 3 m of total length, 500 kg in body weight and has very high economic value. In recent years, the decrease of bluefin tuna resource by increasing pressure of catching tuna has been worrying. Fortunately fisheries resources can be reproduced by natural productivity and has a characteristic to be maintained as a sustainable source of renewable food by appropriate management. In addition to the appropriate utilization and management of tuna resources, it is necessary to promote the technologies for tuna enhancement. In 1970, the experiment of rearing bluefin tuna was started in Japan. At present, the experiments of culture and seed production are conducted by the national sea-farming center, several prefecture fisheries experimental stations, universities and private companies. About hundred yearlings were released by the national sea-farming center in 1998. But mass seed production has not yet been succeeded. In order to establish seed production technologies of bluefin tuna, it is necessary to resolve many problems. The present technical problems include: (i) development of broodstock rearing technology; (ii) solution of broodstock mature mechanism; (iii) development of initial-stage larvae feed; (iv) improvement of larvae and fry survival rate; and (v) development of seed release technology. It is essential for achieving the above problems to survey the behavior of fry, yearling and adult bluefin in natural areas as well as strengthening the research system of seed production to promote bluefin tuna seed production. It is expected that the ecological survey of bluefin tuna will be conducted on a big scale under the international cooperation.

Key words: Tuna, sea-farming, seed production.

RESUME – *"Situation actuelle et perspectives du développement technique de l'élevage en mer des thonidés". Les thonidés regroupent selon leur grande taille, leur chair très appréciée et leur valeur commerciale élevée, des espèces de poissons des plus importantes des pêcheries marines. En particulier, le thon rouge qui constitue l'espèce la plus grande des thonidés peut atteindre une longueur totale de plus de 3 m et un poids total de plus de 500 kg et jouir d'une valeur économique très élevée. Durant ces dernières années, le déclin des ressources de thon rouge par une pression accrue de pêche a été inquiétant. Heureusement, les ressources des pêcheries peuvent se reproduire par une productivité naturelle qui constitue une caractéristique à maintenir en tant que ressource durable d'alimentation renouvelable par un aménagement approprié. En plus d'une utilisation adéquate et une gestion rationnelle des pêcheries des thonidés, il est nécessaire de promouvoir les technologies de reconstitution et de multiplication des stocks naturels. A cet effet, les expérimentations d'élevage du thon rouge ont débuté en 1970 au Japon. Actuellement, les expériences d'élevage et de reproduction sont réalisées par le centre national de sea-ranching, par de nombreuses stations préfectorales d'expérimentation halieutique et par des sociétés privées. Bien que des centaines de juvéniles ont été ainsi produits et relâchés en 1998 par le centre national de sea-ranching, la production de masse des juvéniles n'a pas encore été réussie. En vue d'établir une technologie de production contrôlée de juvéniles du thon rouge, il est nécessaire de résoudre un certain nombre de problèmes. Les problèmes techniques actuels incluent : (i) le développement de la technologie d'élevage des reproducteurs en captivité ; (ii) la résolution du mécanisme de maturation des géniteurs en élevage ; (iii) le développement de l'alimentation initiale des jeunes larves ; (iv) l'amélioration des taux de survie des larves et des alevins ; et (v) le développement de la technologie du relâcher des juvéniles. Pour pallier à ces problèmes, il est essentiel d'entreprendre des études de comportement des alevins, des juvéniles et des adultes du thon rouge en milieu naturel ainsi que de renforcer la recherche du système de reproduction contrôlée afin de promouvoir la production des juvéniles du thon rouge. Il est attendu que les études écologiques sur le thon rouge puissent être réalisées en coopération internationale à grande échelle.*

Mots-clés : *Thonidés, sea-ranching, production de juvéniles.*

Introduction

Tunas in the genus *Thunnus* are classified into seven species by Iwai *et al.* (1965, cited in Shingu, 1978). These are *Thunnus thynnus* (bluefin tuna), *Thunnus maccoyii* (southern bluefin tuna), *Thunnus atlanticus* (blackfin tuna), *Thunnus albacares* (yellowfin tuna), *Thunnus alalunga* (albacore), *Thunnus obesus* (bigeye tuna) and *Thunnus tonggol* (longtail tuna). Tunas migrate in temperate and tropical seas seeking ideal conditions for feeding and spawning. They grow to very large size and are located in the most upper position of food chain in fishes and are one of the most important species in the fisheries because of the large body, the excellent taste and high economical value. Especially, bluefin tuna has the largest size and the highest market price in Japan.

For recent year, the decrease of bluefin tuna resource by increasing pressure of catching tuna has been worried. In the International Conference on the Sustainable Contribution of Fisheries to Food Security held in 1995, it was proposed that Atlantic bluefin tuna had been added in the Appendix of CITES and the international bluefin tuna business should had been prohibited or regulated. However, this proposal was withdrawn because of the positive action of fishery side including consolidating and preservation of Atlantic bluefin tuna management by the International Commission for the Conservation of Atlantic Tunas (ICCAT).

This shows that many organizations have much interest in condition of bluefin tuna resource. Now, in addition to the appropriate utilization and management of tuna resources, it is necessary to promote the technology for bluefin tuna enhancement.

Why, we take up bluefin tuna?

It is great subject to utilize sustainable the aquatic resources as an important natural renewable source of food. Especially, it is very important to maintain and propagate the fishery resources in order to cope with a continuously growing world population. As one of the fisheries promotion, the hatchery enhancement programs of fishes and shellfishes has been promoted in Japan. Bluefin tuna also was not an exception.

Average world catch of the main 5 tuna species between 1991 and 1995 is 165×10^4 t (Fig. 1). The catch composition are as follows: yellowfin tuna 66.8%, bigeye tuna 17.9%, albacore 11.7% and bluefin tuna including southern bluefin tuna 3.2% (modified from FAO Yearbook 1995; cited in material of Federation of Japan Tuna Fisheries Cooperative Associations). The proportion of tunas in total catch of the world is 1.4-1.7% between 1986 and 1995. Bluefin tuna including southern bluefin tuna occupy only 0.05%. Table 1 shows that the highest value in fish wholesale market in Japan is bluefin tuna.

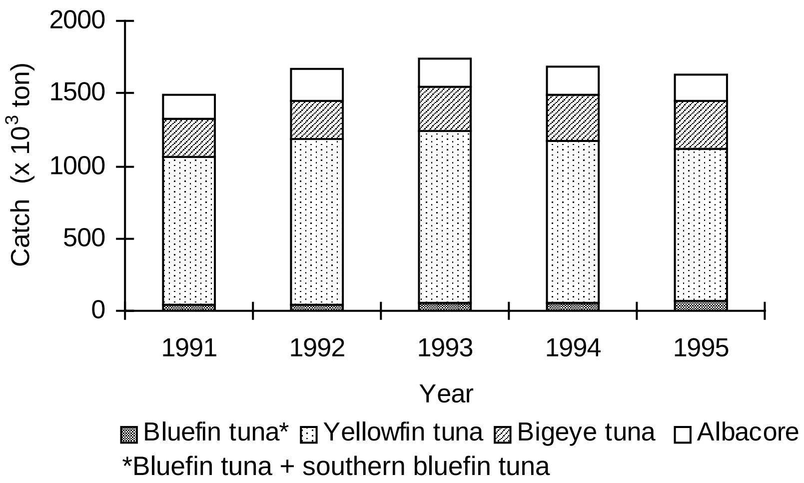

Fig. 1. Total catch of main tunas in the world (modified from FAO Yearbook 1995).

Now, development of tuna sea-farming technique as well as other fishes and shellfishes is being much interested and is needed as a method of maintaining and propagating tuna resources.

Table 1. Average wholesale value in 1998 (yen/kg). Modified from The Suisan-Keizai, February 1999

Fish	Average value (Jan.-Dec. 1998)	
	Fresh fish	Frozen
Bluefin tuna	2878	2624
Bigeye tuna	1393	994
Yellowfin tuna	1047	773
Other tunas	785	–
Skipjack	492	–
Salmons	793	683
Sardine	300	–
Mackerel	291	428
Horse-mackerel	423	306
Yellowtail	785	–
Japanese flounder	2000	–
Red sea-bream	965	–

Process of bluefin tuna culture and seed production

It is very effective and interesting to use artificial seeds in investigating aquatic resources. In 1970, the Fishery Agency, Ministry of Agriculture and Forestry programmed a research project on tuna propagation in large scale. National fishery institute, prefecture fisheries experimental stations and universities took part in this project. The cooperative research project was accomplished from 1970 to 1972. The purpose of the project was development of seed production and experimental certification of possibility of culture. In those days, there were a few experiments of tuna rearing and it was a focus of the project to establish methods of catching and securing natural juveniles and development of culture techniques. It was the results that juveniles of bluefin tuna caught by trap net or trolling line could be used as seeds and the survival rate after transporting juvenile fish to culture site by boat was below 50% but could raised more than 100 days. Between 1973 and 1980, they proceeded with improving culture facilities and making large size (Suda, 1995).

In the field of developing seed production, Kinki University continued the study from 1970 succeeded to get fertilized eggs that 5 years old broodstock (1974 brood year) spawned naturally in the floating pen and succeeded in artificial hatching in 1979 (Harada *et al.*, 1979). In 1975, a Japanese private company began a short-term culture of Atlantic bluefin tuna caught by trap net during several months on the Atlantic ocean side of Canada. In 1970's, the possibility of tuna culture was proved but the aim in those days was to culture broodstock and develop to produce seed and in 1980's the movement trying culture was found. Then private companies began to culture in southern Japan by using natural juveniles as seed (Fig. 2). There was a case that they transported juveniles in long distance by boat installed inboard tank after rearing caught juvenile a certain period. As the result of these trying, the basis of present culture technique was established. While culture technique was developed by private companies, the study on maturity and spawning behavior of bluefin tuna was progressed and institutions have tried to hatch fertilized eggs spawned naturally in net cages and rear larvae (Suda, 1995). As the results of these experiments, considerable data on maturity, spawning, initial feed for larvae, rearing technique of larvae and handling of fries were obtained.

The preliminary work on southern bluefin tuna culture was conducted in Port Lincoln in early 1990's between Australia and Overseas Fishery Cooperation Foundation (OFCF) of Japan. Moreover, OFCF has been involved in the Atlantic bluefin tuna spawning project based in Morocco since Dec. 1992 and the project of yellowfin tuna spawning has been attempted under a joint with the Inter-American Tropical Tuna Commission (IATTC), OFCF and the Republic of Panama.

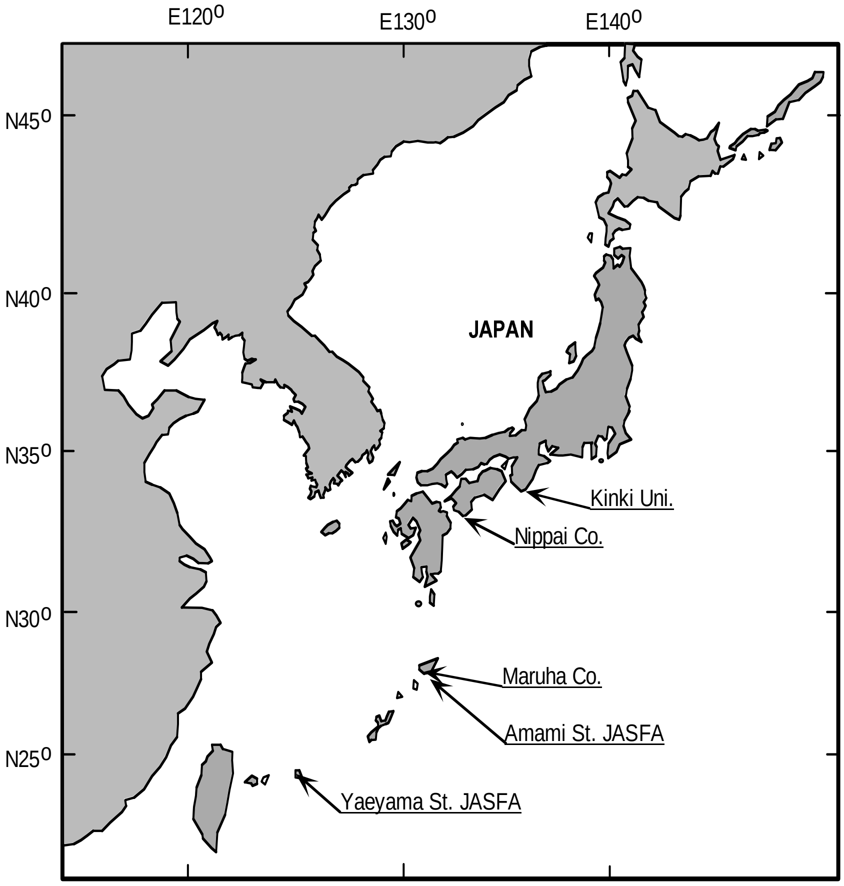

Fig. 2. Location of rearing bluefin tuna institution in Japan.

Current status of seed production technologies

Culture facilities

The conditions of a suitable rearing site are as follows, the appropriate temperature between 15 and 28°C, the area not to be affecting by muddy waters from river, much flow from open sea, high transparency and high dissolved oxygen. The shape of culture pen has changed from rectangle and square to circular type to be fitted to tuna swimming behavior. The frames of floating pens are used steel tubes, steel bars and floats in the area to be affected by high wave faced to open sea (Kumai, 1995). In Amami Station, sikiriami is used. Sikiriami is the enclosure utilizing the natural lay of land and encircling a small inlet by barrier net. A floating net cage, 120 m long, 50 m wide and 30 m deep is used to hold the broodstock in Morocco. Panama project use the onshore tanks; diameter 17 m, deep 6m to equipped with a net wall about 1.2 m high to prevent yellowfin tuna from falling out when they jump from the water.

Broodstock culture

Seed

Natural juveniles are used as seed. In Australia, southern bluefin tuna of 10-20 kg are caught and sold according to demand after being reared during 4-9 months (Suda, 1995). In Japan, 0 aged fish are caught and reared up to the selling size over 40 kg because the spawning ground of bluefin tuna is located in the eastern area of Taiwan and the juveniles migrate to the coast of Japan. They are caught by trap net or trolling line and used as seed of culture. These juveniles are used for seed production experiment and reared up to broodstock (Kumai, 1998).

Feed

Reared bluefin tuna fed on a diet of fishes such as fresh and frozen sand eel, anchovy, mackerel, horse mackerel and squid according to their growth. Mackerel is much used because of obtaining easily various sizes of fish. Various kind of vitamins and digestive enzyme are added to feed as well-balanced nourishing feed is essential for growth. Feeding is 2-5% of body weight (BW) at 1-2 times in a day, depending on water temperature and body size. Artificial assorted feed is of no practical use yet because the study on nutrition of bluefin tuna and feed size is not sufficient (Endo *et al.*, 1989). By developing artificial feed, it may be easier to add a variety of hormonal preparations to induce spawning.

Growth

Growth of fish is different by the conditions of rearing circumstances. In Japan, bluefin tuna in Yaeyama Station, JASFA located at southern-most island reached to 100 kg at 3 years but in Kusimoto experimental station of Kinki University located in the center of main island reached 50 kg at same year, 30-50 kg in Shizuoka located at north from Kinki University, 60 kg Kagoshima located at south from Kinki University and 75 kg in Amami Station JASFA located between Kagoshima and Yaeyama. This shows that bluefin tuna reared in more southern station grow rapidly and water temperature affect with growth (Masuma, 1995).

Figure 3 shows an example of growth of bluefin tuna in Amami Station that started to rear at one year old (BW about 8 kg) during three and half years in circular pen diameter 40 m (Masuma, 1999, from The 1997 Annual Report of JASFA, p. 71). In Morocco, estimated 5 years old Atlantic bluefin tuna grew from 137.6 cm to 180.3 cm in mean fork length and from 55.5 kg to 130 kg in mean BW between Dec. 1996 and Jan. 1998 (Figs 4 and 5; Projet Thon Rouge, 1999). Large size Atlantic bluefin tuna, 230.6 cm in mean fork length and 256.4 kg in mean BW on Dec. 1992 reached 255.5 cm in fork length and 408.6 kg in BW on Feb. 1996 (Figs 6 and 7; Projet Thon Rouge, 1999).

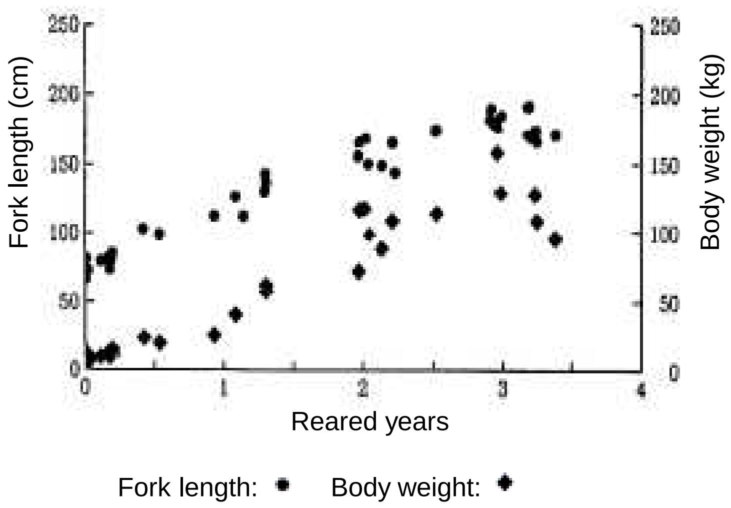

Fig. 3. Growth of 4 years old (1993 brood year) bluefin tuna at Amami Station JASFA (from Masuma, 1999, The 1997 Annual Report of JASFA, p. 71).

In examples of 0 aged bluefin tuna, juveniles reared in Amami Station grew from 26.7 cm (23.1-28.7) in fork length, 327 g (200-450 g) in BW on Sept. 1996 to 45 cm and 2000 g in 58 days (Fig. 8).

Survival rate after stocking in the pen was 84.9% and main reasons of mortality were rubbing against net and a fracture of bone caused by striking against net (Yamazaki, 1998, from The 1996 Annual Report of JASFA, p. 67).

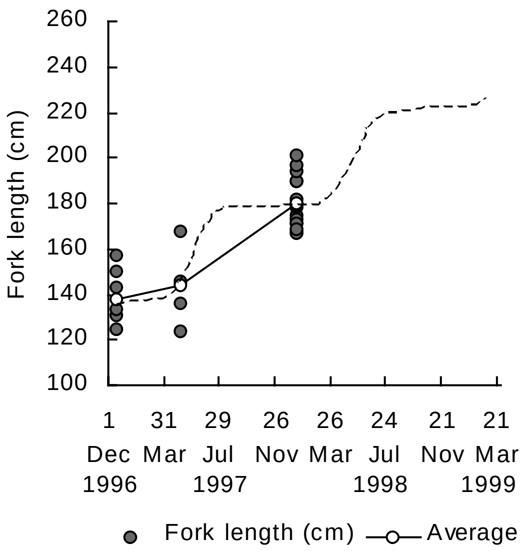

Fig. 4. Growth of rearing bluefin tuna at M'diq in Marocco.

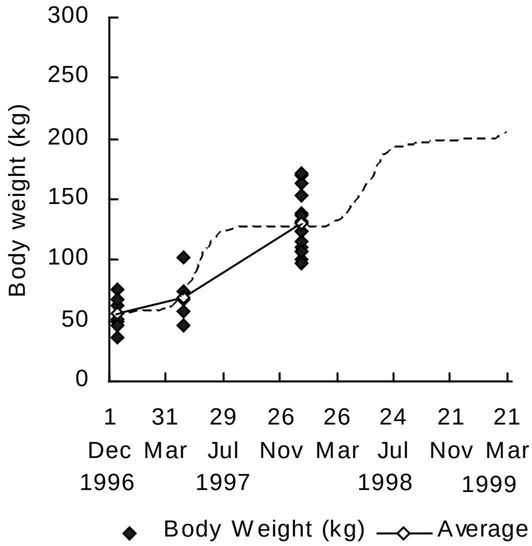

Fig. 5. Growth of rearing bluefin tuna at M'diq in Marocco.

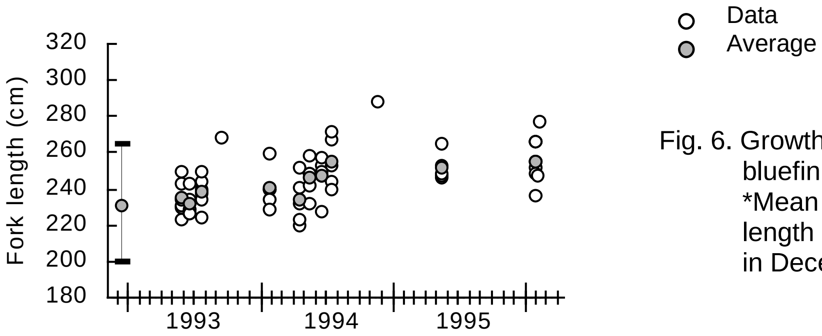

Fig. 6. Growth of fork lenght of bluefin tuna broodstock. *Mean value and range of fork length of landing bluefin tunas in December 1992.

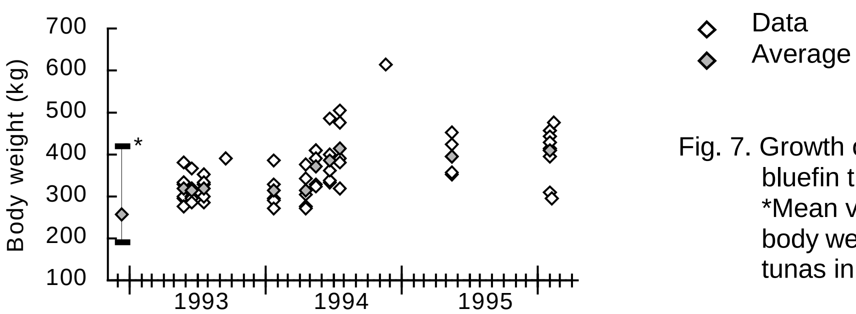

Fig. 7. Growth of body wight of bluefin tuna broodstock. *Mean value and range of body weight of landing bluefin tunas in December 1992.

In Morocco, culture of 0 aged juvenile of Atlantic bluefin tuna caught by trap net as by-catches were carried out in a floating net cage (160 m length, 50 m width and 30 m depth) from Oct. 1995 to Feb. 1996. Estimated mortality rate until Dec. 1995 was 3% but all juvenile tunas were dead or run away, because floating net cage were damaged by heavy storm in Feb. 1996. The size of juvenile at start were 35.6 cm in mean fork length, 888.6 g in mean BW on Oct. 1995 and 51.9 cm in mean fork length, 2877.9 g in mean BW after 4 months, Feb. 1996 (Figs 9 and 10; Projet Thon Rouge, 1999). They grew 3 times in BW during 4 months and it seems that there are no problems on rearing juvenile as an object of culture if techniques of spending in winter would be established.

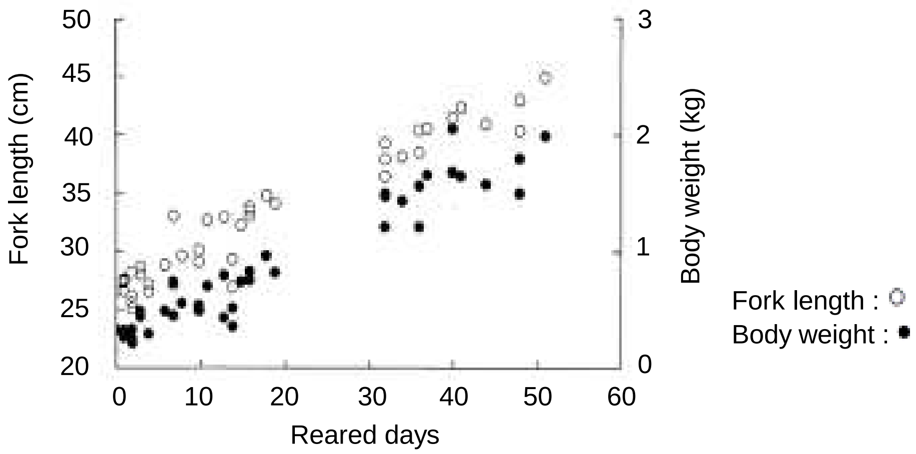

Fig. 8. Growth of 0 year old (1996 brood year) bluefin tuna at Amani Station JASFA (from Yamazaki, 1998, The 1996 Annual Report of JASFA, p. 67).

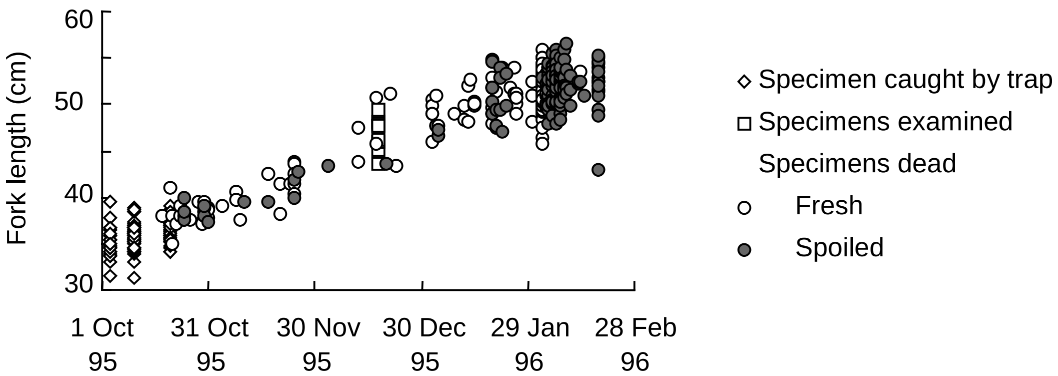

Fig. 9. Growth in fork lenght of juvenile bluefin tuna.

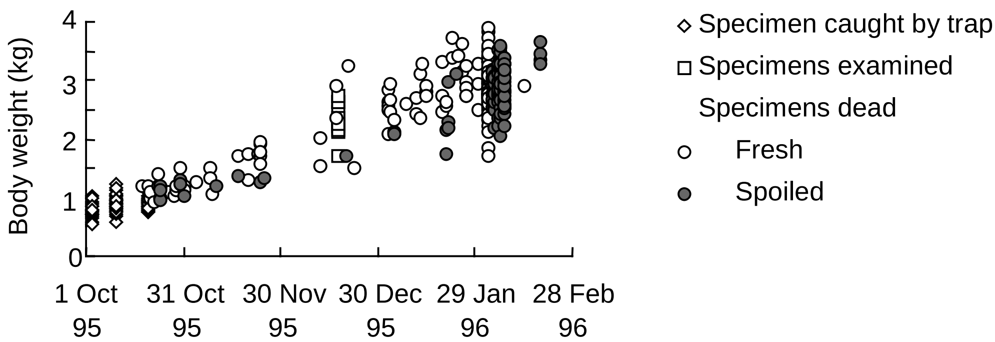

Fig. 10. Growth of total weight of juvenile bluefin tuna.

Spawning

It is difficult to rear bluefin broodstock in a concrete tank as other fishes because of large body. Accordingly, it is not easy to induce spawning by using environmental manipulation or hormonal treatment. Current spawning of bluefin tuna depends on natural spawning in net cage. First natural spawning of bluefin tuna in net cage was confirmed at Kinki University. Spawned broodstock were 5 years old fish of 1974 brood year reared in a circular net cage, diameter 30 m, depth 7 m and spawning occurred in temperature between 21.8-25.6°C. Numbers of fertilized eggs collected were 160 x 10^4 eggs and were reared for 47 days after hatching (Harada *et al.*, 1979; Kumai, 1995).

Afterward, several institutions have collected fertilized eggs spawned naturally in net cages and have made experiments of hatching and rearing.

Before spawning, the behavior that 1-2 males being changed to black color ran after one female like stimulating was observed in Amami. It is estimated that change to black of body color occurred by excitement (Masuma, 1999). All spawning began after 17:00. Broodstock aged 9, 10 at Amami in 1997 was observed spawning behavior around 19:15 and then spawned. Spawning delayed according to the nearness of the end of spawning period and finished at 21:00 in Nippai in 1994 and at 23:00 in Amami on August 1998. Table 2 summaries the spawning published data of bluefin tuna (Odai, 1994; Hirata *et al.*, 1995; Kumai, 1998; Masuma, 1999; S. Masuma, pers. comm.).

Table 2. Spawning of bluefin tuna in Japan

Spawning year	Institution	Age of broodstock	Period of spawning	Eggs collected x 10^4	Spawning temperatures (°C)	No. of female
1979	Kinki Uni.	5	20 Jun.-16 Jul.	160	21.8-25.6	
1980	Kinki Uni.	6	7.8.12.14 Jul.	6	22.0-24.7	
1982	Kinki Uni.	7	13 Jul.	0.5	24.7	
1991	Maruha Co.	4	12 Jun.-19 Jun.	1	–	
1992	Maruha Co.	4-5	27 Jun.-4 Jul.	342	–	
1993	Maruha Co.	4-6	11 Jun.-28 Jul.	10675	–	
1994	Nippai Co.	5, 6, 8	26 May-20 Sep.	1200	20.3-29.2	
		7	–	–		
		5	–	–		
1994	Kinki Uni.	7	3 Jul.-17 Aug.	8400	23.2-29.2	
1995	Kinki Uni.	8	–	–	21.6-26.4	
1996	Kinki Uni.	9	–	–	25.8-26.8	
1997	Amami St.†	9, 10	13 May-12 Jul.	433	23.7-26.7††	17
		7	1 Jul.-3 Jul.	572	25.8-26.8††	28
1998	Amami St.†	10, 11	23 May-13 Aug.	17430	25.2-29.1††	7
		5	28 Jul.-24 Aug.	1691	28.0-29.2††	39

†Amami Station, Japan Sea-Farming Association.
††10 m.

Captive spawners did not always spawn every year. For example, same spawning group of 1994 brood year spawned in 1979, 1980 and 1982 but no further spawning was recorded for 11 years at Kinki University. After that, 7 years old broodstock of 1987 brood year spawned in 1994 and spawned repeatedly in 1995 and 1996 (Kumai, 1995, 1998). At Amami Station, 7 years old broodstock spawned in 1997 did not spawn the following year, but 9-10 years old tuna that had spawned in 1996 at Maruha Co. and were transferred to Amami Station spawned repeatedly in 1997 and 1998 (S. Masuma, pers. comm.). Now, natural spawning from cultured broodstock is possible but it depends on water temperature at rearing site and physical activity of broodstock. So it is necessary to establish technology of maintaining continuously mass fertilized eggs.

Hatchery

Fertilized eggs spawned naturally in cages at Kinki University in 1979 began to hatch out in 32 hours in water temperature of 24°C and finished hatching in 32 and half-hours. The longest-lived larvae were reared for 47 days after hatching (Kumai, 1995, 1998).

Mean hatching rate of fertilized eggs from 9-10 years old broodstock at Amami Station in 1997 was 83.3%, normal hatching rate 57% and mean hatching rate of 7 years old broodstock spawned for the first time was 88.2% and normal hatching rate 38.3%. By the observation of egg generation, number of fish which had spawned was estimated to be 2 of 28 broodstock in a case of 7 years old and to be 1-3 of 17 broodstock in a case of 9-10 years old (Masuma, 1997).

Larval rearing

Larvae are maintained in seawater at a temperature 24.6-27.8°C and fed rotifers, artemia, live fish larvae and chopped whitebait at Amami Station. Figure 11 shows an example of survival rate and growth of larvae. Survival of larvae has been very low with high mortality occurring at development stages, especially 20% at 5 days after hatching and below 10% at 10 days. At 20 days after hatching, mortality increases with cannibalism (Tezuka, 1998, 1999; S. Masuma, pers. comm.). Therefore it is necessary to grade and enough feeding. Moreover, main reasons of mortality after transferring to a floating pen from onshore tank are handling in transferring and collisions with net.

Koiso (1998) reports that many handling cause high mortality and mortality has continued for 1-2 weeks and reached 70% during this period (Fig. 12; from Koiso, 1998, The 1996 Annual Report of JASFA, p. 197).

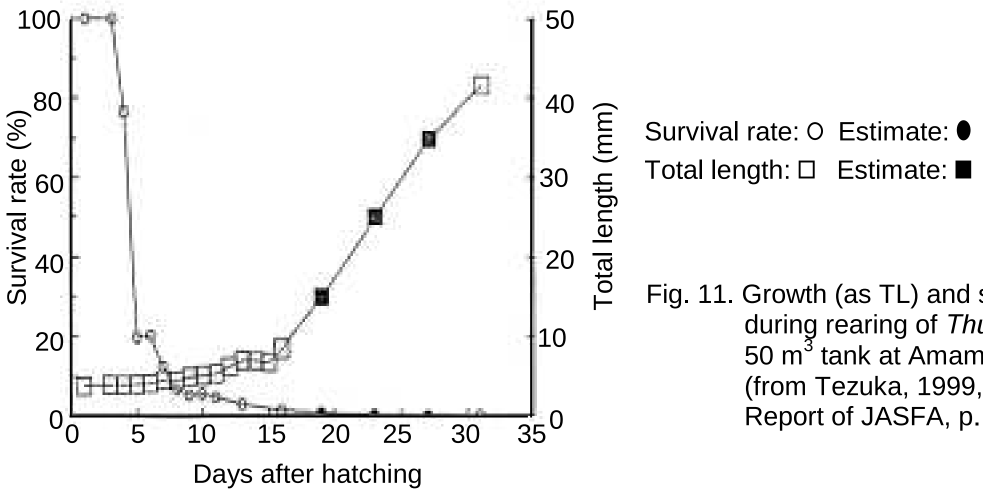

Fig. 11. Growth (as TL) and survival rate during rearing of *Thunnus thynnus* in 50 m^3 tank at Amami Station JASFA (from Tezuka, 1999, The 1997 Annual Report of JASFA, p. 203).

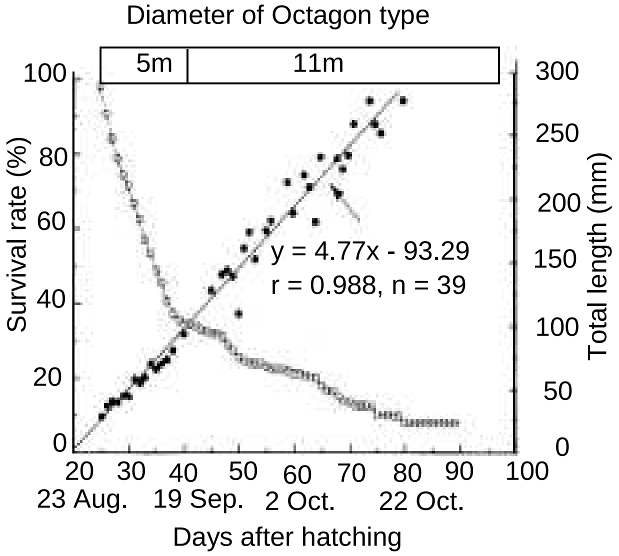

Fig. 12. Survival and growth of bluefin tuna larvae in sea-water pen at Amami Station JASFA (from Koiso, 1998, The 1996 Annual Report of JASFA, p. 197).

Mortality at first stage in rearing larvae and fry is very high, and according to the results of many rearing experiments, survival rate is 40-10% at ten days after hatching, 12-2% at 17 days and 1.2-0.1% at 30 days (Miyashita *et al.*, 1995). But considerable progress in larvae rearing has been made by many institutions.

Closing comment including prospects

Now a great deal of fundamental knowledge on initial stage of larvae is being accumulated and culture technology for bluefin tuna are being established. However, the current culture technology is still inadequate for mass seed production. In order to develop sea farming all the more to be one of the recovery method of bluefin tuna resources, it is necessary to maintain good quality of eggs and rear healthy seed. At present, collecting eggs depend on natural spawning but induced spawning will be expected like other fishes. Especially, to produce initial stage feed such as rotifer, artemia and live fry, large space is needed including culture tanks for initial stage feed. Using assorted feed instead of live feed lead to reduce costs and automation of the works. The big problem in seed production is disease. Preventive measures and complete countermeasures for disease must be developed. Considerable researches are required; comparison of chemical components in the muscle, nutrition, feed development and how to preserve genetic diversity of broodstock in the field of parent culture and larval nutrition, techniques of juvenile production, etc., in the field of larval rearing.

In future, the study on seed production will expand to the study on seed release and the effectiveness of release. Sea farming is a positive method to increase resources and to succeed sea farming, it will have to be promoted in accordance with comprehensive resource management.

In that case, it is expected this study will be conducted in a big scale under the international cooperation and will contribute to the stabilization of resources.

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