Capture-based aquaculture of bluefin tuna

Francesca Ottolenghi
Halieus
Rome, Italy
E-mail: ottolenghi@halieus.it

Ottolenghi, F. 2008. Capture-based aquaculture of bluefin tuna. In A. Lovatelli and P.F. Holthus (eds). Capture-based aquaculture. Global overview. *FAO Fisheries Technical Paper*. No. 508. Rome, FAO. pp. 169–182.

SUMMARY

Tunas belong to Actinopterygii, order Perciformes, family Scombridae which contains about 33 species and sub-species. The four species of high commercial interest for fisheries and capture-based acquaculture are *Thunnus thynnus*, *Thunnus orientalis*, *Thunnus maccoyii* and more recently *Thunnus albacore*. This paper focuses on *Thunnus thynnus* with references to the other tuna capture-based species and is organized in three main sections:

- Species description: a description of the taxonomy and distribution, habitat and biology, schooling and migration movements as well as feeding behaviour by size.
- Fisheries: a description of the fisheries, the global catch in relation to the main catching areas and the main gear used; and
- Capture-based aquaculture: fishing techniques, season and catching size, rearing techniques, aquaculture sites, feeding, harvesting and marketing practices, along with a review of the principal environmental, social, economic, market and management issues.

The further expansion of *Thunnus thynnus* capture-based aquaculture (CBA) is considered viable in the short term. However in the long term, sustainability may depend on the economically viable completion of the full life cycle (i.e. reproduction); improvements in the artificial feed formulation to reduce baitfish consumption and improve the feed conversion ratio (FCR); expanding markets beyond the Japanese market; and reducing illegal, unreported and unregulated (IUU) fishing. Furthermore, farmers need to follow best procedures to ensure traceability of traded tuna. There is also an urgent need to determine precisely the size and age composition of the fish destined for the farming operation as the current lack of biometric information makes stock assessment, and hence effective management and conservation of the bluefin tuna resource, difficult.

The Standing Committee on Research and Statistics (SCRS) of the International Commission for the Conservation of Atlantic Tunas (ICCAT) indicated in its 2006 stock assessment report that the spawning stock biomass continues to decline while fishing mortality is increasing rapidly, particularly for large fish. The growing need to respond to the global decline of most wild bluefin tuna fisheries will be a major driving force in the development of reliable technologies for large-scale production of juvenile tuna, for both commercial food production and fisheries enhancement programmes. As these technologies improve, the economics of full cycle farming should also improve, and quite possibly result in changes in the market structure for hatchery-produced fish.

FIGURE 1
Thunnus thynnus

Source: Fischer *et al.,* 1987.

SPECIES DESCRIPTION

Taxonomy and distribution

Phylum	– Chordata
Subphylum	– Vertebrata
Superclass	– Gnathostomata
Class	– Osteichthyes
Subclass	– Actinopterygii
Infraclass	– Teleostei
Superorder	– Acanthopterygii
Order	– Perciformes
Family	– Scombroidae
Genus	– *Thunnus*
Species	– *thynnus*

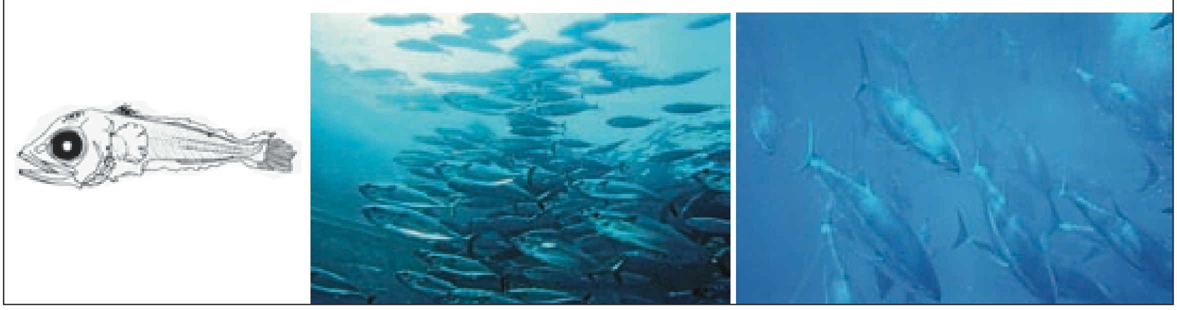
The bluefin tuna was first described by Linnaeus in 1758 as *Scomber thynnus*. Many other denominations followed, such as *Thunnus vulgaris* and *Thunnus thynnus*. One capture-based aquaculture tuna species is considered in this paper – the northern bluefin tuna (*Thunnus thynnus*) (not including *Thunnus orientalis*) (Collette, Reeb and Block, 2001), with reference to the southern bluefin tuna (*Thunnus maccoyii*). The *Thunnus thynnus* (Figure 1) is found in Labrador, Canada and continues south to the Gulf of Mexico and the Caribbean Sea and also off the coast of Venezuela and Brazil in the Western Atlantic. In the Eastern Atlantic it occurs from the Lofoten Islands off the coast of northern Norway south to the Canary Islands and the Mediterranean Sea. There is also a population in South African waters.

Habitat and biology

Northern bluefin tuna are large pelagic marine fish. The juveniles are encountered in epipelagic waters whereas large tunas tend to be mesopelagic and are found also in deeper and cooler waters. The species has considerable thermal tolerances, as it can be found in waters as cold as 10 °C, as well as in tropical areas (Brill, 1994). Generally the most critical environmental parameters for these large pelagic fish are sea surface temperature and the levels of dissolved oxygen and salinity. The species has been observed both above and below the thermocline. Juvenile fish tend to live near the surface.

The following three growth stages can be distinguished: i) larvae – recently hatched individuals which are considerably different in appearance from juveniles or adults; ii) juveniles – similar in appearance to adults, but sexually immature; and adults – sexually mature fish (Figure 2). The maximum reported weight of an adult specimen has been 684 kilograms, with a total length of 458 cm. The species seems to have an average lifespan of around 15 years, while the longevity for both the Atlantic and the southern

FIGURE 2
Thunnus thynnus **larvae (left), a school of juveniles (middle) and adults in a fattening cage (right)**



COURTESY OF R. UGOLINI

FIGURE 3
Thunnus thynnus* juveniles schooling associated with the bullet tuna, *Auxis rochei

bluefin tunas was estimated at around 20 years (Cort, 1990). For adults natural mortality rates range from 0.2 to 0.6, while natural rates for juveniles are higher.

Schooling and migration

All bluefin tuna species move constantly in search for food and to maintain a constant water flow over their gills. The Atlantic bluefin (*Thunnus thynnus*), pacific bluefin (*Thunnus orientalis*), and southern bluefin (*Thunnus maccoyii*) tunas all migrate seasonally over long distances between temperate waters, where they feed, and tropical waters, where they spawn. Spawning of all three species is generally restricted to relatively restricted areas in temperate and tropical waters.

Thunnus thynnus may form giant schools spreading over several nautical miles when migrating into the Mediterranean Sea to spawn during the summer months. Most bluefin school according to their size, however it is not unusual for different size size-groups to school together. Juveniles are, therefore, often associated with smaller tuna species such as the skipjack or bonito (Figure 3). While schooling is believed to be sight-oriented, schools have been observed at night.

Bluefin tuna are excellent swimmers and can swim at high speed for long periods as they are able to absorb and utilize large amounts of oxygen. Their bodies are designed for high performance at both sustainable and burst swimming speeds (Dickson, 1995). Tuna must swim constantly to satisfy their oxygen requirements in order to stay alive. Their swimming pattern seems to be influenced by both the distribution of food and the need to return to their ancestral spawning grounds at the appropriate time. To efficiently transfer oxygen from the gills to the other body tissues, tunas have hearts that are approximately 10 times the size of those of other fish, relative to the body weight, and blood pressure and pumping rate about three times higher.

Tunas have two types of muscle, white and red. The white muscles function during short bursts of activity, while the red muscles, which have a relatively large mass, allow the fish to swim at high speeds for long periods without fatigue, as demonstrated by tagging studies with conventional and sonic tags (Joseph, Klawe and Murphy, 1988; Bushnell and Holland, 1997).

Feeding

Tuna larvae live in warm surface waters and feed primarily on zooplankton, including small crustaceans and the larvae of crustaceans, fishes, molluscs and jellyfish. Tuna larvae are preyed upon by zooplankton foragers, such as larger larvae and early juveniles of other pelagic fish. Juvenile and adult tuna generally prey on fish, squid and crustaceans. The larger specimens, which feed on pelagic fishes, are positioned at the top of the trophic web and locate their prey visually. To satisfy their nutritional requirements tunas have to swim long distances. Their type of locomotion is particularly well adapted to the search for prey in large water volumes with the least expenditure of energy. Tuna break up schools of prey, producing disorientation and straggling (Webb, 1984; Partridge, 1982). When prey is detected, the tuna changes their behaviour and have a general increase of activity, e.g. increase in swimming speed, change in swimming pattern and energetic pursuit to obtain smaller schooling fish such as anchovies.

Reproduction

The spawning of *Thunnus thynnus* has been so far detected in only two areas: the Mediterranean and the Gulf of Mexico. In the Gulf of Mexico, spawning occurs from April to June when the water temperature is 25–30 °C and in the Mediterranean from May/June to August. Karakulak *et al.* (2004a; 2004b) reported bluefin spawning in the Levantine Sea (Eastern Mediterranean basin) with a peak in the activity in May.

Sexual maturity of the Atlantic bluefin tuna is reached at the age of 5 to 8 years, while in the eastern Atlantic maturity is reached earlier, at 4–5 years. Scientists have found that in the Balearic Islands (Mediterranean) bluefin tuna are able to spawn from 3 years old (Abascal, Megina and Medina, 2003). Bluefin tunas may release from 5 to 30 million eggs and spawning occurs in open water close to the surface and in areas where the survival expectations of the larvae is highest.

BLUEFIN TUNA FISHERIES

Thunnus thynnus is the most demanded and expensive tuna species. The fishery is regulated by the International Commission for the Conservation of Atlantic Tunas (ICCAT) which is responsible for the conservation of tunas and tuna-like species in the Atlantic Ocean and adjacent seas. Since 1982 the Commission has managed Atlantic bluefin tuna in two areas with a boundary line at 45 degrees W longitude (north of 10 degrees N) (Figure 4).

As a result of overfishing, beginning in 1982 the fishery in the Western Atlantic management area has been controlled by restrictive catch limits. Catch limits have been in place for the Eastern Atlantic and Mediterranean stock in 1998. The Commission established a total allowable catch (TAC) for both stocks.

The *Thunnus thynnus* global catch shows a considerable yearly reduction. In 1996 it peaked at 52 664 tonnes and dropped to 31 577 tonnes by 2004 as a result of the ICCAT quotas (Figure 5). However, the Standing Committee on Research and Statistics (SCRS) of the Commission affirms that considerable overfishing still goes undetected.

FIGURE 4
The two ICCAT management areas with a boundary line at 45 degrees W longitude (north of 10 degrees N)

Source: ICCAT, 2005

According to the ICCAT global catch statistics for the Western Atlantic tuna stock from 1995 to 2004, the lowest catch was recorded in 2004 at 1 644 tonnes, while the highest was in 1999 at 3 550 tonnes. For the Eastern Atlantic stock, the lowest catch was reported at 29 933 tonnes in 2004 and the highest at 50 274 tonnes in 1996 (Figures 6 and 7).

Thunnus thynnus is captured using a variety of gear types including purse seines, longlines, traps, handlines, bait boats and sport fishing. Since the 1990s, as the majority of the catch has been destined for farming purposes, the capture is mostly carried out by purse seine that allows the capture of live individuals. Minor quantities are still harvested using tuna traps. The major catch area for the Atlantic bluefin tuna is the Mediterranean Sea where 73 percent of the global catch is landed, followed by the Northeast Atlantic (15 percent). The majority of the Mediterranean catch is destined for farming operations (Figure 8).

CAPTURE-BASED AQUACULTURE

Thunnus thynnus is considered a capture-based aquaculture (CBA) species, as the farming activity is entirely based on the stocking of wild-caught individuals (Ottolenghi *et al*., 2004). Scientists at Kinki University, Japan, achieved the completion of the life cycle of the Pacific bluefin tuna (*Thunnus orientalis*) under controlled conditions after 32 years (Sawada *et al*., 2004). For the Northern bluefin tuna (*Thunnus thynnus*), research on reproduction and the rearing of juveniles has been carried out, however the closure of its life cycle has not been achieved on a commercial-scale. Driven by the Japanese market, capture-based aquaculture has developed significantly.

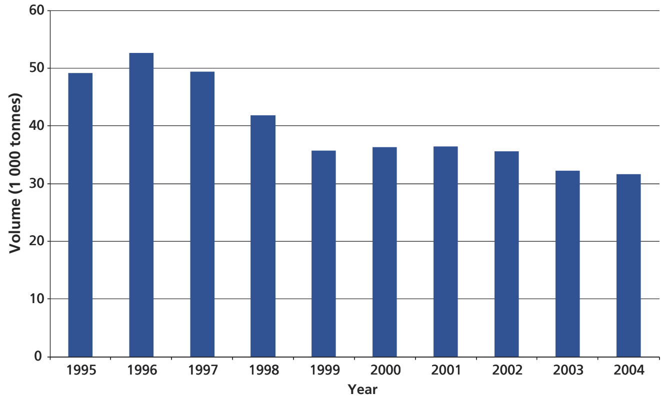
Fishing techniques, season and catching size

For farming purposes, wild tunas are caught at different life cycle stages, ranging from juveniles of less than 8 kilograms to large adult specimens. The capture system is the same for juveniles and adults, i.e. purse seines. This modern and widely used fishing technique basically creates a "purse" net to entrap the school (Figure 9).

In the Mediterranean juveniles are mainly caught in the Adriatic Sea by Italian and Croatian purse seines at the end of spring and in early summer. Juveniles at about 15 kg in weight were also caught around September-October in the Tyrrhenian Sea and during the harvest season in the Balearic Islands (now prohibited by EC Regulation No. 643/2007 of 11/06/2007). The main fishing period in the Mediterranean runs from May to July.

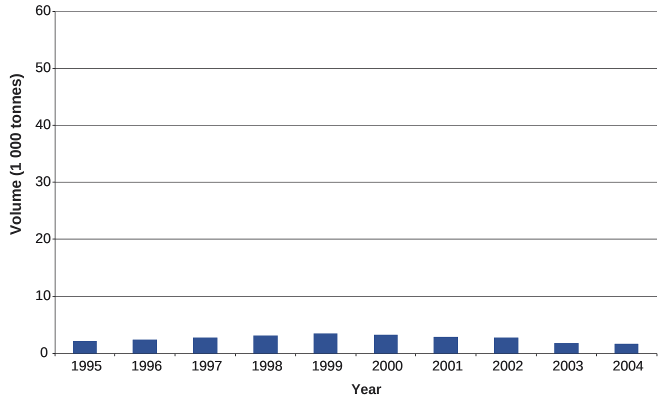
There is strong cooperation among the purse seine vessels, often supported by aerial search. Small aircrafts or even helicopters are used to detect bluefin tuna schools (a practice now

FIGURE 5
***Thunnus thynnus* global catch from 1995–2004**



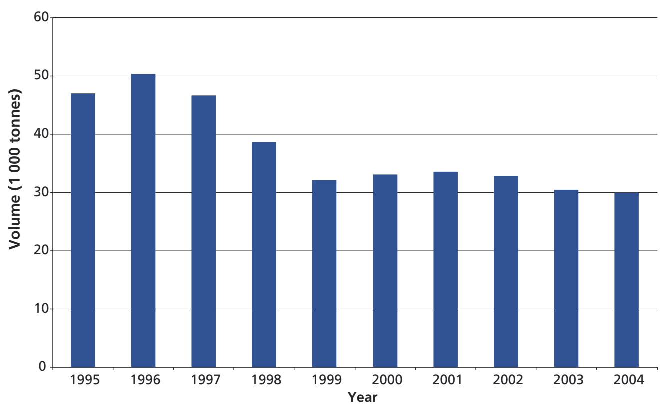
Source: FAO, 2006.

FIGURE 6
***Thunnus thynnus* Western Atlantic global catch from 1995–2004**



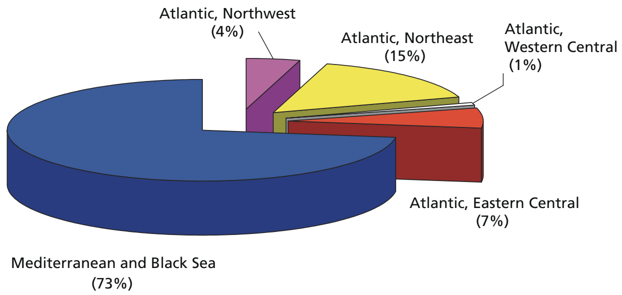
Source: FAO, 2006.

FIGURE 7
***Thunnus thynnus* Eastern Atlantic (incl. Mediterranean and Black Sea) global catch from 1995–2004**



Source: FAO, 2006.

FIGURE 8
***Thunnus thynnus* global catch by area in 2004**



Source: FAO, 2006.

FIGURE 9
Purse seines in the process of fishing bluefin tuna

COURTESY OF R. UGOLINI

FIGURE 10
Tuna traditional trap fishing in Carloforte, Italy

COURTESY OF F. OTTOLENGHI

prohibited by ICCAT), however fish finders and sonar are largely used leaving little possibility for the fish to go undetected. A second capture system is the traditional tuna trap which are a fixed gear anchored to the sea bottom, aimed at intercepting tuna in their migration paths (Figure 10). While these are still in use in some countries (e.g. Italy), they are loosing ground to the purse seiners, which are far more efficient in detecting and capturing the fish.

Aquaculture sites

Following the capture of wild bluefin tuna they are kept alive and carefully transferred to towing cages. The transfer action is a crucial activity as specimens may suffer severe stress that may lead to death. At present there is no efficient method to establish the fish biomass moving into the towing or farm cages making it rather difficult to determine the size and age composition of the fish. During the transfer process the fish are gently forced to move from the purse seine net to the towing cage usually by sewing the nets together (Figure 11). Divers often assist in this delicate operation and use underwater video cameras film as the film will eventually help in the discussions, often animated, between the fishermen and farmers in estimating the number and size of captured fish before a sale price is agreed. The industry considers the need to devise a better solution for determining the size and age composition of the captured fish destined for farming operation to be a priority. The lack of biometric information makes stock assessment and therefore, management and conservation of the bluefin tuna resource, rather difficult.

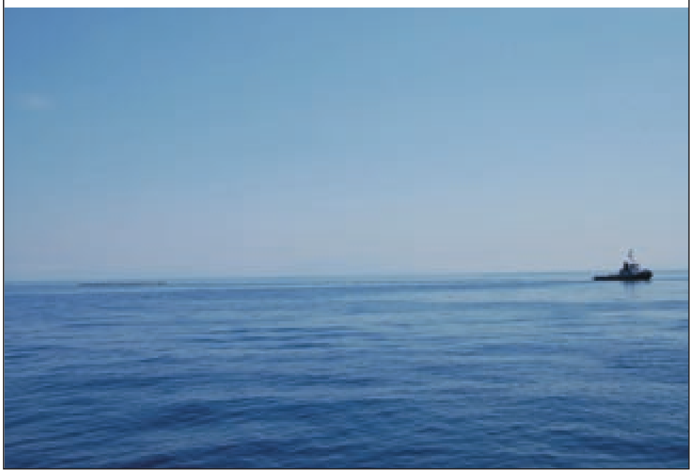
Once the tuna are all moved into the towing cages, tugboats are used to transport the fish from the fishing area to the on-growing or farm site (Figure 12). Towing speed does not usually exceed 1–1.5 knots in order to avoid excessive tuna mortality and to allow tuna to swim easily. However, such a low speed implies long transportation trips that may last days, weeks or even months which are further complicated by the need to adequately feed the confined fish. Mortality rates during transportation are usually quite low (1–2 percent) although there have been rare cases where all the fish have died.

In the Mediterranean, the companies engaged in this form of mariculture start stocking their tuna cages in late spring (May/June). This input season lasts for a couple of months (May/June or June/July), however, in the case of Croatia and Malta the season may extend to late summer (September). Mediterranean tuna farms largely use circular ring-type open-sea floating net cages, either built locally or purchased from several large equipment manufacturers (e.g. Bridgestone, Corelsa, Fusion Marine). The size of the cages varies from 30–90 m in diameter, with net depths commonly ranging from 15 to 20–30 m. The industry mainly uses cages with a 50 m diameter and net depths varying according to sea location. The larger cages (i.e. 90 m in diameter) are mainly used by the Spanish operators while those in Croatia prefer smaller ones in terms of net depth, i.e. 13 m (FAO, 2005). Generally the weight of the stocked tuna is between 150–200 kilograms, however Croatian operations generally start their farming with smaller specimens weighing around 8–25 kilograms, while countries like Italy, Malta and Spain may even stock giant tunas weighing as much as 600 kilograms.

FIGURE 11
Divers sewing nets for bluefin tuna transfer

COURTESY OF R. UGOLINI

FIGURE 12
Bluefin tuna tugboat



COURTESY OF R. UGOLINI

In the Mediterranean, there are mainly two types of cages used, those for "farming" and those for "fattening". The "farming" cages are designed to contain generally small tuna specimens for long periods of time often more than 20 months. Most countries in the region do not retain the fish for such long periods and usually only confine the tuna for periods of 1–7 months. The "fattening" season which may extend to February and generally not beyond December/January is closely linked to the market demand/opportunity. The fish may also be sold few days following capture as harvesting is often agreed beforehand between the producer and the fish trader.

Many Mediterranean countries, including Portugal, are currently farming Atlantic bluefin tuna: Croatia, Cyprus, Greece, Italy, the Libyan Arab Jamahiriya, Malta, Morocco, Spain, Tunisia and Turkey. Farms obtain fish from local fishing fleets as well as from vessels bearing other flags (e.g. Malta and Cyprus often obtain their fish supply entirely from foreign vessels). Croatia, France, Italy and Turkey have the highest number of vessels used in tuna fishing (FAO, 2005).

TABLE 1
Mediterranean countries farming bluefin tuna in 2001 and in 2007

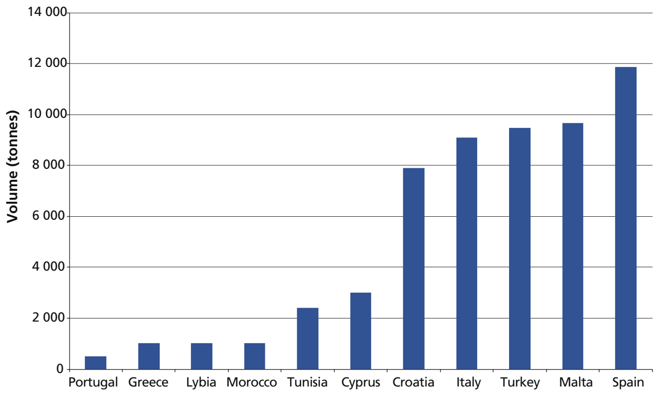
2001	2007
Spain	Spain
Croatia	Croatia
Malta	Malta
Italy	Italy
	Cyprus
	Turkey
	Libyan Arab Jamahiriya
	Tunisia
	Greece
	Morocco
	Portugal

Farm production/capacity

Tuna farming in the Mediterranean area started in Andalusia, Spain, in 1985 and expanded in 1996 to Croatia, in 2000 to Malta and in 2001 to Italy (FAO, 2005). As of 2007, eleven Mediterranean countries (including Portugal) were involved in bluefin tuna farming (Table 1).

The driving force behind this rapid expansion has been the Japanese market. As a result, farmed products are produced to coincide with the optimal fat content demanded by the "sushi" and "sashimi" markets. The total Mediterranean tuna production derived from the farming activities is difficult to calculate as the initial cage stocking information, i.e. biomass and fish size, is only a rough estimate and any weight gain is generally kept confidential by the farmers. For all ICCAT Contracting Parties, bluefin tuna imports must be accompanied by the Bluefin Tuna Statistical Document (BTSD) and any country re-exporting the tuna must attach the original BTSD along with a re-export document. These documents are used to track the volume of farmed tuna exported to Japan which currently absorbs approximately 90 percent of total farmed tuna. In 2007 the potential capacity of all Mediterranean tuna farms authorized by ICCAT was 56 842 tonnes (Figure 13).

FIGURE 13
Mediterranean bluefin tuna farming potential country capacity



Farming mortality

Bluefin tuna mortality rates during the fattening/farming period have been recorded at around 2 percent; however some countries (e.g. Spain and the Libyan Arab Jamahiriya) have reported higher mortalities during the first month the tuna are in cages. This is generally due to the long towing trip which stresses and weakens the fish just before they are moved into the farming cages. Bluefin tuna show great adaptiveness in captivity and so far no specific diseases have been recorded, nevertheless high mortalities may occur due to adverse environmental conditions such as strong currents or elevated water turbidity. Preliminary investigations on the suitability of a selected farm site can prevent and minimize such risks.

Feed

Bluefin tuna are fed mainly with a mixed diet composed principally of a variety of small pelagic species including sardine (*Sardinella aurita*), pilchard (*Sardina pilchardus*), round sardinella, herring (*Clupea harengus*), mackerel (*Scomber japonicus*), bogue (*Boops boops*) and squid (*Illex* sp.). The proportion and volume of the feed varies among the different countries and from farm to farm, with feed composition also based on the availability of the species generally used. Mediterranean countries engaged in the tuna farming obtain bait fish from locally fished stocks or from imports stocks from outside the region, with the latter usually representing the largest proportion of the fish used by the industry

Bluefin tuna are generally fed 1–3 times a day depending on the farm and country, with a mixture of defrosted bait fish. In most countries a scuba diver remains in the cage during feeding, and signals to stop the feeding when tuna are satiated. When the tuna are not fed *ad libitum* the daily feed input varies from 2–10 percent of the estimated tuna biomass and also depends on the water temperature and the fish size composition in the cage.

Without accurate initial length or weight measurements of the fish during cage farming, growth and feed conversion rates are only estimates. Under intensive farming conditions, growth, food intake and feed conversion rates have never been estimated accurately by farmers to avoid loosing the high value tuna as a result of the handling required to take such measurements (Aguado-Gimenez and Garcia–Garcia, 2005).

As for food intake, there is very little information available and it seems that overfeeding is a common practice among farmers. As the baitfish used varies in its nutritional qualities, it is not the quantity of baitfish supplied to the tuna that influence production, but the supply and quality of nutrients obtained from consuming them (Ottolenghi *et al*., 2004). Feed conversion ratios (FCR) are generally high around 15–20:1 for large specimens and 10–15:1 for smaller fish. Bluefin tuna maintain an unusually high body temperature and their constant movement implies a high energy demand (Graham and Dickson, 2001). As a result only a small fraction (5 percent) of the total energy input is used for body growth (Korsmeyer and Dewars, 2001).

Several studies on farmed-raised tuna have demonstrated that the tuna are generally in good health and pose no health risks to consumers. Nonetheless, management control procedures for the tuna industry must be developed to prevent any risk and to provide a qualitative fish health assessment for food quality and safety.

Appropriate freezing procedures decrease health risks in baitfish-fed tuna; however several studies have shown deterioration in baitfish quality after a few days to one month, depending on whether the fish have been chilled or frozen (e.g. the fatty compounds in pilchards readily oxidises and therefore careful handling procedures may need to be adopted) (Munday *et al.*, 2003).

Considering the high volume of baitfish needed to feed tuna (2–10 percent daily of the BFT biomass farmed) there is an urgent need for research to develop artificial diets able to support a better feed conversion ratio and to ensure a better control over the quality of the fish produced (Ottolenghi *et al*., 2004). The absence of formulated feed is of concern to the industry, particularly in view of the current high FCR when using baitfish. Scientific evidence indicates that fish weaned on a formulated diet that replicates normal nutritional intakes will perform considerably better than those fed on baitfish. Furthermore, the availability of artificial feed would partly eliminate or at least ease farm logistics in terms of sourcing, purchasing, transporting and storing the feed, as well as eliminate health risks associated with the use of raw fish.

At present only limited research studies are being carried out on artificial feeds at the farm level. Following the Australian efforts on Southern bluefin tuna (*Thunnus maccoyii*), encouraging results are being obtained in Mexico where the Pacific bluefin tuna (*Thunnus orientalis*) is cultured even though only a small percentage (<20 percent) of the tuna diet is made up of artificial feed (Figure 14). The main problems related to the use of the artificial feed have still to be overcome including high production costs and opposition/resistance from the Japanese market. Because the consumers mainly eat raw tuna meat, the taste of the flesh is important and does vary depending on the feeding strategy used by the farmers. For these reasons farmers prefer not to use pellets in order to avoid consumer rejection.

FIGURE 14
Artificial pelleted feed utilized in Mexican tuna farms

COURTESY OF BURRIS/CARGILL ANIMAL NUTRITION

Environmental impact

At present, bluefin tuna capture-based aquaculture relies entirely on wild-caught seed, as the control of the full life cycle of the tuna at commercial-scale has yet to be achieved. This farming practice which is based on the removal of "seed" material from wild stocks clearly overlaps with the fisheries sector. In 2006 the SCRS has indicated that the spawning stock biomass (SSB) of the Atlantic bluefin tuna continues to decline while fishing mortality is increasing rapidly, particularly for large fish, and warned of a possible stock collapse. As a result in November 2006, ICCAT recommended establishing a multi-annual recovery plan (see section on Management).

It is well known that size and age composition of BFT destined for farming operations are not precisely determined and this affects the quality of available data for stock assessment. It is also apparent that the total allowable catch (TAC) set by ICCAT is not fully adhered to and is largely ineffective in controlling overall catch (ICCAT, 2006a). Therefore, there is a strong need to eliminate illegal fishing to ensure an efficient management of the fish stock.

As in all mariculture practices the grow-out component of BFT capture-based aquaculture poses concerns on the potential deterioration of the environment in the proximity of the farm site. Intensive fish farming generally generates a large amount of organic waste in the form of unconsumed feed, faecal and excretory matter. Such particulate matter can accumulate in the sediments below or close to the farm, causing an undesirable organic enrichment that may adversely affect the surrounding benthic community and, to a lesser extent, water quality (Ottolenghi *et al*., 2004). In the case of BFT farming the fish are generally maintained in cages for short periods of time (often around 7 months, with the exception of Croatia) which allows a rapid recovery of the ecosystem.

Farm site selection, as for all other marine aquaculture practices, is of critical importance to ensure the operational sustainability of tuna farming. The selection of an inappropriate site may result in oxygen depletion in the bottom water layers that may lead to the development of anoxic conditions in the sediment and production of toxic gases such as hydrogen sulphide. These phenomena will adversely affect benthic organism (Ottolenghi *et al*., 2004). Due to the biological nature of these large pelagic fish, farm sites need to be established in areas where there is a good circulation of well oxygenated water, a sufficient depth, etc. Careful site selection is therefore critical for successful and environmentally sustainable operation of tuna farms (Ottolenghi *et. al*, 2004).

As for feeding, the use of baitfish raises several concerns, including the relative impact of the harvest on the small pelagic resources, but also the high FCR (and consequently high discards) and the deterioration risk of the environmental as a result of the accumulation of uneaten bait fish on the sediment.

Socio-economic impacts

It is important to note that the tuna fattening industry has an economic impact in the Mediterranean area. There are huge financial investments, generally through major partnerships with Japanese companies, not only in the tuna farms but also in the capture fishery sector as a whole. This has, in some cases, resulted in modernization of entire fishing fleets, fitted with modern fish detection equipment, improved safety and crew comfort, and the use of new tug boats (e.g. Algeria built a whole new fleet). A modern 40–50 m length purse seine boat fitted with the latest equipment may costs around €3–4 million (US$4.4–5.9 million). During the BFT catching season the daily rent for a tug boat may amount to €3 000 or US$4 450 (excluding the cost of fuel as fish transfer trips may sometimes last for weeks). Furthermore, small airplanes are often used to detect fish, and some large operations had their own aircraft (now prohibited by EC Regulation No. 643/2007, 11/06/2007).

It is obvious that social benefits are often closely related to economic benefits, and the development of the BFT industry has created new job opportunities. At the same time, tuna capture-based aquaculture generates impacts and conflicts with other resource users such as the traditional tuna trap and longline operators. The activity of tug boats towing tuna cages disturbs the traditional longline fisheries in many countries (Italy, Malta, Tunisia) as well as reducing tuna catches. Bluefin tuna farmers in Croatia have caused problems and strong conflicts with tourism activities in the use of the coastal zone.

The BFT industry in the Mediterranean currently engages somewhere between 1 000–2 000 full-time workers, in addition to a considerable amount of casual labour during the farming season. The industry has also been characterised by the development of new skills, including teams of specialized divers, to properly handle harvesting operations, monitor fish mortality, moorings and inspection of cages, transfer of fish to the farm cages and appropriate killing procedures. Furthermore, tuna farms generally operate their own fleet of boats mainly for positioning the cages, bait transportation and feeding and for other routine farm activities.

Feeding constitutes one of the highest operating cost factors in tuna farms and one of the major concerns. Producers purchase bait fish from local fisheries but also through imports from other European Union (EU) countries and as far as the South and North American (mainly from the United States of America). The rising demand for small pelagic fish has had important effects on the market, e.g. sardine prices have doubled in 5 years (1998–2002) (De Mombrison and Guillaumie, 2003).

Market

Bluefin tuna prices have shown a decrease in the last 5 years. The cost/kg of BFT transferred live to the farms from the fishing sites is currently around €4 or US$5.9 (2007 data) depending on the specimen size, while in 2000 and 2002 the price paid to the fishermen was €8–9.5 (US$11.8–14). The value of BFT products sent to Japan has followed the same trend and the final income per kilogram of product exported sometimes barely cover farm expenses. In 2006 there was a significant shift in exports from fresh to frozen fish, also as a result of the high transportation costs. This has had several combined effects on market prices in Japan considering that this Asian country is almost the exclusive destination of farmed products. The high capacity to stock large amount of frozen tuna also allows traders to control the supply of the tuna into this lucrative market. In any case, it is evident that in 2006 the total fresh bluefin import trend into Japan have declined, lowering to 23 000 tonnes compared to 24 000 and 28 000 tonnes in 2005 and 2004, respectively (Table 2). According to data provided by the Globefish service of FAO the Japanese bluefin tuna business is worth ¥42 000 million or US$354 million.

The final bluefin tuna products (mainly as sushi and sashimi) continue to show a positive trend in consumption, with prices depending on the quality of the individual fish specimen. A grading process determines the final destination of a bluefin tuna. This process, though apparently quick and easy to the uneducated eye, is a crucial factor for all the players in the trade network. By taking a thin core of flesh from the fish, the fisherman or wholesaler ascertains the fat and oil contents, appraises the colouring and outside appearance. In less than a minute and taking into consideration the market situation, the fish is tagged with a small slip of paper indicating its quality and final destination.

The main bluefin tuna consumption period in Japan falls during the many festivities in December that marks the end of the year. The whole tuna farming and fattening industry in the Mediterranean is based on such Japanese tradition. As the main tuna harvesting period is in the spring/summer months the fish are simply kept in cages for 6–7 months before they are harvested and exported to Japan to take advantage of the tuna price increase during such festivities.

TABLE 2
Fresh bluefin tuna imports into Japan (in tonnes)

Country	Year				
	2003	2004	2005	Jan-Nov 2005	Jan-Nov 2005
Mexico	1 896	3 849	4 097	3 318	2 359
Australia	2 769	2 839	2 343	2 343	1 693
Spain	2 537	2 693	2 277	1 757	1 643
Korea Rep.	2 579	667	1 479	1 464	1 001
Italy	366	346	314	304	254
Turkey	896	1 011	522	273	190
Croatia	226	123	240	101	162
Tunisia	221	144	212	180	106
Malta	647	449	180	122	97
Others	1 487	909	729	862	559
Total	13 624	13 030	12 393	10 724	8 064

Souce: FAO Globefish.

Management

The introduction of tuna farming activities into the Mediterranean resulted in rapid changes in capture fisheries, with the purse seine fishery becoming the most important provider of live tuna to the farming sector. Catch limits imposed by ICCAT have been in place for the Eastern Atlantic and Mediterranean management units since 1998. In 2002, the Commission fixed the 2002–2006 TAC at 32 000 tonnes. At the Fifteenth ICCAT Special Meeting held in November 2006, the 2007 TAC was set at 29 500 tonnes an amount that would gradually decrease to 25 500 tonnes in 2010. This TAC reduction is a part of a general ICCAT multi-annual recovery plan for bluefin tuna and includes a series of control measures such as closed seasons, minimum size and regulation of caging operations (ICCAT, 2006). The plan aimed partly to respond to the Commission's Standing Committee on Research and Statistics 2006 stock assessment report that indicates that the BFT spawning stock biomass continues to decline while fishing mortality is rapidly increasing.

The SCRS nevertheless admits that the model used to assess the stock status has some limitations considering the increase uncertainties on current harvesting levels. In fact, as the main part of fish catch is destined for farming operations, the fish size and age composition is becoming more difficult to determine with the needed precision. Furthermore, it is believed that severe overfishing takes place and goes undetected hence reducing the efficiency of the TAC system in controlling overall tuna catches. It is clear that there is a strong component of illegal fishing and there are no effective policies against illegal, unregulated and unreported fishing (IUU) fully adopted and implemented by ICCAT's Member States.

The ICCAT attempt to protect the bluefin tuna spawning biomass and to reduce the juvenile catches by imposing a minimum size of 30 kilograms is an effort undermined, if not made useless, by the two exceptions included in the recommendation which allows fishing of 8 kilogram juveniles by (1) bait boats, trolling boats and pelagic trawlers in the Eastern Atlantic (mainly along the Spanish and French Atlantic coasts) for an amount of up to 2 950 tonnes in 2007 (about 368 750 individuals); and (2) boats that harvest in the Adriatic Sea for farming purposes. Furthermore, the ICCAT resolution also allows catching of individuals of <8 kilograms (and not <6.4 kg) for a total quantity not exceeding 200 tonnes. The situation is further complicated by the fact that several Mediterranean countries are currently not ICCAT members. The status of the Mediterranean bluefin tuna stock is in critical condition, and may face stock collapse unless dramatic actions take place at the regional level.

CONCLUSION

Over 90 percent of market demand for bluefin tuna comes from Japan, although important markets in Southeast Asia and the United States of America are emerging. There is an increasing global demand for seafood, a corresponding increase in demand for premium quality tuna for the sushi and sashimi market and a growing need to respond to the decline of most wild BFT fisheries worldwide. These are driving the development of reliable technologies for large-scale production of juvenile tuna, for both commercial food production and fisheries restocking. As these technologies improve, the economics of full cycle farming should also improve, and quite possibly result in changes in the market structure for hatchery-produced fish.

There would be benefits for fisheries, aquaculture and farm managers if BFT could be measured by underwater stereo-video without the trauma caused by capture and handling. In Australia, improved underwater measurements are currently being used with this system. The most significant disadvantage is the delay in the availability of information to farm managers and fisheries/aquaculture management agencies, due to the manual post-processing of video images (Harvey *et al.*, 2003). Similar studies are also being carried out in Italy and hopefully in the near future the quality of the biometric data will help to improve stock assessment which is the basis for an effective management of the resource.

In view of the extensive use of bait fish, the high feed conversion ratios and related farm management problems (e.g. purchasing, transporting, storage, and distribution of bait fish and environmental effects), the industry must intensify studies on artificial feed in order to mitigate the problems associated with the used of bait fish. In the meantime, however, there is a need to standardize control systems to ensure baitfish quality and avoid the introduction of potential pathogens. In order to ensure total transparency of the industry and traceability of traded tuna, farmers need to adopt and follow best farming practices throughout the production process.

Furthermore, urgent management actions are required to mitigate the impact of illegal fishing as it is estimated that 30 percent of total BFT catches derive from IUU fishing. These fishing activities must be controlled and eliminated and the industry must comply with the quotas agreed for the conservation of the wild stock. It is also recommended that the catch data from "recreational fishing" is recorded to curb illegal sport fishing of tuna.

The development of a specific bluefin tuna code of conduct should be shared by fishers, farmers and importers to ensure the implementation of all management regulations. This could also be a tool for the collection and reporting of bluefin tuna capture-based aquaculture data.

REFERENCES

Abascal, F.J., Megina, C. & Medina, A. 2003. Histological and stereological assessment of batch fecundity spawning frequency and maturation of female Atlantic northern bluefin tuna around the Balearic Islands. *Cahiers Options Méditerranéennes*, 60: 13–14.

Aguado-Gimenez, F. & Garcia-Garcia, B. 2005. Growth, food intake and feed conversion rates in captive Atlantic bluefin tuna (*Thunnus thynnus* Linnaeus, 1758) under fattening conditions. *Aquaculture Research*, 36: 610–614.

Brill, R. 1994. A review of temperature and oxygen tolerance studies of tunas pertinent to fisheries oceanography, movements models and stock assessments. *Fish. Oceanogr.*, 3(3): 204–216.

Bushnell, P.G. & Holland, K.N. 1997. Tunas. *Virginia Mar. Res. Bull.*, 29(1&2): 3–6.

Collette, B.B., Reeb, C. & Block, B.A. 2001. Systematics of the tunas and mackerels (Scombridae). In B.A. Block & E.D. Stevens (eds). *Tuna: physiology, ecology and evolution*. London, England, Academic Press. *Fish Physiology Series*, 19: 1–33.

Cort, J.L. 1990. Biologia y pesca del atún rojo, *Thunnus thynnus* (L.), del Mar Cantábrico. *Inst. Español Ocean., Publ. Esp.*, 4: 272 p.

De Monbrison, D. & Guillaumie, B. 2003. Preliminary studies for DOTT symposium – BFT impacts on local development a socio-economic approach. *Cahiers Options Méditerranéennes*, 60: 127–138.

Dickson, K.A. 1995. Unique adaptations of the metabolic biochemistry of tunas and billfishes for life in the pelagic environment. *Env. Biol. Fish.*, 42: 65–97.

FAO. 2005. Report of the third meeting of the Ad Hoc GFCM/ICCA ICCAT Working Group on Sustainable Bluefin Tuna Farming/Fattening Practices in the Mediterranean. Rome, 16–18 March 2005. *FAO Fisheries Report*. No. 779. Rome, FAO.

FAO. 2006. FAO yearbook. Fishery Statistics: capture production 2004. FAO *Fisheries Series* No. 98/1. Rome, Italy, FAO.

Fischer, W., Bauchot, M.L. & Schneider, M. 1987. Fiches FAO d'identification des espèces pour les besoins de la pêche (Révision 1), *Mèditerranée et mer Noire*. Zone de pêche 37. 1. Volume II : vertèbres. Publication préparée par la FAO (Project GCP/INT/422/EEC), Rome, FAO. 1529 pp.

Graham, J.B. & Dickson, K.A. 2001. Anatomical and physiological specializations for endothermy. In Tuna: Physiology, Ecology and Evolution. B.A. Block & E.D. Stevens (eds). Academic Press, San Diego, CA, USA. *Fish Physiology Series*, 19: 121–166.

Harvey, E., Cappo, M., Shortis, M., Robson, S., Buchanan, J. & Speare, P. 2003. *Fisheries Research* 63: 315–326.

ICCAT. 2005. Report for biennal period, 2004–2005. Part I (2004) – Vol. 2. Madrid, Spain. Available on: http://www.iccat.es.

ICCAT. 2006. *Recommendation by ICCAT to establish a multi-annual recovery plan for bluefin tuna in the Eastern Atlantic and Mediterranean* [Rec. 103-06]. ICCAT Doc. No PA2-103F/2006 Dubrovnik, 17–26 November.

ICCAT. 2006a. Report of the 2006 Atlantic Bluefin Tuna Stock Assessment [SCRS/2006/013].

Joseph, J., Klawe, W. & Murphy, P. 1988. Tuna and Billfish – fish without a country. Fourth edition, Inter-American Tropical Tuna Commission (ed), La Jolla, California: 69 pp.

Karakulak, S., Oray, I., Corriero, A., Deflorio, M., Santamaría, N., Desantis, S. and De Metrio, G. 2004a. Evidence of a spawning area for the bluefin tuna (*Thunnus thynnus* L.) in the Eastern Mediterranean. *J. Appl. Ichthyol*., 20: 318–320.

Karakulak, S., Oray, I., Corriero, A., Spedicato, D., Suban, D., Santamaria, N. & De Metrio, G. 2004b. First information on the reproductive biology of the bluefin tuna (*Thunnus thynnus*) in the Eastern Mediterranean. *Collective Volume of Scientific Papers ICCAT,* 56(3): 1158–1162.

Korsmeyer, K.E. & Dewars, H. 2001. Tuna metabolism and energetics. In Tuna: Physiology, Ecology and Evolution. B.A. Block & E.D. Stevens (eds). Academic Press, San Diego, CA, USA. *Fish Physiology Series*, 19: 3–78.

Munday, B.L., Sawada, Y., Cribb, T. & Hayward, C.J. 2003. Disease of tunas, *Thunnus* spp. *Journal of Fish Diseases*, 26: 1–20.

Ottolenghi, F., Silvestri, C., Giordano, P., Lovatelli, A. & New, M.B. 2004. Capture-based aquaculture – The fattening of eels, groupers, tunas and yellowtails. Rome, FAO. 2004. 308 pp.

Partridge, B.L. 1982. The structure and function of fish schools. *Scient. Amer.*, 247: 114–123.

Sawada, Y., Miyashita, S., Murata, O. & Kumai, H. 2004. Seedling production and generation succession of the Pacific bluefin tuna, *Thunnus orientalis*. *Marine Biotechnology,* 6: 1–5.

Webb, P.W. 1984. Body form, locomotion and foraging in aquatic vertebrates. *Amer. Zool.*, 24: 107–120.