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THE PECULIARITIES AND FARMING CHALLENGES OF ATLANTIC BLUEFIN TUNA (*Thunnus thynnus,* L. 1758)

Gorana Jelić Mrčelić[1*], Ivana Miletić[2], Marina Piria[3], Ambroz Grgičević[1], Merica Slišković[1]

[1] *University of Split Faculty of Maritime Studies, Ruđera Boškovića 37, 21000 Split*
[2] *Counsellor for Fisheries, Permanent Representation of Croatia to EU*
[3] *University of Zagreb Faculty of Agriculture, Department of Fisheries, Apiculture, Wildlife management and special Zoology, Svetošimunska 25, 10000 Zagreb, Croatia*

*Corresponding Author, Email: gjelic@pfst.hr

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ABSTRACT

The aim of this paper is to provide an overview of bluefin tuna, with special regard to its farming challenges. Tuna is one of the most prominent species in fisheries worldwide. The high market value of tuna stocks has led to intensified fishing pressure that resulted in drastic population reductions in every ocean where these fish are found. It is very difficult to obtain the necessary data for the appropriate stock assessment analysis, and there is a very high degree of uncertainty in the models used to evaluate Atlantic bluefin tuna stocks. Tuna-farming could help reduce pressure on the tuna population, but the problem is that the majority of cage-farmed fish is caught in its natural environment (wild population), and thus is fattened or farmed to a certain size. Additionally, the challenges in tuna farming are numerous. Tuna is a fast swimmer, a large energy and oxygen consumer, therefore consuming a large portion of available food to maintain its metabolism. However, due to its delicious taste, high market price and a large demand for this species, pressure will probably continue to grow in the future. Therefore intensive farming, which implies the full breeding cycle in captivity, remains one of the possible solutions that could help reduce the pressure on the tuna population.

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INTRODUCTION

The aim of this paper is to provide an overview of bluefin tuna, with special regard to its farming challenges. Tuna is one of the most important species in world fisheries. Due to its delicious taste, high market price and size, there has been an increase in the demand for tuna, which has resulted in the high level of fishing pressure and the impoverishment of otherwise poor natural fishing grounds (Benetti et al., 2016). Atlantic bluefin tuna is a member of the family Scombridae. The scombrid genus Thunnus contains seven species, including bluefin tuna (Committee to Review Atlantic Bluefin Tuna, National Research Council, 1994). There are three species of bluefin tuna: Pacific bluefin tuna (PBFT, *Thunnus orientalis*), Atlantic bluefin tuna (ABFT, *Thunnus thynnus*) and Southern bluefin tuna (SBFT, *Thunnus maccoyii*). ABFT lives in the Mediterranean, in the North-Western Pacific and Atlantic, while SBFT in the Southern Pacific and Indian Oceans. Until recently these species were considered as two subspecies of the same one (Collete et al., 2001). They are powerful swimmers, with range from the tropics to polar latitudes (Mather et al., 1995), found all over the Mediterranean and the Atlantic Ocean from 60°N to 40°S. It is generally considered that there are two separate stocks, eastern and western, conventionally separated by the 45°W meridian. The eastern stock is distributed from Norway to the south of Africa in the Eastern Atlantic (Block et al., 2001). The western stock inhabits the area from Labrador (Newfoundland) to the south of Brazil in the western Atlantic. Data indicate that while spawning is limited to two discrete areas, the Gulf of Mexico and the Mediterranean Sea, there is a movement of individuals between the western and eastern management units. (Block et al., 2001). The new ecological niche modelling approach (Druon et al., 2016) recognized the central Ionian as a secondary potential spawning ground. Cermeño et al. (2015) recognized the Adriatic Sea as a feeding ground by an electronic tagging experiment, while Džoić et al. (2017) recognized it as a spawning ground.

Bluefin tuna is a species native to the moderate climate zone, although in its search for food it covers a wide range of temperature conditions (between 3°C and 30°C), while maintaining a stable internal body temperature (Block et al., 2001). Although it prefers to occupy the surface and subsurface waters (upper 300 m of the water column) of coastal and open-sea areas, both juvenile and adult bluefin tuna frequently dive to depths of more than 1000 m (Block et al., 2001, Brill et al., 2001). Atlantic bluefin tuna is the largest tuna species – its maximum length is approximately 4 m and maximum weight is 726 kg, although some have reported weights of up to 900 kg. Atlantic bluefin tuna has similar characteristics as cold-water species: slower growth, later maturity, a shorter spawning season, a larger size and longer life span than other warm-water predators (Fromentin and Fonteneau, 2001) and this makes tuna vulnerable to exploitation (ICCAT, 2016a).

Juvenile growth is rapid for teleost fish (about 30 cm/year), but slower than for other tunas (ICCAT, 2015). Fish born in June attain a length of about 30-40 cm and a weight of about 1 kg by October. After one year, fish reach about 4 kg and 60 cm (Mather et al., 1995). At 10 years old, Atlantic bluefin tuna is of about 200 cm and 150 kg and reaches about 300 cm and 400 kg at 20 years with considerable variability between individuals (Frometin and Powers, 2005). According to ICCAT (1997) males grow faster than females. Tuna is a long-lived species with a lifespan of 40 years. Age-size relationships are uncertain, especially for 8-year-old individuals, and older; in addition, there is a considerable variation between the von Bertalanffy equation estimated by various authors (Farrugio, 1981; Cort 1991; Turner and Restrepo, 1994...). The growth in length tends to be lower for adults than for juveniles, but growth in weight increases (ICCAT, 2016a). Both juveniles and adults grow rapidly during summer and early autumn (up to 10% per month) (Mather et al., 1995).

Tuna lives in shoals, sometimes congested, at other times more dispersed. The average swimming speed is 5.9 kmh^{-1}, but occasionally it can reach 20-31 kmh^{-1} (Katavić, 2006). Tuna makes great migrations, apart from some exceptions. It has a highly developed orientation mechanism enabling directed movement across large ocean areas. The exact process of this mechanism is still unknown, but it is believed that it uses the sun, electromagnetic fields, odour and ocean currents during its ocean passage. Beside large horizontal migrations, it performs even larger vertical migrations due to changes in temperature distribution, sea limpidity and other environmental factors (Block et al., 2001).

Tuna blood temperature is several degrees (even up to 15 to 20°C) higher than the temperature of the sea in which it lives, and it retains 98% of its muscle temperature. Its fresh blood, enriched with oxygen, is heated on the principle of *rete mirabillae*: warm blood returns to the gills in order to be enriched by oxygen, and there it passes by the colder blood which has just come out of the gills, transferring its warmth to it. The elevated body temperatures of bluefin tuna increase its capacity for rapid migration by enhancing the power output of its muscle (Altringham and Block, 1997).

Although tuna is a migratory species, it seems to display homing behaviour and spawning site fidelity in both the Mediterranean Sea and the Gulf of Mexico, which constitute the two main spawning areas clearly identified today (ICCAT, 2015). Bluefin tuna is oviparous and iteroparus. It has asynchronous oocyte development and is a multiple batch spawner. The spawning temperature ranges from 18 to 25°C (Lioka et al., 2000). In the spawning period (from mid-April to August), it is sensitive to seawater temperature and its salinity, the most favourable value being 38% (Block et al., 2001). Some

Table 1. Life history traits for Bluefin tuna (Fromentin and Fonteneau, 2001)

Species	Spawning duration (month yr^{-1})	Length at maturity (cm)	Weight at maturity (kg)	Age at maturity (year)	Max. length (cm)	Max. weight (kg)	Max. age (year)	Juvenile growth (%L.yr^{-1})
Bluefin tuna (East Atlantic)	1.5	115	27.5	4.5	295	685	20	8.7
Southern bluefin tuna	2	130	43	8	200	320	19	8.1

Table 2. Growth models adopted by the Standing Committee on Research and Statistics (SCRS) for Bluefin tuna (ICCAT, 2016b)

Species/Area/Sex	Parameters	Reference	n	L range	Method
East Atlantic and Mediterranean sexes combined	$L_t = 318.85(1-e^{-0.093(t+0.97)})$	Cort (1991)	192	172-302	Spines
West Atlantic sexes combined	$L_t = 382.0(1-e^{-0.079(t+0.707)})$	Turner and Restrepo (1994)	903	50-300	Tagging

authors suggest that tuna does not spawn every year but only once every two or three years (Lutcavage et al., 1999). Egg production is age-dependent and can vary between 5 million and 45 million eggs (ICCAT, 2016a). It is very important to mention that tuna migrations, undertaken primarily for spawning, have an important role. Tuna can swim across the Atlantic in 60 days (a short time for such a long distance) to reach the area favourable for spawning (Block et al., 2001). In the case of Atlantic bluefin tuna, there are only two areas: the Gulf of Mexico, for the western stock, and the Mediterranean, for the eastern stock. In the Gulf of Mexico, tuna spawns from mid-April to mid-June. In the Mediterranean, the spawning season lasts from June to August. Older tunas spawn earlier, the younger ones later (Block et al., 2001).

An interesting fact is that the individuals of the eastern stock achieve sexual maturity at 110-120 cm at approximately 4 years old (ICCAT, 2016a). Goldstein et al. (2007) reported that tuna in the western Atlantic reach sexual maturity between the ages 7 and 8. According to Baglin (1982), the size and age of bluefin tuna in the western Atlantic at sexual maturity (200 cm and 10 years) are larger and greater, respectively, than for the eastern Atlantic/Mediterranean bluefin tuna (130 cm and five years).

Spawning fertilization occurs directly in the water column, and hatching happens without parental care after an incubation period of 2 days (ICCAT, 2016a). Little is known about the effects of the age-structure of the spawning stock, as well as the condition of the spawners on the viability of the offspring (ICCAT, 2016a). Fertilized eggs float in the sea with a mass of zooplankton and phytoplankton. Initially, their diameter is 1-2 mm. From the just spawned fry, only one out of 40 million has a chance of achieving the adult phase of eight years of age. They form shoals of a size of 1-1.5 cm (Katavić, 2006).

Tunas also migrate for food and ecological conditions, but less is known about feeding migrations than about spawning migrations. The eastern stock ranges from the site of spawning in the Mediterranean to the Atlantic Ocean through the gate of Gibraltar, then north towards the Bay of Biscay and south towards the Canary Islands (Block et al, 2001). The feeding migrations of bluefin tuna vary considerably between individuals, years and areas (Block et al., 2001; de Metrio et al., 2002). Juvenile and adult bluefin tuna are opportunistic feeders (ICCAT, 2016a). Juveniles feed on crustaceans, fish and cephalopods, while adults primarily feed on fish such as *Clupea harengus* (Linnaeus, 1758), *Engraulis encrasicolus* (Linnaeus, 1758), *Ammodytes dubius* (Reinhardt, 1837), *Sardina pilchardus* (Walbaum, 1792), *Sprattus sprattus* (Linnaeus, 1758), *Pomatomus saltatrix* (Linnaeus, 1766) and *Scomber scombrus* (Linnaeus, 1758). *Clupea harengus* and *Pomatomus saltatrix* in the West Atlantic or *Engraulis encrasicolus* in the East Atlantic and Mediterranean dominate the diet (ICCAT, 2016a). In case of shortage, they feed also on other species (demersal fish, occasionally on shrimp). There are no clear relationships between prey length and the size of bluefin tuna, and both small and large bluefin tuna feed on prey of a similar size (ICCAT, 2016a).

Natural mortality rates (M) are poorly known for bluefin tuna, but it is known that Ms vary with age, population density, size, sex, predation and environment (ICCAT, 2016a). According to the Standing Committee on Research and Statistics (SCRS) for Atlantic bluefin tuna, the values of M per year by age vary between 0.10 (at the age of 10) and 0.49 (at the age of 1) for East stock, and the value of M is 0.14 for all age groups between 1 and 10 for the West stock (ICCAT, 2016c).

The high market value of tuna stocks led to intensified fishing pressure and it has also spurred Illegal, Unreported and Unregulated (IUU) fishing, resulting in drastic population reductions in every ocean where these fish are found (Benetti et al., 2016). According to Block et al. (2005), the tuna population decreased by more than 80% due to excessive exploitation from the mid-1980s to the mid-2000s. According to Frometin and Powers (2005), the estimated spawning stock size (SSB) and recruits were relatively stable since the mid-1980s. The potential productivity of the stock, future recruitment levels and the consequences of future catches on SSB trends remain uncertain and still lead to intensive debates (Frometin and Powers, 2005). There have been great uncertainties about the total catches and size composition for many fisheries of the East Atlantic and Mediterranean Atlantic bluefin tuna since the late 1990s (ICCAT, 2005). According to Bard (2013), there is a very high degree of uncertainty in the models used to evaluate Atlantic bluefin tuna stocks.

Therefore, measures for the protection and preservation of the species have been undertaken. Since tuna is a cosmopolitan species, its protection can be achieved only on an international level (Katavić, 2003a). The International Commission for the Conservation of Atlantic Tunas (ICCAT) is an inter-governmental fishery organization responsible for the conservation of tunas and tuna-like species in the Atlantic Ocean and its adjacent seas. The International Convention for the Conservation of Atlantic Tunas was signed in Rio de Janeiro, Brazil, in 1966. The Convention was enforced in 1969 (ICCAT, 2016d; Miletić, 2011).

The management and control measures proposed by the ICCAT include: Total Allowable catch (TAC) and quotas, some restrictions concerning fishing seasons, spawning grounds, the use of aerial means, the minimum size of fish, by-catch, fishing capacity, farming capacity, etc. The ICCAT set the TAC for the West Atlantic stock and the East Atlantic stock (ICCAT, 2016a). In 2017, Rec. 14-04 (Recommendation by the ICCAT Amending Recommendation 13-07 by the ICCAT to Establish a Multi-Annual Recovery Plan for Bluefin Tuna in the Eastern Atlantic and Mediterranean was enforced on 2 August 2015) defined three yearly steps to reach a final TAC of 23,155 t for the East stock and Rec. 14-05 (Recommendation by the ICCAT amending the supplemental recommendation by the ICCAT concerning the Western Atlantic Bluefin Tuna rebuilding program) defined reaching a final TAC of 2,000 t in 2016 for the West stock (ICCAT, 2015).

Atlantic-wide size limit of 6.4 kg was in force from 1975 till 2004, when it was raised to 10 kg for the East Atlantic and Mediterranean Sea, and to 30 kg for the West Atlantic. A 15-year recovery plan was adopted by ICCAT in Dubrovnik in 2006 for Eastern Atlantic bluefin tuna stock (ICCAT, 2006). In 2007, ICCAT increased the minimum catch size from 10 to 30 kg in the East Atlantic and Mediterranean Sea (ICCAT, 2016a). According to ICCAT (2018):

(28.) The minimum size for bluefin tuna caught in the eastern Atlantic and Mediterranean Sea shall be 30 kg or 115 cm fork length. Therefore, the Contracting Parties and Cooperating non-Contracting Parties, Entities or Fishing Entities (CPCs) shall take the necessary measures to prohibit catching, retaining on board, transhipping, transferring, landing, transporting, storing, selling, displaying or offering for sale bluefin tuna weighing less than 30 kg or with fork length of less than 115 cm.

(29.) By derogation from paragraph 28, a minimum size for bluefin tuna of 8 kg or 75 cm fork length shall apply to the following situations listed in Annex I:

a) Bluefin tuna caught in the eastern Atlantic by baitboats and trolling boats;

b) Bluefin tuna caught in the Mediterranean Sea by the small scale coastal fleet fishery for fresh fish by baitboats, longliners and handliners;

c) Bluefin tuna caught in the Adriatic Sea for farming purposes.

Since the majority of tunas are fattened and farmed, precise information (total catch, size composition) is necessary. The Atlantic-wide Research Programme for Bluefin Tuna (GBYP) (started in 2010) outlined the research necessary for improving the scientific advice that the Committee provides to the Commission (ICCAT, 2015). The introduction of fattening and farming activities into the Mediterranean in 1997 resulted in rapid changes in the Mediterranean fisheries for bluefin tuna. In 1996, declared catches in the East Atlantic and Mediterranean (the East stock) reached a peak of over 50,000 t, but according to the ICCAT (2015) the catch was seriously under-reported between the mid-1990s through 2007. The Committee has estimated that the actual catch could have been between 50,000 t and 61,000 t per year based on the number of vessels operating in the Mediterranean Sea and their respective catch rates. Since 2008, the reported catch has significantly decreased as well as the actual catch, according to Committee estimates, due to regulatory measures (more restrictive TACs, change of operational patterns, length of the fishing season and target size, etc.) (ICCAT, 2015).

The spawning stock biomass (SSB) for the East stock peaked at over 300,000 t in the early 1970s and then declined to about 150,000 t by the mid-2000s, but the SSB increased up to 585,000 t in 2013 (ICCAT, 2015).

The total catch for the West Atlantic stock, including discards, has been relatively stable since 1982 due to the imposition of quotas. The catch was 1,626 in 2014. In 2014, it was estimated that the SSB for the West Atlantic stock steadily declined from 1970 to 1992, but since 1998, when the rebuilding plan was adopted, the SSB has increased by 70% (ICCAT, 2015).

The Committee has noted that *management actions taken in the eastern Atlantic and Mediterranean are likely to influence the recovery in the western Atlantic, because even small rates of mixing from East to West can have considerable effects on the West due to the fact that eastern plus Mediterranean resource is much larger than that of the West* (ICCAT, 2015).

Tuna farming

The global decline of wild bluefin tuna populations, as a result of heavy fishing pressure, makes farming an attractive alternative to fisheries, although capture-based farming, a widely adopted type of bluefin production, requires a comprehensive approach to ensure sustainability (Džoić et al., 2017). One of the reasons for the great interest in tuna farming is that the value of fresh fish farmed in the cage is twice as high as deep-frozen first-class fish (Fromentin, 2006). The anatomical, physiological and biochemical characteristics of the fish pose multiple challenges in tuna farming. Its population structure is poorly understood and needs further investigation (ICCAT, 2015).

The first tuna breeding programme was initiated by the Japanese in Canadian waters in the early 1960s, with the idea of keeping it in a cage for several months. During that period, the farmed tuna increased its mass as well as the content of fat. Shortly after the Canadian experience, seiners in the Mediterranean discovered that even a middle-sized tuna could be sold on the Japanese market for a relatively high price under the condition that its meat had a high content of fat and the pink colour of fresh meat. Consequently, the 1970s saw the beginning of tuna farming in the Mediterranean in a similar way as in the Canadian example (Miyake, 2002).

In Croatia, the first farming of tunas caught by seiner net was undertaken in 1996. The Australian Croats who returned to their homeland decided to pass on their Australian experience (Katavić et al., 2003b). That was the first successful attempt of farming tuna caught in the seine nets, not only in the Croatian fisheries, but also in the whole Northern hemisphere. Before that, tuna farming was carried out in 1992 in Spain, but it was based on tuna caught in standing tuna traps (Dujmušić, 2000). Tuna breeding in Croatia is based on catching wild bluefin tuna, in the range of units weighing more than 8 kg to those weighing over 200 kg. While in the Mediterranean and other countries tuna above 30 kg is caught and is fattened intensively for 6-10 months, in Croatia a small fish is caught from 8 to 10 kg and is farmed for periods ranging between 18 and 36 months, depending on the strategy of each company, in order to obtain a medium-quality product for the Japanese sushi and sashimi market. Tunas are detained within large floating cages with nets and are fed until they are caught. Generally, fish brought to the Croatian farms is smaller (mainly weighing from 10 to 80 kg) and has been caught by tuna seiners in the Adriatic (Katavić et al., 2003a). The fishing grounds are around the islet of Jabuka, but tuna can also be naturally caught in other areas of the Mediterranean (Mladineo et al., 2006).

Spawning in captivity

Tuna spawning in captivity plays an important role in reducing the pressure on wild tuna. Although a successful tuna spawning was achieved as early as 1979, it was not possible to achieve the survival of units in a further phase of their development. In 2002 Japanese scientists from the University of Kinki in the Japanese prefecture of Wakayama succeeded extending the developmental cycle of Pacific tuna (*T. orientalis*). This was the first tuna spawned and farmed in captivity. A total of 1.63 million eggs were collected, out of which 17,307 units of progeny were obtained, which were then transferred into net cages off shore. Out of those 17,307, 1,100 individuals survived, which by April 2004 achieved a length of around 95 cm (TL) and a mass of around 14 kg. They were offered on the market in September 2004, with approximately 20 kg of body mass. The market successfully accepted tuna farmed in this manner. By February 2008, 780 farmed tunas were offered on the market (Sawada et al., 2008).

Tuna aquaculture production is still reliant upon the capture of wild-caught juveniles, but intensive effort has been made on closing the life cycle of Atlantic bluefin tuna in Europe since early 2000s. Great progress is reported from the Spanish Institute of Oceanography (IEO) in Mazarron, but also from Cyprus and Turkey. The European Union has invested 10 million euros into major research and development consortiums such as REPRODOTT and SELFDOTT. REPRODOTT was a collaborative research effort supported by the EU between 2003 and 2005. The aim of the research was to evaluate the feasibility of Atlantic bluefin tuna reproduction in captivity. The research was coordinated by the IEO with nine additional research partners from seven Mediterranean countries.

According to Grubišić et al. (2013) and Džoić et al. (2017), the spontaneous spawning of Atlantic bluefin tuna in captivity has been observed in Croatian tuna farms in the middle Adriatic, where spawning behaviour was observed over summer months.

Farming conditions

Bluefin tuna has unique physiological features, including the ability to partially regulate their body temperature. Tuna consumes food even during the winter period when the sea temperature is 11°C. It is obvious that tuna can tolerate a wide temperature range (Katavić et al., 2003c). For farming of Atlantic bluefin tuna, the sea temperature must be within the range of 18 to 26°C (above 14°C). The ability to maintain body temperature above the temperature of the surrounding water makes tuna a partially homeothermic organism, contrary to other fish. Tuna is well-known for its energy consumption because a large amount of the food consumed is spent on maintaining body heat, as well as on continuous swimming. Tuna is also a large oxygen consumer, similar to mammals of equal size and 3 to 4 times larger than that of most active fish. Its respiration depends on continuous forward movement in order to create pressure, propelling water through the gills (Bonačić, B., pers. comm.). Tuna swims with its mouth open, which allows a jet of water to pass through the gills, extracting oxygen (Katavić, 2006). Continuous swimming undoubtedly consumes huge quantities of energy and requires high oxygen consumption (Bonačić, B., pers. comm.).

Although Thurston and Gehrke (1993) drafted a table of data on oxygen consumption for around 300 fish species, data regarding bluefin tuna (*T. thynnus*) have not been found. Data have been found for some other tuna species (*K. pelamis, T. albacores, T. obesus*), and oxygen consumption ranged from 322 to 740 mgO_2 kg^{-1}h^{-1}. For *T. alalunga*, oxygen consumption was 1,784 mg h^{-1} for a unit of 6 kg, while for a unit of 13 kg it was 4,765 mg h^{-1}, and this means that the constant is a≈500 mgO_2 h^{-1} (Thurston and Gehrke, 1993). One fish consumes around 500 mgO_2 $kg^{-1}h^{-1}$, which for example is equivalent to the quantity of oxygen found in around 60 dm^3 of sea water. Even from the aspect of overpopulation by an unsustainably high fish density in cages of more than 5 kg m^{-3}, a decrease in oxygen concentration caused by tuna breathing would mainly be more than 90%, while a greater decrease would occur occasionally when current drifts are of extremely low values (Tudor M., pers. comm.).

After 8 months of farming, Atlantic bluefin tuna shows an increase in mass of 40-50% in smaller specimens, and 10-30% in larger ones. The highest growth rate (5.2%) occurs in the summer, a month and a half after stocking. After that, in the winter period, when there is decrease in temperature, food consumption also decreases (Norita, 2003).

Tuna feeding

In controlled intensive fish farming, feeding is a hard and complex part of production. Fish growth and health are directly dependent on appropriate diet and feeding. Feeding starts 2-3 weeks after catching and then tuna eventually starts adapting to the food. The daily amount of food makes approximately 5-8% of the live tuna mass (Katavić et al., 2003a; b). The amount of food is determined in conjunction with its appetite. During feeding, divers monitor its attitude to food, even after the fish has already adapted to the food. This is very important in order to determine and awaken its interest in food, as well as to determine the appropriate food (Ottolenghi, 2008).

Tunas cannot maintain constant body temperature and this leads to a reluctance in growth during the year – growing faster in summer and more slowly in winter. Increased temperature leads to an increase in food consumption, and fish grows faster. With an increase in temperature by 1°C the intensity of metabolism increases by approximately 10%, while an increase in temperature by 10°C results in an increase of metabolism intensity by 0.5 to 3 times. A part of the energy from a certain quantity of low-quality food is excreted via faeces, kidneys and the gills, a part of the metabolic energy is consumed for the conversion of metabolic energy into pure energy, while the rest is pure energy required for maintaining activity and growth, which is only 5% of the total energy. The energy requirements of tuna depend on its high degree of activity, temperature and mass (Kraljević M., pers. comm.).

Specific physiological characteristics of tuna, such as continuous swimming and the maintenance of high body temperature, imply a very high energy requirement (Graham and Dickson, 2001), while only 5% of the total energy consumed is for growth (Korsmeyer and Dewars, 2001). A positive correlation among muscle temperature, specific growth rate and biochemical muscle indicators wasalso noted in the research carried out with the farmed progeny of *T. maccoyii* in Australia. The research indicated an increase in biochemical activities with amino acid metabolism and protein conversion (Carter et al., 1998).

Data on feeding strategy, conversion coefficients, etc., are restricted and are mainly related to the Australian experience, where the feeding period is short and varies from 3 to 10 months. The average mass of Southern bluefin tuna is between 10 and 20 kg, while the mortality rate ranges between 3% and 7%. Southern bluefin tuna in farming is fed small oily fish, six days a week, twice a day (Clarke, 2002). According to Metian et al. (2014), the global demand for forage fish to supply Atlantic bluefin tuna farms is between 168 and 362 thousand tons. According to Ottolenghi (2008), fish are offered up to 13 daily meals, per day, depending on fish size, water temperature and feeding responses. The calculation of feed conversion rates (FCR) is a rough approximation. From 1995 to 2000, FCR on tuna farms in the Mediterranean decreased from 24.1 to 15.8 (Norita, 2003). According to Farwell (2003) and Katavic et al. (2003b), FCR ranges from 15:1 to 20:1 for animals below 30 kg, while according to De la Gandara and Ortega (2013) FCR is 40:1 for Atlantic bluefin tuna over 150 kg.

Katavić et al. (2003c) state that bluefin tuna is fed two meals daily for 6 days a week, although there are farming examples with the feeding of one meal a day. The feed conversion factor varies depending on the season (10:1 during summer and 17:1 during the winter period), as well as on tuna size. The feeding behaviour of tuna shows seasonal changes, which is particularly evident in the smaller bluefin tunas. Higher feeding activity occurs during autumn months and less during summer months. Fat levels show a decline over winter months, supporting the fact that the summer growth produces better quality fish (FAO, 2007).

A smaller tuna has a better conversion factor than larger specimens due to faster metabolism. According to Benetti et al. (2016), the majority of the tuna diet used in farms is made of forage fish and it is much less diverse than wild tuna diet. The most common species used as feed are small forage fish of the genera Sardinella, Sardina, Clupea, Scomber, Trachurus, sparid *Boops boops* and some cephalopods (Vita et al., 2004; Aguado et al., 2004). Frozen blocks of small oily fish are mainly used for feeding (pilchard, herring, mackerel), as well as cephalopods (calamari). For small oily fish the conversion factor is generally 10-15:1 (Clarke, 2002). Table 3 provides the ratio of food conversion in different areas for *Thunnus thynnus* and *Thunnus maccoyii* (Ottolenghi et al., 2004).

During the fattening season, tuna is usually overfed. The highest food consumption occurs at temperatures of 23-25°C, which can result in an increase of biomass of more than 10% (Katavić et al., 2003c).

Feeding tuna on small low-quality oily fish can cause various health problems and possibly a higher mortality rate in the farmed populations (Ruiz – Capillas and Moral, 2005; Mladineo et al., 2006). All the economically

Table 3. Ratio of food conversion in different areas for *Thunnus thynnus* and *Thunnus maccoyii* (Ottolenghi et al., 2004)

State/area	Ratio of food conversion	Type of food
Australia (winter cycle)	17:1	small oily fish
Australia (summer cycle)	10:1	small oily fish
Australia	15:1	small oily fish
Mediterranean Sea	15–20:1	small oily fish
Japan (older progeny)	8:1	small oily fish
Japan (juvenile specimens)	12,5:1	small oily fish
Murcia (Spain)	30:1	small oily fish
Australia (experimentally)	2:1	mixed, partially moist pellets

prominent species farmed on the western market are predators which hunt and consume primarily fish and crabs. They produce metabolic energy from the proteins and, therefore, carbohydrates do not play an important role in their energy supply (Halver and Hardy, 2002). They also require a high level of certain polyunsaturated fatty acids. In the wilderness, they are provided with these contents from the species they hunt and are concentrated in plankton. In farming, these substances must be included into the feeding programme and they can be found in fish oils (EFSA, 2004).

Diseases, mortality and tuna meat quality

The modern system of wild stock exploitation for farming purpose has shown good results, since tunas entering the farming cycle show very few bacterial and viral diseases during farming. According to Mylonas et al. (2010), there are various reasons for the lack of major disease problems: due to a high oxygen demand of Atlantic bluefin tuna, farming and fattening is done in relatively exposed coastal areas, with strong currents, and the fish are stocked at very low stocking densities (2–4 kgm^{-3}). Also, fish that are stocked in cages are mature adults (for fattening) or advanced juveniles (for farming), and already have a well-developed immune system. Diseases in fish usually occur when their biological integrity has been impaired, or as a result of the simultaneous impact of environmental factors (temperature, salinity, inappropriate feeding, increased concentration of ammonia and other marine pollutants), as well as pathogenic microorganisms (Benetti et al., 2016). The incidence of lipomas, hepatocarcinomas and other structural abnormalities in various Atlantic bluefin tuna organs was reviewed by Perić (2003), Marino et al. (2006), Roberts and Agius (2008), Corriero et al. (2013), Diler et al. (2013) and Passantino et al. (2013).

Perić (2002) provided one of the first reports of asymptomatic pasteurellosis in Atlantic bluefin tuna during harvest; it educed multifocal chronic granulomatous changes in the spleen and liver. Later, two extensive mortality outbreaks in reared tuna in the Adriatic Sea were reported. The first was caused by *Photobacterium damsela* subsp. piscicida (Mladineo et al., 2006), related to a sudden increase in water temperature, and the second was caused by the long-term feeding with low-quality baitfish that subsequently showed high concentrations of volatile amines (Šimat et al., 2009).

In Croatia, tuna represents one of the main export products either in fresh or frozen form, and as such, it is subject to quality assessment. With regard to this, it is above all necessary to know microbiological factors which can greatly influence its quality. Among numerous microbiological factors, parasites take an important place in the assessment of product quality as they decrease quality due to enzyme posthumous changes, such as *Kudoa* sp., *Microsporidia* sp. and digenean trematodes, Didymozoidae, or they represent an immediate threat to human health like *Anisakis* spp. (Mladineo, 2006).

Parasites in the wild fish population are low in number and abundance, and often have an insignificant pathological effect on their hosts. However, when such fish is included in farming, in controlled conditions the parasites tend to reproduce and spread in the form of epizootics onto the previously domesticated population (Athanassopoulou et al., 1999; Company et al., 1999). This becomes apparent in an increased density of fish stock as well as decreased immunity due to everyday stress. In the same way, many metazoan parasites invade tunas, but only a few are health-significant. For example, *Anisakis* spp. and *Hysterothylacium cornutum* (Anisakidae, Nematoda) are nematodes, dangerous to human health, while shrimp *Caliguselongatus, Euryphos branchypetrus* (Caligidae, Copepoda) and *Penella filosa* (Penellidae, Copepoda) are potentially pathogenic for the host only in large numbers (Mladineo, 2006). Shrimp *Penella filosa* (Penellidae, Copepoda) has the greatest influence on product quality. This shrimp can be found in the muscle tissue, where at the point of penetration into the fat tissue it becomes inflamed and necrotized, which decreases tuna meat quality, especially in large numbers (Mladineo, 2006). *Anisakis simplex* (Anisakidae, Nematoda), which is a frequent parasite in sea mammals and oily fish, especially tuna, also affects product quality. This parasite is found in all vertebrates, although humans are not final, but incidental hosts. Humans are usually invaded by consuming raw, lightly marinated or salted and insufficiently cooked fish, molluscs and crabs (Šoša, 2002). *Anisakis* spp. is a nematode capable of invading humans and therefore it represents a potential health risk which can be prevented by adequate treatment (cooking and freezing) of fish and fish products. It can be found on tuna's internal organs such as the visceral surfaces of the oesophagus, stomach, intestines and liver: It is subject to evisceration after catching, which can partly prevent penetration into tuna's muscle tissues (Mladineo, 2006).

Benetti et al. (2016) point out that more diseases are likely to be encountered as farming intensifies and once the life cycle of more species are closed and native fish are put to sea. According to *Atlantic Ocean Bluefin Tuna Seafood Watch Report* (Seafood Watch, 2016), the potential for tuna farms to amplify pathogens continues to be an ongoing concern, due to lack of regulatory measures to monitor and manage the presence of pathogens, although some studies (Mladineo et al., 2011) have shown parasite prevalence and abundance to decrease over the rearing period.

The long summer feeding period significantly increased the mortality rate, as stated by Mladineo et al. (2006).

High mortality during towing to the farms was a very big problem in tuna farming. Mortalities during transfer were significantly reduced from 10% in Turkey and 21% in Spain in 1995 (Oray and Karakulak, 2003; Norita, 2003) to 14% in 2015 (Benetti et al., 2016). From 1995 to 2000, the mortality rate on tuna farms in the Mediterranean decreased from 15.8% to 3.7% (Norita, 2003). According to Mylonas et al. (2010), such levels of mortality can be considered normal for the industry. Research indicates that high mortality can be noted in the period immediately following the transfer of tuna into the farming cages. It is supposed that mortality is caused by the stress experienced after catching and by towing from the landing position. Tuna farmers expect at least a 25% increase in biomass in the course of a six-month feeding and mortality not exceeding 3% during the adaptation period (Katavić et al., 2003 a; b; c).

CONCLUSIONS

The high market value of Atlantic bluefin tuna stocks has led to intensified fishing pressure that resulted in drastic population reductions. Frometin and Powers (2005) estimated that spawning stock size (SSB) has been relatively stable since the mid-1980s, but they also stated that the potential productivity of the stock, future recruitment levels and the consequences of future catches on SSB trends were uncertain and still led to intensive debates.

Tuna-farming could help reduce pressure on the tuna population, but the problem is that the majority of cage-farmed fish is caught in its natural environment (wild population), and thus is fattened to a certain size. Tuna breeding in Croatia is based on catching wild bluefin tuna in a range of units weighing more than 8 kg to those weighing over 200 kg. While in the Mediterranean and other countries tuna above 30 kg is caught and fattened intensively for 6-10 months, in Croatia a small fish is caught from 8 to 10 kg and is farmed for periods ranging between 18 and 36 months, depending on the strategy of each company, in order to obtain a medium-quality product for the Japanese sushi and sashimi markets. Tunas are kept within large floating cages with nets and are fed until they are caught. Generally, the fish brought to Croatian farms is smaller (mainly weighing from 10 to 80 kg) and caught by tuna seiners in the Adriatic (Katavić et al., 2003a). The fishing grounds are around the islet of Jabuka, but tuna can also be naturally caught in other areas of the Mediterranean (Mladineo et al., 2006).

Challenges in tuna farming are numerous. Tuna aquaculture production is still reliant upon the capture of wild-caught juveniles, but intensive effort has been made on closing the life cycle of Atlantic bluefin tuna in Europe since the early 2000s. The European Union has invested 10 million euros into major research and development consortiums such as REPRODOTT and SELFDOTT. Great progress is reported from Spanish Institute of Oceanography (IEO) in Mazarron, but also from Cyprus and Turkey.

Tuna is a fast swimmer and a large energy and oxygen consumer, consequently using most of the food it consumes for maintaining its metabolism. In controlled intensive fish farming, feeding is a hard and complex part of production. Tuna growth and health are directly dependent on appropriate diet and feeding. The majority of the tuna diet used in farms is made of forage fish and it is much less diverse than the wild tuna diet (Benetti et al., 2016). Tuna require a high level of certain polyunsaturated fatty acids. In the wilderness, this is provided by the species they hunt and they are concentrated in plankton. In farming, these substances must be included in the feeding programme and they can be found in fish oils (EFSA, 2004). Global demand for forage fish to supply Atlantic bluefin tuna farms is between 168 and 362 thousand tons (Metian et al., 2014). Feeding starts 2-3 weeks after catching and then tuna eventually starts adapting to the food. The daily amount of food makes approximately 5-8% of the live tuna mass (Katavić et al., 2003a; b).

The modern system of wild stock exploitation in farming has shown good results, since tunas entering the farming cycle show very few bacterial and viral diseases during farming, but there are many other possible reasons for the lack of major disease problems: tunas already have a well-developed immune system, farming and fattening is done in exposed coastal areas due to its high oxygen demand, and the fish are stocked at very low stocking densities (2–4 kgm^{-3}) (Mylonas et al., 2010).

Low-quality food or inappropriate nutrition cause stress in bluefin tuna, which leads to their contracting diseases and dying. The incidence of lipomas, hepatocarcinomas and other structural abnormalities in various Atlantic bluefin tuna organs has been reported by some authors.

In Croatia, tuna represents one of the main export products, either in fresh or frozen form, and as such, it is subject to quality assessment. With regard to this, it is above all necessary to know the microbiological factors which can greatly influence its quality. Among numerous microbiological factors, parasites take an important place in the assessment of product quality as they decrease quality due to enzyme posthumous changes, such as *Kudoa* sp., *Microsporidia* sp. and digenean trematodes, Didymozoidae, or they represent an immediate threat to human health, as with *Anisakis* spp. (Mladineo, 2006).

High mortality during towing to the farms was a serious problem in tuna farming. Tuna farmers expect at least a 25% increase in biomass over the course of a six-month feeding, and mortality not exceeding 3% during the adaptation period (Katavić et al., 2003 a; b; c). Research indicates that a high mortality rate can be noted in the period immediately following the transfer of tuna into farming cages. It is supposed that mortality is caused by the stress experienced after catching and by towing from the landing position.

Due to its delicious taste, high market price and high demand, the pressure upon tuna will probably also continue to increase in the future so that intensive farming, which includes the full farming cycle in captivity, remains one possible solution.

OSOBITOSTI I IZAZOVI UZGOJA ATLANTSKE PLAVOPERAJNE TUNE (*Thunnus thynnus*, L. 1758)

SAŽETAK

Cilj ovog rada je pružiti uvid u osobitosti atlantske plavoperajne tune s posebnim naglaskom na izazove njenog uzgoja. Visoka cijena tune dovela je do intenzifikacije ribolovnog pritiska na zalihe tune, što je rezultiralo značajnim smanjenjem populacije u svim oceanima koje tuna nastanjuje. Vrlo je teško prikupiti potrebne podatke za prikladnu analizu procjene stokova i stupanj nepouzdanosti modela koji se koriste za procjenu stokova plavoperajne tune je vrlo visok. Uzgajanje tuna možda bi moglo pomoći u smanjenu pritiska na populaciju tuna, no problem jest što se većina uzgajane ribe hvata iz prirodnog okoliša (divlja populacija) i tovi se do određene veličine. Osim toga postoje i brojni drugi izazovi uzgoja. Tuna je brz plivač i veliki potrošač energije i kisika, te troši velike količine hrane na održavanje metabolizma. No zbog njenog izvrsnog okusa, visoke tržišne cijene i velike potražnje, pritisak na ovu vrstu će najvjerojatnije i daje rasti. Stoga njen u potpunosti intenzivan uzgoj, koji uključuje zaokruženi ciklus razmnožavnja u zatočeništvu, ostaje jedno od mogućih riješenja koji bi mogli smanjiti pritisak na populaciju tune.

Ključne riječi: rast i razmnožavanje, uvjeti uzgoja, hranidba, bolesti, smrtnost, kvaliteta mesa

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