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The Northeast Atlantic and Mediterranean Bluefin Tuna Fishery: Back from the Brink?

Trond Bjørndal

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Abstract

At the turn of the century, the Northeast Atlantic and Mediterranean bluefin tuna stock (BFT) appeared to be severely overexploited with some commentators believing it was heading towards collapse. In 2006, a 15-year recovery plan was introduced with the purpose of restoring the stock to a level corresponding to maximum sustainable yield (MSY) with a probability of at least 50%. Stock size is now increasing, which has permitted higher TACs in recent years. In fact, the stock is now believed to be sustainably harvested. This represents a total turnaround from the situation of less than 15 years ago. The fishery is managed by the International Commission for the Conservation of Atlantic Tunas (ICCAT), a Regional Fisheries Management Organisation (RFMO) in accordance with the 1995 United Nations Fish Stocks Agreement. BFT is classified as a highly migratory stock harvested by a large number of countries. Several authors have questioned the effectiveness of RFMOs. This paper analyses how cooperation has been achieved for BFT and whether the current cooperative management regime is stable, so as to see what lessons it holds for RFMO management, in particular when it comes to highly migratory stocks.

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1. INTRODUCTION

At the turn of the century, the Northeast Atlantic and Mediterranean bluefin tuna stock (BFT) appeared to be severely overexploited with some commentators believing it was heading towards collapse (Fromentin & Powers, 2005; MacKenzie *et al.*, 2009). Atlantic bluefin tuna, possibly the most valuable fish in the ocean, was harvested by a large number of countries. Management was ineffective, and Bjørndal and Brasao (2006) described the fishery as bordering on pure open access. Unless effective management were introduced, the demise of the stock could be imminent (ICCAT, 2007).

In 2006, a 15-year recovery plan was introduced with the purpose of restoring the stock to a level corresponding to maximum sustainable yield (MSY) with a probability of at least 50% (ICCAT, 2007). As part of this plan, annual total allowable catch quotas (TACs) were reduced and fishing effort was curtailed. Moreover, harvesting was brought in line with quotas, while Illegal, Unreported and Unregulated (IUU) fishing, which in some years might have exceeded legal catches, has largely been eliminated (ICCAT, 2019). Stock size is now increasing, which has permitted higher TACs in recent years (ICCAT, 2020). In fact, according to Nøttestad, Boge and Ferter (2020), the stock is now sustainably harvested. This represents a total turnaround from the situation of less than 15 years ago.

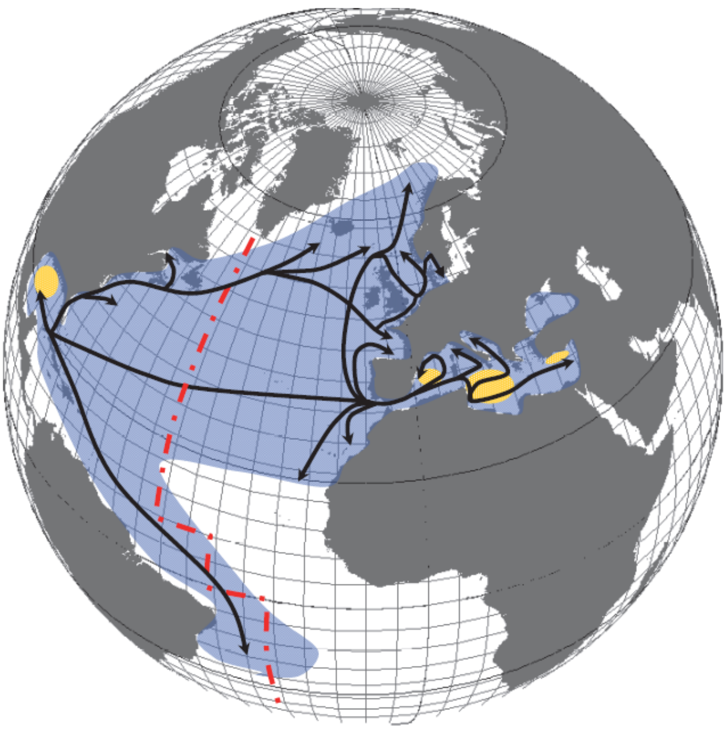
The purpose of this paper is to analyse the remarkable transformation of this fishery from non-cooperative (open access) management to that of cooperative, or sustainable, management, and whether the cooperative management is likely to remain stable in the future. The fishery is now managed through the auspices of the International Commission for the Conservation of Atlantic Tunas (ICCAT), a Regional Fisheries Management Organisation (RFMO) in accordance with the 1995 United Nations Fish Stocks Agreement (UN, 1995). BFT is classified as a highly migratory stock harvested by a large number of countries, coastal states as well as Distant Water Fishing States (DWFSs). In general, the more parties involved, the more difficult it is to arrive at a cooperative solution (Bjørndal & Munro, 2012). Moreover, several authors have questioned the very effectiveness of RFMOs (e.g. Cullis-Suzuki & Pauly, 2012; Pintassilgo *et al.*, 2010; Brooks *et al.*, 2014). Therefore, it is of great interest to learn how cooperation has been achieved for tuna and to see what lessons it holds for management by RFMOs, in particular when it comes to highly migratory stocks.

Non-cooperation in the BFT fishery prevailed until 2007, with the collapse of the fishery a real possibility. However, it is uncertain whether the current agreement for the cooperative management plan that is now in effect will remain stable and prevail in the long run. To address this issue, we will draw on game theory. This distinguishes between two types of games, non-cooperative (competitive) and cooperative: BFT is an excellent illustration of both.

This article is organised as follows. Section 2 will give an overview over the fishery up to about 2007 and outline the legal framework for the management of species such as tuna. In section 3, the recovery plan introduced in 2007 will be presented, and the consequences it has had on the fishery up to the present will be described. In section 4, we will analyse the cooperative management of the stock and, in particular, consider whether the current cooperation is stable. The final section summaries the analysis and gives suggestions for further research.

2. BACKGROUND

The Northern Atlantic and Mediterranean bluefin tuna (*Thunnus thynnus*) is a large oceanic pelagic fish and is also the largest of the tuna species (Fromentin & Powers, 2005). It contributes fully to spawning at age five, grows very rapidly and can grow to a length of over three metres, weighs up to 725 kg and lives up to 40 years (Cort *et al.*, 2013; ICCAT, 2019). In 1982, ICCAT established a dividing line between the east and west Atlantic, separating the stocks in order to facilitate stock assessment (figure 1). Although there is migration from the western stock to the eastern stock and vice versa, the stocks are managed separately. One reason for this is insufficient knowledge about trans-Atlantic mixing to properly quantify this migration (Nøttestad, Mjørlund & Sandberg, 2020).



Source: Bjørndal and Munro (2012)

Figure 1. Map of the spatial distribution of Atlantic bluefin tuna (blue), main migration routes (black arrows) and main spawning grounds (yellow areas) deduced from current and historical fisheries data as well as traditional and electronic tagging information. The vertical dashed line depicts the stock delimitation between the two current ICCAT management units.

The eastern stock, which is the focus of this analysis, is distributed from the east of the Canary Islands to Norway, in the North Sea, in Ireland, in the whole of the Mediterranean and in the south of the Black Sea (ICCAT, 2020). The eastern stock is now estimated to be approximately 10 times larger than the western stock (ICCAT, 2020). Spawning is located in the warm waters of the Mediterranean around the Balearic Islands and in the south of the Tyrrhenian Sea, starting in June and continuing until July.

BFT is highly prized in the sushi and sashimi market. Japan is by far the most important BFT market, however, Miyake *et al*. (2010) point out that, over time, the marketing of sashimi has changed from an exclusive Japanese market to a global one. This implies there have been (positive) shifts in demand for BFT, increasing the price. In an open access fishery, this would lead to greater fishing pressure which might further endanger the stock.

In Japan, most of the BFT – fresh and frozen, domestic and imported – is traded at the Tokyo market[1]. Traditionally, most BFT commercialised was frozen, but in recent years fresh has been more important. There is close substitution between the different product forms, and the Tokyo market price significantly drives the tuna price (Sun *et al.*, 2019).

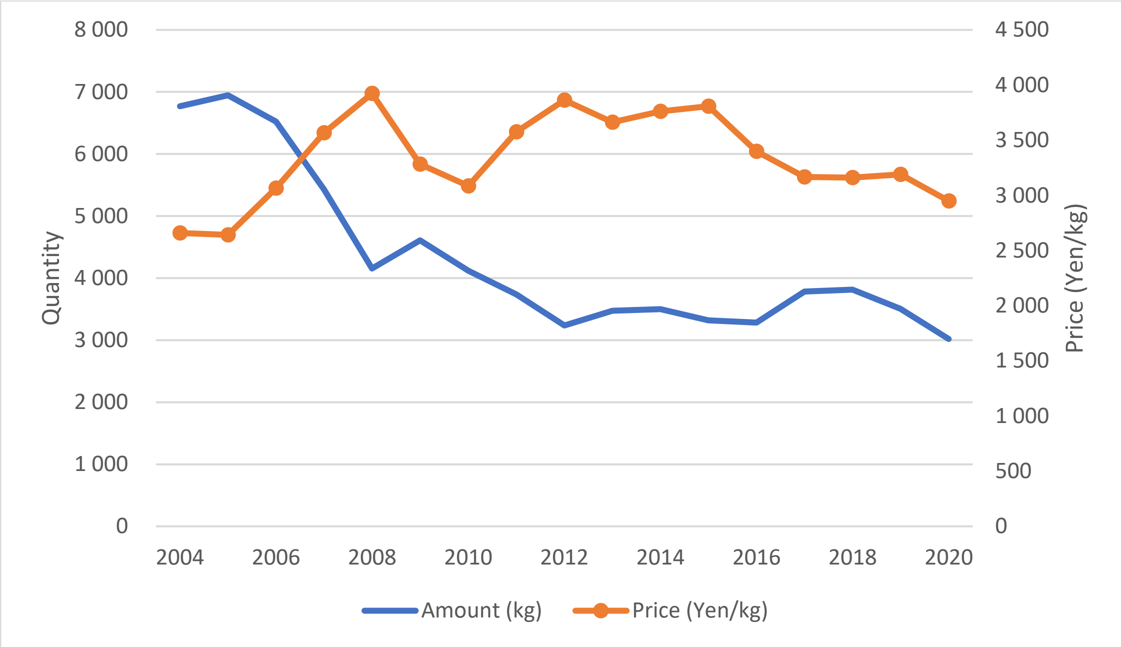
Annual auction wholesale prices for frozen tuna the period 2004-20 are illustrated in figure 2. Data are for the wholesale markets in Tokyo including Tsukiji (Toyosu), Adachi and Ota in Tokyo. Price is estimated as yearly total sales divided by quantity. The price is seen to increase from JP¥ 2,659/kg in 2004 to a peak of JP¥ 3,923 in 2008. The price came down after 2015 and has levelled off in the last three years with JP¥ 3,191/kg recorded for 2019, down to JP¥ 2,948 in 2020. This corresponds to US$ 27.61/kg[2]. After reaching a peak of 6,945 tonnes in 2005, quantity has in recent years levelled off with 3,500 tonnes traded in 2019 and a decrease to 3,019 tonnes in 2020. BFT is to a great degree consumed in fine restaurants. The closure of restaurants during lockdowns due to the COVID-19 pandemic (2020-21) is likely to have had an impact on BFT price.

There are three major BFT stocks, which are in the Atlantic and Mediterranean, the Pacific, and the Southern BFT. In an empirical analysis of demand for bluefin tuna, Sun *et al.* (2019) show that it is the total supply of BFT that determines price. This is logical, as much of the tuna from all three stocks ends up in Japan. The study also shows that increases in TACs for Eastern Atlantic and Mediterranean tuna, by affecting total supply and thereby price, in some instances may actually lower

[1] There is anecdotal evidence about outrageous prices being paid for BFT. In January 2019, US$ 3.1 mill. was paid for a 278 kg tuna at the Toyosu fish market in Tokyo during the new year celebrations at which time prices tend to be hyped up. It must also be noted that this was Pacific bluefin, not Atlantic, which are much rarer and considered better tasting. Nevertheless, this kind of price is not representative for BFT prices.

[2] This is for an exchange rate of US$ 1.00 = JP¥ 106.78, the average exchange rate for 2020. Source: www.federalreserve.gov/releases/g5a/current/.

fishermen's operating profit. This suggests that cooperation between the relevant RFMOs is in order so as to maximise the global economic returns from BFT.



Source: Tokyo Metropolitan Government

Figure 2. Annual Quantity (Tonnes) and Average Auction Price at Tokyo Wholesale Markets 2014-20 (JP¥/kg)

Bluefin tuna is classified as a highly migratory stock, harvested by both coastal states and DWFSs (Japan, Korea, China). Historically, more than 50 countries have participated in the fishery; currently (2018) 22 participate[3] (ICCAT, 2020)[4]. BFT is harvested in both the Atlantic and the Mediterranean. Up to the early 1960s, catches in the Atlantic exceeded those in the Mediterranean. Due to a decline in stock size and a concomitant reduction in the distribution area, harvesting in the North Atlantic collapsed in the early 1960s (Fromentin & Powers, 2005).

The different countries use different fishing technologies, in particular, *purse seine*, *longline*, *trap*, *bait boat* and *remainder*, a catchall term for all other gear types. DWFSs employ longline. Price varies substantially with gear type because the size and quality of harvested fish may vary with technology. According to Bjørndal and Brasao (2006), trap fetches the highest price, followed by remainder, longline, purse seine and bait boat.

[3] The EU is one contracting party in ICCAT, however, several EU countries participate in the BFT fishery.
[4] The number of countries active in the fishery varies from year to year due to quotas and stock distribution. In the 2000s, close to 30 countries have participated in the fishery.

There is also tuna "farming", which means caging of bluefin tuna for a period of perhaps two years, often doubling the weight per fish (Selles *et al.*, 2018). This is opposed to “fattening”, which means caging of bluefin tuna for a short period (usually two-six months), aiming mostly at increasing the fat content of the fish. “Fattening” for six months may increase fish weight by up to 60% (Sun *et al.*, 2019).

The stock grew to a peak of about 650,000 tonnes in 1975. Subsequently the stock went into decline until it levelled out at about 260,000 – 270,000 tonnes in the early 1990s. The stock has been increasing since the end of the 2000s, as we shall discuss in the next section.

At the end of the 1990s and the early 2000s, there was concern about the state of the stock. As the fishery was characterised by open access (Bjørndal & Brasao, 2006), further stock depletion might be anticipated. The situation was aggravated by tuna farming to the degree that wild adult tuna captured for growing purposes in farms did not have the opportunity to reproduce. MacKenzie, Mosegaard and Rosenberg (2009) examined the then ICCAT management plan. According to their modelling, the adult population in 2011 was likely to be 75% lower relative to 2005. Consequently, the population was believed to be at risk of collapse, unless new conservation measures were implemented in the coming years. In 2006, ICCAT itself indicated there might be a possible collapse of the stock “in the near future” unless adequate management measures were implemented (ICCAT, 2007).

There are several reasons for the decline in stock size from the mid-1970s to about 1990. TACs were set at levels that were too high, and there was a failure to enforce regulations (Fromentin & Powers, 2005). MacKenzie, Mosegaard and Rosenberg (2009) state that the decline of the bluefin tuna population was primarily a result of high exploitation for too many years. Moreover, free riding was a serious problem. IUU fishing was in many years believed to amount to 50-100% of legal catches (Bjørndal & Brasao, 2006; ICCAT, 2020). There was a strong incentive for IUU fishing as BFT is very valuable, and regulations were not enforced. The control of fishing on the high seas has been particularly problematic.

Many of the tuna fisheries around the world have been, and some still are, characterised by excess capacity (Joseph *et al.,* 2006). The concept of open or unlimited access to tuna resources has led to too much fishing capacity, resulting in overfishing and waste of capital. Historically, most BFT stocks have been overexploited (Joseph *et al.*, 2006) although, as we shall see below, the situation is more nuanced today. Furthermore, overcapacity has caused severe economic problems in many of the tuna fisheries and made it difficult to implement effective measures to manage the tuna stocks. The efforts of ICCAT to limit fishing capacity were mostly in the form of recommendations to members that they do not increase their fleet capacities and/or greatest catches. These designated levels were often chosen as those of the years with greatest capacity and/or greatest catches. In short, as pointed out by Joseph *et al.* (2006), the excess fishing capacity poses a threat to the sustainability of the tuna resource, represents a waste of capital, and decreases the economic returns of the fishery.

As noted above, the fishery in the North Atlantic collapsed in the early 1960s. According to MacKenzie, Mosegaard and Rosenberg (2009), the declines in abundance and age structure may be factors responsible for the disappearance of bluefin tuna from formerly occupied areas in the Northeast Atlantic and Mediterranean. Many fish species expand (or contract) their geographic ranges when abundant (or rare), probably as a response to density dependent feedbacks as local carrying capacity is reached. A population that is rebuilding could reoccupy former areas of the distributional range.

Nøttestad, Boge and Ferter (2020) point to the drastic reduction in the distribution and extent of bluefin tuna migration patterns in Norwegian waters from the mid-1960s onwards. The reasons for this are uncertain, but major international overfishing of both juvenile and adult fish, probably occurring for decades, is regarded as a potential major reason for the historical decline of bluefin in Norwegian waters (Cort & Nøttestad, 2007; Nøttestad *et al.*, 2020). Studies indicate that the main contributors to the decline of the stock were recruitment overfishing as well as growth overfishing of juvenile bluefin tuna around spawning areas in the Mediterranean during the 1950s and 1960s, and in the Bay of Biscay and off the coast of western Africa during the 1960s onwards (Cort & Abaunza, 2015; 2016).

There are now several indications that the situation appears to be changing. After the collapse of the North Atlantic BFT fishery in the early 1960s, tuna was absent from these waters for almost 50 years. However, in the 2010s, catches have been recorded by the UK, Ireland, the Faroe Islands, Iceland and Norway (ICCAT, 2020). In fact, in the 1950s and early 1960s, Norway had one of the largest fishing fleets targeting bluefin tuna in the Northeast Atlantic. Nearly 470 purse seiners participated in the fishery along the Norwegian coastline, and up to 15,000 tonnes were caught in a single season (Nøttestad, Boge & Ferter, 2020).

Nøttestad *et al.* (2017) point out that if the strict and sustainable management of ICCAT is maintained, it is likely that the quantity and distribution of bluefin tuna in Norwegian waters will continue to increase in coming years. This suggests larger future harvests in the North Atlantic. In the last decade, there have also been catches of bluefin tuna in the Black Sea and the Marmara Sea, an area where the tuna disappeared early in the 1980s (Natale *et al.*, 2019). Thus, the geographical distribution of tuna is definitely widening.

As pointed out by Allen (2010), the key international standards to manage highly migratory fish stocks flow from the 1982 UN Convention on the Law of the Sea (UNCLOS) (UN, 1982) via the

1992 UN Conference on Environment and Development to the 1995 FAO Code of Conduct for Responsible Fisheries (FAO, 2011) and the 1995 UN Fish Stocks Agreement (UN, 1995). UNCLOS established the regime of 200 nautical mile Exclusive Economic Zones (EEZs) for coastal states (UN 1982, Part V). Within the EEZ, the coastal state has "sovereign rights for the purpose of exploring and exploiting, conserving and managing the natural resources, whether living or non-living …" (UN 1982, Article 56 (1.a)). Highly migratory stocks are defined in a special annex to the Convention, and mainly consist of tunas.

Over time, harvesting of straddling[5] and highly migratory fish stocks caused conflicts in many parts of the world (Bjørndal & Munro, 2012). With the aim of mitigating these issues, the UN convened a conference on straddling and highly migratory fish stocks, which resulted in the 1995 UN Fish Stocks Agreement (1995 UNFSA) that is meant to supplement and buttress the fisheries provisions of the 1982 UN Convention. Under the 1995 UNFSA, relevant coastal states and DWFSs with what is called a "real interest" in the fishery are to manage straddling fish stocks and highly migratory fish stocks through Regional Fisheries Management Organisations (RFMOs). In fact, this can be considered a legal obligation (Costa Duarte *et al.,* 2000).

As noted, the management of the Northern Atlantic Bluefin tuna is the responsibility of ICCAT, an RFMO in the sense of the 1995 UN Fish Stocks Agreement. Due to the wide distribution of the stock, ICCAT, as the largest RFMO in world, has a substantial number of members: 52 contracting parties (CPCs) and five "co-operators"[6].

RFMOs are the only legally mandated fisheries management bodies on the high seas. Some authors have questioned the ability of RFMOs to achieve sustainable management. Cullis-Suzuki and Pauly (2010) present a study of 48 stocks managed by 18 RFMOs. Their main conclusion is that RFMO management is inadequate. Of the stocks assessed, they find that *circa* 2007 two-thirds (32) are depleted, overfished or both. Moreover, relative to the time the analysed RFMOs were established, the majority of RFMOs did not seem to have a visible positive effect on stock biomass. The authors point out that the lack of framework for defining a legitimate membership process for countries to join an RFMO (the 'new member problem') has been criticised as a real impediment to successful fisheries management. Finally, as the establishment of some RFMOs preceded severe stock declines, this calls into question the very existence of these organisations. On a more positive note, Cullis-Suzuki and Pauly (2010) point out that there is an opportunity for RFMOs to help turn around some very worrying trends.

[5] These are stocks that cross (straddle) the EEZ boundary into the adjacent high seas (Bjørndal & Munro, 2012).
[6] A CPS is a Contracting Party or Cooperating non-Contracting Party, Entity or Fishing Entity The "co-operators" are Bolivia, Chinese Taipei, Suriname, Guyana, Costa Rica and Colombia. Source: ICCAT website, www.iccat.int (accessed 20th January, 2021).

Brooks *et al.* (2014) are also very dismissive of the effectiveness of RFMOs. Their criticism of ICCAT is particularly scathing, and they point out that the management of Eastern Atlantic and Mediterranean BFT "… is widely regarded as an international disgrace" (op. cit., p 298). Some of the reasons advanced for the failure of RFMOs to achieve their mandates include single species management rather than an ecosystem-based and precautionary approach as well as inadequate enforcement. It should, however, be noted that Cullis-Suzuki and Pauly (2010) and Brooks *et al.* (2014) largely base their empirical observations on the situation in the first decade of this century. As we shall see later, much has since changed.

While numerous studies address BFT from the perspective of biology and population dynamics, there are few economic studies. Bjørndal and Brasão (2006) is the first analysis of optimal management of BFF, based on a bioeconomic optimisation model. In the absence of harvesting, the model predicted that over time the stock will approach a level exceeding 1.2 million tonnes. This can be considered the carrying capacity of the stock.

The optimal policy, analysed for different scenarios, would require rebuilding the stock to a level of 500 - 800,000 tonnes, which would yield very substantial benefits. There would also be large economic gains from eliminating the less efficient gear types and concentrating harvesting on the most efficient gears. At the time of the analysis, however, further stock depletion looked more likely due to competitive behaviour and ineffective management.

Selles *et al.* (2018) have developed an age-structured model to analyse optimal management of BFT. For their "reference" case, they find an MSY of 35,800 tonnes; however, this estimate depends on recruitment. For the base case with a 2% discount rate, the optimal stock is 564,600 tonnes with a steady state harvest of 20,100 tonnes, i.e., in the range for the optimal stock size found by Bjørndal and Brasao (2006). The optimal stock level is considerably higher than S_{MSY}. This is because a higher stock gives lower per unit cost of harvesting, but also because a lower harvest will yield a higher price, as price is quantity dependent. The authors present results also for numerous other cases.

Both Bjørndal and Brasão (2006) and Selles *et al.* (2018) assume cooperative management. In section 4, we will consider relevant game theoretic studies applied to BFT.

3. THE BLUEFIN TUNA RECOVERY PLAN

The ICCAT Commission meeting in Dubrovnik in 2006 appears to have been a watershed when it comes to the management of Eastern Atlantic and Mediterranean bluefin tuna. ICCAT's science committee, the Standing Committee on Research and Statistics (SCRS), gave a clear warning about the state of the bluefin tuna stock, indicating there might be a possible collapse of the stock "in the near future" unless adequate management measures were implemented (ICCAT, 2007, p.130). At the opening of the meeting, numerous countries pointed to the grave situation for the stock. Examples include "…the ICCAT future is at stake…" (Brazil delegate, ICCAT, 2007, p. 81), and "if we don't act now, we could very well see this stock collapse" (Canadian delegate, ICCAT, 2007, p. 82). It was also stated that "[U]rgent and strict conservation a management measures are needed to avoid the collapse of this stock" (Japanese delegate, ICCAT, 2007, p. 85).

At the meeting, the EU, with the support of Japan, introduced a comprehensive 15-year recovery plan. The EU delegate noted that "… if recommendations were not followed, this would result in the likely collapse of the stock. The Delegate commented that the failure of eastern bluefin tuna management was a collective responsibility and thus required a comprehensive solution that included decreasing vessel capacity and implementing new market controls. He also suggested that IUU fishing activities are also undermining the effectiveness of ICCAT management measures in the Mediterranean Sea (ICCAT, 2007, p.219). Several other countries indicated their willingness to act decisively to create a transparent management regime. While many of the recommendations met with approval, it was also felt by many delegations that the measures proposed were insufficient in light of the serious state of the stock and that these would not ensure recovery to sustainable levels.

Norway appears to have played an important role in this regard. In its opening statement, the Norwegian delegation leader said that "Norway will call upon ICCAT's members to join efforts and cooperate with the view of future sustainable harvesting of this important stock in accordance with our obligations and rights under UNCLOS and in particular the UN Fish Stock Agreement" (ICCAT, 2007, p. 87). Moreover, "Based on past poor management performance, the [Norwegian] delegate pointed out that perhaps there should be no eastern harvest at all" (ICCAT, 2007, p. 220). Furthermore, "The Delegate expressed the opinion that the eastern management measures should include a … seasonal closure from May through July" (ICCAT, 2007, p. 221). As most of the fishing in the Mediterranean takes place during the spawning season from May through July, this was essentially a proposal to introduce a fishing moratorium. Several countries proposed management and control measures, many of which went beyond the EU plan. These interventions appear to have had a great impact on the meeting.

In the end, ICCAT adopted "Recommendation by ICCAT to establish a multi-annual recovery plan for bluefin tuna in the eastern Atlantic and Mediterranean" (ICCAT, 2007, pp. 130-143)[7], starting in 2007 and continuing through 2022, with the goal of achieving stock size corresponding to maximum sustainable yield with greater than 50% probability, later increased to 60%. The plan included measures to reduce harvesting, fleet overcapacity and IUU fishing. Reductions in TACs were implemented from 2008.

[7] The recovery plan is given in Annex 5 as recommendation 06-05 of ICCAT (2007), pp. 130-143.

The initial plan agreed upon in 2006 has been updated over time, and the current plan is given in ICCAT (2020). Measures include (ICCAT, 2020):

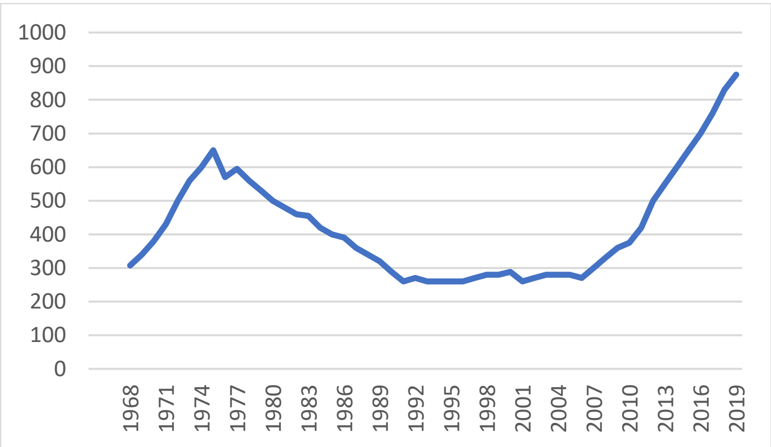
1) Each fishing gear is regulated with regard to season and partly with regard to area; there are also closed seasons.
2) CPCs shall take the measures to prohibit catching of tuna weighing less than 30 kg or with fork length less than 115 cm.
3) CPCs shall take measures to prohibit the use of airplanes, helicopters, or any types of unmanned aerial vehicles in the search for tuna.
4) Each CPC shall adjust its fishing capacity to ensure that it is commensurate with its allocated quota.
5) The Commission shall establish and maintain an ICCAT record of all catching vessels authorised to fish actively for tuna. There are also regulations regarding the reporting of catches.
6) A vessel monitoring system for fishing vessels over 24 m was introduced in 2010; from 2014, this was applied to vessels over 15 m. Stereo video cameras, however, are not used during fishing operations, with exceptions such as when the catch is transferred to a farm for fattening or delivered to a distributor.
7) An observer programme was introduced. Over time this has been extended, and today 100% of purse seiners and 20% of long liners have international observers.
8) Transhipment of bluefin tuna at sea is prohibited; authorised vessels may only tranship catches in designated ports.
9) Market measures require documentation that the traded product conforms with all relevant regulations. Each tuna harvested is issued with a “certificate” that will accompany it until the point of final consumption or trade.

There are also regulations pertaining to bycatch as well as to traps, farming and fattening of BFT.

The sharing of the TAC for the period 2007-10 was not determined in Dubrovnik, but at a meeting in Tokyo in January 2007 (ICCAT, 2007a). Quota sharing is based on several principles, including historical catches (historical fishing rights), stock distribution (coastal states status and zonal attachment), research activity and bargaining power. At the Tokyo meeting, the EU and Japan proposed quota shares as of 2006, but with some adjustments. Some countries objected to the proposal. This included Libya, which felt their quota was too low as a consequence of limited harvesting in the 1990s and early 2000s due to political instability; Turkey, which felt the quota was too low based on historical catches and stock distribution, and Norway, which as a coastal state claimed to be entitled to a higher quota. A slightly modified proposal was accepted after voting. The quota share of the EU was 57%, followed by Morocco (9.5%), Japan (8.5%) and Tunisia (7.9%).

A more "permanent" quota sharing allocation was introduced in 2014[8]. Since then, there have been some adjustments (ICCAT, 2020a). Up to 2017, Norway's quota share was 0.23% which gradually increased to 0.83% in 2020. This increase is due to the fact that Norway is a coastal state with increasing zonal attachment of bluefin tuna and a very substantial history of fishery. Turkey's quota has increased for similar reasons and is now 6.4% (up from 4.15% in 2014). The quotas of Libya and Algeria (4.6%, up from 0.25% in 2014) were originally set at low levels because of the political situation in the countries. Their shares have been increased to better reflect the zonal attachment of tuna to their EEZs. Therefore, quotas of other countries had to be reduced. The EU quota is now 54.06% while that of Japan is 7.8%. Many countries, including the EU and Japan, allocate individual quotas to participating vessels.

The TAC for 2007 was set at 29,500 tonnes, with reductions to 28,500 tonnes in 2008, 27,500 tonnes in 2009 and 25,500 tonnes in 2010. In subsequent years, TACs were revised: the 2009 TAC was reduced to 22,000 tonnes with drastic reductions to 13,500 tonnes in 2010 and 12,900 tonnes in 2011 (ICCAT, 2020a). Moreover, new minimum size regulations led to a dramatic reduction of fishing mortalities among younger age classes (ages 2 and 3). The combination of size limits and the reduction of catch has certainly contributed to a rapid increase in the abundance of the stock. The evolution of the bluefin tuna stock is illustrated in figure 3. The 2007 recovery plan appears to have had almost an immediate effect on stock size.



Source: Derived from Appendix, table A2

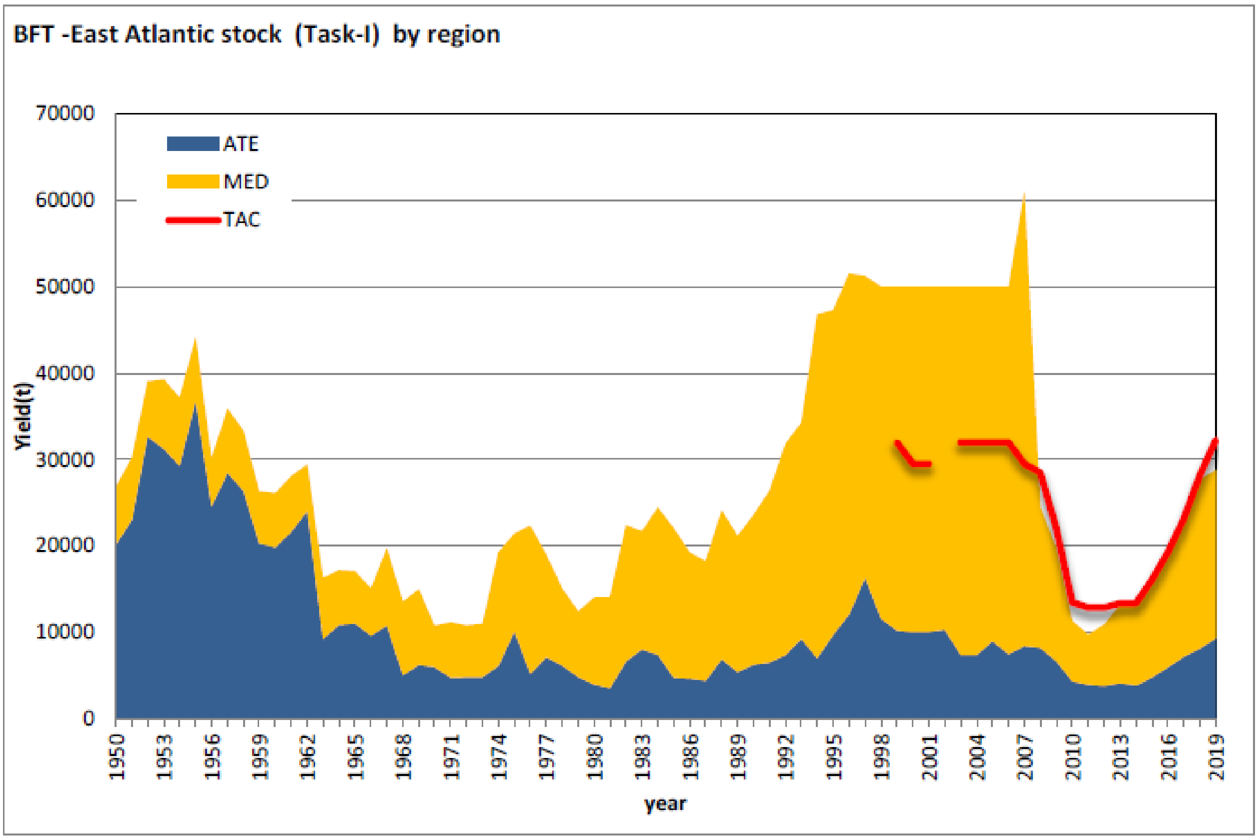
Figure 3. Spawning Stock Biomass Northeast Atlantic and Mediterranean bluefin Tuna 1968-2019. '000 tonnes

[8] It is interesting to note that quota shares in percentages are given with seven decimals, presumably because of the high value of tuna.

Catches from 1950 to the present for both the Atlantic and the Mediterranean BFT are illustrated in figure 4. Total catches peaked in the 1950s, however, they declined in the early 1960s which presumably explains the increase in stock size in the late 1960s and early 1970s. The 1990 catch was just over 26,000 tonnes. After a few years BFT catches doubled and were in the range 49,000 – 54,000 tonnes annually for the period 1994-2006. A peak catch of 62,638 tonnes was recorded in 2007, more than double the TAC. Because of the recovery plan, harvest was reduced to 26,460 tonnes in 2008 and further to 11,781 tonnes in 2011. Thus, the 2011 catch was less than 20% of the 2007 catch. Catches started increasing in 2015 (16,201 tonnes) and reached 28,760 tonnes in 2019.

Figure 4 also gives the TAC for the period 1995-2019. In the first part of the period the total harvest is considerably higher than the TAC. The total harvest in 2007 was 62,638 tonnes, while the official TAC for that year was 29,500 tonnes. Thus, the IUU catch exceeded the legal catch. As noted above, the TAC was reduced from 2008 onwards and, importantly, catches have subsequently not exceeded the TAC. The increase in stock size (figure 3) has actually allowed for an increase in TAC after 2014. TAC for 2019 was 32,240 tonnes, increasing to 36,000 tonnes in 2020. The latter level will be maintained for 2021 and 2022, although the 2022 advice will be reviewed in 2021 based on updated abundance indicators.

The recent increase in stock size is appreciably larger for the 2020 stock assessment than it was in the 2017 stock assessment (ICCAT, 2020). Nevertheless, “The current perception of the stock depends on recruitment estimates which are highly unstable and is also closely related to the assumptions made about stock structure and migratory behaviour, which remain poorly known” (ICCAT, 2020). Thus, although the stock appears to be in good health, there is no room for complacency.



Source: ICCAT (2020). Reported catch for the East Atlantic and Mediterranean BFT from 1950 to 2019 together with unreported catch estimated by the SCRS from 1998 to 2007 and TAC levels since 1998

Figure 4. Bluefin tuna catches, Atlantic and Mediterranean, 1950-2017. TAC 1995-2019. Tonnes

Tuna fisheries worldwide have been characterised by tremendous overcapacity (Joseph *et al*., 2006). According to Adolf (2019, p. 232), several important harvesting countries for BFT had fishing capacity that was many times greater than their quotas. There is now an ICCAT registry of approved bluefin tuna vessel, and each country is obliged to adjust its fishing capacity to ensure that it is commensurate with its allocated quota. Because of these measures, fishing capacity has been severely reduced, in particular in the Mediterranean Sea. Here we provide information for the EU, the single most important harvester, and Japan, the most important DWFS (table 1). For both, there is an immediate and substantial reduction in capacity from 2008 to 2009, measured in both tonnage and vessel numbers. The same applies to other countries in the fishery. Moreover, each year every country submits a capacity plan to ICCAT, including a list of licensed vessels, and fishing capacity must be commensurate with national quota for the year in question.

The EU's total fishing capacity was reduced from 19,335 tonnes in 2008 to 7,233 tonnes in 2012, a reduction of 37%. Capacity has increased in recent years, as a consequence of increasing TACs. In the EU, different gear types are active. As an example, the number of purse seiners over 40 m was almost halved from 38 in 2008 to 20 in 2011, subsequently increasing to 30 in 2021. When considering the changes in purse seine and longline capacity over time, it is particularly noticeable that the share of purse seine capacity out to total capacity has declined, from 57% in 2008 to 27% in 2021. This implies that the share of other gear types has increased. In 2021, capacity of small-scale vessels represented 5,110 tonnes, while those of trap and bait boat were 1,690 tonnes and 1,505 tonnes, respectively.

For Japan, only large longliners over 40 m are now active. The number of vessels declined from 49 in 2008 to 20 in 2012 with a commensurate reduction in fishing capacity from 1,225 tonnes to 500 tonnes. As for the EU, capacity has increased in recent years.

Table 1. EU and Japan fishing capacity. 2008-21

Year	EU purse seine fleet capacity (tonnes)	EU longline fleet capacity (tonnes)	EU total fishing capacity (tonnes)	Japan number of longliners over 40 m	Japan total fishing capacity (tonnes)
2008	10,987	1,685	19,335	49	1,225
2009	4,933	1,044	12,109	33	825
2010	3,019	1,040	9,927	22	550
2011	2,309	897	8,104	22	550
2012	2,309	495	7,233	20	500
2013	2,309	479	7,351	22	550
2014	2,584	554	7,473	22	550
2015	2,600	708	8,352	28	700
2016	2,747	738	9,085	31	775
2017	2,767	476	9,136	33	825
2018	3,597	703	11,977	36	900
2019	4,071	888	14,288	38	950
2020	3,841	431	12,805	40	1,000
2021	4,032	988	14,564	40	1,000

Sources:
-*Eastern Atlantic and Mediterranean bluefin tuna fishing, farming, inspection and capacity management plan. European Union (EU) Fishing Plan Year 2021. ICCAT: PA2 Doc. No. PA2-06C_REV /i 2021 – European Union. February 26, 2021.*
-*Eastern Atlantic and Mediterranean bluefin tuna fishing, farming, inspection and capacity management plan. Japan Fishing Plan Year 2021. ICCAT: PA2 Doc. No. PA2-08A /i 2021 – Japan.*
February 26, 2021.

A detailed set of regulations, corresponding to the measures listed above, are in place and must be followed by all CPCs harvesting BFT. Monitoring, control, and surveillance (MCS) measures are in place, in order not only to ensure that regulations are adhered to, but also to prevent IUU fishing. There is control at sea as well as on land, including harbour (port) state control. Enforcement is the responsibility of the flag state. In the EU, there is control both by member states and at the EU level.

The activities of all vessels are continually monitored in real time by Vessel Monitoring Systems (VMS) and any interruption in the transmission of data will immediately be followed up. In general, vessels must submit daily catch reports to their fisheries administration. It has been noted that transshipment at sea is illegal. Thus, fishing vessels can only tranship BFT catches in designated ports, with relevant port authorities informed in advance. There is full inspection coverage during transshipment.

Special MCS measures are in place in the EU. Under the EU Common Fisheries Policy (CFP), the primary responsibility for control and enforcement lies with the member states. The European Commission and the European Fisheries Control Agency (EFCA) coordinate with the member states to ensure that the provisions laid down by ICCAT are reflected in EU and the member state's law and fully enforced. Moreover, the European Commission has its own permanent team of inspectors whose role is to monitor and evaluate member states' fulfilment of their duties and obligations. EFCA adopts annually a Joint Deployment Plan (JDP), which includes bluefin tuna. This JPD covers all stages of the market chain as well as controls at sea, on land, traps and farms.

Under the JDP, EFCA will coordinate joint inspections and control activities involving several fishery patrol vessels and aircrafts. EFCA also has its own chartered offshore fisheries patrol vessel and aerial surveillance capacity.

When it comes to the market, a tag is attached to each legally harvested tuna. In Japan, bluefin tuna can only be delivered to designated ports where it is subject to inspection. Business operators later in the value chain are prohibited from dealing with fish unless an official tag is attached to the fish. Moreover, in the EU, as part of anti-IUU measures, since 2010 a catch certificate validated by ICCAT is mandatory for both exports and imports (Adolf, 2019, p. 241).

Fishing without quota or fishing more that the assigned quota as well as other transgressions of regulations are considered serious infringements. The follow up is the responsibility of the flag state - in the EU[9], the member states. Measures against an infringement depend on its seriousness, but may include fines, confiscation of harvest, gear and, in extreme cases, also the boat, as well as jail sentences. It is also important to note that, with these measures in place, all aspects of the value chain – from harvesting until the final market – are subject to regulations and monitoring.

When it comes to the overall situation, since 2008, the harvests of BFT have been in line with TACs. This is an indication that regulations work. IUU fishing also appears to have been greatly curtailed, although it is not likely to have been eliminated, as "[There is] existence of unquantified IUU catches which should be taken into account" (ICCAT, 2020). In the infamous *Operation Tarantelo*, Europol in collaboration with the Spanish *Guardia Civil* and other police forces seized more than 80 tonnes of illegally harvested and traded tuna (Europol, 2018).

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[9] In the EU, follow up of such infringement is regulated under Article 84 of Regulation (EC) N° 1224/2009 and of course, Article 42 of Regulation (EC) 1005/2008.

Another important development is the changes in the relative importance of the two main fishing areas. Up to the early 1960s, catches in the Atlantic exceeded those in the Mediterranean. When the fishery in the North Atlantic collapsed in the early 1960s, the Mediterranean became the most important fishing area for BFT and has been so ever since.

The combination reduction of catches and of minimum size limits has contributed to an increase in stock abundance. Moreover, the reappearance of BFT in historical fishing areas (Northern Atlantic and in the Black Sea), suggests that important changes in the spatial dynamics of bluefin tuna may have resulted from interactions between biological factors, environmental variations, and the reduction in fishing effort.

In 2019, the total catch was 28,760 tonnes, of which 9,326 tonnes in the Atlantic and 19,434 tonnes in the Mediterranean (see ICCAT (2020) for details). EU catches represented 17,156 tonnes, those of DWFSs 2,835 tonnes, catches of non-EU Mediterranean and North African countries (Albania, Turkey, Syria, Tunisia, Algeria and Morocco) were 8,736 tonnes and North Atlantic countries (Norway[10]) 18 tonnes[11]. When looking at individual countries, in the EU Spain with 5,389 tonnes, France with 5,381 tonnes, and Italy with 4,286 tonnes are most important. Outside the EU, the largest catches are made by Morocco (2,920 tonnes), Japan (2,514 tonnes) and Tunisia (2,380 tonnes).

As mentioned, different gear types are active in this fishery (see appendix, figure A1). In the Atlantic, trap is the most important gear with 49% (4,594 tonnes) of the total, followed by longline with 34% (3,177 tonnes) (2019 figures). DWFSs active in the North Atlantic all use longline. In the Mediterranean, purse seine is dominant with 88.5% of the total (17,200 tonnes) followed by longline with 7.4% (1,436 tonnes).

As for the reappearance of bluefin tuna in the North Atlantic. MacKenzie, Mosegaard and Rosenberg (2009) state that the decline in abundance may have been responsible for the disappearance of bluefin tuna from formerly occupied areas in the Northeast Atlantic and Mediterranean in the 1960s, but also that a population that is rebuilding could reoccupy former areas of the distributional range as witnessed now.

Nøttestad, Boge and Ferter (2020) point out that BFT has probably been feeding along the Norwegian coastline and in offshore waters for thousands of years, due to the high abundance of nutrient rich schooling prey species such as mackerel, herring and blue whiting found there. They point out that the comeback coincides with the overall increase in spawning stock biomass (figure 3)

[10] In previous years, there have been catches also by Iceland, the Faroe Islands, and the UK; in 2019, only by Norway and Ireland (included in EU figures).
[11] This adds up to 28,745 tonnes, slightly less than the reported harvest of 28,769 tonnes. The difference is due to discards.

observed over the last decade and documented in both the Mediterranean and the Northeast Atlantic, during feeding and long-distance migration events. The tunas visiting the high latitudes of Norwegian coastal waters after the comeback have been mainly larger and mature fish. Fish sizes recorded are equal to those that were present in Norwegian waters from 1960 to 1965. The increase in overall abundance of BFT may explain the expansion of its distribution towards northern productive waters, as the need to make long distance migrations in search for available food is likely to increase with a growing population.

Mackerel in the Northeast Atlantic have expanded their northern distribution in recent years (Nøttestad *et al.*, 2016), and as they are an important food source for BFT, it is likely that the tunas follow the mackerel's migration patterns and therefore expand their own northern distribution (Nøttestad, Boge & Ferter, 2020).

On the other hand, Faillettaz *et al.* (2019) suggest that the reappearance of BFT in North Atlantic waters can also be explained by hydroclimatic variability due to the Atlantic Multidecadal Oscillation (AMO), a northern hemisphere climatic oscillation that increases the sea temperature in its positive phase, as it is now. According to the authors, in the future the Atlantic may become more important for the BFT fishery than the Mediterranean as was the case in the 1950s.

4. ANALYSIS

The management of bluefin tuna has undergone a radical transformation from non-cooperative to cooperative management. To analyse this transformation, we will make use of the theory of strategic interactions, also known as game theory. Game theory is divided into two broad categories, non-cooperative, or competitive games and cooperative games (Grønbak *et al.*, 2020; Bjørndal & Munro, 2012). Both types are relevant to bluefin tuna.

The theory of non-cooperative or competitive games predicts that, under non-cooperation, the players will be compelled to adopt harmful strategies, known as the "Prisoner's Dilemma". The bluefin tuna fishery up to 2007 is a prime example of this as the fishery was characterised by overexploitation, excess capacity and wasted resource rents. In fact, the demise of the stock was predicted (MacKenzie, Mosegaard & Rosenberg, 2009).

The tuna recovery plan has been very successful to the degree that the fishery is now considered sustainable (Nøttestad, Boge & Ferder, 2020). The fundamental question is, what conditions must be met for the current cooperative management regime to remain stable in the future? A stable solution to a cooperative game exists, only if the players are able to enter into a binding agreement[12]. This is the case for bluefin tuna where cooperation has come about because it is in the best interests of all players.

In this section we will analyse cooperative management. We will first consider the stability of cooperative management in RFMOs in general, followed by an analysis of the current management agreement for bluefin tuna. Cullis-Suzuki and Pauly (2007) and Brooks *et al.* (2014) call into question the very existence of RFMOs. Others point out that a large number of players makes it difficult to arrive at a cooperative agreement (Bjørndal & Martin, 2007). Thus, the bluefin tuna case is very important, as it does not appear to conform to “received” wisdom.

RFMO cooperative management: sharing of benefits and stability

In a cooperative game, players play as single agents (singletons) or form coalitions. When all relevant countries cooperate, this is referred to as the Grand Coalition. Since 2008, the Eastern Atlantic and Mediterranean bluefin tuna stock has been cooperatively managed by IICCAT though a Grand Coalition that includes *all* countries participating in this fishery.

Nevertheless, there is also the possibility of sub-coalitions, where some countries agree to cooperate but may be competing against others[13]. In other words, there might be partial cooperation where some countries cooperate while competing against others. As already pointed out, the EU can be considered a coalition[14]. The situation with partial cooperation also needs to be considered.

Costa Duarte *et al.* (2000) and Bjørndal and Brasao (2006) both demonstrate that cooperative management involves substantial payoffs to the Grand Coalition. This gives rise to at least two questions: First, how is the cooperative surplus divided among the members of the Grand Coalition? And second, are there any incentives for any of the parties to break away from this cooperative solution?

For tuna, the allocation “key” for the sharing of the TAC among countries has been adjusted over time, as we shall see below. This allocation key determines the sharing of benefits from the fishery. Let us consider the “fair” allocation of the net economic benefits from a cooperatively managed fishery. A common sharing rule is the Nash bargaining solution which is egalitarian in the sense that the cooperative surplus is shared equally among all parties involved (Bjørndal & Munro, 2012, p. 193). It is implicit in this sharing rule that all players contribute equally to the cooperative solution. Whether the current sharing of the TAC corresponds to a Nash bargaining solution is an interesting topic for further research.

[12] Binding may mean legally binding, however, there are also many examples of agreements that are not legally binding, but nevertheless operate as if they were.
[13] The number of possible coalitions increases exponentially with the number of players.
[14] Other coalitions may also be imagined, e.g. DWFSs, non-EU Mediterranean states and North Atlantic countries.

In a situation with coalitions, the Nash egalitarian rule may no longer be adequate, essentially because the negotiation power of different coalitions varies. In this case, the most common approach to the sharing of the surplus is what is called the characteristic function game (c-game) approach in which the characteristic functions assign values to all possible coalitions (Bjørndal & Munro, 2012, ch. 7.9.1).

Costa Duarte *et al.* (2000), in a game theoretic analysis of Atlantic tuna, define three coalitions (agents): the EU, DWFSs and "other coastal states". In general, the value of a coalition is deemed to be equal to the cooperative surplus generated by the coalition. Their c-game analysis assumes that the Grand Coalition exists and considers how benefits from cooperation should be distributed among members in a "fair" way. Under a c-game the bargaining strength of the different players depends on the power of the coalitions. Three sharing rules are calculated: the nucleolus, the Shapley value, and the Nash bargaining solution. The idea behind the nucleolus is to find a payoff vector that maximises the minimum gains of cooperating. Thus, the benefits of the "least satisfied coalition" are maximised. As an alternative allocation, under the Shapley value, a player's allocation is based upon the average of its contribution to all possible coalitions, in comparison with the average contributions of all other players (Bjørndal & Munro, 2012, pp. 199-201). The Nash bargaining solution, based on equal bargaining strength, has already been defined.

When applying these concepts to tuna, Costa Duarte *et al.* (2000) show that one agent can have clear incentives not to participate in the Grand Coalition**.** Although this result is based on a model with only three agents, and economic and biological conditions from the 1990s, in a situation with very many players it is reasonable to expect that (at least) one country might gain from free riding. This illustrates the importance of the legal status of the RFMO, namely, if countries are legally obliged to abide by the management decisions.

As there may be an incentive for not joining the RFMO, we must consider IUU fishing of which unregulated fishing is of most serious concern. Unregulated fishing is free riding and reflects a lack of clear property rights to the fishery resources under RFMO management. A prospective RFMO member could calculate that its payoff from the cooperative game would be less than the payoff from a competitive game. A report on best practices for RFMOs stated that "…a core conclusion is that the success of international cooperation [pertaining to the management of straddling and highly migratory fish stocks] depends largely on the ability to deter free-riding" (Lodge *et al*., 2007, p. x). RFMOs might be able to encourage prospective free riders to join the organisation by offering them shares of the TAC in exchange for cooperation. The alternative might be to bring legal action against free riders.

The c-game analysis of Costa Duarte *et al.* (2000) does not address free riding. To do so, we consider what is known as partition function games. In such a game, the payoff to a coalition depends not only upon the players within the coalition, but also upon the way the other players are partitioned. In our case, the RFMO is the relevant coalition. Players outside the coalition play as singletons and thus play against the RFMO coalition (Bjørndal & Munro, 2012).

If by forming an RFMO the management of the fishery improves, as has been the case for tuna, this will create a *positive externality* to the benefit of outsiders as well as those within the RFMO. Each player must then look to its potential payoff as a bona fide member of the RFMO and the payoff it would enjoy as an outsider, i.e., the payoff from free riding. A player will join the RFMO if and only if its payoff from participating in the RFMO is greater than or equal to its payoff as an outsider. Moreover, the RFMO will be stable if and only if the total payoff from the RFMO Grand Coalition exceeds the sum of the payoffs to the players acting as singleton free riders, in which case a sharing rule can be devised that will give every player an incentive to remain within the RFMO (Bjørndal & Munro, 2012, pp. 206-207).

Pintassilgo (2003) points to the presence of externalities and free rider incentives which often are present in the context of the management of high seas fisheries. To the extent that an RFMO is successful in the management of a stock, a non-member is typically better off when more players join the RFMO, as it can adopt a free rider strategy. The externality created by the RFMO is not considered in the characteristic function approach.

In Pintassilgo (2003), the payoffs are represented by a partition function which assigns a value to each coalition as a function of the entire coalition structure, and not just the coalition in question. Therefore, it captures the externalities across coalitions, which are assumed not to be present in the characteristic function. The study addresses the stability of the cooperative agreements in the presence of such externalities and how this determines the equilibrium coalition structures.

Pintassilgo *et al.* (2010) analyse stability and success of RFMOs in a general context. The authors point out that the level of participation and the stability of these organisations in effectively mitigating overfishing are key issues in the management of highly migratory fish stocks. Their approach is that of a two-stage partition function. In the first stage, states decide whether or not to join the RFMO. In the second stage, RFMO members coordinate their fishing efforts whereas non-members behave non-cooperatively. The authors provide a comprehensive analysis of the economic and biological fundamentals that influence the success of coalition formation such as the price of fish, the level and asymmetry of unit effort costs, the number of players, the intrinsic growth rate of the stock and the carrying capacity of the environment.

Pintassilgo *et al.* (2010) find that the larger the number of fishing states in the game, the higher the relative gains from full cooperation, but the lower is the likelihood that large RFMOs are stable and their relative success in closing the gap between full and no cooperation. The fundamental conclusion is that, generally, in order to guarantee the stability of the cooperative agreements, it is not sufficient to implement a fair sharing rule for the distribution of the returns from cooperation. Stability requires a legal regime preventing the players that engage in noncooperative behaviour from having access to the resource. Thus, if the international fishing community proved to be incapable of suppressing unregulated fishing, the outlook for the emerging RFMO regime is bleak.

Even if all states with a "real" interest in a fishery join the relevant RFMO that is established to manage a fishery, conditions may change over time and "new" countries may wish to join the fishery. This is what is known as the "new member" problem (Bjørndal & Munro, 2012, ch. 7.9.2), a topic we will return to below.

The stability of ICCAT management for bluefin tuna

The players in the bluefin tuna game have found it in their best interests to enter into a binding agreement[15]. We will here apply the conditions outlined by Bjørndal and Munro (2021) that must be met for a cooperative international management agreement to remain stable and which have also been applied to other fisheries (Bjørndal *et al*., 2021).

The first condition is that the players are able to communicate with one another effectively. In the case of BFT, this is met in the form of ICCAT – an RMFO whose members include both coastal states and DWFSs. Although cooperation in ICCAT in principle might be voluntary, according to Costa Duarte *et al.* (2000), it can in fact be considered a legal obligation. In addition to biannual commission meetings, attended by all contracting parties, ICCAT has several committees and working groups on a wide range of topics, including science. This gives numerous venues for communication. Moreover, Pons, Melnychuk and Hilborn (2017) point out that ICCAT research programmes and workshops that aim to improve and coordinate data collection and sharing programmes among countries could facilitate monitoring, control, and surveillance systems as well.

The second condition is that each and every player at each and every moment through time must anticipate a "payoff" at least as great as one would receive under non-cooperation, where the latter is seen as the payoff resulting from the solution to a non-cooperative game[16]. In game theory terminology, this is referred to as the "individual rationality" condition.

[15] Binding may mean legally binding, however, there are also many examples of agreements that are not legally binding, but nevertheless operate as if they were.

[16] This relates to the fact that cooperative games are not separate and distinct from non-cooperative games. Behind every cooperative game there lurks a non-cooperative game.

Allen (2010) discusses conditions that provide incentives for participating governments to take (or not take) cooperative actions to conserve resources. Apart from complying with global obligations and expectations, the major necessary condition for successful negotiation is that all participants in a negotiation should benefit from an agreement to cooperate rather than from unrestrained competition. This corresponds to the individual rationality condition.

A thorough analysis of this condition would go beyond the scope of this article. From the overviews provided, several countries reduced their harvests post 2007, and it has taken several years for TACs and catches to return to their earlier levels (figure 3). This reduction in harvesting to allow the stock to recover can be considered an investment in the resource (Bjørndal & Munro, 2012). Although this process involved a temporary reduction in revenues, the reduced quantities might have had a positive impact on price. Moreover, harvesting costs were reduced, also because excess fishing, capacity has been reduced. The investment in the resource is now paying off, with TACs increasing more efficient fleets as well with more profitable operations. Moreover, the alternative to the recovery plan might be the demise of the stock which would bring financial misery to all participants in the fishery. On balance, the evidence clearly suggests that the individual rationality condition has been met.

The third condition is that the solution to the cooperative game must be collectively rational in that there cannot exist an alternative solution, which would make one or more player better off, without harming the others – the "collective rationality" constraint. In other words, the solution must be Pareto Optimal. Cooperative management involves payoffs that vastly exceed those of competition (Costa Duarte *et al.*, 2000; Bjørndal & Brasao, 2006). Moreover, the current sharing of the harvest is such that should one party receive a greater payoff, it would be at the expense of someone else. This suggests that the collective rationality constraint is satisfied.

Nevertheless, an important result in Bjørndal and Brasao (2006) is that the mix of gear types at the time of their analysis was inefficient so that a greater surplus could be achieved if the harvest of the more efficient gear types were increased at the expense of the less efficient gear types. This is a topic for further research, but there is every reason to expect this situation to prevail also today. Increasing the harvest share of the more efficient gears would necessitate some kind of compensation for those who have to retire from the fishery. We will return to this issue when discussing quota sharing below.

The fourth condition is that the cooperative management agreement must be resilient, in that it must be able to withstand unpredictable shocks, be they environmental, economic, or political. In fact, bluefin tuna has been subjected to several shocks over time. One was the disappearance from traditional areas in the North Atlantic and elsewhere; another is the reappearance in said waters. Other environmental changes are possible. For example, as a consequence of warming water temperatures in the oceans, migration patterns for many stocks are expected to change (Barange *et al*., 2018). Another example is given by Nøttestad, Boge and Ferter (2020), who point to the fact that mackerel in the Northeast Atlantic in recent years have expanded their northern distribution, and as they are an important food source for the tuna, it is likely that the tunas follow the mackerel's migration patterns and therefore expand their own northern distribution.

This kind of unpredictable shock has put strain on numerous international management agreements (Ellefsen *et al.,* 2017). This may very well be the case for tuna as well. Extended migration will allow "new" countries to harvest the resource and may put a strain on the mechanism for sharing of the TAC among countries, as we will return to.

In order to enhance the likelihood that conditions two, three and four will be satisfied, it is important that the scope for negotiations or bargaining between the parties involved be made as wide as possible. "Side payments" and "side payment" like arrangements are usually thought of as monetary or non-monetary transfers between countries, however, it could also refer to trade, development aid or even security arrangements.

A final complication is that the number of players matters a great deal (Bjørndal & Martin, 2007). Although there is now cooperation, a potential entrant may decide to stay outside ICCAT to enjoy the positive externality as a free rider. Moreover, a player might defect and enjoy the benefits of the cooperation of the others, while incurring none of the costs of cooperation. If free riding is rampant, condition number two, the "individual rationality" constraint, will not be satisfied, and attempts at cooperation will be stillborn. The difficulty in suppressing free riding increases exponentially with the number of players.

As noted above, IUU fishing historically took on very large proportions. It is believed that the amount of IUU fishing has been severely reduced, although not entirely eliminated. The quotas of some developing countries are harvested by developed countries, and the quota owners lack the required infrastructure to control harvests. Currently (2020-21), during the COVID-19 pandemic, many, if not most, vessels do not have international observers, which makes it more challenging to control harvesting and harvests. Harvesting on the high seas represents a particular challenge at it is difficult to monitor, with only 20% of long liners having international observers. Transshipment of tuna at sea is illegal but difficult to monitor. According to ISFF (2021), monitoring of longlining is "deficient".

We will now revert to an issue that was briefly introduced above, what is referred to as the "new member" problem, i.e., the situation that arises when a new player wants to join the fishery, which may lead to strain or even the breakdown of a cooperative agreement (Bjørndal & Munro, 2012). Usually this is considered in the context where a "new" DWFS may commence fishing on the high seas, however, for bluefin tuna new coastal states are also an issue.

When it comes to the potential entry of "new" DWFSs, such states would not be able to get quotas as part of ICCAT management as they would not be able to claim a "real interest" in the fishery. Thus, such entry would be illegal as it would be in contravention of the 1995 UNFSA. Harvesting by a "new" DWFS would be considered IUU fishing. As such, it would be met with numerous reactions including legal action. Bluefin tuna harvested by such an entrant would not have access to the EU and Japanese markets. These reasons are likely to effectively bar entry by any new DWFS (Ferri, 2015).

There is in fact another example where import restrictions have served as a deterrent to free riding in cooperative management of internationally shared fishery resources. This is the North Pacific Fur Seal Treaty, 1911-1984, involving Japan, Russia, Canada, and the US. Under the Treaty, all harvesting of seals at sea was stopped. There was, however, a real danger that Canadian, American, and Japanese sealing vessels would re-flag and then go sealing (Barrett, 2003). Given international treaty law of the time, such re-flagged vessels could not be halted. Nonetheless, the threat did not arise. This was because in the Treaty there was a clause stating that parties to the Treaty would only import North Pacific fur seal skins deemed to be legitimate under the Treaty, i.e., skins from seals harvested on land by Russians and Americans. The market for seal skins was wholly dominated by London. Canada at that time was a self-governing colony, so that in the Treaty negotiations, the U.K. acted on Canada's behalf. The UK was thus a party to the Treaty. Accordingly, "illegal" North Pacific fur seal skins were barred from the all-important London market. This served as an effective deterrent to free riding (Barrett, 2003).

As noted in the introduction, historically over 50 states participated in the fishery, when the resource was healthy, while close to 30 countries have participated in the fishery in the 2010s. Should the stock continue to improve, and the distribution area be further extended, more countries are likely to join the fishery. In the North Atlantic, several countries, including the UK, Ireland, the Faroe Islands, Iceland, and Norway, have joined the fishery in the 2010s, albeit not every year. Other potential entrants may include countries in North Africa and surrounding the Black Sea which currently do not report any catches. "New" coastal states would be entitled to quotas according to UNCLOS.

So far, the cooperative agreement has proved to be resilient. As for the future, the resilience will depend on how new entrants are given quotas as their quotas must come at the expense of existing members. If the TAC is increasing, all countries may in principle benefit in terms of increased absolute quotas, even if relative quotas of countries already in the fishery decline. If, however, the

TAC is unchanged or reduced, a new entrant will imply lower absolute and relative quotas for existing members of the Grand Coalition; this may be more challenging. However, this is what has happened to the quotas of the EU and Japan and some other countries, albeit without reduced absolute quotas, as a consequence of increased quotas for several countries including Norway, Turkey, Libya and Algeria. This suggests there has been flexibility in quota sharing, which is important for the resilience of the management agreement.

In short, there may be strains on the future stability of the tuna agreement, in particular relating to new members and environmental change. Moreover, ICCAT, as an RFMO, has a strong mandate based on the Law of the Sea, in particular UNCLOS and the 1995 UNFSA. Furthermore, Adolf (2019, p. 274) points to the fact that sustainability is increasingly demanded by the consumer market.

Quota management

As noted, Bjørndal and Brasao (2006) find that a reallocation of gear types may improve the overall economic returns from the fishery. Allen (2010) discusses the use of rights-based management systems as a means to address the shortcomings in the current management of tuna fisheries. The elimination of the need to compete for a share of the available catch allows individuals to optimise their investment in fishing effort to match their share of the catch, providing them with an incentive to avoid overcapacity. Secure, exclusive, and long-term rights provide fishers with a collective interest in the efficient use of the resources. Transferability of rights allows fishing opportunities to be used by those fishers who produce the greatest economic benefits and can provide a means of reaching an agreement among different sectors of the industry via a transfer of fishing rights.

Joseph *et al.* (2006) suggest that once regional vessel registries are in place, and capacity is under control, RFMOs should examine the merits and possibilities for introducing more efficient rights-based systems, particularly individual transferable quotas (ITQs). In fact, transferability of quotas is allowed for by the current management plan for BFT: "Private trade arrangements and/or transfer of quotas/catch limits between CPCs shall be done only under authorisation by the CPCs concerned and the Commission" (ICCAT, 2006, paragraph 11).

ICCAT (2021) gives information about transfers between countries for the period 2016-20, so called "quota swaps". For this period, transfers between some countries are reported. For example, the Republic of China has transferred 50 tonnes of its quota to Korea every year since 2018. In 2020, Egypt transferred 204.62 tonnes to Morocco, while Spain transferred 21.8 tonnes to Portugal and 20.5 tonnes to Greece. It is not known if there are any (side) payments for such transfers.

There are also internal quota swaps. For example, in Spain, a significant share of quotas for bait boat in the Atlantic and longline in the Mediterranean, representing just over 36% of the total

Spanish quota, is transferred to purse seiners in the Mediterranean and traps in the Atlantic[17]. Swaps are agreed among vessel owners so as to optimise their operations. Nevertheless, it is understood that quota swaps are short run, i.e., for one season, rather than permanent transfers. Information on payment for quotas is not available. In addition, limited carryovers from one year to the next are permitted. Currently, each CPC may request a transfer of a maximum 5% of its quota from one year to the next (ICCAT, 2020a, p. 109).

As mentioned, many countries have individual vessel quotas for tuna. Overall, this suggests there is a quota market for bluefin tuna which, with carryovers of quotas, an indication of flexibility in management. Learning more about the quota market is an interesting topic for future research.

5. DISCUSSION

The cooperative management of bluefin tuna has been able to withstand several challenges such as changes in the geographical distribution of the stock which has also permitted a number of new members to join the fishery (Ferri, 2015). As far as we can see, there are three main challenges to the future stability of the cooperative agreement. First, (unexpected) changes in the environment. Second, IUU fishing. Third, the new member problem, in particular, accommodating new coastal states into the fishery. Of these, the third challenge might potentially be the most serious. Having said that, hitherto the cooperative management agreement has proved to be very resilient.

A very important result of this analysis is that the bluefin tuna case does not conform with “received” wisdom when it comes to RFMO management. As noted, authors such as Cullis-Suzuki and Pauly (2010) and Brooks *et al*. (2014) call into question the very existence of RFMOs. The current analysis clearly demonstrates successful RFMO management of a very important and valuable fishery.

Moreover, the case study also appears not to conform with parts of the game theoretic literature, in particular when it comes to the issue of how the number of players influences the outcome of cooperative games. ICCAT, with more than 50 contracting parties, has a large number of players. Although this might make it difficult to arrive at a cooperative agreement (Bjørndal & Martin, 2007), this has nevertheless been possible. Pintassilgo *et al.* (2010) find that the larger the number of fishing states in the game, the lower the likelihood that RFMOs are stable and their relative success of closing the gap between full and no cooperation. Moreover, in order to guarantee the stability of the cooperative agreements, it is not sufficient to implement a fair sharing rule for the distribution of the returns from cooperation. Thus, according to Pintassilgo *et al.* (2010), stability requires a legal

[17] Source: Private communication, Antonio Lizcano Palomares, Secretaria General de Pesca, Spain (29th March, 2021).

regime preventing the players that engage in noncooperative behaviour from having access to the resource. In the bluefin tuna case, however, the parties have engaged in cooperation because it is in their interest to do so.

Overall, the case study presented in this article provides very important evidence when it comes to RFMO management. Cooperative management of bluefin tuna gives hope for RFMO management of highly migratory fish stocks in general. This is a very important. There is, however, a different strand of literature that provides explanation for parts of what we observe for bluefin tuna.

An empirical study by Pons *et al.* (2017) shows that, particularly for tunas, stocks were more depleted if they had high commercial value, were long-lived, had small pre-fishing biomass and were subject to intense fishing pressure for a long time. This is very much in line with the situation for BFT before the recovery plan was introduced. Implementing and enforcing TACs had the strongest positive influence on rebuilding overfished stocks. For BFT, reduced TACs post 2007 that have been enforced have been of crucial importance for stock recovery. Pons *et al*. (2017) also show that it is not until tuna stocks are heavily depleted that RFMOs tend to implement strong management measures such as quota controls. They also find that fisheries enforcement was the most important factor associated with trends in biomass. These findings are also corroborated by BFT.

When it comes to RFMOs, Pons, Melnychuk and Hilborn (2017) demonstrate that some RFMOs have been successful in rebuilding tuna stocks when strong management measures are applied. This has very much been the case for BFT. There are many factors associated with the intensity of management among RFMOs across multiple dimensions. These consist not only of differences in the history of exploitation across oceans, but even more so in fleet diversity, economic diversity of member countries and economic dependency on tuna and tuna-related fisheries. These factors affect the ability of RFMOs to apply and enforce management measures and consequently have an impact on the status of the stocks under their jurisdictions. Although these results show that current stock status is highly correlated with biological and economic factors, with management attributes playing a secondary role, management attributes such as the establishment and enforcement of quotas are still important for rebuilding overexploited populations. This is very much in line with Pons *et al*. (2017).

Hilborn *et al.* (2020) found a clear relationship between fishing pressure and changes in stock abundance, as well as between management intensity and fishing pressure. This has clearly been observed for BFT. In a number of countries, the decline in fishing pressure can be directly tied to changes in legislation and subsequent management. More detailed analysis of tuna fisheries has suggested that the status of tuna stocks is primarily influenced by factors other than the fisheries management system, including life-history and market factors. The status of tuna stocks was higher than "expected" also based on management intensity (Hilborn *et al*., 2020), presumably because the high cost of fishing at long distances made the bionomic equilibrium higher.

Melnychuk *et al.* (2021) compiled detailed management histories for 288 assessed fisheries from around the world. The ratification of international fishing agreements, and harvest control rules specifying how catch limits should vary with population biomass, helped to reduce overfishing and rebuild biomass.

Tuna is among the most important species in world fisheries both in terms of value and quantity. In 2019, the global catch of major commercial tunas was 5.3 million tonnes. Sixty percent of it was skipjack tuna, followed by yellowfin (28%), bigeye (7%) and albacore (4%), while bluefin tunas accounted for 1% (ISFF, 2021). According to ISFF (2021), globally, 65% of the stocks are at a healthy level of abundance, 13% are overfished and 22% are at an intermediate level. In relation to catch, 87.6% of the total comes from healthy stocks in terms of abundance. This is due to the fact that skipjack stocks contribute more than one half of the global catch of tunas, and they are all in a healthy situation. The situation for BFT in the Eastern Atlantic and Mediterranean is promising and Adolf (2019) makes the point that this stock has set some kind of precedent when it comes to management of tunas worldwide. Nevertheless, for the other BFT stocks, there is reason for concern. Pacific BFT tuna is heavily overfished, and the biomass continues to be near historically low levels (ISFF, 2021). The stock of Southern BFT is also heavily overfished, however, overfishing is currently not taking place due to the management plan in place (ISFF, 2021).

This research has also highlighted several avenues for further research. An update of Bjørndal and Brasao (2006), analysing optimal policies, would be very interesting. This could also be extended to incorporate a spatial variable to distinguish between the Northeast Atlantic and the Mediterranean. There is also need for further empirical game theoretic studies, for example of the current bargaining solution. Furthermore, tuna farming in the Mediterranean, bioeconomic and policy analyses of the Western Atlantic stock is of interest.

Some very important lessons can be learned from this study. Despite both empirical and theoretical papers claiming that RFMO management of highly migratory fish stocks is bound to be unsuccessful unless bolstered by a legal framework, the large number of countries active in the BFT fishery have found it in their interests to cooperate. This result brings hope for the management of highly migratory fish stocks in general.

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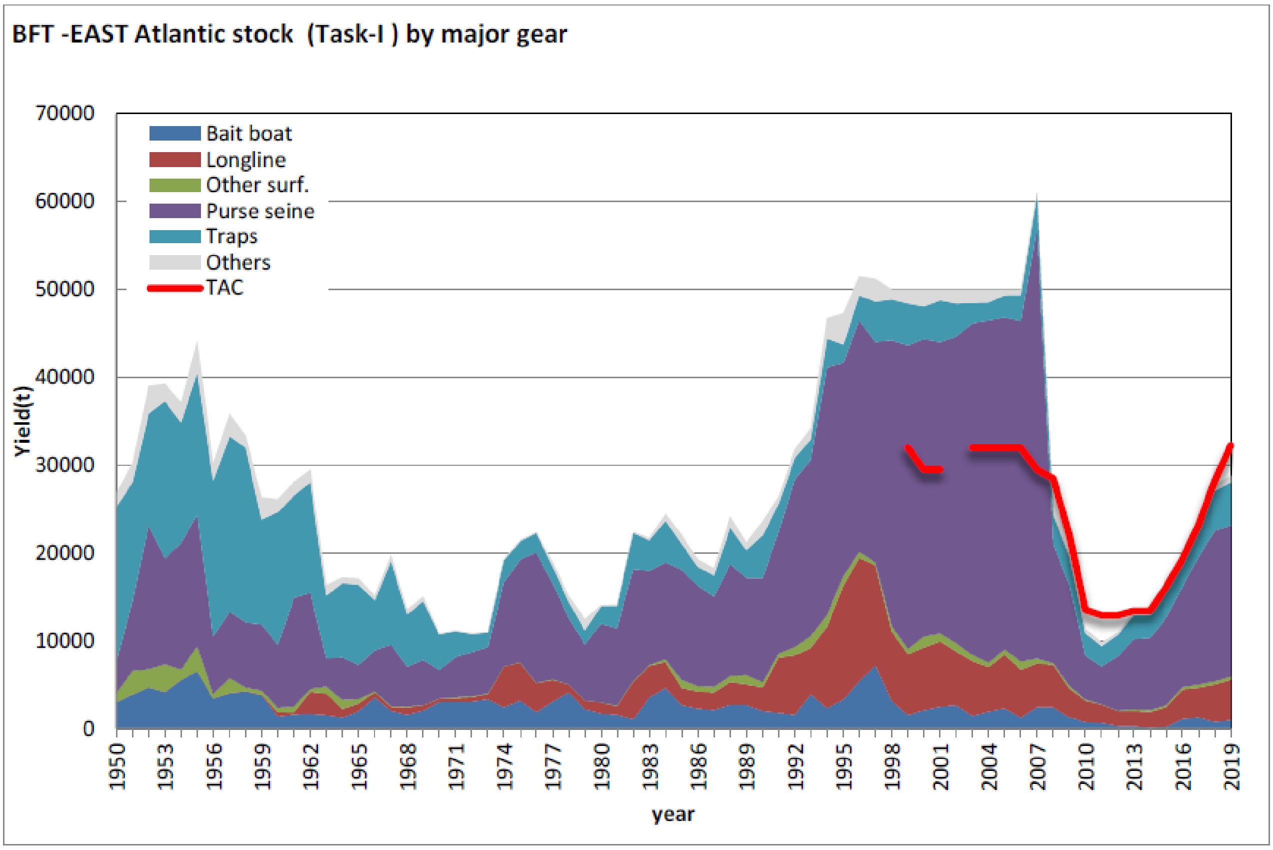
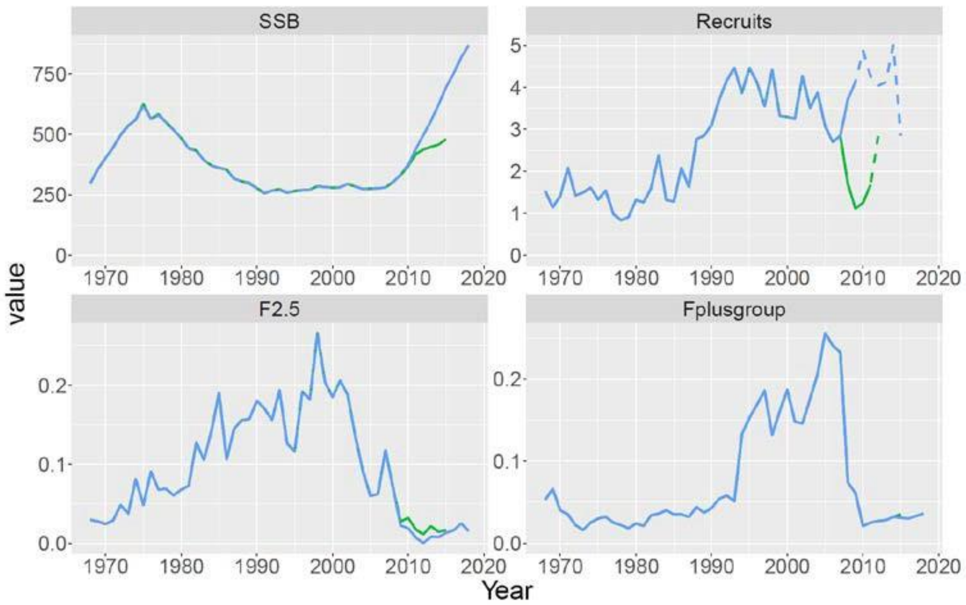
APPENDIX



Source: ICCAT (2020). Reported catch for the East Atlantic and Mediterranean BFT from 1950 to 2019 together with unreported catch estimated by the SCRS from 1998 to 2007 and TAC levels since 1998.

Figure A1. Catches by gear type 1950-2019. Tonnes



Source: ICCAT (2020), BFTE-Figure 3

Figure A2. Spawning stock biomass (in '000 tonnes), recruitment (in million), and fishing mortality (average over ages 2 to 5, and 10+) estimates from VPA base run in the 2020 stock assessment (blue) compared to the 2017 stock assessment (green) for the period between 1968 and 2015. The most recent years' recruitments (dashed line: 2012-2013 for the 2017 stock assessment, and 2010-2015 for the 2020 stock assessment) were poorly estimated

The cooperative management of bluefin tuna has been able to withstand several challenges such as changes in the geographical distribution of the stock which has also permitted a number of new members to join the fishery. As far as we can see, there are three main challenges to the future stability of the cooperative agreement. First, (unexpected) changes in the environment. Second, IUU fishing. Third, the new member problem, in particular, accommodating new coastal states into the fishery. Of these, the third challenge might potentially be the most serious. Having said that, hitherto the cooperative management agreement has proved to be very resilient.

A very important result of this analysis is that the bluefin tuna case does not conform with "received" wisdom when it comes to RFMO management. As noted, authors such as Cullis-Suzuki and Pauly (2010) and Brooks *et al*. (2014) call into question the very existence of RFMOs. The current analysis clearly demonstrates the successful RFMO management of a very important and valuable fishery.

Moreover, the case study also appears not to conform with parts of the game theoretic literature, in particular when it comes to the issue of how the number of players influences the outcome of cooperative games. ICCAT, with more than 50 contracting parties, has a large number of players. Although this might make it difficult to arrive at a cooperative agreement (Bjørndal & Martin, 2007), this has nevertheless been possible. Pintassilgo *et al.* (2010) find that the larger the number of fishing states in the game, the lower the likelihood that RFMOs are stable and their relative success of closing the gap between full and no cooperation. Moreover, in order to guarantee the stability of the cooperative agreements, it is not sufficient to implement a fair sharing rule for the distribution of the returns from cooperation. Thus, according to Pintassilgo *et al.* (2010), stability requires a legal regime preventing the players that engage in noncooperative behaviour from having access to the resource. In the bluefin tuna case, however, the parties involved have engaged in cooperation because it is in their interest to do so.

Overall, the case study presented in this article appears to contradict "received wisdom" when it comes to RFMO management. As such, it gives hope for RFMO management of highly migratory fish stocks. This is a very important result of this study. There is, however, a different strand of literature that provides explanation for parts of what we observe for bluefin tuna.

At the turn of the century, the Northeast Atlantic and Mediterranean bluefin tuna stock (BFT) appeared to be severely overexploited with some commentators believing it was heading towards collapse. In 2006, a 15-year recovery plan was introduced with the purpose of restoring the stock to a level corresponding to maximum sustainable yield (MSY) with a probability of at least 50%. Stock size is now increasing, which has permitted higher TACs in recent years. In fact, the stock is now believed to be sustainably harvested. This represents a total turnaround from the situation of less than 15 years ago. The fishery is managed by the International Commission for the Conservation of Atlantic Tunas (ICCAT), a Regional Fisheries Management Organisation (RFMO) in accordance with the 1995 United Nations Fish Stocks Agreement. BFT is classified as a highly migratory stock harvested by a large number of countries. Several authors have questioned the effectiveness of RFMOs. This paper analyses how cooperation has been achieved for BFT and whether the current cooperative management regime is stable, so as to see what lessons it holds for RFMO management, in particular when it comes to highly migratory stocks.

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