THE CLOSED CYCLE AQUACULTURE OF ATLANTIC BLUEFIN TUNA IN EUROPE

current status, market perceptions and future perspectives

Jonah van Beijnen

2017
Printed through own production

Copyright 2017 ©, all rights reserved

Text and design by: Jonah van Beijnen
Illustrations and design by: Ivan Reverente

DOI: 10.13140/RG.2.2.14033.53601
Version 1.7: June 21, 2017

Feedback: If you see any errors or have any questions or suggestions on what is presented in this report, please provide us with feedback so that we can correct or extend the information provided.

Citation: Van Beijnen (2017). The Closed Cycle Aquaculture of Atlantic Bluefin Tuna in Europe: current status, market perceptions and future potential. 95p.

For more information, please contact: jonah@vb-consultancy.com
“If we could change ourselves, the tendencies in the world would also change. As a man changes his own nature, so does the attitude of the world change towards him”

Mahatma Gandhi
CONTENT

Abbreviations .................................................................................................................. 6
Terminology ..................................................................................................................... 7
Executive Summary ......................................................................................................... 8
Preface .............................................................................................................................. 9
Acknowledgements ......................................................................................................... 10

Chapter 1: Introduction .................................................................................................. 12
  1.1 The Capture-based Tuna Industry ............................................................................. 12
  1.2 Hatchery Developments ......................................................................................... 15
  1.3 Objectives and Methods ......................................................................................... 17

Chapter 2: Production and Major Markets ..................................................................... 18
  2.1 Capture-based Production ....................................................................................... 18
  2.2 Production from Aquaculture ................................................................................ 21
  2.3 Main Markets and Pricing Mechanisms .................................................................... 26

Chapter 3: Recent and Current Hatchery Initiatives in Europe ....................................... 28
  3.1 Main Public Initiatives ............................................................................................. 28
  3.2 Involved Institutes and Public Research Centres ......................................................... 32
  3.2 Main Private Companies and Initiatives .................................................................. 36
  3.3 Summarized Production Efforts ................................................................................ 39

Chapter 4: Current Production Challenges in European Hatcheries and Potential Solutions .. 41
  4.1 Stable Availability of Quality Eggs ......................................................................... 41
  4.2 Floating Death (DAH 1 - 4) .................................................................................... 46
  4.3 Sinking Death (DAH 5 - 10) ................................................................................... 48
  4.4 Other Causes of Mortality during the Early Larval Stage (DAH 5 - DAH 15) .......... 49
  4.3 Cannibalism ............................................................................................................. 54
  4.4 Wall Collisions ......................................................................................................... 59
  4.5 Transfer Mortality .................................................................................................... 61
  4.6 An Updated Larval Rearing Protocol ....................................................................... 63
Chapter 5: Sustainable Tuna and Market Perceptions ................................................................. 65
5.1 Defining Sustainability ........................................................................................................... 65
5.2 Public Concerns about Captured and Farmed Tuna ............................................................... 66

Chapter 6: Future Perspectives ..................................................................................................... 71
6.1 Solving the Remaining Challenges in Hatchery Production .................................................. 71
6.2 Ensuring Sustainability .......................................................................................................... 72
6.3 A United European Approach ............................................................................................... 76

References .................................................................................................................................. 84
Annex 1: Definitions .................................................................................................................... 93
About the Author .......................................................................................................................... 94
<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABT</td>
<td>Atlantic Bluefin Tuna</td>
</tr>
<tr>
<td>BCD</td>
<td>Bluefin tuna Catch Documentation</td>
</tr>
<tr>
<td>CBI</td>
<td>Centre for Promotion of Imports</td>
</tr>
<tr>
<td>DAH</td>
<td>Days After Hatching</td>
</tr>
<tr>
<td>DOTT</td>
<td>Domestication of Thunnus thynnus project</td>
</tr>
<tr>
<td>EATIP</td>
<td>European Aquaculture Technology and Innovation Platform</td>
</tr>
<tr>
<td>EC</td>
<td>European Commission</td>
</tr>
<tr>
<td>EU</td>
<td>European Union</td>
</tr>
<tr>
<td>EMFF</td>
<td>European Maritime and Fisheries Fund</td>
</tr>
<tr>
<td>EU</td>
<td>European Commission</td>
</tr>
<tr>
<td>FAO</td>
<td>Food and Agriculture Organization (UN)</td>
</tr>
<tr>
<td>FCR</td>
<td>Food Conversion Ratio</td>
</tr>
<tr>
<td>FIS</td>
<td>Fish Information &amp; Services</td>
</tr>
<tr>
<td>FIP</td>
<td>Fisheries Improvement Project</td>
</tr>
<tr>
<td>HCMR</td>
<td>Hellenic Center for Marine Research in Greece</td>
</tr>
<tr>
<td>ICCAT</td>
<td>The International Commission for the Conservation of Atlantic Tunas</td>
</tr>
<tr>
<td>IEO</td>
<td>International Oceanographic Institute in Spain</td>
</tr>
<tr>
<td>IFREMER</td>
<td>Institute Français de Recherche pour l’Exploitation de la Mer</td>
</tr>
<tr>
<td>IOTC</td>
<td>Indian Ocean Tuna Commission</td>
</tr>
<tr>
<td>IUCN</td>
<td>The International Union for the Conservation of Nature</td>
</tr>
<tr>
<td>JFRA</td>
<td>Japanese Fisheries Research Agency</td>
</tr>
<tr>
<td>MARC</td>
<td>Malta Aquaculture Research Centre in Malta</td>
</tr>
<tr>
<td>MAST</td>
<td>Multi-stock Age Structured Tag integrated assessment model</td>
</tr>
<tr>
<td>MSC</td>
<td>Marine Stewardship Council</td>
</tr>
<tr>
<td>MT</td>
<td>Metric Ton</td>
</tr>
<tr>
<td>NCM</td>
<td>National Centre for Mariculture in Israel</td>
</tr>
<tr>
<td>NGO</td>
<td>Non-Governmental Organization</td>
</tr>
<tr>
<td>PBT</td>
<td>Pacific Bluefin Tuna</td>
</tr>
<tr>
<td>PPT</td>
<td>Parts Per Thousand</td>
</tr>
<tr>
<td>RFMO</td>
<td>Regional Fishery Management Organization</td>
</tr>
<tr>
<td>SSB</td>
<td>Spawning Stock Biomass</td>
</tr>
<tr>
<td>SBT</td>
<td>Southern Bluefin Tuna</td>
</tr>
<tr>
<td>SKJ</td>
<td>Skipjack Tuna</td>
</tr>
<tr>
<td>TAC</td>
<td>Total Allowable Catch</td>
</tr>
<tr>
<td>YSL</td>
<td>Yolk Sack Larvae</td>
</tr>
<tr>
<td>YFT</td>
<td>Yellowfin Tuna</td>
</tr>
</tbody>
</table>
# TERMINOLOGY

## Tuna Species and their Abbreviations

<table>
<thead>
<tr>
<th>Common Name</th>
<th>Scientific Name</th>
<th>Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Atlantic Bluefin Tuna</td>
<td><em>Thunnus thynnus</em></td>
<td>ABT</td>
</tr>
<tr>
<td>Pacific Bluefin Tuna</td>
<td><em>Thunnus orientalis</em></td>
<td>PBT</td>
</tr>
<tr>
<td>Southern Bluefin Tuna</td>
<td><em>Thunnus maccoyii</em></td>
<td>SBT</td>
</tr>
<tr>
<td>Yellowfin Tuna</td>
<td><em>Thunnus albacares</em></td>
<td>YFT</td>
</tr>
</tbody>
</table>

## Tuna Fattening and Farming Terminology

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Tuna fattening</strong></td>
<td>The farming of tuna using wild-caught young-adult and adult seed stock</td>
</tr>
<tr>
<td><strong>Tuna farming</strong></td>
<td>The farming of tuna using juvenile wild-caught or hatchery produced seed stock</td>
</tr>
<tr>
<td><strong>Closed Cycle Aquaculture</strong></td>
<td>The farming of tuna using captive born seed stock produced by (preferably) captive born breeders</td>
</tr>
</tbody>
</table>
EXECUTIVE SUMMARY

To develop an approach to the sustainable production of Atlantic Bluefin Tuna (Thunnus thynnus) in Europe, the EU and the private sector have started funding research stations and commercial enterprises around the Mediterranean region to close the life cycle of Atlantic Bluefin Tuna (ABT), in the hopes of eventually producing commercial quantities of hatchery-bred fingerlings for farming purposes. To date, hatchery projects are operational or underway in Spain, Malta, Italy, Greece, Egypt, and Turkey. Several of these projects have had major breakthroughs and have successfully started producing small quantities of ABT fingerlings.

Despite these successes, the majority of these projects face a number of challenges that continue to limit the production of fingerlings in commercial quantities. These challenges include a shortage of eggs, early floating and sinking deaths in larvae, cannibalism, wall collisions, and transfer mortality. Each of these challenges is discussed in this literature review and a number of solutions, often drawn from the latest EU and Japanese research, are presented. Solutions include improved broodstock management, modifications in the general tank setup, adjustments in the use of life feeds and an updated protocol for the harvesting and transferring of juvenile tuna. With these improvements in place, the only major remaining challenge is transfer mortality after fingerlings are moved to grow-out cages. When looking at Japan we see that their sector has already overcome these last challenges and is now producing significant quantities of Pacific Bluefin Tuna (PBT) fingerlings, approximately 500,000 pieces annually. Despite this positive outlook, most of the projects working on ABT in Europe seem to be closing down or halting production.

This report also assesses the market perception of hatchery produced ABT with a focus on sustainability issues. Most previous definitions of sustainable tuna do not take aquaculture activities into account, particularly not the closed cycle aquaculture of tunas. For these reasons, this report has provided an updated definition. Additionally this report found that seafood buyers and other stakeholders have difficulties distinguishing between products from capture-based fisheries and fattening operations that use wild seed stock, and products originating from closed cycle aquaculture. Furthermore the main concerns of buyers when buying tuna from aquaculture are quality, sustainability and feed origin.

With the closed cycle aquaculture of ABT, the European Union is in the unique position to solve a number of environmental concerns while developing an enormous economic opportunity. However while the sector for PBT in Japan is starting to flourish, the projects in Europe seem to be having a harder time. To ensure a well-coordinated and sustainable approach, to maximize the potential of this opportunity, this report concludes with the proposed development of a Masterplan for the Sustainable Closed Cycle Aquaculture of Atlantic Bluefin Tuna in Europe. This masterplan focuses on financial support mechanisms for the private sector, emphasis on the development of sustainable artificial feeds, clear and simplified rules and regulations for the sector including a strong offshore approach for grow-out farms and a mandatory uniform traceability system, a training component to ensure the economic viability and sustainability of grow-out farms and finally a strong marketing component which will put sustainable European produced ABT on the map.
The idea for this report came up in 2014 while working on different aquaculture and fisheries projects in the Philippines; I saw first-hand how the global demand for tuna results in decreasing tuna stocks. With a lifelong passion for the hatchery production of high-value marine finfish, I started thinking that the sustainable culture of tuna would not only be very interesting from an economic perspective, but could perhaps also reduce the pressure on wild tuna stocks as well. Then in 2015, after starting an MSc course in Sustainable Aquaculture at the School of Biology, University of St Andrews, Scotland, I further developed the idea of writing my thesis on the hatchery production of tuna.

By early 2016, Benetti et al., released their fantastic new book *Advances in Tuna Aquaculture: From Hatchery to Market*, which presents a superb overview of all aspects of the tuna farming and related fishing industry. However, the release of this book put me in an academic dilemma; since Benetti and his colleagues already did a great job in summarizing the sector worldwide, should I continue with this thesis topic?

Eventually I decided to continue, since writing the thesis would greatly enhance my knowledge on the topic. To keep my thesis relevant, and after realizing that many stakeholders in Europe (seafood buyers, consumer, NGO’s and government agencies) are not up to date with the developments in the sector, I decided to focus my efforts on an updated comprehensive overview on the closed cycle aquaculture of Atlantic Bluefin Tuna in Europe.

Also I have tried to provide solutions to overcome the challenges that the sector is facing based on the extensive review of Japanese literature, which I felt was somewhat underrepresented in the book by Benetti et al. I also tried to shed more light on the sustainability of the sector as perceived by seafood buyers, consumers, and other stakeholders. In addition, I have tried to develop a future vision for the sustainable closed cycle aquaculture of Atlantic Bluefin Tuna in Europe: what can we learn from other countries like Japan? And what would be the best approach by the European Union and its member states to maximize the benefits from this aquaculture opportunity?

After finishing the thesis, I developed it into this more compressive report, incorporating the feedback from numerous reviewers. I hope I have succeeded in creating an interesting and valuable overview for scientists, legislators and other stakeholders in the region. Likewise, I hope my recommendations will be of use to the European Union and its member states in developing a flourishing and sustainable sector for the closed cycle aquaculture sector of Atlantic Bluefin Tuna in Europe.
ACKNOWLEDGEMENTS

I would hereby like to acknowledge and thank my thesis supervisor Dr. Neil Hazon for giving me the opportunity to write the original thesis and for his kind and professional assistance to enhance it into a comprehensive report. In addition, I would like to thank my second course supervisor Dr. Jonathan David.

Furthermore, special thanks is extended to a number of specialists who provided vital information that helped to write this report, including but not limited to Dr. Gidon Minkoff, Jakob Doorn, Dr. de la Gandara, Tsuyoshi Goto, Aurelio Ortega García, Šime Bubičić, Professor Chris Bridges, Theodor Pulver and Dr. Heiko Seilert.

Also, I would like to thank Dr. Gidon Minkoff, Dr. Heiko Seilert, Dr. John Dommerich Stieglitz, Dr. de la Gandara, Dr. Neil Hazon, Dr. Robert Agius Vassallo, Kyra Hoevenaars and Periklis Kleitou for providing valuable feedback on the manuscript.

Dr. de la Gandara Professor Chris Bridges and Tsuyoshi Goto have also been supportive by providing important data and a number of excellent photographs to illustrate this report.

In addition, I would hereby like to take the opportunity to thank all the respondents of the questionnaire.

I would likewise like to thank my two colleagues and friends, Kyra Hoevenaars and Al Gonzales for their support and friendship. Last but certainly not least, I would like to thank my lovely and amazing wife Jenny who always supports and inspires me. Thank you very much! With all these three amazing friends, I have had the pleasure of experiencing many sustainable aquaculture adventures! And maybe this report is the beginning of a next adventure?!

Thank you all.

Sincerely yours,

Jonah van Beijnen
CHAPTER 1: INTRODUCTION

Tuna are large predatory pelagic fish that occur in marine waters throughout most of the globe. They swim at high speeds and at great depths, while hunting for small fish and squid (Kitagawa et al., 2004; NOAA, 2011). There are about a dozen tuna species of major economic importance including Skipjack Tuna (SJIT), Yellowfin Tuna (YFT), and several Bluefin Tuna species. All of these species are appreciated for their thick meat with a high fat content, ranking them globally among the most popular food fish with a corresponding high demand (Benetti et al., 2016).

1.1 The Capture-based Tuna Industry

Despite the high demand, since closed cycle aquaculture of tuna has proven to be difficult, the seafood industry continues to depend on capture-based fisheries for its raw material. Subsequently, fishing effort and landing volumes around the globe have increased significantly over the past 30 years (Harley et al., 2011; Mathews, 2000), from around 400,000 Metric Ton (MT) of tuna in 1974 to over 4,000,000 MT of catch by 2014 (FAO, 2014; Sumaila & Huang, 2012). This large increase in landings and fishing effort in turn has resulted in severe overfishing, Dramatically decreasing stock sizes of most tuna species (Benetti et al., 2016).

In Europe, the tuna species of major commercial interest to fishermen and farmers is the Atlantic Bluefin Tuna (Thunnus thynnus), which occurs in the Atlantic Ocean and the Mediterranean Sea (Ottolenghi, 2008). Atlantic Bluefin Tuna (ABT) can grow up to 700 Kilogram and are highly appreciated in local and overseas sashimi markets, commanding high prices. For these reasons, ABT is historically one of the most important target species of fishermen in Southern Europe. However, in combination with the industrialization of Europe’s fishing fleet in the 20th century, this ensued in severe overfishing. By the early 2000’s it was projected that the stock size of ABT had been reduced to such a low level that a collapse became a realistic possibility (Heffernan, 2014; Mylonas et al., 2010). The IUCN responded to this

Figure 1. Record size Atlantic Bluefin Tuna caught off the coast of Canada.
situation by officially listing ABT as an endangered species (IUCN, 2016) and calling for improved management of the stocks.

Two separate ABT stocks have been identified: the western stock that occurs in Atlantic waters from Brazil to Canada, and the eastern stock that occurs in the eastern part of the Atlantic Ocean from Senegal to Norway and in the Mediterranean Sea (figure 2), with some mixing taking place. Moreover, due to the severe fishing pressure on the eastern stock, the historic distribution range has been significantly reduced: ABT are now rarely found in Europe’s northern waters.

![Figure 2: Global distribution of the 2 ABT stocks (blue and orange), their spawning grounds (dark green) and migratory routes (brown) (PEW, 2016).](image)

The outcomes of stock estimates differ considerably, the International Commission for the Conservation of Atlantic Tunas (ICCAT), the inter-governmental fishery organization in charge of the management of ABT, calculated an estimated spawning biomass of ABT that peaked in the 1950’s at around 300,000 MT (ICCAT, 2014), with a decline of almost 40% between 1970 to 2010 (IUCN, 2017). However, in an effort to develop more accurate estimates of the original unfished stock sizes of ABT, Taylor et al. (2011) extrapolated data from ICCAT and other sources (figure 3). Through their model they estimate that the original size of the two stocks together totalled almost 1 million MT, while by 2007 according to their calculations less than 25 percent of this original unfished biomass of the western stock and less than 20 percent of the original unfished biomass of the eastern stock remained (Taylor et al., 2011).
In response to this drastic decline in stock size, ICCAT and its members gathered in 2006, to improve the management of ABT in both the Mediterranean Sea and Atlantic Ocean (Bayliff, 2016). All members eventually agreed a 15-year recovery plan (European Commission, 2016). A focal point of this improved management has been an annual quota system with a specific catch allocation for each member state. By now, the first indications confirm that these efforts prove to be effective. But because of the complicated nature of the fishery and the challenging management of the stocks, it will most likely take a number of years before the real pay-offs become visible (Taylor et al., 2011).

A similar downward trend in stock size has been observed in other major tuna fisheries. For instance the latest stock estimate for Pacific Bluefin Tuna (PBT) show an ever bleaker picture: the northern PBT stock size has been reduced to approximate three percent of the original unfished biomass by 2014 (Jallut et al., 2014). Consequently, there has been growing public concern about the sustainability of the worlds’ existing tuna fisheries and a rapidly increasing number of consumers in Europe and the United States no longer wish to contribute to overfishing (CBI, 2015; Fernandez-Polanco & Llorente, 2016). Retailers and major tuna buyers have responded to this development and have started prioritizing sustainable tuna products in their assortments (CBI, 2015).

This increased interest in sustainable tuna, in turn has increased demand for MSC certified tuna fisheries and sustainable-labelled, socio-economically viable, small-scale, or artisanal fishing fleets. This increased interest also presents a considerable opportunity for closed cycle...
aquaculture of ABT in Europe. It is for these reasons that during the last ten years the EU and the private sector have started funding research stations and private enterprises around the Mediterranean region to engage in efforts to close the life cycle of ABT. In the hopes of eventually producing commercial quantities of hatchery bred fingerlings for farming purposes (Benetti et al., 2003; Masuma et al., 2011; Ortega et al., 2013; Partridge, 2009; Purcell et al., 2013).

1.2 Hatchery Developments

Projects focusing on the closed cycle aquaculture of ABT have been operational or are underway in Spain, Malta, Greece, Croatia, Egypt and Turkey, and most of these projects have successfully produced small quantities of fingerlings in the past 4 years (Benetti et al., 2016). Moreover, the first tuna products from these efforts have become available to consumers. In December 2014, the Dutch seafood company Jan van As, acquired two pieces of ABT (30 Kilogram each) that were produced in the hatchery of the Instituto Español de Oceanografía (IEO) and raised in grow-out cages by seafood supplier Ricardo Fuentes e Hijos in Murcia, Spain. A world premiere, and these tuna were used to promote the production of sustainable tuna from closed cycle aquaculture (figure 4 on the next page).

Despite these considerable successes, a number of challenges continue to challenge the production of ABT fingerlings in commercially viable quantities (Benetti et al., 2003; Masuma et al., 2011; Ortega et al., 2013). Especially after the large publicly funded hatchery research projects ended in 2015, most of the remaining private hatcheries seem to be having a hard time to sustain their production and several projects have halted production or closed down.

However, there is also more hopeful news. Since the first commercial interest in the hatchery culture of tuna in the 1990’s, Japan has been at the forefront of the hatchery production of Bluefin tuna and the country continues to make noteworthy progress. In the past few years, Japanese hatcheries have already overcome most of the challenges that different projects in other parts of the world are facing, and its closed cycle aquaculture sector for PBT is starting to thrive. By now, approximately 20 hatchery facilities are producing PBT in Japan and the average survival rate is estimated at 3 to 5 percent (Undercurrent News, 2015). The only minor challenges that seem to remain are the production of sufficient copepods as feed, and transfer mortality of fingerlings, which, if overcome, would further boost survival rates (Feed One, 2016; Higuchi et al., 2013).

In 2016, these hatcheries produced almost 500,000 fingerlings and they were responsible for a little over 50 percent of the juvenile PBT used for stocking grow-out cages in Japan (Benetti et al., 2016; Partridge et al., 2016; Nissui, 2017). Fingerlings are currently priced at a hefty USD 50 each (Undercurrent News, 2014) and with annual demand from local farmers
estimated at 600,000 fingerlings (Undercurrent News, 2015), production is expected to increase even further in 2016 and 2017. The sales from grow-out operations using hatchery produced PBT have lifted off as well, with 900 MT of sales in 2016 (Nissui, 2017) and over 1,000 MT of sales expected in 2017 (The Japan Times, 2016), thereby proving that the closed cycle aquaculture of Bluefin tuna is viable.

Figure 4. First hatchery produced Atlantic Bluefin Tuna sold in the Netherlands, hatched by IEO in Spain, farmed by Ricardo Fuentes and eventually sold to sustainable seafood trader Jan van As in 2014 (Jan van As, 2014).
1.3 Objectives & Methods

This report presents a complete literature based overview of the closed cycle aquaculture of ABT in Europe. In order to identify potential issues and gain more insights into the demand for farmed and fattened tuna, this report first looks at current fishing efforts and capture-based aquaculture of ABT in chapters 2 and 3.

This report then continues with a literature review of the challenges that currently constrain the production of ABT fingerlings in different hatchery projects around the Mediterranean region (chapter 4). Additionally, in the same chapter this report presents a number of recommendations to address these hurdles. Many of these solutions are drawn from Japanese literature and from the last publicly funded tuna research projects in Europe.

Furthermore, in chapter 5 this report discusses the market perception of hatchery produced ABT, with a focus on sustainability issues. A number of seafood buyers and retailers have been interviewed through the means of questionnaires. The concerns of these buyers are presented, and an updated definition for sustainable tuna that takes aquaculture into account, is presented. The chapter ends with a number of recommendations that will guide the future sustainability of the closed cycle aquaculture of ABT in Europe.

Finally, in chapter 6 this report compares the success of the closed cycle aquaculture sector of PBT in Japan, with the current status of the ABT closed cycle aquaculture sector in Europe. Through this comparison, this report extracts a number of recommendations to facilitate the European Union (EU) and its member states in their efforts to maximize the potential of the closed cycle aquaculture of ABT in Europe.
CHAPTER 2: PRODUCTION AND MAJOR MARKETS

2.1 Capture-based Production

Of the two ABT stocks, the western stock is mainly fished by the United States of America, Canada and Japan and the stock has been officially listed as depleted (ICCAT, 2014, 2015). This fishery has been managed fairly well since the 1980’s and scientists have estimated a Spawning Stock Biomass (SSB) decline of less than 1% in the past 20 years (IUCN, 2016). Data from ICCAT shows that landings have decreased from 2.780 MT in 1990 to 1.626 MT by 2014 (ICCAT, 2015), with little variance in the last few years.

The eastern ABT stock is mainly fished by Spain, France, Italy, Malta, Turkey, Cyprus and Greece and the stock has been listed as overfished (ICCAT, 2014, 2015). The management of this stock is more complicated since more nations are involved in the fishery. It is estimated that the SSB for this stock has declined by at least 30% in the past 20 years (IUCN, 2016). Figures by ICCAT (figure 5) show that landings for this stock have decreased from over 50.000 MT annually in the 1990’s to 9.774 MT in 2011 (ICCAT, 2015), with catches slowly increasing after that. Though it should be noted that it is believed that the landing figures for the eastern stock have been severely underreported during the past 10 years (Bayliff, 2016).

In an effort to improve the stock status of ABT, members of ICCAT agreed in 2006 to a 15-year recovery plan (European Commission, 2016). As part of this recovery plan, lower annual Total Allowable Catch (TAC) allocations for each member state were set. However, the rather political nature of the annual quota setting and allocation process, initially led to a limited effectiveness of the measure. For example, scientists working for ICCAT recommended a quota...
of just 15.000 MT in 2007, after which ICCAT eventually decided to set the final quota for that year at 30.000 MT. Consequently, there were few measurable positive effects on the stock and subsequently quotas were further reduced to 12.900 MT in 2011 and 2012. By the end of 2014 ICCAT recommended to again increase the TAC by 60% over a 3 year period from 15,821 MT in 2015 to 22.705 MT in 2017 (EU, 2016).


<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Cyprus</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>France</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Greece</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Italy</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Malta</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Portugal</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Spain</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
<tr>
<td>Other</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
<td>0.00</td>
</tr>
</tbody>
</table>

This significant TAC increase for the period between 2014 and 2017 has been attributed by ICCAT to the successful recovery of the stock, as according to the last stock assessment of 2014, in 2012 - 2013 the stock had recovered to a SSB of 520.000 MT (ICCAT, 2014).
be higher than previously estimated peak SSB of 300,000 MT in 1950, whereby ICCAT does recognize the difficulty of developing accurate models for stock assessment, since small adjustments in different variables can have large effects on the outcomes of a model (ICCAT, 2014).

In recent years, it has been increasingly observed that the annual TAC allocation of EU member states is fished within very short time frames. For example, the 2.504.45 MT share of Spain in 2014 was fished within 48 hours, while their 2.956.92 MT share in 2015 was fished within one week after the start of the fishing season (Undercurrent News, 2015). Fishers and local politicians attribute this mainly to the increase in stock size and see it as evidence of the recovery of the stocks. Although this is most probably a correct partial explanation, other factors play a role as well.

By 2016, EU member states had a combined fleet of 910 vessels (and 12 traps) actively fishing on ABT (European Commission, 2016). This large number of vessels and their rapidly increasing fishing efficiency (e.g. the constant increase in vessel size, the use of spotter planes and advanced radar systems) is seen by many as a clear sign of overcapacity (Heffernan, 2014; ICCAT, 2012; Sumaila & Huang, 2012; WWF Mediterranean, 2006). Although it indeed seems the stocks are recovering, this overcapacity complicates fisheries management. Not only for tuna but also of other stocks, as new research indicates that the massive fishing fleet of the EU’s member states now has overfished 93% of the fish stocks in the Mediterranean Sea (Piroddi et al., 2017).

An additional consequence of this overcapacity is that profit margins of fishing vessels targeting tuna have dropped, and it has been calculated that vessels catching less than 50 MT of ABT per trip are now unprofitable (Heffernan, 2014). Thus vessels and their owners have been forced to look for ways to add value to their catch and regain profitability (Mylonas et al., 2010). A very common way to do so, has been to capture live young-adult tuna, and stock these in large floating cages at sea for fattening purposes.

![Figure 7. Purse seine vessel catching tuna for fattening purposes (Greenpeace, 2010).]
2.2 Production from Aquaculture

A clear distinction needs to be made between capture-based aquaculture, wherein seed stock is sourced from the wild and closed cycle aquaculture where the seed stock is produced in captivity by eggs from captive breeders, preferably but not necessarily from captive born parents. Each of these forms of aquaculture will be discussed separately in this chapter.

Capture-based Aquaculture

The vast majority of ABT production from aquaculture is produced by fattening operations based in the Mediterranean Sea that acquire their seed stock from purse seine vessels that are dedicated to the capture of live tuna. These purse seiners mostly target young-adult and mature tuna that are carefully caught, and towed back to fattening farms. Upon arrival, the tuna are transferred to large floating cages where they are fattened to attain a better marketable size and to improve the fat percentage of the meat (Giménez-casalduero & Sánchez-jerez, 2006). The majority of the tuna for these operations are caught immediately after the release of the annual ICCAT fishing quota in May and June. Depending on the size at initial stocking, they are fattened for a period ranging from 7 months (Ottolenghi, 2008) to 2 years (Mylonas et al., 2010).

Since pellet feeds for tuna are still under development and since the use of pellet feeds is valued less by Japanese customers, fresh fish like herring, sardines, and mackerel are mainly used as feed. The Feed Conversion Ratio (FCR) of fresh fish fed to these tuna is not very efficient and approximately 15 to 20 Kilogram of fish is used to produce one Kilogram of tuna (Ottolenghi, 2008). With the number of fattening operations on the increase, a number of NGO’s and other stakeholders have expressed their concerns about the sustainability of these feeding and stocking practices (WWF Mediterranean, 2011).

The first large fattening operation in the Mediterranean Sea became operational in 1979, but the sector started to grow around the year 2000, as fishing vessels and their owners were looking to restore profitability of their fishing operations by adding value to their catch. Fishermen figured out that by fattening the ABT for longer periods they could increase the size of the tuna, but more importantly they could increase the fat content as well (Mylonas et al., 2010), which is one of the major price determinants. Eventually by early 2017, 54 ABT farming companies were registered with ICCAT, and these are located in Croatia (5), Cyprus (3), Greece (2), Italy (14), Libya (1), Malta (7), Morocco (1), Spain (9), Portugal (1), Tunisia (5), Turkey (6) and Portugal (1). These companies are operating 62 farms with a total farming capacity of almost 54.000 MT, as shown in table 2.
Table 2. The number of Fattening and farming operations of Atlantic Bluefin Tuna that are registered with ICCAT, the number of farming sites they use and their farming capacity (2017).

<table>
<thead>
<tr>
<th>Country</th>
<th>Companies (#)</th>
<th>Farming Sites (#)</th>
<th>Farming capacity (MT)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Croatia</td>
<td>5</td>
<td>10</td>
<td>6.020</td>
</tr>
<tr>
<td>Cyprus</td>
<td>3</td>
<td>3</td>
<td>3.000</td>
</tr>
<tr>
<td>Greece</td>
<td>2</td>
<td>2</td>
<td>1.101</td>
</tr>
<tr>
<td>Italy</td>
<td>14</td>
<td>14</td>
<td>10.602</td>
</tr>
<tr>
<td>Libya</td>
<td>1</td>
<td>1</td>
<td>1.000</td>
</tr>
<tr>
<td>Malta</td>
<td>7</td>
<td>8</td>
<td>12.300</td>
</tr>
<tr>
<td>Morocco</td>
<td>1</td>
<td>1</td>
<td>400</td>
</tr>
<tr>
<td>Portugal</td>
<td>1</td>
<td>1</td>
<td>0.5</td>
</tr>
<tr>
<td>Spain</td>
<td>9</td>
<td>10</td>
<td>11.353</td>
</tr>
<tr>
<td>Tunisia</td>
<td>5</td>
<td>5</td>
<td>1.690</td>
</tr>
<tr>
<td>Turkey</td>
<td>6</td>
<td>7</td>
<td>6.140</td>
</tr>
<tr>
<td>Total</td>
<td>54</td>
<td>62</td>
<td>53.606</td>
</tr>
</tbody>
</table>

Of these countries, Malta (12.000 MT), Spain (11.353 MT) and Italy (10.602 MT) have by far the largest farming capacity, followed closely by Croatia (6.020 MT). Major players include Ricardo Fuentes E Hijos S.A and its subsidiaries, with operations in Spain, Portugal and Morocco, Balfego Tuna S. L. (Spain), Kali Tuna (Croatia) and the Kiliç Seafood Co. Group in Turkey. Although some farming companies are operating in remote areas with significant
distances to other farms, most farms are distributed in clusters (figure 8). Besides the small island of Malta, major production centres with larger clusters of farming operations are present in the area around Cartagena in Spain, near Naples in Italy and near Zadar in Croatia.

While the farming capacities of these farms are well known, their exact production figures are somewhat unclear. Most countries tend to report rather different production figures to FAO and EUROSTAT compared to the reported production figures in their national reports (Metian & Pouil, 2014; Sumaila & Huang, 2012; Taylor et al., 2011). Metian and Pouil (2014) conducted a study by compiling reported production figures from 2000 to 2011, and their study points out some interesting differences in reported production figures. For example, in 2011, Croatia reported a total production of 1.610 MT to FAO while it reported a production of 3.223 MT in its national production reports to Eurostat. Additionally, Spain reported a total production of 575 MT to FAO while it reported a production of 2.866 MT in its national production reports to Eurostat.

A similar discrepancy is found between these reported production figures and the recorded production capacities of these farms by ICCAT. For example, in 2013 the total reported production volumes of these fattening operations constituted between 4.772 MT to 11.648 MT, depending on which reports to follow, but when looking at the production capacities of these farms, these figures are much higher (figure 9). In 2013, the production capacity of Mediterranean fattening farms as registered by ICCAT was 60.809 MT, which is between five to tenfold more than the reported production figures. By 2017 the total farming capacity had been reduced almost 20% to 53.606 MT. Although production statistics from FAO and Eurostat have not yet been made available for 2016 and 2017, it seems that most countries have opted to not report their production figures instead of fixing the noted discrepancies.

---

**Figure 9.** Capacity of Atlantic Bluefin Tuna fatting and farming operations (blue) versus reported production figures to Eurostat (orange) and FAO (grey) in 2013 as collected by Metian and Pouil (2014).
These discrepancies between reported production volumes and production capacities can be partially explained by the duration of the fattening period, which in some farms is around 2 years (Mylonas et al., 2010), and in Croatia, where very small ABT are stocked, the farming period can even take 4 to 5 years. However, in many fattening farms the fattening period only lasts 7 months to 1 year, so why the major discrepancy? There seems to be a tendency that most ICCAT member states underreport their catches to ICCAT and FAO in an effort to “support” their national finishing fleets, a big percentage of which are catching young-adult ABT. Thus, when underreporting the landing figures of their fishing fleets, in an effort to maintain some level of consistency in reporting figures, the only option is to underreport production volumes for capture based aquaculture activities.

From these figures, we can conclude that fattening and farming of ABT is a profitable business, but the practice of this seemingly continuing habit of underreporting slows down recovery of the ABT stock, and, moreover, it has a big impact on the reputation on the industry as a whole (see chapter 5).

Figure 10. Fattening operations of Atlantic Bluefin Tuna in Greece (Dimitri Messinis/AP)
Closed Cycle Aquaculture

The production of ABT from closed cycle aquaculture is still limited, no official figures are published, and none of the hatcheries publish their official production figures. What is clear is that hatcheries are ongoing or are underway in Spain (2), Turkey (1), and Egypt (1), and to date at least three of these projects have supplied farmers (external or internal within the company) with some fingerlings to produce marketable fish. Most broodstock still originates from the wild, although the first captive born broodstock are now available.

The little solid information that is available concerning production figures comes from Benetti et al. (2016), who noted that the International Oceanographic Institute in Spain (IEO) in Murcia, Spain, produced approximately 3,000 ABT fingerlings in 2013 and 2014. These fish were then farmed by seafood company Fortuna Mare and the first mature fish were harvested in 2016 (Benetti et al., 2016). They also reported that Kilic Seafood Co. from Turkey, produced around 15,000 fingerlings in 2014. These fish are farmed in the company’s farm and will approach maturity by 2017 (Benetti et al., 2016). With a current survival rate in grow-out operations of approximately 25% and a harvest size of 20 Kilogram, Ricardo Fuentes e Hijos could potentially produce around 1,500 Kilogram of hatchery bred ABT in 2016 while Kilic Seafood Co. could potentially produce 75,000 Kilogram in 2017. The map in figure 11 shows the location of the different farming operations that grow ABT from closed cycle aquaculture in the Mediterranean Sea. The different projects and their production figures will be discussed into detail in chapter 3.

**Figure 11.** Farming operations of Atlantic Bluefin Tuna in the Mediterranean Sea that use hatchery produced seed stock indicated in black.
2.3 Main Markets and Pricing Mechanisms

The main reason behind the rapid growth of the ABT capture-based aquaculture industry in the Mediterranean Sea is the large demand for tuna in Japan, where around 500,000 MT of tuna is consumed annually (Benetti et al., 2016). Hence it is not surprising that Japan is by far the biggest importer of ABT (Ottolenghi, 2008). Six countries provide the majority of the ABT production in the Mediterranean region to Japan: Croatia, Malta, Tunisia, Spain, Turkey and Italy (Ottolenghi, 2008). According to figures provided by the Japanese Fisheries Research Agency (JFRA), in 2006 these countries together exported 22,600 MT of ABT to Japan (Masami, 2016).

However due to an increasing supply from both domestic tuna farms in Japan and Mediterranean farms, prices for tuna in Japan have dropped considerably in recent years, forcing Mediterranean tuna producers to explore alternative markets (Mylonas et al., 2010). As a result, ABT exports from the Mediterranean region to Japan have been declining and by 2012, exports to only measured a mere 8,200 MT (Masami, 2016). Despite this decline, Japan continues to be the largest market for Mediterranean producers of ABT and still imports around 50 percent of the total production of ABT from fisheries and aquaculture (Fernandez-Polanco & Llorente, 2016).

Since cultured ABT is mainly used for sashimi, the tuna farming industry heavily depends on the wellbeing of the global sashimi market (Fernandez-Polanco & Llorente, 2016). Luckily for ABT farmers, the Japanese cuisine has in recent years risen enormously in popularity across the world, ensuring a high market demand (Benetti et al., 2016). Similarly in Europe the market demand has been rising as well, and domestic consumption of ABT has particularly increased in Spain and Italy (Fernandez-Polanco & Llorente, 2016).

Pricing is a big issue for both the ABT fishery and aquaculture sector and different tuna grades fetch very different prices. The majority of the catch landed by Mediterranean purse seiners are young-adult spawners that have migrated from the Atlantic Ocean to the spawning grounds in the Mediterranean Sea, and they have used most of their energy reserves for travelling these long distances. By doing so, the tuna have spent a big portion of their fat content, which happens to be one of the most important features that determines the quality and the price. A higher fat content commands a higher price (Mylonas et al., 2010). Although the fattening period does increase the fat percentage, the fattening duration in most farms is too short to fully please Japanese buyers. A second important quality feature is the meat structure, which is determined by size and age and thus larger tuna (200 Kilogram up) tend to command higher prices compared to medium sized and smaller tuna (Mylonas et al., 2010). However, this large size class is rarely achieved in fattening operations.

With the recent increase in supply, prices in the Japanese market have declined over the past few years and currently (2015 - 2016) lower grade headed and gutted, fresh ABT fetches
between 8 to 17 Euro/Kilogram, while higher sashimi grades fetch between 35 to 80 Euro/Kilogram (Benetti et al., 2016). Unfortunately, most Japanese tuna graders, grade ABT from capture-based fisheries and fattening operation as low to medium grade only (Fernandez-Polanco & Llorente, 2016), with an average corresponding price range of 20 to 40 Euro/Kilogram (Villegas, 2014). Due to the high airfreight costs to Japan, these prices for fresh ABT are not very profitable for most fattening operations (Mylonas et al., 2010) and, thus, in recent years most operators have started exploring different markets and different product lines.

Many producers now sell their products directly from the cage to large freezer vessel operations (Mylonas et al., 2010) who then are responsible for processing and marketing the fish. Despite the lower prices, ranging from 12 Euro/Kilogram for small tuna to 20 Euro/Kilogram for larger tuna (Mylonas et al., 2010), additional costs are at a minimum and profit margins are higher. With an estimated average sales price of 15 Euro/Kilogram and a minimum production volume of around 15,000 MT in the Mediterranean Sea, this currently results in an annual return of at least 225 million Euro for the sector.

Interestingly, in Croatia, farmers have taken a different approach wherein small juvenile ABT are caught and farmed for much longer periods (a minimum of 2 - 3 years). This activity has been classified as farming and not as fattening and currently Croatia is the only Mediterranean nation allowed to do so by ICCAT (Mylonas et al., 2010). By farming the fish from a juvenile stage the fat content of the meat becomes very high (picture 10), resulting in higher prices for these fish on the Japanese market (Ottolenghi, 2008). This again shows the great potential of using hatchery produced ABT fingerlings for farming purposes.
CHAPTER 3: RECENT AND CURRENT HATCHERY INITIATIVES IN EUROPE

3.1 Main Public Research Initiatives

In the past two decades, a number of important EU-funded projects paved the way for the successful experimental culture of ABT (Zohar et al., 2016), including the DOTT project, the REPRODOTT project, the SELFDOTT project and the TRANSDOTT project.

The first Domestication of *Thunnus thynnus* (DOTT) project (2001 - 2002) aimed to develop a strategy for the closed cycle aquaculture of ABT in Europe. The REPRODOTT project (2003 - 2005) evaluated the possibility of reproducing ABT in captivity, while the SELFDOTT project (2008 - 2011) focused on developing a basic larval rearing protocol for ABT and the development of artificial feeds for the sector. Finally, the TRANSDOTT project (2012 - 2014) use the findings of the SELFDOTT and REPRODOTT projects, and to develop these results into a commercially, innovative and marketable application for ABT aquaculture.

The SELFDOTT project, a collaboration between project coordinator IEO in Spain, the Institute Français de Recherche pour l’Exploitation de la Mer (IFREMER) in France, the Hellenic Center for Marine Research (HCMR) in Greece, the Heinrich-Heine University in Germany and other partners, came up with a number of fundamental discoveries and achievements concerning the closed cycle aquaculture of ABT. These achievements include the development of ABT broodstock that spawned on a regular basis (figure 13).

*Figure 13.* The proud lead-scientists of the SELFDOTT projects holding some of the first spawned ABT eggs (IEO / de la Gandara, 2014).
With this, the SELFDOTT team continued developing a basic (experimental) larval rearing protocol for ABT larvae using clear water culture, enriched rotifer, and artemia as main feed, combined with yolk sack larvae of other marine finfish during the later larval stage. This basic larval rearing protocol resulted in fast growing larvae (figure 14) and enabled the project to produce several thousand ABT fingerlings for grow-out purposes (Allan et al., 2009; de la Gandara et al., 2009; Ortega et al., 2013; Reglero et al., 2013).

**Figure 14.** Approximate growth of Atlantic Bluefin Tuna larvae during the SELFDOTT project (IEO / de la Gandara, 2014)

**Figure 15.** Atlantic Bluefin Tuna larvae photographed during the SELFDOTT project, at DAH2 (A), DAH 3 (B), DAH 7 (C) and DAH 8 (D) (SELFDOTT, 2009).
At the same time the ALLOTUNA project was initiated, which was a regional initiative of the Italian province of Apulia, and the project brought together several Italian partners to strengthen further research in the hatchery production of ABT (Zohar et al., 2016).

The last EU-funded DOTT project was the TRANSDOTT (2012 - 2014) project, which was a collaboration between four commercial hatcheries (ARDAG Red Sea Mariculture Ltd. in Israel, Panittica Pugliese Società Agricola SPA in Italy, MFF Ltd in Malta and Futuna Blue S.L. in Spain), one commercial feed producer (Skretting ARC) and three public research stations (Malta Aquaculture Research Centre in Malta, National Centre of Mariculture in Israel and the Heinrich Heine University in Germany). The goals of the project were to use the findings of the SELFDO T and REPRODOTT projects, and to develop these results into a commercially, innovative and marketable application for ABT aquaculture (Böttcher, 2016; Koven et al., 2016; TRANSDOTT, 2012), by doing the following:

I. To develop more efficient egg collection methods;
II. To carry out trials on fish handling techniques for juvenile ABT;
III. To monitoring broodstock through the use of data loggers;
IV. To decrease mortalities at critical stages of the larval development;
V. To improve the larval rearing protocol for ABT in terms of live food enrichment and live food types;
VI. To improve the weaning protocol for ABT larvae from live food to a dry formulated diet;
VII. To establish a larger number of fingerlings for grow-out purposes;
VIII. To create a reliable method for the transportation of fingerlings from the rearing tanks to larger tanks or cages for grow-out;
IX. To prevent high mortality rates of juvenile tuna after transfer to grow-out cages.

The major research topics of the project included: improved broodstock management by using better suited live feeds, the testing of new net designs for egg collection, the use of copepods in the larval rearing protocol, the development of dietary enrichments to increase the survival rate during the larval stage and the testing of a commercial pellet for the late larval and nursery stage (Aquafeed LLC, 2014; de la Gándara et al., 2016; TRANSDOTT, 2012, 2014a).

In the final year of the project, improved broodstock management and egg collection resulted in the collection of over 40 million eggs. Furthermore, the project found a strong relation between larval survival, the taurine content of the feed and retinal development, as well as a strong correlation between the salinity of the culture water and survival. The project also gained a better understanding of the digestibility and required ingredients of artificial feeds for the larval and nursery stage (TRANSDOTT, 2014a).

Despite these major findings, the TRANSDOTT project produced only a limited number of fry (DAH 30) in the main hatchery in Malta: 820 fingerlings in 2013 and 1,300 in 2014. Due to
limitations in the facilities (the hatchery in Malta is rather small), and due to the limited availability of YSL the production capability was limited, but very promising improvements were seen over the years (Vassallo pers. comment, 2017).

Although one of the main goals of the TRANSDOTT project was to commercialize the hatchery production of ABT, with the above mentioned production numbers and current survival rates, fluctuating between 0 to 0.44% at DAH 30 (TRANSDOTT, 2014a), the conclusion is that several serious challenges continue to inhibit the production of ABT fingerlings in commercial quantities. As the project stated “Sustainable aquaculture of Atlantic Bluefin Tuna is at the threshold of becoming as successful as the Japanese industry for the Pacific Bluefin Tuna”, but we are not yet there in full.

Building on and as part of these publicly funded research initiatives, a number of public and private hatcheries and research initiatives for ABT are operational or have been underway in Spain, Malta, Croatia, Italy, Greece, Egypt, Israel and Turkey (Benetti et al., 2016). The next chapter will briefly discuss each of these projects.

Figure 16. One of the Atlantic Bluefin Tuna fingerlings produced in a Turkish hatchery that participated in the TRANSDOTT project. This fingerling is 35 days old and weighs 8 gram (TRANSDOTT, 2014).
3.2 Involved Institutes and Public Research Centres

**Instituto Español de Oceanografía (IEO)**

The IEO is a publicly funded research institute as part of the Ministry of Science and Technology, Spain. The institute operates a hatchery facility in Mazarron that has played a leading role since the early development of ABT aquaculture through the REPRODOTT and SELFDOTT projects (Miyake *et al.*, 2003; Mylonas *et al.*, 2010). Although the institute is not directly involved in the TRANSDOTT project, it did receive eggs from the breeders based in Malta (TRANSDOTT, 2014b).

The institute remains at the forefront of pioneering the hatchery production of ABT and has made considerable progress in commercializing the larval rearing and grow-out protocols of ABT. In 2014, the institute was able to produce over 5,000 fingerlings from the eggs it received from the TRANSDOTT project (TRANSDOTT, 2014b) and by 2015 the institute produced over 15,000 fingerlings. These fingerlings were transferred to floating cages at sea for further grow-out experiments. As shown in figure 17 below, the weight of juvenile ABT in cages increased from 10 gram to 1.2 Kilogram in about 120 days only (IEO / de la Gandara, 2014). Production photographs from IEO are presented on the next page.

---

**Figure 17.** Approximate growth rates of juvenile Atlantic Bluefin Tuna (DAH 30 - 120) in cages at IEO in 2014 (EFARO, 2014).
Figure 18: Growth rates of juvenile Atlantic Bluefin Tuna obtained in cages at IEO

Top left: 43 days after hatching, around 8 gram
Top right: 84 days after hatching, 144 gram
Middle left: 125 days after hatching, 1.2 Kilogram
Middle right: 395 days after hatching, 4 Kilogram
Bottom left: 2.5 years after hatching, 17 Kilogram
Bottom right: 4 years after hatching, 60 Kilogram

All pictures by IEO / de la Gandara 2013 - 2016
IEO has documented impressive growth rates over an extended period. The institute managed to grow some of their hatchery produced ABT fingerlings to 60 Kilogram in 4 years’ time (figure 19), which again shows the potential of the closed cycle aquaculture of ABT. These fish now serve as the first captive born generation of broodstock, thereby for the first time fully closing the life cycle of ABT in captivity (pers. comment de la Gandara, 2017).

**Figure 19.** Approximate growth rates of juvenile Atlantic Bluefin Tuna (0 – 4 Years) in cages at IEO (EFARO, 2014).

Recently IEO has been involved in a number of projects that are related to the hatchery production of ABT (IEO / de la Gandara, 2014). The MALT project is contract research for feed manufacturer Skretting ARC and involves fishing company Caladeros del Mediterráneo and the Technical University of Cartagena (UPCT) The project focuses on advancing the knowledge on the nutritional requirements of ABT larvae and fingerlings and was just concluded by the of 2016. The TCAR project involves Caladeros del Mediterráneo and UPCT and focuses on advancing the knowledge on ABT larval rearing, fingerling transport and grow-out. Finally, the ATAME project in collaboration with UCA, AZTI and others, focuses on several aspects of the biology and ecophysiology of ABT eggs and larvae under controlled conditions (IEO / de la Gandara, 2014). Additionally the institute just initiated a new research initiative with a private company based in Alicante, Spain, to work on improving the nutritional benefits of larval diets by developing improved enrichments products and by using copepods for partial feeding. Two other new EU funded projects include the Climate change and European Aquatic Resources (CERES) projects in which IEO works together with a number of partners including Kılıç Seafood Co. to investigate the potential impacts of climate change on ABT, and the AquaExcel2020 project in which scientists from around Europe can work on tuna related research projects using the facilities and infrastructure of IEO.
Other Publicly Funded Institutes and Research Centres

Other publicly funded research institutes that have been actively working on the hatchery production of ABT in Europe include:

I. The Heinrich-Heine University in Germany, which is engaged in several projects concerning ABT, including the SELFDOTT and TRANSDOTT projects. The university also financed a private spinoff named TunaTech that will be discussed in the next chapter;

II. The Institute Français de Recherche pour l'Exploitation de la Mer (IFREMER), a large French research institute that works on a large variety of projects including fishery and aquaculture related project. The institute has been involved in several ABT hatchery related projects including the SELFDOTT project. Currently the institute is not engaged in any ABT aquaculture related research activities;

III. The Hellenic Center for Marine Research (HCMR), which is a Greek institute focused on marine research and participated in the SELFDOTT project;

IV. The National Centre for Mariculture (IOLR - NCM) in Israel, which is working on a number of pioneering aquaculture projects and also participated in the SELFDOTT and TRANSDOTT projects;

V. The Malta Aquaculture Research Centre (MARC) in Malta, which is focused on aquaculture research including tuna, and has participated in the SELFDOTT and TRANSDOTT projects. Currently this institute is not engaged in any ABT aquaculture related research activities as well.
3.2 Main Private Companies and Initiatives

Limited data is available on the different private companies and initiatives that focus on the hatchery production of ABT. Many of these companies do not release progress reports or production figures, nevertheless an overview of these projects and their progress is provided in this chapter.

**Futuna Blue España S.L. (Spain)**

The Futuna Blue España S.L. hatchery is a subsidiary of Danish Futuna Blue ApS, with Australian, American, Danish and Spanish shareholders (FIS, 2016). The company was founded in 2007 and has constructed one of the largest privately owned marine finfish hatcheries in Europe (Futuna Blue, 2016). The hatchery is based in Cadiz, Spain, and mainly produces Amberjack and Sole, while experimenting with the culture of ABT. The company has some state of the art facilities including four very large tanks for the production of copepods. Futuna Blue was a partner in the TRANSDOTT project and had, besides Killiç Seafood Co., the best hatchery results within the project as shown in figure 20 (TRANSDOTT, 2014a). Unofficial updates suggest that no ABT have been produced in 2016.

**Fortuna Mare AS (Spain)**

Fortuna Mare, originally a Norwegian company with ties to the Ricardo Fuentes E Hijos S.A. group, has been working for over a decade in collaboration with IEO and research company SINTEF in Norway to further develop the aquaculture of ABT. The company first focused on supporting the hatchery activities of IEO, while simultaneously working on grow-out
operations of fingerlings produced through these joint efforts. The company has been farming hatchery produced ABT since 2011, and has started selling the first ABT products from closed cycle aquaculture since the end of 2015 (Villegas, 2014). Additionally, the company has contracted SINTEF to further develop a rearing protocol that would allow for production of ABT fingerlings in commercial quantities. By the end of 2015 the company was in the process of developing its own hatchery facilities (Villegas, 2014) to further expand production. Surprisingly, by early 2017 the company reported a loss of 4 million Euro due to transfer mortalities from the hatchery to the cages and it is unclear if the company will continue with its efforts (Intrafish, 2017). Additionally, the company ended its collaboration with IEO by the end of 2016 (de la Gandara pers. comment, 2017).

Kiliç Seafood Co. (Turkey)
Kiliç Seafood Co. is a large Turkish seafood company that produces a variety of seafood from both fishery and aquaculture activities. The company owns four hatcheries for assorted marine finfish, and began developing its ABT farming and hatchery capacity in early 2014 (Undercurrent News, 2015). According to the companies’ own records (Hatchery International, 2015a), production took off quickly and they successfully produced 14,000 ABT fingerlings in 2014 and 28,000 fingerlings in 2015. The company is planning its first sales of farmed ABT to Japan in 2016 (Undercurrent News, 2015). Kiliç Seafood Co. also received eggs from the TRANSDOTT project from which it was able to produce thousands of fingerlings (TRANSDOTT, 2014b). However in 2016, the company released a statement that despite the successes it was not sure if it would continue its hatchery efforts, since the company was unsure it is financially viable at this stage (Seaman, 2016), and eventually the company decided for the moment to not continue producing ABT.

TunaTech GmbH (Germany / Egypt)
TunaTech is a spinoff company from the Heinrich-Heine-University of Düsseldorf, one of the partners in the TRANSDOTT project. The company was founded 10 years ago and its goal is to contribute to a sustainable and eco-friendly aquaculture for the future (TunaTech, 2016). Initially, the company focused on providing advice on a variety of topics including ABT spawning induction, tagging and sampling, diagnostics (TRANSDOTT, 2012) and the development of artificial feeds for the ABT farming sector. Recently however, the company released plans (Hatchery International, 2015b) for the development of a hatchery for ABT in Egypt. The company has an impressive 40 Million Euro budget for this endeavour and preliminary construction activities begun in 2016. No official updates on this development have been made available in 2017, but it seems construction has temporarily halted.
Besides these larger companies and initiatives, several other private initiatives have been recently concluded or are underway, including hatchery efforts by:

- Royalthon SA., in Leros, Greece, which produced over 1,500 ABT fingerlings in their first operational year in 2015. However, production has ceased for 2016;
- SINTEF Fisheries and Aquaculture is the largest independent research company in Norway and carries out hatchery experiments on ABT on behalf of seafood company Fortuna Mare but now that Fortuna Mare has halted most activities in Spain it is unclear how the research will proceed;
- Panittica Pugliese SpA in Italy, which is a seafood company that operates a marine fin fish hatchery in Italy and has been involved in the REPRODOTT and ALLOTUNA projects;
- Tuna Graso which is a subsidiary of Grupo Ricardo Fuentes e Hijos, a Spanish seafood company based in close proximity of IEO. The company has been working on farming hatchery reared ABT from IEO in collaboration with Fortuna Mare and has a number of cages with broodstock as well. It seems these activities have been halted since the end of 2016 as well (de la Gandara pers. comment 2016);
- Umami Sustainable Seafood in Croatia, which for now is focusing on ABT broodstock collection and management;
- MFF Ltd. in Malta, which maintains a number of breeders but is not engaged in any hatchery activities;
- ARDAG Red Sea Mariculture Ltd., located as the name suggests, near the Red Sea in Israel, and working on the commercial production of a number of marine finfish including ABT.
3.3 Summarized Production Efforts

The map in figure 21 shows the approximate locations of the different public and private hatchery initiatives around the Mediterranean region that are operational, underway or have ended. This includes a number of projects that only focus part-time on the hatchery production of ABT through international collaborations such as the SELFDOTT and TRANS DOT T projects.

Figure 21. The approximate locations of various public (marked in blue) and private (marked in back) projects around the Mediterranean Sea that focus on the hatchery production of Atlantic Bluefin Tuna.

Since most private hatcheries are hesitant to release their production figures, it is hard to estimate the total annual production of ABT fingerlings in hatcheries around the Mediterranean region. Nevertheless, in table 3 and figure 20, an effort has been made to summarize some production figures from 2012 to 2016 from publicly available reference material. Please note that these production figures are rough estimates only.

Table 3. Estimated production figures of Atlantic Bluefin Tuna fingerlings of different hatchery initiatives around the Mediterranean region (2011 - 2016). Please note that these figures are rough estimates only.

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Futuna Blue España S.L.</td>
<td>Private company</td>
<td>Spain</td>
<td>0</td>
<td>200</td>
<td>1.000</td>
<td>1.300</td>
<td>4.000</td>
<td>0</td>
</tr>
<tr>
<td>Instituto Español de Oceanografía</td>
<td>Governmental Institute</td>
<td>Spain</td>
<td>0</td>
<td>1.000</td>
<td>5.000</td>
<td>10.000</td>
<td>15.000</td>
<td>4.000</td>
</tr>
<tr>
<td>Royalthon SA</td>
<td>Private company</td>
<td>Greece</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>1.500</td>
<td>0</td>
</tr>
<tr>
<td>Kiliç Seafood Co.</td>
<td>Private company</td>
<td>Turkey</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>14.000</td>
<td>27.000</td>
<td>0</td>
</tr>
<tr>
<td><strong>Total annual production (#):</strong></td>
<td></td>
<td></td>
<td>0</td>
<td>1.200</td>
<td>6.000</td>
<td>25.300</td>
<td>47.500</td>
<td>4.000</td>
</tr>
</tbody>
</table>
Figure 22. Estimated production figures of Atlantic Bluefin Tuna fingerlings from different public and private hatchery initiatives around the Mediterranean region (2011 - 2016) including the total estimated annual production (TRANSDOTT 2013, 2014; Undercurrent News 2015, 2016, Bridges pers. comment 2017).

As seen in Figure 22, the successful EU funded research projects SELFDOTT and TRANSDOTT (2009 - 2014) initially seem to have spurred the number of hatcheries engaged in the production of ABT and their production figures. However, since the last of these projects completed early 2015 and funding has halted, the majority of the public and private initiatives that have remained seem to be halting production or slowing down their production activities, Except for IEO, after 2015 all hatcheries including, Futuna Blue España S.L., Royalton SA and Kiliç Seafood Co. halted their production efforts.
CHAPTER 4: CURRENT PRODUCTION CHALLENGES IN EUROPEAN HATCHERIES AND POTENTIAL SOLUTIONS

As previously discussed, across the Mediterranean region substantial progress has been made in the development of closed cycle aquaculture activities for ABT. Regularly spawning breeders have been developed and basic larval rearing protocols, that allow for the production of some fingerlings, have become available (Benetti et al., 2014; Partridge, 2009; Sawada et al., 2005). Despite this progress in broodstock management and larval rearing, a number of challenges continue to constrain the hatchery production of ABT fingerlings in commercial quantities. This chapter provides an overview of these remaining challenges and presents a number of recommendations to address these.

4.1 Stable Availability of Quality Eggs

To ensure the production of ABT fingerlings in commercial quantities it is important to have a more stable production of high quality eggs. Moreover, due to the low survival rate of tuna larvae, comparatively a large number of eggs are required to allow for the production of commercial quantities of fingerlings. Figure 23 shows the relationship between the quantity of available eggs of PBT in Japan and the number of fingerlings produced by local hatcheries. By 2011, Japan had approximately 1 billion eggs available annually, with which it’s hatcheries were able to produce approximately 200,000 fingerlings (Benetti et al., 2016).

In comparison, the TRANSDOTT project in Europe, which provides eggs to most of the hatcheries around the Mediterranean region working on ABT, was able to produce 40 million eggs in 2013 (TRANSDOTT, 2014a) and, produced a few thousand fingerlings. An increased survival rate would somewhat reduce the required volume of eggs, but some intrinsic characteristics of tuna larvae and fingerlings like their cannibalistic nature and their high sensitivity, affirm a future dependence on large volumes of eggs. Thus, if hatcheries around the Mediterranean region wants to produce commercial quantities of ABT fingerlings, substantial larger volumes of eggs need to be produced.
Relationship between the Available Volume of Eggs and Fingerling Production of Pacific Bluefin Tuna in Japan (2003 - 2011)

Figure 23. The relationship between the available number of tuna eggs (orange) and the production of fingerlings (blue) in Japan between 1994 to 2011 as per Benetti et al., (2016).

Current Situation
Most ABT broodstock in Europe are kept in floating cages at sea and through the development of hormonal implants seasonal spawning in mostly under control (EU, 2011; De Metrio et al., 2010; Reglero et al., 2013; TRANSDOTT, 2014b). However, the spawning season in these cages remains very short at about 2 months per year (EFARO, 2014) and this limited seasonal availability of eggs makes it hard to plan a consistent commercial production of fingerlings (de la Gándara et al., 2016). Since part of the year sea temperatures are too low to stock fingerlings in the Mediterranean Sea, this does not necessarily mean that year-round spawning is required, but more control then at present is desirable.

An additional problem with the use of these floating cages is that the collection of eggs is often difficult, resulting in a substantial loss of eggs (TRANSDOTT, 2014a). Furthermore in this open cage environment, eggs are frequently contaminated with eggs from other species, resulting in additional difficulties during the larval rearing process (EFARO, 2014). Besides the bottleneck in the volume of available eggs and the limited seasonality of this availability, there are also some remaining quality issues (TRANSDOTT, 2014a), with hatching rates and larval survival during the first few days after hatching not always being stable (Koven et al., 2016; de la Gándara et al., 2016).
Broodstock Tanks
By controlling environmental factors that regulate egg maturation and spawning, such as temperature, light intensity and day length, more control over the continuity and quantity of egg production can be gained (Masuma et al., 2011). It is very hard to control these factors in cages at sea; however, by using land based broodstock tanks more control can be gained. Also by using broodstock tanks, the issue of egg collection during wavy seasons will become a worry of the past. In addition, eggs will no longer be contaminated with eggs from other species (TRANSDOTT, 2014a).

The use of broodstock tanks has already been tested with YFT in both Panama and Indonesia, where they were kept in tanks of between 1.000 to 1.300 m³. After initial acclimatization and reaching maturity, the broodstock spawned for several years on an almost daily basis (Hutapea & Permana, 2009; Uillén et al., 2014). Experiments with SBT in Australia show similar results with over 100 spawning events recorded in 2009 in a single 3.000 m³ broodstock tank (see figure 22), however in other years numbers were much lower and went almost down to zero (Chen et al., 2016). These results show the enormous potential of broodstock tanks to increase the stable availability of ABT eggs. However, further research is needed to optimize results as several concerns have been reported.

These concerns include breeders hitting the walls of tanks and dying as a result (Chen et al., 2016; Hutapea & Permana, 2009). In most of these cases, breeders seem to collide with the tank wall during evasive swimming behaviour in reaction to environmental stressors (Hutapea & Permana, 2009). To avoid the majority of these wall collisions, a number of measures can
be taken into consideration. The tank walls should be painted with a vertical striped pattern to make it easier for the breeders to identify the walls (Benetti et al., 2014; TRANSDOTT, 2014a). Additionally, the parameters of the tank environment and its surroundings should be constant and without sudden changes (Masuma et al., 2011). As such, staff presence should be limited to avoid any disturbances. Light intensity should only change gradually and the lighting system should have an Uninterruptable Power Supply (UPS) backing it up. Also loud sounds, especially low vibrating sounds (Partridge et al., 2013) created by drilling devices and generators should be avoided at all times as to ensure no sudden stress reaction and evasive swimming behaviour of the breeders.

**Floating Cages**

Despite the numerous advantages of broodstock tanks, most hatcheries will never become solely reliant on breeders contained in broodstock tanks, because the construction of these tanks requires a substantial investment. Also, breeders tend to become unproductive after being kept for longer periods in a tank environment (Chen et al., 2016; Hutapea & Permana, 2009). Large floating cages seem to provide a more natural environment with natural annual and monthly cycles of environmental parameters (light intensity, temperature, water movement etc.) and abundant wild prey items; this gives the breeders the opportunity to revitalize. Therefore, it is advised to use several groups of breeders, one or two groups in tanks, while the remainder can be maintained in cages. Once a group of breeders in the broodstock tank becomes less productive, a fresh group from the cages can replace the whole group, while the tired breeders can revitalize themselves in the cages.

For those hatcheries that continue to operate floating cages, for some or for all of their breeders, a number of measures can be taken to improve egg production and egg collection. Since the maturity rate of ABT in captivity remains low (Masuma et al., 2008) everything should be done that could improve the percentage of spawning breeders and thus the amount of eggs available to the hatchery. It is foremost recommended to take time to select a suitable location for the cages that contain the breeders (Masuma et al., 2011). Make sure the area has stable currents and water temperatures of at least 22°C during the spawning season (TRANSDOTT, 2014a), but warmer waters, up to 27°C, may be better to stimulate gonadal development (TRANSDOTT, 2012). Additionally select a quiet site (Tsuda et al., 2012), with little traffic from vessels and other potentially disturbing activities (so not too close to fattening operations) with excellent water quality and that is rich in natural feed items.

Last, when maintaining breeders, egg quality and general health of the stock can be improved by using high quality diets of fresh fish in combination with at least 50% squid, this increases gonadal development (Estess et al., 2014; Margulies et al., 2007; TRANSDOTT, 2014a).

**Improved Egg Collection Methods**

To improve egg collection in large cages at sea, a very efficient trawl net setup has recently been designed by Korean researchers (TRANSDOTT, 2012). Furthermore, it is advised to place
cages in areas with a stable current that does not change too much in direction, and which is not too strong. A flowrate of 10 cm/second on the surface inside the cage is reported to work best (TRANSDOTT, 2014a). Since numerous rearing problems have been encountered due to contamination issues with eggs of other species, it is advised to only activate the egg collection net during spawning hours of ABT (midnight to 3 AM) and to immediately collect the eggs after most spawning activities have ceased. This simple measure will prevent contamination and improve egg quality, since eggs are moved to the hatchery before they start developing.

It should also be considered to sterilize the eggs immediately after collection using a peroxycetic acid solution or ozone. This practice seems to be not commonly used in Mediterranean hatcheries working on ABT, but it is known to kill external pathogens, parasites, and carnivorous copepods that might be transferred from the breeders to the eggs and from the cage water to the eggs.

**Surrogate Breeders**

To overcome the obstacles of large breeders that mature at a late age, that need costly broodstock tanks, very large amounts of feed and that are often difficult to spawn, the Japanese have been developing a technique wherein mackerel species (Benetti et al., 2016) and Eastern little tuna (Yazawa et al., 2015) are used as a surrogate broodstock. By using spermatogonial transplantation, these surrogate breeders are able to produce PBT gametes. If further developed, this technique could significantly decrease the costs of maintaining broodstock.
4.2 Floating Death (DAH 1 - 4)

The early stage floating mortality (DAH 1 - 4) observed in ABT larvae continues to be a significant cause of mortality during the larval rearing process (Benetti et al., 2016; Matsuura et al., 2010). This issue is associated with the first inflation of the swim bladder, which allows the larvae to control buoyancy and their position in the water column (Kurata et al., 2011). During the first days after hatching, larvae gather at the surface to gulp air to inflate their swim bladder. However, due to a high surface tension they can become trapped between the interface of the water and air, resulting in significant mortality (Buentello et al., 2016).

Oily Emulsions

The problem of early floating deaths has been partly solved, by using oily emulsions during the first days after hatching to reduce the surface tension (Chen, 2011; Ellis & Kiessling, 2016; Kaji et al., 2003), and by improving egg quality to create stronger larvae that will less likely be trapped at the surface (Buentello et al., 2016). However, some mortality continues to prevail as adding an oily emulsion to the surface inhibits the larvae from contacting the air directly, which in turn results in a delayed inflation of the swim bladder, or even in the prevention of inflation (Nakagawa et al., 2011). This delay in swim bladder inflation results in weaker larvae and thus increased mortality at later stages of the larval rearing process (Kurata et al., 2011).

Surface Skimmers

A different approach to decrease the surface tension in larval rearing tanks is the use of surface skimmers. These skimmers clean the surface of the culture water of debris and of any oil film on the surface, so that larvae can access the air (at specific time intervals) without obstruction. Although it seems that the use of surface skimmers improves the rate of swim bladder inflation in the larvae, it most likely also causes increased mortality of a different source; since oily emulsions cannot be used to remove the surface tension, the surface tension becomes higher and again more larvae get trapped (Kurata et al., 2011).

Hereby it should be noted that there is a temperature dependent time window for the initial swimming bladder inflation (Kurata et al., 2011), which depending on the temperature of the culture water ranges from DAH 2 to DAH 7. During this inflation window of around 24 hours, the surface skimmers need to be activated. Additionally, new research by Kurata et al. (2015), shows that larvae are mainly triggered to gulp air between 16:00 to 19:00 hours during the inflation window (when light intensity is reduced) and activating the surface skimmers during these hours ensures a high inflation rate (> 80 percent). Consequently, surface skimmers need to only be activated during these hours, while oily emulsions can be added before and after this period, thereby taking advantage of both methods to increase survival.
Green Water Techniques
Another option to reduce the surface tension is the use of green water techniques, in which a predetermined density of live algae is maintained in the larval rearing tanks (Partridge et al., 2013). Although many European hatchery experiments for tuna started with clear water techniques, green water techniques are very popular in the culture of marine finfish in Asia and adding a regular dosage of live assorted algae species to the larval rearing tank holds many advantages. First of all, it results in a healthier and more stable culture environment with improved water quality (Tendencia et al., 2015). These algae also serve as food for the live prey population (rotifer, copepods etc.) that are maintained in the larval rearing tanks, thus ensuring the nutritional value of these prey items, which in turn improves larval growth and overall survival (van der Meeren et al., 2007). By maintaining a lower water transparency, cannibalism at the earlier larval stages (DAH 10 - DAH 20) is reduced and feeding rates are improved through the increased contrast between the prey items and the culture water (Partridge, 2009). In addition, these live algae reduce the surface tension in a natural low cost way, without the need for artificial additives or high-tech equipment (Partridge et al., 2013).

Increased Aeration
A last simple method to further reduce surface tension is to increase aeration. However increasing aeration is known to cause mortality at night when larvae are resting (Kurata et al., 2011). This in turn can be countered by providing 24 hour lighting during the first few days (Partridge et al., 2011), which will ensure that the larvae remain active and are not caught up in the aeration. An additional important benefit is that night-time lighting also gives the larvae more time for feeding, resulting in stronger larvae and reduced mortality in the first few days of the larval rearing process. Hereby it should be noted that the required aeration flowrates are species specific (Ellis & Kiessling, 2016) and for PBT at this age a velocity of 900 ml min \(^{-1}\) has been deemed appropriate (Nakagawa et al., 2011).

Concluding, to decrease surface mortality in the first days after hatching, a combination of green water culture with medium aeration, 24-hour lighting, active surface skimmers between 16:00 - 19:00 hours and if needed the adding of some oily emulsion in between, is the best approach to increase airbladder inflation rates, while improving growth rates and overall health of the larvae.
4.3 Sinking Death (DAH 5 - 10)

A second buoyancy issue is the occurrence of sinking deaths that mainly occur at night between DAH 5 to 10 (Allan et al., 2009; Nakagawa et al., 2011). Sinking mortality has been recorded for different marine finfish larvae and is primarily caused by the fact that larvae are less active at night during the absence of light (Takashi et al., 2006), and since their density is higher than that of seawater, the larvae start sinking as a result (Masuma et al., 2011). In their natural environment this sinking behaviour is not an issue, since the larvae are not likely to hit the seafloor, but in shallow larval rearing tanks (1 - 2 meter water depth), the larvae will hit the tank bottom. When doing so, the larvae damage their fins and skeleton and they come into contact with bottom dirt and the high bacterial load this dirt contains, eventually resulting in significant mortality (Kurata et al., 2014; Masuma et al., 2011).

Sinking deaths are also partly attributed to weakened larvae which experienced delayed swim bladder issues (DAH 2 - 5) as larvae with a well inflated swim bladder sink less quickly than larvae that have not inflated their bladder properly (Kurata et al., 2011; Nakagawa et al., 2011). Thus, by implementing the measures mentioned to prevent floating death, the occurrence of sinking death is also reduced.

**Increased Aeration at Night**

The easiest way to further reduce the amount of sinking deaths is by increasing the aeration at night so that upwelling currents prevent the larvae from sinking (Kurata et al., 2011), again a velocity of at least 900 ml min$^{-1}$ has been deemed appropriate (Nakagawa et al., 2011).

**Upwelling Devices**

This can be taken a step further by installing an upwelling pumping system that continuously ensures that upward currents dominate the larval rearing tank shown in figure 34 on page 62. A number of trials have shown that an upwelling system can increase survival at DAH 10 by fivefold (Masuma et al., 2011).
4.4 Other Causes of Mortality during the Early Larval Stage (DAH 5 - DAH 15)

Other remaining causes of mortality in ABT larvae are often less clearly understood and, as a result, have been less investigated. In recent years however more research has been conducted on the relationship between general nutritional requirements and salinity on the survival of ABT larvae and juveniles, with some very interesting and conclusive results (Allan et al., 2009; Ottolenghi, 2008; TRANSDOTT, 2012, 2014a).

The need for Copepods
Gut analysis of wild PBT larvae shows that they almost solely feed on copepods and, more specifically, larvae seem to have a strong preference for copepods of the genus Corycaeus and to a lesser extent of the genus Clausocalanus (Uotani et al., 1990), including a preference for specific size classes (Lopiz et al., 2015). ABT larvae in the Gulf of Mexico and western Mediterranean Sea also showed large amounts of Larvacea (Class: Appendicularians), which are small free swimming tunicates, and other fish larvae in their gut content (Laiz-Carrion et al., 2015; Lopiz et al., 2015).

Copepods are, unlike rotifers, able to synthesize highly unsaturated fatty acids from the algae they consume (Kraul, 2006). These fatty acids are very important in ensuring healthy development of the ABT larvae and thus by feeding mainly on copepods, larvae have the ability to meet their nutritional requirements (Kotani, 2008; TRANSDOTT, 2012). Larvacea however are not particularly rich in fatty acids and it has been suggested that tuna larvae only consume these when preferred feed items like copepods, are not present in sufficient amounts (Laiz-Carrion et al., 2015; Lopiz et al., 2015).

It has been known for many years that general nutritional deficiencies are inhibiting the survival of ABT larvae during the larval rearing stage. The survival rate in hatcheries is strongly influenced by the availability of live feeds with high protein levels and high levels of unsaturated fatty acids, especially DHA and EPA (Biswas et al., 2006; Kinky University, 2009). While this evidence confirms the major importance of copepods as a main feed item in the culture of tuna larvae, practical considerations have made it impossible for most hatcheries to use large quantities of copepods as feed. Copepods are relatively difficult to culture (de la Gándara et al., 2016) and require more labour and other inputs compared to the culture of rotifer (Kraul, 2006) and therefore most hatcheries have opted to the use the latter instead.

Since rotifer are not able to synthesize fatty acids, they can be artificially enriched by feeding rotifer with feeds that are rich in fatty acids (Hagiwara et al., 2007; Kraul, 2006). Since rotifer are not natural feed items of ABT larvae and since they do not seem to trigger a feeding response in most ABT larvae survival of larvae is low (Partridge et al., 2013). However not all experts seem to agree on this. Furthermore, once rotifer pass their enriched gut content, they lose their nutritional value again.
Experiments with the copepod *Acartia tonsa* at Futuna Blue and at SINTEF in Norway have shown a big increase in survival, increased growth rates and a big reduction in deformities in ABT fed with copepods compared to those fed on diets of rotifer and artemia only (Aquafeed LLC, 2014; Zohar *et al.*, 2016). Thus in order to have a realistic chance of producing commercial quantities of ABT fingerlings hatchery operations will need to prioritize the mass production of copepods at their facilities.

Futuna Blue in Spain, has understood the vital importance of copepod culture in relation to larval rearing success, and their hatchery in Spain is supported by 4 massive 3.200 m$^3$ copepods culture tanks (Partridge *et al.*, 2013) in which a patented culture process is employed. Similarly, SINTEF in Norway, has created a commercial spinoff company named C-Feeds AS, that focuses on the development of copepod production systems and the sales of copepod to hatchery clients (Hatchery International, 2014). The company is already producing one copepod species (*Acartia tonsa*) in commercial quantities and these can be bought live or as eggs as shown in figure 26 (C-FEED, 2016). Additionally, AlgaGen LLC, a company based in Florida, the United States, is working on a similar initiative and they are already producing an impressive 6 species of copepods in commercial quantities, which are sold live and as eggs (AlgaGen, 2016). However, with the very high daily energetic demands of ABT larvae and fry, it will be inevitable to use Yolk sack larvae (YSL) of other fish species as partial feed (Minkoff pers. comment 2017).

![Image of copepod culture process](image_url)

**Figure 26.** C-Feed product line of copepod pods for hatcheries.
Densities and Enrichments
To prevent nutritional deficiencies and to promote the healthy development of larvae, it is recommended to maintain a high population of prey items in the larval tank ( Margulies et al., 2016 ). Furthermore, feeding should consist of at least a mixture of half rotifer, half copepods whereby it is best to keep the copepod density in the tank at medium to high levels while keeping rotifer population in a lower range. Rotifer should be enriched using commercial or home-made enrichments with a preferred DHA/EPA ratio of 3:1 ( Chen, 2011 ). Additionally, it would help to maintain a certain minimum algae density in the larval rearing tank, of nutritious species like Chlorella that are high in fatty acids and that will help in maintaining the nutritious value of both rotifer and copepods. If copepods are not available in sufficient densities, it is advised to maintain a higher rotifer density in the larval rearing tank ( Margulies et al., 2016 ).

The importance of Prey Size
Tuna larvae have a relatively small head and mouth opening just after hatching ( Uotani et al., 1990 ). As shown in figure 27 , the relative width of the mouth opening is very small after hatching and increases significantly in the first 6 days after hatching, this has a big impact on feeding behaviour. Analysis of the gut content of wild PBT larvae shows that larvae smaller than 5 mm tend to only feed on copepod nauplii of less than 0.3 mm in length, while larger larvae feed only on larger sized copepods only ( Uotani et al., 1990 ). Adult rotifer and copepods are thus too large to pass through the small mouth opening of first feeding tuna larvae and therefore it is important to only use nauplii during first feeding. This can be done by using a 50 – 100 micron sieve to sort larger rotifer and copepods from the smaller nauplii. Feeding protocols need to be adjusted accordingly.

![Relative Mouth Size in relation to Total Length in Larvae of Pacific Bluefin Tuna (3 to 14 mm)](image)

Figure 27. The relationship between the total length (mm) in larvae of Pacific Bluefin Tuna larvae and the length of the head (H), mouth size (d) and body length (D) as per Uotani et al. (1990).
Hatcheries should consider culturing smaller strains of rotifer and smaller copepods species for first feeding, it is also advised to maximise the presence of small nauplii in the larval rearing tank by feeding smaller amounts of feeds, multiple times a day. Co-feeding with small ciliates might improve survival during the first days after hatching as well (TRANSDOTT, 2014a).

**Taurine Levels in Enrichments**
Recent experiments by the TRANSDOTT project have shown a strong correlation between taurine levels in the enrichment media used for live feeds and overall survival of ABT larvae (TRANSDOTT, 2014a). Taurine seems to be very important in guaranteeing proper retinal development in ABT, which in turn is needed prevent other causes of mortality such as wall collisions. After several experiments it has been recommended that enrichment media for live feeds contain 400 mg taurine per litre of enrichment (TRANSDOTT, 2014a).

**Salinity**
Other recent experiments from the same team show that ABT larvae have a significant higher survival rate at a salinity of 40 ppt compared to larvae reared at 30 ppt (TRANSDOTT, 2014b). Although larvae in both experiments had the same growth rates and prey ingestion rates, those raised at lower salinities eventually died. This mortality is most likely attributed to osmoregulatory challenges. However, at 40 ppt the larvae developed large amounts of urinary calculi, which would suggest a very narrow salinity range for ABT larvae: most probably at 35 - 36 ppt.

This salinity range corresponds with several studies on the salinity preferences of wild ABT tuna larvae; who are mainly restricted to areas with a salinity of 35 - 36 ppt (TRANSDOTT, 2014b) and a maximum salinity of 38 ppt (Laiz-Carrion et al., 2015). Interestingly, despite the wide distribution of the eastern ABT stock, their range of spawning areas is very limited (figure 28). This would be additional evidence to support the hypothesis of a limited distribution range and salinity tolerance of wild ABT larvae.

![Figure 28](image_url). Spawning areas of the eastern ABT stock indicated in red (de la Gandara, 2014).
Concluding, in order to further improve the survival of ABT larvae during the first few weeks of the larval rearing period, it is advised to make use of copepods as a partial feed, to use enrichment products that are high in DHA, EPA and taurine, and to use a salinity of 35 - 36 ppt.

[Figure 29. A Calanoid copepod (*Corycaeus speciosus*), preferred live feed of PBT larvae (Slotwinski / CSIRO, 2011)]
4.3 Cannibalism

Another major cause of mortality that inhibits the production of ABT fingerlings in commercial quantities is cannibalism in both the larval and fingerling stage (Chen et al., 2016; Nakagawa et al., 2011; Sawada et al., 2005; TRANSDOTT, 2014a). Although most marine finfish only become cannibalistic during the later stages of their larval period, in tuna the problem starts much earlier at around DAH 10 (Sabate et al., 2010). In addition starting around DAH 20, the problem can become so severe that the survival rate is reduced by 50 percent within a few days, often because in many cases both fish involved in the act of cannibalism perish as well illustrated in figure 30 (Masuma et al., 2011).

With many marine finfish larvae, cannibalism is associated with aggressiveness and social hierarchy, but this is not the case with tuna (Sabate et al., 2010). Since tuna larvae have very high levels of growth hormones (Margulies et al., 2007) and correspondingly high growth rates of up to 30 to 50 percent per day, they need to consume large amounts of protein rich feeds to sustain their growth and health development (Partridge et al., 2013). In order to achieve sufficient protein intake, tuna larvae will consume other fish larvae and start cannibalising each other if other protein sources are not sufficient.

Figure 30. Top: An Atlantic Bluefin Tuna fingerling preying on a smaller relative during one of the experiments in the SELFDO TT project (de la Gandara, 2014). Bottom: Cannibalism in Bonito (Sarda sarda), that depicts the seriousness of cannibalism in tuna-like species.
Yolk Sack Larvae

Gut analysis of wild tuna larvae shows that fish larvae are part of the natural diet of ABT and other tunas (Laiz-Carrion et al., 2015). Some studies found no fish larvae in the gut (Uotani et al., 1990), while the results of other studies indicate that the consumption of fish larvae starts around DAH 5 and strongly increases after that (Lopiz et al., 2015). In the studies were fish larvae were found in the gut of ABT larvae, larvae of approximately 9 mm had in 71 percent of the instances other fish larvae in their gut (Lopiz et al., 2015), and this suggests that some fish larvae will need to be fed to ABT larvae in order to reduce cannibalism.

Using fish larvae of other species as live feed, and preferably fish larvae that still retain their yolk sac continues to be the most successful approach to produce healthy ABT fingerlings (Biswas et al., 2009; Gandara et al., 2013; TRANSDOTT, 2014a). As a result most hatcheries produce large volumes of yolk sack YSL of Gilthead Seabream (Sparus aurata), to feed live to their tuna larvae (Kinky University, 2009; De Metrio et al., 2010). However it is hard to produce sufficient numbers of these YSL on a year-round basis (Hutapea & Permana, 2009) thus other solutions are needed (Masuma et al., 2011; Reglero et al., 2013). Feeding minced fish or other live feed like artemia has been tried, but turned out to be not sufficient to produce strong and healthy fingerlings (Gandara et al., 2013; Tanaka et al., 2014).

Figure 31. Bonito feeding on a yolk sack larvae (left top) of seabream (SELFDO T 2012).
Copepods
In the studies reviewed for this report, the gut of tuna larvae often also contained *Larvacea*. It has been hypothesized that non-copepod feed items like *Larvacea*, and possibly other fish larvae, are only consumed when preferred feed items are not present in sufficient quantities (Laiz-Carrion *et al.*, 2015). Meaning that cannibalism could possibly be further reduced by feeding the larvae with sufficient copepods, and preferably copepods species that show a strong feeding response in the larvae (Laiz-Carrion *et al.*, 2015).

Although the use of copepods might further reduce cannibalism, it seems that without the use of at least a portion YSL as feed, the completion of the larval stage is very difficult (TRANSDOTT, 2014a). As long as no suitable alternative is found, like high protein artificial feeds that are accepted by the ABT larvae, hatcheries that want to produce ABT fingerlings in commercial quantities have no option but to factor in the production of sufficient YSL as live feed.

Artificial Feeds
In order to fully commercialize the hatchery production of ABT, efficient pellet feeds for the hatchery and nursery stage are a must (Masuma *et al.*, 2011) and numerous companies and projects are trying to achieve this. The TRANSDOTT project has been working in collaboration with Skretting ARC to test a newly developed artificial feed for ABT larvae and fry. Although the project was able to wean larvae successfully on this new diet, survival, and growth were much lower compared to ABT larvae that were fed with YSL. The project concluded that possibly the nutritional value and attractiveness of this particular pellet needs to be further improved (TRANSDOTT, 2014a).

Additionally, Sparos feeds, in collaboration with Futuna Blue España S.L. and other partners, has recently released their WIN FAST feed line for larvae (figure 32 below) and fingerlings of high value marine finfish including ABT (SPAROS, 2016). A similar feed produced for PBT larvae and fingerlings by Japanese Feed One has become recently available as well (Feed One, 2016).

![Sparos WIN FAST feedline](image-url)

**Figure 32.** WIN FAST feedline for fast growing marine finfish larvae and fingerlings, including Atlantic Bluefin Tuna, developed by SPAROS (SPAROS, 2016).
Sorting
In most marine finfish hatchery operations, cannibalism is further reduced by minimizing size differences through intensive sorting of the fry and fingerlings (García-Ortega et al., 2012; Yang et al., 2015). This has also proven to be efficient in reducing cannibalism in ABT fingerlings (Sabate et al., 2010). Yet it is a different situation with ABT larvae and fry (DAH 15 - DAH 30), which due to their sensitive nature tend to easily perish during sorting (Masuma et al., 2011).

Recent research however suggests that ABT larvae can be sorted starting DAH 20 - 30 by using anaesthetics (50 - 100 ppm of phenoxy-ethanol) and by using very soft sorting nets to minimize possible skin damage (Partridge et al., 2013). The advantages of sorting at this early age is that size differences can be reduced before the onset of severe cannibalism (DAH 25 - DAH 35). Additionally at this age the swimming speed of the larvae is still low, making sorting much easier (Sabate et al., 2010). More research is needed to see if this approach can be commercialized and it would for example be interesting to test more environmental friendly organic anaesthetics, like clove oil, that leave no residue in the fish tissue or in the aquatic environment (Javahery et al., 2012).

Other Factors
A few other important factors that can reduce cannibalism in ABT larvae, fry and fingerlings, includes the promotion of schooling behaviour, using green water techniques, adjusting the intensity of overhead lighting and using proper stocking densities, all of which are interlinked.

Promoting schooling behaviour is known to reduce cannibalism in a number of species including tuna (Sabate et al., 2010). In a natural setting, schooling behaviour in ABT should develop around DAH 25 (Sabate et al., 2010) and thus it is advised that hatchery operators stimulate this behaviour around this age. However, this is easier said than done; with other cannibalistic marine finfish, tank shape, light intensity, and stocking density are known to influence schooling behaviour in a tank environment and although this is not yet investigated, this is also most probably the case for tuna. It has already been proven that schooling behaviour in juvenile PBT is highly affected by retinal adaptation with changing light intensities (Torisawa et al., 2007): in lower and fluctuating light intensities schooling behaviour is decreased. Thus it is recommended to keep juvenile ABT at light intensities of at least 100 Lux but preferably under daylight conditions (2000 lux) whereby light intensity is stable throughout the day. More research is needed to determine the potential relationship between stocking density in the larval and juvenile stage and cannibalism, so that recommendations for stocking densities can be updated accordingly.

Concluding, cannibalism can be drastically reduced by a combination of measures; including guaranteeing the nutritional value of the diet by mainly feeding copepods and YSL. Once DAH 25 has passed, the fry can be slowly weaned on the artificial feeds from SPAROS or Feed One. Regular sorting is recommended, accompanied by the use of anaesthetics in the late larval
and fry stage, accompanied by the use of very soft nets. Lastly, it will help to stimulate schooling behaviour by keeping the fish at higher light intensities and by further adjusting the tank environment depending on the observed behaviour of the fish.

Figure 33. A larval rearing tank for Atlantic Bluefin Tuna employing green water techniques during the ALLOTUNA project (Caggiano et al., 2009)
### 4.4 Wall Collisions

After DAH 30, considerable mortality is caused during situations in which the fry, that have just completed their metamorphosis, collide into the tank wall (Chen et al., 2016; de la Gandara et al., 2013; Honryo et al., 2013; National Aquaculture Council of Australia, 2016). Honryo et al. (2013) found that these collisions often result in the dislocation of the vertebral column and fractures in the parasphenoid (figure 34), which results in the immediate death of the fry. In other cases these collisions first only result in skin abrasions that eventually cause bacterial infections and mortality at a later stage (Honryo et al., 2013; Partridge et al., 2013).

![Figure 34. Mortality in a juvenile Atlantic Bluefin Tuna caused by collision with the thank wall (de la Gandara, 2014).](image)

The underlying causes of these wall collisions have been less well investigated and are not fully understood (Honryo et al., 2013). As of now, the main causes seem to be twofold, whereby collisions in the late larval rearing stage are caused by different reasons (caused by incomplete development of neural and retinal systems) than wall collisions during the fingerling stage (the result of evasive swimming behaviour in response to stressors). Since major mortalities in the late stage of the rearing protocol are comparatively more costly to hatchery operators, more effort is needed to find viable solutions to overcome this obstacle.

**Incomplete Development of Neural and Retinal Systems**

The main reason for wall collisions in the late larval stage has been narrowed down to the incomplete development of neural and retinal systems, whereby the larvae lack the visual ability to avoid obstacles like tank walls (Partridge et al., 2013). It is likely that this problem will soon be overcome, since recent findings by the TRANSDOTT project showed a strong need for increased levels of taurine in feeds and enrichment products to safeguard proper retinal development (TRANSDOTT, 2014a). The use of large amounts of copepods, which contain healthy amounts of DHA and taurine, has also shown to be beneficial in preventing wall collisions related to incomplete retinal development (TRANSDOTT, 2012).
Stress Responses

Wall collisions in the fry and fingerling are mainly triggered by sudden environmental changes (Honryo et al., 2013; Masuma et al., 2011), including changes in light intensity, loud noises and the presence of other predatory larvae (from eggs contaminated at broodstock cages) that result in evasive swimming manoeuvres of the fish.

At this age the fry have just completed their metamorphosis and have a fully developed, very powerful, caudal fin for propulsion allowing them to quickly increase their swimming speed (Torisawa et al., 2007). However, their pectoral and abdominal fins, that serve as a breaking mechanisms (Partridge et al., 2013), are not yet fully developed at this age; causing the fry to crash into the tank wall when executing an evasive swimming response.

To prevent this from happening, a stable culture environment is recommended wherein the stress responses of juvenile ABT are not triggered. This would for example include the installation of a backup power system that will ensure no sudden changes in overhead lighting and limited access of staff (Masuma et al., 2011; Partridge et al., 2013). Also, the tank walls could best be painted with a vertical striped pattern or with dots to make it easier for the larvae and fingerlings to identify the tank walls (Benetti et al., 2014; Ishibashi et al., 2013; TRANSDOTT, 2014a). Additionally, it is recommended to employ some night light so that night-time wall collisions can be avoided, light intensities above 150 Lux are proven to reduce mortality considerably (Honryo et al., 2013; TRANSDOTT, 2012). Another novel but not very practical solution, is the use of plastic sheets along the tank wall that absorb the impact of the fingerling without damaging them (TRANSDOTT, 2012).
4.5 Transfer Mortality

The last main cause of mortality that still constrains the production of ABT in commercial quantities is the so-called transfer mortality, which is actually not a real hatchery issue. This type of mortality occurs right after fingerlings are transferred from the indoor hatchery to their grow-out environment in floating cages (Higuchi et al., 2014). In the early days, transfer mortalities reached over 80 percent within the first month of cage stocking (Benetti et al., 2016) and even today it is not uncommon to experience a 40 percent mortality rate within the first week after stocking (Honryo et al., 2013). According to many experts, including those in Japan, this is the largest remaining challenge for the sector.

Adjustment and Visual Thresholds

Although the reasons for transfer mortality are multiple, one of the main causes is the unfamiliarity of the fish with the new cage environment and fish accidently or on purpose try to swim into the nets and damage themselves badly in the process (Higuchi et al., 2014). As previously discussed, juvenile ABT seem to have a rather poorly developed scotopic visual threshold compared to other juvenile marine fish, and this makes it difficult for them to detect the exact locations of obstacles like cage nets, especially during lower light intensities at night, dusk and dawn (Ishibashi et al., 2009).

Research from Japan, using infrared cameras, indicated that fingerlings and juvenile tuna mainly swim against the cage nets at night, confirming the low scotopic visual threshold of ABT as a main cause of transfer mortality (Ishibashi et al., 2009). A night light (figure 35 on the next page) allows not only for the prevention of wall collisions in larval rearing tanks but also in grow-out cages (Ishibashi et al., 2009). In the experiments of Ishibashi et al. this resulted in an increase in survival from 12 percent to 73 percent in the first three weeks after stocking (Partridge et al., 2013). It is also recommended to stock fingerlings and larger seed stock only early morning so the tuna can get used to their new environment at daytime.

Stressors

Besides the problems with newly stocked ABT swimming against the nets because of their low visual threshold under lower light conditions, the change from a stable indoor hatchery environment to a floating cage where environmental variables vary greatly, also causes stress and additional transfer mortality (Tsuda et al., 2012). These stressors include, night-time flashlights from local fishermen and noises from passing vessels (Masuma et al., 2011). Also staff working at the cages should be taken into consideration as well as predatory fish, birds and potentially marine mammals outside the cages.

The presence of these stressors should be avoided whenever possible and proper site selection for the cages and strict company protocols are able to greatly assist in the matter. Additionally, since it seems juvenile fish are more easily stressed and more easily damaged, it should be considered to grow fingerlings to larger sizes in land-based facilities, with more
environmental control and less potential stressors. Experiments have already shown that hatchery bred fingerlings can be very successfully grown in outdoor tanks from ten gram to two Kilogram in four months only (TRANSDOTT, 2014b).

**Other Factors**

It is recommended to minimize the travel time before stocking and to transport the fingerlings in buckets with a plastic liner or foam, again to prevent wall collisions during transport (TRANSDOTT, 2014b). Hereby it could also be considered to only stock fingerlings during the warmer months of the year when seawater temperatures are optimal, resulting in less stress in the fingerlings. This would mean that production needs to be adjusted accordingly whereby again fingerlings would be grown to a larger size on land in a stable tank or pond environment before stocking them in cages at sea during the correct season.

![Nighttime cage lighting](image)

*Figure 35. Nighttime cage lighting is known to prevent fish from swimming into the nets (BGB Technology, 2017)*
4.6 An Updated Larval Rearing Protocol

Incorporating all these suggested improvements discussed in this report, the following updated summarized larval rearing protocol for ABT emerges as shown in figure 36 below. The tank setup as designed according to Masuma et al. (2011) and is shown in figure 37.

**Suggested tank design and setup:**
- Size: 10 - 20 ton
- Depth: 1.5 - 2 meter
- Rounded tank corners
- Colour: Yellow, light grey or light blue with striped vertical pattern
- Lighting: 2000 Lux at daytime + small nightlight (>150 lux)
- Upwelling system
- Point aeration system
- Increased aeration at night
- Salinity: 35-36 ppt
- Temperature: 23 – 27 °C

**Enrichment:**
- Always enrich live feed animals, especially rotifer
- DHA/EPA Ratio 3:1
- Taurine at 400mg/Litre

**Figure 36.** Suggested updated larval rearing protocol for ABT (DAH 1 - 33).
Figure 37. Aeration and surface skimmer setup in larval rearing tanks to prevent floating death in PBT larvae and to improve swimming bladder inflation as designed by Masuma et al. (2011). Top view shown in Figure 10A, side view of the setup shown in Figure 10B and the direction of the current visualized in Figure 10C. (Masuma et al., 2011)
CHAPTER 5: SUSTAINABLE TUNA AND MARKET PERCEPTIONS

5.1 Defining Sustainability
In recent years the sustainability of fishery and aquaculture products has become a growing concern in first world countries, especially in Europe. After numerous scandals with both fishery and aquaculture products, consumers have become more focused on the sustainability of their seafood purchases. Resulting there is a fast increasing demand, and corresponding price premium, for sustainable seafood products, especially for tuna products labelled as such (CBI, 2015). But how can sustainable tuna be defined?

FAO has defined sustainable development in a report from 2007 as "the management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations. Such sustainable development (in the agriculture, forestry, and fisheries sectors) conserves land, water, plant and animal genetic resources, is environmentally non-degrading, technologically appropriate, economically viable and socially acceptable" (Corsin et al., 2007).

Furthermore, in the same report, FAO defines sustainable agriculture and rural development, which includes aquaculture and fisheries related activities, as processes and activities that meet the following criteria (Corsin et al., 2007):

I. They ensure that the basic nutritional requirements of present and future generations, qualitatively and quantitatively, are met while providing a number of other agricultural products;

II. They provide durable employment, sufficient income and decent living and working conditions for all those engaged in agricultural production;

III. They maintain and, where possible, enhance the productive capacity of the natural resource base as a whole, and the regenerative capacity of renewable resources, without disrupting the functioning of basic ecological cycles and natural balances, destroying the socio-cultural attributes of rural communities, or contaminating the environment;

IV. They reduce the vulnerability of the agriculture sector to adverse natural and socio-economic factors and other risks, and strengthen self-reliance.

So what exactly does this mean with regards to tuna and how should sustainable tuna be defined? By looking at the concerns raised by tuna buyers, consumers and other stakeholders in questionnaires and different literature references, provides clearer picture about the current concerns of tuna produced from fisheries and aquaculture, which allows to propose an updated definition for sustainable tuna.
5.2 Public Concerns about Captured and Farmed Tuna

In an effort to get a clear understanding of the concerns of seafood buyers and NGO’s on farmed ABT, this report developed a questionnaire that was handed out to several stakeholders in the ABT industry, including seafood buyers (5), retailers (3) and NGO representatives (6). Ninety percent of the wholesalers and retailers that were contacted responded and filled-out the questionnaire, while none of the contacted NGO representatives was willing or able to respond. In addition, a few other stakeholders were interviewed, including one investment fund that invests in aquaculture, one online seafood database, one European tuna farming company and three tuna hatchery experts.

Looking at seafood wholesalers and retailers, the most important parameters when sourcing tuna products from fisheries or aquaculture (figure 38) are quality and sustainability, very closely followed by the trustworthiness of the supplier and pricing. Less important parameters that are mentioned are shelf life, year-round availability, and traceability. When asked about the main concerns of products originating from closed cycle aquaculture in the Mediterranean region (figure 39 on the next page), a similar picture can be seen, with quality and sustainability again as main concerns, followed by concerns on the origin of the feed and pricing. Interestingly more seafood buyers seem to be worried that the pricing of the hatchery produced ABT products is not competitive with products sourced from fisheries. When asked about their main concerns on the sustainability of these products (figure 40 on the next page) it can be seen that by far the biggest concern is the feed source used in grow-out operations, closely followed by animal welfare aspects and the use of antibiotics.

![Important decision-makers of European Seafood Buyers when Sourcing Tuna Products (Top 3)](image)

Figure 38. Important parameters of European seafood buyers when sourcing tuna products (top 3).
Main Concerns of European Seafood Buyers with regards to Tuna Products originating from Closed Cycle Aquaculture (Top 3)

- Sustainability: 22%
- Quality: 18%
- Feed source: 17%
- Pricing: 9%
- Availability: 4%
- Shelf life: 4%
- Traceability: 4%
- Trustworthiness of supplier: 4%

**Figure 39.** Main concerns of European seafood buyers concerning hatchery produced tuna products (top 3).

Main Concerns of European Seafood Buyers with regards to the Sustainability of Tuna Products originating from Closed Cycle Aquaculture (Top 3)

- Feed source: 31%
- Animal welfare aspects: 19%
- Use of antibiotics: 13%
- Environmental pollution: 6%
- Use of other medicines: 6%
- Welfare of workers: 6%
- Sustainability: 4%
- Quality: 4%
- Feed source: 4%
- Pricing: 4%
- Availability: 4%
- Shelf life: 4%
- Traceability: 4%
- Trustworthiness of supplier: 4%

**Figure 40.** Main concerns of European seafood buyers concerning the sustainability of hatchery produced tuna products (top 3).
From these questionnaires, interviews and reviewed literature, a number of main concerns were extracted. Please note that the concerns for fisheries products and aquaculture products are often similar and interlinked, since most farming operations use wild seed stock and since they use fresh fish from (often) depleted fish stocks as feed. Therefore, this report uses one list with concerns only:

**Overfishing**

As discussed in the introduction of this report, figures by ICCAT estimate that in 2007 less than 25% of the original unfished biomass of the western ABT stock and less than 20% of the original unfished biomass of the eastern ABT stock remained (Taylor et al., 2011). A similar downward trend has been observed in all other major tuna fisheries, with some, like the stock of PBT, being in even worse shape (Jallut et al., 2014). Although ICCAT in recent years has introduced a quota system for all member states fishing on ABT, and made a very important step in the right direction of sustainable management, it may take years before actual stock improvements can be observed (Taylor et al., 2011). Subsequently, many consumers and stakeholders in the tuna industry remain worried about the stock status of ABT (Ottolenghi, 2008; Phyne et al., 2013; WWF Mediterranean, 2006).

Interestingly, it also seems that buyers and consumers have difficulty in distinguishing between well-managed tuna stocks and stocks that are badly managed, thereby negatively influencing their perception of tuna products in general, but especially their perception of Bluefin tuna products. More important for this discussion, these buyers and consumers also seem to have difficulty in distinguishing between ABT products originating from closed cycle aquaculture from products originating from capture-based fisheries and associated fattening operations.

Although both ABT stocks are showing indications of recovery (Karakulak et al., 2016), the systematic continuation of overfishing of some Bluefin tuna stocks (Greenpeace, 2012; PEW Charitable Trust, 2016), and the lack of will or ability of some RFMO’s to halt and reverse overfishing, negatively influences public perception of ABT products. Including those originating from closed cycle aquaculture (Karakulak et al., 2016).

**Illegal Fishing and Underreporting**

As discussed in chapter 2, several reports suggest that the catch figures of ABT that are annually reported by member states to ICCAT, the EU and FAO are severely underreported (Bayliff, 2016; Benetti et al., 2016; Boon, 2013; Karakulak et al., 2016; Phyne et al., 2013; Sumaila & Huang, 2012) and that actual catches by far exceed the annual TAC (Ottolenghi, 2008). These excess landings are considered illegal and NGO’s like WWF have regularly accused ICCAT of failing to address illegal fishing activities (Karakulak et al., 2016; WWF Mediterranean, 2006). These NGO’s have started campaigning against the consumption of ABT and with their large impact on public perception, this campaign has not only harmed the
reputation of ABT fisheries but also those of farming and fattening activities, including the closed cycle aquaculture sector.

**Traceability**

The issue of traceability is strongly related to illegal fishing and underreporting, since a sound traceability system creates transparency and accountability in supply chains, thereby reduces the possibility of underreporting and illegal fishing. Improved traceability is a key element to regain the trust of seafood buyers, NGO’s and consumers.

The continuing lack of traceability in tuna supply chains, and with regards to ABT especially those supply chains that are part of ABT fattening operations, enables the selling of illegally caught tuna through legal means (WWF Mediterranean, 2011). As previously discussed, ICCAT has been working hard to combat the issue of illegal fishing and underreporting by implementing a Bluefin Tuna Catch Documentation (BCD) system for all vessels and fattening operations in 2007 (Karakulak *et al.*, 2016; Miyake *et al.*, 2010). However, several NGO’s have expressed their concern that the system did not require record keeping between the catching of the tuna and the harvesting at fattening farms, thereby providing these fatting operations with the possibility to whitewash unreported catches (WWF Mediterranean, 2011). In an effort to address these concerns and improve the traceability of ABT products, a new electronic Bluefin Tunas Catch Documentation (eBCD) system has been implemented by the EU in 2016 (EU, 2016) and this improved traceability is supposed to restore confidence of buyers and consumers.

**Feed Origin**

Since artificial feeds for ABT farming operations in Europe are not yet commercially available (Miyake *et al.*, 2003; Allan *et al.*, 2009; de la Gandara *et al.*, 2009), the sector continues to rely on fresh and frozen fish as feed source for their operations (Buentello *et al.*, 2016). The FCR of the use of fresh fish as feed is deemed as a major sustainability concern by buyers, consumers and other stakeholders since these fattening and farming operations are using on average 15 to 20 Kilogram of fish for each farmed Kilogram of tuna (Masami, 2016). Of additional concern is that the pelagic resources of these food fishes are already extensively fished and the required volumes of fresh fish for fattening operations might result in additional pressure on these stocks (Ottolenghi, 2008).

The use of fresh, raw fish as feed could also spread diseases to wild populations of the feed fish and a mass mortality of sardines in southern Australia has been linked to the use of these sardines as feed by tuna fattening operations in the area (Mylonas *et al.*, 2010).

One of the main reasons of the delayed development of pellet feeds for ABT fattening and farming operations is that Japanese buyers previously were very particular about the quality of the tuna meat and prefer tuna fed with fresh fish (Ottolenghi, 2008). This attitude is changing slowly now that the first pellets have been introduced in Japan and more Japanese farms have started using them. An additional factor for the delayed development of pellet
feeds in Europe is that wild-caught seed stock are often not willing to consume pellet feeds and only hatchery produced fingerlings can be properly trained to feed on artificial feeds. Since hatchery produced ABT fingerlings are not yet available in commercial quantities, demand for pellet feeds is absent.

Pollution and other Impacts on Natural Ecosystems
Most cage farming operations have a considerable impact on their surrounding environment, especially the benthic environment directly below the cages (Karakassis et al., 2002). In most cases, tuna are fattened for relatively short periods and in areas with a strong water circulation, therefore having a lower impact on the surrounding benthic environment (Ottolenghi, 2008).

Nevertheless, coastal pollution is worrying stakeholders around the Mediterranean region and several conflicts have already been reported. In 2016 there were numerous complaints in Malta about beaches being flooded with a mucus like substance that probably originated from nearby fattening operations (Malta Independent, 2016), and similar complaints arose in Croatia where farming operations are competing with tourism over the utilization of the coastal zone (Ottolenghi, 2008).

Besides the impact on the surrounding environment, tuna fattening and farming operations are known to have an impact on wild tuna stocks as well. Similar to what has happened with caged salmon, captive tuna could spread diseases to their wild counterparts and thus future farming operations for tuna would need to be integrated in national and regional level management plans.
CHAPTER 6: FUTURE PERSPECTIVES

6.1 Solving the Remaining Challenges in Hatchery Production

Currently, significant progress is being made to overcome the challenges that constrain the production of fingerlings in commercial quantities. The availability of eggs has already been improved through the use of hormone implants (Chen et al., 2016; Zohar et al., 2016) and by late 2016, IEO, with the use of additional funds from the European Regional Development Fund (FEDER), has finished the construction of two very impressive broodstock tanks (figure 41) which is hoped to increase the availability of eggs even further (EFARO, 2014).

![Figure 41. Recently constructed broodstock tank for ABT at IEO in Spain (de la Gandara, 2016).](image)

Of the two constructed tanks, one tank measures 3.500 m³, while the second tank measures 2.500 m³. The general idea is that eggs from this facility will become available for other hatcheries so that these do not need to maintain their own brood stock. This will be a major boost for the sector. At the same time, MFF in Malta also vouched to continue to commit themselves to ABT egg production for distribution purposes by maintaining a number of breeders contained in cages (TRANSDOTT, 2014a) and the same efforts are undertaken in Croatia.

In addition, several companies reported major progress with the production of copepods as discussed in chapter 4. Some hatcheries have also started testing upwelling devices and night time lighting systems to combat sinking mortality (TRANSDOTT, 2014a) and improved stocking and transfer techniques (Chen et al., 2016; Higuchi et al., 2013, Tsuda et al., 2012). Last, the analysis of larval rearing methods and the updated larval rearing protocol as presented in this study might contribute to a further increase in survival. With these recent findings and milestones in place it seems that all of the main challenges in the hatchery production have been overcome except for the transfer mortality in the early stages of the grow-out. With proper coordination between the academe and the private sector and
sufficient government support, it will only be a matter of limited time before European hatcheries will be at a similar level as those in Japan. If done properly and sustainable, this will most probably take less than 2 years to achieve.

### 6.2 Ensuring Sustainability

As discussed in chapter 5, there are a number of major concerns from European buyers of tuna, consumers, and other stakeholders about the sustainability and transparency of the ABT capture-based fishery, fattening and farming sectors. This seems to partly be the result of the fact that most stakeholders have a hard time distinguishing between ABT capture-based fisheries, fattening operations and closed cycle aquaculture operations. The concerns raised for the first two, including their reputation for overfishing, underreporting, and a lack of transparency throughout the supply chain, negatively affects the market perception on products originating from closed cycle aquaculture operations. It seems to be of vital importance that the emerging closed cycle aquaculture sector for ABT in Europe finds ways to address these concerns and is capable of separating itself from the ABT capture-based fishery and fattening sector, and market itself as a truly sustainable and transparent sector.

Before any strategic marketing campaign could take place, such efforts would first require a clear updated definition of sustainable tuna that takes the closed cycle aquaculture of ABT into account.

**An Updated Definition of Sustainable Tuna**

Most previous definitions of sustainable tuna do not take aquaculture activities into account, particularly not the closed cycle aquaculture of tunas. For these reasons, this report sees the need to address the fattening and farming of tuna in an updated definition. In addition, this report includes current concerns raised by seafood buyers, consumers, and other stakeholders that have been left out of previous descriptions.

As such, sustainable tuna is defined here as tuna, that originates from a responsible fishery, fattening or farming activity and which does not negatively affect:

I. The wild tuna stock;
II. The surrounding natural environment and ecosystem;
III. The wellbeing and health of the caught or farmed tuna;
IV. The wellbeing and health of workers employed in the industry;
V. The wellbeing and health of consumers.

To ensure that these sustainability principles can be objectively verified, the supply chain should be transparent and traceable, from the fishing vessel or hatchery up to the final consumer, and this should be certified by a reputable third party certifier.
Most stakeholders in ABT fisheries, fattening and farming activities using wild seed stock, are working hard to improve their practices towards a sustainable approach. For example, the Spanish purse seine fleet consortium OPAGA has recently started a Fishery Improvement Project (FIP) to improve its practices (Undercurrent News, 2016). However, the ABT stocks are still depleted, and catches and production figures seem to continue to be underreported by at least some EU member states and producers (Seafood Watch, 2016). For these reasons, these activities currently do not match the above definition of sustainable tuna. The closed cycle aquaculture sector of ABT on the other hand has the potential to meet the definition as outlined above, and to develop the sector in a sustainable manner.

Sustainability in the Closed Cycle Aquaculture Sector

Producers of hatchery bred tuna and associated grow-out operations are in a unique position to produce tuna that addresses the discussed concerns and meets the definition of sustainable tuna. For this to become reality, a number of issues will still need to be tackled.

The major challenges in terms of sustainability lie not with the hatcheries, but with the grow-out sector that has recently started farming hatchery produced ABT. These grow-out operations in most cases also farm wild-caught ABT and use the same farming techniques and farm inputs for their hatchery bred tuna. To ensure the sustainability of these operations these farms will have to implement the use of a sustainable artificial feed, lessen their impact on the coastal zone, and implement strict traceability in their supply chains.

This sustainable feed source should be an artificial feed as to limit pollution in and around the grow-out cages, and to halt the current spread of diseases from the food fish to wild populations of these food fishes. This feed will also need to have an efficient FCR, and preferably, a significant non-animal protein based component to reduce the amount of wild fish used as protein source. Furthermore, the animal protein content contained in the feed, most likely a form of fishmeal, should originate from well-managed fish stocks wherein no overfishing occurs, preferably an MSC or similarly certified fishery.

Several initiatives in Europe are working on the development of such sustainable feeds for farming operations of ABT, including Skretting ARC and TunaTech GmbH. Although in recent years significant progress has been made by these companies, their feeds are not yet available for commercial use. However, Japan based Nippon Suisan Kaisha, Ltd. (better known as Nissui) has recently released an internationally patented pellet feed for use in grow-out operations of PBT. When designing the pellet feed, the company not only incorporated the required nutritional profile of PBT, but also incorporated colour, smell, texture, and shape preferences of PBT. They eventually came up with a sausage shaped (figure 42 on the next page) high calorie (42.00 kcal/Kilogram) feed with an FCR of 3.8.

The company uses a rather revolutionary production process that has resulted in pellets with a separate moist filling mass, containing high concentrations of fish and vegetable oil in combination with a highly palatable outer shell (Goto et al., 2014). Feeding trials indicate that
the pellets are well accepted by PBT and growth rate and survival are very similar to tuna fed on fresh fish (Goto, 2015). For now, pellets are only available to farms owned by Nissui. It is important to note that when translating this FCR back to fresh fish this would still result to around 20 Kilogram of fish. However, the advantage is that pellets can be further developed to replace an increasing percentage of animal-based protein with vegetable-based protein.

Hayashikane Sangyo Feed Company has developed a similar feed for PBT in Japan and, in collaboration with Ridley Aqua-Feed Pty. Ltd., they have also developed a feed for SBT in Australia. Again, feeding response seems to be appropriate, with growth rates very similar to tuna grown on a diet of fresh fish (Smullen, 2010).

With the rapid expansion of fattening and farming operations of ABT, it is feared that the sector could develop in an uncontrolled fashion, similar to what happened when the salmon industry first lifted off: pollution of the coastal zone significantly increased, diseases, and parasites started prevailing in the cultured stock and conflicts with other users of the coastal zone increased. An additional concern is that with the current feeding practices, these farming

---

**Figure 42.** A new revolutionary grow-out feeds for Pacific Bluefin Tuna develop by Japanese Nissui, scale for size (Nissui, 2016).
operations might put the overfished fishing stocks in the Mediterranean Sea (Piroddi et al., 2017) under even more pressure.

To prevent this from happening it is advised to develop a unified European approach to the future development of the sector and start developing offshore strategies, so that eventually all grow-out operations of ABT can be shifted away from the coast. This would result in less pollution of the coastal zone, and less pollution in general since offshore waters have a higher capacity to assimilate cage effluents (Rust, 2014). Additionally, there will be lower risks of diseases and cross-infection between farms, since the distance between different farms can be increased and since pathogens and parasites occur in lower densities in offshore waters compared to coastal waters. Finally, most likely conflicts with other users of the coastal zone, like the current issue between tuna fattening operations in Malta and local tourist operators, will also be solved once farms are moved further offshore (Knapp, 2013).

To ensure the faith of seafood buyers and consumers in the sector, a strong traceability system will need to be implemented by all ABT hatcheries, associated nursery operations, and grow-out farms. ICCAT has been working for numerous years on a traceability system for ABT fisheries and fattening activities, the electronic Bluefin Tuna Catch Document Programme (eBCD), but at this stage, no evidence could be found that this system includes mandatory record keeping for hatchery operators. To maintain uniformity and to take advance of the enormous experience ICCAT has on this topic, it is advisable to further expand the eBCD programme to include all producers involved in the closed cycle ABT aquaculture sector and to ensure the system clearly distinguishes between farming activities using wild seed stock and those using hatchery produced fingerlings.

Figure 43. An automatic feeding system for pellet feeds developed by Nissui for Pacific Bluefin Tuna in Japan (Nissui, 2016).
6.3 A United European Approach

Support Mechanisms for Aquaculture in Europe
Despite the serious efforts of the EU to support its aquaculture industry, growth in the sector has stagnated in the past decade (European Commission, 2013; FAO, 2016). Mentioned reasons for this stagnation include the limited amount of available areas for coastal aquaculture farms, the large amount of regulations and restrictions when setting up new aquaculture operations and the limited competitiveness of European companies in the global market (Jansen et al., 2016). In 2013, the European Commission acknowledged these issues and vouched to intensify its approach to support its aquaculture industry by creating more transparent and simplified regulations, by establishing numerous funding mechanisms, by improved spatial planning and by improving the competitiveness of European aquaculture operators (European Commission, 2013). This has been a very welcome development to the aquaculture industry bringing many benefits to the sector as a whole. However, it seems that there is no strategy in place for the closed cycle aquaculture sector of ABT and the sector has remains somewhat undervalued and overlooked.

The vision of the EU for its seas and oceans has been outlined in the strategic document The Innovation in the Blue Economy: Realizing the Potential of our Seas and Oceans for Jobs and Growth (European Commission, 2014). This document presents a bold and daring vision with a dominant role in the European economy for its seas and oceans, which generate 5.4 million jobs and generate an added value of 500 billion Euro annually (European Commission, 2016). However, despite the fact the tuna farming industry in the Mediterranean Sea already has an estimated minimal annual turnover of 225 Million Euro, and has considerable economic potential, for unknown reasons the sector is not mentioned in the document.

The mission of the EU funded European Aquaculture Technology and Innovation Platform (EATIP) is "to advance aquaculture industry technologies and systems so that Europe can become an environmentally and economically sustainable net supplier of seafood, characterised by a safe and attractive working environment". EATIP previously released a very thorough and comprehensive document on its strategic vision for European aquaculture (EATIP, 2012) and this document only mentions tuna once in the chapter where it is proposed to produce a desktop study of new candidates for aquaculture. Nonetheless it must be acknowledged that EATIP funded a very large number of important initiatives, including the in chapter 3 discussed SELFDOTT project, its document outlining a strategic vision for European aquaculture,

One of the other main documents in which the EU outlines its future approach to aquaculture is the Strategic Guidelines for Aquaculture in the EU (EU, 2013), and again tuna are not mentioned.
Furthermore, as part of its strategy to support its blue economy, the EU has established the massive European Maritime and Fisheries Fund (EMFF), which pursues four main goals:

- Helps fishermen in the transition to sustainable fishing;
- Supports coastal communities in diversifying their economies;
- Financing of projects that create new jobs and improve quality of life along European coasts;
- To make it easier for applicants to access financing.

Of a total EMFF budget of 1.5 billion Euro, Spain, the EU member state with the only 2 fully operational tuna hatcheries present in the EU, has allocated 205.9 million Euro of its share to achieve the Spanish national strategic plan for aquaculture (Ministerio de Agricultura, 2014a). In this very comprehensive and impressive 228 page operational plan of the programme (Ministerio de Agricultura, 2014b), tuna are mentioned in a number of important measures to further improve fishery controls and inspections, but tuna are only mentioned once in relation to aquaculture activities; the inspection of tuna farms. The support of hatchery operations and the improvement of farming operations are not discussed.

This report would like to reiterate the completeness and comprehensiveness of the strategies and approaches outlined in these documents of the European Commission, its member states, platforms, and commissions. Nonetheless, it can only be concluded that the closed cycle aquaculture of ABT is not prioritized in these documents.

The successful EU funded research and development activities for the hatchery production of ABT, like SELFDOIT and TRANSDOIT, have been completed and the private initiatives that are left seem to be somewhat struggling. For example, Futuna Blue, which had significant production results in 2014 and 2015, decided to not commence in any production activities in 2016. Additionally, Fortuna Mare, halted its hatchery and grow-out efforts in December 2016. Also in August of the same year, Turkish seafood producer Kiliç Seafood Co. released a statement saying they were not sure whether the company would continue its pioneering hatchery efforts (Seaman, 2016) and eventually halted production. Only the publicly funded research institute IEO, which is backed by the Spanish government and EU, continues its ABT hatchery development programs.

It will be very difficult for this limited number of private and public initiatives to carry the burden of developing this promising sector. They need to be backed by a strong EU and a bolder, more daring and optimistic plan might be needed to take full advantage of the exceptional opportunity the sustainable closed cycle aquaculture of ABT presents for Europe.
The Japanese Way
When looking at the situation in Japan we see that the country has clearly found a suitable way to successfully commercialize the production of PBT. As extensively discussed in Chapter 4, Japan has clearly solved most of the challenges that European hatcheries are still facing, and the country’s hatcheries are now producing PBT fingerlings in commercial quantities (figure 44). The number of farms that are solely using hatchery produced PBT is on the rise as well (figure 45).

**Figure 44.** Production figures of Pacific Bluefin Tuna fingerlings in Japan compared to the production figures of Atlantic Bluefin Tuna in the Mediterranean region from 2011 to 2016 (Japanese Ministry of Fisheries / Nissui, 2017)

**Figure 45.** Farmers of hatchery produced Pacific Bluefin Tuna in Japan and the number of cages used by these farmers 2013 - 2016 (Japanese Ministry of Fisheries / Nissui, 2017)
A very important reason for Japan’s advancement in the culture of PBT is the fact that industry partners and the government have united to tackle big challenges like the hatchery production of tuna and the national government and the local prefectures have made large financial contributions to support the efforts of the sector. Additionally, Japan has a very strong long-term national aquaculture and fisheries strategy that focuses on self-sufficiency of the country through innovation and the sustainable management of natural resources through ecosystem management and sustainable aquaculture (Ikuta, 2007). One of the key components of this strategy is the promotion of sustainable aquaculture production through the massive funding of research, the development of activities focused on multi-trophic aquaculture, the development of environmental friendly pellet feeds and alternative protein sources for feeds, the establishment of suitable traceability systems for all aquaculture products, large scale offshore aquaculture (with special attention for PBT) and the promotion of innovative aquaculture technologies that allow for the production of high value species. Hereby PBT, grouper, and sea cucumber are some of the main target species. Additionally, to prevent pollution of coastal areas, and conflict of interest with other users of coastal areas, the government has established a plan to move all PBT grow-out operations to offshore areas by the end of 2017 (Ikuta, 2007). Furthermore, to push fattening and farming operations to improve the sustainability of their operations by using sustainable hatchery produced fingerlings, the government reduced the TAC of wild juvenile PBT by half in 2015 (Nuwer, 2014), with further reductions planned in the near future.

In addition, to demonstrate to seafood buyers and consumer that supply chains are traceable, the Japanese Agriculture Standards Bureau has developed a system to certify the traceability of PBT grow-out operators. This approach of certifying PBT farmers can be very beneficial for farmers. For example, Maruha Nichiro was the first farming company to able to achieve this certification for its grow-out farms. Immediately after certification, the company was offered to supply Japan’s largest retail chain Aeon with fresh PBT from their farm nationwide (Masami, 2016).
A Masterplan for Sustainable Closed Cycle Aquaculture of Atlantic Bluefin Tuna in Europe

All stakeholders agree on the need of the EU and its member states to considerably improve the sustainability of Mediterranean fisheries. There is also uniform agreement on the need for the EU to become more self-reliant in terms of food production, especially through aquaculture, and the need to create more employment in member states around the Mediterranean Sea. The sustainable closed cycle aquaculture presents a unique opportunity to solve these problems.

In addition, when analysing the current status and practices of the capture-based fishery, fattening and farming activities of ABT, it can be concluded that there is a strong need for these industries, and the governmental bodies managing them to:

- Reduce fishing effort in the capture-based fishery of ABT juveniles;
- Find alternative livelihoods for fishers who have lost their source of income due to TAC reductions, the transfer of quota to large fishing companies, and decreased fish stocks in general;
- Increase the transparency and traceability of ABT fattening and farming operations;
- Ensure that fattening and farming operators switch to a sustainable (hatchery produced) source of seed stock;
- Develop a more sustainable feed source for ABT fattening and farming operations;
- Increase spatial planning of fattening and farming operations including a strong offshore approach that will decrease the impact of these operations on coastal ecosystems and that decreases their potential pressure on fish stocks.

The sustainable closed cycle aquaculture sector of ABT presents a solution to many of the above listed issues. When matching this with the huge market demand for tuna and the quickly increasing market demand for sustainable tuna, this brings the EU and its member states in the unique position to solve a number of environmental and social issues, while simultaneously taking advantage of a very substantial economic opportunity.

To ensure a well-coordinated and sustainable approach that maximizes the potential of this opportunity, similar in many ways to the Japanese approach to the closed cycle aquaculture sector of PBT, this report proposes the development of a Masterplan for the Sustainable Closed Cycle Aquaculture of Atlantic Bluefin Tuna in Europe.

It is proposed that this masterplan includes the following elements:

1. A mechanism to provide financial support for existing and new private and public hatchery initiatives whereby long-term investments and commitments from the private sector are encouraged and matched with public funding;
II. Financial support to supportive industries with a focus on capacitating European feed producers to develop sustainable artificial feeds for the sector;

III. An approach whereby ABT eggs continue to be freely distributed to hatcheries around the region (e.g. further long-term financial support for IEO in Spain) so that hatcheries have no need to maintain their own breeders and can incorporate this significant cost reduction in their business plans;

IV. The development of a simple but efficient set of rules and regulations that ensure the future sustainability of the sector, with a special focus on grow-out operations, including:
   ▪ A clear offshore approach whereby coastal farming operations will be phased out in the long-term and which takes into account the previously raised potential concerns about offshore farming (Naylor, 2006). Positively Spain and Malta are already in the process of moving their farms offshore (Vassallo pers. comment, 2017);
   ▪ Eventually banning the use of fresh and frozen fish of overfished stocks as feeds in fattening and farming operations;
   ▪ Eventually banning the use of wild captured seed stock for all fattening and farming operations;
   ▪ Prioritizing a role in the sector for displaced fishers and operators of fattening operations;
   ▪ Ensuring mandatory traceability of all supply chain actors part of the sector, preferably by the development of an updated version of the eCDB system of ICCAT. An important component of this traceability system would be a reliable method to record fish numbers and sizes inside cages and it is recommended to use the recently released automatic acoustic measurement system developed by IEO and the Polytechnic University of Valencia (FIS, 2017).

V. An approach in which producers work together with certification bodies (BAP, ASC, etc.) to warrant the timely development of a certification standard for the sector;

VI. A training component for hatcheries and grow-out operations to promote Good Aquaculture Practices, to disperse the latest technological advancements and to guarantee a healthy balance between sustainability and farm profitability. Additionally, a special training component will be needed for grow-out operations in order for them to learn how to handle the somewhat more sensitive hatchery produced fingerlings during stocking and to ensure proper harvesting methods which are known to strongly influence grading and thus pricing and farm profitability;

VII. A long-term approach that ensures not only ecological sustainability, but also economical sustainability; by avoiding overproduction and maintaining healthy profit margins;
VIII. A strong marketing component to educate European consumers on the sustainability and transparency of the sustainable closed cycle aquaculture sector of ABT and to put sustainable European produced ABT on the map.

However, to make this masterplan and its implementation a reality, the EU will need to make sufficient direct funding available. With the very significant amount of existing funding mechanisms, it would be most logical to allocate a small portion of several of these funds for the development and implementation of the Masterplan for Sustainable Closed Cycle Aquaculture of Atlantic Bluefin Tuna in Europe.

The implementation of this plan will not only bring together the EU member states that are producing ABT (Spain, Portugal, Italy, Croatia, Greece and Cyprus), but also member states and countries that are part of developing ABT hatchery technologies outside the Mediterranean region (United Kingdom, Germany, Denmark and Norway). Moreover, the implementation of this plan will also benefit member states that provide general technology and equipment in the culture of marine finfish (including Netherlands, France, and Sweden), and European businesses that are pivotal in the development of sustainable feeds for the industry (Denmark, Netherlands and others). This masterplan will also benefit other Mediterranean countries that have an interest in the sustainable culture of ABT (including Egypt, Israel, Libya, Tunisia, and Morocco) and as such will lift up the economy of the whole region, which would be a very welcomed and needed development to the region.

As such, this masterplan will bring EU member states and neighbouring nations together to solve a number of environmental and social issues while developing an enormous economic opportunity that will spur the growth of European aquaculture, thereby making tuna farming not only economically very rewarding but more importantly also very sustainable!

*Figure 46. Inspection of farmed Southern Bluefin Tuna in Australia (Gordon, 2014)*
Figure 47. Hatchery bred Pacific Bluefin Tuna in Japan eating pellet feed developed by Nissui (Nissui, 2016)
REFERENCES


EFARO. (2014). Farming Bluefin tuna Closed life cycle coming to a solution.


EU (2011). From capture based to SELF-sustained aquaculture and Domestication Of bluefin Tuna, 4-7.


Hatchery International (2015a). Turkey testing the waters with Bluefin Tuna.


Piroddi, C., Coll, M., Liquete, C., Macias, D., Greer, K., Buszowski, J., ... Christensen, V. (2017). Historical changes of the Mediterranean Sea ecosystem: modelling the role and impact of primary productivity and fisheries changes over time. *Scientific Reports, 7*(February), 44491. doi:10.1038/srep44491


Undercurrent News (2015). Spain catches entire bluefin tuna quota in less than a week.

Undercurrent News (2016). WWF, Spanish sector join forces for fisheries improvement project.


# Annex 1: Definitions

<table>
<thead>
<tr>
<th>Term</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Animal welfare</td>
<td>How an animal is coping with the conditions in which it lives. An animal is in a good state of welfare if (as indicated by scientific evidence) it is healthy, comfortable, well nourished, safe, able to express innate behaviour, and if it is not suffering from unpleasant states such as pain, fear, and distress. Good animal welfare requires disease prevention and veterinary treatment, appropriate shelter, management, nutrition, humane handling and humane slaughter/killing. Animal welfare refers to the state of the animal; the treatment that an animal receives is covered by other terms such as animal care, animal husbandry, and humane treatment (OIE)</td>
</tr>
<tr>
<td>Antibiotics</td>
<td>A medicine (such as penicillin or its derivatives) that inhibits the growth of or destroys microorganisms</td>
</tr>
<tr>
<td>Aquaculture</td>
<td>Aquaculture is the farming of aquatic organisms, including fish, molluscs, crustaceans and aquatic plants (FAO)</td>
</tr>
<tr>
<td>Artemia</td>
<td>Small aquatic crustaceans also known as brine shrimp and an important live feed in fish hatcheries</td>
</tr>
<tr>
<td>Closed cycle aquaculture</td>
<td>Aquaculture activities which are independent of wild resources except for the occasional renewal of breeders</td>
</tr>
<tr>
<td>Compliance</td>
<td>Adherence to laws, regulations, guidelines and specifications</td>
</tr>
<tr>
<td>Consumer</td>
<td>A person or organization that uses economic services or commodities</td>
</tr>
<tr>
<td>Contamination</td>
<td>The unwanted pollution of something by another substance</td>
</tr>
<tr>
<td>Copepods</td>
<td>Tiny crustaceans, most of which are considered zooplankton, and that form an important part of the diet of many marine fin fish</td>
</tr>
<tr>
<td>Farming</td>
<td>The culture of tuna in captivity using small juvenile wild caught stock or hatchery bred juveniles</td>
</tr>
<tr>
<td>Fattening</td>
<td>The fattening of tuna in captivity using medium to large size wild caught individuals</td>
</tr>
<tr>
<td>Fingerlings</td>
<td>A juvenile fish with developed scales and fins</td>
</tr>
<tr>
<td>Fish stocks</td>
<td>A stock comprises all the individuals of fish in an area, which are part of the same reproductive process</td>
</tr>
<tr>
<td>Food additives</td>
<td>Non-nutritious substances which are added intentionally to food, generally in small quantity, to improve its appearance, flavour, texture or storage properties</td>
</tr>
<tr>
<td>Food safety</td>
<td>The conditions and practices that preserve the quality of food to prevent contamination and foodborne illnesses</td>
</tr>
<tr>
<td>Legislation</td>
<td>Law which has been enacted by a legislature or other governing body or the process of making it</td>
</tr>
<tr>
<td>Microbe</td>
<td>A microorganism, especially a bacterium causing disease or fermentation</td>
</tr>
<tr>
<td>Rotifer</td>
<td>Microscopic pseudo coelomate animals that are easy to cultured and that are often used as a life feed in fish hatcheries</td>
</tr>
<tr>
<td>Social responsibility</td>
<td>An ethical framework which suggests that an entity, be it an organization or individual, has an obligation to act for the benefit of society at large</td>
</tr>
<tr>
<td>Sustainability</td>
<td>The management and conservation of the natural resource base, and the orientation of technological and institutional change in such a manner as to ensure the attainment and continued satisfaction of human needs for present and future generations</td>
</tr>
<tr>
<td>Traceability</td>
<td>Traceability as defined by the Codex Alimentarius is the ability to follow the movement of a food through specified stage(s) of production, processing, and distribution</td>
</tr>
</tbody>
</table>
ABOUT THE AUTHOR

Jonah van Beijnen is a passionate biologist with a focus on sustainable fisheries and aquaculture projects around the globe. He strongly believes that sustainable production and consumption of seafood is key in ensuring a better world for all of us.

Ten years ago, he co-founded the Centre for Sustainability in the Philippines and developed one of the country’s first grouper (*Epinephelus*) hatcheries. For a number of years, he and his colleagues worked on fine-tuning a sustainable hatchery protocol, which allowed for production of commercial quantities of fingerlings without the use of antibiotics or chemicals. The Centre was able to commercialize the production of several grouper species and a number of other high value marine finfish. Additionally, he has a great interest in tuna and has been working with different tuna fisheries and conservation projects in Southeast Asia and Europe.

Recently, the author moved back to Europe where he expanded his interest in the sustainable closed cycle aquaculture of tuna. From his home base in southern Spain he continues to provide consultancy services to assist projects, private companies, and governments in improving the sustainability of their fisheries and aquaculture operations focusing on high-value marine species like grouper and tuna.

For more information, please contact: jonah@vb-consultancy.com
The Closed Cycle Aquaculture of Atlantic Bluefin Tuna in Europe

Current status, market perceptions and future perspectives
Jonah van Beijnen, 2017

This report presents the latest overview of the developments in the closed cycle aquaculture of Atlantic Bluefin Tuna in Europe, focusing on recent and current private and public hatchery projects and their achievements. This report also discusses the challenges that these projects are facing and presents potential solutions.

Additionally this report examines the market perception of hatchery produced tuna with a focus on sustainability. Concerns from buyers are discussed and an updated description for sustainable tuna is presented, including a number of recommendations for grow-out farmers.

To ensure a well-coordinated and sustainable approach that will maximize the potential of this opportunity, similar in many ways to the Japanese approach to the closed cycle aquaculture of Pacific Bluefin Tuna, this report concludes with the proposed development of a Masterplan for the Sustainable Closed Cycle Aquaculture of Atlantic Bluefin Tuna in Europe.