CHAPTER 13

Spain's Atlantic Bluefin Tuna Aquaculture

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Introduction

The Atlantic Bluefin tuna (ABT), *Thunnus thynnus*, L. 1758, is a scombrid with a highly migratory behavior. It has been feeding human populations, especially in the Mediterranean area, for centuries. In the middle of the 1990s, a process called "fattening" was developed (Ottolenghi 2008). The bluefin tuna (BFT) schools are caught by purse seiners in the reproductive areas in the Mediterranean in June and July. After capture, the tuna are transferred into transport cages and towed to the fattening facilities. During a period of time (usually six months, from July to December) they are fed with defrosted baitfish. Once fattened, tunas are slaughtered and sent mainly to the Japanese market (de la Gándara et al. 2016). This activity resulted in an overfishing of the wild stocks, with important implications for the population. To avoid the collapse of the ABT populations, the International Council for the Conservation of the Atlantic Tunas (ICCAT) implemented a multi-annual recovery plan in the eastern Atlantic and the Mediterranean (Fromentin 2009), with a maximum allowed capture (quota).

One way to alleviate the pressure on the wild fishery of the ABT and aid in its conservation is the domestication of ABT and the development of a self-sustained industry based on integral aquaculture practice.

In this chapter, we outline the advances in Spain's ABT aquaculture between 2011 and 2015 and conclude with the details of the new land-based facility designed to take us into the future.

Research on ABT aquaculture in Spain started eighteen years ago with a number of European projects such as REPRODOTT and SELFDOTT, which were funded by different European Framework Programmes for Research. Through these projects, the basics of reproduction and larval

Table 13.1. Murcia Oceanographic Centre production, 2011–2015

	2011 season	2013 season	2015 season
Number of inoculated eggs	1,500,000	800,000	2,450,000
Number of batches	4	2	6
Number of 0.1 to 0.2 g larvae produced	20,000	8,000	41,000
Survival rate during larval rearing	1.3%	1.0%	1.67%
Number of 3.0 to 4.0 g fingerlings	3,500	3,800	16,000
Survival rate during weaning	15%	48%	39%
Total survival rate from eggs to fingerlings	0.20%	0.48%	0.65%

Notes: Larvae from 0.1 to 0.2 g are 24 to 25 days post hatching (dph). Larvae from 3.0 to 4.0 g. are 36 to 38 dph.

rearing of ABT were established (García-Gómez 2007, de la Gándara and Ortega 2008, de la Gándara et al. 2012a).

Between 2011 and 2015, most of the fingerlings produced in Spain came from Murcia Oceanographic Centre (COMU), an aquaculture research center belonging to the Spanish Institute of Oceanography (IEO). Researchers at the COMU are developing their work within the framework of RDI Spanish research, development, and innovation programs but are also supported by private companies such as Caladeros del Mediterráneo (CM) and Fortuna Mare (FM). These companies have funded several projects in the past and have managed the broodstock and the ABT fingerlings when they were stocked in the cages (Ortega 2015).

Apart from the IEO, the company Futuna Blue, which is situated in Puerto de Santa Maria in southwestern Spain, was involved in another European project, Translation of Domestication of *Thunnus thynnus* into an Innovative Application (TRANSDOTT), and it has started to culture ABT fingerlings (Christopher C. Bridges, coordinator of the TRANSDOTT project, pers. com. 2015). See Table 13.1.

Broodstock

Three broodstock groups were used between 2011 and 2015:

1. The eldest broodstock group, consisting of 30 approximately 30 kg individuals, was held in fattening cages, after being caught in the Balearic Sea, until being placed in cage 1 at the end of 2007 (de la Gándara et al. 2010). This group was spawning until 2012, after which these spawners were lost due to sabotage.

2. The second broodstock group was also captured in the Balearic Sea, in June 2008. The fish were fattened during the following seven months, and in early 2009, 25 of the bluefin tunas were moved to cage 2. These tunas were approximately 40–45 kg, and they spawned from 2010 to 2014 (Ortega 2015).

   Both cages were placed in El Gorguel (Cartagena, in southeastern Spain). Their dimensions were 25 m in diameter and 20 m in depth. The cages were fitted with a 2 cm mesh net to restrict the entry of opportunistic small pelagic fish that could eat the eggs being released. Cages were managed by CM during the first three years and by FM in the 2014 season (Ortega 2015).
3. A broodstock group from a commercial cage was used during the 2015 season. Tunas were captured around the Balearic Islands in May 2014 and then moved to San Pedro del Pinatar (Murcia, in southeastern Spain), where CM owns a second facility. Fish were placed in a 50 m diameter cage, with 16 m wall depth (approximately 25 m in depth in the center of the cage), and they were fattened over a period of 11 months. At the end of May there were ~400 tunas, weighing approximately 230 kg each (Ortega 2015), and their eggs were collected during June and July.

   Egg collection was carried out by placing a solid PVC sheet (tarpaulin) into the cage; it surrounded the inside perimeter of the cage from 0.5 m above the water surface to a depth of 1.5 m (Figure 13.1). This allowed the floating eggs to be maintained within the cage and not washed out owing to light currents. Every night the cage was checked from 03:00 to 06:00 a.m., and if spawned eggs were observed, they were collected by hand net and transported to COMU facilities (de la Gándara et al. 2010).

The spawning season usually extends from early-mid June to mid July, although severe weather, in which there is a significant drop in temperature, can cause an abrupt end to the season. See Figure 13.2.

The tarpaulin system is most effective during low currents and a relatively calm sea; it is much less so during stormy conditions, which occur a number of times during the season. The shortest seasons were in 2012 and 2014, when egg collection was limited to 15 days. But in 2015 the spawning season increased to 50 days, from June 1 to July 20.

Figure 13.1. Egg collection from the solid PVC sheet (tarpaulin) that surrounded the inside perimeter of the cage.

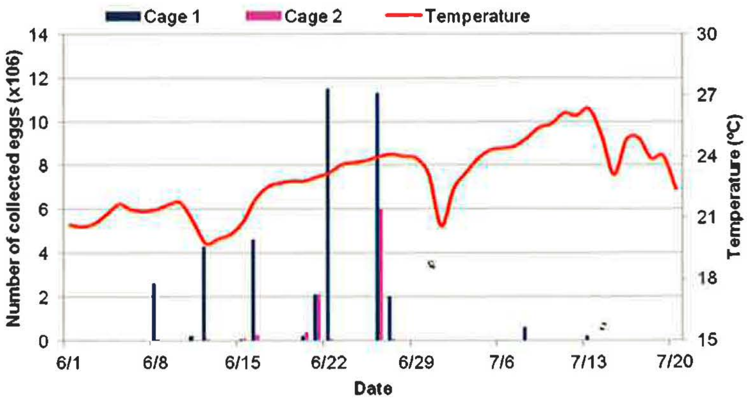

Figure 13.2. Temperature and number of eggs collected in cages 1 and 2 during the 2012 season.

Larval Rearing

The larval rearing system consists of tanks 40–55 m^3 round and 2 m deep, with an upwelling water inlet and aeration. These features keep the larvae in suspension and homogeneously distributed to help prevent sinking death. A few ml of fish oil are frequently added to the water surface from 0 to 7 days post hatching (dph) to prevent surface death (Honryo et al. 2016), which occurs when the larvae adhere to the water surface, secrete stress-

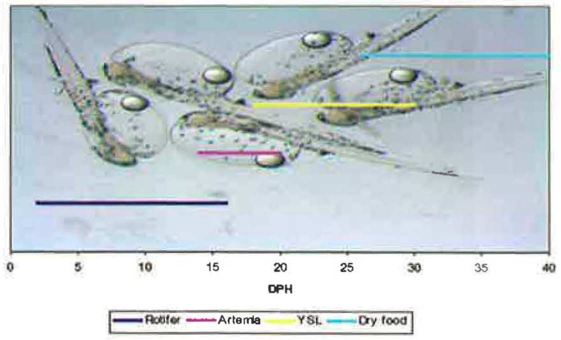

Figure 13.3. Feeding schedule of bluefin tuna larval rearing. DPH = days post hatching; YSL = yolk sac larvae.

modulated mucus, and are immobilized there. A surface skimmer is also used to keep the water surface as clean as possible, to allow the larvae to try to gulp air bubbles to inflate their swim bladders. According to Kurata et al. (2015), this happens in the first week after the larvae hatch.

Sea water temperature and photoperiod is typical of the area. It ranges between 21 and 27°C and between 14 and 15 hours of light to 9 to 10 hours of dark. As the tanks are placed in a greenhouse, the larvae are exposed to natural sunlight, although artificial light is supplemented. The stocking density is ~10 eggs/liter, and the pseudogreen method described in de la Gándara et al. (2012b) is used. A flow-through system is employed from the first day, and the inflow rate increases with time. To maintain a specific density of microalgae in the tanks, the phytoplankton species *Nannochloropsis* sp., *Chlorella* sp., and/or *Isochrysis galbana* are added twice per day. The live food sequentially fed during larval rearing (Figure 13.3) consists of enriched rotifers (*Brachionus plicatilis*), followed by enriched *Artemia*, and then sea bream (*Sparus aurata*) yolk sac larvae (YSL). The weaning onto a dry diet starts when larvae are approximately 25 dph.

During 2014 and 2015, we started to produce copepods (*Acartia tonsa*) to replace or reduce rotifer and *Artemia* feeding. The advantage of using copepods for marine larval rearing is well known, as these zooplankton have excellent nutritional quality and a suitable size from first-stage nauplii to last-stage copepodits (Abate et al. 2015; Figure 13.4). The first trials carried out in 2014 improved survival and growth, but intensive copepod production is still a challenge, and the culture protocol needs to be improved (Ortega et al. 2015). Consequently, in 2015, copepods were fed to the fish along with rotifers and not as a sole alternative.

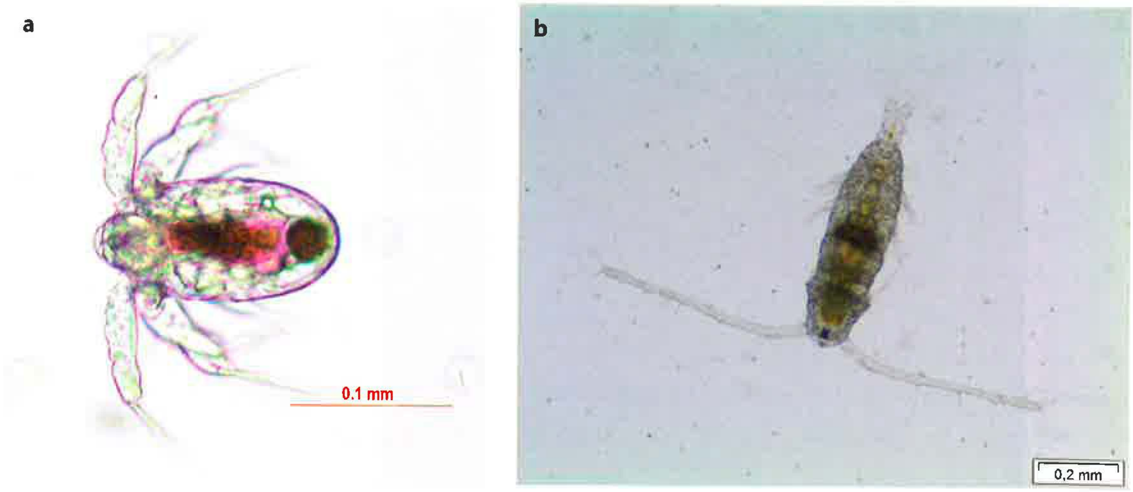

Figure 13.4. (*a*) *Acartia tonsa* nauplius; (*b*) last stage of copepodit.

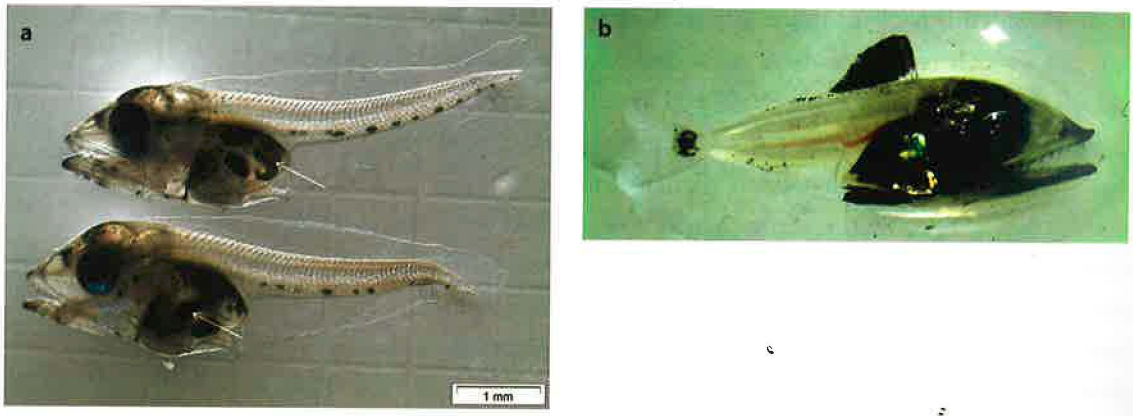

Figure 13.5. Little tunny (*Euthynnus alleteratus*) at (*a*) 5 and (*b*) 12 days post hatching. The younger larvae are shown with the eyes of freshly eaten Atlantic bluefin tuna larvae.

The main challenge during this period is to reduce early mortality, which is caused by several factors, including egg and larval quality, sinking death, surface death, and unbalanced nutrition in the live prey. Another serious problem is that BFT eggs collected at sea may also include eggs from other species spawning close to the cages, whose fast-growing larvae are hard to identify and may prey upon the smaller tuna larvae. This was the case when eggs from bonito (*Sarda sarda*), barracuda (*Sphyraena sphyraena*), horse mackerel (*Trachurus* sp.), and groupers were mixed together with the BFT eggs. Five-dph little tunny (*Euthynnus alleteratus*) in particular are able to feed on five-dph ABT larvae, whereas one 12-dph little tunny larva can weigh more than 0.1 g and is able to eat several dozens, even hundreds, of ABT larvae every day (Figure 13.5).

Weaning

In general, the larvae are taken from the larval rearing tanks at 24–26 dph, when average weight is ~0.1–0.2 g. After counting and removing the small and large juveniles, the remaining fish are split into different tanks (20–55 m^3) at a density of 100–200 fingerlings/m^3. The natural temperature of seawater at this time ranges between 24 and 28°C. Although the fish are exposed to the natural photoperiod, a low-intensity light is placed above the tank during the night.

The success of weaning the BFT juveniles onto an inert diet or baitfish has been mixed; it resulted in only 15% survival in 2011. Consequently, bait fish (*Ammodytes* sp.) has been used since. Nevertheless, dry diet performance is improving. Figure 13.6 shows little difference in survival with age when weaning with baitfish and two dry diets—a commercial diet (Magokoro, by Marubeni Nisshin Feed Co. Ltd.) and an experimental diet made by Skretting.

In 2015 the dry diet Magokoro was used with promising results: the survival rate was close to 40% during the weaning process in large tanks (Ortega, unpublished data).

During the first days of weaning, YSL are also supplied, but from 30 dph onward, when tunas weigh between 0.5 and 1 g, only inert diet is provided.

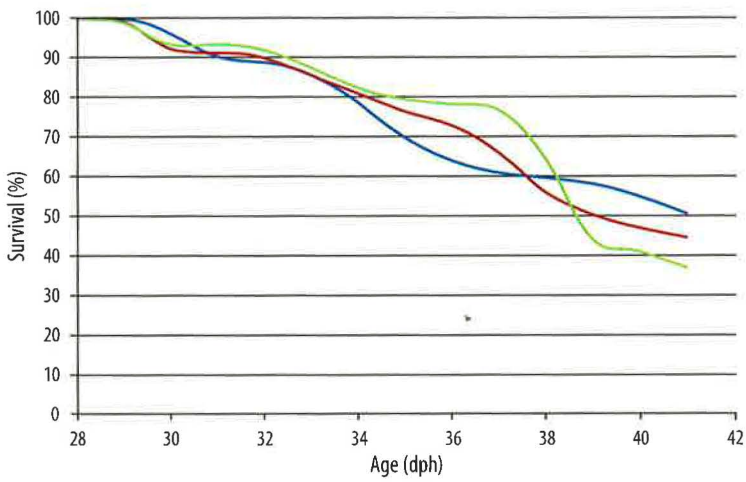

Figure 13.6. Survival rate (%) in the weaning process obtained in an experiment carried out in 2014. Blue line shows survival with bait fish, and red and green lines show survival with a couple of dry diets. dph = days post hatching.

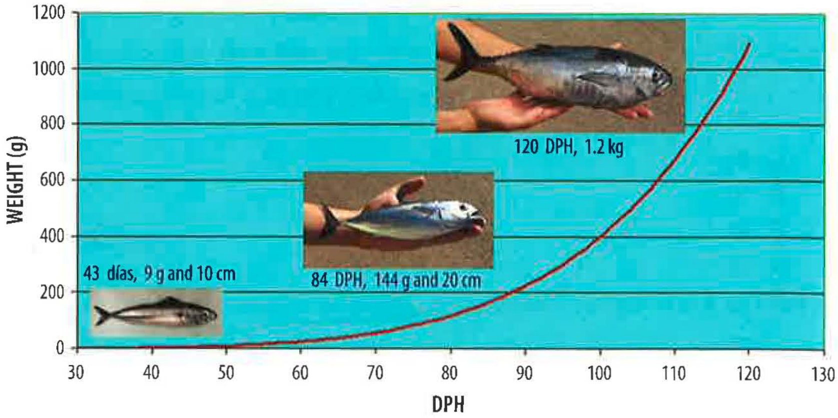

Figure 13.10. Growth of juvenile Atlantic bluefin tuna in the cages. DPH = days post hatching.

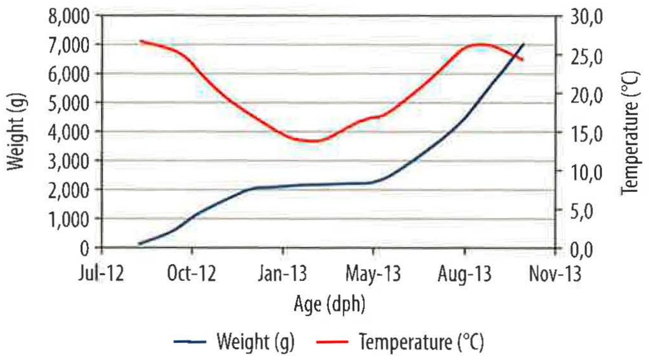

Figure 13.11. Growth of juvenile Atlantic bluefin tuna in oceanic cages and temperature profiles in southeastern Spain.

winter when temperatures were below 18°C, and stopping altogether when temperatures were below 16°C (Ortega et al. 2014).

Improving the success of grow-out, understanding the nutritional requirements at different stages of growth, and developing a suitable dry diet are essential for industrial ABT aquaculture to advance and to be able to close the life cycle in captivity.

Land-Based Facility to Control the Reproduction of Atlantic Bluefin Tuna

A new land-based facility to control ABT reproduction in tanks, Infrastructure for Controlling the Reproduction of Atlantic bluefin tuna (ICRA), was built by IEO in 2015 (Ortega 2015), and the broodstock was introduced during 2016.

The ICRA (Figure 13.12) was 80% funded by the European Regional Development Fund (FEDER), and the IEO contributed the remaining 20%.

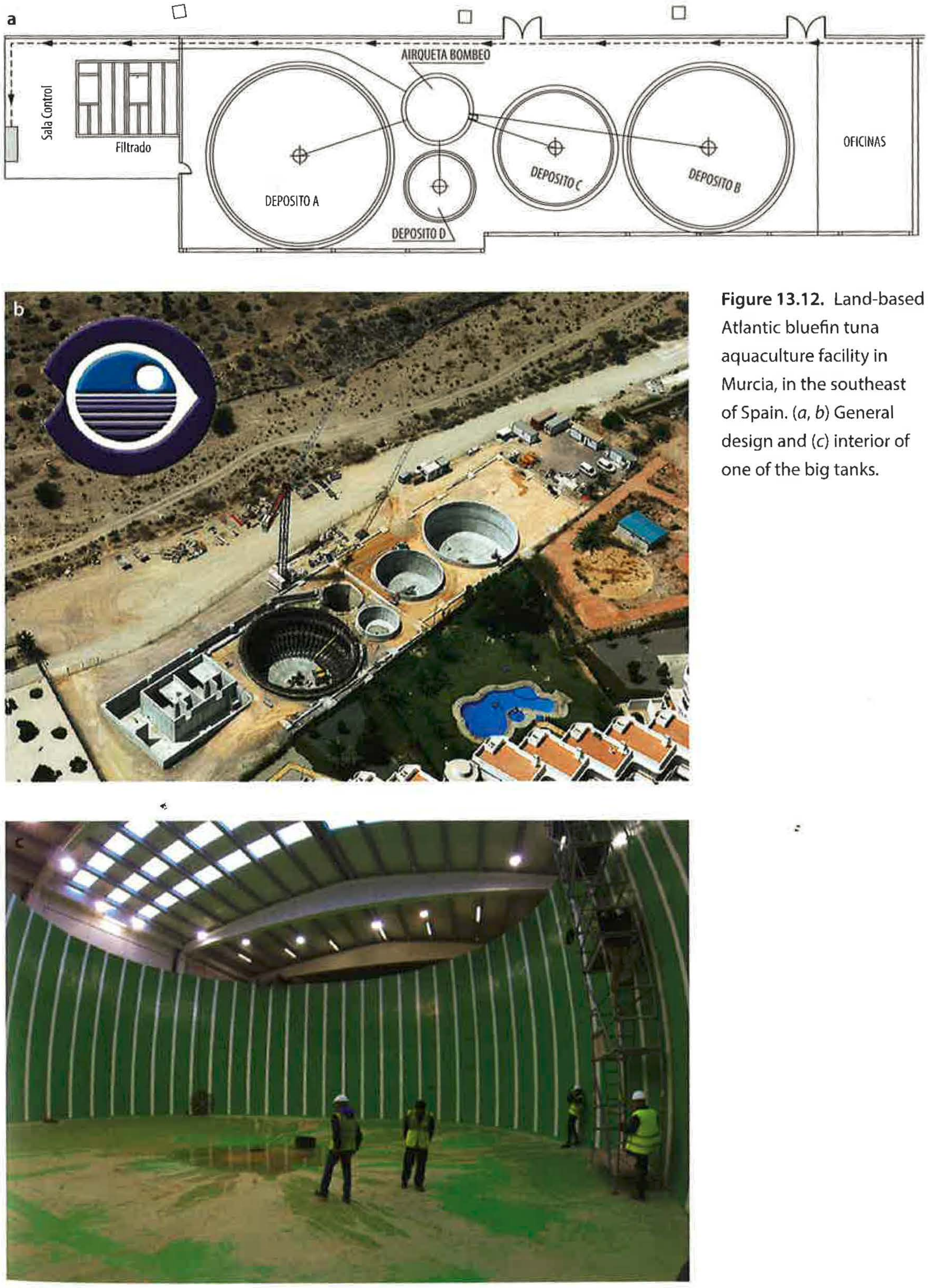

Figure 13.12. Land-based Atlantic bluefin tuna aquaculture facility in Murcia, in the southeast of Spain. (*a*, *b*) General design and (*c*) interior of one of the big tanks.

This was enabled by an agreement between the IEO, the Spanish Science Ministry, and the Regional Government of Murcia. The facility consists of two large tanks for broodstock (A and B tanks have volumes of 3,500 and 2,600 m^3, respectively) and two smaller tanks for ongrowing juvenile tunas (C and D tanks have volumes of 900 and 150 m^3, respectively). To maintain constant seawater parameters and good water quality, a recirculation system (mechanical and biological filters, a heating and chilling system, skimmers, and ozone, ultraviolet, and oxygen injection) was implemented and is completely automated.

In June 2016 we achieved, for the first time, the closing of the life cycle of ABT in captivity. A batch of 30 tunas from the 2011–12 season, weighing an average of 35 kg each, together with another batch of ~70 tunas born in 2013 and 2014 and weighing ~12 kg each, were moved in late May to 28 m diameter cages and then transported from El Gorguel, Cartagena, to another facility in San Pedro del Pinatar (both in southeastern Spain). Tunas were fed with minced fish (herring and mackerel), and ten days after the tuna arrived in San Pedro, a tarpaulin egg collector system was placed around the cage perimeter. A batch of 50,000 fertilized eggs was collected on June 18. The eggs were incubated and hatched ~30 hours later. Then they were moved to a tank to carry out the larval rearing. Twenty-five days later, ~300 larvae were moved to a larger tank to start the weaning process. This broodstock spawned only a few times more, and only low numbers of eggs were collected.

The reason for the low number of eggs obtained could be the youth of the broodstock. This was their first spawning event, and possibly only one or two females contributed spawning eggs. This fact should have been confirmed in the next spawning season, but unfortunately a great storm broke the cages where the broodstock was located, and all escaped.

Fingerlings produced from these eggs as well as those produced the following years will set up broodstock lots for ICRA that could contribute to production and offer ABT eggs for research projects and/or for commercial production purposes in the years to come.

To even consider the fattening of captured ABT as a highly profitable commercial activity is a new perspective gained from the recent progress in tuna aquaculture; it was brought about by fully closing the cycle of ABT, producing seeds and fish up to marketable sizes, similar to what is occurring with other cultured marine fish.

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