Chapter 9

Ranching of Southern Bluefin Tuna in Australia

David Ellis and Ilse Kiessling
David Ellis and Associates, Port Lincoln, SA, Australia

9.1 INTRODUCTION

Southern bluefin tuna (*Thunnus maccoyii*) (SBFT) belong to the family Scombridae, which includes all mackerels and tunas (Lagler et al., 1977). The specific name, maccoyii, was bestowed by de Castelnau (1872) noting, "the flesh of this fish is not eaten, or at least is not esteemed as food." The species is one of the largest bony fishes, living up to 40 years, growing to a length of 2.25 m, and weighing over 200 kg (Patterson et al., 2009, 2010). One specimen that washed up on a beach at Glenelg, South Australia in 1890 was reported to have weighed over 350 kg (Serventy, 1956).

SBFT are a single, highly migratory stock (Patterson et al., 2009, 2010) found primarily between the latitudes of 30° and 50° South (Collette and Nauen, 1983). The only known spawning ground for SBFT is located in the warm oceanic waters south of Java, Indonesia in the north-east Indian Ocean between 10°−20° South and 105°−120° East. The spawning season spans from September to April. Following spawning, developing juveniles move with the Leeuwin Current along Australia's north-western coast to the south-west tip of Australia and east into the Great Australian Bight or west toward South Africa (Campbell, 2001; Patterson et al., 2009) (Figure 9.1). It is uncertain when SBFT reach spawning age, but it is generally understood that females between the ages of 8 and 12 produce several million eggs each spawning event (Hayes, 1997).

Tuna are distinguished by a number of anatomical and physiological adaptations that minimize anterior resistance and maximize caudal thrust (Bushnell and Jones, 1994; Dewar and Graham, 1994; Brill, 1996; Fitzgibbon et al., 2008). These adaptations include a streamlined shape designed for speed, maneuverability, drag reduction, and efficiencies in

D.D. Benetti, G.J. Partridge, A. Buentello (Eds): Advances in Tuna Aquaculture.
DOI: http://dx.doi.org/10.1016/B978-0-12-411459-3.00010-2

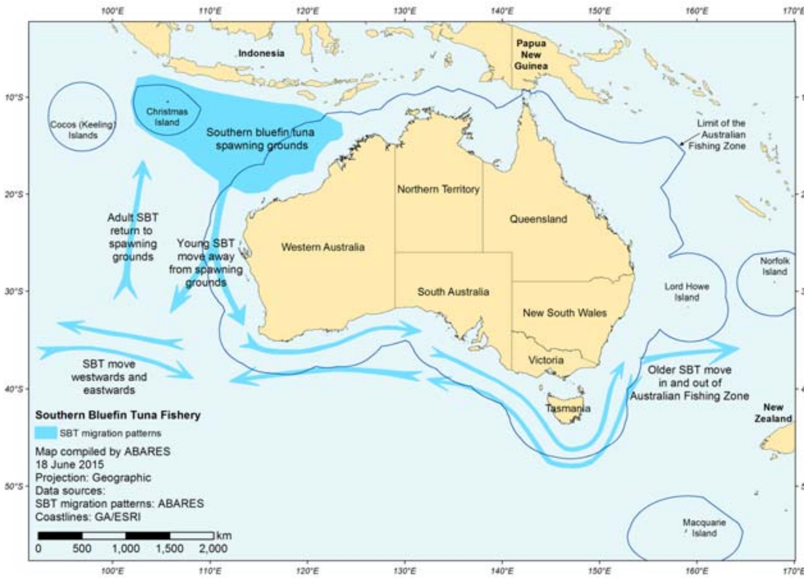

FIGURE 9.1 SBFT migration patterns. *Map provided by ABARES (Australian Bureau of Agricultural and Resource Economics and Sciences).*

locomotion (Magnuson, 1978; Dewar and Graham, 1994). The dorsal, pelvic, and pectoral fins of SBFT provide guidance but serve no role in propulsion. When moving at high speed (approximately 70 km/h, Wardle et al., 1989), SBFT use long propulsive beats of their tail and retract their fins within defined body grooves to minimize drag. Caudal keels along the top and bottom edges of the body act as spoilers to prevent turbulence (Attenborough, 1979; Altringham and Shadwick, 2001). These adaptations enable SBFT to feed rapaciously in the epipelagic layers of oceans, opportunistically targeting fish, crustaceans, cephalopods, salps, and other marine animals (Dickson, 1996; Young et al., 1996, 1997; Itoh et al., 2011).

9.2 HISTORY

The history of the SBFT industry in Australia began in 1936 when Mr. Stanley Fowler from the Commonwealth Scientific Industrial Research Organisation (CSIRO) initiated a survey using a military plane and fishing vessels to assess tuna stocks. The survey was undertaken to stimulate economic development as, until that time, SBFT were largely unexploited (Serventy, 1956). The survey was interrupted during World War II when the survey vessel, *F.R.V. Warreen*, was commandeered by the Royal Australian Navy for use in the war effort. At the end of the war, the *Warreen* was recommissioned as a survey vessel until 1951 when the Royal Australian

Navy acquired the vessel again. The SBFT fishery survey was continued using the *F.R.V. Stanley Fowler*, and the first commercial SBFT trolling fishery is believed to have started in 1949 (Serventy, 1956).

During the 1950s the South Australian state government provided financial support for the building of the purse-seine vessel, *F.V. Tacoma*, in Port Fairy, Victoria (Plevin, 2000) from where it made its way west to Port Lincoln, South Australia. The *F.V. Tacoma* caught its first catch of 10 tonnes of SBFT in February 1953, which was sent to the local Boston Bay cannery near Port Lincoln. In 1956 the South Australian Government involved experts from the United States using the *F.V. Tacoma* in a survey to determine the extent of the tuna fish stock (Plevin, 2000). The results of the survey initiated an expansion of the tuna fishing industry and fishermen began to use poling, long-line, and purse-seine gear to catch SBFT.

The 1960s and 1970s witnessed a rapid and unregulated increase in SBFT fishing with record numbers of fish caught. Spotting planes were introduced to locate and direct fishing vessels to schools of SBFT. Fishing vessels evolved from wood to metal, and fishing effort further increased through cooperation between purse-seine and pole-fishing vessels resulting in significantly more SBFT landings (Campbell, 2001). Between the 1950s and 1970s the SBFT fishery started to become very important to both the Port Lincoln economy and the South Australian state economy with large numbers of local residents employed in the Port Lincoln tuna cannery.

In 1979, fishery biologists began to warn that the SBFT stock was fully exploited, that parental biomass was being reduced at an alarming rate (standing at only 30% of its pre-exploitation size at that time), and that poor recruitment of juvenile SBFT would result (Geen and Nayer, 1989). Despite these warnings, fishing effort was maintained and the Australian catch of SBFT reached a peak of 21,000 tonnes in 1982 (Geen and Nayer, 1989). An Australian federal government inquiry in 1983 subsequently found the fishery was biologically overexploited and heavily over-capitalized (Geen and Nayer, 1989). In 1984 the Australian federal government imposed Individual Transferable Quotas (ITQs) to control the fishery's expansion.

To reduce pressures on declining stocks internationally, the two other countries targeting SBFT at the time, Japan and New Zealand, also began to apply quotas in 1985. Continuing concerns about tuna stocks and excessive quotas set between 1984 and 1988 led the Australian, Japanese, and New Zealand governments to further reduce catch limits and introduce annual reviews (Geen and Nayer, 1989), and the three countries established a joint voluntary management arrangement in 1989 limiting the combined total yearly quota for all three countries to 11,750 tonnes (Geen and Nayer, 1989).

Management of SBFT take by Australia, Japan, and New Zealand was formalized in 1994 with the entering into force of the Convention for the Conservation of SBFT. The Convention formed the Commission for the Conservation of SBFT (CCSBT). Today there are six members of the

CCSBT: Australia, Japan, New Zealand, Republic of Korea, Indonesia, and Taiwan. The Philippines, South Africa, and the European Community are cooperating nonmembers (CCSBT, 2015a).

With Australia's introduction of SBFT catch limits, Port Lincoln fishermen quickly realized that to remain in business, the value of their SBFT catch would need to increase. With the lucrative Japanese sashimi market in mind, the Port Lincoln fishing industry began to investigate options for increasing SBFT yield through farming of wild tuna (Ellis, 2013). A study was undertaken by the Tuna Boat Owners Association of Australia, the Federation of Japan Tuna Fisheries Co-operative Association, and the Japanese Overseas Fishery Cooperation Foundation, with the support of the South Australian state government and the Australian federal government (Government of South Australia, 1993; Jeffriess, 1999). The study showed that Australian SBFT tended to be larger and more adaptable than tuna species found in the northern hemisphere, and it described handling techniques and farming technology for SBFT that could be easily applied by local fishermen.

On the basis of the study, the industry changed from poling individual SBFT into vessel tanks to the purse-seine capture of schools of SBFT for on-growing in static ranching pontoons. This change in catching approach was developed and established by the Lukin and Sons fishing company and facilitated the rapid expansion and development of the Port Lincoln tuna ranching industry. As Australian ranching of SBFT developed, international market prices for SBFT grew steadily to reach a peak in 2002, and an increased value of Australian SBFT in premium Japanese sashimi markets was realized.

9.3 SBFT CAPTURE METHODS

The current Australian harvest of SBFT generally targets 2- to 3-year-old fish using purse-seine gear within the Great Australian Bight during the Australian summer. Spotting aircraft direct chum vessels to schools of SBFT observed from the air. To lead SBFT schools close to vessels towing specialized pontoons, deckhands on the chum vessel cast thawed and live local baitfish (*Sardinops sagax*) into the water. Once the school of SBFT is in close proximity to the towing pontoon, a commercial purse-seine vessel encircles the chum vessel and the SBFT school with a purse-seine net measuring 1000 m long by 130 m deep. The purse-seine vessel then retrieves the purse cable that runs along the bottom of the net containing the chum vessel and SBFT school in a net "bowl". Before the purse-seine net is hauled in, the chum vessel leaves the net enclosure. Smaller vessels powered by outboard engines help to keep the purse-seine net open while it is hauled and at the same time the towing pontoon is moved to meet the purse-seine net containing the SBFT (Figure 9.2).

FIGURE 9.2 Purse-seine vessel F.V. Independence with majority of net on board with purse-seine net connected to tow pontoon while small vessels hold the net open.

Once the towing pontoon and net (150 mm Badinotti 450 ply net, 45 m diameter by 12 m deep) and the purse-seine net are alongside each other, commercially trained divers connect the enclosures via a specially designed underwater gate. The purse-seine net continues to be hauled on board the purse-seine vessel thereby reducing the swimming area for the SBFT to a point where they move through the underwater gate from the purse-seine net into the towing pontoon. The pontoon containing the fish is then slowly towed back to Spencer Gulf on a journey that can take up to 3 weeks. Stocking densities in the towing pontoon are generally between 5 and 10 kg/m^3 and the SBFT are fed baitfish during their transport as weather and sea conditions permit.

9.4 SBFT RANCHING

Ranching of SBFT occurs near Port Lincoln, South Australia within the clean waters of Spencer Gulf. The ranching area is contained in a designated Lincoln Aquaculture Zone covering an area of 27,385 ha comprising an inner and outer sector. Leased area within the inner sector is limited to 1825 ha and a maximum biomass of 10,500 t. The outer sector is limited to 5000 ha and a maximum biomass of 14,000 t. Water depth in the inner sector is between 20 and 24 m and wind driven swells are generally 1–2 m. Water depths in the outer sector are between 40 and 50 m and oceanic swells tend to be between 2 and 2.5 m. Water temperatures across the zone reach a high of 23°C in summer and fall to 13°C in winter.

Leases and licenses for SBFT aquaculture are allocated by the state government agency, Primary Industries and Regions South Australia (PIRSA) through an Aquaculture Tenure Allocation Board. An individual or company must own a minimum of 60 t of tuna quota to be eligible for a lease. Lease sites are generally allocated at 1 ha per 3 t of tuna quota. A series of environmental performance measures must be met by operators annually to maintain lease access (PIRSA, 2015a,b,c).

Towing pontoons containing schools of SBFT netted in offshore waters are transported to the allocated ranching sites, where samples of 100 fish are taken from each tow pontoon by baited hook and handline. The length and weight of each sampled fish are recorded and an average weight for the 100 fish sample is determined. Following sampling, each towing pontoon is paired with a static ranching pontoon and the SBFT are encouraged through a gate (measuring 3 m × 3 m) by the hydraulic hauling of strategically placed ropes to dry the towing pontoon (Figure 9.3). Static ranching pontoons are typically 45 m in diameter and made up of a 450 mm diameter polyethylene buoyancy ring supporting a 415 ply knotless net (150 mm stretched mesh) with 10 m deep walls creating an enclosure of 15,906 m^3.

As the SBFT swim through the transfer gate from the towing pontoon into the static ranching pontoon they are observed and manually counted via video. Once the transfer is complete, the number of SBFT in each ranching pontoon is multiplied by the average sampled weight and total tonnage is recorded against the company's Statutory Fishing Rights represented as quota for the season managed by the Australian Fisheries Management Authority.

FIGURE 9.3 Tow pontoon connected to static ranching pontoon and SBFT being herded through transfer gate by the hauling of strategically placed ropes.

When the SBFT first arrive in the ranching pontoon, their appetite is voracious. To optimize growth, commercially ranched SBFT are generally fed two times per day, 6 days per week for up to 8 months as weather conditions allow (Gunn et al., 2002; Ellis, 2013). As water temperatures cool with the changing seasons, the appetite of the fish decreases (Glencross et al., 2002).

SBFT are harvested for processing as chilled/fresh or super frozen product. Harvesting involves the fish being crowded into a small purse-seine net within the static ranching pontoon where they are manually caught by divers and passed onto a fish travelator conveying them to the deck of a harvest vessel (Figure 9.4).

At the harvest vessel, the fish are slaughtered by a spike through the brain, followed by coring of the brain and insertion of a fiberglass rod into the exposed spinal column to destroy the central nervous system. SBFT are then bled by severing lateral blood vessels located close to the skin in the pectoral fin recess, and the gill basket and viscera are removed. The slaughtering process usually lasts less than 30 s. Harvested SBFT are placed in ice slurry and transported either to Japanese tuna longline/factory vessels for super freezing at −65°C or to onshore-processing facilities for chilled harvest or super freezing.

Ranching wild caught SBFT enables significant improvement to the value of harvested product through regular feeding over a relatively short time frame. The practice effectively doubles the pre-ranching weight of fish (Carter et al., 2010) and promotes fish conditioning (protein and fat content) attractive to the premium sashimi market. Japan consumes most of Australia's ranched

FIGURE 9.4 Diver catching a SBFT during harvest and placing it into a fish travelator.

FIGURE 9.5 Feeder cage moored in the middle of a static ranching pontoon.

SBFT , but in recent years markets for Australian ranched SBFT have grown domestically as well as in Korea, China, Singapore, and the United States.

9.5 FEEDING METHODS

When SBFT ranching in Australia first began, ranched fish were fed fresh and thawed baitfish delivered manually by shovel. As the ranching effort expanded and greater numbers of hungry SBFT required feeding, alternative methods of delivering food were developed. Feeding methods now include: fish pumps that transfer thawed baitfish to the center of a pontoon via a buoyed pipe; siphons that suck thawed or fresh baitfish from fish bins through an extended pipe to the center of the ranching pontoon; and the two methods currently most commonly employed in Australia's SBFT ranching industry, hydraulic rotating disc feeders and feeder cages.

The rotating disc feeder developed by Sarin Marine Farm spins thawed or freshly caught baitfish into the ranching pontoon. This method allows large volumes of fresh caught sardines to be delivered over a large area, thereby reducing feeding competition and scavenging from seabirds.

Feeder cages are small, lidded enclosures made of weld mesh or nylon netting moored in the center of a ranching pontoon (Figure 9.5). Frozen baitfish placed in the cage fall through the bottom of the cage as they thaw. This feeding technique has been significantly improved by the Blaslov Tuna Farming Company in partnership with AQ1 Systems, enabling feed to be monitored and regulated according to the appetite of the ranched SBFT using underwater cameras, and a door that can be opened and closed via a video link.

9.6 NUTRITION AND FEED MANAGEMENT

Ranched SBFT in Australia are generally fed baitfish. More than 20 species of domestic and internationally caught baitfish are used in the ranching industry (Ellis and Rough, 2005; van Barneveld and Ellis, 2007), although the local sardine (*Sardinops sagax*) accounts for over 50% of ranching feed requirements.

The size of individual baitfish used for feed is variable and proximate nutritional content ranges from <1 to 20% lipid and 13.3 to 20.1% protein (Ellis and Rough, 2005). Evidence shows that, depending on size, an individual SBFT can consume over 3 kg (or approximately 10% body weight) of baitfish per day during peak feeding periods (Ellis, 2013). An individual SBFT fed manufactured feeds (rather than baitfish) during the same period will only consume a maximum of 1.8 kg of feed per day (van Barneveld and Ellis, 2007; Ellis, 2013). It is hypothesized that the binding of manufactured feed, differences in feeding regimes, and relative absorption of nutrients, and the fat coating on manufactured feed pellets may influence the quantity of manufactured feed consumed by ranched SBFT (van Barneveld and Ellis, 2007).

The nutritional requirements of SBFT are not well determined. A small number of studies have investigated requirements based on the nutritional content of baitfish (Gunn et al., 2002; Ellis and Rough, 2005; van Barneveld and Ellis, 2007; Ellis, 2013), but most information is derived largely from analysis of manufactured feed (Clarke et al., 1997; Carter et al., 1998; Glencross et al., 1999, 2002; van Barneveld et al., 1999, 2009; Gordon et al., 2006a,b; van Barneveld and Ellis, 2007).

Species used in baitfish feed tend to be mixed to improve fish growth and product quality, the composition of the species mix often being determined by the preference, or "gut feel" of the farmer. Some farmers prefer to feed high lipid diets early in the ranching season (when feeding intake is high) to "pack the weight on" and condition SBFT for early marketing opportunities. Some farmers prefer to feed SBFT with low lipid/high protein baitfish species blends to allow the length of the SBFT to increase before switching to high lipid diets later in the ranching season to condition fish in the last phase of the grow-out cycle (Ellis, 2013). Other farmers prefer consistent use of a medium lipid/medium protein baitfish species blend throughout the ranching season, and some farmers associated with companies that own sardine fishing vessels only use local sardines for feed. The software program, "Formubait," has been developed to assist farmers determine the composition of baitfish feed to optimize production based on feed cost and fish growth (van Barneveld and Ellis, 2007).

The quality of SBFT product is assessed on its fat content, color, texture, chemical residue, and shelf life. To realize the full value of market-ready SBFT , Australia's tuna industry has invested heavily in research into feed that promotes quality but leaves little residue (Padula et al., 2007). Vitamins, in particular vitamins E, C, and selenium, and naturally occurring antioxidants have been shown to improve SBFT flesh color while increasing product shelf life (Thomas, 2007). These vitamins and antioxidants are provided by fresh local baitfish (Thomas et al., 2009), or can be delivered as supplements injected into baitfish feed using an Accujector 450 (D'Antignana et al., 2008), or included in manufactured diets.

There have been attempts over a number of years to fully replace baitfish feed with manufactured diets for ranched SBFT in Australia (Clarke et al., 1997; Carter et al., 1998; Glencross et al., 1999, 2002; van Barneveld et al., 1999, 2009; Gordon et al., 2006a,b; van Barneveld and Ellis, 2007). Most attempts have been unsuccessful due to problems with the weaning of SBFT to an "artificial" food source, the physical form and ingredients of manufactured diets, and manufacturing costs (van Barneveld and Ellis, 2007).

9.7 RANCHED SBFT HEALTH

Fish health has been a focus since the beginning of tuna ranching in Australia. The first comprehensive study of ranched SBFT identified four parasites of particular concern to SBFT in ranching environments: a scuticociliate (*Uronema nigricans*), copepods (*Caligus sp.*), blood fluke (*Cardicola forsteri*), and gill fluke (*Hexostoma thynni*) (Nowak et al., 2003).

Uronema nigricans, more recently identified as *Miamiensis avidus* (Nowak et al., 2013), is a scuticociliate parasite that causes fish mortality through "swimmers disease," a disease causing SBFT to swim erratically with sharp head movements at the water's surface. SBFT tend to be infected with this parasite when water temperatures are low. The reservoir(s) for this parasite is unknown.

Sea lice (*Caligus chiastos)* is associated with eye damage in SBFT . It is thought that sea lice either graze directly on the cornea of the SBFT , or that SBFT self-injure as they rub against pontoon nets in an attempt to remove the lice (Hayward et al., 2008, 2009, 2010). The reservoir of sea lice infecting ranched SBFT is a fish species (Degen's leatherjackets, *Thamnaconus degeni*) that scavenges on waste tuna feed (Hayward et al., 2011). To manage this parasite, farmers closely manage feed quantities and maximize the distance between the bottom of the net enclosure and sea floor (Kirchhoff et al., 2011a,b,c).

Blood flukes (*Cardicola forsteri)* infect ranched SBFT within 6−8 weeks of their confinement in the ranching pontoon (Aiken et al., 2006) and have been responsible for a significant number of mortalities in ranched SBFT (Nowak et al., 2013). Blood fluke is a sanguinicolid requiring two hosts to complete its life cycle: the terrebellid polychaete (*Longicarpus modestus)* and SBFT (Cribb et al., 2011). To manage blood fluke infections, praziquantel is dissolved in a solution of propylene glycol and water, injected into freshly caught sardines (*Sardinops sagax*) using an Accujector 450, and fed to ranched SBFT under veterinary supervision. This treatment does not leave residue, it has shown to significantly reduce the prevalence of adult blood flukes in SBFT hearts and minimize blood fluke infections, and SBFT readily accept the treated feed (Hardy-Smith et al., 2012). Blood fluke is also managed by locating SBFT ranching pontoons in deeper waters (between 40 and 50 m) to increase the distance between the ranched SBFT and the seafloor (Kirchhoff et al., 2011c) where the intermediate host lives in broken shell deposits. Together these treatments have been responsible for reducing mortalities of ranched SBFT from approximately 15% in 2010 to less than 1% in 2014.

The gill fluke, *Hexostoma thynni*, and gill copepods, *Pseudocycnus appendiculatus* and *Euryphorus brachyterus*, have also been identified in ranched SBFT but no relationship between the presence of these parasites and SBFT health has been observed (Nowak et al., 2010).

9.8 THE FUTURE OF SBFT RANCHING IN AUSTRALIA

Since 1990, Australian production of SBFT through ranching has grown steadily (Figure 9.6). SBFT ranching is now the single-most valuable sector of South Australia's aquaculture industry (PIRSA, 2012). Up to 9,000 tonnes of gilled and gutted SBFT are now produced annually with an estimated annual value of between AUD$150−$300 million (PIRSA, 2012). The SBFT ranching industry is a significant employer: more than 1,000 full-time

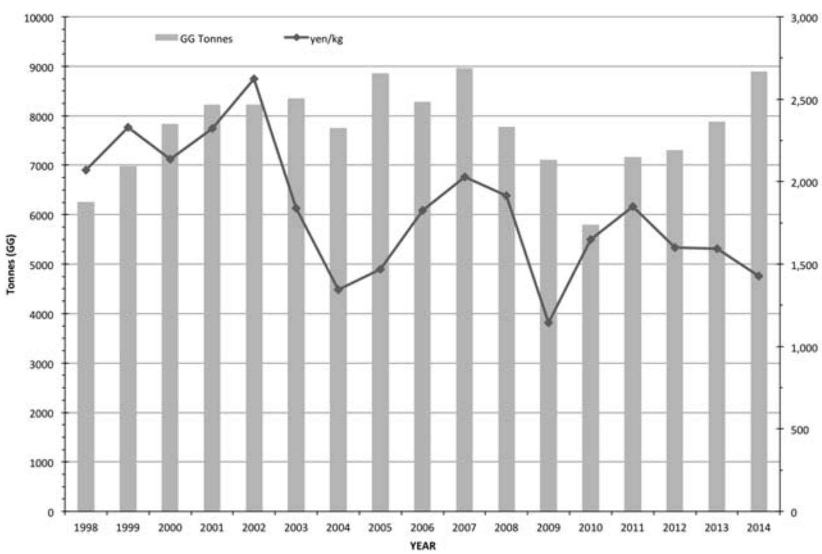

FIGURE 9.6 SBFT production volume and value. *Data provided by the Australian Southern Bluefin Tuna Industry Association.*

equivalent jobs were directly and indirectly generated by the industry in 2009/2010 (Econsearch, 2011).

To become the economic success that it is today the development of SBFT ranching in Australia has had to overcome a number of challenges. In 1996, in the early days of the industry, a mass mortality occurred coinciding with the remnants of a tropical cyclone that swept across southern Australia (Munday and Hallegraeff, 1998).

Rapid growth in the industry between 1996 and 2002 was possible with refinement of husbandry techniques, high demand from the Japanese sashimi market, limited competition, and high product values (peaking at an average of ¥2650 per kg) (Figure 9.6).

However in 2002, as commercial quantities of ranched bluefin tuna began to be produced by Japan, Mexico, and countries surrounding the Mediterranean Sea, an over-supply of premium quality bluefin product began to flood the market. Compounded by the global financial crisis in 2009, international market prices for ranched SBFT steeply declined (Figure 9.6). Since 2009, the price of ranched SBFT in the Japanese market has stabilized around ¥1500 per kg (Figure 9.6).

As the sustainability of global stocks of SBFT comes under increasing scrutiny, Australia's SBFT ranching industry will need to continue to evolve to maintain viability and success. Fundamental to the sustainability of the industry is the growing understanding of wild SBFT stocks and SBFT ecology (CCSBT, 2015b). On this foundation, future challenges include the need to diversify markets both domestically and internationally, improvements in product quality that will enable extended shelf life, and development of better links between production and market preferences. Fish health will remain a critical determinant in productivity, and greater understanding of the nutritional requirements of SBFT will help to minimize production costs through optimized feeding strategies (Montague et al., 2008).

Key to the future of SBFT ranching in Australia, however, is the replacement of baitfish feed with manufactured diets. The single biggest cost to SBFT ranching operations is feed. There are significant biosecurity risks and strict quarantine import requirements that must be met for imported baitfish. The nutritional content of baitfish feed is variable (Ellis and Rough, 2005), quantities of catch and timing of delivery of baitfish feed are often unpredictable, and freight costs are high. The use of manufactured feed in the SBFT ranching industry will allow a reliable, consistent, and more cost-effective feed source free from biosecurity risks. It will also better enable the industry to tailor SBFT products to market preferences while maintaining optimal health of fish through improved nutrition and husbandry practices. Current Australian research into manufactured feed shows promising results and may shape the development of the Australian SBFT ranching industry in the years ahead (Plentex, 2015).

9.9 CONCLUSION

Australia's SBFT ranching industry developed out of concerns about the impacts of wild harvest on SBFT populations and the need for technical innovation to enhance product value. Ranching of SBFT caught in the clean waters of the Great Australian Bight off southern Australia adds significant value to harvested products through regular feeding, effectively doubling the pre-ranching weight of fish over a relatively short time frame, and promoting product quality attractive to the premium sashimi market. The industry now earns hundreds of millions of dollars for local, regional, and national economies. While significant advances have been made in developing knowledge and technologies to support improvements in fish health, product quality, nutrition, and feed management, the future of the SBFT ranching industry in Australia depends on furthering understanding of SBFT populations, health, and nutritional requirements, in addition to continuing innovation in product development and manufactured feeds.

REFERENCES

Aiken, H.M., Hayward, C.J., Nowak, B.F., 2006. An epizootic and its declines of a blood fluke, *Cardicola forsteri*, in farmed southern bluefin tuna, *Thunnus maccoyii*. Aquaculture 254, 40–45.

Altringham, J.D., Shadwick, R.E., 2001. Swimming and muscle function. In: Block, B.A., Stevens, E.D. (Eds.), Tuna Physiology, Ecology, and Evolution. Academic Press, San Diego, pp. 313–344.

Attenborough, D., 1979. Life on Earth. Little, Brown and Company, Boston.

Brill, R.W., 1996. Selective advantages conferred by the high performance physiology of tunas, billfish, and dolphin fish. Comp. Biochem. Physiol. 113A, 3–15.

Bushnell, P.G., Jones, D.R., 1994. Cardiovascular and respiratory physiology of tuna: adaptations for support of exceptionally high metabolic rates. Environ. Biol. Fish. 40, 303–318.

Campbell, D., 2001. Change in fleet capacity and ownership of harvesting rights in the Australian southern bluefin tuna fishery. In: Shotten, R., (Ed.), Case Studies on the Effects of Transferable Fishing Rights on Fleet Capacity and Concentration of Quota Ownership. FAO Fisheries Technical Paper 412, pp 134–150.

Carter, C.G., Seeto, G.S., Smart, A., Clarke, S., van Barneveld, R.J., 1998. Correlates of growth in farmed juvenile southern bluefin tuna Thunnus maccoyii (Castelnau). Aquaculture 161, 107–119.

Carter, C., Nowak, B., Clarke, S., 2010. The tunas (Family: Scombridae). In: Le Francois, N.R., Jobling, M., Carter, C., Blier, P. (Eds.), Finfish Aquaculture Diversification. CAB International, Wallingford, pp. 432–449.

de Castelnau, F., 1872. Contribution to the ichthyology of Australia. Proc. Zool. Acclim. Soc. Vict. 1, 29–248.

CCSBT, 2015a. Origins of the convention Commission for the Conservation of Southern Bluefin Tuna. <http://www.ccsbt.org/site/origins_of_the_convention.php> (viewed May 2015).

CCSBT, 2015b. Origins of the convention Commission for the Conservation of Southern Bluefin Tuna. <http://www.ccsbt.org/site/research.php> (viewed May 2015).

Clarke, S., Smart, A., van Barneveld, R., Carter, C., 1997. The development and optimisation of manufactured feeds for farmed southern bluefin tuna. Austasia Aquaculture 11 (3), 59–62.

Collette, B.B., Nauen, C.E., 1983. FAO Species Catalogue. Vol. 2. Scombrids of the World. An Annotated and Illustrated Catalogue of Tunas, Mackerels, Bonitos and Related Species Known to Date. Food and Agriculture Organization of the United Nations, Rome.

Cribb, T.H., Adlard, R.D., Hayward, C.J., Bott, N.J., Ellis, D., Evans, D., et al., 2011. The life cycle of *Cardicola forsteri* (Trematoda: Aporocotylidae), a pathogen of ranched southern bluefin tuna, Thunnus maccoyii. Int. J. Parasitol. 41 (8), 861–870.

D'Antignana, T., Thomas, M., Bowyer, J., Chick, R., Thomas, P., 2008. Provide a Baitfish Supplement Diet for the Effective Delivery of Specific Nutrient Requirements to Juvenile Farmed SBT (*Thunnus maccoyii*) Aquafin CRC Project 2.2(2) (FRDC Project No. 2004/209).

Dewar, H., Graham, J.B., 1994. Studies of tropical tuna swimming performance in a large water tunnel—Energetics. J. Exp. Biol. 192, 13–31.

Dickson, K.A., 1996. Locomotor muscle of high-performance fishes: what do comparisons of tunas with ectothermic sister taxa reveal?. Comp. Biochem. Physiol. 113A (1), 39–49.

Econsearch. 2011. The Economic Impact of Aquaculture on the South Australian State and Regional Economies, 2009/10. <http://pir.sa.gov.au/__data/assets/pdf_file/0005/237227/AquaImpacts10_Final_110617.pdf>.

Ellis, D., Rough, K., 2005. Quality and Nutritional Evaluation of Baitfish used for SBT Farming (Including Baitfish Profiles). Aquafin CRC, Adelaide.

Ellis, D., 2013. The measurement of visceral temperature patterns and implications for feeding practices in ranched southern bluefin tuna *Thunnus maccoyii*. Unpublished MSc thesis.

Fitzgibbon, Q.P., Frappell, P., Clark, T., Buchanan, J., Ellis, D., Carter, C., et al., 2008. Activity Metabolism in Live-Held Southern Bluefin Tuna (*Thunnus maccoyii*). Aquafin CRC Project 1 A.7 (2), (FRDC Project No. 2005/200). SARDI, South Australia.

Geen, G., Nayer, M., 1989. Individual Transferable Quotas and the Southern Bluefin Tuna Fishery, Economic Paper. Occasional Paper 105, Project 62336. Australian Publishing and Printing Co, Fyshwick, A.C.T.

Glencross, B.D., van Barneveld, R.J., Carter, C.G., Clarke, S.M., 1999. On the path to a manufactured feed for farmed southern bluefin tuna. World Aquaculture Mag. 30 (3), 42–47.

Glencross, B.D., Clarke, S., Buchanan, J., Carter, C.G., van Barneveld, R.J., 2002. Temporal growth patterns of farmed juvenile southern bluefin tuna, *Thunnus maccoyii* (Castelnau) fed moist pellets. J. World Aquaculture Soc. 33, 138–145.

Gordon, R., Bayly, G., Foster, C., 2006a. Commercialisation Trials for a Manufactured Feed. Aquafin CRC Project 1 A.3, (FRDC Project No. 2001/201). Printed by SARDI, South Australia.

Gordon, R., Bayly, G., Foster, C., 2006b. Industry report on commercial pellet trial on southern bluefin tuna (*Thunnus maccoyii*) Skretting Australia, Cambridge, Tasmania.

Government of South Australia, 1993. Report on the Joint Feasibility Study Project for Southern Bluefin Tuna Farming in Boston Bay, Port Lincoln, South Australia. Government of South Australia, Tuna Boat Owners Association of Australia, Overseas Fishery Cooperation Foundation.

Gunn, J., Hartog, J., Rough, K., 2002. Experimental Analyses of the Effects of Ration and Feeding Frequency on the Thermodynamics, Energetics, Growth and Condition of Farmed Southern Bluefin Tuna. Fisheries Research and Development Corporation Final Report, Project 97/363.

Hardy-Smith, P., Ellis, D., Humphrey, J., Evans, M., Evans, D., Rough, K., et al., 2012. In vitro and in vivo efficacy of anthelmintic compounds against blood fluke (*Cardicola forsteri*). Aquaculture 337, 39–44.

Hayes, E.A., 1997. A Review of the Southern Bluefin Tuna Fishery: Implications for Ecologically Sustainable Management. A TRAFFIC Oceania Report.

Hayward, C.J., Aiken, H.M., Nowak, B.F., 2008. An epizootic of Caligus chiastos on farmed southern bluefin tuna *Thunnus maccoyii* off South Australia. Dis. Aquat. Org. 79, 57–63.

Hayward, C.J., Bott, N.J., Nowak, B.F., 2009. Seasonal epizootics of sea live, Caligus spp., on southern bluefin tuna, *Thunnus maccoyii* (Castelnau), in a long-term farming trial. J. Fish Dis. 32, 101–106.

Hayward, C.J., Ellis, D., Foote, D., Wilkinson, R.J., Crosbie, P.B.B., 2010. Concurrent epizootic hyperinfections of sea lice (predominantly *Caligus chiastos*) and blood flukes (*Cardicola forsteri*) in ranched southern bluefin tuna. Vet. Parasitol. 173 (1–2), 107–115.

Hayward, C.J., Svane, I., Lachimpadi, S.K., Itoh, N., Bott, N.J., Nowak, B.F., 2011. Sea lice infections of wild fishes near ranched southern bluefin tuna (*Thunnus maccoyii*) in South Australia. Aquaculture 320, 178–182.

Itoh, T., Kemps, H., Totterdell, J., 2011. Diet of young southern bluefin tuna (*Thunnus maccoyii*) in the southwestern coastal waters of Australia in summer. Fish Sci. 77, 337–344.

Jeffriess, B., 1999. Growout of Southern Bluefin Tuna. Fisheries Research and Development Corporation, Project No. 91/56.

Kirchhoff, N.T., D'Antignana, T., Leef, M., Hayward, C.J., Wilkinson, R.J., Nowak, B.F., 2011a. Effects of immunostimulants on ranched southern bluefin tuna *Thunnus maccoyii*: immune response, health and performance. J. Fish Biol. 79, 331–355.

Kirchhoff, N.T., Leef, M.J., Ellis, D., Purser, J., Nowak, B.F., 2011b. Effects of the first two months of ranching on the health of southern bluefin tuna *Thunnus maccoyii*. Aquaculture 315, 207–212.

Kirchhoff, N.T., Rough, K.M., Nowak, B.F., 2011c. Moving cages further offshore: effects on southern bluefin tuna, *T. maccoyii*, parasites, health, and performance. PLoS ONE 6 (8), e23705.

Lagler, K.F., Bardach, J.E., Miller, R.R., May Passino, D.R., 1977. Ichthyology, second ed. John Wiley and Sons, Brisbane.

Magnuson, J.J., 1978. Locomotion by scombrid fishes: hydromechanics, morphology, and behaviour. In: Hoar, W., Randall, D.J. (Eds.), Fish Physiology, vol. 7. Academic Press, New York, pp. 239–313.

Montague, P., Downes, E., Ham, J., 2008. Achievements and Impacts (2001–2008), the Cooperative Research Centre for the Sustainable Aquaculture of Finfish. Stallard and Potter, Adelaide.

Munday, B.L., Hallegraeff, G.M., 1998. Mass mortality of captive southern bluefin tuna (*Thunnus maccoyii*) in April/May 1996 in Boston Bay, South Australia: A complex diagnostic problem. Fish Pathol. 33 (4), 343–350, 1998.10.

Nowak, B.F., Rough, K., Ellis, D., Crane, M., Cameron, A., Clarke, S., 2003. A Risk Assessment of Factors Influencing the Health of Southern Bluefin Tuna. FRDC 2001/253. Aquafin CRC, Adelaide.

Nowak, B.F., Evans, D., Ellis, D., Wilkinson, R., Porter, M., Crosbie, P., et al., 2010. Improving Husbandry and Performance of Southern Bluefin Tuna Through Better Understanding of the Relationship Between Fish Stress and Health. Aquafin CRC, Adelaide.

Nowak, B., Ellis, D., Kirchoff, N. (Eds.), 2013. Understanding Parasites And Investigating Ways to Mitigate their Influence on SBT Production. FRDC 2008/228. University of Tasmania.

Padula, D.J., Daughtry, B.J., Phua, S.T.G., Balshaw, S., 2007. Management of Food Safety Hazards in Farmed Southern Bluefin Tuna to Exploit Market Opportunities. Aquafin CRC, Adelaide.

Patterson, H., Begg, G., Curtotti, R., Vieira, S., 2009. Southern bluefin tuna fishery. In: Wilson, D.T., Curtotti, R., Begg, G.A. (Eds.), Fishery Status Reports 2009 − Status of Fish Stocks and Fisheries Managed by the Australian Government. Union offset printers, Canberra, A.C.T., Canberra, pp. 422−433.

Patterson, H., Begg, G., Hormis, M., 2010. Southern bluefin tuna fishery. In: Woodhams, J., Stobutzki, I., Vieira, S., Curtotti, R., Begg, G. (Eds.), Fishery Status Reports 2009 − Status of Fish Stocks and Fisheries Managed by the Australian Government. Union offset printers, Canberra, ACT, Canberra, pp. 359−367.

PIRSA, 2012. <http://www.pir.sa.gov.au/aquaculture/aquaculture_industry/tuna>. (viewed April, 2012).

PIRSA, 2015a. <http://pir.sa.gov.au/aquaculture/leasing_and_licensing/marine_license_holder_responsibilities> (viewed May 2015).

PIRSA, 2015b. <http://www.legislation.sa.gov.au/LZ/C/R/AQUACULTURE%20REGULATIONS%202005.aspx> (viewed May 2015).

PIRSA, 2015c. <http://www.legislation.sa.gov.au/LZ/C/A/AQUACULTURE%20ACT%202001/CURRENT/2001.66.UN.PDF> (viewed May 2015).

Plentex, 2015. Local demand for aquafeed. <http://www.plentex.com.au/irm/content/local-demand-for-aquafeed1.aspx?RID = 347> (viewed July, 2015).

Plevin, J.E., 2000. MFV Tacoma and the Haldane family, viewed January 18, 2012. <http://tacoma.org.au/documents/Tacoma_Haldane_History.pdf>.

Serventy, D.L., 1956. The southern bluefin tuna, *Thunnus thynnus maccoyii* (Castelnau), in Australian waters. Aust. J. Marine Freshw. Res. 7, 1−43.

Thomas, P., 2007. Maximising the Control of Quality in Farmed SBT. Aquafin CRC, Adelaide.

Thomas, P., Thomas, M., Schuller, K., D'Antignana, T., 2009. Application of the use of Dietary Supplements for Improving Flesh Quality Attributes of Farmed SBT. Aquafin CRC, Adelaide.

van Barneveld, R., Ellis, D., 2007. Practical Nutrition of Farmed Southern Bluefin Tuna Thunnus maccoyii. Aquafin CRC, Adelaide.

van Barneveld, R.J., Carter, C.J., Tivey, D.R., Brooker, J.D., 1999. Development of an Invitro Assay for the Assessment of Alternative Protein Sources for Use in Artificial Diets for Farmed Southern Bluefin Tuna (*Thunnus maccoyii*). Fisheries Research and Development Corporation Final Report, Project 95/068.

van Barneveld, R.J., Buchanan, J., Ellis, D., 2009. Optimisation of Farmed Southern Bluefin Tuna (Thunnus maccoyii) Nutrition to Improve Feed Conversion Efficiency and Reduce Production Costs. Aquafin CRC, Adelaide.

Wardle, C.S., Videler, J.J., Arimoto, T., Franco, J.M., He, P., 1989. The muscle twitch and the maximum swimming speed of giant bluefin tuna, *Thunnus thynnus L.* J. Fish Biol. 35, 129−137.

Young, J.W., Bradford, R.W., Lamb, T.D., Lyne, V.D., 1996. Biomass of zooplankton and micronekton in the southern bluefin tuna fishing grounds off eastern Tasmania, Australia. Mar. Ecol. Prog. Ser. 138, 1−14.

Young, J.W., Lamb, T.D., Le, D., Bradford, R.W., Whitelaw, A.W., 1997. Feeding ecology and interannual variations in diet of southern bluefin tuna, *Thunnus maccoyii*, in relation to coastal and oceanic waters off eastern Tasmania, Australia. Environ. Biol. Fish. 50, 275−296.