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MARINE SCIENCE ASSESSMENT OF
CAPTURE-BASED TUNA (*Thunnus orientalis*)
AQUACULTURE IN THE ENSENADA
REGION OF NORTHERN BAJA
CALIFORNIA, MEXICO

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Tuna ranch in northern Baja California, Mexico

Final Report of the Binational Scientific Team¹ to the Packard Foundation

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Background and Objectives of the Study

We assembled an experienced group of international scientists¹ in fisheries, aquaculture and the social sciences to conduct a marine science assessment of capture-based tuna aquaculture (CBTA) in Mexico. The binational group conducted multidisciplinary reviews of bluefin tuna and Pacific sardine fishing and ranching as impacted by CBTA in order to inform the bluefin tuna and sardine fisheries/aquaculture policy, science, and government communities in Mexico and internationally. The work was based over approximately a 2-year period at the Universidad Autonoma de Baja California (UABC) in Ensenada, Mexico, with contributions from multiple Mexican and US institutions.

This scientific assessment of the status of CBTA in the Ensenada region of Baja California, Mexico includes a review of all available published and unpublished data sources as well as from extensive interviews with stakeholders, but cannot be considered complete since not all of the data sources in government, on ranches, or in the offices of multinational corporations were available to the team. Our science team relied upon published and unpublished studies that were made available upon request; as such, we can only capture available details in 2006-2007. CBTA ranches are complex and dynamic, and even if a complete information base was available to us, we believe this review presents an accurate as possible story, since we have brought together many recent studies from Mexico and elsewhere, and have identified what is known or not. Plus, we have given our collective, expert scientific opinions on this information, so that we have identified knowledge gaps, and made recommendations for future directions.

This report is based upon findings of the multidisciplinary assessments regarding the current situation of Northern Pacific bluefin tuna farming in Mexico and identifies current status of Mexican tuna and sardine stocks, and aquaculture culture practices, plus presents knowledge gaps and recommended actions. The main objectives of these studies were to conduct:

- I. Fisheries Assessments of Tuna and Sardines: Assemble, analyze, and synthesize the existing scientific basis of Pacific tuna and sardine stocks in terms of fish abundances, distributions, size classes, migration patterns, fishing pressure, and impacts of capture-based tuna aquaculture.
- II. Aquaculture Assessments: Husbandry, aquaculture production networks, management structures, live feed and nutrition issues; environmental impacts; disease reports, management and control procedures.
- III. Governance and Social Assessments: Assemble, analyze, and synthesize the existing locations and document sites; current governance and regulatory frameworks, access rights, quotas and farm leases, worker conditions, labor issues, entitlements, transferability schemes, and permitting issues. Conduct social science evaluations of interactions between tuna and sardine fishers and tuna farming operations.

Executive Summary

Northern Bluefin Tuna (NBT, *Thunnus orientalis*) are found in the Eastern Pacific Ocean (EPO) from the Gulf of Alaska to southern Baja California and in the Western Pacific Ocean (WPO) from the Sakhalin Islands to the northern Philippines. They are usually oceanic but seasonally come close to shore, school by size, and tolerate a wide range of temperatures. They spawn in the WPO in the vicinity of Okinawa, Japan and the Philippine archipelago, then disperse to other areas of the WPO. Some fish apparently remain their entire lives in the WPO, while others migrate to the EPO during their first and second years of life. Fish in the EPO have an increasingly restricted north-south distribution as they grow older. Migrations between and within the WPO and EPO are related to oceanographic and prey conditions. Fish migrate back to the WPO between ages 2-3. During El Niño events, NBT are distributed further to the north in the EPO and catches decrease. Large impacts related to changes associated with global warming may limit the amount of NBT available off Baja California. Japan currently accounts for about 64% of the catch of NBT in the North Pacific Ocean (NPO). The other two nations involved in this fishery to a significant degree are Taiwan and Mexico. Catches historically have been 2-3 times higher in the WPO than in the EPO. The catch in the EPO in 2006 was ~10,000 metric tons (MT). Most of the catches in the EPO are fish of ages 1-3. Modeling studies have shown that a strong recruitment event occurred in 2001 and *could* maintain NBT spawning stock biomass until ~2010. The results of yield-per-recruit and cohort analyses indicate that greater catches in the NPO could be obtained if the catches of ages 0 and 1 fish were reduced or eliminated, mainly in the WPO. Increased fishing pressure on NBT juveniles from CBTA would not necessarily decrease recruitment, since spawner-recruit analyses indicate that the recruitment of NBT would not necessarily increase by permitting more fish to spawn. Even though fishing mortality (F) has been higher than F_{MAX} , or is above the reference point, recruitment overfishing has not occurred. Nevertheless, it is recommended that fishing mortality not be further increased and catches reduced. According to international institutions (IATTC, ISC and FAO), NBT is "Fully Exploited". NBT is *not* included on the IUCN red list. There is no scientific evidence that NBT are overfished in the NPO. Estimated

retained catches of NBT have fluctuated widely between 500 and 10,000 MT in the EPO over the last 30 years (from 1976 to 2006). Regarding the CBTA activity, there is no evidence that it has affected the NBT stock since its beginning in 1996. Considering that not all NBT migrate to the EPO, increasing the catch of NBT would not necessarily decrease recruitment. Current CBTA production levels do not appear to compromise the NBT stock. However, catches of NBT juveniles and fishing effort should be regulated and not be increased, both in the WPO and EPO.

Most of the capture-based tuna aquaculture (CBTA) facilities in Baja California use fresh, locally-caught Pacific sardine (*Sardinops sagax caerulea*) as feeds. Pacific sardines are oviparous, multiple-batch spawners that can reach a maximum size of 41 cm with a life span of 14 years. Fecundity is size and age dependent. Older fish spawn more times during a year, with spawning dependent on water temperatures. Most recent stock assessments show that the stock productivity of Pacific sardines (recruits, age-0 fish, per spawning biomass) is declining, with stock spawning biomass (age +1) leveling off at 1.06 million metric tons (MT) in 2005. Studies suggest that the equilibrium of the spawning stock biomass and potential sustainable yield are dependent on environmental conditions. Recruitment success is variable in long, decadal, time scales, depending on oceanographic conditions. There are three stocks of Pacific sardines. The sardine fishery based in Ensenada is the northern stock of this species. This stock is also fished by the USA and Canada. Other solely Mexican sardine fisheries comprise the southern and Gulf of California stocks. The fishery in Ensenada has traditionally been based on catches of small Pacific sardines of the northern stock. There are a high proportion of juveniles in these catches, since Ensenada vessels operate close to the coast (less than 40 nautical miles). Studies suggest that older and larger sardines move offshore where little fishing effort is currently occurring. Traditionally, the Mexican catch has been used for reduction to fishmeal and oil, canned for human consumption, or used fresh for bait. Landings of Pacific sardines at Ensenada increased from an annual average of 2,133 MT during the 1980s, to an average of ~48,000 MT in the 1990s. Landings decreased to ~41,000 MT during 2003 and 2004 and rose to 57,000 MT in 2006. Management of the Pacific sardine fishery in Mexico incorporates several measures, including minimal sizes, closed seasons, and moratoriums on efforts. Fresh Pacific sardines have become important resources for CBTA in Mexico. In 2006, ~53% of the Pacific sardines landed in Ensenada were used for CBTA. However, this is likely an underestimate. Some catches were not recorded when they were delivered directly to the CBTA cages. Recently, a new Baja California State sardine fisheries committee that included fishing and frozen fish processing companies was reorganized to include CBTA in the management of the Mexican portion of the northern Pacific sardine stock.

CBTA effects the marine environment and marine species associated with farm sites (sea mammals, marine birds, and marine organisms that inhabit the water column and benthos). Unconsumed or macerated sardines and fish feces are the main sources of solid, suspended, and soluble wastes. However, this waste stream is quite different from other, commercially fed finfish aquaculture such as salmon: tuna farming is seasonal; does not use antibiotics, chemicals, or any agricultural pesticides or additives; and it depends on natural feeds (sardines). Soluble nutrients are commonly detected only in close proximity to the tuna cages and dissipate rapidly. However, changes in the benthic

community derived from enrichment of waste organic matter to the sediments could be more persistent, and even a 6 month fallow period may not be sufficient for the benthic community to recover. The extent of the increase in benthic enrichment is still to be determined since accumulations of tuna farming wastes are strongly dependent on the hydrodynamics and oceanographic characteristics of the farm site, and farm management practices, and no such studies have been done. Non-lethal methods of controlling marine mammals, such as placing high nets and electrified wires around the cages have effectively discouraged sea lions. The non-lethal use of whips and sounds to reduce bird predation on sardines are additional, successful measures that ranchers have implemented to avoid conflicts with protected species. CBTA has a number of environmental, social and economic impacts which can be considered as positive or negative, as judged by society. CBTA is a new economic activity within the fisheries sector of Baja California, México which has brought new jobs. CBTA is closely monitored by the federal authorities, and the management is carried by the proper government agencies. A new Mexican law on sustainable fisheries and aquaculture addresses CBTA. All CBTA farms in Mexico are required by law to monitor marine water quality and sediments; monitoring programs must be verified by both the Mexican Navy and the Ministry of the Environment. To date, neither agency has declared any negative environmental action on any of the tuna farms. Governance of tuna ranching in Mexico is still underdeveloped; several issues need to be addressed in order to assure a minimum impact on the environment, especially in regards to better scientific determinations of the carrying capacity of each site, and development of better technological and management alternatives to reduce the impact of fish wastes on the benthos.

Chapter 1

Capture-Based Tuna Aquaculture (CBTA) in the Ensenada Region of Baja California, Mexico

Introduction

Tuna is one of the most important seafood commodities in the world with global production of ~3.5 million metric tons (MMT)/year, accounting for ~5% of the total fisheries for human consumption (FAO 2007). One third of the landed tuna is sold as fresh, chilled, or frozen fish and is exported to the major tuna markets of Japan, the United States, and the European Union (Paquotte 2003). The nations with largest tuna catches are Japan (33%), United States (13%), Taiwan, and South Korea. Other countries that fish tuna are Russia, Philippines, Ghana, France, Holland, Spain, Canada, Ecuador, Venezuela, Costa Rica, and México.

The US fleet began tuna fisheries in the eastern Pacific in 1906 and expanded to Baja California, Mexico, with the focus on the capture of yellowfin tuna and skipjack ("barrilete"). In the early 1900s white-fleshed tuna began to be marketed as an alternative to chicken, and international markets expanded rapidly. San Diego, California, USA and Ensenada, Baja California, Mexico soon became the major Pacific center for tuna fishing and canning to supply the new international markets.

In 1950, the first company devoted to the capture and processing of tuna was established in Ensenada. The Mexican fleet grew slowly until the 1980's when it became the most important fleet in the eastern Pacific Ocean (EPO), and Ensenada became the "tuna capital of Mexico" (Dreyfus *et al.* 2002). Due to the large bycatch of dolphins by Mexican tuna purse seiners, the USA placed an embargo on Mexican tuna, first in 1980, and second in 1990. As a result, thousands of Ensenada tuna fishermen lost their jobs, and Mexico lost more than US\$ 44 million annually from the export of about 30,000 metric tons (MT) of tuna (Buenrostro 1999). With the loss of its US export markets, the Mexican government first developed European export markets and then launched a very successful campaign to increase domestic tuna consumption. The Mexican tuna fleet relocated to the Mazatlan and Manzanillo ports in the southern Mexican Pacific, because these ports were closer to the main fishing areas and the new domestic markets that were created (Vaca-Rodriguez 2003). The USA embargo was lifted in 1997, but the damage had already been done to the tuna industry in the Ensenada region.

Today, the Pacific coast of Mexico supports large yellowfin tuna and skipjack fisheries, and tuna fisheries have the highest economic value after shrimp. Traditionally, tuna fishing has focused on yellowfin tuna, bonito, and skipjack tuna for the canning industry. Bluefin tuna has been considered incidental catch. Yellowfin tuna have provided a critically needed protein for the Mexican canned tuna market. In the late 1990's increased market demands in Japan for high quality northern bluefin tuna and the advent of new capture-based tuna aquaculture (CBTA) in the Mediterranean and Australia led to the first experiments with CBTA along the Pacific Coast of Baja California, Mexico.

In the Pacific Ocean, especially the Western and Central Pacific regions, there is great concern over the status of yellowfin and bigeye tuna stocks which are considered to be “vastly overfished” with failed management regimes (Petersen 2006) and substantial losses in potential economic returns (Kompas and Che 2006). In addition, there are concerns about the status of northern bluefin tuna stocks which are poorly known and, since 1996 are being targeted for the development of CBTA in Baja California, Mexico.

Unlike closed systems’ aquaculture, where organisms are bred from captive broodstock, fed formulated feeds (or nutrients) and reared in captivity (Costa-Pierce 2003), Mexican tuna operations use wild caught fish for stocks and feeds. FAO has termed this practice “capture-based aquaculture” (Ottolenghi *et al.* 2004).

CBTA is among the fastest growing forms of aquaculture in the world (FAO 2007). It is estimated that in the future 80% of tuna will come from aquaculture (Doumenge 2001). Northern Baja California in Mexico is well suited to CBTA due to its temperate weather conditions, proximity to the Los Angeles international airport in the USA, lack of hurricanes, an abundant supply of locally caught sardine feeds, favorable regulations, and low labor costs (Sylvia *et al.* 2002).

CBTA was started in Mexico in 1996 by Atunera Nair near Cedros Island south of Ensenada. This company produced 64 MT of ranched tuna over its 3 years of operation with marginal success. Adverse weather conditions such as El Niño events and Hurricane Nora and a general lack of experience with the operations led to high mortalities.

However, development of many innovative techniques by leading Mexican CBTA operations in recent years and moving operations further north to reduce the risk of hurricanes, has allowed some companies to emerge as significant international competitors in a relatively young, but growing industry. Most notable among these innovators is Mr. Philippe Charat, who left shrimp fishing on Mexico's Gulf Coast and began fishing tuna out of Ensenada in 1983. In 1997 Mr. Charat established Maricultura del Norte in the Ensenada region. Today, Maricultura del Norte is Mexico’s largest and most successful tuna farm (Anonymous 2005a).

In 2008, there are 10 government authorized concessions and one permit for CBTA for bluefin tuna in the vicinity of Ensenada (Figure 1), but only 9 are in operation (Table 1). Mexican law defines a difference between “permits” and “concessions”. Permits are short-term (up to five years) and can be renewed. Concessions are long-term (up to 20 years for a fishery, and up to 50 years for an aquaculture operation). In 2006, the CBTA farms exported 4,350 MT of tuna at an average price of US\$ 17,000/MT, producing an estimated US\$ 74 million (Table 2). The commercial value in 2005 was US\$ 80 million, about US\$ 21 million more than in 2004 due to better market prices (Bancomext 2005).

Operational Management

CBTA is a fishing activity where added value is obtained by fattening captured juvenile tuna with wild-caught Pacific sardines. From a technical/operational point of view,

CBTA can be broken into the following operational phases: 1) capture and transportation, 2) feeding/fattening, 3) harvesting and, 4) sale.

Capture and transportation

CBTA operations in northern Baja California, Mexico rely exclusively on wild Northern Pacific bluefin tunas (*Thunnus orientalis*) (NBT) for stocking. Nearly all of the NBT for the CBTA are captured by purse seiners in the EPO from the Pacific coast of Mexico between 23°N and 33°N, and within 100 nautical miles of the coast.

Purse seiners typically catch seasonally from June to September, depending on when and how long the fish reside off the coast of Ensenada. Purse seiners will travel 30-50 km offshore to find schools of tuna. The largest schools targeted for capture are typically two year old, 15-45 kg tuna (Sylvia 2007).

Once a tuna school is located, the boat is positioned on the side of the school while the net is released. The net is then pulled by the “pangon” (fast boat) at one end and by the tuna boat at the other to enclose the school. Once enclosed, the net is kept open until the arrival of a towboat with a tow pen. This procedure is one of the most critical since if the net closes or collapses, the fish can be damaged.

The towboat and tow pen travel at 3-4 knots with empty pens, depending on the type of tow pen being used. Once the boat is about a nautical mile from the catch, the “pangon” is launched towards the purse seine net. The towboat brings the tow pen towards the catching net to try to match the “door” of the tow pen to the “door” of the catching net. At that point towing rope from the tow pen is released from the towing boat and passed to the tuna boat, and the tow pen is tied to the purse seine net (Figure 2).

Conveying of tuna to the tow pen is done by lifting the capturing net to the tow pen, a process that is carried out very slowly. Divers manually open gates in the nets and herd the fish into the tow pen. Tuna are forced to pass through a tunnel formed by the two doors connecting the net and the tow pen, and fish pass from the net to the tow pen. During this procedure, a diver remains on the side of the doors filming the movement of fish from net to pen to quantify the total capture. Simultaneously, two other divers remain swimming both around the tow pen and the purse seine net to free entangled fish and to observe the species and amount of associated bycatch that was captured with the tuna in the purse seine in order to have an accurate knowledge of the contents of the tow pen.

Once all the tuna has been conveyed to the tow pen, its door is closed and the tow pen is released from the purse seine net. The towing boat then embarks on its trip to the CBTA farm (Figure 3). Towing may take days to weeks, depending on the distance between the capture zone and the farm. The tow boat travels at around 1 knot as far as 50 km to the CBTA farm. From this moment on the tuna are treated very carefully to reduce stress and increase their value, and several activities are conducted in route to better quantify the capture.

Some tuna are captured and sacrificed to record size and weight and, using data as well from the video filmed during the conveying of the tuna, estimates of the numbers and biomass of the catch are made. Care and maintenance given to the tuna during transportation is very important to reduce mortalities. During towing, tuna are fed daily with unfrozen sardines stored previously in the towboat. The amount of food given in this period is small, no more than 100 kg/day. Feeding of the tuna during the trip is done mainly to begin to acclimatize and train the animals to captivity and formulated diets. Manager observations indicate that the tuna tend to “relax” and gradually start accepting sardines during the trip. Frequent visual inspections are done on the pen both at the surface and underwater by divers. During these inspections any damage to the net is repaired, and entrapped or dead animals are removed. Captured sharks are also removed or killed to protect the tuna as well as the divers that work on the maintenance of the pen during transportation.

Upon arrival at the farm, two kinds of maneuvers take place: (1) anchoring of the tow pen; and (2) conveying of tuna from the anchored tow pen to the established fattening pen (Figure 4).

Grow-out cages are circular with a 30-40 m diameter of pontoon floats and 60-90 mm mesh nets that are 12-20 m in depth and set no less than 5 m from the bottom. Cages are stocked with 1,500-2,000 fish/cage (May 2002). In some cases, an outer 150-200 mm mesh predator net is placed around the inner net. The predator net acts as a barrier to keep sea lions, sharks, and other predators from eating and stressing the tuna. A freeboard net is used to prevent the tuna from jumping out of the cage. Many cages also have a handrail 1 m above the circumference of the cage making working around them easier. Each net must also have screw anchors placed into the sediment to hold the cage in place. All together each cage costs ~US\$ 80,000-100,000.

Feeding/fattening

CBTA in northern Baja California use Pacific sardines (Chapter 3) or mackerel, fresh or frozen, and occasionally squid, to feed the captured NBT. These species are preferred because they are part of NBT's natural diet and have a high lipid content. To obtain sardines, CBTA ranches in Baja California have either their own sardine boats, buy from sardine companies, or hire sardine boats to capture feed fish.

Pacific sardines occur in the waters off of Ensenada and are heavily fed on by migrating tuna (see Chapter 3; Baumgartner 2000). Baja California Mexico CBTA farms have the ability to feed their NBT fresh sardines and other clupeids from wild populations that occur naturally in large populations off the coast of Mexico.

Fresh food is the optimal food for NBT fattening because of its acceptance by the NBT as well as its quality. The availability of fresh sardines depends upon their presence at a relatively short distance from the CBTA farms. Sardines and mackerel have very limited storage times and degradation is rapid due to their high lipid contents.

By feeding the NBT fresh, oily sardines, and without the NBT swimming for miles chasing its food, the captured NBT meat becomes an oily, rosy red color, marbled with fat, increasing its quality and making it very valuable. The feeding of NBT varies during different periods of fattening. There are three phases: acclimation, initial feeding, and fattening.

Acclimation Phase: Recently captured NBT have to pass through an acclimation phase during which feeding and ingestion is low. This period lasts from transportation after capture to 3-4 weeks at the CBTA farm. During this acclimation period, sardines are placed in the cage to induce feeding.

Initial Feeding: At the beginning of this next stage, NBT are fed three times a day, with workers trying not to provide extra food to avoid its accumulation and decomposition at the bottom of the cage, and thus ripping of the net by other animals feeding through the net, leading to excessive operational costs. In order to verify the amount of food to be provided, visual observations are done at the surface and underwater. From the boat, workers observe when tuna stop eating and return to normal passive swimming around the pen. Underwater, divers observe tuna feeding below the surface as well as when the food reaches the end of the net uneaten.

One day a week the fish are not fed so that damage isn't done to their livers from overfeeding. Feeding techniques include: broadcast feeding where the sardines are manually shoveled into the cage; machine-feeding by conveyor belts that blow sardines out onto the surface of the cage; and feeding by a central pipe that introduces sardines into the water.

Fattening Phase: Commonly cages have stocking densities of $\sim 4 \text{ kg/m}^3$ (Aquaculture SA 2000) (range 2-5 kg/m^3 ; Rojas and Wadsworth 2007) and contain $\sim 1,500$ -2,000 fish/cage (May 2002). With water temperatures ranging from 14-17°C, feed conversion ratios (FCRs) are about 12:1 (Sylvia 2007). For *T. orientalis*, dry FCRs are reported to range from 1.9 to 5.9, and wet FCRs from 7 to 20 (Table 3).

Mortalities in the early stages of development of CBTA in Mexico were between 10-20% during transport (towing), and ~ 10 -15% during feeding and fattening (Lozano-Huguenin and Vaca-Rodriguez 2004). Presently, towing mortalities are between 1-3% and 6% during feeding and fattening (Anonymous 2005b). In South Australia, mortalities ranged between 3-3.25% for all of these stages (Fernandes et al. 2007).

The time from capture to harvesting depends on biological conditions as well as economic factors and can vary from 4 to 9 months. In the NBT CBTA farms in Baja California, animals are kept until reaching an increase in biomass of 30-35%. As tuna acclimate to captivity, the amount of food is increased, from a few kilograms of sardines in the beginning, to an amount representing 8-15% of the biomass of NBT in the cage. The frequency of feeding is reduced from three to two times a day, but the amount stays the same. In other words, the NBT eat less frequently but higher amounts are fed at each meal, increasing their sizes and fat reserves.

Normal routine maintenance is practiced on the cages and the NBT within them. These activities are very similar to those practices performed during the transportation: visual inspections to repair the net or to change the anchoring ropes; underwater inspections to check the condition of the cage as well as the condition of the NBT; divers removing any dead animals and keeping records on mortalities; drift or attached seaweeds removed from the side of the nets to maintain a better water flow through the cage. This maintenance is done two or three times a day during the fattening period.

Harvesting and Sale

The final stage of CBTA in Mexico is harvesting and selling the product. Unlike the traditional tuna fishery for canning that must sell its catch once it reaches the dock, farmed NBT can be sold whenever the market is best to make the most profit. CBTA ranchers carefully watch the Japanese tuna market. Ninety-five percent of the Mexican CBTA goes to Japan, with half of that going to the Tsukiji fish market. The other 5% of the NBT goes to the west coast of the USA (Apple 2002). A small amount also stays in Mexico.

Before harvesting, NBT are isolated into smaller groups to lower the risk of fish injuring each other and degrading the meat. A net is brought up below the fish, and divers grab individual NBT holding their tail and gills. The divers pass the fish to a barge where the fish is sacrificed with a spike through its head. NBT are bled by severing a main artery, and a fine steel wire is run down the fish's spinal cord to paralyze it and prevent flopping around. The gills are cut out and the carcass is dropped into a 0°C saline water solution. The entire harvest and slaughtering process is done extremely fast to keep the NBT meat in the best condition. If the fish become too stressed, lactic acid will build up in their muscles and degrade the flavor. If fish are allowed to flop around they can "burn" the meat due to their *rete mirabile* circulatory system.

Once fish are cleaned, weighed, tagged, measured and cold-packed, they are driven across the border to the Los Angeles International Airport and flown to Japan, arriving the next day. The Japanese refer to the tuna coming from Mexico as "laxfish" because they are flown out of Los Angeles (LAX) airport and are known to have high quality meat.

Literature Cited

- Aguado-Giménez F, García-García B. 2005. Growth, food intake and feed conversion rates in captive Atlantic bluefin tuna (*Thunnus thynnus* Linnaeus, 1758) under fattening conditions. *Aquaculture Research*. 36: 610-614.
- Aguado-Giménez F, García-García B, Hernández-Lorente MD, Cerezo-Valverde J. 2006. Gross metabolic waste output estimates using a nutritional approach in Atlantic bluefin tuna (*Thunnus thynnus*) under intensive fattening conditions in western Mediterranean Sea. *Aquaculture Research*. 37: 1254-1258.
- Anonymous. 2005a. Interview with Mr. Felipe Charat, President of Maricultura del Norte, S. de R.L. de C.V.. *Panorama Acuicola Magazine*, Sep-Oct, 2005: 28-32.

- Anonymous. 2005b. Maricultura del Norte. A pioneer company in bluefin tuna *Thunnus thynnus* farming in Mexico. *Panorama Acuicola Magazine*, Sep-Oct, 2005: 19-26.
- Apple, RW. 2002. How to Grow a Giant Tuna. *New York Times*, April 3.
- Aquaculture SA. 2000. Farming of Southern Bluefin Tuna. *Primary Industries and Resources SA*. pp. 4.
<http://govdocs.aquaculture.org/cgi/reprint/2004/802/8020800>
- Bancomext. 2005. Banco Nacional de Comercio Exterior SNC. Consejería Comercial en Japón 2005. Participación de México en FOODEX Japan 2005. 8-11 Marzo. Informe Final.
http://www.bancomext.com/Bancomext/publicasecciones/secciones/7164/Reporte_Foodex_2005.doc
- Baumgartner T. 2000. Conference given at the San Diego Natural History Museum. Researcher at CICESE-Ensenada, Mexico.
- Buenrostro G. 1999. Ensenada: El Puerto del Atún. Ensenada, B.C.
- Bunce, A. 2001. Prey consumption of Australasian gannets (*Morus serrator*) breeding in Port Phillip Bay, southeast Australia, and potential overlap with commercial fisheries. *ICES Journal of Marine Science*, 58: 904-915.
- Costa-Pierce, BA. 2003. Use of ecosystems science in ecological aquaculture. *Bull. Aquacul. Assoc. Canada* 103(2): 32-40.
- Doumenge F. 2001. Anonymous. 2001. Bull market in bluefin tuna aquaculture. *SPC Fisheries Information Newsletter No. 99*. (October-December, 2001).
http://64.233.179.104/scholar?hl=es&lr=&q=cache:YYA8JsUmA3MJ:www.spc.org.nc/Coastfish/News/Fish_News/99/Fish_News_99.pdf+Doumenge+Bull+market+in+bluefin+tuna+aquaculture+fisheries+information+newsletter
- Dreyfus M, Robles H, Ulloa P. 2002. Atún. In: *Sustentabilidad y Pesca responsable en México. Evaluación y manejo. 1999-2000*. INP. p. 51-72.
- FAO. 2007. *State of Fisheries and Aquaculture*. FAO, Rome, Italy.
- Fernández M, Lauer P, Cheshire, A, Angove, M. 2007. Preliminary model of nitrogen loads from southern bluefin tuna aquaculture. *Marine Pollution Bulletin* 54:1321-1332.
- Fernandes M, Lauer P, Cheshire A, Svane I, Putro S, Mount G, Angove M, Sedawie T, Tanner J, Fairweather P, Barnett J, Doonan A. 2007. Evaluation of waste composition and waste mitigation. *AQUAFIN CRC - Southern bluefin tuna aquaculture subprogram: Tuna environmental subproject, Final Report*. Aquafin CRC Project 4.3.2. (FRDC Project No. 2001/103), 289 pp. // Fisheries Research & Development Corporation and South Australian Research & Development Institute (Aquatic Sciences), Adelaide. SARDI Publication No. RD03/0037-9. SARDI Research Report Series No. 207, 289 pp.
- Fernandes M, Angove M, Sedawie T, Cheshire A. 2007. Dissolved nutrient release from solid wastes of southern bluefin tuna (*Thunnus maccoyii*, Castelnau) aquaculture. *Aquaculture Research* 38 (4), 388-397.
- Graham JB, Dickson, KA. 2004. Tuna comparative physiology. *J. Exp. Biol.* 207: 4015-4024.
- Ikeda S. 2003. Market and domestic production of cultured tuna in Japan-Cultured tuna in the Japanese market. *Cahiers Options Méditerranéennes*, 60:83-84.
- Kompas T, Che N. 2006. Economic profit and optimal effort in the Western and Central Pacific tuna fisheries. *Pacific Economic Bulletin* 21: 46-62.

- Lozano-Huguenin MA, Vaca-Rodríguez JG. 2004. Análisis técnico de la industria de engorda de atún aleta azul (*Thunnus thynnus orientalis*) en Baja California. El Vigía, Órgano Informativo del Programa Nacional de Aprovechamiento del Atún y Protección de Delfines (PNAAPD), Año 9 No. 21, Abril-Junio 2004. p. 9-15.
- May J. 2002. Feedlots of the Sea. Earthbeat.
<http://www.abc.net.au/rn/science/earth/stories/s677134.htm>
- Norita T. 2003. Feeding of bluefin tuna: Experiences in Japan and Spain. Cahiers Options Méditerranéennes, 60:153-156.
- Ottolengui F, Silvestri C, Giordano P, Lovatelli A, New MB. 2004. Capture-based aquaculture. The fattening of eels, groupers, tunas and yellowtails. Rome, FAO. 308p.
- Paquette P. 2003. Tuna in the international market for seafood. In: Bridges CR, Gordin H and García A. 1. Domestication of the bluefin tuna *Thunnus thynnus thynnus* *Zaragoza*. International Symposium on Domestication of the Bluefin Tuna, Cartagena, Spain. 12-18.
- Peric, Z. 2003. Malta national programme towards farming of the bluefin tuna - Present and future. Cahiers Options Méditerranéennes, 60:167.
- Petersen EH. 2006. Institutional Economics and Fisheries Management: The Case of Pacific Tuna. Edward Elgars, Cheltenham, UK.
- Rojas A, Wadsworth S. 2007. A review of cage aquaculture: Latin America and the Caribbean. In Halwart M, Soto D, Arthur JR (eds). Cage aquaculture- Regional reviews and global overview, pp. 70-100. FAO Fisheries Technical Paper. No. 498. Rome, FAO. 2007. 241 pp.
- Smart A, Sylvia PC, Belle S. 2003. Nutritional management and development of manufactured feeds for tuna aquaculture. Cahiers Options Méditerranéennes, 60:187-190.
- Smart A. 1996. Feed intake and growth of sea-caged southern bluefin tuna *Thunnus maccoyii* (Castelnau), fed manufactured diets. Master of Applied Science Thesis, University of Tasmania, 23 pp.
- Sylvia PC, Belle S, Smart A. 2003. Current Status and Future Prospective of Bluefin Tuna (*Thunnus thynnus orientalis*) Farming in Mexico and the West Coast of the United States. Cahiers Options Méditerranéennes, 60:197-200.
- Sylvia P. 2007. Current Status of Bluefin Tuna Farming in North America. World Aquaculture Society.
- Vaca-Rodríguez JG. 2003. Modelo multiobjetivo de la pesquería del atún aleta amarilla (*Thunnus albacares*) en el océano Pacífico oriental. PhD Thesis, Facultad de Ciencias Marinas, Universidad Autónoma de Baja California, Ensenada, México. pp.202.

Table 1. CBTA Farms in Baja California, México^{1,2}

#	Farms	Locations	Sources of Capital Investments
1	Acuacultura de Baja California, S.A. de C.V.	Salsipuedes	Japan (Mitsubishi Corporation)
2	Administradora Pesquera del Noroeste, S.A. de C.V.	N.A.	N.A.
3	Baja Acuafarms, S.A. de C.V.	Islas Coronados	Iceland
4	Bajamachi, S.A. de C.V.	Isla Todos Santos	Japan/US
5	Duarcuícola, S.A. de C.V.	Salsipuedes	Japan (Explorer Corporation)
6	Frescatún, S.A. de C.V.	Bahia Soledad	Japan
7	Intermarketing de México, S.A. de C.V.	Salsipuedes	Japan (Explorer Corporation)
8	Maricultura del Norte, S.A. de C.V.	Puerto Escondido	Mexican-USA
9	Mexican Bluefin, S.A. de C.V.	Salsipuedes	Iceland
10	Operadora Pesquera de Oriente, S.A. de C.V.	Punta Banda	Japan (Explorer Corporation)
11	Rancho Marino Guadalupe, S.A. de C.V.	Salsipuedes	Iceland

¹N.A. = Not Available; Locations are in the coastal zone of Ensenada, except #3 which is located off the coast of Rosarito, Baja California.

²There are two other concessions (Isla de Cedros and Tokaido) that are not in operation.

Table 2. Northern bluefin tuna production from CBTA in Baja California, Mexico¹

Years	Production (MT)	Total Value (million of US\$)	Estimated prices (US\$/kg)
1999	64	1	15.60
2000	500	9	18.00
2001	550	10	18.20
2002	750	12	16.00
2003	2,125	35	16.30
2004	3,849	59	15.40
2005	4,822	80	16.60
2006	4,350	74	17.00

¹Sources: Bancomext, Consejería Comercial in Japan, 2004 (period 1999-2004) and company Operadora de Oriente, S.A. de C.V. (period 2005-2006).

Table 3. Feed conversion rates in CBTA¹

Species	Dry Basis FCR	Wet Basis FCR	Sizes	Food Types	Sources
<i>T. orientalis</i>	1.9	7	45 kg	<i>S. sagax</i>	Sylvia et al. (2003)
<i>T. orientalis</i>	2.9-4.1	10-14	<=40 kg	Mix Sm Pelagic	Ikeda (2003)
<i>T. orientalis</i>	3-6				Smart et al. (2003)
<i>T. orientalis</i>	4.1-5.9	14-20	>60 kg	Mix Sm Pelagic	Ikeda (2003)
<i>T. thynnus</i>	3.8	13	50--300 kg	Mix Sm Pelagic	Peric, Z. (2003)
<i>T. thynnus</i>	4.8	15.38	32 kg	Mix Sm Pelagic	Aguado et al. (2006)
<i>T. thynnus</i>	7.8	24.87	219 kg	Mix Sm Pelagic	Aguado et al. (2006)
<i>T. thynnus</i>	8.0	25.6	180 kg +	Mix Sm Pelagic	Aguado et al. (2005)
<i>T. maccoyii</i>	2.7-4.9	10-17	17kg	<i>S. neopilchardus</i>	Fernandes et al. (2007)
<i>T. maccoyii</i>	3.2-3.8	11-13		Mix Sm Pelagic	Smart (1996)

¹Dry FCR was computed from reported wet FCRs. For Ikeda (2003) and Smart (1996) a 71% moisture composition for a mixed, small pelagic diet was used from a survey of literature including articles cited in the table and Bunce (2001), Fernandes et al. (2007) and Norita (2003). Besides species, individual size and food composition, water temperature is a contributing factor to FCR (Ikeda 2003; Smart et al. 2003; Graham and Dickson 2004).

Figure 1. Baja California Peninsula (A) and Ensenada region, with the approximate location of the CBTA ranches. The numbers represent the individual companies (Table 1).



A)



B)

Figure 2. Purse seiner that has captured bluefin tuna (net near the boat) transferring tuna to the tow pen (right), with three speed boats keeping the purse seine net from collapsing (Source: Courtesy of Maricultura del Norte).



Figure 3. Tow net being brought to the grow-out (“fattening”) site (Source: ATRT Tuna-Ranching Intelligence Unit 2004).



Figure 4. Grow-out (“fattening”) pens anchored in the nearshore areas off Ensenada, Baja California, Mexico (Source: Authors)



Chapter 2

Northern Pacific Bluefin Tuna: Biology, Population Dynamics and Fisheries (including CBTA) in Mexico

Biology of the Northern Pacific Bluefin Tuna (*Thunnus orientalis*)

Taxonomy

Bluefin tuna occur as three species: *Thunnus thynnus*, *Thunnus maccoyii*, and *Thunnus orientalis*. The first one, *Thunnus thynnus*, is found in the Atlantic as well as in the Mediterranean and Black Seas (Mather and Jones 1972, Parrack 1979) and is occasionally referred to as a subspecies, *Thunnus thynnus thynnus*. The second one, *Thunnus maccoyii*, is found in the South Pacific (Froese and Pauly 2007). The third one, *Thunnus orientalis*, often referred to as a subspecies *Thunnus thynnus orientalis*, is found in the Northern Pacific. This report will refer to the species used for CBTA in Mexico as the Northern Pacific bluefin tuna (NBT) (*Thunnus orientalis*).

Age and Growth

Bayliff (1993a) reviewed different estimates of age and length, finding ranges of lengths for different ages (Table 1). Bayliff (1993b) used length-frequency data to obtain an estimate of 0.675 mm per day for the growth of NBT in the EPO. He found growth to be more rapid in the summer than in the winter. Maximum fork length is over 300 cm, but the common length is 200 cm (Collette and Nauen 1983), although some authors reviewed by Bayliff (1993a) give estimates of maximum length from 219 to 320.5 cm.

Maturation and Spawning

Onset of maturity is about 4-5 years (Collette and Nauen 1983, Bayliff 1993a, Itoh 2006). Lengths and weights of 5 year-old spawning fish are about 150 cm and 60 kg respectively (Harada 1980). Bluefin spawn fractionally; that is, they release eggs over several days. Given their tremendous mobility, they have the potential to broadcast eggs over several hundred square miles within a few days (www.tunalab.unh.edu/Bluefinlifehistory.htm). No information is available on the frequency of spawning. In the Pacific Ocean, spawning occurs near Japan and the Philippines in April, May, and June, off southern Honshu in July, and in the Sea of Japan in August (Yamanaka *et al.* 1963, Yabe *et al.* 1966, Okiyama 1974 and 1979, Nishikawa *et al.* 1985, Collette and Nauen 1983). In recent surveys, larvae have been discovered east of the Kuroshio Current, in the transitional fronts. Females weighing between 270-300 kg may produce as many as 10 million eggs per spawning season (Collette and Nauen 1983). Although there were some reports of larvae of NBT near the Hawaiian Islands prior to 1979, no larvae were found in 460 plankton samples collected 1 to 15 nautical miles off Oahu during 1985 and 1986 (Bayliff 1993a).

Population Dynamics of the Northern Pacific Bluefin Tuna

Recruitment

Recruitment in recent decades has fluctuated. The 2001 year class appears to be strong. There is no evidence of recruitment failure in recent years (ISC 2006). NBT recruitment is said to vary between 10 to 30 million organisms per year (1952-2002 period), with a strong recruitment (41 million) in 2001 (<http://isc.ac.affrc.go.jp/>).

Distribution and Migration Patterns

The NBT is found in the EPO from the Gulf of Alaska to southern Baja California (Koski 1967, Bayliff 1980). In the WPO, it occurs from the Sakhalin Islands, in the southern Sea of Okhotsk, south to the northern Philippines (Collette and Nauen 1983). NBT are usually oceanic, but seasonally come close to shore. Up to a size of 40-80 kg, they school by size, sometimes together with albacore, yellowfin, bigeye, skipjack, eastern Pacific bonito, and/or yellowtail amberjack, among others. NBT exhibit strong schooling behavior while they are young. While schooling is believed to be sight oriented, schools have been observed at night. Therefore, other senses (particularly the lateral line) appear to be involved in this behavior (IATTC 2005).

NBT tolerate a wide range of temperatures. During their sojourn in the EPO, NBT are residents of the California Current, a region of upwelling off California and Baja California. NBT are found and caught most often in the EPO in waters with surface temperatures between 17° and 23°C (Bell 1963, Flittner 1966, Roden 1991). In the WPO most of the NBT inhabit the Kuroshio Current (Marr 1970, Stommel and Ishida 1972, Sugawara 1972, Takenouti 1980).

It appears that spawning occurs only in the WPO, in the vicinity of Japan, and the survival of larvae is strongly influenced by the environment. After spawning, the fish probably disperse from the spawning areas to other areas of the WPO. Some may even migrate to the EPO, as large fish are found there. The following year, if they have not traveled too far, they presumably return to the spawning areas to spawn again (Bayliff *et al.* 1991). Larval, postlarval, and early juvenile NBT have been caught in the WPO, but not the EPO, so it is likely that there is a single stock of NBT in the Pacific Ocean (IATTC 2006).

There is extensive research on migration and movement of Atlantic bluefin tuna (Block *et al.* 1998, 2001a, 2001b; Boustany *et al.* 2001; Stokesbury *et al.* 2004; Block *et al.* 2005; Teo *et al.* 2007), and NBT in the NPO (Marcinek *et al.* 2001, Kitagawa *et al.* 2007) by a group of researchers “focused on gathering scientific data that will provide information necessary to solve critical stock structure issues surrounding bluefin tuna” (<http://www.tunaresearch.org/>). Tagging studies, conducted with conventional and archival tags, have revealed a great deal of information about the life history of NBT. Some fish apparently remain their entire lives in the WPO, while others migrate to the EPO. Polovina (1996) put forward the hypothesis that migration of juvenile NBT into the EPO increased in years when the abundance of sardines off Japan was declining.

Matsukawa (2006) suggested that the migration from the WPO to the EPO occurs as an evolutionary response to population excess.

NBT migrate over 11,000 km to the EPO, eventually returning to their birth waters to spawn. The journey from the WPO to the EPO takes as little as 7 months, or perhaps even less. A young NBT took two months to traverse the whole Pacific Ocean, which was much shorter than expected from previous records (Itoh *et al.* 2003). Tuna migrations begin mostly, or perhaps entirely, during their first and second year of life. Conditions in the WPO influence the numbers of juvenile fish that move to the EPO, and also the timing of these movements. Likewise, conditions in the EPO probably influence the timing of the return of juvenile fish to the WPO (IATTC 2006). In the EPO, the NBT tend to migrate northward along the coast of Baja California, Mexico and southern California, USA from May to October.

Domeier *et al.* (2005) analyzed the data recovered from 11 pop-up archival tags and 3 surgically implanted archival tags to juvenile NBT. Fish spent winter and spring off central Baja California, and summer through fall was spent moving as far northward as Oregon, with a return to Baja California in the winter months. The migration south to north in the EPO is related to migrations and/or local abundance of their prey (Yamanaka *et al.* 1963; Lozano-Huguenin and Vaca-Rodríguez 2004b; Kitagawa *et al.* 2007). Fish of ages 2-3 migrate back to Japan. Off the Pacific coast of Japan they migrate northward in summer and southward during winter. Large fish enter the Sea of Japan from the south in early summer and move as far north as the Okhotsk Sea; most leave the Sea of Japan through Tsugara Strait, north of Honshu (Collette and Nauen 1983).

General patterns of migrations, but not the precise routes, are shown in Figure 1. For example, it appears that the route of migration of juveniles bound for the EPO is south of the route of migration of maturing fish bound in the opposite direction, but such is not necessarily the case (Bayliff 1980). A map showing a specific route of migration of a young NBT is given by Itoh *et al.* (2003).

The fish which migrate from the WPO to the EPO form the basis for the fishery in the EPO, which takes place principally during May through October. In Figure 1 it appears that the fish in the EPO have an increasingly restricted north-south distribution as they grow older. Fish less than ~100 cm in length, which make up the bulk of the EPO catch, may or may not leave the EPO each fall or winter. NBT of that size are seldom caught in the EPO during November-April, which might indicate that they have left that region. If so, they probably do not go all the way to the WPO. Also, the energy costs of making such a long migration are so great that it would probably not be feasible for a fish to make two such migrations each year for several years (Bayliff 1980), although it may be possible (Figure 2).

After a sojourn in the EPO, which may or may not be interrupted by visits to the central or WPO, the survivors return to the WPO, where they eventually spawn. Nakano and Bayliff (1992) show catches of NBT by longlines between 25°N and 35°N and 120°W and 150°W during the first and fourth quarters of the 1981-1987 period. These were most likely migrating from the EPO to the WPO, but they might have been arriving in the

EPO after a trip from the WPO. The population of age-2 fish is greater in the EPO and that of age-3 fish is greater in the WPO (Bayliff 1994; IATTC 2006), confirming the migration back to the WPO between ages 2 and 3.

The distributions of the catches in the EPO by months are described by Calkins (1982), Hanan (1983), Vaca-Rodriguez and Compeán (2001), Pérez (2004, 2006), Pérez and Hernández-González, (2006), Fleischer, *et al.* (2006), IATTC (2006) and Dreyfus *et al.* (2007). During January through April there are typically only light and sporadic catches. Most of these are off the coast of Baja California between 24°N and 26°N and in the vicinity of Isla Guadalupe. In May and June the catches increase, and most of them are between 24°N and 27°N. During July the fishing area spreads to the north and is at its widest extent of the year; most of the catch is made between 25°N and 33°N. In August there are usually only light catches at the southern end of the fishing area, most of the catch being between 28°N and 33°N. During September most of the catch is made in the same area as in August, but the amount of catch is usually considerably less. In October the catches continue to decline, and most of them are north of 30°N. During November and December, as in the first months of the year, the catches are light and sporadic.

Impacts of Oceanic Conditions

The survival of larval and early juvenile NBT is undoubtedly strongly influenced by the environment (IATTC 2006). Age-0 fish about 15 to 60 cm in length are caught in the vicinity of Japan during the second half of the year (Yabe *et al.* 1966; Yukinawa and Yabuta 1967). The Kuroshio Current plays an important role in transporting larvae and postlarvae northward from the spawning grounds between Japan and the Philippines, and southeast of Japan to waters off Japan. NBT are found most often in the WPO in waters with surface temperatures between 14° and 19°C (Uda 1957; Kida 1936). Kida (1936) states that the temperature ranges increase with increasing size. NBT are much more plentiful off Japan in years when the sea surface temperatures are above normal than when they are below normal (Uda 1962, 1973).

Tuna abundances, distributions, and migrations have been shown to be sensitive to environmental variability. In particular, the El Niño Southern Oscillation (ENSO) appears to have important consequences for spatial distributions and migrations of the tuna populations. For skipjack and yellowfin tuna (tropical water tunas) in the EPO, a strong recruitment is usually related to a powerful El Niño event. La Niña negatively affects their recruitment. This pattern seems to be reversed for tunas like albacore, found in temperate waters, similar to the NBT. Scenarios of climate change due to greenhouse warming used in several coupled atmosphere-ocean simulations have suggested that the changes in the mean state of the tropical Pacific Ocean would result in climate conditions similar to present-day El Niño conditions with an increased interannual variability (www.spc.int/OceanFish/Html/Globec/index.asp).

The Mexican NBT tuna catches have been, in general, higher during La Niña events, and lower during El Niño events (Moreno-Alva and Vaca-Rodríguez 2003; Pérez 2006). NBT in the EPO are distributed further to the north in years when the sea surface temperatures are above normal (warm phase of the ENSO), and further to the south in

years when those temperatures are below normal (cold phase of ENSO) (Hester 1961). NBT has been caught as far north as the Shelikoff Strait, Alaska. These occurrences far to the north of the usual range of this species have been attributed to greater than normal sea surface temperatures (Radovich 1961). During the warm phase of the ENSO, sea surface temperatures in the EPO increase. This warm water wave may reach all the way to the USA-Mexico border. Based on these findings, we can also envision large impacts related to changes associated with global warming, limiting the amount of NBT available off Baja California.

Low-frequency variability, such as Pacific decadal oscillation, affects the catch of small pelagic fish (anchovies and sardines), but similar effects soon emerge for larger fish such as salmon, various groundfish species, and some tuna species (Allain *et al.* 2006). Scientists working in the International Scientific Committee (ISC) are working with decadal oscillations and other environmental factors to try to model NBT recruitment and population dynamics.

Interactions with Other Species

Yamanaka *et al.* (1963) reported that the route of the northward migration of NBT coincides with that of the migration of Pacific sardines. When sardine populations suddenly decreased, the fishing of NBT declines. Uda (1973) reported that: (i) the resources of both this species and of sardines were large from 1933 to 1940, but from 1941 on, decreased; (ii) with the decrease in food resources, fish in the northern part of the range moved south. Catches of sardines in Japan increased greatly during the 1976–1985 period (Yamanaka *et al.* 1988); catches of NBT in the western Pacific increased from 1976 to 1981, but then decreased from 1981 to 1985.

Variations in the food spectrum of NBT are attributed to behavioral differences in feeding. Vigorous pursuit would be required to prey on small schooling fishes (anchovies, sauries, hake) or on squids, while modified filter-feeding is used to feed on red crabs and other less agile organisms (Collette and Nauen 1983). Their major competitors for food are marine mammals and other large fish, notably other scombrids and billfishes (Bell 1963, Yamanaka *et al.* 1963, <http://www.flmnh.ufl.edu/fish/Gallery/Descript/BluefinTuna/BluefinTuna.html>).

Yamanaka *et al.* (1963) summarized the available information on the feeding and food of NBT in the WPO. Fish 20 to 65 cm in length consume anchovies and other fish, plus crustaceans and squid, while longline-caught (larger) fish eat fish and squid. They consume both pelagic and demersal fish, of many different species (Doi 1960; Yokota *et al.* 1961), including other tunas (Mori 1972).

In turn, NBT are preyed upon by killer whales, pilot whales and other marine mammals. However, the rather large size of adults drastically reduces the number of potential predator species. Other predators include sharks, other large predatory fishes, and seabirds (<http://www.flmnh.ufl.edu/fish/Gallery/Descript/BluefinTuna/BluefinTuna.html>).

Fisheries for the Northern Pacific Bluefin Tuna

Information on the fisheries which exploit NBT in the WPO is given by Yamanaka (1958 and 1982), Yamanaka *et al.* (1963), Tatsuki *et al.* (1963), Yukinawa and Yabuta (1967), Shingu *et al.* (1974), Honma and Suzuki (1978), and Bayliff (1980).

Fishing Gears

All the NBT caught and taken to the CBTA locations come from purse seiners (Figure 3). A purse seine is made of a long wall of netting framed with floatline and leadline having purse rings hanging from the lower edge of the gear, through which runs a purse line made from steel wire or rope which allow the pursing of the net. It is the most efficient gear for catching large and small pelagic species that shoal (<http://www.fao.org/fishery/geartype/249>).

The major part of a purse seine operation is searching for fish aggregations, then checking (when possible) the fish species, evaluating school sizes and their catchabilities prior to surrounding them. The purse seine is set around a detected school of fish. After that, the net is closed underneath the school by hauling the purse line running through the rings (pursing). To locate NBT schools, natural signs of fish aggregations (often observed with binoculars and/or helicopters or planes) are used, like concentrations of sea birds or ruffling of the water surface (www.fao.org/figis/servlet/static?dom=root&xml=tech/gears_search.xml). These are called free-swimming or school-sets (IATTC 2006). When targeting yellowfin tuna, the purse seines are \pm 190 to 200 m deep, but purse seiners targeting NBT for CBTA use nets 240-260 m deep and 1600-2200 m long.

Fishing Catch and Effort for NBT

NBT was an incidental catch in Mexico before the CBTA started (prior to 1996), but was classified as “tuna” to be canned, since there was no direct market for it (Lozano-Huguenin and Vaca-Rodríguez 2004a; Fleischer *et al.* 2006; Dreyfus *et al.* 2007). Today, NBT catches represent a very small (but very valuable) proportion of the total tuna catch (including mainly yellowfin tuna and skipjack tuna) by the Mexican tuna fleet (Fleischer *et al.* 2006, Dreyfus *et al.* 2007).

Japan currently accounts for ~64% of the NBT catch (all ages, including ages 0,1), virtually all of which is taken in the WPO. The only other nations involved in tuna fisheries to a significant degree are Taiwan and Mexico, which account for 20% and 15%, respectively, of the total catch. The Taiwanese catch comes from the west central Pacific (primarily) and northwest Pacific (secondarily). The Mexican catch comes entirely from the EPO (www.soest.hawaii.edu/oceanography/courses_html/OCN331/CHAPTER8.doc).

The high-seas longline fisheries are directed mainly at tropical tunas, albacore, and billfishes, but small amounts of NBT are caught by these fisheries. Small amounts of NBT are also caught by Japanese pole-and-line vessels on the high seas (IATTC 2006). The first-year migrants are exposed to the summer and fall troll fisheries for NBT and

other species off Japan before beginning their journey to the EPO in the fall or winter. The second-year migrants are also exposed to the winter troll fishery and other fisheries which take place in the vicinity of Japan before beginning their journey to the EPO in the spring, summer or fall. The migrants, after crossing the ocean, are fished by purse seiners off California and Baja California. Eventually, the survivors return to the WPO (Bayliff 1991). Large fish are occasionally caught in the EPO, especially in the vicinity of Guadalupe Island, Mexico, and the Channel Islands, off Southern California (Calkins 1982; Foreman and Ishizuka 1990; Bayliff 1993c).

Catch records of NBT for the WPO and central Pacific have historically been less complete and accurate than those for the EPO (Bayliff 1991). This is partly due to the take of small, immature tunas of several species, which are caught in large numbers by small local fisheries and marketed as "meji" in Japan. Meji can refer to small tuna of several species, and there are no exact records of which species are taken. Apparently, there are recent efforts in Japan to impose NBT quotas in its own waters to prevent extinction (<http://www.atuned.biz/public/ViewArticle.asp?ID=4329>). There are no limits on the catches of NBT, but the scientific staff of the Inter-American Tropical Tuna Commission (IATTC) has advised that if small NBT were not harvested, the total catch of that species could be increased (www.fao.org/docrep/006/y4849e/y4849e08.htm).

Catches of NBT have almost always been higher (2-3 times) in the WPO than in the EPO (Table 2). Most of the catch is obtained with purse-seiners (Tables 2 and 3). The catch in the EPO is variable (Figure 4, Figure 5, Table 2), due to migration and availability, as well as to a lack of targeting and variable fishing effort. However, prior to that, for many years catches reached over 10,000 MT (Bayliff 1993a). Ninety percent of the catch is estimated to be between 10 to 30 kg, representing mostly ages 1, 2 and 3 (Figure 6) (Bayliff 2001; IATTC 2006). Due to the migration pattern of the NBT, mean sizes vary from year to year.

However, since 1996, targeted catches of NBT in the EPO by the Mexican fleet have increased due to CBTA (Fleischer *et al.* 2006; Dreyfus *et al.* 2007). Catches in 1996 and 2004 (Fleischer *et al.* 2006), and 2006 (Dreyfus *et al.* 2007, <http://www.iattc.org/CatchReportsSPN.htm>) are historic for the Mexican fleet, but not for the EPO fleet (Table 2, Bayliff 1993a). The average NBT catch from 1995-2006 (by the Mexican fleet) was ~3,200 MT, and was limited mainly by oceanographic conditions in the NPO (Dreyfus *et al.* 2007).

During 1990-2004 the annual retained catch of NBT from the EPO by purse-seine and pole-and-line vessels averaged 3,000 MT (range 400-9,000 MT). The retained catch of NBT in 2005 was 5,000 MT, 2,000 MT greater than the average for 1990-2004. Small amounts of NBT are discarded at sea by purse-seine vessels (Table 3, IATTC 2006). According to the IATTC (<http://www.iattc.org/CatchReportsSPN.htm>), in 2005 the NBT catch in the EPO was 4,545 MT, in 2006 9,786 MT, and preliminary catch estimate for 2007 was 4,009 MT.

In the EPO, nearly all of the NBT purse-seine catch is taken west of Baja California and California, USA, within ~100 nautical miles of the coast, between about 23°N and 35°N,

from June to October (IATTC 2006; Lozano-Huguenin and Vaca-Rodríguez 2004a; Fleischer *et al.* 2006; Dreyfus *et al.* 2007; (<http://cripens.inp.gob.mx/atun/atunaletaazul.php>), when the NBT migrates through the region. Because NBT is found in colder waters than yellowfin tuna, their main commercial fishing zones do not overlap (Vaca-Rodríguez and Compeán 2001).

The catches of NBT in the EPO consist mostly of age-1 and 2 fish. The catches of age-2 fish in the EPO exceed those of age-2 fish in the WPO in most years, whereas the opposite is the case for age-3 fish (Bayliff 1994). This probably indicates that the population of age-2 fish is greater in the EPO and that of age-3 fish greater in the WPO, although it is possible that area- and/or size-related differences in fishing effort and/or vulnerability to capture are responsible for the differences (IATTC 2006). In the EPO, NBT are caught mostly by Mexico and the USA (Table 4), between Cabo San Lucas, Baja California, Mexico and Point Conception, California, USA (Brock 1938; Oregon Fish Commission 1948; Neave 1959; Radovich 1961; Squire 1983; Oliphant *et al.* 1990; IATTC 2006).

Age-0 fish (~15-65 cm in fork length) are caught by trolling in Japan, and age-1 and older fish are caught by purse-seining. NBT of various sizes are also caught nearshore by traps, gillnets, and other gear, especially in the Sea of Japan (IATTC 2006). The Taiwanese small-scale longline fishery takes NBT over 180 cm in length when they aggregate for spawning. The Korean purse-seine fishery catches age-0 NBT fish with mean lengths ranging from 33.6 cm to 55 cm (IATTC 2006).

Stock Assessment

In fisheries, catches are not used as abundance indices, since many other factors are involved. In some fisheries, Catch per Unit of Efforts (CPUEs) can be good abundance indices (Hilborn and Walters 1992). However, for tunas, CPUEs are not good abundance indices due to the tuna schooling behavior and the communication among fishermen (Dreyfus-León and Gaertner 2006).

Various indices of NBT abundance in the EPO have been calculated, but none of these is entirely satisfactory (IATTC 2005). A preliminary stock assessment carried out by the ISC has indicated that the spawning stock biomass had local peaks during the early 1960s, late 1970s, and late 1990s, with a decline after the last peak. However, the relative strengths of these peaks are highly variable. The total catches of NBT have fluctuated considerably during the last 50 years. The presence of consecutive years of above average catches (mid-1950s to mid-1960s) and below-average catches (early 1980s to early 1990s) could be due to consecutive years of above-average and below-average recruitment. An index of abundance for the predominantly young NBT in the EPO has been calculated, based on standardization of catch per vessel day using a generalized linear model, which includes latitude, longitude, SST, SST2, month, and vessel identification number. The index is highly variable, but shows a peak in the early 1960s, very low levels for a period in the early 1980s, and some increase since that time (IATTC 2006).

Recruitment was estimated to be highly variable, with 4 to 7 strong cohorts produced during the 1960-2003 period. A strong recruitment event may have occurred in 2001, which would maintain spawning stock biomass above recent levels until about 2010. The results of yield-per-recruit and cohort analyses indicate that greater catches could be obtained if the catches of age-0 and age-1 fish were reduced or eliminated. Spawner-recruit analyses do not indicate that the recruitment of NBT could be increased by permitting more fish to spawn (IATTC 2006; Yamada *et al.* 2006). Even though fishing mortality (F) has been higher than F_{MAX} (Yamada *et al.* 2006) or is above the reference point (Bayliff *et al.* 2005), recruitment overfishing has not occurred. Nevertheless, it is recommended that current fishing mortality not be further increased (Yamada *et al.* 2006) and catches reduced (Bayliff *et al.* 2005). According to Maguire *et al.* (2006), the exploitation state of NBT is "Fully Exploited". NBT is *not* included on the IUCN red list (Froese and Pauly 2007; <http://www.iucnredlist.org/>). There is no evidence that CBTA has affected the NBT stock since its beginnings in 1996. Considering that not all NBT migrate to the EPO and that increasing the catch would not necessarily decrease recruitment, current CBTA production levels do not appear to compromise the NBT stock. However, catches of NBT juveniles should be regulated and/or avoided, and fishing effort should not be increased, both at the WPO and EPO.

The ISC (http://isc.ac.affrc.go.jp/isc7/ISC7_Plenary_Report-FINAL4.pdf) has scheduled workshops to complete a full stock assessment of the NBT, to be completed by May-June 2008. At the 7th plenary meeting of the ISC, it was concluded that the recommendation given at the 6th plenary meeting still holds, recommending that, noting the uncertainty of the current assessment, NBT fishery mortality not be increased above recent levels as a precautionary measure (http://isc.ac.affrc.go.jp/isc7/ISC7_Plenary_Report-FINAL4.pdf).

Literature Cited

- Allain G, Lehodey P, Kirby DS. 2006. The influence of environment on horizontal and vertical bigeye tuna movements investigated by analysis of archival tag records and ecosystem model outputs. 57th Annual Tuna Conference, Lake Arrowhead, California, May 2006.
- Bayliff WH. 1980. Synopsis of biological data on the northern bluefin tuna, *Thunnus thynnus* (Linnaeus, 1758), in the Pacific Ocean. *Spec.Rep. IATTC* (2):261-93.
- Bayliff WH. 1991. Status of northern bluefin tuna in the Pacific Ocean. *Spec.Rep. IATTC* (7):29-88.
- Bayliff WH. 1993a. A review of the biology and fisheries for northern bluefin tuna, *Thunnus thynnus*, in the Pacific ocean. In: Shomura RS, Majkowski J, Langi S. (eds.). Interactions of Pacific tuna fisheries. Proceedings of the first FAO Expert Consultation on Interactions of Pacific Tuna Fisheries. 3-11 December 1991. Noumea, New Caledonia. Volume 2: papers on biology and fisheries. FAO Fisheries Technical Paper. No. 336, Vol.2. Rome, FAO. 1993. 439p. (<http://www.fao.org/DOCREP/005/T1817E/T1817E13.htm>).
- Bayliff WH. 1993b. Growth and age composition of northern bluefin tuna, *Thunnus thynnus*, caught in the eastern Pacific Ocean, as estimated from length-frequency data, with comments on trans-Pacific migrations. *Bull. IATTC* 20(9):501-40.

- Bayliff WH. (ed.) 1993c. Annual report of the Inter-American Tropical Tuna Commission 1992. *Annu.Rep.IATTC* (1992).
- Bayliff WH. 1994. Interactions among fisheries for northern bluefin tuna, *Thunnus thynnus*, in the Pacific Ocean. In: Shomura, RS, Majkowski J, Langi S, (eds.), Interactions of Pacific tuna fisheries. Proceedings of the First FAO Expert Consultation on Interactions of Pacific Tuna Fisheries, 3-11 December 1991, Noumea, New Caledonia. Vol. 1: Summary report and papers on interaction. *FAO Fish. Tech. Pap.* (336/1): 249-263
- Bayliff WH, 2001. Status of Bluefin Tuna in the Pacific Ocean. Inter-American Tropical Tuna Commission. Status of Pacific tuna and billfish stocks in 1999. Stock Assessment Report 1. La Jolla, California. pp. 211-241
- Bayliff WH, Ishizuka Y, Deriso, RB. 1991. Growth, movements, and mortality of northern bluefin, *Thunnus thynnus*, in the Pacific Ocean, as determined from tagging experiments. *Bull. IATTC* 20(1):1-94.
- Bayliff WH, Leiva-Moreno JI de, Majkowski J (eds). 2005. Second Meeting of the Technical Advisory Committee of the FAO Project: Management of Tuna Fishing Capacity: Conservation and Socio-economics. Madrid, Spain. 15-18 March, 2004. FAO Fisheries Proceedings No. 2, Rome.
- Bell RR. 1963. Synopsis of biological data on California bluefin tuna *Thunnus saliens* Jordan and Evermann 1926. *FAO Fish.Rep.*, 6(2):380-421.
- Block BA, Dewar H, Williams T, Prince E, Farwell C. 1998. Archival tagging of Atlantic bluefin tuna (*Thunnus thynnus thynnus*). *Marine Technological Society Journal*. 32: 37-46.
- Block BA, Dewar H, Blackwell S, Williams T, Prince E, Boustany A, Farwell C, Dau D, Seitz A. 2001a. Archival and pop-up satellite tagging of Atlantic bluefin tuna. *Methods and Technologies in Fish Biology and Fisheries*, Vol 1. In: Sibert J, Nielsen J (eds.), Kluwer Academic Press, Dordrecht, The Netherlands.
- Block BA, Dewar H, Blackwell S, Williams T, Prince E, Farwell C, Boustany A, Teo S, Seitz A, Walli A, Fudge D. 2001b. Migratory movements, depth preferences, and thermal biology of Atlantic bluefin tuna. *Science* 293: 1310-1314.
- Block BA, Teo S, Walli A, Boustany A, Stokesbury M, Farwell C, Weng K, Dewar H, Williams T. 2005. Electronic tagging and population structure of Atlantic Bluefin Tuna. *Nature* 434: 1121-1127.
- Boustany AM, Marcinek D, Keen J, Dewar H, Block BA. 2001. Movements and temperature preferences of Atlantic bluefin tuna (*Thunnus thynnus*) off North Carolina: A comparison of acoustic, archival and pop-up satellite tags. *Methods and Technologies in Fish Biology and Fisheries*, Vol 1. In: Sibert J, Nielsen J, (eds.), Kluwer Academic Press, Dordrecht, The Netherlands.
- Brock VE. 1938. A new tuna record from Washington. *Copeia*, (2):98.
- Calkins TP. 1982. Observations on the purse-seine fishery for northern bluefin tuna (*Thunnus thynnus*) in the eastern Pacific Ocean. *Bull.IATTC*, 18(2): 121-225.
- Collette BB, Nauen CE. 1983. FAO species catalogue. Vol. 2. Scombrids of the world. *FAO Fish.Synop.*, 125(2):137 p.
- Doi T. 1960. On the predatory relationships among bluefin tuna and coastal fishes in the southern waters of Japan. *Bull.Japan.Soc.Sci.Fish.*, 26(2):99-102.
- Domeier ML, Kiefer D, Nasby-Lucas N, Wagschal A, O'Brien F. 2005. Tracking Pacific bluefin tuna (*Thunnus thynnus orientalis*) in the northeastern Pacific with an

- automated algorithm that estimates latitude by matching sea-surface temperature data from satellites with temperature data from tags on fish. *Fish. Bull.* 103: 292-306.
- Dreyfus-León M, Gaertner D. 2006. Modeling performance and information exchange between fishing vessels with artificial neural networks. *Ecological Modelling* May 2006, 195(1-2): 30-36
- Dreyfus M, Fleischer LA, Klett-Traulsen A, Ulloa-Ramirez PA, Robles H. 2007. Mexican Progress Report to the 7th ISC. July 2007. 16 pp
- Flittner GA. 1966. Bluefin tuna in the north Pacific Ocean. *Pac.Sci.Congr.*, 11(7):3.
- Fleischer L, Dreyfus M, Robles H, Ulloa P. 2006. Mexican Progress Report to the 6th ISC. March 2006. 20 pp.
- Foreman TJ, Ishizuka Y. 1990. Giant bluefin off Southern California, with a new California size record. *Calif.Fish Game*, 76(3):181-6.
- Froese R, Pauly D. (Eds.). 2007. FishBase. World Wide Web electronic publication. www.fishbase.org, version (12/2007).
- Hanan DA. 1983. Review and analysis of the bluefin tuna, *Thunnus thynnus*, fishery in the eastern north Pacific Ocean. *Fish.Bull.NOAA-NMFS*, 81(1):107-19.
- Harada T. 1980. Development and future outlook of studies on the aquaculture of tunas. *Maguro Gyogyo Kyogikai Gijiroku, Suisancho-Enyo Suisan Kenkyusho* (Proceedings of the Tuna Fishery Research Conference, Japan Fisheries Agency-Far Seas Fisheries Research Laboratory):50-8.
- Hester FJ. 1961. A method of predicting tuna catch by using coastal sea-surface temperatures. *Calif.Fish Game*, 47(4):313-26.
- Hilborn, R. and C. Walters. 1992. Quantitative fisheries stock assessment: Choice, dynamics and uncertainty. Routledge, Chapman y Hall, New York, 570 pp.
- Honma M, Suzuki Z. 1978. Japanese tuna purse seine fishery in the western Pacific. *Ser.Far Seas Fish.Res.Lab.*, (10):66 p.
- IATTC. 2006. Inter-American Tropical Tuna Commission. Fishery status report No 4. Tunas and billfishes in the Eastern Pacific ocean in 2005. La Jolla California, 2006.
- IATTC. 2005. Inter-American Tropical Tuna Commission. Working group on stock assessments 6th meeting. La Jolla, California, 2-6 May 2005. Document sar-6-09
- ISC. 2006. [Report of the 4th ISC PBF Working Group \(http://isc.ac.affrc.go.jp/\)](http://isc.ac.affrc.go.jp/).
- Itoh T, Tsuji S, Nitta A. 2003. Migration patterns of young Pacific bluefin tuna (*Thunnus orientalis*) determined with archival tags. *Fish. Bull.* 101(3):514-534.
- Itoh T. 2006. Sizes of adult bluefin tuna *Thunnus orientalis* in different areas of the Western Pacific ocean. *Fisheries Science* 72:53-62.
- Kida T. 1936. On the surface temperature of water in the tunny fishing grounds off Kusiro and Urakawa in summer. *Bull.Jap.Soc.Sci.Fish.*, 5(2):87-90.
- Kitagawa T, Boustany AM, Farwell C, Williams TD, Castleton MR, Block BA. 2007. Horizontal and vertical movements of juvenile bluefin tuna (*Thunnus orientalis*) in relation to seasons and oceanographic conditions in the eastern Pacific Ocean. *Fisheries Oceanography* 16:5, 409-421.
- Koski RT. 1967. Age and growth determinations of bluefin tuna in the North Pacific Ocean. M.S. Thesis, Calif. State College, Long Beach, Calif. 51 p.

- Lozano-Huguenin MA, Vaca-Rodríguez JG. 2004a. Ranchos de engorda de atún aleta azul (*Thunnus thynnus orientalis*) en Baja California: Historia. El Vigía - órgano informativo del PNAAPD. Año 9 Num. 20, Enero-Marzo 2004.
- Lozano-Huguenin MA, Vaca-Rodríguez JG. 2004b. Análisis técnico de la industria de engorda de atún aleta azul (*Thunnus thynnus orientalis*) en Baja California. El Vigía - órgano informativo del PNAAPD. Año 9 Num. 21, Abril-Junio 2004.
- Maguire JJ, Sissenwine M, Csirke J, Grainger R, Garcia S. 2006. The state of world highly migratory, straddling and other high seas fishery resources and associated species. FAO Fisheries Technical Paper No. 495, Rome.
- Marcinek D, Blackwell S, Dewar H, Freund E, Farwell C, Dau D, Seitz A. 2001. Depth and muscle temperature of Pacific bluefin tuna examined with acoustic and pop-up satellite archival tags. *Marine Biology* 138: 869-885.
- Marr JC. (ed.) 1970. The Kuroshio: a Symposium on the Japan Current. Honolulu, East-West Center Press, 611 p.
- Mather FJ III, Jones AC. 1972. A preliminary review of the stock structure of bluefin tuna in the Atlantic Ocean. 18 P. Unpubl. manuscript. Woods Hole Oceanographic Inst., Woods Hole, MA. 02542.
- Matsukawa Y. 2006. Carrying capacity and survival strategies for the Pacific bluefin tuna, *Thunnus orientalis*, in the Western Pacific. *Fisheries Oceanography* 15:2, 104-112.
- Moreno-Alva M, Vaca-Rodríguez JG. 2003. Migración de algunas especies de atún en el Pacífico oriental por cambios climáticos generados por el fenómeno de "El Niño". El Vigía - órgano informativo del PNAAPD, Año 8 No. 19, Octubre-Diciembre 2003. p. 5-6.
- Mori K. 1972. Geographical distribution and relative apparent abundance of some scombroid fishes based on the occurrences in the stomachs of apex predators caught on tuna longline-I. Juvenile and young of skipjack tuna (*Katsuwonus pelamis*). *Bull.Far Seas Fish.Res.Lab.*, (6):111-68.
- Nakano H, Bayliff WH. 1992. A review of the Japanese longline fishery for tunas and billfishes in the eastern Pacific Ocean, 1981-1987. *Bull. IATTC*, 20(5):185-355.
- Neave F. 1959. Records of fish from waters off the British Columbia coast. *J.Fish.Res. Board Can.*, 16(3):383-4.
- Nishikawa Y, Honma M, Ueyanagi S, Kikawa S. 1985. Average distribution of larvae of oceanic species of scombroid fishes, 1956-1981. *S Ser.Far Seas Fish.Res.Lab.*, (12):99.
- Okiyama M. 1974. Occurrence of the postlarvae of bluefin tuna, *Thunnus thynnus*, in the Japan Sea. *Bull.Japan Sea Reg.Fish.Res.Lab.*, (25):89-97.
- Okiyama M. 1979. Successful spawning of some holoepipelagic fishes in the Sea of Japan and zoogeographical implications. In Japan-Soviet Joint Symp. Aquaculture, (7):223-33.
- Oliphant MS, Gregory PA, Ingle BJ, Madrid R. 1990. California marine fish landings for 1977-1986. *Fish Bull.Calif.Dep.Fish Game*, (173):52 p.
- Oregon Fish Commission. 1948. Blue-fin tuna taken in Oregon waters. *Res.Briefs Oregon Fish Comm.*, 1(2):32.
- Parrack ML. 1979. An assessment of Atlantic bluefin tuna resources. In: Sakagawa GT (chairman), Unit stock management of highly migratory species: Is it an

- imperative? p. 37-39. Proc. 30th Ann. Tuna Conf., Southwest Fisheries Center, La Jolla, CA 92038.
- Pérez H. 2004. Distribución de la captura de atún aleta azul por la flota atunera cerquera mexicana con observadores del PNAAPD: 1999 - 2003. *El Vigía - órgano informativo del PNAAPD*. Año 9 Num. 21, Abril-Junio 2004
- Pérez H. 2006. Captura de atún aleta azul por la flota atunera cerquera mexicana con observadores del PNAAPD: 2005. *El Vigía - órgano informativo del PNAAPD*. Año 11 Num. 29, Abril-Agosto 2006. pp 6-9.
- Pérez H, Hernández-González ME. 2006. Distribución mensual de la captura de atún aleta azul por la flota atunera cerquera mexicana con observadores del PNAAPD: 1992 - 2004. *El Vigía - órgano informativo del PNAAPD*. Año 11 Num. 28, Enero-Marzo, 2006. pp 10-15.
- Polovina JJ. 1996. Decadal variation in the transpacific migration of northern bluefin tuna (*Thunnus thynnus*) coherent with climate induced change in prey abundance. *Fish. Oceanogr.* 5:114-119.
- Radovich J. 1961. Relationships of some marine organisms of the northeast Pacific to water temperatures particularly during 1957 through 1959. *Fish Bull. Calif. Dep. Fish Game*, (112):62 p.
- Roden GI. 1991. Subarctic-Subtropical Transition Zone of the North Pacific: large-scale aspects and mesoscale structure. *NOAA Tech. Rep. NMFS*, (105):1-38.
- Shingu C, Warashina Y, Matsuzaki N. 1974. Distribution of bluefin tuna exploited by longline fishery in the western Pacific Ocean. *Bull. Far Seas Fish. Res. Lab.*, (10):109-40.
- Squire JL Jr. 1983. Abundance of pelagic resources off California, 1963-78, as measured by an airborne fish monitoring program. *NOAA Tech. Rep. NMFS SSRF*, (762):75 p.
- Stokesbury MJW, Teo SLH, Seitz A, O'Dor RK, Block BA. 2004. Movement of Atlantic bluefin tuna (*Thunnus thynnus*) as determined by satellite tagging experiments initiated off New England. *Can. J. Fish. Aquat. Sci.* 61: 1976-1987.
- Stommel H, Ishida K. (eds.). 1972. *Kuroshio: Physical Aspects of the Japan Current*. Seattle and London, University Washington Press, 517 p.
- Sugawara K. (ed.). 1972. *The Kuroshio II: Proceedings of the Second Symposium on the Results of the Cooperative Study of the Kuroshio and Adjacent Regions*. Tokyo, Saikon Publishing Company Limited, 562 p.
- Takenouti AY (ed.). 1980. *The Kuroshio IV: Proceedings of the Fourth Symposium for the Co-operative Study of the Kuroshio and Adjacent Regions*. Tokyo, Saikon Publishing Company Limited, 1029 p.
- Tatsuki K, Uto M, Kitamura K. 1963. On the landings of the yokowa (young bluefin) and its size composition off the Cape Shionomisaki. *Rep. Nankai Reg. Fish Res. Lab.*, (17):55-61.
- Teo SLH, Boustany A, Dewar H, Stokesbury MJW, Weng KC, Beemer S, Seitz AC, Farwell CJ, Prince ED, Block BA. 2007. Annual migrations, diving behavior, and thermal biology of Atlantic bluefin tuna, *Thunnus thynnus*, on their Gulf of Mexico breeding grounds. *Marine Biology* 151:1-18.
- Uda M. 1957. A consideration on the long years trend of the fisheries fluctuation in relation to sea conditions. *Bull. Jap. Soc. Sci. Fish.*, 23(7-8):368-72.
- Uda M. 1962. Cyclical fluctuation of the Pacific tuna fisheries in response to cold and warm water intrusions. *Spec. Sci. Rep. U.S. Fish Wild. Serv. (Fish.)*, (415):39.

- Uda M. 1973. Pulsative fluctuations of oceanic fronts in association with the tuna fishing grounds and fisheries. *J Fac.Mar.Sci.Technol.Tokai Univ.*, (7):245-66.
- Vaca-Rodríguez JG, Compeán G. 2001. La pesquería mexicana del atún aleta azul (AZ). *El Vigía - Órgano informativo del PNAAPD*. Año 6 Num. 12 Mayo.
- Yabe H, Ueyanagi S, Watanabe H. 1966. Studies on the early life history of bluefin tuna *Thunnus thynnus* and on the larvae of the southern bluefin tuna *T. maccoyii*. *Rep.Nankai Reg.Fish.Res.Lab.*, (23):95-129.
- Yamada H, Takeuchi Y, Ichinokawa M. 2006. Updated stock assessment of Pacific bluefin tuna using a tuned VPA. Fourth Meeting of the Pacific Bluefin Tuna Working Group of the ISC, January 2006.
- Yamanaka H. 1958. Studies on the bluefin tuna. I. The modes of the weight compositions of the catch. *Rep.Nankai Reg.Fish.Res.Lab.*, (9):125-35.
- Yamanaka H. 1982. *Fishery Biology of the Bluefin Tuna Resource in the Pacific Ocean*. Tokyo, Japan Fisheries Resources Conservation Association, 140 p.
- Yamanaka H *et al.* 1963. Synopsis of biological data on kuromaguro *Thunnus orientalis* (Temminck and Schlegel) 1942 (Pacific Ocean). *FAO Fish.Rep.*, 6(2):180-217.
- Yamanaka I, Ito S, Niwa K, Tanabe R, Yabuta Y, Chikuni S. 1988. The fisheries forecasting system in Japan for coastal pelagic fish. *FAO Fish.Tech.Pap.*, (301):72 p.
- Yokota T, Toriyama M, Kanai F, Nomura S. 1961. Studies on the feeding habit of fishes. *Rep.Nankai Reg.Fish.Res.Lab.*, (14):1-234.
- Yukinawa M, Yabuta Y. 1967. Age and growth of bluefin tuna, *Thunnus thynnus* (Linnaeus), in the north Pacific Ocean. *Rep.Nankai Reg.Fish.Res.Lab.*, (25):1-18.

Table 1. Estimated lengths for each age of NBT from different authors, reviewed by Bayliff (1993a)

Age	Minimum estimate (cm)	Maximum estimate (cm)
1	43	76.4
2	69	101.2
3	90.65	125
4	106.95	154
5	128.5	178
6	142	198
7	176.1	215
8	190.3	229
9	203	241
10	214.6	250

Table 2. Annual retained catches of Pacific bluefin tuna, by gear type and flag, in metric tons. Source: Western and Central Pacific Fisheries Commission, International Scientific Committee, Report of the Fourth ISC Pacific Bluefin Tuna Working Group (IATTC 2006).

PBF	Western Pacific flags									Eastern Pacific flags					Total
	JPN				KOR		TWN		Sub-total	USA		MEX		Sub-total	
	PS	LP	LL	Otr	PS	Otr	PS	LL		PS	Otr	PS	Otr		
1976	1,964	1,082	520	5,143				17	8,726	10,646	23	1,968		12,637	21,363
1977	3,960	2,256	712	5,519				131	12,577	5,473	21	2,186		7,680	20,257
1978	8,878	1,154	1,049	9,486				66	20,633	5,396	5	545		5,946	26,579
1979	12,266	1,250	1,223	9,418				58	24,215	6,118	12	213		6,343	30,558
1980	10,414	1,392	1,170	5,945				114	19,036	2,938	8	582		3,528	22,563
1981	23,219	754	796	6,428				179	31,376	867	21	218		1,106	32,482
1982	16,180	1,777	880	4,161	31		0	207	23,236	2,639	11	506		3,156	26,392
1983	14,105	356	707	3,883	13		0	175	19,239	629	155	214		998	20,237
1984	4,016	587	360	4,797	4		0	477	10,242	673	65	166		904	11,146
1985	4,239	1,817	496	5,475	1		0	210	12,237	3,320	210	676		4,206	16,443
1986	7,466	1,086	249	4,944	344		0	70	14,159	4,851	346	189		5,386	19,545
1987	7,771	1,565	346	3,536	89		0	365	13,672	861	135	119		1,115	14,787
1988	2,931	907	241	2,436	32		197	108	6,852	923	85	447	1	1,456	8,308
1989	5,624	754	440	1,977	71		259	205	9,330	1,046	135	57		1,238	10,568
1990	2,960	536	396	2,359	132		149	189	6,721	1,380	205	50		1,635	8,356
1991	8,217	286	285	3,994	265			342	13,389	410	68	9		487	13,876
1992	6,147	166	573	3,102	288		73	464	10,813	1,928	221			2,149	12,962
1993	5,675	129	857	1,645	40		4	471	8,820	580	217			797	9,617
1994	6,919	206	1,138	4,887	50			559	13,758	906	184	63	2	1,155	14,913
1995	15,978	307	769	6,715	821		2	335	24,928	689	215	10	0	914	25,842
1996	6,641	256	978	4,722	102			956	13,655	4,523	100	3,700		8,323	21,978
1997	11,123	71	1,383	3,859	1,054			1,814	19,304	2,240	175	367		2,782	22,086
1998	4,371	120	1,260	3,814	188			1,910	11,662	1,771	484	1		2,256	13,918
1999	13,440	124	1,155	4,483	256			3,089	22,547	184	482	2,369	35	3,070	25,617
2000	14,021	256	1,005	5,899	794		2	2,780	24,757	693	281	3,025	103	4,102	28,859
2001	6,727	332	1,004	5,089	995	10	104	1,839	16,100	149	273	863		1,285	17,385
2002	8,009	187	889	4,049	674	1	4	1,523	15,335	50	360	1,708	6	2,124	17,459
2003	5,680	59	1,230	1,950	1,591	0	21	1,863	12,395	22	246	3,211	46	3,525	15,920
2004	6,340	237	1,311	2,533	636	0	0	1,714	12,771	0	45	8,880	11	8,936	21,707
2005	3,090	604	870	1,870	950	0	0	1,366	8,749	165	56	4,542		4,763	13,512

PBF=Pacific bluefin tuna, PS=purse Seine, LP=pole and line, LL=longline, Otr=others, JPN=Japan, KOR=Republic of Korea, TWN=Chinese Taipei, USA=United States of America, MEX=Mexico

Table 3. Estimated retained catches, by gear type, and estimated discards (purse-seine only), of Pacific bluefin tuna in metric tons, in the EPO, 1976-2005, Ret= retained, Dis=discarded, PS= purse seine, LP= Pole and line, LL= Longline, Otr= other (IATTC 2006).

	PS		LP	LL	Otr	Total
	Ret.	Dis.				
1976	10,621		22	13	3	10,659
1977	5,449		10	11	34	5,504
1978	5,389		4	9	8	5,410
1979	6,102		5	6	19	6,132
1980	2,909			0	31	2,940
1981	1,085			4	9	1,098
1982	3,145			7	12	3,164
1983	835			2	34	871
1984	840		0	3	65	908
1985	3,996			1	111	4,108
1986	5,040			1	66	5,107
1987	980			3	54	1,037
1988	1,380			2	49	1,431
1989	1,102		5	4	124	1,235
1990	1,430		61	12	90	1,593
1991	420			5	94	519
1992	1,928			21	116	2,065
1993	579	0		11	329	919
1994	969	0		12	121	1,102
1995	629	0		25	264	918
1996	8,223	0		19	80	8,322
1997	2,608	3	2	14	256	2,883
1998	1,772	0	0	94	504	2,370
1999	2,553	54	5	152	552	3,316
2000	3,712	0	61	46	374	4,193
2001	891	3	1	148	389	1,432
2002	1,709	6	3	71	358	2,147
2003	3,233	0	3	88	751	4,075
2004	8,880	19		16	63	8,978
2005	4,743	14			100	4,857

Table 4. Estimates of the retained catches of Pacific bluefin tuna, by flag, gear type, and species, in metric tons, in the EPO, 2001, 2002, 2003, 2004 and 2005 (IATTC 2006).

Pacific bluefin tuna		2001	2002	2003	2004	2005
BLZ	LL	131	67	42		
JPN	LL	2	2	3	2	
KOR	LL	10	1			
MEX	LL		1	43	14	
	LP		1	0	0	
	PS	863	1,709	3,211	8,880	4,542
USA	GN	34	7	14	10	5
	LL	5				
	LP	1	2	3	0	
	PS	28	0	22	0	
	RG	355	351	737	53	95
OTR	LL					
	PS	0	0	0	0	201

BLZ=Belize, CAN=Canada, CHL= Chile, CHN=China, COK= Cook Islands, COL=Colombia, CRI=Costa Rica, ECU=Ecuador, HND=Honduras, ESP=Spain, JPN=Japan, KOR=Republic of Korea, MEX=Mexico, NIC=Nicaragua, PAN=Panama, SLV=El Salvador, PER=Peru, PYF=French Polynesia, TWN=Chinese Taipei, USA=United States of America, VEN=Venezuela, VUT=Vanuatu, Otr=others, LL=longline, LTL=troll, NK= unknown, PS=purse seine, RG=recreational, GN=gillnet.

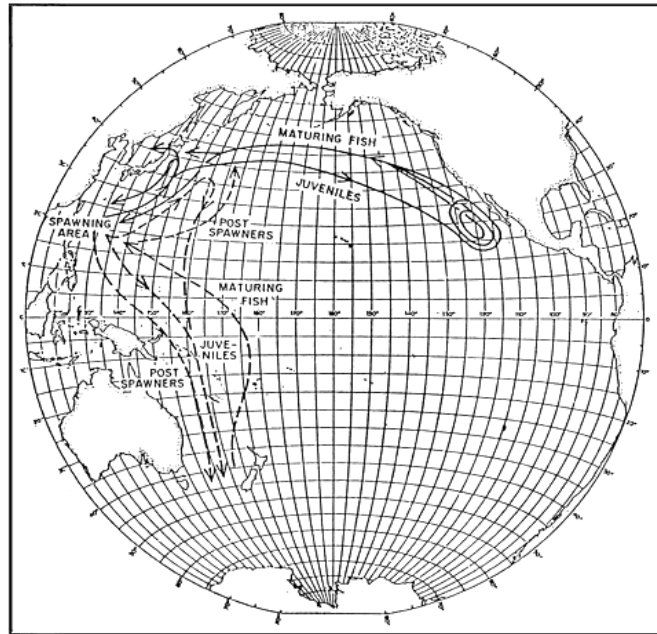


Figure 1. A model for northern bluefin migration in the Pacific Ocean (from Bayliff 1980).



Figure 2. Migration of a Northern Pacific bluefin tuna (from
<http://www.telegraph.co.uk/news/main.jhtml?xml=/news/2005/12/15/wtuna15.xml>

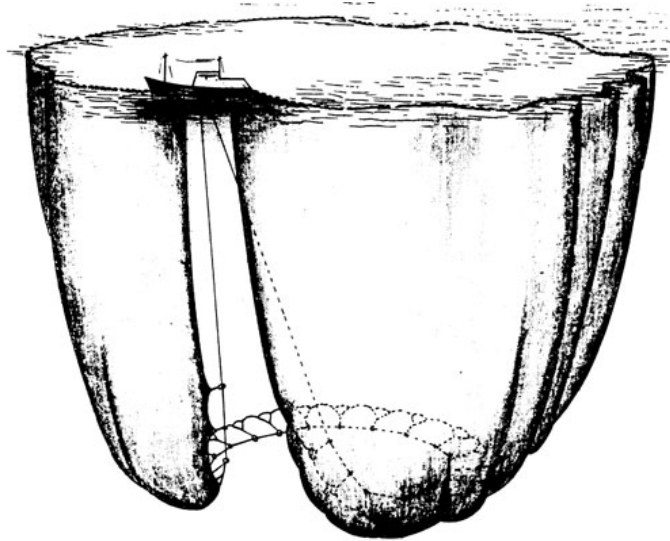


Figure 3. Purse seine operations (<http://www.fao.org/fishery/geartype/249>).

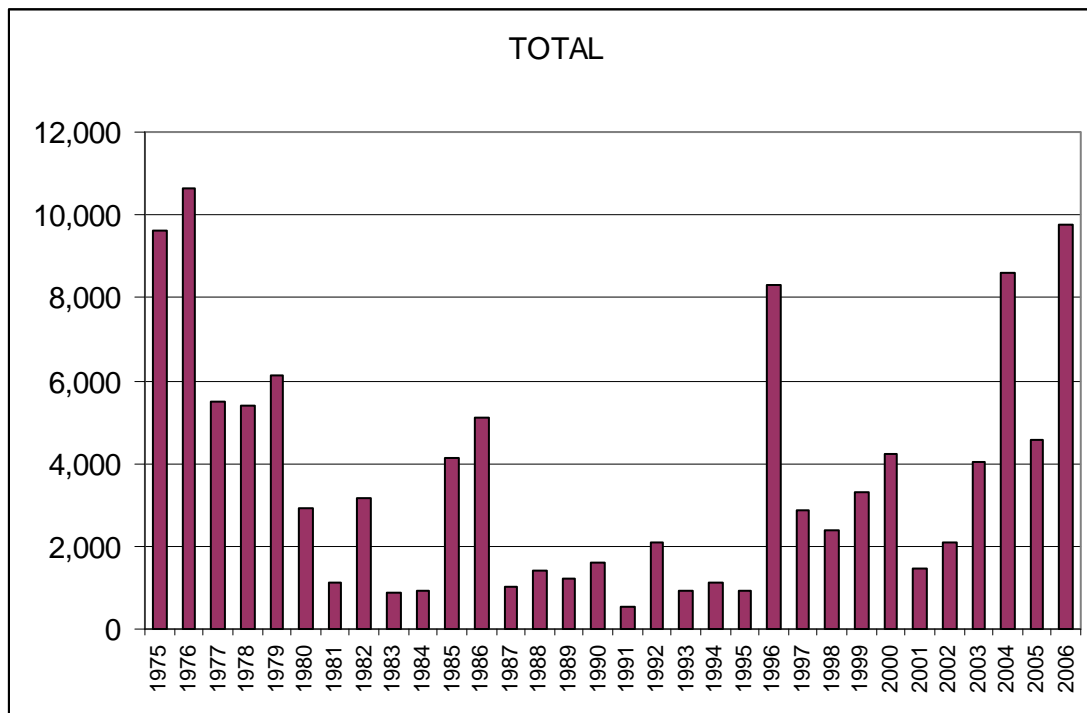


Figure 4. Eastern Pacific ocean bluefin tuna catch in MT (<http://www.iattc.org/>).

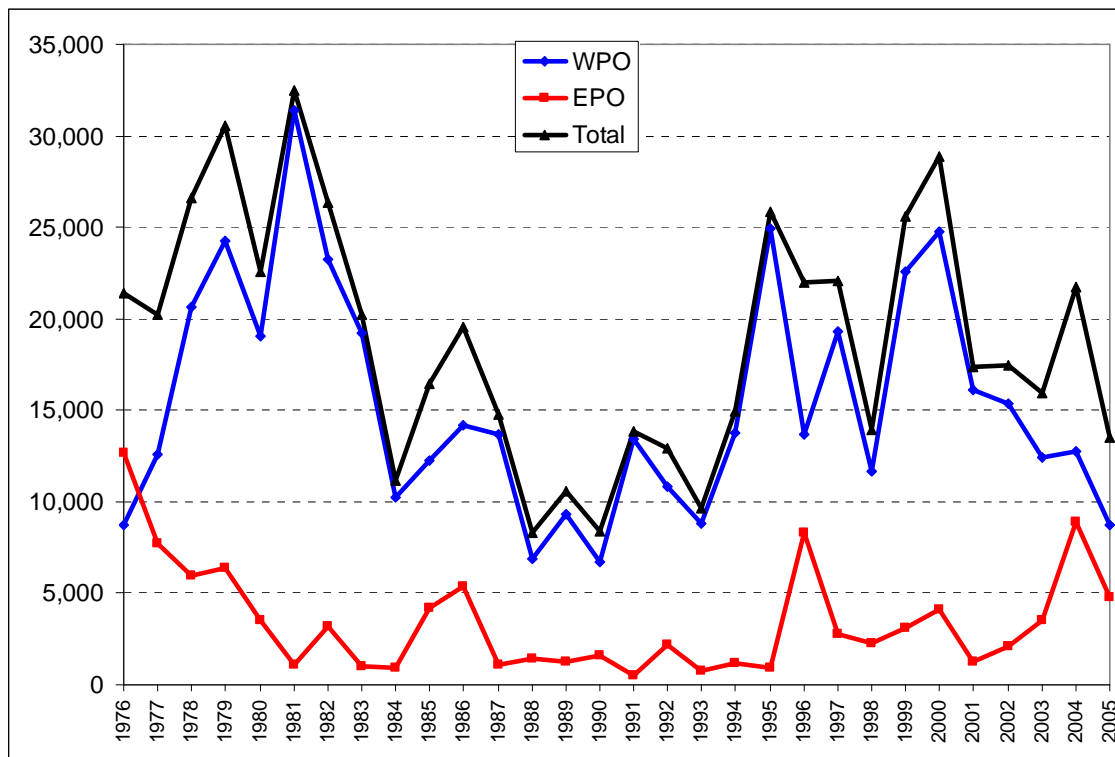


Figure 5. North Pacific bluefin tuna catch in MT (IATTC 2006).

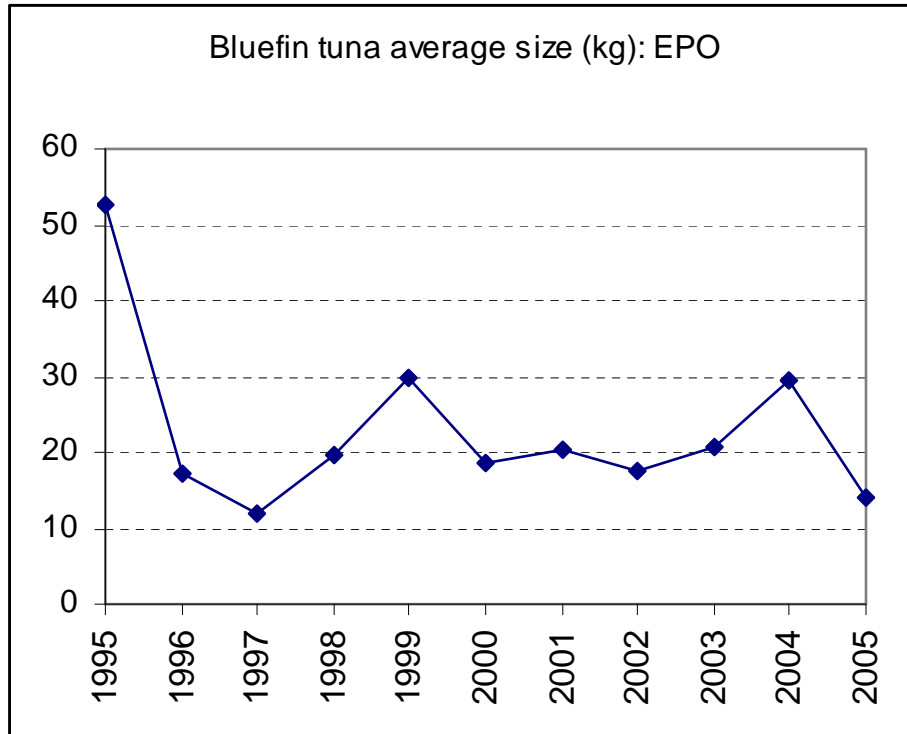


Figure 6. Average sizes (weight) of Pacific bluefin caught by purse-seine and recreational gear in the EPO during 1995-2005 (Bayliff 2001, IATTC 2006)

Chapter 3

Impacts of Capture-Based Tuna Aquaculture on Sardine Fisheries in Mexico

Introduction

Farming northern bluefin tuna (NBT) in the Ensenada region involves feeding 3,000 to 5,000 MT of tuna and producing between 2,000 to ~3,000 MT of fish biomass per season, in the CBTA facilities of 11 companies (only 9 currently operating) (Chapter 1). During the 6 to 9 month growth-out period, the NBT are primarily fed fresh Pacific sardine (*Sardinops sagax caerulea*), amounting to between 20,000 to 30,000 MT. Feeding relies on sardine caught locally by the sardine purse seine fishery based in Ensenada, though some CBTA facilities have their own fishing boats. This chapter reviews available literature related with the Pacific sardine fishery in Mexico, focusing primarily on the Ensenada fishery. At the end of this chapter, future scenarios of the Pacific sardine fishery are discussed related to the CBTA.

Pacific Sardine Biology

Taxonomy

Pacific sardines belong to the genus *Sardinops* found in eastern boundary currents of the Atlantic and Pacific Oceans and in western boundary currents of the Indo-Pacific Oceans. Parrish et al. (1989) indicated that sardines in the Alguhas, Benguela, California, Kuroshio, and Peru Currents, and off New Zealand and Australia are single species (*Sardinops sagax*), but stocks in the different areas of the globe may be different at the subspecies level (Bowen and Grant 1997; Grant et al. 1998). In the northeastern Pacific, the subspecies *Sardinops sagax caerulea* is distributed. However, Grant et al. (1998) suggested that this subspecies should be dominated *Sardinops sagax sagax*, with a distribution in all eastern Pacific. In recent assessments of the region (Hill et al. 2006), Pacific sardine is defined as *Sardinops sagax*, and we use that definition.

Distribution and natural fluctuations

Pacific sardines are frequently the dominant pelagic fish in the California Current. However, fishery independent data (Baumgartner et al. 1992) has shown that over the last several millennia their abundances have fluctuated greatly. Variability in the sardine populations, which can be sustained periods longer than a decade, are due to regime shifts in ocean conditions. Sizes of Pacific sardine populations alternate with the northern anchovy (*Engraulis mordax*) (Luch-Belda et al. 1989; Baumgartner et al. 1992; Chavez et al. 2003) (Figure 1). During periods of high abundance and warmer ocean temperatures, Pacific sardines are found from the tip of the Baja California Peninsula to Alaska and throughout the Gulf of California (Hill et al. 2006). In the northern portion of their range, occurrences also seem to be seasonal (McFarlane and Beamish 2001). When sardine abundances are low, as during the 1960s and 1970s, Pacific sardines do not occur

in commercial quantities north of Point Conception, California, USA (Hill et al. 2006), but the northern anchovy population grows to a significant size. Abundances of Pacific sardines appear to be increasing from the low values in the mid 1970's, and now sustain a large fishery in Baja California and California (Figure 2).

Stock Structure

Although an earlier electrophoretic study (Hedgecock et al. 1989) showed no genetic variation among sardines from the different stocks in the north eastern Pacific, it is now widely accepted that sardines of the northeast Pacific Ocean are of three subpopulations or stocks: a northern stock, from northern Baja California to southern Alaska, a southern stock off central Baja California, and a Gulf of California stock (Felix-Uraga et al. 2005) (Figure 3). There are Mexican fisheries on all three stocks (Figure 3; Table 1). Stock discrimination is based on tagging, size-at-age, isolated spawning centers, blood groups, vertebral column counts, estimated natural mortality rates, and bimodal seasons of recruitment (Smith 2005); also, temperature at capture analysis (Felix-Uraga et al. 2004) and otolith morphometry (Felix-Uraga et al. 2005) have been used. Pacific sardines probably migrated extensively during historical periods when abundances were high, moving north as far as British Columbia in the summer and returning to southern California and northern Baja California in the fall; movements that could explain the genetic results. Tagging studies (Clark and Janssen 1945) indicate that the older and larger fish move farther north. Migratory patterns were probably complex, and the timing and extent of movement were affected by oceanographic conditions (Hart 1973) and stock biomass. The 1950-70s were a period of reduced stock sizes and unfavorably cold sea surface temperatures which apparently caused the stock to shift south (Hart 1973).

Life History

Pacific sardines spawn in loosely aggregated schools in the upper 50 meters of the water column (Hill et al. 2006). Sardines are oviparous, multiple-batch spawners with an annual fecundity that is indeterminate and highly age- or size-dependent (Macewicz et al. 1996). Butler et al. (1993) estimated that two-year-old sardines spawn on average six times per year whereas the oldest sardines spawn up to 40 times per year. Both eggs and larvae are found near the surface. Sardine eggs are spheroid, have a large perivitelline space, and require about three days to hatching at 15°C. Off California, sardine eggs are most abundant at sea surface temperatures of 13°C to 15°C and larvae are most abundant at 13°C to 16°C. The spatial and seasonal distribution of spawning is influenced by temperature. During periods of warm water, the center of sardine spawning shifts northward and spawning extends over a longer period of time (Butler 1987; Ahlstrom 1960). Recent spawning has been concentrated in the region offshore and north of Point Conception (Lo et al. 1996). Historically, spawning may also have been fairly regular off central California. Spawning was observed off Oregon (Bentley et al. 1996), and young fish were seen in waters off British Columbia in the early fishery (Ahlstrom 1960) and during recent years (Hargreaves et al. 1994). The main spawning area for the historical population off the U.S. was between Point Conception and San Diego, California, out to

about 100 miles offshore, with evidence of spawning as far as 250 miles offshore (Hart 1973).

Pacific sardines may reach 41 cm, but are seldom longer than 30 cm. They may live as long as 14 years, but individuals in historical and current California commercial catches are usually younger than 5 years. In contrast, the most common ages in the historical Canadian sardine fishery were 6-8 years. There is a good deal of regional variation in size-at-age, with size increasing from south to north, and from inshore to offshore (Phillips 1948; Hill et al. 2006). Size- and age-at-maturity may decline with a decrease in biomass, but latitude and temperature are likely also important (Hill et al. 2006). At low biomass levels, sardines appear to be fully mature at age one, whereas at high biomass levels only some of the two-year-olds are mature (MacCall 1979).

Sardine Fisheries

Landings

The sardine fishery in Mexico began following the fall of the sardine fishery in California, USA during the 1940's. Mexican catches have been used for reduction to fishmeal and oil, canned for human consumption, and used fresh for bait (Cisneros-Mata et al. 1995). The first recorded catches of Pacific sardines along the Mexican western coast were in Ensenada during 1951. Fishing extended southward arriving at Cedros Island in 1961 and Magdalena Bay in 1972 (Murphy 1966) (Figure 3). During the late 1960s Mexican Pacific sardine landings decreased, and fishmeal plants and canneries were built in Guaymas, in the Gulf of California, where sardine resources were abundant (Cisneros-Mata et al. 1995).

Today the principal species in the fishery is the Pacific sardine; however, depending on the region (western coast of the Baja Peninsula or Gulf of California, Fig. 3), sardine fleets harvest other species. In Ensenada, recent landings include four species: Pacific sardines representing 80%, Pacific mackerel (*Scomber japonicus*) 11%, northern anchovy (*Engraulis mordax*) 8%, and jack mackerel (*Trachurus symmetricus*) 1% (Nevárez et al. 2006). Because of this mix of species, the official fisheries management term for the Mexican fishery is "Small Pelagic Fisheries". Using this definition, historical records are confused and include different species in their reports, especially at the beginning of the fishery. In this report, we will concentrate on the period of 1983 to 2005 when separation between species is clear.

Landings of Pacific sardines at Ensenada increased from an annual average of 2,133 MT during the 1980s, to an average of nearly 48,000 MT in the 1990s, then diminished to a level around 41,000 MT during 2003 and 2004 (Table 2; Hill et al. 2006). In Table 2, landings for 2000 to 2004 incorporate estimates of sardines delivered directly to the CBTA farms off Northern Baja California. Sardine catches are thus 37% higher than reported in the official statistics, for example as reported by Nevárez et al. (2006). For 2006, Cota and Troncoso (2007) reported that 61,109 MT of small pelagics were landed at Ensenada, where 93% (57,070 MT) was Pacific sardines, 1% chub mackerel, and 3% northern anchovy; however, these authors did not specify, in the case of sardines, if they

made adjustments to consider the unreported additional catch delivered directly to CBTA farms.

The sardine fishery in Ensenada has traditionally been based on catches of small Pacific sardines with a high proportion of juveniles, as sardine boats operate close to the coast (less than 40 nautical miles). Studies suggest that older and larger fish might move offshore where little fishing effort occurs. Development of a new, offshore, trawl fishery that could relieve fishing pressure on juveniles near the coast has been discussed (Baumgartner et al. 2006).

In Baja California state, most of the sardine catches are landed in Ensenada; other ports are the Isla de Cedros on the Pacific side, and San Felipe on the Gulf of California side, but the information on sardine landings from both of these ports is irregular. The state of Sonora is the most important producer of sardines in Mexico; this fishery is based on the Gulf of California sardine stock. Based on official government statistics, during the 10 year period from 1995 to 2005, the state of Sonora was the most important sardine producer in the country followed by the state of Baja California (Table 1).

Fishing Efforts

The small pelagic fishery operates with purse seine vessels between 10-30 m long. These vessels have a storage capacity of 20 to more than 100 MT (a few have 300 MT capacity) (Nevárez et al. 2006). During the 1970s up to 60 vessels operated out of Ensenada, when the anchovy fishery was at its maximum. In 2003, 28 sardine fisheries vessels were permitted in Baja California (Anónimo 2006), but not all were operational. In recent years, the operational fleet size has fluctuated from 7 to 19 boats (Nevárez et al. 2006). In 2006, Cota and Troncoso (2007) reported that only 9 fishing vessels operated in waters off Ensenada. This low number of fishing vessels in operation suggests that only 25% of the vessel holding capacity from Ensenada has been in use in recent years (Nevárez et al. 2006). During 2005 a mean catch of 2,760 MT/vessel/year was estimated, ranging from 200-7,000 MT/vessel/year. This high variation is due to the poor condition of most fishing vessels (76% are in poor condition); most of the vessels based in Ensenada are 25-30 years old (SPPMBC 2006).

Population Dynamics

Estimates of the abundances of sardines from 1780 through 1970 have been derived from the deposition of fish scales in sediment cores from the Santa Barbara basin off southern California (Baumgartner et al. 1992; Hill et al. 2006) (Figure 1). Significant sardine populations existed throughout the period with biomass levels varying widely. Both sardine and anchovy populations tend to vary over periods of roughly 60 years, although sardines have varied more than anchovies. Sardine population declines were characterized as lasting an average of 36 years; recoveries lasted an average of 30 years. Biomass estimates of the sardine population inferred from scale-deposition rates in the 19th and 20th centuries (Smith 1978) indicate that the biomass peaked in 1925 at about 6 million MT. Sardines aged three and older were fully recruited to the historical fishery until 1953 (MacCall 1979). Recent California fisheries data indicate that sardines begin to

recruit at age zero and are fully recruited to the southern California fishery by age two. Age-dependent availability to the fishery likely depends upon the location of the fishery; young fish are unlikely to be fully available to fisheries located in the north, and old fish are unlikely to be fully available to fisheries south of Point Conception.

Off California, sardine spawning biomass estimated from catch-at-age analysis averaged 3.5 million MT from 1932 through 1934. Biomass fluctuated between 1.2-2.8 million MT over the next ten years, then declined steeply from 1945 through 1965, with some short-term reversals following periods of particularly successful recruitment (Murphy 1966; MacCall 1979). During the 1960s and 1970s, spawning biomass levels were thought to be less than about 5,000-10,000 MT (Barnes et al. 1992). The sardine stock began to increase by an average rate of 27% annually in the early 1980s (Barnes et al. 1992). Recent estimates of the northern stock (Conser et al. 2004) indicate that the total biomass of sardine age one or older is greater than 1 million MT.

Recruitment success in sardines is generally autocorrelated and affected by environmental processes occurring on long (decadal) time scales. Lluch-Belda et al. (1991) and Jacobson and MacCall (1995) demonstrated relationships between recruitment success in Pacific sardine and sea surface temperatures measured over relatively long periods (i.e., 3-5 years). Their results suggest that equilibrium spawning biomass and potential sustained yield are highly dependent upon environmental conditions associated with elevated sea surface temperatures.

Recruitment of Pacific sardines is highly variable. Analyses of the sardine stock recruitment relationships have been controversial, with some studies showing a density-dependent relationship (production of young sardines decline at high levels of spawning biomasses) and other studies showing no relationship (Clark and Marr 1955; Murphy 1966; MacCall 1979). The most recent study (Jacobson and MacCall 1995) found both density-dependent and environmental factors to be important. MacCall (1979) estimated that the average potential population growth rate of sardines was 8.5% during the historical fishery off California while the population was declining. He concluded that, even with no fishing mortality, the population on average was capable of little more than replacement. Jacobson and MacCall (1995) obtained similar results for cold, unproductive regimes, but also found that the stock was very productive during warmer regimes.

The maximum sustainable yield (MSY) for the historical Pacific sardine population was estimated to be 250,000 MT annually (MacCall 1979; Clark 1939), which is far below the catch of sardine during the peak of the historical fishery. Jacobson and MacCall (1995) found that MSY for sardines depends on environmental conditions, and developed a stock-recruitment model that incorporates a running average of sea-surface temperatures measured off La Jolla, California. This stock-recruitment model has been used in recent assessments.

Status of the Populations

The US National Marine Fisheries Service conducts annual Pacific sardine northern stock assessments to establish annual harvest guidelines (quotas) for the US coast-wide fishery. The most recent assessments for the northern stock, northern Baja California to Alaska, were conducted and by Hill et al. (2006) using an Age Structured Assessment Program (ASAP), a forward simulation, likelihood-based, age structured model; and Hill et al. (2007) using a Stock Synthesis 2 (SS2) model. For the assessments, they included Ensenada landings (Table 2), because they belong to the northern stock, so these catches have to be considered in the fishing mortality parameters. These results reflect the biological potential of the stock that Ensenada fishermen are exploiting.

Results from the final base model indicate a decline in stock productivity (recruits per spawning biomass) which began in the mid-1990s. Recruit (age-0) abundance increased rapidly from low levels in 1982-83, peaking at 24.6 billion fish in 1998. Recruitment has subsequently declined to between 1.0 and 9.7 billion fish/year since that time, with the exception of a strong 2003 year class (YC). Recruit abundance is poorly estimated for the most recent years; however, the 2003 YC was estimated to be 16.5 billion fish (Hill et al. 2007). There was a large proportion of 2003 YC in the catch, as well as a relatively high abundance of this YC in fishery-independent trawl surveys off California and the Pacific northwest. Stock biomass (fishes age 1 and older) estimates from the base model begin at very low levels in 1981 (Hill et al. 2006), rapidly increase to a peak of over 1.7 million metric tons in 2000, and subsequently trend downward to 832,706 metric tons in 2007 (Figure 4) (Hill et al. 2007). Total exploitation rate (catch/stock biomass) was relatively high during the early period (mid-1980s) in the northern stock, but declined as the stock underwent the most rapid period of recovery. Total exploitation was lowest (~7%) in 2000 and has since gradually increased to approximately 15% (Hill et al. 2007).

Sardine products

Before the 1990's sardine canneries were well established in Ensenada, but due to changes in demand, the canneries closed at the end of the 1990's. Today, Pacific sardines in Ensenada yield fresh fish, frozen fish, fish oil, fishmeal, and other derivatives from reduction. The reduction industry for fishmeal and fish oil started during the 1970s, 1980s and part of the 1990s when anchovy began to be processed. After landings of the northern anchovy were gone due to natural population changes between the two species, Pacific sardines were the most important resource for fishmeal. Today the demand is less than 10,000 MT/year (~0.5% of the annual sardine landings at Ensenada), and they produce mostly fish meal, fish oil, and pharmaceuticals (Table 3 and Figure 5).

There has been an increase in international demand for frozen sardines for tuna ranching, bait, and human food, causing the closure of all sardine canneries in Ensenada by the end of the 1990s (Raúl del Moral, personal communication). This development has resulted in high prices per ton paid to sardine boats (depending on the fish quality [Table 4]). Recently, processors of frozen sardines used ~70% of the Pacific sardine landings at Ensenada (Figure 5), although in 2006 they used less than 50% of landings (Table 3; Martínez Guerrero 2007).

With the development of CBTA in the area, demand for fresh sardines has grown (Figure 5), becoming the most important use of the Pacific sardine landings in 2006 (~50%; Table 3; Martínez Guerrero 2007). However, in 2007, due to an intense upwelling, coastal waters were unusually cold in the main sardine fishing grounds for the northern stock. As a result, the stock moved offshore where sardine boats usually did not fish. Stocks also moved south off San Quintin, where fish quality diminishes after transport to Ensenada (Timothy Baumgartner, CICESE, personal communication). As a result, during the 2007 tuna growing season, Pacific sardines of the right quality for the CBTA ranches were scarce. For the first time, bluefin tuna producers were forced to use frozen Pacific sardines acquired from San Pedro, California, USA (Raul del Moral, UABC, personal communication).

Management History

The most important management regulations used today were enacted in 1983. Before that, one national regulation was the prohibition of using Pacific sardines as a source of fish meal; all was to be used as human food (issued in 1934). After the results of several fish biology studies, in 1983 the authorities began to issue regulations for the management of the fishery in the Gulf of California; they established a minimum fishing size of 150 mm standard length (SL), allowing only 20% of the catch to be below this size. In 1987 a minimum allowable size of 150 mm was established for the sardine fishery of the western coast of the Baja California peninsula, except that 30% of the catch was allowed to be smaller than 150 mm. During 1987 to 1990 several closed areas and closed seasons were established for both the west coast of the peninsula and in the Gulf of California. In 1993, and only for the Gulf of California, a closed season of two weeks was established during the reproductive peak in this area.

During the same year (1993), a new approach was used for the normalization of the management of several fisheries in Mexico, including small pelagics. The Official Mexican Norm (NOM), NOM-003-PESC-1993, was published in December 1993 and established minimal sizes of 150 mm SL; species minimal sizes were also established for other small pelagics. The NOM also established a moratorium on fishing effort. New fishing vessels were not allowed to enter the sardine fishery in Mexican Pacific waters north of the 20° N. The only new vessels allowed to enter the fishery were new vessels that replaced old ones; these vessels were required to have new refrigeration systems on board. Sardine fishing vessels without refrigeration were not permitted to fish further than 40 nautical miles (nm) off the coast. Also, the NOM rules stated that fisheries authorities would implement closed fishing seasons if it was determined that sardine reproductive capacities had declined to the point where the fish required protection. However, to date, for the sardine fishery based in Ensenada, no closed seasons have been established.

Recently, a new set of baseline rules were published for all fisheries in Mexico (National Fisheries Chart 2004), where in addition to the NOM standards, reference points were established. A maximum sustainable yield of 410,000 MT for small pelagics was established; however, this yield is for all small pelagic species grouped together. Also,

the National Chart recognized that there is an underutilization of the industrial infrastructure of this fishery.

Traditionally, the sardine industry of Ensenada was composed of fishing companies, canneries and fish reduction companies (fishmeal, oil and other products). Recently this structure has changed, with the addition of frozen fish processing companies for the national and international commercialization of frozen sardine used as bait and feed (including capture based bluefin tuna aquaculture companies in other countries). Sardine canneries went out of business in Ensenada ~8 years ago with these changes (SPPMBC 2006).

During 2005, these industries organized themselves and formed the State Committee of the Small Pelagic Production System of Baja California (SCSPPSBC). This organization tries to analyze the production chain of the Pacific sardine and develop a plan to solidify the fishery in the region (SPPMBC 2006). The SCSPPSBC is composed of 14 fishing companies, 9 processing companies, 3 fish meal companies, 3 commercialization companies, and 10 capture bluefin tuna aquaculture companies, all based in Ensenada. Also represented in this organization are the federal government, the National Chamber of Fishery and Aquaculture Industry, the National Institute of Fisheries, and the local university (UABC). This organization has finished its development plan (SPPMBC 2006) and is looking for funding sources in order to enhance the product value chain.

Pacific Sardines and the CBTA Ranches: Future Scenarios

Ensenada's Pacific sardine fishery catches a high proportion of juveniles. While it is known that fishing on recruits can cause problems to a fishery, sardine stock assessments to now have found no effects of the Mexican fishery on the northeastern Pacific sardine stock. Total catch (Ensenada, US and Canada) for the northern stock has not yet reached the level of the MSY of 250,000 MT. However, the recent increase of mortality rates and the decrease of spawning biomass have to be addressed. If the stock productivity continues to decline, management agreements between the USA, Canada and Mexico might be needed.

Studies suggest that in Pacific sardine the equilibrium of the spawning biomass and maximum sustainable yield is highly dependent on the variability of oceanographic conditions. The future of the population status of Pacific sardines depends on future environmental conditions. Nevertheless, we can envision three possible scenarios for the future of the CBTA industry with respect to their demands for Pacific sardines:

1. If CBTA production continues at today's level, sardine production can continue for some years, although recruitment overfishing could occur with the present practice of fishing on juvenile sardines near the coast;
2. If CBTA production is increased, the demand for sardines will be higher and six possible options could occur: a) acquire sardines from other Mexican stocks (southern and Gulf of California stocks); b) It has been shown that the Ensenada sardine fleet operates at only 25% of its storage capacity (an estimated 75% of the

sardine fleet is in poor condition); so, improving the current fleet capacity could cover the demands for sardines; c) develop a new trawl fishery offshore (greater than 40 nm) targeting larger fish with a potential larger catch; d) import sardines from USA; e) import sardines from other countries (other international stocks); or f) change the fish species used for feeding the tuna to, for example, Pacific mackerel (*Scomber japonicus*), as is being done in Japan.

3. Develop formulated diets for bluefin tuna to reduce dependence on stocks of Pacific sardines.

Literature Cited

- Ahlstrom, E. H. 1960. Synopsis on the biology of the Pacific sardine (*Sardinops caerulea*). Proc. World Sci. Meet. Biol. Sardines and Related Species, FAO, Rome, 2: 415-451
- Anónimo. 2006. Anuario Estadístico de Pesca y Acuicultura. CONAPESCA, SAGARPA, Mazatlán, México.
http://www.conapesca.sagarpa.gob.mx/wb/cona/cona_anuario_estadistico_de_pesca
- Anonymous, 2007. *Open Ocean Aquaculture and the Channel Islands National Marine Sanctuary-Feedlots in the Wilderness?* L. Krop, Chair, Conservation Working Group of the Channel Islands National Marine Sanctuary Advisory Council, NOAA (DOC), Draft Conservation Working Group Report, January 12, 2007. 82 pp including appendices.
- Baumgartner, T.R., A. Soutar, and V. Ferreira-Bartrina. 1992. Reconstruction of the history of the Pacific sardine and northern anchovy populations over the past two millennia from sediments of the Santa Barbara Basin, California. CalCOFI Rep. 33: 24-40.
- Baumgartner, T.R., C. Sanchez, S. de la Campa, N. Lo. R. Charter, Y. Green, and E. Coter. 2006. Spawning biomass estimates for the Pacific (*Sardinops sagax caeruleus*) off Baja California, Mexico, during April, 2002, and April, 2003. Oral presentation abstract, in N.C.H. Lo, A. Allen, and S.Z. Herzka (eds.) Minutes of the 2005 trinational sardine forum, Ensenada, Baja California, Mexico, November 14-15, 2005. NOAA, NMFS, SWFSC, Administrative Report LJ-06-06: 97-118.
- Barnes, J. T., L. D. Jacobson, A. D. MacCall, and P. Wolf. 1992. Recent population trends and abundance estimates of the Pacific sardine (*Sardinops sagax*). CalCOFI Rep. 33: 60-75.
- Bentley, P. J., R. L. Emmett, N. C. H. Lo and G. Moser. 1996. Egg production of Pacific sardine (*Sardinops sagax*) off Oregon in 1994. CalCOFI Rep. 37:193-200.
- Bowen, B.W. and W.S. Grant. 1997. Phylogeography of the sardines (*Sardinops* spp.): Assessing biogeographic models and population histories in temperate upwelling zones. *Evolution* 51: 1601-1610.
- Butler, J. L. 1987. Comparisons of the larval and juvenile growth and larval mortality rates of Pacific sardine and northern anchovy and implications for species interactions. Ph. D. Thesis, Univ. Calif., San Diego, 240 pp.
- Butler, J.L., P.E. Smith, and N.C.H. Lo. 1993. The effect of natural variability of life-history parameters on anchovy and sardine population growth. CalCOFI Rep. 34: 104-111.

- Chavez, F.P. J. Ryan, S.E. Lluch-Cota, C.M. Niquen. 2003. From anchovies to sardine and back: multidecadal change in the Pacific Ocean. *Science* 229: 217-221.
- Cisneros-Mata, M.A., M.O. Nevárez-Martínez, and M.G. Hammann. 1995. The rise and fall of the Pacific sardine, *Sardinops sagax caeruleus*, Girard, in the Gulf of California, Mexico. *CalCOFI Rep.* 36:136-143.
- Clark, F. N. 1939. Can the supply of sardines be maintained in California waters? *Calif. Fish and Game* 25: 172-176.
- Clark, F.N., and J.F. Janssen. Jr. 1945. Movements and abundance of the sardine as measured by tag returns. *Calif. Div. Fish Game Fish. Bull.* 61: 7-42.
- Clark, F. N., and J. C. Marr. 1955. Population dynamics of the Pacific sardine. *CalCOFI Prog. Rep.* 1 July 1953-31 March 1955: 11-48.
- Conser, R., K. Hill, P. Crone, N. Lo, and R. Felix-Uraga. 2004. Assessment of the Pacific sardine stock for U.S. management in 2005: Pacific Fishery Management Council, November 2004. 135 p.
- Cota Villavicencio, A., y R. Troncoso Gaytán. 2007. Comportamiento de la pesquería de pelágicos menores durante la temporada 2006 en Baja California. En: *Memorias del XV taller de pelágicos menores. Comité técnico de pelágicos menores. La Paz, BCS, 2-4 de mayo de 2007.*
- Félix-Uraga, R. R.M. Alvarado-Castillo, and R. Carmona-Piña. 1996. The sardine fishery along the western coast of Baja California, 1981 to 1994. *CalCOFI Rep.* 37: 188-192.
- Felix-Uraga, R., V.M. Gómez-Muñoz, C. Quiñónez-Velázquez, F. Neri Melo-Barrera, and W. García-Franco. 2004. On the existence of Pacific sardine groups off the west coast of Baja California and southern California. *CalCOFI Rep.* 45: 146-151.
- Felix-Uraga, R., V.M. Gómez-Muñoz, C. Quiñónez-Velázquez, F. Neri Melo-Barrera, K. Hill, and W. García-Franco. 2005. Pacific sardine stocks discrimination off the west coast of Baja California and southern California using otolith morphometry. *CalCOFI Rep.* 46: 113-121.
- Grant, W.S., A.-M. Clark, and B.W. Bowen. 1998. Why restriction fragment length polymorphism analysis of mitochondrial DNA failed to resolve sardine (*Sardinops*) biogeography: insights from mitochondrial DNA cytochrome b sequences. *Can. J. Fish. Aquat. Sci.* 55: 2539-2547.
- Hargreaves, N.B., D.M. Ware, and G.A. McFarlane. 1994. Return of the Pacific sardine (*Sardinops sagax*) to the British Columbia coast in 1992. *Can. J. Fish. Aquat. Sci.* 51: 460-463.
- Hart, J.L. 1973. Pacific fishes of Canada. *Fish. Res. Board Can. Bull.* 180: 740 p.
- Hedgecock, D., E.S. Hutchinson, G. Li, F.L. Sly, and K. Nelson. 1989. Genetic and morphometric variation in the Pacific sardine, *Sardinops sagax caerulea*: comparisons and contrast with historical data and with variability in the northern anchovy, *Engraulis mordax*. *Fish. Bull.* 87: 653-671.
- Hill, K.T., E. Dorval, N.C.H. Lo, B.J. Macewicz, C. Show and R. Felix-Uraga. 2007. Assessment of the Pacific sardine resources in 2007 for U.S. management in 2008. Pacific Fishery Management Council working paper. 250 pp.
- Hill, K.T., N.C.H. Lo, B.J. Macewicz, and R. Felix-Uraga. 2006. Assessment of the Pacific sardine (*Sardinops sagax caerulea*) population for US management in 2006. NOAA-TM-NMFS-SWFSC-386: 66 pp.

- Jacobson, L. J. and A. D. MacCall. 1995. Stock-recruitment models for Pacific sardine (*Sardinops sagax*). *Can. J. Fish. Aquat. Sci.* 52:566-577.
- Lehodey P., J. Alheit , M. Barange , T.R. Baumgartner McBride, G. Beaugrand, K. Drinkwater , J.M. Fromentin , S.R. Hare , G. Ottersen , R. Ian Perry , C. Roy , C.D. Van Der Lingen , and F. Werner . 2006. Climate variability, fish, and fisheries. *Journal of Climate.* 19(20): 5009-5030.
- Lluch-Belda, D., R.J.M Crawford, T. Kawasaki, A.D. MacCall, R.A. Schwartzoles, and P.E. Smith. 1989. Worldwide fluctuations of sardine and anchovy stocks: the regime problem. *S. Afr. J. Mar. Sci.* 8: 195-205.
- Lluch-Belda, D., D.B. Lluch-Cota, S. Hernandez-Vazquea, C.A. Salina-Zavala. 1991. Sardine and anchovy spawning as related to temperature and upwelling in the California Current system. *CalCOFI Rep.* 32: 105-111.
- Lo, N. C. H., Y. A. Green Ruiz, Mercedes J. Cervantes, H. G. Moser, R. J. Lynn. 1996. Egg production and spawning biomass of Pacific sardine (*Sardinops sagax*) in 1994, determined by the daily egg production method. *CalCOFI Rep.* 37:160-174.
- MacCall, A. D. 1979. Population estimates for the waning years of the Pacific sardine fishery. *CalCOFI Rep.* 20: 72-82.
- Macewicz B. J, J. J. Castro-Gonzalez, C. E. Coteró Altamirano, and J. R. Hunter. 1996. Adult reproductive parameters of Pacific Sardine (*Sardinops sagax*) during 1994. *CalCOFI Rep.* 37:140-151.
- Martínez Guerrero, S.A. 2007. Diagnóstico del sistema de producto pelágicos menores en B. C. Informe Interno, Guía instruccional No. 4, Comité Estatal Sistema Producto Pelágicos Menores en B. C. 42 pp.
- McFarlane, G.A., and R.J. Beamish. 2001. The re-occurrence of sardines off British Columbia characterizes the dynamic nature of regimes. *Prog. Oceanogr.* 49:151-165.
- Murphy, G.I. 1966. Population biology of the Pacific sardine (*Sardinops caerulea*). *Procc. Cal. Ac. Sci. Fourth series* 34:1-84.
- Nevárez Martínez, M.O., M.A. Martínez Zavala, C.E. Coteró Altamirano, M.L. Jacob Cervantes, Y. Green Ruiz, G. Gluyas Millán, A. Cota Villavicencio, y P. Santos Molina. 2006. Peces Pelágicos Menores. En: Instituto Nacional de la Pesca (eds.), *Sustentabilidad y Pesca Responsable en México: evaluación y manejo*. SAGARPA, México DF. 263-301.
- Parrish, R.H., R. Serra, and W.S. Grant. 1989. The monotypic sardines, *Sardina* and *Sardinops*: their taxonomy, distribution, stock structure and zoography. *Can. J. Fish. Aquat. Sci.* 46: 2019-2036.
- Phillips, J. B. 1948. Growth of the sardine, *Sardinops caerulea*, 1941-42 through 1946-47. *Calif. Div. Fish Game Fish Bull.* 71: 33 p.
- Smith, P. E. 1978. Biological effects of ocean variability: time inferred from fish scales in anaerobic sediments off California. *CalCOFI Rep.* 13: 63-70.
- Smith, P. 2005. A history of proposal for subpopulation structure in the Pacific sardine (*Sardinops sagax*) population off western North America. *CalCOFI. Re.* 46: 75-82.
- SPPMBC. 2006. Plan Rector del Sistema Producto de Pelágicos Menores de Baja California. CIDETE-UABC, Ensenada, BC, México. 270 pp.

Table 1. Mean Mexican Pacific sardine landings in metric tons (MT, live weight) during the 1995-2006 period, by fishing area and stock, with percentages of national landings (Hill et al 2007).

<i>Fishing Areas/Stocks</i>	<i>Landings (MT)</i>	<i>%</i>
Baja California (Pacific side) /Northern stock	50,616	23
Southern Baja California/Southern stock	30,344	13
Gulf of California/Gulf of California	140,696	63
Other regions in the Mexican Pacific	1,234	<1
TOTAL	222,891	

Table 2. Coast-wide landings (MT) of Pacific sardines from 1983 to 2006 (modified from Hill et al. 2006). Ensenada landings for 2005 were taken from SPPMBC (2006) and for 2006 from Cota and Troncoso (2007).

<i>Years</i>	<i>Ensenada</i>	<i>USA</i>	<i>Canada</i>	<i>Total</i>
1983	274	1	0	274
1984	0	1	0	1
1985	3,722	6	0	3,728
1986	243	388	0	631
1987	2,432	439	0	2,871
1988	2,035	1,188	0	3,223
1989	6,224	837	0	7,061
1990	11,375	1,664	0	13,040
1991	31,392	7,587	0	38,979
1992	34,568	17,950	0	52,518
1993	32,045	15,345	0	47,390
1994	20,877	11,644	0	32,520
1995	35,396	40,327	25	75,748
1996	39,065	32,553	88	71,706
1997	68,439	43,245	34	111,718
1998	47,812	42,956	745	91,514
1999	58,569	60,039	1,250	119,858
2000	67,845	67,985	1,718	137,549
2001	46,071	75,800	1,600	123,472
2002	46,845	96,896	1,044	144,785
2003	41,342	71,864	954	114,159
2004	41,897	89,338	4,259	135,494
2005	56,684	90,130	3,232	156,046
2006	57,070	90,776	1,595	149,809

Table 3. Percentages of final use are for Pacific sardines by Mexican states in 2006. Frozen fish are intended for export; “Other” means local markets or intermediary companies. CBTA is capture-based tuna aquaculture (Martínez Guerrero 2007).

<i>States</i>	<i>Fishmeal</i>	<i>Canneries</i>	<i>Frozen</i>	<i>CBTA</i>	<i>Other</i>
Baja California	0.5	0	42.4	53.0	4.1
Baja California Sur	20.0	29.9	50.1	0	0
Sonora	77.0	18.5	4.5	0	0

Table 4. Pacific sardine prices (US\$/MT) are for final use in the Mexican market (Martínez Guerrero 2007). Frozen fish prices are for those destined for export. CBTA is capture-based tuna aquaculture.

<i>Sardine types</i>	<i>Prices US\$/MT</i>	<i>Purposes</i>
Fresh sardines	80	Frozen fish
Fresh sardines	45	Fishmeal
Fresh sardines	70-80	CBTA
Frozen sardines	200	CBTA
Fresh sardines A class (large)	85	CBTA
Fresh sardines B class (medium)	75	Frozen fish
Fresh sardines C class (small)	55	Frozen fish
Sardines in poor condition	60	Frozen fish

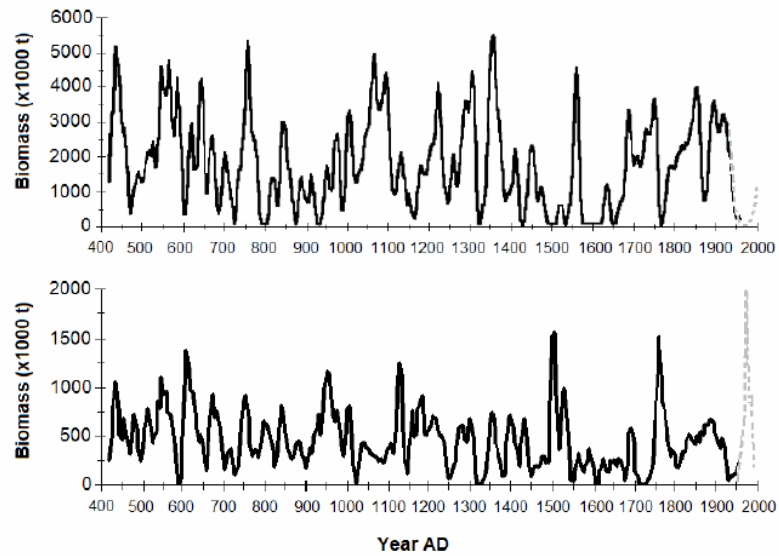


Figure 1. Abundance indices of Pacific sardines (top) and northern anchovies (below) based from fish scales in sediment cores in the Santa Barbara basin. The gray dotted line is the recent catch (Lehodey et al. 2006).

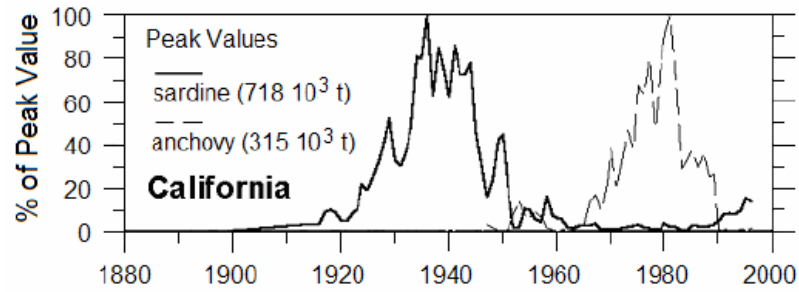


Figure 2. Observed catch by species in metric tons of Pacific sardines and northern anchovies relative to the maximum peak value during the last century in California, USA (Lehodey et al. 2006).

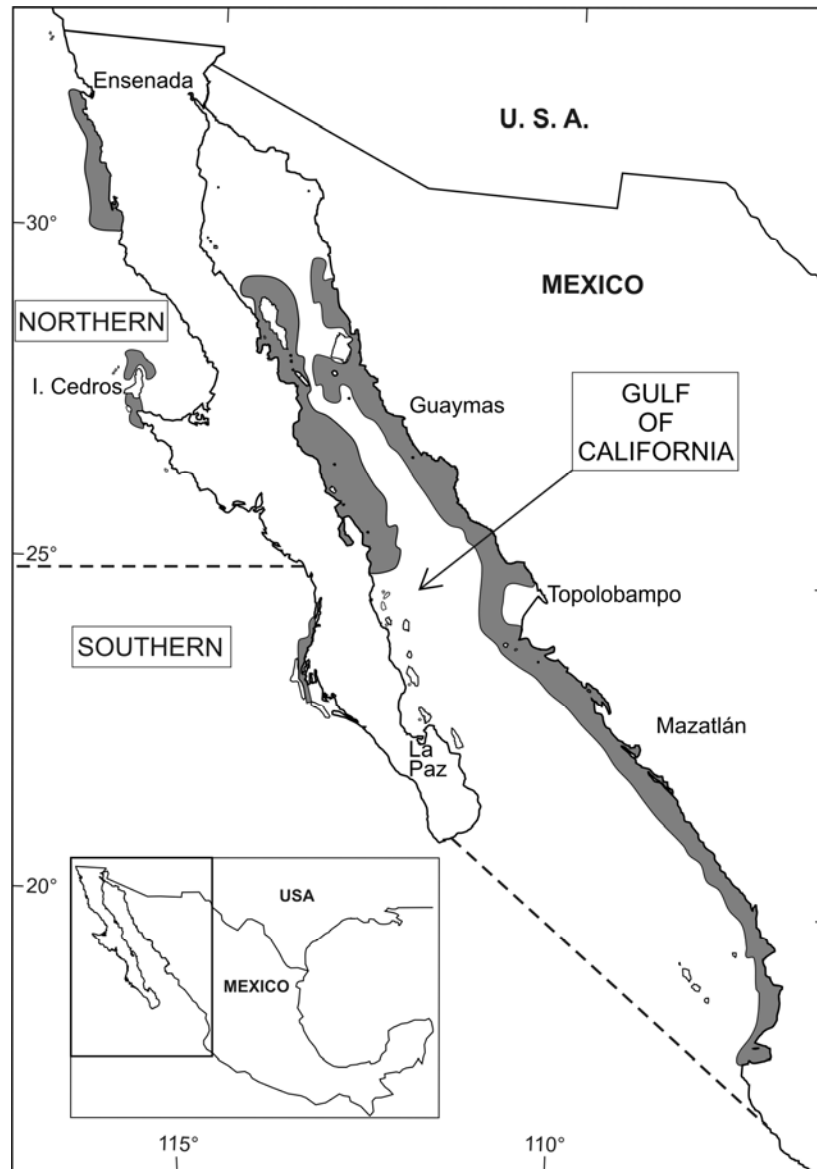


Figure 3. Distribution of Pacific sardine stocks (dashed lines show limits) and main Mexican fishing areas (grey areas) (modified from Nevárez et al. 2006).

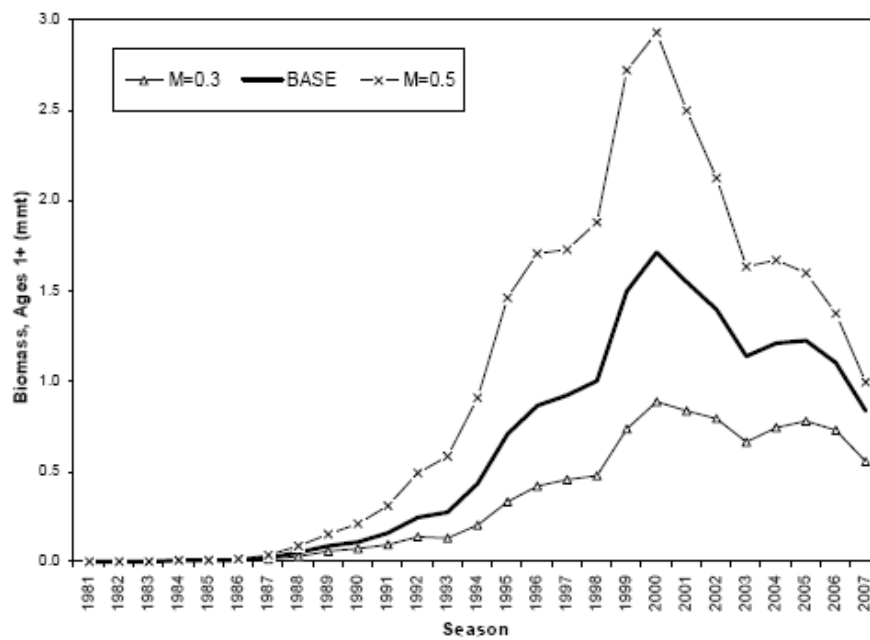


Figure 4. Stock biomass (fish age 1 and older) estimates from Hill et al. (2007) for the Pacific sardine northern stock.

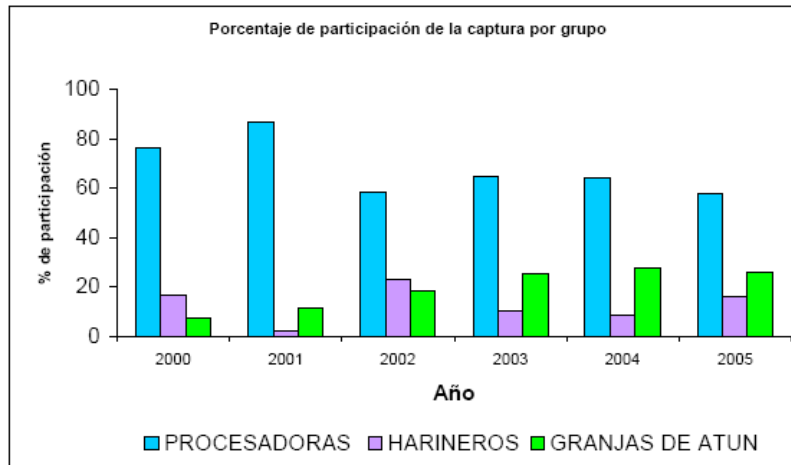


Figure 5. Yearly percentages of use of the Pacific sardines landed in Ensenada (SPPMBC 2006). “Procesadoras” is frozen fish; “Harineros” is fishmeal, and “Granjas de Atun” means delivered to capture-based tuna aquaculture. Data for 2006 can be seen in Table 3.

Chapter 4

Environmental and Socio-Economic Impacts of Capture-Based Tuna Aquaculture (CBTA) in Mexico

Environmental Status of Capture-Based Tuna Aquaculture (CBTA) in Mexico

CBTA shares similar concerns with cage culture of other carnivorous fish, such as organic pollution in the water column and the sediments, concerns about diseases, impacts on feedstock and forage fisheries, and impacts on sea mammals and birds (Cheshire *et al.* 1996). The degree of impact from the effluent wastes of cage aquaculture is dependent on the species biomass, culture and feeding methods, and on the nature of the receiving environment in terms of its physics, chemistry, and biology (Wu 1995).

The key environmental impacts of CBTA are related to the feeding of sardines and fish excretion, which is high due to the use of fresh and defrosted sardines, and because bluefin tuna have poor food conversion ratios (Chapter 1; Vita and Marin 2007). Bluefin tuna are normally overfed and food conversion ratios commonly range from ~15 to 25:1 (on a wet weight basis) (Chapter 1; Aguado-Giménez & García-García 2005; Aguado-Giménez *et al.* 2006). The daily feeding rate of defrosted sardines is approximately 5-8% of body biomass (FAO 2004). High intensity feeding of sardines may result in an excess of sardine wastes entering the environment, leading to an organic enrichment of the sediments, and disturbance of benthic communities. In addition, birds and sea lions eat a considerable amount of the sardines fed to tuna, and this causes a large amount of bird feces to enter the water.

CBTA, however, represents in many ways a lower risk to the environment compared with cage aquaculture of other carnivorous fish, such as salmon. In the case of CBTA, fish are grown for four to nine months. The site is fallow for the remainder with no food or feces introduced, thus giving an opportunity for ecosystem recovery. Ranched Northern Bluefin Tuna (NBT) are fed frozen or fresh sardines; no feed pellets containing large amounts of organic carbon are wasted (Chapter 1). Also, because farmed NBT comes from natural populations, there is no risk of introducing exotic or genetically improved species into the system that could cause negative interactions with wild stocks if they escape from the pens. NBT, in particular, is also recognized as a species resistant to disease (Munday *et al.* 2003; Sawada *et al.* 2005). Although several parasites have been identified for NBT, so far they have not represented serious problems (Deveney *et al.* 2005; Munday *et al.* 2003).

Recently, Fernandes *et al.* (2007 a,b) estimated nitrogen loads from southern bluefin tuna aquaculture in south Australia based on feed inputs, fish metabolism, and environmental data. The authors estimated that 86-92% of the nitrogen (N) was lost as dissolved wastes and only a small proportion was retained in fish tissue (7-12% of feed inputs) or excreted as feces. The low nitrogen retention in southern bluefin tuna is partially explained by the high metabolic rates of tuna (Korsmeyer and Dewar 2001),

which are three or more times higher than other finfish aquaculture species. These processes, combined with the low settling velocity of tuna feces, and the effects of scavenger feeding, lead to minimal impacts to the benthos. The authors concluded that the nature of tuna wastes suggest low and localized impacts at current stocking densities and ranching practices.

The extent of environmental impact by CBTA in Mexico may be difficult to determine due to its recent development. For the same reason, the amount of scientific studies related to CBTA in the region is very scarce. Nevertheless, we were able to obtain recent local information, in some cases from studies presently in progress, which may lead to drawing some preliminary conclusions. We also addressed some specific, critical issues of CBTA in Mexico regarding the level of governance and enforcement presently practiced, especially the killing of sea mammals (Dalton 2004).

Environmental Impact Assessments (EIAs)

Environmental Impact Assessments (EIAs) are required by Mexican law for CBTA. These EIA state potential physical-chemical impacts on the pelagic and benthic ecosystems derived from three sources: direct excretion of NBT; uneaten food that reaches the bottom and consumes oxygen during decomposition; and waste from workers from vessels around the tuna cages. It is well known that nitrogen and phosphorus are the main pollutants arising from CBTA (Aguado-Giménez *et al.* 2006; Fernandes *et al.* 2007). The main effects would be a reduction of oxygen in the water column or at the bottom that may cause changes or mortalities to benthic fauna, and, possibly, tuna mortalities. Another potential effect could be the spillage of oil or gasoline from the boats working around the cages.

Concessions for CBTA state that a company is obligated to maintain an environmental monitoring program. Initially, no specific variables or sampling frequencies were defined. However, all ranchers were required to maintain an environmental monitoring program. Some ranches hired the services of UABC, CICESE, or private consulting companies. Others hired external services and maintained their own monitoring programs. SEMARNAT (Ministry of the Environment and Natural Resources) requested environmental quality data from the ranches, which required reports on the amount of nutrients in the water column. However, due to changes in the law, the Mexican Navy became the official entity responsible for requesting and verifying the quality of the seawater and sediment around the ranches. The parameters and sampling frequencies became uniform for all companies as of January 2007 (Table 1). For a brief time period, sediment samples for lead, copper, zinc and iron were also required, but these are not required today. The Navy does their own sampling, at least twice a year, to verify the reports given by the companies. When red tide events occur, the Navy does specific sampling at the sites they consider pertinent as a way to have an independent verification of water quality.

Companies have more reasons than the government enforcement agencies to maintain an environmental monitoring program. In most cases, ranches are concerned about polluting the environment around their ranches, because they will be the first affected.

In places where several companies share the same bay, as in Salsipuedes Bay, it is important for each company to have evidence that they are not the source of an environmental problem that can affect neighboring ranches. We know of at least one case where ranching activities are insured by an international company that demands a monitoring program in order to assure compensation for possible losses. Therefore, environmental monitoring is often practiced by ranches without the need for strict enforcement by government. In fact, while phytoplankton monitoring is not demanded by the Navy, some companies maintain regular phytoplankton analysis (Parlange-Lamshing 2006). Occasionally, trace metal analyses of the sediments and the tuna have been requested by the companies and performed by UABC and CICESE.

Impacts on the Water Column

In spite of the fact that there are several institutions devoted to research and education in marine sciences in the Ensenada region, environmental baseline data at the sites where the CBTA ranches are located is very scarce. However, for nutrients and bacteria there are studies in adjacent coastal areas that provide ranges of values to be expected in polluted (at the discharge of the city water treatment plant) and pristine areas (such as the FDA certified areas for shellfish culture in the southern part of Ensenada Bay). However, data for ammonia (NH_4) for the Ensenada Bay are scarce (Table 2).

Because nutrient analyses are required by law, and The Navy is responsible for verifying the information, presently there is a nearly continuous monitoring of nutrients at the tuna ranches and adjacent marine areas. The Navy is responsible for declaring if there is any damage to the environment. So far, there have been no adverse reports due to CBTA. Data from April 2007 obtained by The Navy and made available for this report shows minimum-maximum values of NO_3 , NH_4 and PO_4 of 0.039-1.75, 0.020-0.082, and 0.033-0.279 mg/l, respectively, taken at the surface and the bottom in a series of 21 stations along the Salsipuedes Bay. Low nutrients around the ranches are not surprising since, presently, all CBTA ranches in Mexico are located in relatively open areas with significant circulation.

Red tides

Red tides may occur every year off the Pacific coast of Baja California during the spring and can remain through the summer (Peña-Manjarrez *et al* 2001). Red tides are a major threat to CBTA. Ranches have had to move cages offshore to avoid tuna mortalities and, although this practice solves the problem, it represents an important increase in costs.

Historical data, at least since 1901, on red tides in the southern California region shows that they occur during the spring and early summer (Holmes *et al.* 1967). However, the frequency of blooms is quite variable. The Mexican Navy maintains a routine monitoring program on the water quality of the Pacific Coast, Gulf of Mexico, and the Mexican Caribbean with the purpose of contributing to the protection and conservation of the marine environment. This program includes the monitoring of red tides (Acosta-Chamorro *et al.* 2003, Curiel-Mondragón 2007, Juárez-Romero *et al.* 2005). From 1975 to 1994, there was an interruption in the annual blooms in this region except for some

localized events along the coast of Los Angeles, during 1976 and 1977. The intensity and population structure of the blooms are also variable; before 1975, the dominant species was *Prorocentrum micans*, while the most intense blooms during late summer and early fall were associated with *Lingulodinium polyedrum* (Peña-Manjarrez *et al.* 2001). Since 1995, red tides have occurred in the region regularly. It has been speculated that this is caused by the increase in the surface temperature and the increased availability of inorganic nutrients (Acosta-Chamorro *et al.* 2003).

After the El Niño 1997-98 event, two strong red tides appeared in Todos Santos Bay, the first in February and March of 1999, and the second from April to June of 2000 (Acosta-Chamorro *et al.* 2003). No major events were present in 2001. In 2002, an isolated event 20 km south of Todos Santos Bay affected two tuna ranches (Acosta-Chamorro *et al.* 2003, Orellana-Cepeda *et al.* 2002). A *Ceratium furca* patch, with concentrations of 10^7 cell/l, was observed days prior to the event 10-12 km south of the ranches. A sudden change in wind direction caused by Hurricane Hernán transported the patch to the area of the NBT cages causing a massive die off of NBT within six hours. The authors considered that even the most seemingly benign phytoplankton species at great densities could cause serious damage to NBT (Orellana-Cepeda *et al.* 2002). In order to reduce the effect of red tides, one company sponsored a study to determine the proper phytoplankton sampling frequency for different times of the year (Parlange-Lamshing 2006).

Since 2003, The Mexican Navy, in collaboration with the National Program for Bivalve Mollusks, started monthly monitoring for red tides in four stations in Todos Santos Bay (Acosta-Chamorro *et al.* 2003). When a red tide event is present, weekly samples are taken and the number of stations is increased by sampling directly on the sites affected (Curiel-Mondragón 2007, Juárez-Romero *et al.* 2005). At the beginning of 2005 a large red tide event covered a large area of Todos Santos Bay. The Navy reported that this red tide event occurred in three phases: initially, the dominant species was *Lingulodinium polyedrum*; next, a mixture of species was present (*L. polyedrum*, *Gyrodinium undulans* and *Ceratium furca*); in phase three, at the end of August, the bloom was dominated by the diatom *Cylindrotheca closterium* (Juárez-Romero *et al.* 2005). During this bloom ranchers moved their cages, and fish mortalities were reduced.

Baja California is a region recognized for its mollusk cultivation. Oysters have been grown commercially since the mid-seventies and mussel farms present since the mid-eighties. Since its beginning, the industry has had to deal with red tide events. Some of the mollusk production is exported to the USA. In order to comply with the requirements for export, a bi-national program was established in the mid-eighties (Programa Nacional de Sanidad de Moluscos Bivalvos) led by the Ministry of Health (Secretaría de Salud). Mollusk farmers must meet US FDA sanitation requirements which include the certification of the areas where the cultures are located, as well as the regular analysis of shellfish. In order to certify an area for mollusk cultivation, two years of bi-monthly sampling are required. The water bodies and mollusks must meet US FDA standards. All analyses are carried out at a US FDA certified laboratory located at the Institute of Oceanography (Instituto de Investigaciones Oceanológicas) of UABC.

Presently, there is a contingency plan to monitor the presence of red tides. The plan is led by the Ministry of Health (SSA) with the participation of the Ministry of the Environment and Natural Resources (SEMARNAT), the Ministry of Agriculture, Rural Development, Fisheries and Food (SAGARPA), and the Mexican Navy (SEMAR). SSA is responsible for the coordination of all the participants and is also responsible for establishing fishing bans, sampling and establishing any actions to protect the population. Several academic institutions collaborate (UABC, CICESE, CETMAR) providing expertise on the analyses, toxins, and the identification of toxic organisms.

Impacts on Benthic Species

The deposition of particulate matter as uneaten food and fecal matter from cages has been identified as one of the main causes of the negative environmental impact of aquaculture (Gowen *et al.* 1991; Fernandes *et al.* 2007). The accumulation of wastes in the sediments causes an enrichment of organic matter that causes low oxygen values, carbon, nitrogen and phosphorous enrichment and a change in the sediment texture (Karakassis *et al.* 1998; Pawar *et al.* 2001). These conditions cause changes in the abundance and diversity of the benthic macrofauna that can be seen under the cages which decreases with distance from them (Brooks *et al.* 2003; Ritz *et al.* 1989; Vita and Marin 2007). However, according to Graham and Dickson (2001) the extremely high metabolic rates of endothermic fish, such as bluefin, not only account for high nutrient loads to the environment, but also for a different partition between solid and dissolved wastes.

Vita *et al.* (2004) evaluated the particulate organic waste output originated by CBTA in the Mediterranean Sea through direct measurements in the field with sediment traps. Particulate waste output from tuna fattening is qualitatively and quantitatively different from that produced in the culture of other Mediterranean fish such as sparids. The high digestibility of proteins in feeds results in a lower quantity of total particulate nitrogen discharged, but a higher dissolved inorganic nitrogen load. A similar result has been found in studies of CBTA in South Australia (Fernandes *et al.* 2007 a,b). As a result, the deposition rates of particulate organic matter from CBTA were lower than the values mentioned in the literature for the culture of other species.

Vita and Marin (2007) recently reported the environmental impact of CBTA cages of 32 m depth on benthic communities in the western Mediterranean. Benthic surveys carried out by these authors indicated that a zone of high impact was restricted to a radius of roughly 5 m from the cages with a transitional radius at 35 m. This zone was characterized by high densities of opportunistic species. There was a further zone of moderately stressed benthic communities extending to ~180 to 220 m from the cages. This moderately stressed zone showed an increase in the densities of some opportunistic species. At distances greater than 220 m from the tuna ranch, the ecosystem apparently returned to normal conditions. The fallow period produced partial remediation of the area affected, except in the sediments underneath the cages where a 6 month fallow period was not sufficient for the community to totally recover.

The presence of the ranches and the impacts on the benthic community have been studied in the area of Salsipuedes Bay, 15 km north of Ensenada, where three ranches are located. Most of these studies are in recent research theses (Díaz-Castaneda and Harris 2004; Rodríguez-Villanueva 2005; Valenzuela-Solano 2006). Rodríguez-Villanueva (2005) studied the structure of the macrobenthic invertebrates and its relationship with physical-chemical variables of the sediment along the coastal zone from Tijuana to Ensenada including Salsipuedes Bay. Samples were obtained in August and September of 1998 and July 2001, just after the installation of the ranches. Fauna under the cages were composed mainly of polychaete worms, crustaceans, echinoderms, and mollusks. The study includes the description of the polychaete community, widely used as pollution indicators, in relation to temperature, salinity, dissolved oxygen, grain size, % organic carbon, PCBs, DDTs, and several trace metals. Two years later, Valenzuela-Solano (2006) specifically characterized the polychaetes of Salsipuedes Bay near the CBTA ranches to evaluate possible impacts. The study included samples taken in March 2003 and October 2004 and concluded that, so far, no important negative effects were detected in relation to the organic loading of the NBT cages. This was hypothesized to be due to the low density of the cages and the fact that the position of these cages is in an open, well flushed bay; however, the nearest samples were taken 250 m from the cages (Valenzuela-Solano 2006).

Preliminary results of a study in progress of samples collected in April of 2006 in Salsipuedes Bay, reported important changes in the polychaete community structure when compared with a study performed in 1998 by Valenzuela-Solano (2006). Observations reveal a displacement of the 1998 dominant species *Amphiodia urtica* and the presence of opportunistic species previously reported for polluted areas such as *Tellina modesta*, *Monticellina sibilina*, and *Armandia brevis* associated with high values of organic matter (1-3.5%) (Valenzuela-Solano, personal communication).

Impacts on marine mammals

Tuna cages are very attractive environments for sea lions; they represent food and resting sites. For CBTA ranchers, however, sea lions are major nuisances since they can get inside the cages and eat tuna. Because all sea mammals in Mexico are protected by law, ranchers cannot kill or harass them. Besides the risk of losing their concessions, the killing of a marine mammal is penalized under Mexican law with one to nine years in prison (Artículo 420, Código Penal Federal Mexicano).

Sea lions (*Zalophus californianus*) are very common along the coast of Baja California. Dense colonies inhabit the area near the ranches. They also are very efficient at colonizing new niches. All ranches have to deal with the presence of sea lions. During feeding operations 15 to 35 animals can be seen resting on the tuna cages (Figure 2). Sometimes, sea lions succeed in getting into the cages. Fishermen reported that one morning, one sea lion was able to bite 6 tuna of ~20-25 kg each. There have been reports of up to four sea lions within the same cage (J. Guzman, personal observations). Ranchers have established several measures to deal with the sea lions. A net of 2.2 m high is placed around the cage to avoid the sea lions getting in, sirens that emit sound at

a frequency not audible to the human ear scare the animals, and, commonly, solar powered, electrified wires are placed around the cages (Figure 3).

In 1998, a group of volunteers working in a non-governmental organization Ensenada Marine Mammal Research and Conservation (ICMME by its Spanish acronym) started systematically recording data from strandings that occur along Todos Santos Bay (Herrera 2002; Bravo *et al.* 2005). ICMME includes scientists and students from the Schools of Biology and Oceanography from UABC and volunteer citizens. One of the main objectives of this organization is to investigate and report cases of sea lions in distress. They maintain a census of live animals that have been beached and dead animals washed ashore. From January 1998 to September of 2004, 276 animals were found washed ashore. Eighty percent of the animals were sea lions (*Zalophus californianus*) followed by *Phoca vitulina richardsi*, *Mirounga angustirostris*, *Delphinus delphis*, *Tursiops truncatus*, *Lagenorhynchus obliquidens*, *Steno bredanensis*, *Eschrichtius robustus*, and *Balaenoptera musculus*, on the coast of Bahía Todos Santos, from Punta San Miguel to Rincón de Ballenas to the south. According to ICMME, it is estimated that in the region around Todos Santos Bay, where most of the CBTA ranches are located, there are about 400 marine animals (<http://icmme.ens.uabc.mx>).

Mortalities of marine mammals may be caused by natural or anthropogenic factors. Marine mammals die as a result of starvation, predation, trauma, and diseases (Geraci *et al.* 1999). Sea lions are also killed by entanglement in fishing gears (Zavala-González and Mellink 1997). This is related to the fact that sea lions frequently approach both commercial and sport fishing vessels and take fish from the lines and the nets.

During a census of stranded marine mammals from 1998 to 2001 (before most of the NBT ranches were established), 153 stranded animals were found along 30 km of coast around Todos Santos Bay. Most of them (76%) were California sea lions (*Zalophus californianus*) (Bravo *et al.* 2005). Bravo *et al.* (2005) also reported a strong seasonality of stranded marine mammals during their beach monitoring from 1999 to 2001. The majority of strandings (81%) occurred during winter and spring and consisted mainly of adult male sea lions. It is important to point out that most ranches do not have NBT in their cages during this time of the year (winter to spring). *Zalophus californianus* was the species that was most impacted by humans, caused mainly by shootings. Probable human-induced injuries were observed in 17% (26) of all animals. Most of these were *Z. californianus* (24), probably due to their known interaction with fisheries. On average, there are 40 strandings of marine mammals/year; however, the number of beached marine mammals was 2-4 times higher during an El Niño year (1998), or during the presence of the 2002 red tides, which are natural events in the region (Herrera 2002).

Impacts on Sea Birds

Similar to the case of sea lions, marine birds (mainly seagulls and pelicans) can be a nuisance to tuna ranching. Birds interfere during the feeding of tuna, stealing the sardines before they reach the NBT. Marine birds are also protected species; therefore, ranches, cannot use methods that would hurt or kill sea birds. During feeding, ranchers use non-lethal methods (a whip, or throw a plastic ball attached to a string for easy

recovery) to scare the bird. So far, we are not aware of complaints against NBT ranchers for harming sea birds but, as far as we know, there have been no studies that would determine the effect of NBT ranchers on neighboring sea bird colonies or vice-versa. Observations by our team show clear evidence of large sea bird colonies on the shorelines in bays having NBT ranches.

Health issues

Transmission of harmful diseases and parasites from marine aquaculture facilities to wild stocks is a risk identified in marine aquaculture assessments (Anonymous 2007). Parasites are a regular issue for any food-related resource. They commonly use predator-prey links in trophic food webs to find appropriate hosts. Due to their complex lifecycles, macroparasites acquired through trophic interactions reflect the diet and the habitats of their hosts. Due to its diet, Pacific sardines are an easy target for several parasites, because the majority of parasites use as their first hosts small crustaceans such as copepods and euphasids, which sardines feed upon. Macroparasites can be located in the sardine body cavity, muscle, intestinal tract, stomach, and gills (Kunnenkeri 1962; Sánchez-Serrano 2005). Some could represent a risk for the tuna or even for the humans that consume them (Sánchez-Serrano 2005; Janine Caira, personal communication).

Sánchez-Serrano (2005) studied the parasite composition in sardines caught off Ensenada in order to evaluate potential risks for CBTA. He found three genera of trematodes present: *Myosaccium*, *Parahemiurus*, and *Bucephalus*; two genera of nematods: *Anisakis* and *Hysterothylacium*; and two cestodes of the family Tetraphyllidae. Each of the parasites showed preferences for their location in the host. Nematods were located in the body cavity, adult trematods in the stomach, their metacercariae in the fin rays, while cestods were located in the sardine mid-intestine. Of these, the metacercariae of *Bucephalus* sp. represented a potential risk for bluefin tuna, while the *Anisakis* sp. and *Hysterothylacium* sp. could also represent a potential risk to humans. Sánchez-Serrano (2005) also studied the minimal lethal temperature for these parasites, concluding that all parasites died after being at -20°C for 24 hours.

During the past 10 years there has been an increased awareness that viral hemorrhagic septicemia virus (VHSV) is present in many marine fish populations of the North Pacific Ocean and other regions. The interest in marine reservoirs for VHSV in North America began in 1988 with the first observations of the virus among returning adult salmon in the Pacific Northwest (Hedrick et al. 2003). The virus has been labeled as a cause for mass mortalities for several species. In order to understand the prevalence of infection with VHSV in the northeastern Pacific Ocean, Hedrick et al. (2003) isolated VHSV from Pacific sardine, Pacific mackerel *Scomber japonicus*, and smelt *Thaleichthys pacificus* populations from several locations between the coast of Vancouver Island, Canada, and southern California, USA. The prevalence of VHSV among groups of apparently healthy sardines, mackerels and smelts ranged from 4 to 8% in California and Oregon. A greater prevalence of infection (58%) occurred in groups of sardines sampled in Canada that sustained a naturally occurring epidemic during 1998-99. They mention that naturally occurring epidemics due to VHSV in marine fish most likely result from several environmental, nutritional and other stressors that predispose a large native population

to infection from carrier fish. The spread of the virus either rapidly or slowly through the population may result in either mass mortality or a slow, chronic course of infection. In the case of sardines, they could not detect the origin of the virus, although they suspect that it is spread between populations during north-south migrations. Also, their results suggest that the presence of VHSV in sardines and mackerels in California may represent the most southerly distribution expected, since water temperatures increase significantly further south. However, until now there has been no analysis of VHSV in Pacific sardine populations from Mexican waters.

Social-Economic Status of CBTA in Mexico

Industry structure

CBTA in Mexico is not a vertically integrated industry; today, only one company is fully integrated. Ranchers hire boats to catch and transport wild fish; hire sardine boats to get the food; and hire boats to transport workers. Some ranchers also contract out the processing of their fish. Since Mexico has a moratorium on increasing fishing efforts in sardine and tuna fisheries (Norma Oficial Mexicana 003-PESC-1993 and Carta Nacional Pesquera, Diario Oficial, 2nd edition, August 25, 2006), all concessions given so far provide only the right to ranch tuna, not to capture wild tuna. The majority of ranches have contract with tuna and sardine boats having existing fishing rights to obtain juvenile NBT. For an industry with a high level of risk, contracting is the best option.

Economic impacts

The ranched NBT is a very valuable fish, and there is an accelerating demand for it. In 2005, Japan imported ~15,000 metric tons (MT) of ranched tuna for sashimi; ~4,500 MT was from Mexico (Jerónimo Ramos, personal communication). It is estimated that tuna ranching is worth ~US\$ 75-100 million/year, most of which is spent as operational costs (Del Moral-Simanek and Vaca-Rodríguez, in review; Jerónimo Ramos, personal communication). Also, it is estimated that the NBT ranching industry in Mexico generates ~1,000-1,500 direct jobs, depending on the catch volume and fish price (Del Moral-Simanek and Vaca-Rodríguez, in review; Jerónimo Ramos, personal communication). These jobs are classified in Mexico as administrative and production positions. Administrative jobs range from high-ranking administrative positions (directors, managers, accountants, scientists) to office people (secretaries, drivers, security personnel, and others). Similarly, production positions include highly qualified personal (boat captains, crew, divers, maintenance, etc.). The CBTA industry also generates ~100 other direct jobs in supply companies such as frozen sardine processing, ice production, freezing, and cold storage facilities.

According to the Mexican Mariculture Association, the total fleet that participates in the CBTA in Mexico is ~15 tuna purse seiners, ~50 towing boats, and ~10 sardine boats (Jerónimo Ramos, personal communication). These boats are serviced at the Ensenada and El Sauzal harbors. In spite of the fact that ~15 tuna boats catch NBT, their average total catch per season (~4,000 MT) is small, equivalent to the average annual catch of one yellowfin tuna boat.

It has been estimated that the industry generates ~2,500 to 3,500 indirect jobs (Lamas Lorena, lunes 24 de Septiembre; El Vigía newspaper: <http://elvigia.net/noticias/?seccion=generales&id=38322&como=pordia>). Several other companies (including government agencies) benefit from CBTA and have increased incomes from the hiring of mechanics, refrigeration businesses, custom agencies, hardware and fishing gear stores, dive shops, gas stations, etc. (Del Moral-Simanek and Vaca-Rodríguez, in review).

The purse seine fishery targeting NBT for CBTA does not necessarily generate new jobs but re-directs those resources that would otherwise be absorbed in the yellowfin and skipjack tuna fleets throughout the Eastern Pacific Ocean, unloading their products in Mazatlan and Manzanillo. Now these boats fishing NBT for CBTA base their operations in Ensenada, creating new jobs in this region during the NBT season. Similarly, sardine boats bring their catch to the CBTA ranches rather than to processing plants for fishmeal. In both cases, more income is generated by the same amount of fish. Tuna boats get three times more money for their NBT by selling it to tuna ranches (~US\$ 3,000/MT) than selling it for canning (~US\$ 1,000/MT). Fresh and frozen sardines are sold to NBT ranches for ~US\$ 100-120/MT (fresh) and ~US\$ 200 MT (frozen), respectively (depending on supply), while the price of sardines sold to processing plants is only US \$80/MT (Del Moral-Simanek and Vaca-Rodríguez, in review).

Added value

In practical terms, CBTA is adding value to a fish that has already been caught. Ranched tuna was sold for ~US\$ 17± 2/kg in 2006, which means that the added value for ranched tuna increased from ~US\$ 6/kg (when caught for canning) to ~US\$ 17/kg in Mexico. Once the product reaches Japan, most of the Mexican NBT is sold directly to wholesalers (ASEAN 2006). In Japan, NBT in supermarkets is sold for ~US\$ 160-200/kg, and in restaurants at US\$ 380-400/kg. In Mexico, NBT is sold at restaurants for ~US\$ 240/kg (Del Moral-Simanek and Vaca-Rodríguez, in review). These prices explain the enormous interest in this industry. Considering final prices of NBT in Mexico (~US\$17/kg), and an average for Japanese supermarket and restaurant prices (~US\$ 280/kg), it is estimated that Mexico obtains only ~6% of the total final sale price of this product, and Japan 94% (Del Moral-Simanek and Vaca-Rodríguez, in review).

Economic risks

Besides the good management skills any business must have, and assuming that the market conditions are adequate for supporting this business, CBTA is exposed to uncontrollable natural factors (red tides, storms, etc.) that may affect its success (Orellana-Cepeda *et al.* 2002; Parlange-Lamshing 2006). From the beginning of the process to the sale of the tunas, many factors must be overcome to make CBTA successful. Initially, the major constraint is the fact that ranchers depend on catching tuna during their migration off Mexican coasts from May to September. If they are not successful in capturing NBT, the season is lost, and a company could lose the year's investments, with no chance to recover until the following season. If they succeed in catching juvenile NBT and are able to transport it to the CBTA ranches with relatively

low mortalities, the next major challenge is to supply enough sardines to feed the animals. Ideally, ranchers seek fresh sardines. Although the Pacific waters of Mexico are recognized for their abundance of small pelagics (Chapter 3), these are not always available on a daily basis to feed NBT. A second alternative is to provide frozen sardines from the same region or from different locations. Sardine availabilities affect prices.

If ranchers succeed in catching NBT and are able to provide sardines to feed them, they are still exposed to two major natural factors; the presence of red tides (usually at the beginning of the fattening season) that may kill the NBT, and winter storms (usually towards the end of the season) that may destroy the cages. Because red tides and winter storms cannot be controlled, the only measure that can be taken is to be prepared for them. In the case of red tides, there is a monitoring program that alerts the ranchers and gives them the opportunity to temporarily move their cages offshore. In order to avoid damages from winter storms, ranchers must decide in advance the best site selection that would provide protection and good anchorage, as well as having good cage design. In any case, to protect from red tides or storms means significant increases in investment and operational costs.

Working Conditions

Working conditions and wages are similar to other manufacturing industries in the Baja California region. Every CBTA worker gets a temporary or permanent contract. All workers enjoy the benefits established in the Mexican Labor Law which include contributions by the workers, the companies, and the federal government:

1. Medical coverage for workers and their families (Instituto Mexicano del Seguro Social, http://www.boletin-infomail.com/leyes_isr_imss_lft_sar/index.html);
2. Retirement (Sistema de Ahorro para el Retiro, http://www.boletin-infomail.com/leyes_isr_imss_lft_sar/index.html);
3. Housing subsidies (Instituto del Fondo Nacional de la Vivienda para los Trabajadores, http://www.boletin-infomail.com/leyes_isr_imss_lft_sar/index.html);
4. Vacations (from 1-2 weeks), including 2 extra weeks of salary paid at the end of the year, and 10% of the company's net annual income divided among the employees, http://www.boletin-infomail.com/leyes_isr_imss_lft_sar/index.html;
5. Training, uniforms, equipment and tools for their work.

The minimum wage in Baja California is 50.57 MX pesos/day (http://www.sat.gob.mx/sitio_internet/asistencia_contribuyente/informacion_frecuente/salarios_minimos/) (US\$ 4.60/day or ~US\$ 138/month). The average unskilled employee working for a Mexican NBT ranch earns ~US\$ 327-409/month and skilled workers and employees with university degrees earn above US\$ 750/month plus benefits. To date, there are no unions for NBT ranch workers.

Community receptiveness

The tuna industry in Ensenada started in 1930 (Beltran et. al. 2001). For decades fishing was one of the most important industries in the region and made the State of Baja

California the number one producer of fish and seafood in Mexico. Although the fishing industry has declined, Baja California remains one of the top three states in the nation in marine fish production. Baja California was also a pioneer in developing mariculture. Oyster cultivation was introduced and has been practiced commercially since the mid-seventies. Besides oysters, today mussels and abalone are cultivated commercially. Other species of clams and fish are being studied for commercial cultivation. This development has been promoted, in part, due to the fact that Ensenada has a relatively large community of marine scientists, and many of them are devoted to the study of aquaculture. These facts make this region relatively receptive to fishing and aquaculture. Presently, the new State government of Baja California is in the process of establishing a Ministry for Fisheries and Aquaculture for the State. It would become the second state in the country, after the State of Baja California Sur to have a Ministry for Fisheries and Aquaculture.

Conflicts with other industries

NBT ranches require convenient sites which often shared with other industries, activities, or interests. Most of the ranches in Mexico are located north or south of Todos Santos Bay where the city and harbor of Ensenada are located (see map, Chapter 1). Today, all ranches are in areas with good marine water qualities, but many of the CBTA sites are threatened by industries nearby that could potentially affect them. Presently, the installation of a liquid gas terminal, 3 km north of Salsipuedes Bay (where 3 NBT ranches are located), the dredging of Ensenada Harbor, and future plans to expand the El Sauzal Harbor (15 km south of Salsipuedes Bay) are potential threats to the CBTA ranching industry.

The coast where CBTA are located is an area rich in commercially important benthic species such as sea urchins, sea cucumbers and lobsters, among other commercially valuable species. Some conflicts have arisen between sea urchin fisherman and NBT ranchers over the issue of wastes produced from the CBTA ranches that reach the bottom and could deteriorate the benthic environment. The conflict was resolved by the ranchers' commitment to keep the cages anchored in depths beyond the depth ranges of the urchin divers (>25 m).

There is a conflict of interest between the CBTA ranchers and the sardine boat owners. Sardine boat owners do not want the NBT ranchers to have their own sardine boats, arguing that they may lose control of production and prices. Another issue is the competition between the NBT ranchers and the sardine processing plant owners for the sardine supply. The CBTA ranches pay higher prices for fresh sardines than the frozen sardine packing and fishmeal/oil reduction industries. The Association of the Small Pelagic Fleet has requested that no more CBTA permits of concessions be issued in order to maintain the sardine stocks. They recognize that the sardine fisherman benefit from higher prices the CBTA ranchers pay compared to the fishmeal industry (Pringle, El Mexicano newspaper, 1 de Octubre de 2007).

Governance: National Regulations

CBTA is a relatively new activity in Mexico. It started first as an experiment in 1996 and failed after three years of operation (see Chapter 1). The first company to still be in operation started in 1997. Mexican law defines a difference between “permits” and “concessions”. Permits are short-term (up to five years) and can be renewed. Concessions are long-term (up to 50 years). Two pioneering companies were granted concessions that were defined by area, not by the number of cages. As the industry developed, new companies requested concessions, and the government developed terms for a standard concession. Today, the standard concession allows a maximum of 10 cages with 40 MT of tuna each (400 MT total). However, concessions for the two pioneering companies are still defined by area, and, over time these companies have deployed more than 10 cages in their areas.

Fisheries and aquaculture in Mexico are regulated under the General Law for Sustainable Fisheries and Aquaculture (Ley General de Pesca y Acuicultura Sustentable) by the National Fisheries and Aquaculture Commission (Comision Nacional de Pesca y Acuicultura, CONAPESCA), which is within Ministry of Agriculture, Cattle, Rural Development, Fisheries and Feeding (Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación, SAGARPA). On July 24, 2007 a new Fisheries and Aquaculture law was passed by the Mexican government. Although this new law provides certain rights to the states to regulate some local fisheries, it does not include large or small pelagics. Therefore, all issues dealing with the management of CBTA are under the jurisdiction of the Federal Government through CONAPESCA. Relevant statutes are detailed in Table 3. Other laws protect the marine environment and wildlife (marine mammals, birds, etc.) from being harmed or harassed by NBT ranchers.

Concessions given by CONAPESCA for CBTA have well defined requirements. If the CBTA ranches do not comply with these, they could lose concessions without any compensation. In order to have a lease for CBTA, the CONAPESCA requirements are: CONAPESCA-01-027 application; applicant’s (company’s) legal documentation; economic and technical study; environmental impact assessment; invoices, contracts or acquisition program of the equipment needed for development; geographic location; and payment of a tariff (http://www.conapesca.sagarpa.gob.mx/wb/cona/cona_requisitosa).

Regulations on CBTA in Mexico have been changing as the industry has developed (Table 3). Initial concessions had fewer restrictions than the newer ones. CBTA ranchers have created a chapter within the National Chamber of Fisheries and Aquaculture (CANAINPESCA). In the Carta Nacional Pesquera (CONAPESCA http://www.sagarpa.gob.mx/conapesca/ordenamiento/carta_nacional_pesquera/cnp.htm, published on August 25, 2006), a recommendation was made regarding the possibility of separating the administration of the NBT from the yellowfin tuna fisheries due to the fact that the former is being used almost exclusively by the CBTA ranchers.

International affairs

The fact that CBTA is based on a pelagic species and that the NBT rached in Mexico is practically all exported to foreign countries makes this industry subject to external regulations and pressures. Catches of NBT by Mexico are made within its EEZ (Perez 2005; Fleischer *et al.* 2006; Dreyfus *et al.* 2007). No other country fishes in this area. Mexico is a member of the Inter-American Tropical Tuna Commission (IATTC), which establishes seasonal limits and closures for tuna capture fisheries. In the Eastern Pacific Ocean (EPO) there is a limit on fleet capacity, and other restrictions have been established by IATTC and FAO, such as international trade, observers, etc. In the past, there was a limit on total catches. However, for the last 4 years, instead of a quota on the total catch, a closed season of 41 days was implemented under the recommendation of IATTC who proposed a closed season for 41 days to be applied in any of two periods in a year (www.iattc.org). Mexico applies its closed season in winter. Although this ban is applied in Mexico for all of the purse-seiner tuna fleet, it has no effect on the NBT fishing because the capture of NBT is limited from May-June to mid-August when the fish are within the Mexican waters. In other words, the NBT fishing in Mexico is auto-regulated by the period of availability near the Mexican coast during its migration (see Chapter 2).

NBT fisheries are not completely within the IATTC jurisdiction but are also managed by the International Scientific Committee for tuna and tuna-like species of the North Pacific (ISC). The ISC (<http://isc.ac.affrc.go.jp/>), of which Mexico is a member, was established in 1995 for the purpose of enhancing scientific research and cooperation for the conservation and rational utilization of tuna and tuna-like species (TTLS) of the North Pacific Ocean (NPO), and to establish the scientific groundwork if, at some point in the future, it was decided to create a multilateral regime for the conservation and rational utilization of the TTLS in the NPO.

The ISC functions are to assess and analyze fisheries and other relevant information concerning the species covered and prepare reports of its findings or conclusions on the status of the species, including trends in population abundance, developments in fisheries, and conservation needs. ISC promotes research cooperation and collaboration among its members by developing proposals for the conduct and coordination of international and national programs. The members of the ISC are: Canada, Chinese Taiwan, Japan, Republic of Korea, Mexico, People's Republic of China and the United States of America. There are also observers such as the IATTC, FAO, North Pacific Marine Science Organization (PICES), Secretariat of the Pacific Community (SPC), and the Commission for the Conservation and Management of Highly Migratory Fish Stocks in the Western and Central Pacific Ocean.

Ecological Aquaculture Approach to CBTA

One goal for sustainable aquaculture is to ensure that commercial aquaculture has minimal adverse effects on the environment. One way of achieving this goal is through development of improved methods of waste management for open water based or coastal/offshore aquaculture. Seaweeds take up nitrogen and phosphorus, which are used for growth and production of proteins, structural components, and energy storage

products. In a balanced Integrated Multi-Trophic Aquaculture (IMTA) system, nutrients are removed when multiple products (fish, invertebrates, seaweeds, shellfish, etc.) are harvested, thus reducing solid and soluble nutrient loadings to the marine environment. The fact that up to 92% of excretion of tuna is soluble (Fernandes 2007a,b,c), makes CBTA ideal for integrated aquaculture. In IMTA systems, coastal or offshore, seaweeds can be used as extractive components to remove nutrients, mitigate adverse environmental impacts, and provide economic diversification (Chopin *et al.* 2001; Neori *et al.* 2004; Neori *et al.* 2007).

On a global basis, seaweed aquaculture is a multi-billion dollar industry representing 27% of world marine aquaculture production on a weight basis and 24% on a monetary basis (FAO 2006). Nearly, all seaweed aquaculture occurs in China, Korea, Japan and Chile. North America has very few seaweed aquaculture operations. The most notable is the Acadian Sea Farms in Charlesville, Nova Scotia, Canada, producing the red seaweed *Chondrus crispus* for export to the Japanese food market (Craigie *et al.* 1999). The primary commercial use of seaweed is for human consumption, but it is also used as a source of colloids for the food and cosmetic industry, as a source of pharmaceuticals, as a supplement in livestock feed, and as a soil amendment in agriculture (Sahoo and Yarish 2005). In Baja California, Mexico it has been used as a food source for abalone and is currently being investigated as a replacement for fishmeal in finfish diets. In the 1980s, there was significant interest in seaweeds as a biomass source for methane production (Flowers and Bird 1984), and there is current renewed interest in seaweed as a biofuel source for ethanol and methane gas production. Seaweeds have also been cultivated for habitat restoration (Carney *et al.* 2005) and have been proposed as large-scale carbon sinks, as a method of removing heavy metals from marine environments, and even as a way to detoxify and remove TNT from seawater (Cruz-Uribe *et al.* 2007).

Seaweeds have been successfully incorporated into a number of demonstration and pilot scale IMTA systems. Nutrient loads in the effluent were significantly reduced and converted to abalone biomass (Troell *et al.* 2006). In projects supported by the National, Connecticut, Maine and New Hampshire Sea Grant programs (Sahoo and Yarish 2005; Carmona *et al.* 2006; He and Yarish 2006; Blouin *et al.* 2007), a demonstration-scale land-based IMTA was developed to grow Atlantic cod (*Gadus morhua*) and two native species of the red seaweed *Porphyra* (=nori). A pilot-scale coastal IMTA project in New Brunswick, Canada uses kelp (*Saccharina latissima* and *Alaria esculenta*) and mussels (*Mytilus edulis*) as the extractive components in close proximity to salmon (*Salmo salar*) cages (Chopin *et al.* 2007). In Portugal, Matos *et al.* (2006) demonstrated the effectiveness of three red seaweeds, *Palmaria palmata*, *Gracilaria bursa pastoris* and *Chondrus crispus* in removing nutrients from the effluent of tank-based production of turbot (*Scophthalmus maximus*) and sea bass (*Dicentrarchus labrax*). In Israel, Neori *et al.* (2003, 2004, 2007) developed a commercial-scale IMTA system incorporating gilthead seabream (*Sparus aurata*), the green seaweed *Ulva lactuca*, abalone and sea urchins. In South Africa, kelp (*Ecklonia maxima*) grown in the effluent of abalone aquaculture tanks was fed back to the abalone to reduce the footprint of finfish and abalone production as well as to create economic diversification (Troell *et al.* 2006).

Final Remarks

CBTA in Mexico has provided a significant economic benefit to the region of Ensenada without significant environmental impacts on the environment. Operational practices to “fit” tuna ranching into the marine environment and to accommodate enhanced marine mammal and bird populations appear successful at the level of current production and regulatory systems. However, although governance has improved, there are concerns about the future expansion of tuna ranching, and there is not enough practical information at the commercial scale to provide guidance for the next generation of advanced systems incorporating IMTA and socio-ecological approaches, as recently adopted by the FAO (Costa-Pierce 2007). It is urgent to strengthen applied, cooperative (government, industry, universities and NGOs) monitoring and research programs in order to assure more sustainable CBTA. The relative success that CBTA has had in Ensenada suggests that the Pacific coast of Baja California is particularly suitable for highly profitable marine aquaculture, especially the cultivation of marine finfish. Baja California’s internationally known marine science institutions, highly productive waters, local infrastructure, and closeness to international markets make this region particularly attractive for marine aquaculture. It is apparent that in the near future there will be many requests for the establishment of commercial aquaculture projects and enterprises. Presently, there is insufficient information for the comprehensive planning needed to assure an orderly sustainable development of aquaculture.

Literature Cited

- Acosta-Chamorro V, Jiménez-Pérez LC, Curiel-Mondragón C. 2003. Estudio de Mareas Rojas en la Bahía de Todos Santos Baja California. Dir. Gral. de Inv. y Desarrollo. Estación de Investigación Oceanográfica de Ensenada. Secretaría de Marina-Armada de México. 22 pp.
- Aguado-Giménez F, García-García B, Hernández-Lorente MD, Cerezo-Valverde J. 2006. Gross metabolic waste output estimates using a nutritional approach in Atlantic bluefin tuna (*Thunnus thynnus*) under intensive fattening conditions in western Mediterranean Sea. *Aquaculture Research*. 37: 1254-1258.
- Aguado-Giménez F, García-García B. 2005. Growth, food intake and feed conversion rates in captive Atlantic bluefin tuna (*Thunnus thynnus* Linnaeus, 1758) under fattening conditions. *Aquaculture Research*. 36: 610-614.
- ASEAN (Association of Southeast Asian Nations) 2006. Chapter 2. Market Conditions in Japan. p110. www.asean.or.jp/eng/trade/information2006/B-2.%20Tuna.pdf.
- Beltran PR, Ortega-García S, Campos-Alfaro T, Tome-Vázquez A, Bravo-Mendoza FG. 2001 Desarrollo de la Industria Atunera en Mazatlán Sinaloa. (Primera parte) El Vigía, Órgano Informativo del Programa Nacional de Aprovechamiento del Atún y Protección de Delfines (PNAAPD), Año 6 No. 12, Mayo 2001: 8.
- Blouin N, Fei XG, Peng P, Yarish C, Brawley SH. 2007. Seeding nets with neutral spores of the red alga *Porphyra umbilicalis* (L.) Kützinger for use in integrated multi-trophic aquaculture (IMTA). *Aquaculture* 270: 77-91.
- Bravo E, Heckel G, Schramm A, Escobar-Fernandez, R. 2005. Occurrence and Distribution of Marine Mammal Strandings in Todos Santos Bay, Baja California, México, 1998-2001. *The Latin American Journal of Aquatic Mammals*. 4(1):15-25.

- Brooks KM, Stierns AR, Mahnken CV, Blackburn DB. 2003. Chemical and biological remediation of benthos near Atlantic salmon farms. *Aquaculture* 219: 355-377.
- Carmona R, Kraemer GP, Yarish C. 2006. Exploring Northeast American and Asian species of *Porphyra* for use in an Integrated Finfish-Algal Aquaculture System. *Aquaculture* 252: 54-65.
- Carney LT, Waaland JR, Klinger T, Ewing K. 2005. Restoration of the bull kelp *Nereocystis luetkeana* in nearshore rocky habitats. *Mar. Ecol. Prog. Ser. Vol. 302*: 49-61
- Cheshire A, Westphalen G, Smart A, Clark S. 1996. Investigating the environmental effects of sea cage tuna farming. II. The effect of sea cages. A Reprint to the FRDC and Tuna Boat Owner Association, University of Adelaide, South Africa. 52 pp.
- Chopin T, Yarish C, Wilkes R, Belyea E, Lu S, Mathieson A. 1999. Developing *Porphyra*/salmon integrated aquaculture for bioremediation and diversification of the aquaculture industry. *J. Appl. Phycol.* 11: 463-472.
- Chopin T, Buschmann AH, Halling C, Troell M, Kautshy N, Neori A, Kraemer GP, Zertuche-Gonzalez JA, Yarish C, Neefus C. 2001. Integrating seaweeds into mariculture systems: a key towards sustainability. *J. Phycol.* 37(6): 975-986.
- Chopin T, Sawhney M, Shea R, Belyea E, Bastarache S, Armstrong W, Reid GK, Robinson SMC, MacDonald B, Haya K, Burrige L, Page F, Ridler N, Justason A, Sewuster J, Powell F, MarvinCraigie R. 2007. An interdisciplinary approach to the development of Integrated Multi-trophic Aquaculture (IMTA): the inorganic extractive component. World Aquaculture Society Meeting Abstracts.
- Costa-Pierce, BA. 2007. *An Ecosystems Approach to Marine Aquaculture*. FAO Working Group on an Ecosystems Approach to Aquaculture. FAO, Rome, Italy.
- Craigie JS, Staples LS, Archibald AF. 1999. Rapid bioassay of a red food alga: accelerated growth rates of *Chondrus crispus*. *World Aquaculture* 30 (1): 26-28.
- Cruz-Uribe O, Cheney DP, Rorrer GL. 2007. Comparison of TNT removal from seawater by three marine macroalgae. *Chemosphere* 67: 1469-1476
- Curiel-Mondragón C. 2007. Reporte de datos de Mareas Rojas en la Bahía de Todos Santos, Baja California durante 2006. Dir. Gral. de Inv. y Desarrollo. Estación de Investigación Oceanográfica de Ensenada. Secretaría de Marina- Armada de México. 26 pp.
- Dalton R. 2004. Fishing for trouble, *Nature*. 431: 502-504.
- Del Moral-Simanek R, Vaca-Rodríguez JG, in review. Captura del atún aleta azul en Baja California: Pesquería Regional o Maquiladora Marina.
- Deveney MR, Bayly TJ, Johnston CJ, Nowak BF. 2005. A parasite survey of farmed southern bluefin tuna, *Thunnus maccoyii*. *J. Fish. Dis.* 28:279-284.
- Diaz-Castaneda, V, Harris LH. 2004. Biodiversity and structure of the polychaete fauna from soft bottoms of Bahia de Todos Santos, Baja California, Mexico. *Deep-Sea Research II*. 51: 827-847.
- Dreyfus M, Fleischer LA, Klett-Traulsen A, Ulloa-Ramirez PA, Robles H. 2007. Mexican Progress Report to the 7th ISC. July 2007. 16 pp
- Espinosa-Carreón TL, Gaxiola-Castro G, Robles-Pacheco JM, Nájera-Martínez S. 2001. Temperature, salinity, nutrients and chlorophyll a in coastal waters of the Southern California Bight. *Cien. Mar.* 27: 397-422.
- FAO 2006. State of world fisheries and aquaculture. Electronic edition. <http://www.fao.org/docrep/009/A0699e/A0699e00.htm>

- Fernandes M., Angove, M, Sedawie T, Cheshire A. 2007a. Dissolved nutrient release from solid wastes of southern bluefin tuna (*Thunnus maccoyii*, Castelnau) aquaculture. *Aquaculture Research*. 38: 388-397.
- Fernandes M, Laurer P, Cheshire A, Angove M. 2007b. Preliminary model of nitrogen loads from southern Bluefin tuna aquaculture. *Marine Pollution Bulletin*. 54: 1321-1332.
- Fernandes M., Lauer P, Cheshire A, Svane I, Putro S, Mount G, Angove M, Sedawie T, Tanner J, Fairwather P, Barnett J, Doonan A. 2007. Aquafin CRC-southern Bluefin tuna aquaculture subprogram: tuna environment subproject evaluation of waste composition and waste mitigation. Aquafin CRC Project 4.3.2. (FRDC Project No. 2001/103. 311pp.
- Fleischer L, Dreyfus M, Robles H, Ulloa P. 2006. Mexican Progress Report to the 6TH ISC. March 2006. 20 pp.
- Flowers, AB, Bird K. 1984. Marine biomass: A long-term methane supply option. *Hydrobiologia*. 116-117: 272-275.
- Galindo-Bect MS, Galindo-Bect LA, Hernández-Ayón JM, Ley-Lou F, Alvarez-Borrego S. 1999. The effect of el Nino on the nutrients and total organic carbon of a coastal lagoon of northwestern Baja California. *Cien. Mar.*. 25:225-237.
- Geraci JR, Harwood J, Lounsbury VJ. 1999. Marine mammal die-offs. Causes, investigation and issues. In Twiss Jr., J.R. and Reeves, R.R. (eds) *Conservation and Management of Marine Mammals*. Smithsonian Institution Press, Washington, DC. USA. 367-395 pp.
- González-Morales AT, Gaxiola-Castro G, Lara-Lara JR. 1993. Daily photosynthetic parameters and biomass from size-fractionated phytoplankton off Baja California. *Estuar. Coast. Shelf Sci*. 36: 147-158.
- Gowen RJ, Weston DP, Ervik A. 1991. Aquaculture and the benthic environment: a review. In: *Nutritional Strategies and Aquaculture Waste. Proceedings of the 1st International Symposium on Nutritional Strategies and Management of Aquaculture Waste*, Guelph, ON, Canada. Cowey C.B. & C.Y. Cho (eds). 187-205.
- Graham JB, and Dickson KA. 2001. Anatomical and physiological specializations of endothermy. In Block, BA and Stevens ED (eds), *Tuna: Physiology, Ecology and Evolution*. Academic Press, San Diego, pp. 121-166.
- He P, Yarish C. 2006. The developmental regulation of mass cultures of free-living conchocelis for commercial net seeding of *Porphyra leucosticta* from Northeast America. *Aquaculture* 257:373-381.
- Herrera N. 2002. Contingencia ambiental por varameintos extraordinarios de lobos marinos de California. *TODOS@CICESE*. 57. (<http://gaceta.cicese.mx/>).
- Holmes RW, Williams PM, Eppley RW. 1967. Red tide in La Jolla Bay, 1964-1966. *Limnol. Oceanog*. 12: 503-512.
- Juárez-Romero, R., Peña-Manjarrez JL, Jiménez-Pérez LC, López-Castillo G. 2005. Estudio de Mareas Rojas en el 2005 en la Bahía de Todos Santos, B.C. Dir. Gral. de Inv. y Desarrollo. Estación de Investigación Oceanográfica de Ensenada. Secretaría de Marina- Armada de México. 56pp.
- Karakassis I, Tsapakis M, Hatzimaya E. 1998. Seasonal variability in sediment profiles beneath fish farm cages in the Mediterranean. *Mar. Ecol. Prog. Ser.* 162: 243-252.

- Korsmeyer KE, Dewar H. 2001. Tuna metabolism and energetics. In: Block BA, Stevens ED (eds), *Tuna: Physiology, Ecology and Evolution*. Academic Press, San Diego, pp. 35-78.
- Kunnenkeri, J.K. 1962. Preliminary Report on the Parasites of the California Sardine and the Parasitic Distribution in Clupeidae. *The Journal of Parasitology*, 48 (1): 149.
- Millán-Núñez R, Rivas-Lozano AM. 1988. Nutrients and Chlorophylls in the Todos Santos Bay (May 1983). *Cien. Mar.*. 14(4): 23-42.
- Munday BL, Sawada Y, Cribb T, Hayward CJ. 2003. Diseases of tunas, *Thunnus spp.* *Journal of Fish Diseases* 26:187-206.
- Myrick CA. 2002. Ecological impacts of escaped organisms. Pages 225-245 in J. Tomasso, ed. *Aquaculture and the Environment in the United States*. U.S. Aquaculture Society, A Chapter of the World Aquaculture Society, Baton Rouge, LA
- Neori A, Chopin T, Troell M, Buschmann AH, Kraemer G, Halling C, Shpigel M, Yarish C. 2004. Integrated aquaculture: rationale, evolution and state of the art emphasizing seaweed biofiltration in modern aquaculture. *Aquaculture*. 231: 361-391.
- Neori A, Shpigel M, 2003. Algae: a key for sustainable integrated mariculture. *Proceedings of the Aquaculture Europe 2003 –Beyond Monoculture*, August 8–12, 2003. Trondheim, Norway, pp. 52–57.
- Neori A, Troell M, Yarish C, Critchley A, Chopin T, Buschmann AH. 2007. The Need for Ecological Balance in “Blue Revolution” Aquaculture. *Environment* 49 (3): 36-42.
- Orellana-Cepeda E, Granados-Machuca C, Serrano-Esquer J. 2002. *Ceratium furca*: One possible cause of mass mortality of cultured blue fin tuna at Baja California, México. *Proceedings of the Xth International Conference on Harmful Algae*. St. Pete Beach, Florida, USA. October 21 to 25, 2002: 514-516.
- Parlange-Lamshing DK 2006. Monitoreo del Fitoplancton en el Rancho de Engorda de Atún Aleta Azul (*Thunnus orientalis*) Puerto Escondido, B.C., México. Tesis de Licenciatura en Oceanología. Facultad de Cien. Mar., UABC. Ensenada, B.C. México. 44 pp.
- Pawar V, Matsuda O, Yamamoto T, Hashimoto T, Rajendran N. 2001. Spatian and temporal variation of sediment quality in and around fish cage farm: A case study of aquaculture in the Seto Inland Sea, Japan. *Fish. Sci.* 67: 619-627.
- Peña-Manjarrez JL, Gaxiola-Castro G, Helenes-Escamilla J, Orellana-Cepeda E. 2001. Cysts of *Lingulodinium polyedrum*, red tide producing organism in the Todos Santos Bay (winter-spring 2000). *Cien. Mar.*. 27: 543-558.
- Perez H. 2005. Captura de atún Aleta Amarilla por la flota atunera cerquera mexicana con observadores del Programa Nacional del Atún Aleta Amarilla y Protección al Delfín. *El Vigia. Órgano Informativo del Programa Nacional de Aprovechamiento del Atún y Protección de Delfines (PNAAPD)* Año 11 (29) abril-agosto 2005: 6-9.
- Ramos J. 2007. “Desarrollo de la industria de la engorda de atún aleta azul en Baja California. Seminar for Graduate Studies, presented at the Instituto de Investigaciones Oceanológicas of the Universidad Autónoma de Baja California. Ensenada, BC October 26, 2007.
- Russell BD, Elsdon TS, Gillanders BM, Connell SD. 2005. Nutrients increase epiphyte loads: broad-scale observations and an experimental assessment. *Marine Biology*. 147:551-558.

- Ritz DA, Lewis ME, Shen M. 1989. Response to organic enrichment of infaunal macrobenthic communities under salmonid seacage. *Mar. Biol.* 103: 211-214.
- Rodriguez-Villanueva LV. 2005. Estructura de las comunidades de invertebrados macrobénticos y su relación con variables fisico-químicas en la zona costera Tijuana-Ensenada, Baja California, México. Doctoral Thesis. FCM-IIO. Universidad Autónoma de Baja California. 264 pp.
- Sahoo D, Yarish C. 2005. Mariculture of seaweeds. In R. Andersen (Ed.) *Phycological Methods: Algal Culturing Techniques*. Ch. 15. Academic Press, Elsevier Publ. Pp. 219-237.
- Sawada Y, Tokihiko O, Miyashita S, Murata O, Kumai H. 2005. Completion of the Pacific Bluefin tuna *Thunnus orientalis* (Temminck et Schlegel) life cycle. *Aquaculture Research* 36:413-421.
- Soto-Balderas MGL, Alvarez-Borrogo S. 1991. Inorganic nutrients in the inundation channels of tidal marshes of a coastal lagoon of northwestern Baja California. *Cien. Mar.* 17: 1-20.
- Troell M, Robertson-Andersson DV, Anderson RJ, Bolton JJ, Maneveldt G, Halling C, Probyn T. 2006. Abalone farming in South Africa: An overview with perspectives on kelp resources, abalone feed, potential for on-farm seaweed production and socio-economic importance. *Aquaculture* 257: 266-281.
- Valenzuela-Solano S. 2006. Caracterización de la Poliquetofauna en un area adyacente a una zona de cultivo de atún aleta azul en Bahía Salsipuedes, B.C. M.S. Thesis. CICESE. Ensenada, B.C. México. 139 pp.
- Vita R, Marin. A 2007. Environmental impact of capture-based bluefin tuna aquaculture on benthic communities in the western Mediterranean. *Aquaculture Research*. 38: 331-339.
- Vita R, Marín A, Jiménez-Brinquis B, Cesar A, Marín-Guirao L, Borredat M. 2004. Aquaculture of Bluefin tuna in the Mediterranean: evaluation of organic particulate wastes. *Aquaculture Research*. 35: 1384-1387.
- Wu RSS. 1995. The environmental impact of marine fish culture: Toward a sustainable future. *Mar. Poll. Bull.* 31: 159-166.
- Zavala-González A, Mellink E. 1997. Entanglement of California sea lions, *Zalophus californianus*, in fishing gear in the central-northern part of the Gulf of California, Mexico. *Fishery Bulletin* 95: 180-184.
- http://www.sat.gob.mx/sitio_internet/asistencia_contribuyente/informacion_frecuente/salarios_minimos/
- http://www.conapesca.sagarpa.gob.mx/wb/cona/cona_archivo_veda_atun
- <http://www.inaoep.mx/oic/documentos/LEYFEDERALDELTRABAJO.pdf>
- http://www.boletin-infomail.com/leyes_isr_imss_lft_sar/index.html
- http://www.conapesca.sagarpa.gob.mx/wb/cona/cona_requisitosa

Table 1. List of parameters required to be reported by the CBTA farmers to the Mexican Navy.

Variables	Water	Frequencies	# of stations/# of depths	Sediment	Frequencies	# of stations ¹
NO ₃	X	monthly	2/3			
NO ₂	X	monthly	2/3			
NH ₄	X	monthly	2/3			
PO ₄	X	monthly	2/3			
*BOD	X	monthly	2/3	X	6 months	2
**COD	X	monthly	2/3	X	6 months	2
***TSS	X	monthly	2/3	X	6 months	2
Sulfides				X	6 months	2
Cyanide				X	6 months	2
Total N				X	6 months	2
%Org. Matter				X	6 months	2

¹One station is located within the pen and a second at 400 m; * BOD: Biochemical Oxygen Demand; ** COD: Chemical Oxygen Demand; ***Total Suspended Solids including organic and inorganic fractions.

Table 2. Nutrient baseline data for the Ensenada, Mexico region.

Sites	NO ₃ (μM)	NH ₄ (μM)	PO ₄ (μM)	References	Notes
Todos Santos Bay	10.0 (50 m) 2.0 (0 m)	-	1.3 (50m)	Espinosa-Carreón T.L. <i>et al.</i> 2001. <i>Cien. Mar.</i> 27: 397-422.	Average max concentration from 5 cruises in 1994. Samples from surface to 50 m
Todos Santos Bay	8.9	-	0.5	Millán-Nunez & Rivas-Lozano. 1988. <i>Cien. Mar.</i> 14:23-42	Maximum values. Data from May 1983. Nitrogen is NO ₃ +NO ₂
Outside Todos Santos Bay	10	-	1.0	González-Morales <i>et al.</i> 1993. <i>Estuar. Coast. Shelf Sci.</i> 36:147-158.	Maximum surface values
Estero de Punta Lagoon	10	27	7	Soto-Balderas & Alvarez-Borrego. 1991. <i>Cien. Mar.</i> 17: 1-20	Maximum values. Data from May 1983. Nitrogen is NO ₃ +NO ₂
Estero de Punta Lagoon	6.8	-	3.5	Galindo-Bect <i>et al.</i> 1999. <i>Cien. Mar.</i> 25:225-237.	Data 1992-93 Nitrogen is NO ₃ +NO ₂

Table 3. General Law for Sustainable Fisheries and Aquaculture (Ley General de Pesca y Acuicultura Sustentable) published on July 24, 2007

Revelant Aquaculture Regulations	Descriptions
Article 4	Defines aquaculture
Article 40 to 59	Defines leases
Article 78 to 82	Defines development plans
Article 85 to 88	Defines management
Article 89 to 102	Administration
Article 103 to 108	Sanitation
Article 109 to 117	Sanitary control
Article 118 to 119	Product quality



Figure 1. Water quality monitoring conducted by the Universidad Autonoma de Baja California (UABC).



Figure 2. Sea lion resting on an unprotected tuna cage.



Figure 3. Cage with a net and electric wire to prevent the intrusion of sea lions.

Chapter 5

Knowledge Gaps and Recommendations for the Future

Baja California is one of the most arid states of Mexico with ~700 km of coastline on each coast that has few commercial activities other than limited, dry land agriculture and tourism. Although Baja California remains among the three main fishing states in Mexico, practically all wild fisheries are exploited at maximum capacity. Aquaculture activities have been seen as a “natural” activity to provide sustainable livelihoods to coastal communities. The State of Baja California is a pioneer in Mexico in the development of commercial aquaculture of oysters, mussels, abalone, seaweeds, and marine fish. Aquaculture is considered as one of the main opportunities for the State along with tourism and fishing (commercial and recreational). If well planned and practiced, aquaculture could also be an activity that could permit the conservation of the natural environment. The west coast of Baja California is presently a relatively pristine environment with enormous pressures for development. Due to Baja’s strategic position having good access to transportation networks, international markets, and suitable environments, aquaculture has been aggressively promoted by Mexico’s state and federal governments. In order to develop a model industry in terms of sustainability, it is imperative that the necessary information be provided to coastal managers, decision-makers and business entrepreneurs that would guarantee minimal impacts on the environment. At this point, we believe that CBTA, as currently permitted, has had a positive impact on the social fabric of Baja California’s coastal communities. If properly integrated and redesigned ecologically to incorporate integrated multi-trophic aquaculture (IMTA) systems, CBTA would have minimal impacts on the environment. However, the main challenge is to enforce and improve on the existing regulatory structure to control any further expansion of CBTA and to insure its long term economic, social, and environmental sustainability.

Knowledge Gaps and Recommendations

1. There are no studies on the impacts to eutrophic oceans with frequent upwellings (producing high background levels of nutrients) where these marine ecosystems also receive large, concentrated amounts of sardine wastes and tuna feces from CBTA.

Implement remediation management practices including integrated multi-trophic aquaculture (IMTA) and innovative coastal management plans that include aquaculture.

2. In Baja California’s eutrophic ocean, there are no carrying capacity models appropriate for this marine environment that integrate hydrodynamic and biogeochemical parameters to establish cage limits. Baseline environmental information is lacking along much of the Baja California coast. As a result, the State of Baja California cannot effectively deal with requests for new concessions and expansion of the industry in other pristine bays.

Estimates of the carrying capacity of impacted coastal regions will be required to properly determine the maximum number of cages and stocking densities of tuna for ranches and to minimize the risk of environmental pollution and maximize the production of healthy fish. Improve environmental monitoring using new technologies (including DNA assays, environmental sensors, probes and remotely operated buoys) in designated ranch areas that will be able to provide real time data acquisition and analysis to minimize environmental impacts. New technologies will also be needed to better monitor the impacts on benthic communities and to develop trained specialists to assist with this work.

3. There are enhancements (and/or new production) of wild fish, marine mammals, sea birds, and other marine life in and around the CBTA sites that are not well understood.

Conduct population studies on marine mammals, sea birds, wild fish, and other marine life in CBTA regions.

Conduct studies on the impacts of large amounts of wastes from wild marine fish, sea birds and marine mammals being added to the marine environment due to CBTA.

4. There are no studies on the use of alternative (and more abundant) pelagic fish species as feedstocks for CBTA.

Investigate the use of other small pelagic fish species to feed tuna, for example, chum mackerel, and encourage the development of economically and ecologically viable formulated diets for NBT in the cages.

5. There are no internationally agreed upon guidelines for best practices for all stages of the ranching process that could be more economically, socially and environmentally responsible.

Work internationally to develop guidelines and best practices for all stages of CBTA.

6. There is little research on the transmission of viruses and other diseases from sardine feedstocks to tuna.

Investigate health issues, such as the VHS virus in Pacific sardines, e.g. its role in decreasing the quality of sardines as tuna feed, and its risks to the marine ecosystem.

Increase the level of biosecurity on CBTA farms. Prohibit the uncontrolled movements of untreated sardines from separate sardine stocks in the USA, Gulf of California, and southern Mexican sardine stocks and others arriving internationally for use in the CBTA in northern Baja California ranch sites.

7. The stock status and size of a potential sustainable fishery for adult sardines that are present offshore of northern Baja California is unknown.

Encourage the existing sardine fleets to protect current stocks and to develop a new, experimental trawl fishery targeting larger sardines offshore in the northern Baja region to meet the existing and future demands of CBTA in this bioregion.

8. Closed cycle aquaculture for NBT is neither scientifically nor economically viable at the present time in Mexico.

Develop a commercial scale research and development farm in Baja California to simultaneously develop economically viable IMTA, tuna hatcheries, and feeds for closed cycle tuna aquaculture.

General Recommendations

Governance

In Mexico, keep the current moratorium in place on the development of CBTA of NBT and sardine boats until new models of sustainability are demonstrated.

In the WPO, work internationally with Asian nations (Japan, Philippines, Indonesia, Taiwan, etc.) to evaluate the closure of NBT spawning and nursery areas south of Okinawa and elsewhere in the WPO to commercial fishing.

In the EPO, reserve the NBT quota for CBTA and other valued added products.

Institution and Capacity-Building

In order to become a more environmentally and socially sustainable practice in Mexico, CBTA needs a Center of Excellence in research/education/outreach and extension that would be a university, government, and industry partnership.

The industry has broad and frequent global communications and a solid network of contacts between the major CBTA centers in Australia, Japan, the Mediterranean and Mexico, but scientists, policy-makers and extension specialists are poorly organized and scattered. Such local institution-building would need to be closely connected to international institutions in order to develop trust and a sustainable funding base. Such a Center would need to be a long-term investment. Encourage Japan to actively work with this Mexican Center of Excellence to maintain robust stocks of NBT in the WPO and EPO.

Develop an innovative, collaborative (government, industry, university, NGO) marine Center of Excellence in Mexico as a research and training center to develop new models of sustainable aquaculture (IMTA).

Study the innovative model developed in Australia, the South Australian Research and Development Institute (SARDI).

MARINE SCIENCE ASSESSMENT OF CAPTURE-BASED TUNA AQUACULTURE IN NORTHERN BAJA CALIFORNIA, MEXICO

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