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Abstract

Mexico is an ideal location for the production of northern bluefin tuna (Thunnus orientalis) with its extensive coastline, available work force, proximity to sardine and tuna stocks, and "aquaculture friendly" environmental regulations. Current tuna and sardine productivities of the Eastern Pacific Ocean allows for stable and healthy catches. However, sustainability of the existing industry and any further expansion of it is not possible without adoption of new practices such as closing of the life cycle of the tuna in captivity and use of formulated feeds. Recent closing of the life cycle and use of artificial diets in Latin America and Japan are milestones. Adoption of closed life cycle techniques will allow the tuna farming industry to be less dependent on wild stocks. Also, the Mexican government must establish a clear regulatory framework for tuna aquaculture. Mexico can be an environmentally, economically, and socially sustainable tuna aquaculture model for the world.

Introduction

Tunas are high value products in wide demand worldwide particularly in Japan, the United States, and Europe. Commercial fishing for the expanding global tuna markets has come under fire because of the adverse effects of overfishing. In response, some countries have established tuna ranches. Tuna ranches can be located in near shore or offshore (exposed areas) net pens. Wild juvenile or "seed" tuna 60-100cm in length are caught in purse seines and towed for transfer into net pens. Here they are fattened with sardines and other small clupeid fish before going to market. Because the tuna are enclosed in pens, they can be fed and harvested using controlled methods to ensure high meat and fat quality. It is estimated that 80% of the world's bluefin tuna will be from tuna aquaculture in the near future (Pacific Fishing, 2001).

Northern bluefin tuna aquaculture was first commercially conducted in the early 1990s in Australia (Montgomery, 2005). Presently, commercial tuna ranches exist in Croatia, Morocco, Malta, Spain, Portugal, Japan, Australia, and Mexico. It is unlikely that the U.S. will enter the competitive tuna farm market because of stringent environmental regulations, political opposition to aquaculture, and user conflicts in nearshore areas (Pacific Fishing, 2001). In the Mediterranean, tuna ranching has come under heavy fire because of illegal catches and the projected unsustainability of the operations. In contrast, the goal of the Mexican tuna ranching industry is to become a model for sustainable aquaculture. Mexico provides a highly suitable location for tuna aquaculture because of its temperate climate, readily available tuna and sardine resources, lax environmental regulations (compared to the United States), available labor force, and extensive coastline.

Northern Pacific Bluefin (*Thunnus orientalis*) is the focus of the Mexican industry. Northern bluefin tuna is found from the Gulf of Alaska to Baja California and across the northern Pacific Ocean from the Sea of Okhotsk, Japan and the Philippines to north and central America. A tagging study revealed that the Pacific bluefin tuna spawn in the Western Pacific, migrate to the Eastern Pacific at age 1-2, then return to the Western Pacific as adults to spawn. The tuna reach a maximum length of 300cm. The Pacific bluefin tuna is a voracious predator that feeds on many clupeid fish, squid, crabs, and other organisms (Fishbase, 2001). A 2006 Fishery Status report on tunas and billfishes in the Eastern Pacific Ocean (IATTC, 2005) revealed that stocks of the northern Pacific bluefin tuna have been highly variable, witch catches corresponding closely to years of high and low juvenile recruitment (Figure 1).

Figure 1. Retained catches of Pacific Bluefin, 1952-2004
(IATTC Fishery Status Report No. 4, 2006)

Social Aspects

Tuna fishing industry

As of 2001 approximately 270,000 Mexicans were employed in fisheries-related industries. The estimated value of these products was $1.3 billion. The export value was $600 million (FAO, 2003). Fisheries-related industries play a vital role in the Mexican coastal economy.

However, products such as the high value tuna are not widely consumed in Mexico. Instead they are sold to foreign markets where they command the highest prices. Most of Mexico’s tuna operations are in partnership with foreign countries such as Japan, Australia, and the USA.

Tuna fishermen have been competing among themselves for the resource. The active yellowfin tuna fishery faces periods of low catches and consequently supplements their catch with the more abundant bluefin tuna. Low catches are associated with years when the younger fish are primarily harvested; fish that are approximately 80cm. Years when juvenile fish are caught allow adult fish to reproduce (Jimenez and Leon, 1995). Having an additional fleet targeting the northern Pacific bluefin stocks during lag years puts more pressure on the resource used for the tuna ranches.

Purse Seining

Mexico once had a thriving wild tuna fishery that exported canned tuna almost exclusively to the United States. The Ensenada tuna fishery was devastated when the U.S. placed an embargo on Mexican tuna imports in 1990 due to the fact that dolphins were being killed in large numbers during the purse seining of the tuna. Fishermen, their processing facilities, and fleets went into ruin because they no longer had a suitable market for their high volume product. The ban has since been lifted; but current fishermen have a new, higher value market for their tuna: the ranching industry (Gaubatz, 2005). The use of purse seines is used exclusively when catching juveniles for the tuna farms.

Sardines

Feeding the caged tuna requires large amounts of wild sardines. Presently, sardines are in relatively high abundance in the coastal waters in the Eastern Pacific. However, sardine fishermen have faced some troubled times in the past. The sardine population collapsed in the 1960s due to over harvesting and oceanic/climate changes. From 1967 until the mid-1980s a fishing ban was in place off of the California coast to rebound stocks. Favorable nutrient rich, cold-water upwellings returned to the area and the ban was lifted in the 1990's, but sardine stocks are still highly cyclical due to such oceanic changes (Baumgartner and Seller, 2000).

This tuna feed fishery is adding demand to an already high demand for sardines for feeds and other industrial purposes. A major hindrance to managing sardine stocks is that the populations are mobile in the Pacific waters and are under United States, Canadian, and Mexican jurisdiction. These three countries have not came together to draft and enforce a common management plan and still have different regulations that can effect the other countries catch (OECD, nd). The United States operates under a quota system. Mexico's sardine fishery remains largely unregulated (Conser et al., 2002).

Technical Aspects

Catching juveniles for seed

The primary method for catching bluefin tuna seed for aquaculture is purse seining. A purse seine targets identified schools of fish. Tuna farming/ranching in Mexico relies mainly on harvests from July to August. Tuna are located at night by bioluminescence. Juveniles caught average a couple kilograms each. A boat will lay out an end of the net from the stern and another smaller vessel will circle the identified school of fish in the opposite direction.

The bottom will then be cinched closed and the catch hauled towards the ship. Figure 1 shows a typical purse seine as it would look before cinching closed at the bottom. The purse seine method also allows fish to be easily maneuvered into transport cages (approximately 90m circumference) or growout net pens (cages) with minimal handling by means of a passage to swim through between the cages. Cages are towed to holding pens at 1-2 knots. Some journeys may take days but typically they are several hours (Ottolenghi et al., 2004). In 2004, a record catch of Pacific bluefin tuna was landed in Mexico of 8,973MT (ISC, 2005).

Fig. 1 – A Typical purse seine set
http://www.ejfoundation.org/modules/PagEd/medipics/purse-seine.jpg

In tuna farming, it is essential that the animals do not become stressed or has to fight hard because flesh quality will deteriorate, and the stressed fish may not adjust well to captivity, resulting in unacceptably high mortalities. Flesh quality will deteriorate because tuna generate lactic acid and cause the flesh to be classified as “burnt”. Also, stress may cause physiological damage. Purse seining technology has been upgraded in response to outcry over bycatch, specifically dolphin (Sylvia et al., 2003).

Net Pen Cages

Tuna are held in floating cages for 3-6 months where they increase in size 50-100%. Fish cages are located in the native waters of the tuna, having temperatures raging from 18-26C. Cages must be large enough to allow the tuna a natural swimming area. It is important to remember that these fish are truly wild and are not descended from domesticated stocks. Cage technologies vary between growers but share some similar characteristics (Agius, 2002). Cages must be able to withstand the wave forces present. Cages range in size from 150m circumference to as large as 270m. A typical stocking density averages 3kg/m3. Most cages are rimmed by a flexible collar. A site must be located in deep enough water with some current to allow for wastes to be dispersed instead of accumulating below the cage. Net material must be strong, drag free, non-abrasive, and easily repairable.

Fig. 2 – Aerial view of Maricultura del Norte grow out cages in Puerto Escondido
http://www.baja-web.com/punta-banda/images/tuna-pen2.jpg

Fig. 3 – Typical tuna cage in Mexico.
http://www.lib.noaa.gov/docaqua/images/bluefintunacage.jpg

Feeding

Feeding of tuna in the pens requires large amounts of baitfish such as sardines, anchovies, and other small clupeids. Feed fish are introduced fresh or can be frozen into blocks. Generally tuna are fed two times a day for 6 days. Because specialized artificial diets are not used the food conversion ratio (FCR) is high at 10-15:1 while feeding whole fish (Clark, 2002). When the waters are cooler the FCR is higher. Warmer waters result in a lower FCR. Use of formulated diets is one of the major goals of current bluefin tuna research; however, these fish are wild and have short grow out times, so adjusting to a fully formulated diet will be a difficult goal.

Sardines

The primary diet of farmed bluefin tuna is the Pacific sardine (Sardinops sagax). This high quality whole fish diet is also exported from Mexico and the west coast of the United States to Australia for feeding caged tuna. These clupeid fish are small and silver and form large schools numbering sometimes in the millions. They can grow to an average of 38cm in their 12-year life span. Their diet consists of phytoplankton and zooplankton. Historically, sardines have occurred as far north as southeastern Alaska to South America. It is a species under high commercial pressure for fish oil, meal, food, and feed.

Fishing methods for sardines are highly selective and result in minimal bycatch. Sardines are located by plane and harvested with purse seines. The fish are then crowded and pumped directly from the net on to the vessel and immersed in 0oC brine ice solution (Morrissey, nd.).

The importance of the sardine fishery dates back to the early 1900s when peak landings were greater than 600,000MT/year off the west coast of Mexico and United States. During the 1960s the sardine fishery collapsed to a point of commercial extinction. It has since recovered due to aggressive management techniques and now supports a large and sustainable fishery in the Baja California region. It is estimated that the current populations will remain sustainable for the next few decades to come if fishing pressure does not increase and favorable oceanic conditions continue (Baumgartner and Seller, 2000). In 2004, Pacific sardines stocks were estimated at 1 million metric tons. From this estimate, the United States harvest was set at approximately 120,000 MT. These numbers are predicted to fluctuate with climatic changes despite human interactions (Schweigert and McFarlane 2004).

Closing the Tuna Life Cycle

In 2002, Japanese scientists successfully completed the life cycle of the Pacific bluefin tuna in an artificial setting (Sawada et al., 2005). Captive broodstock tuna spawned erratically in late summer with unstable egg production. Tuna larvae were raised in concrete tanks 20-30m circumference with 23-26C sterilized water and fed a mixed diet of clupeids. There is not a broad knowledge of how to culture tuna artificially but this research provides a baseline study to further develop techniques. Once techniques become fully understood, the artificial propagation of larvae and juveniles can help reduce fishing pressures on wild fish for seed. It also introduces the possibility of selective breeding and may lead to the development of more efficient artificial diets (Sawada et al., 2005). Artificial diets have been studied in Australia and Japan since the mid 1990s. Some problems with developing artificial feed is the high value of the fish used in the experiments. Also, growers are hesitant to convert to artificial diets because there is fear of lowered consumer acceptance (FAO State of World Fisheries and Aquaculture, 2004).

Harvest

One of the most important steps of tuna farming is harvesting. Tunas must be harvested in such a way that the meat quality is maintained. Ottolenghi et al (2004) records the characteristics of a high quality tuna as being fresh, fast bleeding after kill, no flesh burns from lactic acid during struggle, little to no histamine, and high fat content in the flesh.

Typically, when it is time to harvest the tuna are crowded in the pen to a confined area where divers can jump in and immediately bring the fish out of the water where they are killed with a puncture to the brain. Fish are then immediately immersed into an ice-brine solution. Some farmers also use electrofishing. In this procedure an electric probe is shot into the fish and a current is sent to kill it. This procedure is not fully refined yet (Mateo et al., 2003). After bleeding, fish are processed and either sent directly to the Japanese market as fresh fish, or are frozen.

Market

The main market for tuna is for Japanese sashimi. Harvesting of farmed tuna is timed to occur when the volume of tuna from the wild is low so that the highest prices can be received - this is a delicate balance because of other competing tuna farms and the wild harvest.

Bluefin tuna is one of the most popular tunas because of its large quantity of "toro". "Toro" is the 6-10cm outer portions of the fish with the belly side commanding the highest prices. Toro grades are determined by fat content. The particular niche that the cultured tuna has filled is between the extremely high quality and low quality sashimi and sushi products (Ottolenghi et al., 2004). Farmed tuna is now bringing a higher quality product to people that could not afford the highest grade product.

Mexican farmers export most of their product in November but continue to export lesser amounts throughout the year. Table 1 shows the prices in Yen of farmed bluefin tuna on the Tsukiji fish market in Japan. Currently, 1kg of Mexican farmed tuna is selling for $25-$40 (Ottolenghi, 2004). Almost all the tuna produced in Mexico is for the Japanese market with little to no exports elsewhere (Asian Economic News, 2004).

Table 1. Farmed bluefin tuna prices in Tsukiji fish market (120 Yen = 1 US$) (INFOFISH, 2003).

Dates	Spain	Spain	Croatia	Croatia	Mexico	Mexico	Japan	Japan
	pieces	Yen/kg	pieces	Yen/kg	pieces	Yen/kg	pieces	Yen/kg
2/3/1998	15	5807	5	5100	46	2997	11	2826
12/7/1998	21	4250	3	3800	33	3623	4	5200
12/14/1999	23	3960	4	3500	31	4183	5	4560
12/25/1999	14	5900	1	4500	26	4376	6	5360
1/14/1999	9	4900	7	3286	67	3351	11	4254

Problems and Opportunities

Regulatory and social climate

Currently Mexico has a poor regulatory climate for tuna farming. Establishing a framework will be of utmost importance if the industry is to continue thriving and remain sustainable. Currently, a team of scientists is working on an assessment of tuna aquaculture in Mexico that will gather data on tuna and sardine stocks, aquaculture practices, and the regulatory and social climate of Mexico (Zertuche et al., nd).

Reliance on wild caught seed

A major problem for the sustainability of tuna farming worldwide is the reliance on wild caught "seed" or juveniles. With Mexico being on the western range of the Pacific bluefin tuna, it is quite possible that other countries could fish the stocks down to low levels leaving little to be caught by the Mexicans after the westward migration. Recently, Japanese scientists have successfully completed the life cycle of the Pacific bluefin tuna in the laboratory (Sawada et al., 2005). Adoption of closed cycle culture techniques for tuna would result in the possibility of more production and could relieve fishing pressures on tuna stocks for seeding purposes. Also, it is believed that with a complete hatchery raised tuna, the transition to an artificial diets could be accomplished which would also allow for selective breeding to improve tuna quality and growth rates. There is still more work to be done to make the closed life cycle an efficient method of culture because of high stress mortalities and physical damage causing mortalities upon stocking into nets (Sawada et al., 2005).

Environmental impacts

Environmental impacts of net pen aquaculture in the open sea are of concern. Mexico currently has no regulatory environment regarding the environmental impacts of tuna farming. This lack of a regulatory framework is a problem because it could allow unsustainable practices to take place. Recently in the Mediterranean, Vita and Arnaldo (2007) studied the environmental effects of tuna farming there. Effects from the tuna cages could be observed for 220m around the cages. Directly surrounding the cages, opportunistic fish had elevated populations. Under the cages and 5-35m surrounding the bottom had stressed populations of benthic organisms. In Mexico, many tuna cages are situated in near shore bays where tidal current and flushing are not as high as offshore. Better siting offshore would remediate some of these environmental effects and create logistical concerns for feeding and cage construction.

Sardine feeds

Current feeds for tuna ranching are mainly comprised of fresh sardines caught in the Western Pacific. The sardine harvest has historically been one of the most important fisheries for the western coast of the United States. It is now known the sardine harvest varies considerably following climate cycles with periods of heavy harvest followed by a period of lower harvests. Currently, the sardine fishery is highly productive and is estimated to be sustainable well into the future at modest harvest rates. Harvest quotas for Pacific sardines in 2004 for the United States alone were 122,000 MT (Conser et al., 2003). Cooperative management efforts between Canada, U.S., and Mexico are necessary to ensure no overfishing occurs for the continued success of this species.

Sardines are considered a high quality food for tuna. Tuna ranches in Australia import frozen sardines for their feeds from the Western United States because of low local catches.

However, in the spring of 2002, Australia banned import of Pacific sardines because sardines had tested positive for Viral Hemorrhagic Septicemia (VHS) (CA Sea Grant, 2003). It is unknown whether the virus has the potential to cause mass mortalities, and has never been identified in Mexico. Sardine diseases do present a problem if they become-s widespread because of their importance as tuna feeds. Scientists are now studying VHS to determine its scope of infection and if it will have any effect on tunas. The development of artificial diets can calm fears over a potential disease occurring in wild caught fish. Artificial diets can also be stored for longer periods of time than fresh sardines, will not exhibit natural variation in quality, and result in a more efficient food conversion. The gains in food conversion efficiency would also result in less waste input to the growing waters (CA Sea Grant, 2003).

Recommendations

Establish a regulatory framework

A regulatory framework will help monitor and maintain the tuna farming industries. Such a regulatory framework should aim to include social, economic, and environmental sustainability factors. Recommendations could include the establishment of a harvest quota for sardines and Pacific bluefin tuna. Also, site suitability should be thoroughly investigated to minimize environmental impacts.

Closed life cycle research

The recent completion of the Pacific bluefin tuna life cycle in Japan serves as a bright indicator for the future. Research should be pursued aggressively for a reliable closed life cycle to provide for the tuna industry. With the domestication of tuna will come an artificial diet that will ease reliance on wild stocks for direct consumption. The present tuna and sardine fisheries in the western Pacific Ocean are at sustainable levels. To remain this way, the fisheries regulations and practices must adapt to the changing situation. It would be wise to not abuse this resource and look for ways in the future to maintain this status. The adoption of closed life cycle techniques and the use of an artificial diet would help remediate the host of problems outlined above.

Conclusions

A sustainable future is on the horizon for Mexico and can serve as a model for the industry in other countries. Favorable climatic conditions and current wild stocks of both sardines and northern bluefin tuna are stable enough to allow production to continue while scientists research ways to increase production

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