

# Fish Oil Replacement, By-Products Utilization in Aquafeeds, and Prospective Species for Mariculture Development in Sonora: A Review of Research in Aquaculture Nutrition at the University of Sonora

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## Abstract

Aquaculture, specifically shrimp culture, is one of the economic activities that characterize the northwest of Mexico, particularly the state of Sonora. However, the industry is currently looking for alternative species to diversify and the culture of marine fish species appears to be a promising option. Several institutions have made progress in the culture of various marine fish species, but a steady and abundant supply of fry and the availability of cost-efficient aquafeeds have kept the fish farming industry in Mexico from developing. Aquafeeds for carnivorous marine fish usually contain high levels of fish meal and fish oil, but their high prices make the use of high inclusion levels objectionable. At the Nutrition Laboratory of the Department of Scientific and Technological Research of the University of Sonora, alternative protein and oil sources are being sought and evaluated using a sustainable approach, for instance, ray fish liver oil and tilapia by-products silage. Research work with the Cortez halibut (*Paralichthys aestuarius*) and totoaba (*Totoaba macdonaldi*) has started and will continue to expand and diversify, a modest contribution to the development of fish mariculture in our state.

*Keywords: Marine fish culture, fish oil replacement, by-products.*

## I-Introduction

One of the economic activities that characterize the northwest of Mexico, particularly the state of Sonora, is aquaculture, specifically, shrimp culture. Up until 2009 the state of Sonora was the top shrimp producer in the country. However, the industry has recently suffered a major drawback due to the manifestation of white spot syndrome virus (WSSV). This situation has everyone looking for alternative pond management, feed management, culture systems, probiotics, prebiotics, and even alternative species to diversify the aquaculture industry in Sonora. The mariculture of other species, particularly marine fish species, appears to be a promising alternative to diversify this economic activity. According to FAO (2008), marine fish culture had a considerable production growth from the year 2000 to 2006 around the world. Marine fish were among the most cultivated organisms with a world production volume near 1,551,000 tonnes in 2006, that was 3% of the world aquaculture production and represented 8% of the economic value generated by aquaculture, indicating their significant market value.

Several institutions have made progress in the culture of various marine fish species such as *Sphoeroides annulatus* and *Lutjanus guttatus* at C.I.A.D. (Centro de Investigación en Alimentación y Desarrollo, A.C.) Mazatlán, *Paralichthys californicus* and *Seriola lalandi* at C.I.C.E.S.E. (Centro de Investigación Científica y de Educación Superior de Ensenada), *Totoaba macdonaldi* at U.A.B.C. (Universidad Autónoma de Baja California) and the Nutrition Laboratory of the Department of Scientific and Technological Research of the University of Sonora (D.I.C.T.U.S.), to cite a few examples in the northwest of Mexico. However, in response to the industry demand for the development of marine fish culture, the government, the private industry and research institutions and universities are working together for the first time to help marine fish aquaculture finally take off in Mexico, focusing the effort on a few priority species like *Seriola lalandi*, *S. rivoliana*, *Totoaba macdonaldi*, *Cynoscion othonopterus*, *Lutjanus guttatus*, *Ocyurus chrysirius*, and *Centropomus undecimalis*.

One of the bottlenecks the marine fish culture industry needs to overcome to be able to run a profitable business is the availability of cost-effective balanced feeds specifically

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formulated for these species. It is evident that research on the nutritional requirements and physiology of the mentioned species will be essential. Moreover, the utilization of fish meal and fish oil as main ingredients for aquafeeds needs to be reconsidered. Fisheries have been at the maximum sustainable level for quite some time; according to FAO (2008), in 2006, more than 110 million tonnes (77%) of the world fish production was used for direct human consumption. Almost all of the remaining 33 million tonnes was destined for non-food products, in particular the manufacture of fishmeal and fish oil. Consequently, the limited availability and high cost of fish meal and fish oil have driven the search for alternative protein and oil sources to satisfy requirements for essential amino acids and fatty acids of several cultured species, including marine fish and shrimp (González-Félix *et al.* 2010).

The aquaculture industry utilized almost 835,000 tonnes of fish oil for production of aquafeeds in 2006, which represents 88.5% of the total reported fish oil production for that year (Tacon & Metian 2008). Sustained production of cost-effective aquafeeds requires alternative sources of high quality oils. Ray fish liver oil, for instance, is an interesting alternative because it has important concentrations of the essential n-3 highly unsaturated fatty acids (HUFA), eicosapentaenoic and docosahexaenoic acids (EPA and DHA, respectively) (Ould el Kebir *et al.* 2007; Navarro-García *et al.* 2004a, b).

On the other hand, alternative protein sources for cultured shrimp and fish have been investigated for some years now. An interesting alternative for fish meal replacement is the utilization of by-products from the fish-processing industry (e.g. heads, tails, guts, fins, bones and/or skin) to produce fish silage and fish protein hydrolysates which are already being used in the pet feed and the fish feed industries (FAO 2008; Brown & Summer 1985). This approach is also valuable for reasons of sustainability because during processing a significant amount of these resources are not used or wasted.

In this work a review of the research in aquaculture nutrition, particularly of the topics of fish oil and fish meal replacement through by-products utilization in aquafeeds, as well as the evaluation of prospective species for mariculture development in Sonora, all conducted at the University of Sonora, is presented.

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## II-By-products utilization for replacement of fish oil and fish meal in aquafeeds

### II.1. Fish oil

One of the most important sources of n-3 HUFA is fish oil. It serves a number of industries that vary from human nutrition to aquafeeds production. Since total world fish oil production is at its limit, new alternative sources of high quality oils need to be explored. In the northwest of México the fish ray fishery is an important economic activity, but the meat (pectoral fins) is exclusively used and the rest is discarded (Pérez-Velazquez *et al.* 2008). The unused liver is a lipid storage organ rich in poly- and highly unsaturated fatty acids (PUFA and HUFA, respectively) that may very well be used by the aquafeed industry, particularly if we consider the annual production in Mexico is over 6,000 tonnes (SAGARPA 2006).

At the Nutrition Laboratory of D.I.C.T.U.S., there have been a number of projects dealing with the characterization of the extracted lipid from the liver of several ray fish species from the Gulf of Mexico, as well as from the Pacific coast of Mexico. The first reports on the lipid content of ray fish liver in Mexico were published by Navarro-García *et al.* (2004a, b) at D.I.C.T.U.S. They reported that in the species from the Gulf of California, the liver represents between 5 to 11% of the animals' weight, and 50% of the liver's weight is lipid. The oil from the studied species showed a concentration of EPA and DHA that represented 16-18% of the fatty acids, a similar level to that reported for other fish oils, such as cod oil, which is recognized as a great source of n-3 HUFA (Navarro *et al.* 2010).

Among the studied species at the Nutrition Laboratory are *Dasyatis brevis*, *Rhinoptera steindachneri*, *Urotrygon chilensis*, *Urobatis halleri*, and *Rhinobatos glaucostigma* from the Gulf of California and the Pacific coast of Mexico, as well as *Aetobatus narinari* and *Rhinoptera bonasus* from the Gulf of Mexico.

Additionally, a comparative feeding trial was performed at the Wet Nutrition Laboratory of Kino Bay Experiment Station from D.I.C.T.U.S. by Perez-Velazquez *et al.* (2008) to evaluate the nutritional value of four different ray fish liver oils for the Pacific white shrimp

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*Litopenaeus vannamei*. The liver oils evaluated were extracted from *D. brevis*, *R. steindachneri*, *A. narinari*, and *R. bonasus*, and compared to a control feed prepared with Menhaden fish oil. Ray fish liver oils were largely composed of PUFA and HUFA, with levels of EPA and DHA comparable to those of Menhaden oil, except for *A. narinari* liver oil, which had moderately low concentrations of EPA and DHA but a high level of arachidonic acid (ARA), more than six times greater than that of Menhaden oil. The diet with Menhaden oil promoted a significantly higher shrimp muscle DHA level than diets with oil from *D. brevis*, and *A. narinari*, but not than diets with oil from *R. steindachneri* and *R. bonasus*. In spite of these differences, all four ray fish liver oils evaluated were as efficient in promoting growth and survival of *L. vannamei* as Menhaden oil, demonstrating with this study that one of the many possible applications of this discarded resource is their use in aquafeeds.

## II.2. Fish meal

Although tilapia production in Sonora is recently emerging and only 1,034.6 tonnes were harvested in 2010 (COSAES 2010), its processing generates fish by-products that can be utilized to develop a new ingredient for the aquafeed industry with an economic benefit for the small-scale producers. Thus, a similar approach for the utilization of the discarded ray fish liver was the utilization of by-products from the tilapia-processing industry of Sonora in order to produce fish silage for the aquafeed industry, a work that has also been carried at the Nutrition Laboratory of D.I.C.T.U.S. by Bringas-Alvarado *et al.* (2011). By-products from tilapia filleting were used to prepare fish silage. A silage can be prepared through acid preservation or microbe anaerobic fermentation; the last procedure is cheaper and uses simple technology that can be implemented in rural areas (Dhatemwa 1989).

At the Nutrition Laboratory, the fish silage was prepared using the microbe anaerobic fermentation (*Lactobacillus* spp.) procedure. Tilapia's by-products samples (300 g) were homogenized and mixed with 6% lactic acid as a starter, 45 g of molasses as a carbohydrate source for fermentation to proceed, and sorbic acid (0.009 g) as a preservative, then incubated anaerobically at  $30 \pm 2^\circ\text{C}$  for 13 days.

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The fish silage obtained showed good organoleptic properties (Bertullo 1992; Tatterson 1982), had a pH ranging from 4.3-4.6, an adequate pH range to achieve product stability (Fagbenro & Jauncey 1993; Toledo & Llanes 2007) and its proximate composition showed a protein content of 41.5% of crude protein, 10.5% crude fat, and 9% ash. Among the most abundant amino acids in the fish silage were glutamic and aspartic acids, methionine, lysine, and valine and the peptides generated with this process showed good digestibility. Potentially, they may also work as chemoattractants and stimulate feed consumption when incorporated into aquafeeds.

### **III-Prospective species for mariculture development in Sonora**

The culture of marine fish species seems like a promising alternative to diversify aquaculture in Mexico. In the northwest region of Mexico the first data available on fish culture were generated at research institutions like C.I.A.D. Mazatlán, working with bullseye puffer (*S. annulatus*) and the spotted rose snapper (*L. guttatus*), as well as by C.I.C.E.S.E. with their work on California halibut (*P. californicus*) and the yellowtail amberjack (*S. lalandi*) (Chávez-Sánchez *et al.* 2008), and last but not least, the work on totoaba (*T. macdonaldi*) at the U.A.B.C.

Recently, at the Wet Nutrition Laboratory of D.I.C.T.U.S. in Kino Bay, we have conducted research with the Cortez halibut or the Cortez flounder (*Paralichthys aetnarius*), which is also an endemic species of the Gulf of California that distributes geographically from the northern Gulf of California to the southwest coast of Baja California Sur, Mexico (Castro-Aguirre 1999). As well as for other flat fish, their meat is appreciated in the national and international markets where it fetches a price between \$10.00 and \$20.00 dollars depending on the presentation (Lazo 2007; Carta Nacional Pesquera 2004). Therefore, from the commercial and biological point of view, the Cortez halibut is an interesting potential species to be evaluated for mariculture.

In addition to the research with the Cortez halibut, we also have conducted some research work with totaba, a marine species of the Sciaenidae family, again, endemic to the Gulf of California (Román-Rodríguez & Hammann 1997). This species was declared an endangered species in 1991. Totoaba used to be fished to obtain the swim bladder which was sold in the gourmet oriental market and used as the main ingredient of a soup. At some point, the exquisite meat was even discarded.

In spite of the efforts to protect it during the past years, clandestine fishing of adults during the reproduction season (January-May) is still observed. Incidental catches from shrimp trawls are also reported, and it may be captured during six months of the year with recreational fishing permits, both cases are officially registered as incidental catches (Martínez-Delgado & Corona-García 1992).

Fortunately, research with this species paid off, and at the U.B.P. (Unidad de Biotecnología en Piscicultura) from the U.A.B.C., researchers have managed to reproduce this species in captivity, with more than two reproductive cycles per female per year, and up to 2.5 million fertile eggs per spawn (SEMARNAT 2010). This has made fry and juvenile available for research, and in 2011, for the first time, for attempting to culture commercially a marine fish species in submersible sea cages off the coast of Guaymas, Sonora, Mexico by a private company (Pesquera Delly, S.A. de C.V.). However, fry production is still limited in number; more hatcheries are required to provide enough animals to help this industry take off.

Besides a steady and abundant supply of fry, cost-efficient aquafeeds formulated to satisfy the nutritional requirements of this species throughout their life cycle and under intensive culture conditions are also required. These are in fact the two common problems that have kept the fish farming industry in Mexico from developing, and apply to all marine fish species of interest.

Aquafeeds for carnivorous marine fish usually contain a significant amount of animal protein, generally provided as fish meal. However, the economic pressure from elevated fish meal prices and the realization that sustainable practices need to be applied to

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aquaculture makes the use high levels of fish meal objectionable. Alternative protein sources are being sought and evaluated all around the world, many of them of vegetable origin, but animal by-products are also included. So far, the research conducted at D.I.C.T.U.S. Nutrition Laboratory with the Cortez halibut was simple and focused on the evaluation of the species under laboratory culture conditions and the conditioning of wild organisms to accept balanced feeds of different protein levels. For totoaba, growth performance was evaluated when fed similar diets with different protein levels, but the preliminary analysis of data is still being performed. Follow up studies will include fish meal and fish oil replacement, digestibility evaluation of ingredients and feeds formulated with alternative protein sources, and the investigation of essential fatty acids' requirements for various marine fish species.

## Conclusions

The opportunities to develop mariculture in the state of Sonora are vast, as well as the opportunities to diversify the industry with the development of marine fish aquaculture. There are necessities that should be addressed in order to help the activity take off, such as a steady and abundant supply of fry and the production of cost-efficient aquafeeds. At the Nutrition Laboratory we are trying to contribute, not only by developing cost-efficient balanced feeds, but at the same time, by searching for alternative sources of protein and oil for fish meal and fish oil replacement, using a sustainable approach to do so.



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