DNA barcode identification of commercial fish sold in Mexican markets

Journal:	<i>Genome</i>
Manuscript ID	gen-2017-0222.R2
Manuscript Type:	Article
Date Submitted by the Author:	18-Feb-2018
Complete List of Authors:	Sarmiento-Camacho, Stephanie; Benemerita Universidad Autonoma de Puebla, Facultad de Ciencias Biológicas Valdez-Moreno, Martha; El Colegio de la Frontera Sur, Ecología y Sistemática Acuática
Is the invited manuscript for consideration in a Special Issue? :	N/A
Keyword:	COI, shark, seafood, Mexico, threatened species

SCHOLARONE™
Manuscripts

1 **DNA barcode identification of commercial fish sold**
2 **in Mexican markets.**

3 S. Sarmiento- Camacho¹, M. Valdez-Moreno²

4
5 1 Facultad de Ciencias Biológicas, Benemérita Universidad Autónoma de Puebla,
6 Edificio 112-A, Blvd. Valsequillo y Av. San Claudio, Ciudad, Universitaria, Col.
7 Jardines de San Manuel, 72570, Puebla, Puebla, Mexico.

8
9 2 Necton Lab, Department of Aquatic Ecology and Systematics, El Colegio de la
10 Frontera Sur, Chetumal Unit, 77014, Chetumal, Quintana Roo, Mexico.

11
12 Corresponding author email: mvaldez@ecosur.mx (M. Valdez-Moreno)

Abstract

The substitution of high-value fish species for those of lower value is common practice. Although numerous studies have addressed this issue, few have been conducted in Mexico. In this study, we sought to identify fresh fillets of fish, sharks, and rays using DNA barcodes. We analyzed material from “La Viga” in Mexico City, and other markets located on the Gulf and Caribbean coasts of Mexico. From 134 samples, we obtained sequences from 129, identified to nine orders, 28 families, 38 genera, and 44 species. The most common species were *Seriola dumerili*, *Pangasianodon hypophthalmus*, *Carcharhinus falciformis*, *Carcharhinus brevipinna*, and *Hypanus americanus*. *P. hypophthalmus* was most commonly used as a substitute for higher-value species. The substitution rate was 18% of the total. A review of the conservation status of the specimens identified against the IUNC list enabled us to establish that some species marketed in Mexico are threatened: *Makaira nigricans*, *Lachnolaimus maximus*, *Hyporthodus flavolimbatus* and *Isurus oxyrinchus* are classified as vulnerable; *Lopholatilus chamaeleonticeps* and *Sphyrna lewini* are endangered; and the status of *Hyporthodus nigritus* is critical. These results will demonstrate to the Mexican authorities that DNA barcoding is a reliable tool for species identification, even when morphological identification is difficult or impossible.

Keywords: COI, fish, sharks, *Pangasius*, seafood, conservation species, endangered species.

Introduction

Fisheries in Mexico have for a long time been reported to be operating at their maximum level (FAO 1997). In spite of this, however, the fishing effort is still increasing (CONAPESCA 2013). As a consequence, the catch per unit effort for marine species of economic importance had fallen by 30% between the end of the 1980s and 2011, and in the coming years could fall by a further 50% (Rodríguez Sánchez et al. 2011).

The scarcity of some species that are most appreciated by consumers has led to an increase in their value, or they have unknowingly been replaced with lower-priced products. This latter problem frequently occurs when the fish products have been processed or frozen, because by this time it is generally impossible to determine species identity by visual identification (Bartlett and Davidson 1992; Mackie et al. 1999; Filonzi et al. 2010).

DNA barcoding has been widely used to detect this fraud since 2008 (Ogden 2008). To date, there have been more than 25 studies from different countries dealing with this topic; for example, those undertaken in Brazil (Carvalho et al. 2015a), Canada (Hanner et al. 2011; Steinke et al. 2017), China (Shen et al. 2016), France (Bénard-Capelle et al. 2015a), Italy (Cutarelli et al. 2014), and South Africa (Cawthorn et al. 2015).

In all these studies, the application of barcoding in fresh and processed products has facilitated the detection of substituted and mislabeled seafood, which has different effects on the final consumers. These include economic losses due to

potential commercial fraud (Filonzi et al. 2010; Ropicki et al. 2010; Huxley-Jones et al. 2012; Cutarelli et al. 2014; Forbes and Alexander 2015; Pappalardo and Ferrito 2015; Carvalho et al. 2015b; Galal-Khallaf et al. 2016; Xiong et al. 2016), public health repercussions due to ingestion of contaminated food (Chang et al. 2008; Todd 2011; Raimann et al. 2014), trade promotion of invasive species (Pilger et al. 2008), uncontrolled impacts on fish species of threatened status (Stevens et al. 2000; Ardura et al. 2010, 2011), and damage to populations due to overfishing (Tokeshi et al. 2013). All of these studies have provided evidence to the necessary authorities that would enable the application of penalties against commercial establishments that have committed fraud.

The substitution and mislabeling of fresh or processed seafood are considered a global problem, and the prevalence of these practices has been increasing as there is currently no standard system for seafood labeling (Cawthorn et al. 2015). In the case of Mexico, since 1995, there has been legislation for labeling fresh-chilled and frozen fish products, which is set out in the following publication: (http://www.dof.gob.mx/nota_detalle.php?codigo=4870248&fecha=03/03/1995).

This document contains regulations regarding the labeling of products. In the case of refrigerated products, labels must include the following details: Lot Number; Day, Month, and Year of elaboration; the text "Keep refrigerated at maximum 4°C"; and Expiry Date, indicating day, month, and year. Similarly, for a frozen product, labels should include the following: Lot Number; Day, Month, and Year of elaboration; an indication of the food additives used, and the texts "Keep frozen at a maximum

temperature of -18°C" and "Once thawed it should not be refrozen." It is, nevertheless, clear that this legislation is incomplete, and is lacking in details. Against this background, we examined the potential of implementing barcoding analysis for a wide range of seafood (bony fish, sharks, and rays) to confirm the identity of these products, with the aims of demonstrating the effectiveness of this method to the concerned Mexican authorities, raising the level of awareness among consumers, and promoting the introduction of precise product labeling.

Materials and methods

Sample collection

Fresh muscle samples of bony fish, sharks, and rays were collected from seven different markets in Mexico: "La Viga," the largest seafood market in Mexico City (in December 2010 and May 2015); and six markets in Quintana Roo State [one in Cancún (February 2011), one in Cozumel (January 2011), and four in Chetumal (January 2011 and February 2015)].

All the samples were fixed with 96% ethanol and immediately placed in ice. Product details such as the commercial name, description of the goods (fillet, minced, or groundfish meat), and the scientific name (when the sample was obtained from the whole fish and identified in situ by employing standard taxonomic guides) were recorded. Almost all commercial products were photographed.

DNA extraction, amplification, and sequencing

A small piece (1–3 cm³) of muscle from the inside of each fresh sample was extracted and washed with alcohol to prevent contamination. A total of 134 samples were then sub-sampled (approx. 1 mm³ tissue size), each of which was placed in a well of an Eppendorf plate with a drop of 96% ethanol for preservation until DNA extraction.

DNA was extracted employing the glass fiber protocol described by Ivanova and Hebert (2006). The first 652 bp of the *COI* gene (barcode) were amplified by polymerase chain reaction (PCR) using the protocol and primers described by Ivanova and Grainger (2007).

The polymerase chain reaction (PCR) reagents used were as follows: 12.5 µL of PCR reaction mix included 6.25 µL of 10% trehalose, 2 µL of distilled deionized water and 1.25 µL of 10× PCR buffer for the enzyme Taq Platinum, 0.625 µL of MgCl₂ (50 mM), 0.125 µL of each primer (0.01 mM), 0.0625 µL (10 mM) dNTP mix, 0.06 µL Platinum Taq polymerase (5 U/µL), and 2.0 µL of template DNA. The thermocycler program used for amplification was as follows: DNA denaturation at 94°C for 1 min, followed by 35 cycles of denaturation at 94°C for 30 s, annealing at 52°C for 30 s, elongation at 72°C for 1 min, and a final extension at 72°C for 10 min. The PCR products were visualized on agarose gels (E-Gel®, Invitrogen™) and analyzed with E-Editor™ 2.0 software.

The sequencing was carried out by the Canadian Centre for DNA Barcoding and the Institute of Biology at the National Autonomous University of Mexico (UNAM).

In both laboratories, the PCR products were processed using BigDye® Terminator v.3.1. Purification of the PCR products was performed using Sephadex^R G-50 in a

MultiScreen® Column, and the sequences were obtained using a 3730xl DNA analyzer (Applied Biosystems). The sequences were edited and aligned using the Codon Code v. 5.0.1 program.

Data analysis

Sequences were compared with previously published sequences that reached the standard to get a Barcode Index Number (Ratnasingham and Hebert 2013), using specimen identification tool provided in the Barcode of Life Data System (BOLD) (Ratnasingham and Hebert 2007).. The criteria for sequence identification to the species level were similarity values $\geq 99\%$ and within the same BIN. Specimens with values $< 99\%$ to 95% were assigned to genus, family, and order following the same criteria as Valdez-Moreno et al. (2012), whereas those with values $< 95\%$, were just assigned to a class level.

Neighbor-Joining (NJ) trees (Saitou and Nei 1987) were constructed using pairwise genetic distances based on the Kimura two-parameter model (K2P) (Kimura 1980) and pairwise deletion of missing data using MEGA 3 software (Kumar et al. 2004). Specimen images, collection, and molecular data can be viewed at the Boldsystems web site (www.boldsystems.org) within the Fish Market (FMK) project. The sequences have also been deposited in GenBank (Accession Numbers: MG837880–MG838002).

Label analysis and IUNC list conservation status

We evaluated the percentage of mislabeling by comparing the commercial name of the samples with the identification of the products using BOLD tools. The sample was declared mislabeled if the species name determined through molecular identification was not the same as that on the label in the market. Finally, we consulted the IUNC list (<http://www.iucnredlist.org>) to determine the conservation status of each of the identified species. All common names are in accordance with those published by Page et al. (2013).

Results and Discussion

From the 134 samples collected, we obtained 129 sequences, representing a 96% success rate. This value is comparable with or even higher than that obtained in other studies of this type (Ward et al. 2005; Richardson et al. 2007; Valdez-Moreno et al. 2010; Xiong et al. 2016). The sequence lengths ranged from 586 to 652 base pairs (bp), all of which were of high quality without insertions, deletions, or stop codons.

Of the 129 sequences, 128 matched sequences in the BOLD reference library with similarity values $\geq 99\%$. One sequence showed a 94% similarity, and was identified as belonging to the class Actinopterygii.

On the basis of these results, 47 clusters had a BIN assignment, from these, 44 had species assignment, with 38 genera, and 28 families (Fig.S1 and Table 1)¹.

¹ Fig. S1. Full neighbor-joining tree based on genetic distances (K2P) from the *COI* gene, with their respective species names, sample IDs and BIN numbers.

173 Three specimens could not be identified, these cases will be explained later.

174 Fourteen specimens belong to the group of sharks and rays (class

175 Elasmobranchii), and 33 belong to the group of bony fishes (class Actinopterygii).

176 The families represented by the largest number of species were the

177 Carcharhinidae (six), Serranidae (six), and Carangidae (four). The remainder of the

178 families was represented by one or two species.

179 All the species included in the ID tree grouped in single clusters that are non-

180 overlapping with other species cluster and show relatively high interspecific

181 divergences in BOLD, even between the most closely related species (Fig. S1)

182 These results allowed us to make highly reliable species assignments (Hanner et

183 al. 2011; Costa et al. 2012; Bénard-Capelle et al. 2015b)

184 For most species, the designated BIN was associated with a single specific name.

185 In nine cases, however, a single BIN was associated with multiple names:

186 *Rhizoprionodon terraenovae*, *Hyporthodus nigritus*, *Caranx latus*, *Carcharhinus*

187 *brevipinna*, *Carcharhinus limbatus*, *Carcharhinus falciformes*, *Merluccius*

188 *productus*, *Thunnus* sp., and *Oreochromis* sp. This problem occurs when species

189 are closely related, and therefore the genetic distance between them is very small

190 (Ward et al. 2005; Anbarasi et al. 2015).

191 However, for the first seven of these species, we could assign a scientific name

192 because we had identified the specimens in situ using identification guides, and

193 these designations were posteriorly corroborated by identification with the BOLD ID

194 tools.(see some photos at

http://www.boldsystems.org/index.php/MAS_Management_Recordlist). Of the remaining two species, *Thunnus* sp., with the BIN: AAA7352, was associated with nine species, whereas *Oreochromis* sp., with the BIN: AAA8511, was associated with at least six species. In these two cases we were unable to assign a species name as we did not have any complete specimens. One more case had not any name associated, so it was left as Actinopterygii (BIN: ACV0720).

On the basis of an analysis of the 134 original samples, 81 were identified as bony fishes, 40 were sharks, and eight rays (Table 1). The most represented bony fishes were the greater amberjack or medregal (*Seriola dumerili*), striped catfish, panga, or Basa (*Pangasianodon hypophthalmus*), and king mackerel, sierra or carito (*Scomberomorus cavalla*) with 10, seven, and six specimens, respectively. It is of interest to note that one of the most commonly sold fillets (*Pangasianodon hypophthalmus*) is not a Mexican species, but is of Asian origin and is imported here mainly from Vietnam.

In the case of sharks and related species, the silky shark or tiburón piloto (*Carcharhinus falciformis*), spinner shark or tiburón curro (*Carcharhinus brevipinna*), and southern stingray or raya latigo americana (*Hypanus americanus*) were represented by 10, seven, and six specimens, respectively (Table 1). The first two are the most commonly caught shark species in the Gulf of Mexico and the Caribbean Sea, and they are among the 10 species most captured in the whole country, with *C. brevipinna* being the fifth most commonly reported in catches (SAGARPA 2014). The states where this species is most frequently captured are all on the Gulf of Mexico coast (Tamaulipas, Veracruz, Campeche, Tabasco, and

218 Yucatan) (SAGARPA 2014). Due to the high demand for fish fillets in Mexico, in
219 the last 14 years, manta rays and rays have become important trade products. The
220 most important families with commercial importance are Myliobatidae,
221 Rhinopteridae, Rajidae, and Dasyatidae (SAGARPA 2007). *H. americanus*
222 belonging the family Dasyatidae, ranks as the third most commercially caught
223 species in the Atlantic Ocean (SAGARPA 2014).

224 The results of our analysis of the labels of the 129 sequenced samples indicates
225 that 106 (82%) were labeled correctly, whereas the remaining 23 (18%) were
226 mislabeled. This mislabeling rate is lower in comparison with the substitution rates
227 previously reported in other countries, which range from 19% to 50% (Wong and
228 Hanner 2008; Filonzi et al. 2010; Von Der Heyden et al. 2010; Hanner et al. 2011,
229 Series 2011; Cawthorn et al. 2012). An exception, however, is a study from France
230 that reports a substitution rate of only 3.7% (Bénard-Capelle et al. 2015b).

231 The most substituted species was the sea catfish or flounder for basa (*P.*
232 *hypophthalmus*). Among other species, the southern stingray (*H. americanus*) and
233 giant electric ray (*Narcine entemedor*) were sold as cazon (small shark) or shark
234 (adult shark); silver carp (*Hypophthalmichthys molitrix*) was sold as red snapper
235 (*Lutjanus campechanus*) or cazon (common name); yellow-edge grouper
236 (*Hyporthodus flavolimbatus*) was sold as a ray (common name); the spinner shark

237 (*Carcharhinus brevipinna*) was sold as a horse eye jack (*Caranx latus*); and the
238 blacktip shark (*Carcharhinus limbatus*) was labeled as blue marlin (*Makaira*
239 *nigricans*) (Fig. 1, Table 1)².

240 Obviously, mislabeling has a direct effect on the price of a fillet—in most cases, we
241 found that the price was more than double that of the authorized price for the
242 correct product (Table 2). This mislabeling practice is common among traders
243 around the world. Ironically, however, we came across one case in which a species
244 with high economic value, the yellow-edge grouper (*H. flavolimbatus*), fillets of
245 which have a trade price of MX\$120–180.00/kg (US\$6.70–10.00), was sold as a
246 low-cost species, a ray (MX\$40.00/kg; US\$2.10). However, this case could
247 possibly be explained by the fact that the quality of the meat was no longer optimal,
248 and thus it was sold at a lower price, or perhaps simply the seller made an error
249 when labeling the product.

250 Interesting cases are the fillets of the so-called cazon. In Mexico, this word is a
251 common name that can be assigned to any shark up to 2 m in length, with a
252 cylindrical body, five-gill openings, two dorsal fins, and sharp teeth. Its meat is
253 white, soft, and somewhat dry (RAE 2017). Due to these characteristics, it is
254 appreciated in the market and can reach higher prices (sometimes more than
255 double) than those for larger sharks, as it forms part of many traditional foods in
256 coastal states of the country. Consequently, many species are sold under this
257 name (Fig. 1), although we also noticed the sale of a large number of small-sized

² Fig. 1. Price comparison between products labeled vs. barcode identification

sharks. These results are consistent with those reported by the National Fisheries Institute (INAPESCA). Approximately 50% of the shark production associated with artisanal and river fisheries from the Gulf of Mexico are represented by newborn and juvenile organisms (SAGARPA 2007). These groups of organisms have slow growth, low reproductive potential, late sexual maturity, a long gestation period, and a small number of offspring (Castro 1993), and accordingly the stock populations of adults can be severely affected, leading to the possible local extirpation of some species (as for some of the species reported here).

Mexican legislation on seafood labeling focuses mainly on the dates of production and expiration of the product and provides some recommendations for its maintenance. It is evident, however, that our current legislation is incomplete, and there is little that specifically addresses the problems of illegal fishing and mislabelling or fraud when the product is on sale. Accordingly, it is necessary that our authorities undertake a thorough review and renewal of this legislation, which includes new requirements for the labeling of seafood. A good example in this regard is the Organization of the Markets in Fishery and Aquaculture Products Regulation (COM) in the European Union, published in 2013 as a renewal plan of the Common Fisheries Policy (Reg. (EU) n. 1379/2013, Cape IV). In this document, the Europeans introduced new mandatory requirements for fisheries and aquaculture products, including Commercial designation, Scientific Name, Production Method, Catch area/country, Body of water/country of production, and Fishing gear used (Jacquet and Pauly 2008; D'Amico et al. 2016). Special attention is devoted to label information, which should include the trade name and the

scientific name, which is even more necessary for filleted products, where the loss of morphological characteristics makes it difficult (if not impossible) to identify the species (D'Amico et al. 2016).

The aim of such legislation is to establish minimum standards to ensure the credibility of the certifications and uniformity in the labeling of the fish products (Jacquet and Pauly 2008), thereby providing complete information for their identification. This will provide consumers with an the opportunity to choose which items to purchase and which ones to avoid, and thus prevent fraudulent practice and illegal fishing (D'Amico et al. 2016).

Among different institutions there is already discussion regarding the implementation of "Ecolabelling" in the sale of products. This new labeling procedure is a voluntary method of environmental performance certification that is practised around the world (Jacquet and Pauly 2007; Cawthorn et al. 2012; Reid et al. 2013; FAO 2014, 2016; Lamendin et al. 2015). An ecolabel identifies products or services proven environmentally preferable overall, within a specific product or service category (<https://globalecolabelling.net/what-is-eco-labelling/>). This is important because the consumers prefer to purchase and pay more for wild products (Polymeros et al. 2015).

A further problem is that although there are some rules in place that regulate the labeling of seafood products in Mexico, there is currently no capacity for the supervision and regulation of the places where these products are sold, particularly in local markets. In this regard, our review of the conservation status of all the

species we identified based on the IUCN list (<http://www.iucnredlist.org>) indicated that almost all the sharks we identified are near threatened.

Among the entire dataset, we found four species, the blue marlin (*Makaira nigricans*), hogfish (*L. maximus*), yellow-edge grouper (*H. flavolimbatus*), and shortfin mako (*Isurus oxyrinchus*), that are vulnerable (<http://www.iucnredlist.org>).

Marlins are important not only as a food source but also as game species. In the Caribbean, marlin populations are diminishing, mainly in the Istiophoridae, and particularly *M. nigricans* (Valdez-Moreno et al. 2010). Indeed, in many fish tournaments, captured marlins are now routinely released, although the survival of these specimens remains uncertain as they are typically subjected to prolonged exhaustion and shock after being hooked. The hogfish or boquinete and the yellow-edge grouper or mero extraviado are economically valuable species with distributions in the Gulf of Mexico and the Caribbean Sea (McBride and Murphy 2003, Seyoum et al. 2015). Both species are highly appreciated in the southeast of Mexico. The Yucatan State has the highest catch of boquinete (Rodriguez-Gil 2009), whereas the mero extraviado is an important component of flake fishing and constitutes between 70% and 80% of the catch in this area (SAGARPA 2015). In spite of this, few studies been undertaken to analyze the fishery, and there is no specific close season for these species (Cass-Calay, S.L., and Bahnick, M 2002; Cook and Lombardi-Carlson 2007; Rodriguez-Gil 2009). The shortfin mako is a species with slow growth and maturation, which makes it highly susceptible to overfishing, and this shark is accordingly classified as a vulnerable species (Ribotcarballal et al. 2005).

Among the other threatened species, the golden tilefish (*Lopholatilus chamaeleonticeps*) and scalloped hammerhead (*Sphyrna lewini*) are currently listed as endangered, whereas the Warsaw grouper (*Hyporthodus nigrurus*) is considered critically endangered (IUCN 2017). Of the remaining species identified in this study, 98% are registered in the red list, of which the 46% are considered to be of least concern status, whereas for four species (three rays and one shark) there is insufficient information available to assess their current status (Table 2).

In Mexico, although there are rules in place to regulate fisheries, there is currently no capacity for the supervision and regulation of the places where these products are sold. The data obtained in the present study can be used to inform the concerned authorities as to the value of DNA barcoding as a proven technique for determining which species are being traded in the Mexican markets. Currently, it is possible to obtain short sequences or mini-barcodes that facilitate taxa identification with 90% confidence in just minutes and at a comparatively low cost, as demonstrated with different species from Calakmul reserve (Ivanova et al. 2009). We believe that it is critically important to make the authorities aware of the potential of these new tools.

Finally, we hope that this work will provide an opportunity to initiate new projects on vulnerable species, to develop government programs for sustainable use of marine resources by providing better control for all fisheries to avoid overfishing, and to instigate better control over Mexican customs; for example, determining the precise identity of the shark fins or sea cucumber that are exported in high quantities to the Asian markets.

Funding source

This study received support from the Mexican Barcode of Life (MEXBOL) network, which provided funds through grants 194045 and 194025 by CONACyT. The Chetumal node from this network assisted in processing the samples.

Acknowledgments

We thank our Mexican team, Jose Angel Cohuo and Miguel Valadez, from the Instituto Tecnológico de Chetumal, for assistance in collection and sampling processing, and Thomas McElwaine, for a review of the language used in this paper.

Draft

References

- Anbarasi, G., Vignesh, R., Arulmoorthy, M.P., Rathiesh, A.C., and Srinivasan, M. 2015. Barcoding Profiling and Intra Species Variation Within the Barcode Region of Two Estuarine Fishes *Oreochromis Mossambicus* and *Oreochromis Niloticus*. **4**(1): 59–68.
- Ardura, A., Linde, A.R., Moreira, J.C., and Garcia-Vazquez, E. 2010. DNA barcoding for conservation and management of Amazonian commercial fish. *Biol. Conserv.* **143**(6): 1438–1443. doi:10.1016/j.biocon.2010.03.019.
- Ardura, A., Planes, S., and Garcia-Vazquez, E. 2011. Beyond Biodiversity: Fish Metagenomes. *PLoS One* **6**(8): e22592. doi:10.1371/journal.pone.0022592.
- Bartlett, S.E., and Davidson, W.S. 1992, March. Erratum: FINS (Forensically Informative Nucleotide Sequencing): A procedure for identifying the animal origin of biological specimens.
- Bénard-Capelle, J., Guillonneau, V., Nouvian, C., Fournier, N., Le Loët, K., and Dettai, A. 2015a. Fish mislabelling in France: substitution rates and retail types. *PeerJ* **2**(April): e714. doi:10.7717/peerj.714.
- Bénard-Capelle, J., Guillonneau, V., Nouvian, C., Fournier, N., Le Loët, K., and Dettai, A. 2015b. Fish mislabelling in France: substitution rates and retail types. *PeerJ* **2**(April): e714. doi:10.7717/peerj.714.
- Carvalho, D.C., Palhares, R.M., Drummond, M.G., and Frigo, T.B. 2015a. DNA Barcoding identification of commercialized seafood in South Brazil: A governmental regulatory forensic program. *Food Control* **50**(February 2016):

- 394 784–788. doi:10.1016/j.foodcont.2014.10.025.
- 395 Carvalho, D.C., Palhares, R.M., Drummond, M.G., and Frigo, T.B. 2015b. DNA
396 Barcoding identification of commercialized seafood in South Brazil: A
397 governmental regulatory forensic program. Food Control **50**: 784–788.
398 doi:10.1016/j.foodcont.2014.10.025.
- 399 Cass-Calay, S.L., and Bahnick, M 2002. Status of the Yellowedge Grouper Fishery
400 in the Gulf of Mexico: Assessment 1.0. Govt Reports Announc. Index (GRA&I),
401 Issue 18, 2011 (18).
- 402 Castro, J.I. 1993. The shark nursery of Bulls Bay, South Carolina, with a review of
403 the shark nurseries of the southeastern coast of the United States. Environ.
404 Biol. Fishes **38**(1–3): 37–48. doi:10.1007/BF00842902.
- 405 Cawthorn, D.M., Duncan, J., Kastern, C., Francis, J., and Hoffman, L.C. 2015. Fish
406 species substitution and misnaming in South Africa: An economic, safety and
407 sustainability conundrum revisited. Food Chem. **185**: 165–181.
408 doi:10.1016/j.foodchem.2015.03.113.
- 409 Cawthorn, D.M., Steinman, H.A., and Witthuhn, R.C. 2012. DNA barcoding reveals
410 a high incidence of fish species misrepresentation and substitution on the
411 South African market. Food Res. Int. **46**(1): 30–40.
412 doi:10.1016/j.foodres.2011.11.011.
- 413 Chang, S.-C., Kung, H.-F., Chen, H.-C., Lin, C.-S., and Tsai, Y.-H. 2008.
414 Determination of histamine and bacterial isolation in swordfish fillets (*Xiphias*
415 *gladius*) implicated in a food borne poisoning. Food Control **19**(1): 16–21.

- doi:10.1016/j.foodcont.2007.01.005.
- CONAPESCA. 2013. La pesca y acuicultura en cifras.
- Cook, M., and Lombardi-Carlson, L. 2007. Yellowedge grouper (*Epinephelus flavolimbatus*) and golden tilefish (*Lopholatilus chamaeleonticeps*) distributions, habitat preferences and available biological samples. *In* NOAA Fisheries Service. Panama City.
- Costa, F.O., Landi, M., Martins, R., Costa, M.H., Costa, M.E., Carneiro, M., Alves, M.J., Steinke, D., and Carvalho, G.R. 2012. A Ranking System for Reference Libraries of DNA Barcodes: Application to Marine Fish Species from Portugal. *PLoS One* **7**(4): e35858. doi:10.1371/journal.pone.0035858.
- Cutarelli, A., Amoroso, M.G., De Roma, A., Girardi, S., Galiero, G., Guarino, A., and Corrado, F. 2014. Italian market fish species identification and commercial frauds revealing by DNA sequencing. *Food Control* **37**: 46–50. doi:10.1016/j.foodcont.2013.08.009.
- D'Amico, P., Armani, A., Gianfaldoni, D., and Guidi, A. 2016. New provisions for the labelling of fishery and aquaculture products: Difficulties in the implementation of Regulation (EU) n. 1379/2013. *Mar. Policy* **71**: 147–156. doi:10.1016/j.marpol.2016.05.026.
- FAO. 1997. El estado mundial de la pesca y la acuicultura. Roma. Available from <http://orton.catie.ac.cr/cgi-bin/wxis.exe/?IsisScript=CIDAB.xis&method=post&formato=2&cantidad=1&expresion=mfn=006500>.

- 438 FAO. 2014. The state of world fisheries and aquaculture. *In* Food and Agriculture
439 Organization of the United Nations. doi:92-5-105177-1.
- 440 FAO. 2016. El estado mundial de la pesca y la acuicultura 2016. El estado mundial
441 de la pesca y la acuicultura 2016. Contribución a la seguridad alimentaria y la
442 nutrición para todos. Roma.
- 443 Filonzi, L., Chiesa, S., Vaghi, M., and Nonnis Marzano, F. 2010. Molecular
444 barcoding reveals mislabelling of commercial fish products in Italy. *Food Res.*
445 *Int.* **43**(5): 1383–1388. doi:10.1016/j.foodres.2010.04.016.
- 446 Forbes, D., and Alexander, P. 2015. Breach with Intent: A Risk Analysis of
447 Deliberate Security Breaches in the Seafood Supply Chain. *In* Global Supply
448 Chain Security. *Edited by* A.R. Thomas and S. Vaduva. Springer New York,
449 New York, NY. pp. 133–162. doi:10.1007/978-1-4939-2178-2.
- 450 Galal-Khallaf, A., Ardura, A., Borrell, Y.J., and Garcia-Vazquez, E. 2016. Towards
451 more sustainable surimi? PCR-cloning approach for DNA barcoding reveals
452 the use of species of low trophic level and aquaculture in Asian surimi. *Food*
453 *Control* **61**(2065): 62–69. doi:10.1016/j.foodcont.2015.09.027.
- 454 Hanner, R., Becker, S., Ivanova, N.V., and Steinke, D. 2011. FISH-BOL and
455 Seafood Identification: Geographically Dispersed Case Studies Reveal
456 Systemic Market Substitution Across Canada. *Mitochondrial DNA* **22**(S1):
457 106–122. doi:10.3109/19401736.2011.588217.
- 458 Von Der Heyden, S., Barendse, J., Seebregts, A.J., and Matthee, C.A. 2010.
459 Misleading the masses: Detection of mislabelled and substituted frozen fish

- 460 products in South Africa. *ICES J. Mar. Sci.* **67**(1): 176–185.
461 doi:10.1093/icesjms/fsp222.
- 462 Huxley-Jones, E., Shaw, J.L.A., Fletcher, C., Parnell, J., and Watts, P.C. 2012.
463 Use of DNA barcoding to reveal species composition of convenience seafood.
464 *Conserv. Biol.* **26**(2): 367–71. doi:10.1111/j.1523-1739.2011.01813.x.
- 465 IUCN. 2017. The IUCN Red List of Threatened Species.
- 466 Ivanova, N.V., Borisenko, A.V., and Hebert, P.D.N. 2009. Express barcodes:
467 Racing from specimen to identification. *Mol. Ecol. Resour.* **9**(Suppl. 1): 35–41.
468 doi:10.1111/j.1755-0998.2009.02630.x.
- 469 Ivanova, N.V., Dewaard, J.R., and Hebert, P.D.N. 2006. An inexpensive,
470 automation-friendly protocol for recovering high-quality DNA. *Mol. Ecol. Notes*
471 **6**(4): 998–1002. doi:10.1111/j.1471-8286.2006.01428.x.
- 472 Ivanova, N.V., and Grainger, C. 2007. CCDB Protocols: Sequencing. *Appl. Biosyst.*
473 (1): 3–5.
- 474 Jacquet, J.L., and Pauly, D. 2007. The rise of seafood awareness campaigns in an
475 era of collapsing fisheries. *Mar. Policy* **31**(3): 308–313.
476 doi:10.1016/j.marpol.2006.09.003.
- 477 Jacquet, J.L., and Pauly, D. 2008. Trade secrets: Renaming and mislabeling of
478 seafood. *Mar. Policy* **32**(3): 309–318. doi:10.1016/j.marpol.2007.06.007.
- 479 Kimura, M. 1980. A simple method for estimating evolutionary rates of base
480 substitutions through comparative studies of nucleotide sequences. *J. Mol.*

- 481 Evol. **16**(2): 111–120. doi:10.1007/BF01731581.
- 482 Kumar, S., Tamura, K., and Masatoshi, N. 2004. MEGA3: Integrated software for
483 Molecular Evolutionary Genetics Analysis and sequence alignment. Brief.
484 Bioinform. **5**: 150–163.
- 485 Lamendin, R., Miller, K., and Ward, R.D. 2015. Labelling accuracy in Tasmanian
486 seafood: An investigation using DNA barcoding. Food Control **47**: 436–443.
487 doi:10.1016/j.foodcont.2014.07.039.
- 488 Mackie, I., Pryde, S., Gonzales-Sotelo, C., Medina, I., Pérez-Martín, R., Quinteiro,
489 J., Rey-Mendez, M., and Rehbein, H. 1999. Challenges in the identification of
490 species of canned fish. Trends Food Sci. Technol. **10**(1): 9–14.
491 doi:10.1016/S0924-2244(99)00013-8.
- 492 McBride, R.S., and Murphy, M.D. 2003. Current and potential yield per recruit of
493 Hogfish, *Lachnolaimus maximus*, in Florida. Gulf Caribb. Fish. Inst.
- 494 Ogden, R. 2008. Fisheries forensics: The use of DNA tools for improving
495 compliance, traceability and enforcement in the fishing industry. Fish Fish.
496 **9**(4): 462–472. doi:10.1111/j.1467-2979.2008.00305.x.
- 497 Pappalardo, A.M., and Ferrito, V. 2015. DNA barcoding species identification
498 unveils mislabeling of processed flatfish products in southern Italy markets.
499 Fish. Res. **164**: 153–158. Elsevier B.V. doi:10.1016/j.fishres.2014.11.004.
- 500 Pilger, T.J., Franssen, N.R., and Gido, K.B. 2008. Consumption of Native and
501 Nonnative Fishes by Introduced Largemouth Bass (*Micropterus salmoides*) in
502 the San Juan River, New Mexico. Southwest. Nat. **53**(1): 105–108.

- doi:10.1894/0038-4909(2008)53[105:CONANF]2.0.CO;2.
- Polymeros, K., Kaimakoudi, E., Schinaraki, M., Batzios, C., Nassivera, F., and Sillani, S. 2015. Analysing consumers' perceived differences in wild and farmed fish. *Br. Food J.* **117**(3): 970–986. doi:10.1108/BFJ-12-2013-0362.
- RAE. 2017. DLE: Lista de entradas - Diccionario de la lengua española - Edición del Tricentenario.
- Raimann, X., Rodríguez O.L., Chávez, P., and Torrejón, C. 2014. Mercury in fish and its importance in health. *Rev. Médica Chile* **142**(9): 1174–80. doi:10.4067/S0034-98872014000900012.
- Ratnasingham, S., and Hebert, P.D.N. 2007. BARCODING, BOLD : The Barcode of Life Data System (www.barcodinglife.org). *Mol. Ecol. Notes* **7**(April 2016): 355–364. doi:10.1111/j.1471-8286.2006.01678.x.
- Ratnasingham, S., and Hebert, P.D.N. 2013. A DNA-Based Registry for All Animal Species: The Barcode Index Number (BIN) System. *PLoS One* **8**(7). doi:10.1371/journal.pone.0066213.
- Reid, G.M., Contreras Macbeath, T., and Csat??di, K. 2013. Global challenges in freshwater-fish conservation related to public aquariums and the aquarium industry. *Int. Zoo Yearb.* **47**(1): 6–45. doi:10.1111/izy.12020.
- Ribotcarballal, M., Galvanmagana, F., and Quinonezvelazquez, C. 2005. Age and growth of the shortfin mako shark, , from the western coast of Baja California Sur, Mexico. *Fish. Res.* doi:10.1016/j.fishres.2005.05.004.

- 524 Richardson, D.E., Vanwyne, J.D., Exum, A.M., Cowen, R.K., and Crawford, D.L.
525 2007. High-throughput species identification: from DNA isolation to
526 bioinformatics. *Mol. Ecol. Notes* **7**(2): 199–207. doi:doi:10.1111/j.1471-
527 8286.2006.01620.x.
- 528 Robins, C.R., Bailey, R.M., Bond, C.E., Hooker, J.R., Lachner, E.A., Lea, R.N., and
529 Scott, W.B. 1991. *Common and Scientific Names of Fishes from the United*
530 *States and Canada. Fifth Edition. American Fisheries Society.*
- 531 Rodriguez-Gil, L.A. 2009. La pesca de fomento del boquinete *Lachnolaimus*
532 *maximus* en la costa del Estado de Yucatán, México. *Proc. Gulf Caribb. Fish.*
533 *Inst.* **61**: 218–229.
- 534 Rodríguez Sánchez, A., Peckham, H., Maldonado Díaz, D., and Hernández
535 Cardoso, B. 2011. Esfuerzo (CPUE) en la pesca de escama de primera en
536 Bahía de Ulloa, BCS , Loreto BCS.
- 537 Ropicki, A.J., Larkin, S.L., and Adams, C.M. 2010. Seafood Substitution and
538 Mislabeling: WTP for a Locally Caught Grouper Labeling Program in Florida.
539 *Mar. Resour. Econ.* **25**(1): 77–93. doi:10.5950/0738-1360-25.1.77.
- 540 SAGARPA. 2007. NORMA Oficial Mexicana NOM-029-PESC-2006, Pesca
541 responsable de tiburones y rayas. Especificaciones para su aprovechamiento.
542 *In* *Diario Oficial de la Federación.*
- 543 SAGARPA. 2014. Periodos y zonas de veda de pesca de tiburón en el Golfo de
544 México y Mar Caribe.
- 545 SAGARPA. 2015. Norma Oficial Mexicana 003-PESC-1993, para regular el

- 546 aprovechamiento de las especies de sardina Monterrey, piña, crinuda,
547 bocona, japonesa y de las especies anchoveta y macarela, con
548 embarcaciones de cerco, en aguas de jurisdicción federal del océano. *In*
549 Diario Oficial de la Federación. Mexico.
- 550 Saitou, N., and Nei, M. 1987. The neighbour-joining method: a new method for
551 reconstructing phylogenetic trees. *Mol. Biol. Evol.* **4**(4): 406–425. doi:citeulike-
552 article-id:93683.
- 553 Series, S. 2011. Fish Labelling Survey.
- 554 Seyoum, S., Collins, A.B., Puchlutegui, C., McBride, R.S., and Tringali, M.D.
555 2015. Genetically determined population structure of hogfish (Labridae:
556 *Lachnolaimus maximus*) in the southeastern United States. *Fish. Bull.* **113**:
557 442–455. doi:10.7755/FB.113.7.
- 558 Shen, Y., Kang, J., Chen, W., and He, S. 2016. DNA barcoding for the
559 identification of common economic aquatic products in Central China and its
560 application for the supervision of the market trade. *Food Control* **61**: 79–91.
561 doi:10.1016/j.foodcont.2015.08.038.
- 562 Steinke, Di., Bernard, A.M., Horn, R.L., Hilton, P., Hanner, R., and Shivji, M.S.
563 2017. DNA analysis of traded shark fins and mobulid gill plates reveals a high
564 proportion of species of conservation concern. *Sci. Rep.* **7**(1): 5–10. Springer
565 US. doi:10.1038/s41598-017-10123-5.
- 566 Stevens, J.D., Bonfil, R., Dulvy, N.K., and Walker, P.A. 2000. The effects of fishing
567 on sharks , rays , and chimaeras (chondrichthyans), and the implications for

- 568 marine ecosystems. *J. Mar. Sci.* **57**(3): 476–494. doi:10.1006/jmsc.2000.0724.
- 569 Todd, E.D. 2011. Procedures to Investigate Foodborne Illness. *In* Procedures to
570 Investigate Foodborne Illness. doi:10.1007/978-1-4419-8396-1_1.
- 571 Tokeshi, M., Arakaki, S., and Daud, J.R.P. 2013. Consuming Diversity: Analysis of
572 Seasonal Catch Patterns in Multispecies Artisanal Reef Fisheries in North
573 Sulawesi, Eastern Indonesia 1. *Pacific Sci.* **67**(1): 1–13. doi:10.2984/67.1.1.
- 574 Valdez-Moreno, M., Vásquez-Yeomans, L., Elías-Gutiérrez, M., Ivanova, N.V., and
575 Hebert, P.D.N. 2010a. Using DNA barcodes to connect adults and early life
576 stages of marine fishes from the Yucatan Peninsula, Mexico: potential in
577 fisheries management. *Mar. Freshw. Res.* **61**(6): 655. doi:10.1071/MF09222.
- 578 Valdez-Moreno, M., Quintal-Lizama, C., Gómez-Lozano, R., and García-Rivas, M.
579 2012. Monitoring an Alien Invasion: DNA Barcoding and the Identification of
580 Lionfish and Their Prey on Coral Reefs of the Mexican Caribbean. *PLoS One*
581 **7**(6): 1–8. doi:10.1371/journal.pone.0036636.
- 582 Ward, R.D., Zemlak, T.S., Innes, B.H., Last, P.R., and Hebert, P.D.N. 2005. DNA
583 barcoding Australia's fish species. *Philos. Trans. R. Soc. Lond. B. Biol. Sci.*
584 **360**(1462): 1847–1857. doi:10.1098/rstb.2005.1716.
- 585 Wong, E.H.K., and Hanner, R.H. 2008. DNA barcoding detects market substitution
586 in North American seafood. *Food Res. Int.* **41**(8): 828–837.
587 doi:10.1016/j.foodres.2008.07.005.
- 588 WWW.boldsystems.org, B.-S. (n.d.). www.boldsystems.org.

Xiong, X., Guardone, L., Giusti, A., Castigliego, L., Gianfaldoni, D., Guidi, A., and
Armani, A. 2016. DNA barcoding reveals chaotic labeling and
misrepresentation of cod (Xue) products sold on the Chinese market. Food
Control **60**: 519–532. doi:10.1016/j.foodcont.2015.08.028.

Draft

Figure captions

Fig. 1. Comparison between the price of labeled products vs. barcode identifications. The exchange rate at the time of collections was 1 US dollar = 18.00 Mexican pesos.

Supplementary material

Fig. S1. Full neighbor-joining tree showing genetic distances (K2P) based on a sequence of the *COI* gene, with respective species names, sample IDs, and BIN numbers.

Draft

Table1. List of fresh fillets sold in two Mexican markets identified by barcoding of bony fishes, sharks, and rays

** Market located in Mexico city, * Market located in Quintana Roo state, Bold letters indicate substituted species

Sample ID	Label. (Spanish / English)	Collection Place	Type of fish product	Similarity in BOLD (%)	Barcode Identification	Common name (Spanish/English)	Mislabeled
MXV0001	Sierra / King Mackerel	La Viga**	Fillet/Slice	100	<i>Scomberomorus cavalla</i>	Sierra y/o Carito / King Mackerel	No
MXV0003	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Carcharhinus limbatus</i>	Tiburón volador / Blacktip Shark	No
MXV0004	Sierra/ King Mackerel	La Viga**	Fillet/Slice	100	<i>Scomberomorus cavalla</i>	Sierra y/o Carito / King Mackerel	No
MXV0006	Pez español	La Viga**	Fillet	100	<i>Lopholatilus chamaeleonticeps</i>	Conejo amarillo / Golden tilefish	Yes
MXV0008	Pez español	La Viga**	Fillet	100	<i>Lopholatilus chamaeleonticeps</i>	Conejo amarillo / Golden tilefish	Yes
MXV0009	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Mustelus sinuatus</i>	Cazon del Golfo /Gulf Of Mexico Smoothhound	No
MXV0010	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Carcharhinus falciformes</i>	Tiburón piloto / Silky Shark	No
MXV0012	Bragre / Gafftopsail Sea Catfish	La Viga**	Fillet	100	<i>Bagre marinus</i>	Bragre / Gafftopsail Sea Catfish	No
MXV0013	Papelillo / Atlantic lookdown	La Viga**	Fillet	100	<i>Selene vomer</i>	Papelillo / Atlantic lookdown	No
MXV0014	Medregal / Greater amberjack	La Viga**	Fillet / Slice	100	<i>Seriola dumerili</i>	Medregal / Greater amberjack	No
MXV0015	Medregal / Greater amberjack	La Viga**	Fillet / Slice	100	<i>Seriola dumerili</i>	Medregal / Greater amberjack	No
MXV0016	Papelillo / Atlantic lookdown	La Viga**	Fillet	100	<i>Selene vomer</i>	Papelillo / Atlantic lookdown	No
MXV0017	Papelillo / Atlantic lookdown	La Viga**	Fillet	100	<i>Selene vomer</i>	Papelillo / Atlantic lookdown	No
MXV0018	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Galeocerdo cuvier</i>	Tintorera / Tiger Shark	No
MXV0024	Mero / Grouper	La Viga**	Fillet	100	<i>Mycteroperca microlepis</i>	Abadejo, Mero / Gag, Grouper	No
MXV0026	Medregal / Greater amberjack	La Viga**	Fillet / Slice	100	<i>Seriola dumerili</i>	Medregal / Greater amberjack	No
MXV0027	Lenguado / Southern Flounder	La Viga**	Fillet	100	<i>Paralichthys lethostigma</i>	Lenguado / Southern Flounder	No
MXV0028	Robalo / Barred grunt	La Viga**	Fillet	100	<i>Conodon nobilis</i>	Robalo / Barred grunt	No
MXV0029	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Carcharhinus falciformis</i>	Tiburón piloto / Silky Shark	No
MXV0030	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Hypanus americanus</i>	Raya látigo americana / Southern stingray	Yes
MXV0031	Lenguado / Southern Flounder	La Viga**	Fillet	100	<i>Paralichthys lethostigma</i>	Lenguado / Southern Flounder	No
MXV0032	Medregal / Greater amberjack	La Viga**	Fillet / Slice	100	<i>Seriola dumerili</i>	Medregal / Greater amberjack	No
MXV0033	Pez español	La Viga**	Fillet	100	<i>Caulolatilus cyanops</i>	Pez español I / Blackline	No
MXV0034	Mero / Grouper	La Viga**	Fillet	100	<i>Epinephelus morio</i>	Mero / Red grouper	No
MXV0035	Lenguado / Gulf flounder	La Viga**	Fillet	100	<i>Paralichthys albigutta</i>	Lenguado / Gulf flounder	No
MXV0036	Sierra / King Mackerel	La Viga**	Fillet/Slice	100	<i>Scomberomorus cavalla</i>	Sierra y/o Carito / King Mackerel	No
MXV0037	Bragre / Gafftopsail Sea Catfish	La Viga**	Fillet	100	<i>Bagre marinus</i>	Bragre / Gafftopsail Sea Catfish	No

MXV0038	Bragre / Gafftopsail Sea Catfish	La Viga**	Fillet	100	<i>Bagre marinus</i>	Bragre / Gafftopsail Sea Catfish	No
MXV0039	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Galeocerdo cuvier</i>	Tintorera / Tiger Shark	No
MXV0041	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Carcharhinus falciformis</i>	Tiburón piloto / Silky Shark	No
MXV0042	Medregal / Greater amberjack	La Viga**	Fillet / Slice	100	<i>Seriola dumerili</i>	Medregal / Greater amberjack	No
MXV0043	Sierra / King Mackerel	La Viga**	Fillet/Slice	100	<i>Scomberomorus cavalla</i>	Sierra y/o Carito / King Mackerel	No
MXV0044	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Carcharhinus falciformis</i>	Tiburón piloto / Silky Shark	No
MXV0045	Salmon / Atlantic salmon	La Viga**	Fillet	100	<i>Salmo salar</i>	Salmon / Atlantic salmon	No
MXV0046	Mero / Grouper	La Viga**	Fillet	100	<i>Mycteroperca microlepis</i>	Abadejo y/o Mero / Gag y/o Grouper	No
MXV0047	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Carcharhinus falciformis</i>	Tiburón piloto / Silky Shark	No
MXV0048	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Sphyrna tiburo</i>	Cornuda cabeza de pala /Bonnethead Shark	No
MXV0049	Bragre / Gafftopsail Sea Catfish	La Viga**	Fillet	100	<i>Bagre marinus</i>	Bragre / Gafftopsail Sea Catfish	No
MXV0050	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Galeocerdo cuvier</i>	Tintorera / Tiger Shark	No
MXV0051	Bragre / Gafftopsail Sea Catfish	La Viga**	Fillet	100	<i>Bagre marinus</i>	Bragre / Gafftopsail Sea Catfish	No
MXV0052	Mero / Grouper	La Viga**	Fillet	100	<i>Mycteroperca microlepis</i>	Abadejo y/o Mero / Gag y/o Grouper	No
MXV0053	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Isurus oxyrinchus</i>	Mako / Shortfin Mako	No
MXV0055	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Carcharhinus falciformis</i>	Tiburón piloto / Silky Shark	No
MXV0057	Medregal / Greater amberjack	La Viga**	Fillet / Slice	100	<i>Seriola dumerili</i>	Medregal / Greater amberjack	No
MXV0059	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Mustelus sinuasmexicanus</i>	Cazon del Golfo /Gulf Of Mexico Smoothhound	No
MXV0060	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Carcharhinus limbatus</i>	Tiburón volador / Blacktip Shark	No
MXV0061	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Carcharhinus limbatus</i>	Tiburón volador / Blacktip Shark	No
MXV0062	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Hypanus americanus</i>	Raya látigo americana / Southern stingray	Yes
MXV0063	Lenguado / Southern Flounder	La Viga**	Fillet	100	<i>Paralichthys lethostigma</i>	Lenguado / Southern Flounder	No
MXV0064	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Carcharhinus falciformis</i>	Tiburón piloto / Silky Shark	No
MXV0065	Mero / Grouper	La Viga**	Fillet	100	<i>Epinephelus morio</i>	Mero / Red grouper	No
MXV0066	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Carcharhinus brevipinna</i>	Tiburón curro / Spinner Shark	No
MXV0067	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Carcharhinus brevipinna</i>	Tiburón curro / Spinner Shark	No
MXV0068	Medregal / Greater amberjack	La Viga**	Fillet / Slice	100	<i>Seriola dumerili</i>	Medregal / Greater amberjack	No
MXV0069	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Hypanus americanus</i>	Raya látigo americana / Southern stingray	Yes
MXV0070	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Isurus oxyrinchus</i>	Mako / Shortfin Mako	No
MXV0071	Robalo / Barred grunt	La Viga**	Fillet	100	<i>Conodon nobilis</i>	Robalo / Barred grunt	No
MXV0072	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Galeocerdo cuvier</i>	Tintorera / Tiger Shark	No
MXV0073	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Carcharhinus brevipinna</i>	Tiburón curro / Spinner Shark	No
MXV0074	Robalo / Barred grunt	La Viga**	Fillet	100	<i>Conodon nobilis</i>	Robalo / Barred grunt	No
MXV0075	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Carcharhinus falciformis</i>	Tiburón piloto / Silky Shark	No
MXV0076	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Isurus oxyrinchus</i>	Mako / Shortfin Mako	No

MXV0077	Salmon / Atlantic salmon	La Viga**	Fillet	100	<i>Salmo salar</i>	Salmon / Atlantic salmon	No
MXV0078	Sierra / King Mackerel	La Viga**	Fillet/Slice	100	<i>Scomberomorus cavalla</i>	Sierra y/o Carito / King Mackerel	No
MXV0079	Robalo / Barred grunt	La Viga**	Fillet	100	<i>Conodon nobilis</i>	Robalo / Barred grunt	No
MXV0080	Medregal / Greater amberjack	La Viga**	Fillet / Slice	100	<i>Seriola dumerili</i>	Medregal / Greater amberjack	No
MXV0081	Bragre / Gafftopsail Sea Catfish	Cozumel *	Fillet	100	<i>Pangasianodon hypophthalmus</i>	Panga, Bassa / Striped catfish	Yes
MXV0082	Angel / Grey angelfish	Cozumel *	Fillet	100	<i>Pomacanthus arcuatus</i>	Angel / Grey angelfish	No
MXV0083	Mero / Grouper	Cozumel *	Fillet	100	<i>Epinephelus morio</i>	Mero / Red grouper	No
MXV0084	Bragre / Gafftopsail Sea Catfish	Cozumel *	Fillet	100	<i>Pangasianodon hypophthalmus</i>	Panga, Bassa / Striped catfish	Yes
MXV0085	Cazon / Small shark	Cozumel *	Fillet / Hunk	100	<i>Carcharhinus falciformis</i>	Tiburón piloto / Silky Shark	No
MXV0087	Bragre / Gafftopsail Sea Catfish	Cozumel *	Fillet	100	<i>Pangasianodon hypophthalmus</i>	Panga, Bassa / Striped catfish	Yes
MXV0090	Xcochin / Queen triggerfish	Cozumel *	Fillet	100	<i>Balistes vetula</i>	Xcochin / Queen triggerfish	No
MXV0094	Bacalao / Walleye pollock	Cozumel *	Fillet	100	<i>Gadus chalcogrammus</i>	Bacalao / Walleye pollock	No
MXV0325	Barracuda / Great barracuda	Cancun*	Slice	100	<i>Sphyræna barracuda</i>	Barracuda / Great barracuda	No
MXV0326	Barracuda / Great barracuda	Cancun*	Slice	100	<i>Sphyræna barracuda</i>	Barracuda / Great barracuda	No
MXV0327	Palometa / Crevalle Jack	Cancun*	Fillet	100	<i>Caranx hippos</i>	Palometa / Crevalle Jack	No
MXV0328	Pargo / Red porgy	Cancun*	Fillet / Slice	100	<i>Pagrus pagrus</i>	Pargo / Red porgy	No
MXV0329	Sierra / King Mackerel	Cancun*	Fillet/Slice	100	<i>Scomberomorus cavalla</i>	Sierra y/o Carito / King Mackerel	No
MXV0330	Medregal / Greater amberjack	Cancun*	Fillet / Slice	100	<i>Seriola dumerili</i>	Medregal / Greater amberjack	No
MXV0331	Medregal / Greater amberjack	Cancun*	Fillet / Slice	100	<i>Seriola dumerili</i>	Medregal / Greater amberjack	No
MXV0332	Boquinete / Hogfish	Cancun*	Fillet	100	<i>Lachnolaimus maximus</i>	Boquinete / Hogfish	No
MXV0335	Bragre / Gafftopsail Sea Catfish	Chetumal*	Fillet	100	<i>Pangasianodon hypophthalmus</i>	Panga, Bassa / Striped catfish	Yes
MXV0336	Tilapia / Mozambique tilapia	Chetumal*	Fillet	100	<i>Oreochromis sp.</i>	Tilapia / Mozambique tilapia	No
MXV0337	Abadejo / Gag	Chetumal*	Fillet	100	<i>Mycteroperca microlepis</i>	Abadejo y/o Mero / Gag y/o Grouper	No
MXV0339	Bragre / Gafftopsail Sea Catfish	Chetumal*	Fillet	100	<i>Pangasianodon hypophthalmus</i>	Panga, Bassa / Striped catfish	Yes
MXV0344	Corvina / Spotted seatrout	Chetumal*	Fillet	100	<i>Cynoscion nebulosus</i>	Corvina / Spotted seatrout	No
MXV0345	Corvina / Spotted seatrout	Chetumal*	Fillet	100	<i>Cynoscion nebulosus</i>	Corvina / Spotted seatrout	No
MXV0346	Bragre / Gafftopsail Sea Catfish	Chetumal*	Fillet	100	<i>Pangasianodon hypophthalmus</i>	Panga, Bassa / Striped catfish	Yes
MXV583	Mero / Grouper	Chetumal*	Fillet	100	<i>Hyporthodus nigrilus</i>	Mero / Warsaw grouper	No
MXV595	Boquinete / Hogfish	Cancun*	Fillet	100	<i>Lachnolaimus maximus</i>	Boquinete / Hogfish	No
MXV668	Actinopterygii	La Viga**	Fillet	94	Actinopterygii	unidentifiable	
MXV669	Limon / Blacknose Shark	La Viga**	Fillet / Hunk	100	<i>Carcharhinus acronotus</i>	Tiburón cangüay / Limón	No
MXV670	Lucero / Spotted sand bass	La Viga**	Fillet	100	<i>Paralabrax maculatofasciatus</i>	Lucero / Spotted sand bass	No
MXV671	Chopa / Atlantic tripletail	La Viga**	Fillet	100	<i>Lobotes surinamensis</i>	Chopa / Atlantic tripletail	No
MXV672	Raya / Ray	La Viga**	Fillet / Hunk	100	<i>Hypanus americanus</i>	Raya látigo americana / Southern stingray	No
MXV673	Atun / Tuna	La Viga**	Fillet/Hunk	100	<i>Thunnus sp.</i>	Atun / Tuna	No

MXV674	Chopa / Atlantic tripletail	La Viga**	Fillet	100	<i>Lobotes surinamensis</i>	Chopa / Atlantic tripletail	No
MXV675	Raya / Ray	La Viga**	Fillet / Hunk	99	<i>Gymnura micrura</i>	Raya cola de rata / Smooth Butterfly Ray	No
MXV676	Raya / Ray	La Viga**	Fillet / Hunk	100	<i>Hypanus americanus</i>	Raya látigo americana / Southern stingray	No
MXV678	Raton / Southern kingfish	La Viga**	Fillet	99	<i>Menticirrhus americanus</i>	Raton / Southern kingfish	No
MXV679	Cazon / Small shark	La Viga**	Fillet / Hunk	99	<i>Rhizoprionodon terraenovae</i>	Cazon de ley / Sharpnose Shark	No
MXV680	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Carcharhinus brevipinna</i>	Tiburón curro / Spinner Shark	No
MXV681	Caña	La Viga**	Fillet / Hunk	100	<i>Mustelus canis</i>	Cazón dientudo / Dusky Smoothhound	Yes
MXV682	Abadejo / Gag	La Viga**	Fillet	100	<i>Mycteroperca microlepis</i>	Abadejo y/o Mero / Gag y/o Grouper	No
MXV683	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Carcharhinus brevipinna</i>	Tiburón curro / Spinner Shark	No
MXV684	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Carcharhinus falciformis</i>	Tiburón piloto / Silky Shark	No
MXV686	Raya / Ray	La Viga**	Fillet	100	<i>Hyporthodus flavolimbatus</i>	Mero / Yellowedge grouper	Yes
MXV687	Tuburón martillo /Scalloped Hammerhead	La Viga**	Fillet / Hunk	100	<i>Sphyrna lewini</i>	Tuburón martillo /Scalloped Hammerhead	No
MXV688	Tuburón martillo /Scalloped Hammerhead	La Viga**	Fillet / Hunk	100	<i>Sphyrna lewini</i>	Tuburón martillo /Scalloped Hammerhead	No
MXV689	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Carcharhinus acronotus</i>	Tiburón cangüay / Limón	No
MXV690	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Carcharhinus acronotus</i>	Tiburón cangüay / Limón	No
MXV691	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Carcharhinus acronotus</i>	Tiburón cangüay / Limón	No
MXV692	Cazon / Small shark	La Viga**	Fillet / Hunk	99	<i>Rhizoprionodon terraenovae</i>	Cazon de ley / Sharpnose Shark	No
MXV693	Marlin / Blue marlin	La Viga**	Fillet / Hunk	100	<i>Makaira nigricans</i>	Marlin azul / Blue marlin	No
MXV694	Sierra / Mackerel	La Viga**	Grouthmeat	99	<i>Merluccius productus</i>	Merluza nortea / Pacific hake	Yes
MXV695	Cazon / Small shark	La Viga**	Fillet / Hunk	100	<i>Carcharhinus brevipinna</i>	Tiburón curro / Spinner Shark	No
MXV696	Huachinango / Red snapper	La Viga**	Fillet	100	<i>Hypophthalmichthys molitrix</i>	Carpa plateada / Silver carp	Yes
MXV697	Huachinango / Red snapper	La Viga**	Fillet	100	<i>Hypophthalmichthys molitrix</i>	Carpa plateada / Silver carp	Yes
MXV698	Tiburon / Shark	La Viga**	Fillet / Hunk	100	<i>Narcine entemedor</i>	Raya eléctrica gigante / Giant electric ray	Yes
MXV699	Huachinango / Red snapper	La Viga**	Fillet	100	<i>Hypophthalmichthys molitrix</i>	Carpa plateada / Silver carp	Yes
MXV700	Lenguado / Flounder	La Viga**	Fillet	100	<i>Pangasianodon hypophthalmus</i>	Panga, Bassa / Striped catfish	Yes
MXV701	Tuburón martillo / Scalloped Hammerhead	La Viga**	Fillet / Hunk	100	<i>Sphyrna lewini</i>	Tuburón martillo / Scalloped Hammerhead	No
MXV703	Gato / Cat-fish	La Viga**	Fillet / Hunk	100	<i>Makaira nigricans</i>	Marlin azul / Blue marlin	Yes
MXV704	Marlin / Blue marlin	La Viga**	Fillet / Hunk	100	<i>Carcharhinus limbatus</i>	Tiburón volador / Blacktip Shark	Yes
MXV705	Tiburon / Shark	La Viga**	Fillet / Hunk	100	<i>Hypanus americanus</i>	Raya látigo americana / Southern stingray	Yes
MXV706	Cazon / Small shark	La Viga**	Fillet	100	<i>Hypophthalmichthys molitrix</i>	Carpa plateada/ Silver carp	Yes
MXV707	Robalo / Snook fish	La Viga**	Fillet	100	<i>Caranx latus</i>	Jurel / Horse eye jack	Yes
MXV709	Jurel / Yellow jack	La Viga**	Fillet / Hunk	100	<i>Carcharhinus brevipinna</i>	Tiburón curro / Spinner Shark	Yes

Table 2. Threatened status of the species identified using a barcode database

Barcode Identification	Bin number	Protection Status in Mexico	IUCN Red List Status
<i>Actinopterygii</i>	BOLD:ACV0720	None	Least concern
<i>Bagre marinus</i>	BOLD:AAM3078	None	Least concern
<i>Balistes vetula</i>	BOLD:AAB6283	None	Near threatened
<i>Caranx hippos</i>	BOLD:AAB9930	None	Least concern
<i>Caranx latus</i>	BOLD:AAB0584	None	Least concern
<i>Carcharhinus acronotus</i>	BOLD:ABY4484	Fixed temporary closure	Near threatened
<i>Carcharhinus brevipinna</i>	BOLD:AAA3388	Fixed temporary closure	Near threatened
<i>Carcharhinus falciformis</i>	BOLD:AAA3387	Fixed temporary closure	Near threatened
<i>Carcharhinus limbatus</i>	BOLD:AAA5251	Fixed temporary closure	Near threatened
<i>Caulolatilus cyanops</i>	BOLD:AAU6310	None	Least concern
<i>Conodon nobilis</i>	JBOLD:AAM9279	None	Least concern
<i>Cynoscion nebulosus</i>	BOLD:AAI9478	None	Least concern
<i>Epinephelus morio</i>	BOLD:AAF1000	Fixed temporary closure	Near threatened
<i>Gadus chalcogrammus</i>	BOLD:AAA3069	None	Unregistered
<i>Galeocerdo cuvier</i>	BOLD:AAA2006	Fixed temporary closure	Near threatened
<i>Gymnura micrura</i>	BOLD:AAL3437	Fixed temporary closure	Data deficient
<i>Hypanus americanus</i>	BOLD:AAA5613	Fixed temporary closure	Data deficient
<i>Hypophthalmichthys molitrix</i>	BOLD:AAF6633	None (Introduced)	Near threatened
<i>Hyporthodus flavolimbatus</i>	BOLD:AAC5444	Fixed temporary closure	Vulnerable
<i>Hyporthodus nigrilus</i>	BOLD:AAF0389	Fixed temporary closure	Critically endangered
<i>Isurus oxyrinchus</i>	BOLD:AAA4689	Fixed temporary closure	Vulnerable
<i>Lachnolaimus maximus</i>	BOLD:AAC3462	None	Vulnerable
<i>Lobotes surinamensis</i>	BOLD:AAC1878	None	Least concern
<i>Lopholatilus chamaeleonticeps</i>	BOLD:AAK6870	None	Endangered
<i>Makaira nigricans</i>	BOLD:ABZ5150	Permanent closure	Vulnerable
<i>Menticirrhus americanus</i>	BOLD:AAB5199	None	Least concern
<i>Merluccius productus</i>	BOLD:AAB5094	None	Least concern
<i>Mustelus canis</i>	BOLD:ABY7045	Fixed temporary closure	Near threatened
<i>Mustelus sinuatusmexicanus</i>	BOLD:AAB2974	Fixed temporary closure	Data deficient
<i>Mycteroperca microlepis</i>	BOLD:AAB9158	Fixed temporary closure	Least concern
<i>Narcine entemedor</i>	BOLD:AAN2285	Fixed temporary closure	Data deficient
<i>Oreochromis</i> sp.	BOLD:AAA8511	None (Introduced)	
<i>Pagrus pagrus</i>	BOLD:AAC8526	None	Least concern
<i>Pangasianodon hypophthalmus</i>	BOLD:AAE3237	None (Imported)	Endangered
<i>Paralabrax maculatofasciatus</i>	BOLD:AAK5063	None	Least concern
<i>Paralichthys albigutta</i>	BOLD:AAO1988	None	Least concern
<i>Paralichthys lethostigma</i>	BOLD:AAG2602	None	Near threatened
<i>Pomacanthus arcuatus</i>	BOLD:AAB6281	None	Least concern
<i>Rhizoprionodon terraenovae</i>	BOLD:AAB3213	Fixed temporary closure	Near threatened
<i>Salmo salar</i>	BOLD:AAA3435	None	Least concern
<i>Scomberomorus cavalla</i>	BOLD:AAA7856	None	Least concern
<i>Selene vomer</i>	BOLD:AAF1235	None	Least concern
<i>Seriola dumerili</i>	BOLD:AAB5912	None	Least concern
<i>Sphyrna barracuda</i>	BOLD:AAA6100	None	Least concern
<i>Sphyrna lewini</i>	BOLD:AAA2402	Permanent closure	Endangered
<i>Sphyrna tiburo</i>	BOLD:ADK7234	Fixed temporary closure	Least concern
<i>Thunnus</i> sp.	BOLD:AAA7352	None	Least concern

Fig. 1. Comparison between the price of labeled products vs. barcode identifications. The exchange rate at the time of collections was 1 US dollar = 18.00 Mexican pesos.

274x351mm (300 x 300 DPI)