INTER-AMERICAN TROPICAL TUNA COMMISSION

2ND TECHNICAL MEETING ON DORADO

Lima (Peru)
27-29 October 2015

REPORT OF THE MEETING[1]

CONTENTS

EXECUTIVE SUMMARY

Dorado (*Coryphaena hippurus*) Linnaeus, 1758, also called *dolphinfish*, *mahi mahi*, *doradilla*, *lampuga*, *palometa*, *dorado de altura*, and *perico*, is one of the most important species caught in the artisanal fisheries of the coastal nations of the eastern Pacific Ocean (EPO). The species is also caught incidentally in the purse-seine tuna fishery in the EPO. Under the Antigua Convention and its ecosystem approach to fisheries, it is therefore appropriate that the IATTC staff study the species, with a view to determining the impact of fishing and recommend appropriate conservation measures if required. In this context, some Members of the IATTC with coastlines in the EPO have requested that collaborative research on dorado be carried out with the IATTC staff, so that solid scientific information is available for the management and conservation of this important resource in the region.

The Republic of Peru organized and hosted the second IATTC Technical Meeting on Dorado, held in Lima, Peru, on 27-29 October 2015. The IATTC staff facilitated sessions of collaborative work aimed at analyzing and discussing available data, and answering two important questions that need to be addressed in order for regional management of dorado to be possible: 1) what are reasonable stock structure assumptions to consider for regional management of dorado in the EPO?; and 2) which indicators of stock status should be monitored as a basis for scientific advice for regional management?

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[1] Suggested reference:
Anonymous. 2016. Report of the 2st Technical Meeting on Dorado. Inter-American Tropical Tuna Commission. Lima, Peru, 27-29 October 2015. 20 pp.

This report describes the work, discussions, and knowledge generated during the three sections of the meeting (see agenda, Appendix 1): 1) update on knowledge about the fisheries (13 presentations; Appendix 3); 2) review of biological aspects and defining stock structure assumptions for population modeling; and, 3) potential stock assessment methodologies for dorado.

1. BACKGROUND

Dorado (*Coryphaena hippurus*) Linnaeus, 1758, also called *dolphinfish, mahi mahi*, *doradilla*, *lampuga*, *palometa*, and *perico*, is one of the most important species caught in the artisanal fisheries of the coastal nations of the eastern Pacific Ocean (EPO). The species has been thought of as highly resilient to overfishing due to its high productivity in all the oceans of the world (Palko *et al.* 1982). In the EPO in particular, dorado shows high rates of growth during a very short lifespan (about three years), early maturity (50% maturity at 0.5-1 years of age), high fecundity, and spawning that occurs throughout the year (Goicochea *et al.* 2012; Zúñiga-Flores 2014). However, caution is necessary because dorado is subject to intense commercial exploitation in most nations in the EPO (Peru, Ecuador, Colombia, and most of the Central American nations) (Dapp *et al.* 2013; Lasso and Zapata 1999; Martínez-Ortiz and Zúñiga-Flores 2012; Solano-Sare *et al.* 2008). The available fisheries statistics indicate that the major fraction of the total global production of dorado is taken in the EPO (47-70% between 2001 and 2012) (Aires-da-Silva *et al.* 2014). It is estimated that the average total annual catch of dorado in the region was about 71,000 metric tons (t) during 2008-2012. In Ecuador, for example, it represents more than 65% of the estimated landings of pelagic fish, and 35 to 40% of the exports of such fish to the United States (Martínez-Ortiz and Zúñiga-Flores 2012). Although Peru has the greatest catches of dorado in the EPO, it is second to Ecuador in terms of exports (filleted and fresh) to the United States. Information from various sources indicates that most of the Peruvian catch is consumed domestically, while most of the Ecuadorian catch, and those of other nations of the EPO, is exported to the United States.

The Antigua Convention establishes that one of the functions of the Inter-American Tropical Tuna Commission (IATTC) is to “adopt appropriate measures to avoid, reduce and minimize … impacts on associated or dependent species.” Dorado is caught incidentally in the purse-seine tuna fishery in the EPO (Martínez-Rincón *et al.* 2009), although in very small quantities (<5%) compared to the total volume of the commercial catches in the EPO (Aires-da-Silva *et al.* 2014). It is therefore appropriate that the IATTC staff study the species, with a view to determining the impact of fishing and recommend appropriate conservation measures if required. In this context, some Members of the IATTC with coastlines in the EPO requested that collaborative research on dorado be carried out with the IATTC staff, and asked for assistance in designing data collection forms and data entry programs for the dorado fisheries (Aires-da-Silva *et al.* 2014).

Following the success of the recent collaborative work between the IATTC staff and scientists from Member countries to develop an assessment of silky sharks (*Carcharhinus falciformis*), various IATTC Members in the region asked that the IATTC staff organize a series of technical meetings aimed at improving knowledge of the status of the dorado stocks, with the eventual aim of managing and conserving the species in the EPO.

The first IATTC Technical Meeting on Dorado was held in Manta, Ecuador, in October 2014, with participants from various government research institutions, management agencies, universities, the industry, and non-governmental organizations (NGOs). It helped to establish the collaborative forum that is necessary for research on dorado at the large regional scale of the EPO. A large and diverse amount of fishery and biological data for dorado available from IATTC Member countries was identified. In addition, priority items for a collaborative regional research plan were identified.

The Republic of Peru organized and hosted the second IATTC Technical Meeting on Dorado, held in Lima, Peru, on 27-29 October 2015 (see agenda, Appendix 1). The meeting was chaired by Dr. Alexandre Aires-da-Silva, and co-facilitated with Drs. Carolina Minte-Vera and Juan Valero; the participants are listed in Appendix 2. The IATTC staff facilitated sessions of collaborative work aiming to analyze and discuss available data, and provide answers to two important questions that need to be addressed in order for regional management to be possible: 1) what are reasonable stock structure assumptions to consider for regional management of dorado in the EPO?; and 2) which indicators of stock status should be monitored as a basis for scientific advice for regional management?

This report describes the work, discussions, and knowledge generated during the three sections of the meeting (see agenda, Appendix 1): 1) update on knowledge about the fisheries (13 presentations; Appendix 3); 2) review of biological aspects and definition of stock structure assumptions for population modeling); and 3) potential methodologies for stock assessments of dorado.

2. UPDATE ON KNOWLEDGE ABOUT FISHERIES

The presentations updated knowledge about the fisheries and the biology of dorado in the EPO (Appendix 3) from Mexico to Chile. The themes ranged from genetic studies to oceanographic influences.

Miguel Ñiquen Carranza presented an overview of the investigations of dorado in Peru, with emphasis on the 2014-2015 period. Peru is the world's largest producer of dorado, with annual catches averaging about 50,000 t. Dorado in Peruvian waters is a fast-growing, highly fertile, opportunistic-feeding species, captured by artisanal longline fleets in the austral spring and summer. The fishery in Peru is regulated through temporal closures and minimum sizes. The open season is from 1 October to 30 April of the following year. The minimum size limit is 70 cm fork length (FL). Three fishing zones (north, center, and south) are defined in Peru. Catches vary according to environmental conditions, the greatest catches are generally in the central zone (8°S to 10°S). It is believed that warm El Niño conditions generate larger recruitments. This supports the hypothesis of two population units: a Northern unit between 2° and 10°N, and a Southern unit between 2°N and 15°S, off Ecuador and Peru. The southern unit is dominated by the Humboldt Current system. In 2015, spawning occurred as late as March in southern Peru (Ilo). The catches of dorado, squid, and skipjack tuna were similar during 2000-2014, and these species have similar life strategies, and a growing trend in availability has been observed for all of them.

A participant suggested that consideration be given to the region between the ports of Santa Elena (Ecuador) and Paita (Peru) as a potential spawning area for dorado, due to the high concentration of chlorophyll-a in the region. Catches of larger sizes only have been reported off Colombia.

Regarding the distribution of the catches of dorado by purse seiners fishing on floating objects, one IATTC staff member stressed that the lower catches of dorado observed between 130° and 150°W do not necessarily mean lower dorado density; there are less floating objects in the area because there are many mesoscale events (eddies) that can create an oceanographic constraint on the use of floating objects, and thus less sets are made.

Ana Alegre Norza Sior presented a study on dorado diet and its interaction with the Peruvian anchoveta. The Humboldt Current creates an area rich in nutrients and increases the fishing zones off Peru. The feeding study was done using an IMARPE collection of about 1,500 stomachs obtained from fishing trips from 1998 to 2015, with about 50 stomachs sampled per trip. Dorado feed on 59 prey species of 15 functional groups; their main prey in Peru are anchovetas, flying fish, and giant squid. The larger dorados consumed more flying fish, while the medium-size and smaller dorado consumed more anchoveta and giant squid.

A partipant asked if an ontogenetic shift in diet might be inferred from this information; the presented answered that more studies are needed to make such an inference. The larger dorado and dorados caught far from the coast had smaller proportions of filled stomachs. Also, flying fish were more common in dorado caught in the north and more than 100 miles from the coast. Anchovetas are not part of the diet of dorado caught in Ecuador, but dorado caught in the two countries share many prey species, which may be an indication that fish from those two regions are from the same population unit. One participant remarked that since juvenile dorado eat giant squid, there might be a spawning area of giant squid in the region, allowing small dorado to eat juvenile giant squid.

Carlos Goicochea presented a study of age and growth of dorado in northern Peru from 80 females and 30 males sampled during a survey in February 2010. The study was performed by counting otolith micro-increments, which had been previously shown to be deposited daily. Females have slower growth rates than males.

Renato Gozzer presented the results of an investigation in progress of the genetic characterization of dorado in Peru, as well as a comparison with Mexican samples. In 2014, samples were obtained from the Peruvian fishery for genetic analysis. At the local level, genetic diversity was high (indicating good genetic health), and all dorado found in Peru had similar genetic profiles, which indicated that there is only one population in Peru. There are two dominant haplotypes. The genetic profile of the fish sampled in Peru was similar to that of the Mexican samples, suggesting that there is only one population, in the genetic sense, in the EPO. One participant suggested that genetics may not be the way to establish population differences because oceanographic factors lead to mixing of populations, which creates a great diversity of population units.

One staff member asked what percentage of a population unit should be mixed with another population unit in order to promote homogeneity between them. Gozzer stated that just a small percentage is needed. Another staff member pointed that it is a reasonable start to use the genetic studies as a basis for creating a management unit for dorado. The staff asked if any assistance is needed from IATTC for the study to be continued and expanded to more locations in the EPO. Gozzer prepared a preliminary draft of what would be needed to expand and continue the study.

Samuel Amoros described the efforts made since 2012 to implement a fishery improvement project in Peru as a step towards an MSC (Marine Stewardship Council) certification. These include establishing a working group, and implementing a logbook system and fishing closures as management measures.

Jimmy Martinez presented the results of research into a possible correlation between the interannual variability of the catch per unit of effort (CPUE) of dorado and sea-surface temperature (SST), using data from 2008-2015. There may be a negative correlation between CPUE and SSTs 4 to 5 months earlier.

Participants commented that these correlations may be considered positive had different time lags been considered. They also suggested an analysis of the correlation between SST anomalies and peaks in CPUE with different time lags.

Patricio Barría and **Francisco Contreras** presented an overview of the dorado fishery in Chile. In Chile, dorado mature at 4 to 5 months of age (65 cm TL for females), and may spawn up to 1 million eggs. The maximum size found in Chile is 160 cm (25 kg). Dorado are caught with small longlines (*espinel*) near the coast and large longlines (*palangre*) in oceanic waters, with size-2 or 3 hooks and squid and flying fish as bait. The fishing takes place at 12 m average depth, mainly in the austral spring and summer (80% of the catches). The average annual landings are 500 t. There is a very high sampling coverage both in port and on board. The main ports are Arica and Iquique. In recent years, the yield has increased greatly. The average size caught in the coastal *espinel* fishery is 85 cm, and the size distribution is unimodal. For the oceanic longliners, the sizes are markedly bimodal, with peaks at 80 and 120 cm. Males are always larger than females. The length distribution of females has a steeper negative slope at larger sizes, which indicates higher mortality rates than males. Dorado is caught from 18 to 28^{o}S, with the largest catches in the north. The sex ratio is almost 1:1.

One participant asked about management measures for dorado in Chile. There are no direct management measures for this fishery, but there are indirect measures such as controlling the number of vessels in the fleet. The fleet size is not allowed to increase, and all boats need to be registered for fishing in order to operate. Fishing licenses are given by species group. One participant noted that Chile, Peru, and Ecuador have similar timing of the peaks in catches; in the three countries there is a thermal dome that favors fishing for dorado at the end of a year/beginning of the next. In Colombia, however, there is also a smaller peak in catches at mid-year. This poses the question whether two different stocks are mixing in

Colombian waters. Another participant pointed that in Central America the peak in catches occurs in November, with a smaller peak in August.

Luis A. Zapata Padilla described the dorado fishery in the Colombian Pacific. All dorado in Colombian waters are reproductively active. The sex ratio is 1:1. The fisheries are done by shrimp boats that use longlines. The average annual catch is 600 tons, but up to 2,600 t have been recorded. The sizes range from 60 to 190 cm TL; 90 cm TL is the size at sexual maturity. The modal size of spawning fish is 120 cm TL. The catches are smaller when the waters are cold and much greater during El Niño conditions. Studies of spatial distribution of larvae have been performed. Genetic analysis pointed to the existence of two fish stocks in Colombia, one genetically "older" in the south and the other, genetically more recent, around the northern region, where the trade winds coming from Panama bring the resource to Colombia. The average CPUE at the peak of the fishing season was 597.7 kg day^{-1} in 2014 and 369.5 kg day^{-1} in 2015.

A participant pointed out that growth depends on temperature, and dorado grow faster in areas where the temperature is higher than 26-28°C.

Ernesto Godelman presented data on dorado in Panama for the discussion of stock structure (see next section).

Eduardo Juárez Donis showed the size distribution of dorado in Guatemala, using the data from the commercial categories (5-10 (average 75 cm TL), 10-15 (90 cm), 15-20, and > 20 lbs). Most fish in the catches are over 70 cm TL. The largest length from the market categories was estimated to be 133 cm TL, but the largest fish measured from biological samples was 198 cm TL.

A participant pointed out that there are also data for El Salvador that could be used to update the knowledge about the fisheries.

Sofía Ortega presented a study of morphometric analysis of otoliths as a tool for distinguishing stocks of dorado. They analyzed otolith morphometry in Cabo San Lucas, Baja California, using an elliptical Fourier analysis. The results indicated differences by gender and fish size. The morphology of the otoliths varies more in smaller individuals, while that of adults did not show significant differences, so otolith contours may be useful for discriminating stocks of dorado. This morphometric methodology can be applied throughout the EPO for that purpose. Ortega also showed the results of tagging studies in Mexico. One hundred and forty dorados were tagged with conventional and satellite tags. Conventional tags were recovered near the coast which indicate south-to-north and north-to-south movements. The information collected by the satellite tags indicated numerous immersions by dorado to about 100 m deep. These were very short in time, with dorado spending most time at depths between 0 and 15 m. Their temperature preferences were in waters above 22^{o} with 24^{o}C being the preferred temperature. They prefer to use ocean currents to navigate. The presenter also showed and analysis of dorado bycatch by the international tuna fleet as well as the results of a predictive model under ENSO phases.

3. REVIEW OF BIOLOGICAL ASPECTS AND DEFINING STOCK STRUCTURE ASSUMPTIONS FOR POPULATION MODELING

Carolina Minte-Vera, of the IATTC staff, presented a review of biological factors related to stock structure and assessment of dorado in the eastern Pacific Ocean (DOR-02-20). The review covered genetic studies, spatial distribution, seasonality, size distribution, movement, growth, natural mortality, length-weight relationships, and reproduction. Hypotheses about stock structure to be included in the stock assessment model were proposed for discussion. The biological review comprised published information, information contained in the presentations at the first workshop on dorado, and new analyses done by the staff based on datasets from some countries.

It was proposed that the definition of stock structure by Cadrin *et al.* (2014) be adopted to guide the discussion; this states that the study of stock structure aims at identifying self-sustaining components within the natural population. In practical terms, a stock can be considered to be a group of fish that has limited interactions with other groups, so that fishing on one group has a limited impact on the dynamics of another group. While two groups of fish may be considered different stocks for the purposes of fisheries stock assessment, genetically they may be indistinguishable, because it takes only one immigrant per generation to reproduce to mix the two gene pools. Nevertheless, if two groups of fish are genetically distinct from each other, they will certainly be so in practical stock assessment terms.

Genetic studies of dorado in the EPO indicate high genetic variability, and no evidence of genetically different populations. In the equatorial region off Colombia there is evidence that two different groups of dorado visit the area: fish caught at the peak of the season have different allele frequencies than those caught in the off-season (Téllez and Caballero 2014). The authors suggest that there might be a resident group and a transient group in those waters. In the Gulf of California, Tripp-Valdez *et al.* (2014) detected high genetic variability and no evidence of population separation. In Ecuadorian waters there is evidence of only one panmictic population (Concepto Azul, unpublished data).

Dorado are widely distributed in the warm waters of the EPO. They are caught throughout the area of operation of Class-6[2] purse seiners, all of which carry observers (SAC-05-11b). The known distribution of dorado larvae indicates that the highest abundance is in areas closer to the coast. Presence of larvae was reported for Central America (Ortega-García 2014), Colombia (Zapata and Baos 2014) and Ecuador (Calderón 2011 *apud* Martínez-Ortiz and Zúñiga-Flores 2012). Juvenile fish (FL < 60 cm) appear in oceanic waters in the middle of the year: from April to September the highest CPUE of juveniles is in the purse-seine fishery on floating objects. In areas close to the coast of Peru the highest incidence of juveniles is from July to September (Ñiquen-Carranza 2014). Adults (FL >60 cm) appear in the purse-seine fishery on floating objects throughout the year, with the highest CPUE close to the coast of Ecuador, Peru, and Chile in the first quarter (January-March). The Ecuadorian artisanal dorado fleet follows the fish as they approach the coast along with subtropical waters with moderate SSTs south of the Equatorial front. In Ecuador and Peru, dorado seem to follow the 23°C isotherm bordering the colder and nutrient-rich waters of the Humboldt Current that contracts during the austral summer (Ñiquen-Carranza 2014, Martínez-Ortíz *et al.* 2015). In Guatemala, dorado occur at SSTs from 27.5 to 30.5 °C, with the highest abundance at 29-29.5°C (Ixquiac and Juárez 2014).

A marked seasonality in the dorado catches is found at the extremes of its distribution, both in the north and in the south (Table 1). Off Central America and southern Mexico, catches occur throughout the year, but there is an increase from September to February. In Colombia the catches are highest in February and March.

TABLE 1. Seasonality of catches of dorado in the EPO. The catches range from black (highest) to white (none or negligible, *e.g.* bycatch)

Localidad	Latitud	Jul	Ago	Set	Oct	Nov	Dic	Ene	Feb	Mar	Abr	May	Jun	Referencia
Cerqueros (objetos flotantes)	10 N - 10 S													Datos CIAT
Mexico Cabo San Lucas	23 N													Zúñiga-Flores et al (2008)
Mexico Oaxaca	16 N													Ortega-García et al. (2012)
Guatemala	13 N													Ixquiac & Juárez (2014, Pres. 11)
El Salvador	13 N													Com. personal Jorge López OSPESCA
Costa Rica	9 N													SAC-05-11b
Panama	7 N													Guzmán et al (2015) y datos CEDEPESCA
Colombia	5 N													Lasso & Zapata (1999)
Ecuador	5 S													Mendoza (2014, Pres. 2) & SAC-05-11b
Peru	12 S													Ñiquen Carranza (2014)
Chile	19 S													Barria & Contreras (2015)

2 Carrying capacity greater than 363 t

A marked seasonality was also found in the size distributions of dorado. The size data submitted by the countries allowed the IATTC staff to perform exploratory data analyses in search of patterns that might indicate direction and synchronicity of movement and growth. The average fork length of dorado in the Ecuadorian fisheries increases by about 30-40 cm between the middle of the year and the end of the dorado season (February-March), when it reaches 95-100 cm FL. In Colombia, dorado is generally caught during December- January; its average size of about 100-105 cm FL is almost invariably larger than the dorado fished by the Ecuadorian fleet in the same months. In Guatemala, the average sizes were generally larger when the industrial fleet operated (2002-2003) and smaller when only the artisanal fleet was in operation (2005-2008). The largest average sizes in the Guatemalan fisheries are highly variable from year to year, while for Ecuador and Colombia they are very similar among years. This may indicate that two different groups of dorado are exploited by the Guatemalan fleets, while Colombia and Ecuador exploit predominantly one group, potentially shared by the two countries. A marked seasonality is evident in the average sizes of dorado from both Guatemala and Ecuador. The seasonal component modelled using generalized additive models (GAMs) shows a difference of about a month between the largest and smallest average sizes forthe two countries: January and June in Guatemala, and February and mid-July in Ecuador, respectively. Data for April-August 2008 in El Salvador show the largest sizes in May and the smallest in July. Tagging studies in Mexico indicate that dorado are capable of movements greater than 500 km (Ortega-García 2014). Large-scale movements can also be inferred from the spatio-temporal distribution of length frequencies of dorado from the Ecuadorian fleet, which seems to be following mainly one cohort as it moves closer to the continent. This large georeferenced dataset allowed histograms by fishing area and months to be computed that showed a modal size that clearly increases as the fish move from 85-95^{o}W in September-December to areas closer to the coast during January-March. As more countries gather data on size distribution, more comparative and spatio-temporal analyses can be performed in the future.

Several growth studies of dorado in the EPO have been done. Different methodologies (otoliths, scales, and length frequencies) were used in different places, so this information cannot be used for drawing conclusions about regional differences in growth that might reveal stock structures, because the difference may be related to the type of data used (Chang and Maunder 2013). The growth curve with the largest asymptotic size (194.0 cm FL) was estimated by Lasso and Zapata (1999), using length-frequency samples from Colombia. The studies using hard parts (otoliths and scales) indicate dimorphic growth, with females reaching smaller sizes than males. The growth study by Goicochea *et al.* (2012) based on otolith increments from fish sampled in the Peruvian fisheries indicated faster growth from 0 to 1 years of age than studies based on scales (*e.g*. Martínez-Ortíz and Zúñiga-Flores 2012). The growth curve obtained by Goicochea *et al.* (2012) indicated growth from age 0 to 1 of 14 to 93 cm for males and 10 to 88 cm for females grow. It is recommended that this growth curve be used for the base case in population models for dorado (von Bertalanffy growth function, males: L_{inf} = 146.86 cm FL, k = 0.89 year^{-1}, t_0 = -0.12 year, females: L_{inf} = 128.47 cm FL, k = 1.08 year^{-1}, t_0 =-0.08 year). The original curve is in total length; the transformation on page 51 of Martínez-Ortíz and Zúñiga-Flores (2012) was used to compute fork length. The natural mortality estimated with the method of Pauly (1980) was 1.11 for males and 0.94 for females (based on the Goicochea *et al*. (2012) growth parameter estimates and 23^{o}C average SST). The natural mortality estimated using the Hoenig (1983) method was 1.7 (males) and 1.6 (females) (corresponding to the maximum age found by Goicochea *et al.* (2012) in Peru of 2.5 years for males and 2.7 years for females, using otoliths), and 1.2 (males) and 1.4 (females) (corresponding to the maximum age found in Ecuador of 3.5 for males and 3 for females, using scales, by Martínez-Ortiz and Zúñiga-Flores 2012). Length-weight relationships for dorado has been reported for Mexico (Zúñiga-Flores 2009), Colombia (Lasso and Zapata 1999), and Ecuador (Martínez-Ortíz and Zúñiga-Flores 2012). It is recommended that the equation estimated for fish landed at the Ecuadorian port of Santa Rosa/Anconcito (Zúñiga-Flores 2014) be used for population modeling, because the area of operation of this fleet is closest to the area where the bulk of the catches is taken:

$$W= 2.39 \times 10^{-5} FL^{2.75} \text{ (females, n= 6733, } r^2 = 0.94)$$

$$W = 1.59 \times 10^{-5} FL^{2.85} \text{ (males, n= 4766, } r^2 = 0.94)$$

where W is total weight in kg, and FL is fork length in cm.

Studies of the reproductive biology of dorado have been done in Mexico, Ecuador, and Peru. For Colombia, Lasso and Zapata (1999) computed gonadosomatic indices for a few months during 1994-1996. Each study developed its own maturity stage classification. In Mexico, Zúñiga-Flores *et al.* (2011) found the highest proportion of mature fish in June, and most of the reproductive activity from May to November. In Colombia, the gonadosomatic indices were highest in December and April, indicating that reproduction happens during those months. At Esmeraldas, in the north of Ecuador, mature fish are found year-round in high proportions, and immature fish are found only in July and August (Martínez-Ortiz and Zúñiga-Flores 2012), whereas at Manta and Santa Rosa, toward the south, the highest proportion of mature fish is found from December to February, while immature fish dominate from May to August. In Peru, mature fish dominate from December to March (Solano-Sare *et al*. 2008).

The size at 50% maturity for female dorado has been reported to be from 66 cm TL (about 55 cm FL) in Peru to 93 cm FL at Esmeraldas, Ecuador (Zúñiga-Flores 2014). Males have a greater length at 50% maturity (*e.g*. Zúñiga-Flores 2014). For the population modelling, the size at 50% maturity for females was assumed to be 78.275 cm FL, and the slope of the logistic curve equal to -0.08 (Zúñiga-Flores 2014). Those correspond to fish sampled at the Ecuadorian port of Santa Rosa/Anconcito, whose landings are from areas where the bulk of the catches occurs. The batch fecundity of dorado is about 46,500 eggs kg^{-1} (in Ecuador, from Figure 27 in Zúñiga-Flores 2014).

The two hypotheses of stock structure in the EPO to be assumed in the stock assessment model proposed for discussion were a single stock, or two stocks separated around the Equator.

Discussion:

A suggestion was made that the countries work in collaboration on standardizing the collection of length data; currently some countries use total length and others fork length. It was suggested that all countries use fork length, so that data can be comparable. Ecuador and Peru already have a bilateral scientific agreement for standardization of methodologies.

During the meeting, participants shared information on dorado sex ratios by area. A compilation of the available data was presented and discussed, with a focus on identifying potential processes behind apparent changes in the sex ratios of dorado. It is not clear so far whether the variability in sex ratios is due to biological, fishery, or sampling processes. The impact of some of these alternatives was explored during the session on Stock Synthesis modeling (see sections below).

During the discussion it was decided that modelling for stock assessment should start with the information from the “core” region of the known catches, which is also the most detailed information available, and comprises the catches of Ecuador and Peru. The decision to start with the core region took into account the fact that including the catches of other countries would also include local processes that are currently not well understood. Continuing work and improvements in data collection in other countries was emphasized. If or when data are available, the in-season mortality of the cohorts can be computed using the models developed by the IATTC staff and presented at this workshop.

One participant showed a graph with the temporal frequency of adults and juveniles in Peru. From October to January the frequency of adults is higher. From mid-September to December spawning occurs, and there are larvae in the area. From April to October there are more juveniles, while during the rest of the year the adults dominate. Peak abundance of juveniles is in mid-June, and of adults in December-January. In November the fishing is better at the northern port of Paita. By the end of the fishing season (January-February) the higher catch rates are of adults in the south. Participants noted that it is important to have on-board observers who can measure the fish and record the position of the catches, because the landing port might not always be related to the fishing area. A participant mentioned that at a bilateral

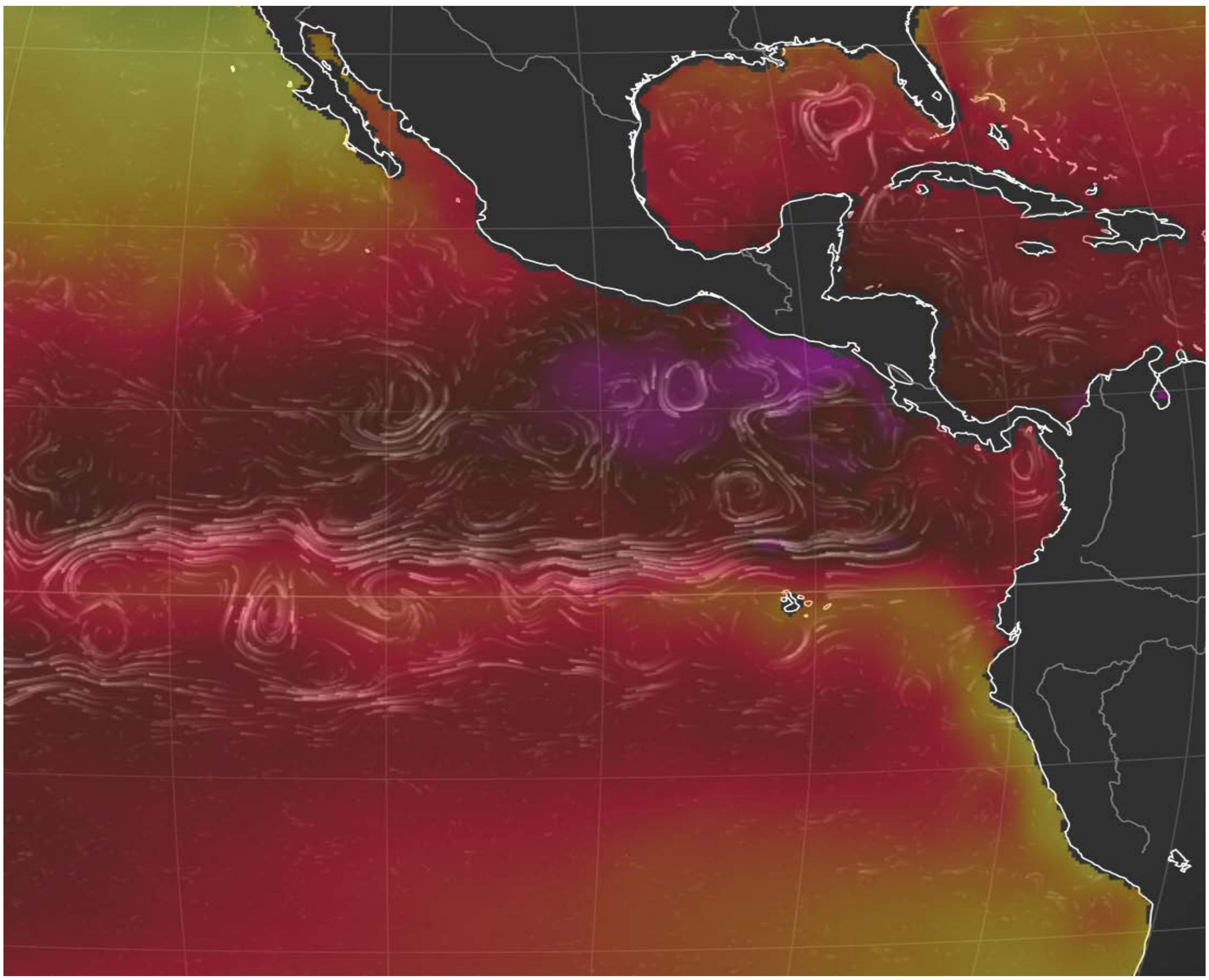

FIGURE 1. Currents and sea-surface temperature around the fishing areas for dorado in the EPO, 7 May 2016 (Source: http://earth.nullschool.net/#current/ocean/surface/currents/overlay=sea_surface_temp/orthographic=-108.29,5.67,671)

meeting between Peru and Ecuador, information on fishing areas (as opposed to landing ports) was analyzed to study the distribution of dorado. Participants stated that new cohorts are spawned off Peru and off Chile in February, and the cycle repeats every year. The movements of fish 1.5 to 3 years old are unknown. A participant remarked that a more plausible hypothesis is that spawning might occur all along the coast and not only in the southern hemisphere.

Another participant noted that the currents must be analyzed (see Figure 2), and the graph should be

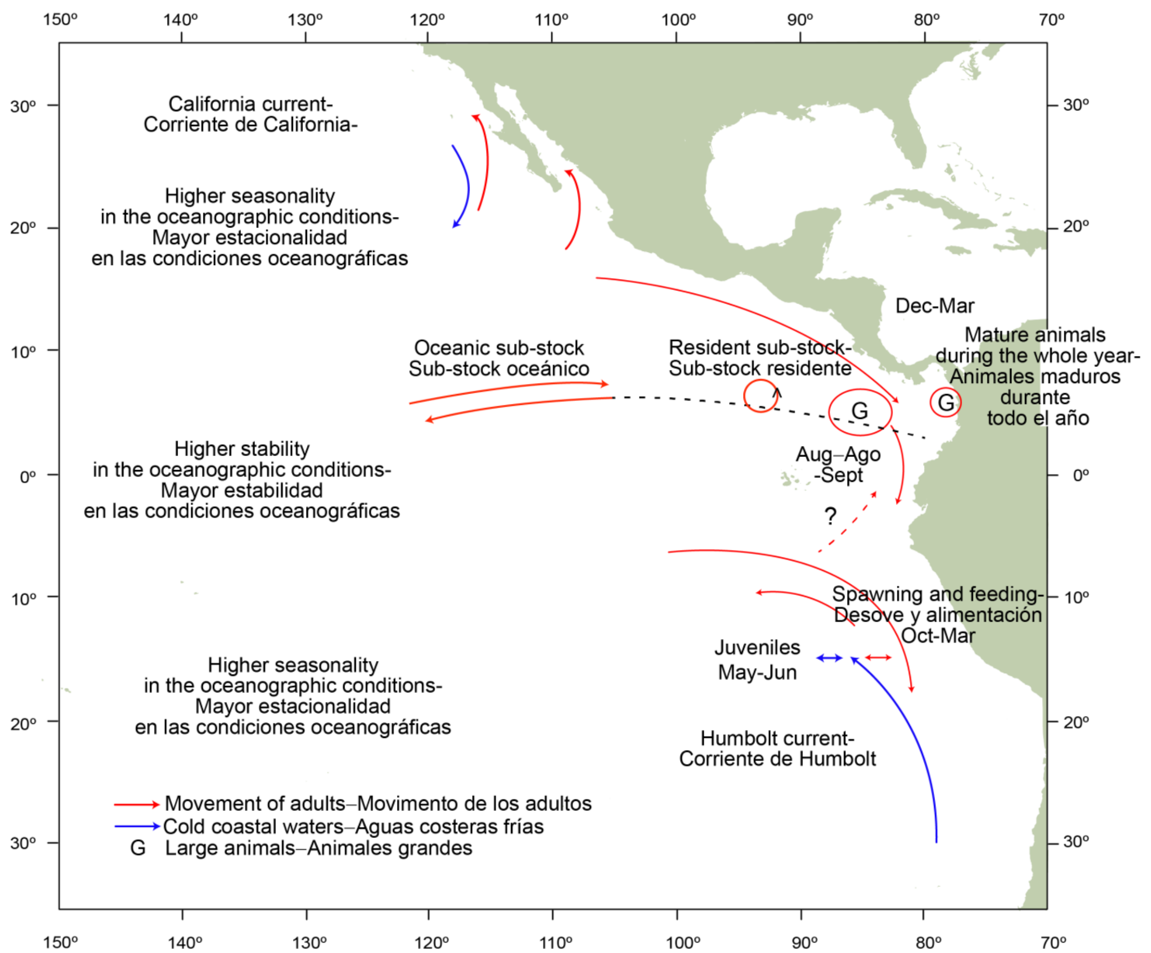

FIGURE 2. Conceptual model of stock structure and movement of dorado in the EPO produced following discussions during the meeting.

compared with the current flows. A Peruvian fishermen recalled that at the beginning of the 2011-2012 fishing season, large individuals were caught off Colombia, around 5°N, and by the end of the season the fishery had moved south to 9°S, off Chimbote, Peru, and caught smaller individuals. A participant noted that when the trade winds weaken, dorado are found off Mexico. In June and July there are very strong westward-flowing currents that favor migration. Another participant pointed out that Costa Rica, Ecuador, and southern Mexico catch dorado year-round, while Peru and Chile have marked seasonality in the catches, suggesting that there is one stock in the EPO that moves closer to the coast from October to January due to oceanographic conditions.

Based on the matters reviewed and following the previous discussion, the group produced a conceptual model for the dorado population in the EPO (Figure 2). Genetically, it seems that there is only one population in the EPO, although there might be an oceanic component of the stock that moves closer to the coast seasonally, and a coastal resident component in some areas. The latter would be located slightly north of the Equator, while the oceanic component would migrate to coastal areas of the EPO around October-November for feeding and spawning. The rationale for this hypothesis is:

(i) Optimal temperatures for dorado appear to be different north and south of the Equator. Between the Equator and about 10°N the temperatures are higher (Figure 1) and more stable during the year, and reproductive activity is seen all year round. South of the Equator, both the high temperatures and spawning activity are markedly seasonal.

(ii) Some genetic data from Colombia support the existence of two sub-stocks in waters slightly north of the Equator.

(iii) The size composition of the catches by the Ecuadorean fleet indicates that a single cohort with a high rate of natural mortality is targeted as it moves closer to the coast south of the Equator.

(iv) While there are catches of dorado throughout the year north of the Equator, there are two peaks (mainly off Panama and Costa Rica): a marked one around the end / beginning of the year, and a smaller one around May. South of the equator, only one strong peak is observed, from October to March.

Ernesto Goldeman presented Panamanian catch data by fishing area that support this conceptual model. Although the Panamanian fleet targets tuna between April and October, it also has significant catches of predominantly small dorado in that period, which increase significantly between November and January , with a predominance of larger sizes. On the other hand, the fleet is not too far from the Gulfs of Panama and Chiriqui throughout the year, which is consistent with the idea of a resident coastal sub-stock. There are strong local oceanographic phenomena, such as the Costa Rica Dome and upwelling in the Gulf of Panama, which may have an influence on the existence of a resident coastal sub-stock.

4. POTENTIAL STOCK ASSESSMENT METHODOLOGIES FOR DORADO

Define the assumptions regarding stock structure and identify potential stock status indicators for dorado in the EPO	Stock assessment staff	IATTC	DOR-02-15

4.1. General review of stock assessment methodologies

Potential methodologies for assessing dorado: general review of stock assessment methodologies	Stock assessment staff	IATTC	DOR-02-16

4.2. Stock status indicators (SSIs)

Potential methodologies for assessing dorado: monthly depletion estimator (step-by-step tutorial in Excel)	Stock assessment staff	IATTC	DOR-02-17

4.3. Bayesian surplus production model

An overview of stock assessment of dorado (*Coryphaena hippurus*) based on fishery information from Peru	Edgar Torrejón-Magallanes and Ricardo Oliveros-Ramos	IMARPE (Peru)	DOR-02-14

A participant asked about CPUE and catch rates. Torrejón-Magallanes said that the data came from fisheries that use the same gear. A participant noted that changes in catchability over time can also explain the model well, and asked whether the model was reliable. Another participant commented that the dorado fishery in the south of Peru fluctuates with fishing opportunities; for example, at the end of the El Niño year of 1998 there was a sharp increase in vessels larger that 1 t in southern Peru, and they fished as close as one mile from the coast. All code for the analyses presented by Torrejón-Magallanes is available on IMARPE's page at https://github.com/imarpe

4.4. Depletion estimator (step-by-step tutorial in Excel)

In order to explain the basis of the monthly depletion estimator in the Stock Synthesis model for dorado that the IATTC staff is building, in Document DOR-02 (Maunder *et al*. 2015) four progressively more complex models are presented. The simplest model is a log-linear regression of within-year monthly CPUE, similar to a catch-curve analysis, then a depletion estimator was introduced in which selectivities and fishing mortality deviations were added in sequence. The final model was a monthly depletion estimator that has several modifications similar to those used in the full Stock Synthesis model. Alexandre Aires-da-Silva conducted a hands-on step-by-step tutorial of some of the models.

4.5. Stock Synthesis length-based age-structured model (demonstration)

In this presentation (DOR-02-18), Juan Valero discussed the implementation of a preliminary model for dorado in the stock assessment platform *Stock Synthesis* (SS). SS is an age-structured model that allows an integrated analysis of multiple data types for fisheries stock assessment, such as length and age frequencies and abundance. There are multiple options already implemented in the SS platform that allow building simple to very complex models, as well as performing stock assessments and simulation testing in the same platform. The preliminary SS implementation for dorado is a two-sex model with a monthly time step during 2001-2014. It uses all the catch known for the EPO as well as monthly CPUE and length-frequency data from Ecuador. Life-history information, such as growth, maturity, and natural mortality, was based on previous studies of dorado. The model estimates recruitment, catchability, size-based selectivity, equilibrium initial fishing mortality and monthly fishing mortalities. The model fits to the CPUE from Ecuador are very good. Fits to the size-frequency data vary by sex: although females are fitted reasonably well for most months, males are over-fitted; that is, the model expects to see more males than are present in the data. Alternative models were fitted, including more female recruits than males, males less selected than females, males with higher natural mortality than females, and various degrees of dome-shaped selectivities, by sex and for both sexes.

Stock Synthesis seems an appropriate platform for conducting stock assessment work on dorado in the EPO. The preliminary SS model produces good fits to monthly CPUE and length data from Ecuador. Although annual CPUE and length data from Peru were not included in the model, the model predictions are very consistent with those data. The estimated status of dorado depends on the model selected, and also on the reference point chosen. Management strategy evaluation (MSE) seems a promising framework for evaluating the performance of alternative harvest strategies, given the uncertainty within and between models, and alternative harvest control rules and reference points. The staff will continue to explore the applicability of SS for the dorado stock assessment.

5. DISCUSSION OF A MANAGEMENT STRATEGY EVALUATION (MSE) FOR DORADO

In this presentation (Document DOR-02-19), Juan Valero discussed the potential use of the preliminary dorado model implementation in Stock Synthesis (SS) for evaluating alternative harvest strategies. A harvest strategy is a combination of monitoring, stock assessment, harvest control rule and management actions designed to achieve fishery objectives. Management actions include input (*e.g*. season length) and output (*e.g*. catch limit) controls. Formally evaluating alternative harvest strategies involves intensive simulation and estimation modeling, along with comparisons of results, such as performance in relation to fishery objectives. As a demonstration of what could be achieved for dorado, the IATTC staff used the preliminary SS implementation to evaluate the current strategy based on season closures. They used 5 different alternatives: the current one, and with closures starting either in January, February, March, or April. The effect of recruitment variability on the results was also demostrated.

Alternative strategies were discussed, including: no seasonal closure; fixed seasonal closure but later in the year; dynamic seasonal closure based on a minimum size limit, recruitment timing, and growth; seasonal closure based on impact of SST and CPUE; and preserving a percentage of the initial CPUE.

Stock Synthesis is a promising platform for complementing a possible stock assessment of dorado in the EPO with MSE work. This combined approach would allow the evaluation of alternative models, reference points, and harvest strategies robust to the uncertainties in the system.

6. OTHER MATTERS

The participants from CEDEPESCA-Panama expressed interest in organizing the 3rd IATTC Technical Meeting on Dorado in 2016. Although still subject to coordination and confirmation with the Panamanian fisheries authorities, the meeting is tentatively planned to take place in Panama City, probably in October 2016. Alexandre Aires-da-Silva thanked all the participants for their strong support and their attendance at the meeting. He also thanked PRODUCE and IMARPE for taking the initiative and organizing the meeting.

Participants at the 2nd IATTC Technical Meeting on Dorado, Lima, Peru, October 2015. See list of participants in Appendix 2.

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Appendix 1.

2^{ND} TECHNICAL MEETING ON DORADO

Defining stock structure assumptions and identifying potential stock status indicators for dorado in the eastern Pacific Ocean

27-29 October 2015, Lima, Peru

AGENDA

SCHEDULE:

8:00 Monday only: Registration (open all day)
9:00 Start (except Monday: inauguration at 8:30)
10:30-10:45 Coffee break
13:00-14:30 Lunch
15:30-15:45 Coffee break
18:00 Close (flexible)

AGENDA ITEMS:

1. **Inauguration and opening (starting at 8:30 on Monday)**
    1. Welcome. *Juan Carlos Requejo Alemán, Vice-Minister of Fisheries and Aquaculture, Peru*
    2. Presentation of the event. *Guillermo Compeán, Director, Inter-American Tropical Tuna Commission (IATTC)*
    3. Review of results from 1st Meeting on Dorado and structure of the 2nd Meeting. *Alexandre Aires-da-Silva, IATTC*

2. **Update on knowledge about the fisheries (brief presentations by participants)**

3. **Review of biological aspects and defining stock structure assumptions for population modeling**

4. **Preliminary stock assessment methodologies**
    1. Review of stock assessment methodologies
    2. Stock status indicators (SSIs)
    3. Bayesian surplus production model
    4. Depletion estimator (step-by-step tutorial in MS Excel)
    5. Stock Synthesis length-based age-structured model (demonstration)

5. **(tentative) Building a Management Strategy Evaluation (MSE) for dorado**

6. **Others**

7. **Adjournment**

Appendix 2.

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Appendix 3 - Presentations that updated knowledge about the fisheries and the biology of dorado in the EPO

Presentation	Presenter	Country	Institution/ Organization	Link
The fishery for dorado (*Coryphaena hippurus*) in Chile.	Patricio Barría and Francisco Contreras	Chile	Instituto de Fomento Pesquero (IFOP)	DOR-02-01
The fishery for dorado (*C. hippurus*) in the Colombian Pacific 2009-2015	Luis A. Zapata Padilla	Colombia	WWF Colombia	DOR-02-02
Possible correlation between the interannual varialbility of the CPUE of dorado and sea-surface temperature (SST)	Jimmy Martínez-Ortiz	Ecuador	WWF Ecuador	DOR-02-03
Catch length distribution in the fishery for dorado in Guatemala. Estimates based on catch weight	Eduardo Vinicio Juárez Donis	Guatemala	FUNDAECO and DIPESCA/MAGA	DOR-02-04
Morphometric analysis of otolith sagittae as a tool for distinguishing stocks of dorado (*Coryphaena hippurus*) in the Mexican Pacific	Sofía Ortega-García	México	Instituto Politécnico Nacional-Centro Interdisciplinario de Ciencias Marinas, La Paz, B.C.S. México	DOR-02-05
Migratory movements, depth distributions, and thermal preferences of dorado (*Coryphaena hippurus*) in the northeastern Mexican Pacific	Sofía Ortega-García	México	Instituto Politécnico Nacional-Centro Interdisciplinario de Ciencias Marinas, La Paz, B.C.S. México	DOR-02-06
Analysis of bycatches of dorado in the EPO during 1997-2006	Sofía Ortega García	México	Instituto Politécnico Nacional-Centro Interdisciplinario de Ciencias Marinas, La Paz, B.C.S. México	DOR-02-07
Contribution for the discussion of stock structure. Work in progress with data from Panama.	Ernesto Godelman	Panama	Centro Desarrollo y Pesca Sustentable (CEDEPESCA –Panama)	DOR-02-08
Age and growth of *Coryphaena hippurus* in the northern are of the Peruvian sea, February 2010	Carlos Goicochea	Perú	IMARPE-Perú	DOR-02-09

Presentation	Presenter	Country	Institution/ Organization	Link
General overview of research into dorado (*Coryphaena hippurus*) in Peru with emphasis on the 2014 – 2015 period	Miguel Ñiquen Carranza	Perú	IMARPE-Perú	DOR-02-10
Feeding of dorado *Coryphaena hippurus* in Peru. Interactions with anchoveta	Ana Alegre Norza Sior	Perú	IMARPE-Perú	DOR-02-11
Fisheries improvement project (FIP) for dorado in Peru	Samuel Amoros	Perú	WWF Peru	DOR-02-12
Genetic characterization of dorado (*Coryphaena hippurus*) of the Eastern Pacific Ocean	Renato Gozzer	Perú	WWF Peru	DOR-02-13