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Perceived length at first maturity in the lane snapper, *Lutjanus synagris* (Linnaeus, 1758) (Perciformes: Lutjanidae), along the Caribbean coast of Colombia

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Abstract. Fishery management measures based on knowledge of fish reproductive biology involve estimation of indicators like length at first maturity, Lm. This indicator, as the case is for length-based indicators, is attractive due to its easy of calculation, in particular, in settings where sophisticated fishery assessment is not in place. On the basis of data originated in the artisanal fishery (2008-2014) estimation was made of length at first maturity of the lane snapper *Lutjanus synagris* in the Colombian Caribbean and the existence or not of spatial patterns in this indicator was investigated. Tests via resampling showed that length at first maturity vary significantly among regions in range of 16.9 cm to 28.9 cm, total length. Differences in gear (handlines and longlines, gillnets) regional size selectivity correlate with the Lm observed spatial pattern. It is hypothesised that fishing has gone so far as to alter the demography of *Lutjanus synagris* along the coast in terms of a feedback loop and concomitantly, has altered its length at first maturity, at least as perceived from the fishery data. A plea is made as to redefine management objectives, practice and research needs for the Colombian Caribbean artisanal fishery in view of new paradigm shifts proposals regarding life-history effects of selective fishing on the species concerned.

Keywords: Lane snapper, Colombian Caribbean, artisanal fishery, length at first maturity, selectivity

Resumen. Talla percibida de primera madurez en el pargo rayado, (*Lutjanus synagris*, Linnaeus, 1758) (Perciformes: Lutjanidae), en la costa Caribe de Colombia. Medidas de manejo pesquero basadas en conocimiento de la biología reproductiva de los peces incluyen la estimación de indicadores como la talla de primera madurez, Lm. Este indicador, como en general los indicadores basados en tallas, es atractivo por su fácil implementación, en particular, en escenarios donde aún no se cuenta con evaluaciones pesqueras sofisticadas. A partir de datos originados en la pesquería artesanal (2008-2014) se estimó la talla de primera madurez del pargo rayado *Lutjanus synagris* en la costa Caribe de Colombia y se buscó establecer la existencia o no de variación espacial en este indicador. Tests vía remuestreo mostraron que la talla de primera madurez varía significativamente entre regiones con un rango de 16.9 cm a 28.9 cm de longitud total. Dicha variación espacial correlaciono con características de selección de tallas de las artes usadas regionalmente (líneas de mano, palangres y redes agalleras). Se hipotetiza que en términos de un circulo de retroalimentación la pesquería ha alterado la demografía de *Lutjanus synagris* a lo largo de la costa y en consecuencia su talla de primera madurez, al menos según se percibe de los datos pesqueros. Se hace un llamado en el sentido de reformular los objetivos de manejo, la práctica y las necesidades de investigación en relación a la pesquería artesanal del Caribe colombiano en vista de propuestas de cambio de paradigma en relación a efectos de la pesca selectiva sobre rasgos de la historia de vida de las especies afectadas.

Palabras clave: Pargo rayado, Caribe colombiano, pesca artesanal, talla de primera madurez, selectividad.

Introduction

Several fishing management measures rest upon knowledge on the reproductive biology of fishes (e.g., minimum landing size). Hence, length at first maturity (from hereon, Lm) has been proposed as an indicator of the state of the fishery under the moto "let them spawn" with a target of 100% mature fish in the catch (Froese 2004). The conceptual easy of such approach is attractive in particular in settings where sophisticated fisheries assessment is not in place as the case still is in many tropical countries.

Artisanal fisheries at the Caribbean coast of Colombia are important in terms of food security and employment. Sadly, as the case is in many other places where resources are open access, the fishery is in a state of decline (García 2010) and in much need of administration if there is hope of restauration of its productivity (Saavedra-Díaz *et al.* 2015). In the search of easy to implement management measures the "Autoridad Nacional de Acuicultura y Pesca" (National Authority of Aquaculture and Fisheries), AUNAP (Spanish acronym), launched a campaign of recollection of maturity stages of landed fishes that covered most of the Caribbean coast of Colombia (MADR-IICA 2011, AUNAP-UNIMAGDALENA 2013, Fig. 1). This afforded the opportunity of addressing questions about potential spatial patterns of Lm of fishes in a tropical marine ecosystem and concomitantly, of assessing the current management practice of estimating an all valid Lm for the entire Caribbean coast of Colombia.

The lane snapper (*Lutjanus synagris*), taken as our case study, is (still) the most valued demersal fish targeted by the artisanal fishery in the Caribbean coast of Colombia (García 2010). This fish has supported heavy fishing for decades (Erhardt 1977). Various authors have proposed estimates of Lm for this fish, in particular, for the northern part of the Colombian Caribbean while for the southern part no antecedent was found (see Table I below). The present paper aims to stablish and discuss spatial patterns in perceived (as data are fishery-dependent) Lm, i.e. the length at which 50% of the population become mature for the first time (Tsikliras *et al.* 2013), of *L. synagris* as a contribution to its life-history and as input for its correct management.

Materials and Methods

Study area **.** The Caribbean coast of Colombia has an extension of 1600 km approximately (Fig. 1). Situated well in the neotropic it harbours a variety of habitats: coral reefs, mangroves, sea grass beds, extended soft bottoms, etc., all of which are subject to fishing, even when in the interior of natural parks. The lane snapper is to be found in all these habitats and, although often signalled as coral reef representative, it is very well represented in soft bottoms (García and Armenteras 2015). The Magdalena river, the main geographic accident, roughly divides the coast into two mayor areas: to the northeast of its delta (Magdalena-Atlántico and Guajira regions, Fig. 1) as an area subject to a more or less strong upwelling and low precipitation conditions (Andrade & Barton 2005), and the southwest as an area subject to notorious riverine input and high precipitation (all other regions, Fig. 1). Climate is bimodal with a rainy season and a dry season that take place in different months according to the location along the coast but with a tendency of dry months from December to April and rainy months the rest of the year.

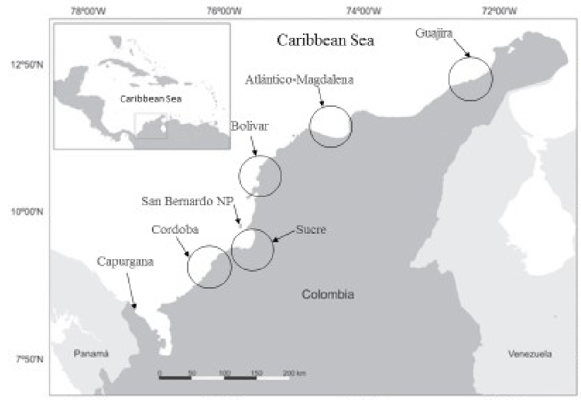

Figure 1. Study area signalling the regions where lane snapper (*Lutjanus synagris*) maturity data were collected along the Caribbean coast of Colombia.

Data bases. Data correspond to the classification of measured individuals (total length, from hereon, TL;

all mentions of length in the paper refer to TL, under otherwise stated) caught by the artisanal fishery (mostly gillnets, hook and lines and longlines) into macroscopic defined maturation stages. The database assembled by AUNAP is divided into several areas: Guajira, Magdalena-Atlántico (merged here), Bolivar, Sucre and Cordoba that correspond to the political divisions (departments) in Colombia (Fig. 1).

This division was maintained, except for Magdalena-Atlántico, as they reflect different seascapes. Additionally two independent databases were included, one for Guajira originated in the work of the NGO ECOSFERA for comparative purposes, and another for the Parque Nacional Natural Corales del Rosario y San Bernardo (National Natural Park Corales del Rosario and San Bernardo, from hereon, San Bernardo NP; Jaimes 2011). Overall, the data covers the period 2008 to 2014 in monthly steeps.

Data processing

Data from the NGO ECOSFERA came divided into six progressive maturation stages (I, II, IIR, III, IV, V and VI), whereas data from AUNAP came divided into four maturation stages (Agudelo *et al.* 2011): I (virgin or immature), II (maturating), III (mature) and IV (spawned), thus the ECOSFERA data were constrained to fit the maturation stages in AUNAP data base by relabelling individuals in stages IIR, IV, V (just one individual) and VI as in stage IV. Data from San Bernardo NP came divided into five maturation stages (I, II, III, IV and V; Jaimes, 2001) but with just one individual in stage V that was counted then as in stage IV.

Individuals labelled as "indeterminate" in AUNAP database were excluded from analysis as they represented fishes whose maturation stage was not evaluated. For individuals with total weight but not total length this was estimated by means of the following equation: $TL = (W/0.037)^{(1/2.677)}$, where TL stands for total length and W stands for weight, obtained by fitting existing length-weight data to a linear model to estimate the parameters and then solving for TL (n=4780 data pairs).

Length data and their corresponding maturation stage were organized in 2 cm length classes. Sexually mature individuals, i.e., individuals that potentially have reproduced at least one time, were taken as those in mature stages III and IV. Regional values of Lm were estimated by means of a linearized logistic curve fitted to the proportion of sexually mature individuals by length class (the mean of the length class; length classes with less than 10 individuals were not considered) adjusted by the maximum proportion of mature fishes in the sample so that that length class represented 100% mature individuals (King 2007). In order to generate confidence intervals and statistically compare the regional Lm an ad hoc procedure was use as follows: The x-y pairs of the original regression were resampled with replacement 1000 times, each time outputting an intercept and slope. For each round, an Lm was calculated as the ratio between intercept and slope with sign changed of the linear regression (King 2007). The mean value of the 1000 resamples is taken as the most representative Lm for the samples. Bias corrected and accelerated 95% confidence intervals were fitted to the mean Lm of the 1000 resamples.

A statistical comparison was conducted between the Lm estimated as above for each pair of regions. The resamples were shuffled together 1000 times and the difference in resampled means recorded and compared with the observed difference in means. The percentage of times the resampled differences were larger or equal than the observed difference was taken as the p value with significant difference at $P < 0.05$. The above calculations were conducted with a demo version of the Excel add-in application Resampling Stats, to be found at http://www.resample.com/download-excel/.

The hypothesis that the length distribution and mean length between all possible pairs of regions was the same was tested by means of a Kolmogorov-Smirnov test and a t-test, respectively, both based on permutations (10000 permutations) as implemented in the program PAST (Hammer *et al.* 2001).

Results

Table I shows previous Lm estimates for *L. synagris* in the Colombian Caribbean. The southern Colombian Caribbean has not receive much attention in this respect (compare Table I with Fig. 1) and estimates are heterogeneous. Table II shows a basic description of the database. Data are rather heterogeneous in numbers and mean sizes. Mean length of landed fishes between regions was significantly different ($P < 0.05$) in all pairwise comparisons excepting the comparison San Bernardo NP vs. Cordoba AUNAP ($P > 0.05$). Length distribution is statistically different between regions (Kolmogorov-Smirnov test, $P < 0.05$) with the exception again of San Bernardo NP vs. Cordoba AUNAP (Kolmogorov-Smirnov test, $P = 0.05$).

Table I. Previous estimates of length at first maturity (Lm) of *Lutjanus synagris* for the Colombian Caribbean. TL is total length.

Source	Spatial coverage	Time coverage	Data type	Stages	Lm (TL, cm, both sexes)
Posada-Peláez *et al.* (2012)	Magdalena	2008-2010	Artisanal fishery	5, mature: IIR, III to V	28,0[1]
Posada-Peláez *et al.* (2012)	Magdalena	2008-2010	Artisanal fishery	5, mature: IIR ,III to V	31,6
Arteaga *et al.* (2004)	La Guajira	2000-2001	Artisanal Fishery	6, mature: IIR, III to V	30,1
Arteaga *et al.* (2004)	Tayrona Park (Magdalena)	2000-2001	Artisanal fishery	6, mature: IIR, III to V	34,0
Rodriguez *et al.* (1999)	Colombian Caribbean	1995-1996	Demersal survey	5, mature: III to V	26,9
Barreto and Borda (2008)	Colombian Caribbean	2006-2007	Artisanal fishery	4, mature: II to IV	29,3
Rodriguez and Páramo (2012)	La Guajira	2006	Demersal survey	5, mature: III to V	21,4[1,]**
Altamar *et al.* (2015)	La Guajira	2007-2014	Artisanal fishery	Not stated	25,1[2]

[1]Estimated via maximum likelihood. [2]Estimated via generalized linear models, otherwise estimations based on linearized version of logistic model. **For females only.

Table II. Basic description of the data bases used in investigating spatial patterns of length at first maturation (Lm) of the lane snapper (*Lutjanus synagris*) in the Caribbean coast of Colombia. Length of fish is total length (TL). Confidence intervals (CI) are bias corrected and accelerated 95 % confidence intervals.

Region	N	MinTL (cm)	MaxTL (cm)	MeanTL (cm)	CIinf (cm)	CIsup (cm)
Guajira ECOSFERA[1]	697	14,4	56,0	28,8	28,4	29,2
Guajira AUNAP	1035	19.3	44.6	28.0	27.7	28.2
Magdalena-Atlántico AUNAP	619	18.6	54.0	30.5	30.1	30.9
Bolivar AUNAP	259	17.0	41.0	26.2	25.6	26.8
San Bernardo NP[2]	826	12,2	36,2	21,5	21,2	21,8
Sucre AUNAP	1588	11.6	44.5	19.4	19.2	19.6
Cordoba AUNAP	98	13.0	35.2	22.0	21.0	23.0

[1]Temporal coverage goes from 2010 to 2011. [2]Temporal coverage goes from 2008 to 2009. For all other regions, (AUNAP) temporal coverage goes from 2012 to 2014.

Table III shows the estimated Lm for each region. Values are heterogeneous. AUNAP data suggest a parabolic change of Lm as one moves to the south with maxima in Bolivar (Table III; Fig. 1). ECOSFERA and AUNAP data yield fairly different Lm estimates for Guajira (Table III) that turned out to be significantly different ($P<0.05$). Lm for Guajira ECOSFERA, Magdalena-Atlántico AUNAP and Bolivar AUNAP were not different statistically among each other ($P > 0.05$) as well as Bolivar AUNAP and San Bernardo NP ($P > 0.05$), whereas all other Lm comparisons were significant ($P < 0.05$) which suggest a decreasing gradient in Lm to the south.

The mechanistic explanation of the different Lm among regions is shown in Fig. 2. For a given maturation stage its mean length is quite different among regions. Thus, for instance, a fish of size 20 cm in Cordoba AUNAP, where it is included as in stage IV, would probably be regarded as in stage I in the other regions, except Sucre AUNAP (Fig. 2).

Discussion

The lane snapper appears to reach maturity (Lm) at different mean sizes along the Caribbean coast of Colombia. Spatial variation in Lm are not rare in particular for well distributed species like *L. synagris*, e.g., Stahl & Kruse (2008), Head *et al.* (2014). However, the data in this study are fishery dependent and thus, how accurately they represent what is actually happening in the water is an open question.

Possible explanations of the patterns seen here include (1) different gears and gear selectivity among regions such that the proportion on mature fish per size class is perceived as different,

Table III. Estimation of length at first maturity (Lm) of the lane snapper (*Lutjanus synagris*) per region in the Caribbean coast of Colombia. Lm is the mean Lm value of 1000 resampling rounds of the linearized logistic curve fitted to the data (see Materials and Methods) and refers to total length. Confidence intervals (CI) are bias corrected and accelerated 95 % confidence intervals.

Region	Lm (cm)	CIinf (cm)	CIsup (cm)
Guajira ECOSFERA	27.4	27.2	27.6
Guajira AUNAP	22.3	22.2	22.4
Magdalena-Atlántico AUNAP	27.6	27.0	28.0
Bolivar AUNAP	28.9	23.8	31.4
San Bernardo NP	25.9	25.8	26.0
Sucre AUNAP	16.9	16.8	17.0
Cordoba AUNAP	17.3	17.2	17.4

(2) actual existence of different stocks each with its own peculiar demography, (3) marked inconsistency in the observers (different teams for each region) when classifying individual fish into stages of the reproductive cycle, (4) bias due to different sampling sizes.

Incidence of fishing gears used in the regions is shown in Table IV. In all regions the bulk of gears are hooks (hook and line and longlines) and, secondarily, gillnets, except in Guajira, thus, differences in gear type can be counted out. On the other hand, each region is idiosyncratic in terms of the size, i.e., selectivity, of gears used (see Table V) and hence, the differences in landed fish size structure (Kolmorov-Smirnov test), mean TL and mean Lm among regions (pairwise tests) most likely respond to such features.

Support for this assertion comes from the finding that regional mean Lm positively responds to regional mean TL (Fig. 3), and regional mean TL, in turn, responds to regional hook size (negatively as scale is inverse, mean size category as defined by the manufacturer) and gillnet mesh size (positively, Figs. 4 and 5, respectively). In summary, regions such as Sucre AUNAP and Cordoba AUNAP with the lowest Lm (Table III) and low to no incidence of gillnets (Table V) concomitantly show the smallest hooks (Table V), which suggests that the fishery has been adapting to progressively smaller fish as decimation of bigger fish took place. The effect of fishing in the demography of exploited fish species is well known. In terms of reproduction, fish maturate early, i.e., at a smaller size and younger age because gear selectivity and heavy fishing mortality favours early manifesting traits (Sharpe & Hendry 2009, Enger *et al.* 2012, Audzijonyte *et al.* 2013).

Hooks and gillnets produce bell-shaped selectivity curves that provide refuge for fishes above and below the catchable size range. This feature has been postulated as a partial protection against the so-called fisheries-induced evolution (Hutchings 2009, Jorgensen *et al.* 2009). Nevertheless, Jorgensen *et al.* (2009) do recognize that once fishing mortality reach a certain point maturity age drops.

By far predominant gears in the artisanal fishery in Colombian Caribbean are hooks and gillnets. The observed spatial pattern of Lm would then suggest that southern stocks (San Bernardo, Sucre, Cordoba) are in very bad condition compared to the northern stocks and that fishery selection has probably gone so far as to change their genetic make-up.

The hypothesis that the observed spatial pattern in Lm originates in the existence of different stocks with differential demography, cannot be totally dismissed, however. To our knowledge two studies exist on stock differentiation of *L. synagris* in the Colombian Caribbean. One, based on morphometric and meristic data (Gómez-Canchong *et al.* 2004) and the other based on microsatellite-type molecular markers (Landinez-García *et al.* 2009). These studies identified three distinct stocks: Guajira-Rosario Archipelago (that includes San Bernardo NP), Santa Marta (intermediary between Guajira and Magdalena-Atlántico regions) and Capurgana (outside our study area, Fig. 1). Thus, there is some indication that detected differences in size structure in the fishery may have a correspondence in population genetics of *L. synagris* along the Caribbean coast of Colombia. The finding that mean TL and size structure of San Bernardo NP and Cordoba AUNAP are not statistically different, but that Lm is, further supports the reality of different stocks of *L. synagris* in the Caribbean coast of Colombia. Nevertheless, further detailed and extended studies are needed to settle this point.

Table IV. Incidence (percentage) of gear type used by the artisanal fishery in the Caribbean coast of Colombia in capturing lane snapper (*Lutjanus synagris*). Hooks include hook and line and longlines. Gillnets include fixed and drifting gillnets and beach seines. A marginal number of fish traps and cast nets are included in the database.

Region	Hooks	Gillnets	Skin diving	Traps	Cast nets
Guajira ECOSFERA	40.1	59.6	< 1	0	0
Guajira AUNAP	3.4	95.3	0	1.3	0
Magdalena-Atlántico AUNAP	81.8	16.6	0	1.6	0
Bolívar AUNAP	79.2	20.8	0	0	0
San Bernardo NP	98.3	1.7	0	0	0
Sucre AUNAP	99.8	0	0	0	< 1
Córdoba AUNAP	80.0	19.0	0	0	1

Table V. Size characterization of hooks and gillnets used by the artisanal fishery in the Caribbean coast of Colombia in capturing lane snapper (*Lutjanus synagris*). Hooks size according to size categories as given by the manufacturer, in inverse scale with respect to its actual size; gillnet size is mesh size in inches. NG= not given. NDB= not in database.

Region	Hooks	Gillnets (mesh size)
Guajira ECOSFERA	8.6	3.3
Guajira AUNAP	7.6	3.5
Magdalena-Atlántico AUNAP	9.5	2.3
Bolívar AUNAP	10.9	2.8
San Bernardo NP	NG	NG
Sucre AUNAP	11.4	NDB
Córdoba AUNAP	11.9	2.7

One feature that warrants explanation is the difference in Lm between Guajira ECOSFERA and Guajira AUNAP (Table III). Both region and time period of origin of the data are similar and so are their mean lengths (Table II), although statistically different (ICs in Table II). On the other hand, size structure is different (Kolmogorov-Smirnov test, P< 0.05) which would be the mechanistic explanation for the difference in Lm.

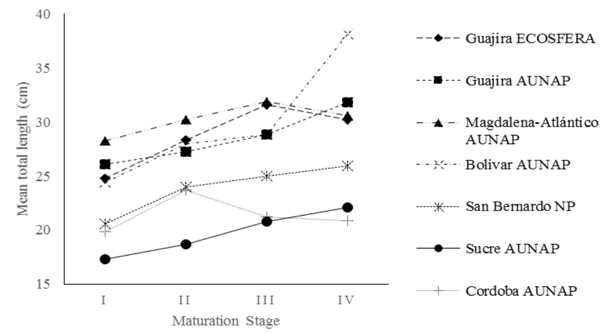

Figure 2. Mean size (total length) per maturity stage and region of the lane snapper (*Lutjanus synagris*) as landed by the artisanal fishery at the Caribbean coast of Colombia.

The incidence of gillnets with a smaller mesh size in Guajira AUNAP, which would be conductive to smaller fish landed and hence smaller Lm, is much higher compared to Guajira ECOSFERA (Tables IV and V). A t-test based in 10000 permutations (PAST, Hammer 2001) confirms that fishes of stages III and IV (as constrained here) in ECOSFERA data are significantly bigger than fishes in the same stages in AUNAP data (P < 0.05). The ECOSFERA data includes more landing places in the region and broader fishing deep (J. Ramirez unpublished data) than AUNAP data that rather concentrates in urban settlements. This would bring bigger fish to port, as it is common pattern that bigger (probably) mature fish predominates in deeper waters.

In summary, the emerging scenario appears to be one in which heavy fishing conductive to progressively smaller landed fish as attested by fishermen (García 2010), occurs in (and interacts with) a background of differentiable stocks of *L. synagris* as the most plausible explanation for the correlation between varying regional Lm and selection characteristics of regional fishing gears.

In which extend sample size and evaluation teams differences influence the results is an open question. The number of fishes looked at in the regions goes to the hundredths and even to the thousands, thus sample size does not appear to be a problem. Estimation of bias caused by different teams of evaluators would require a process of field validation that has not taken place. However, in view of the constrains imposed by the size range of the landed fishes and the selectivity characteristics of the fishing gears, it appears unlikely that the observed spatial pattern in Lm be just the result of

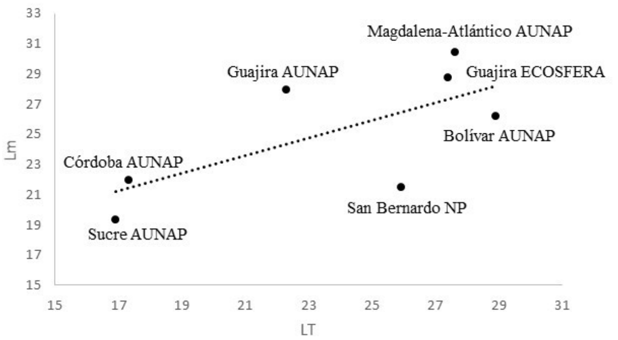

Figure 3. Relation between length at first maturity (Lm) and mean total length (TL) in the lane snapper (*Lutjanus synagris*) fishery across regions in the Caribbean coast of Colombia.

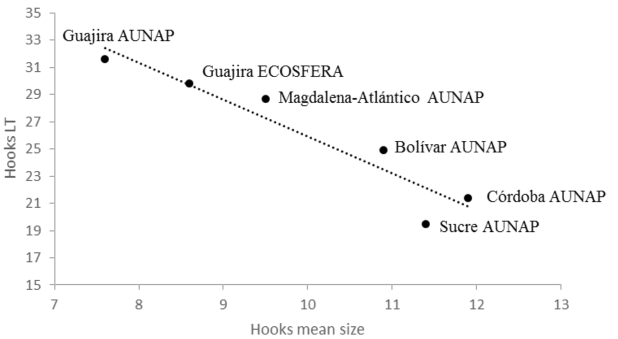

Figure 4. Relation between mean total length (TL) for hooks and hook mean size (inverse scale, mean size category as defined by the manufacturer) in the lane snapper (*Lutjanus synagris*) fishery across regions in the Caribbean coast of Colombia. Note that San Bernardo NP database does not report on hook size.

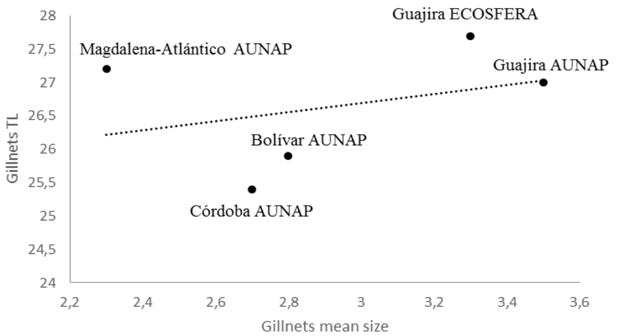

Figure 5. Relation between mean total length (TL in cm) for gillnets and gillnet mean mesh size in lane snapper (*Lutjanus synagris*) fishery across regions in the Caribbean coast of Colombia. Note that San Bernardo NP database does not report on gillnet size. In Sucre AUNAP no fishing is done with gillnets at least according to the AUNAP database.

differences between evaluators.

The estimation of Lm is quite sensible to the procedures in calculating it, even the decision of employing the lower, upper or mean size class point when fitting size at maturity data to a linearized logistic regression alters the result. Table I testifies of the variety of previous Lm estimates for *L. synagris* in the Colombian Caribbean, that are, however difficult to compare with the results here or among them as technical but crucial details are lacking, not to mention that the number of maturity stages, the stages considered mature and the estimation method differ among studies (Table I).

Lessons to be learned from this exercise concerning the management of this important species for the artisanal fishery in Colombian Caribbean include: (1) it is wrong to postulate an all valid single Lm for *L. synagris* covering the Colombian Caribbean by pooling maturity data from such different places, as the practice has been so far, e.g., Barreto and Borda (2008), AUNAP-UNIMAGDALENA (2013); (2) the target of 100% mature fish in the catch should probably be abandoned as it would exacerbate the truncation of natural size distribution structure and hence increase the risk of fishing induced evolution that might be irreversible (Stenseth & Rouyer 2008, Marty *et al.* 2015); (3) in future campaigns of gathering biological data more attention should be paid to the design of field work so as to achieve standardization of sampling effort and coverage, in particular, the depth range affected by the fishery should be properly covered; (4) intercalibration exercises among evaluation groups should be conducted before field work and (5) an analysis protocol for fish maturity data should be agreed upon by researches as to allow comparison of studies.

In view of the new proposed paradigm shift regarding selectivity in fisheries that postulates that in the context of ecosystem-based fisheries management (EBFM) a more appropriate approach would be to strive towards balanced harvesting meaning distributing fishing mortality across trophic levels such that ecosystem properties like size-spectrum slopes and biodiversity be conserved, i.e., away from excessive selectivity (Zhou *et al.* 2010, Rochet *et al.* 2011, Garcia *et al.* 2012), a profound reflexion and reconsideration of objectives (and associated research needs) regarding the management of Colombian Caribbean artisanal fisheries is necessary, if our seas are to continue providing food security and employment.

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References

Agudelo, E., Ajiaco, R. E., Alvarez, L. E., Barreto, C. G., Borda, C. A., Bustamante, C. C., Caldas, J. P., De la Hoz, J., Diazgranados, M. C., Melo, Giovanni., Perucho, E., Puentes, V., Ramirez, A., Ramírez, A., Rueda, M., Salinas, J. C. & Zapata, L. A. 2011. **Protocolo de captura de información pesquera, biológica y socio-económica en Colombia**. Ministerio de Agricultura y Desarrollo Rural - Dirección de Pesca y Acuicultura- Subgerencia de Pesca y Acuicultura INCODER - Conservación Internacional. Colombia. 80 p.

Altamar, J., Manjarrés-Martínez, L., Duarte, L. O., Cuello, F. & Escobar-Toledo, F. 2015. **Qué tamaños deberíamos pescar?.** Autoridad Nacional de Acuacultura y Pesca (AUNAP), Universidad del Magdalena, Santa Marta, Colombia. 54 p.

Andrade, C. A. & Barton, E. D. 2005. The Guajira upwelling system. **Continental Shelf Research**, 25(9): 1003-1022.

Arteaga, E., Criales-Hernández, M. I., Rodriguez, D. J., Gómez-Canchong, P. & Manjarrés, L. 2004. Dinámica reproductiva de los stocks del pargo rayado *Lutjanus synagris* (Linnaeus, 1758) en el área norte del Caribe colombiano. Pp. 203-215. *In*: L. Manjarrés (Ed.). **Pesquerías demersales del área norte del mar Caribe de Colombia y parámetros biológico-pesqueros y poblacionales del recurso pargo.** Universidad del Magdalena, Santa Marta, Colombia, 317 p.

Audzijonyte, A., Kuparinen, A., Gorton, R. & Fulton, E. A. 2013. Ecological consequences of body size decline in harvested fish species: positive feedback loops in trophic interactions amplify human impact. **Biology Letters**, 9, 20121103. doi: 10.1098/rsbl.2012.1103

AUNAP-UNIMAGDALENA. 2013. **Tallas mínimas de captura para el aprovechamiento sostenible de las principales especies de peces, crustáceos y moluscos comerciales de Colombia**. Autoridad Nacional de Acuicultura y Pesca y La Universidad del Magdalena. Colombia. 58 p.

Barreto, C. G. & Borda, C. A. 2008. **Propuesta técnica para la definición de cuotas globales de pesca para Colombia, vigencia 2009.** Instituto Colombiano Agropecuario, Ministerio de Agricultura y Desarrollo Rural, Bogotá, Colombia. 263 p.

Erhardt, H. 1977. Beiträge zur Biologie von *Lutjanus synagris* (Linnaeus, 1758) an der kolumbianishen Atlantikküste. **Zoologische Beiträge**, 23(2): 235-266.

Enger, K., Jørgensen, C., Dunlop, E. S., Varpe, O., Boukal, D. S., Baulier, L., Eliassen, S. & Heino, M. 2012. Fishing-induced evolution of growth: concepts, mechanisms and the empirical evidence. **Marine Ecology**, 33: 1-25.

Froese, R. 2004. Keep it simple: three indicators to deal with overfishing. **Fish and Fisheries**, 5: 86-91.

García, C.B., 2010. Conocimiento tradicional: lo que los pescadores artesanales del Caribe colombiano tienen para decirnos. **Panamerican Journal of Aquatic Sciences**, 5(1): 78-90.

García, C. B. & Armenteras, D. 2015. **Atlas de la ictiofauna demersal de fondos blandos del Caribe continental Colombiano: aproximación a su biodiversidad.** Universidad Nacional de Colombia, Bogotá, Colombia, 766 p.

Garcia, S. M., Kolding, J, Rice, J, Rochet, M. J., Zhou, S., Arimoto, T., Beyer, J. E., Borges, L., Bundy, A., Dunn, D., Fulton, E. A., Hall, M., Heino, M., Law, Makino, M., Rijnsdorp, A. D., Simard., F. & Smith, A. D. 2012. Reconsidering the consequences of selective fisheries. **Science**, 335: 1045-1047.

Gómez-Canchog, P., Rodriguez, D., Arévalo, J. C. & Manjarrés, L. 2004. Identificación de stocks de pargo rayado *Lutjanus synagris* (Linnaeus, 1758) en el área norte del Caribe colombiano. Pp. 155-179. *In*: L. Manjarrés (Ed.). **Pesquerías demersales del área norte del mar Caribe de Colombia y parámetros biológico-pesqueros y poblacionales del**

recurso pargo. Universidad del Magdalena, Santa Marta, Colombia, 317 p.

Hammer, Ø., Harper, D. A. T. & Ryan P. D. 2001. PAST: Paleontological Statistics Software Package for Education and Data Analysis. **Palaeontologia Electronica**, 4(1): 1-9.

Head, M. A., Keller, A. A. & Bradburn, M. 2014. Maturity and growth of sablefish, *Anoplopoma fimbria*, along the U.S.West Coast. **Fisheries Research**, 159: 56-67.

Hutchings, J. A. 2009. Avoidance of fisheries-induced evolution: management implications for catch selectivity and limit reference points. **Evolutionary Applications**, 2(3): 324-334.

Jaimes, L. 2011. Algunos Aspectos Biológico-Pesqueros de las Principales Especies Ícticas Capturadas en el Sector de San Bernardo, Parque Nacional Natural Corales del Rosario y de San Bernardo, Caribe Colombiano. **Tesis de Grado**, Universidad de Bogotá Jorge Tadeo Lozano, Santa Marta, 78 p.

Jørgensen, C., Ernande, B. & Fiksen, Ø. 2009. Size-selective fishing gear and life history evolution in the Northeast Arctic cod. **Evolutionary Applications**, 2(3): 356-370.

King, M. 2007. **Fisheries biology, assessment and management**. Second Edition: Blackwell Publishing. 382 p.

Landínez-García, R. M., Ospina-Guerrero, S. P., Rodríguez-Castro, D. J., Arango, R. & Márquez, E. 2009. Análisis genético de *Lutjanus synagris* en poblaciones del Caribe Colombiano. **Ciencias Marinas** 35(4): 321-331.

Ministerio de Agricultura y Desarrollo Rural-Instituto Interamericano de Cooperación para la Agricultura (MADR-IICA). 2011. **Agenda nacional de investigación en pesca y acuacultura.** Ministerio de Agricultura y Desarrollo Rural, Bogotá, D.C, Colombia. 154 p.

Marty, L., Dieckmann, U. & Ernande, B. 2015. Fisheries-induced neutral and adaptive evolution in exploited fish populations and consequences for their adaptive potential. **Evolutionary Applications**, 8: 47-63.

Posada-Peláez, C., Santafé-Muñoz, A., Grijalba-Bendeck, M., Bustos-Montes, D., Gonzalez-Sarmiento, E., De la Hoz-Maestre, J., Castro-Martinez, L., Gómez-Cubillos, C., Guerrero-Bernal, P., Olaya-Reyes, C., Palacio-Barros, C.M. & Restrepo-Gómez, D. 2012. Aspectos biológicos de las principales especies comerciales de la zona costera del departamento del Magdalena, Caribe colombiano. Pp 115-415. *In*: Grijalba-Bendeck, M., Bustos-Montes, D., Posada-Peáez, C. & Santafé-Muñoz, A. (Eds.). **La pesca artesanal marítima del departamento del Magdalena (Colombia). Una visión desde cuatro componentes.** Fundación Universidad de Bogotá Jorge Tadeo Lozano, Ministerio de Agricultura y Desarrollo Rural, Bogotá, Colombia. 454 p.

Rochet, M. J., Collie J. S., Jennings, S. & Hall, S. J. 2011. Does selective fishing conserve community biodiversity? Predictions from a length-based multispecies model. **Canadian Journal of Fisheries and Aquatic Sciences**, 68(3): 469-486.

Rodríguez, J. Arévalo, J.C. & Manjarrés, L. 1999. Aspectos biológico-pesqueros de los pargos rayado (*Lutjanus synagris*) y cebal (*L. analis*). **Boletin Cientifico INPA** 6: 53-75.

Rodríguez, A. & Páramo, J. 2012. Distribución espacial del pargo rayado *Lutjanus synagris* (Pisces: Lutjanidae) y su relación con las variables ambientales en el Caribe colombiano. **Actualidades Biológicas** 34(96): 55-66.

Saavedra-Díaz, L., Rosenberg, A. A. & Martin-Lopez, B. 2015. Social perceptions of Colombian small-scale marine fisheries conflicts: Insights for management. **Marine Policy**, 56: 61-70.

Sharpe, D. M. & Hendry, A. P. 2009. Life history change in commercially exploited fish stocks: an analysis of trends across studies. **Evolutionary Applications**, 2(3): 260-275.

Stahl, J. P. & Kruse, G. H. 2008. Spatial and Temporal Variability in Size at Maturity of Walleye Pollock in the Eastern Bering Sea. **Transaction of the American Fisheries Society**, 137: 1543-1557.

Stenseth, N. C. & Rouyer, T. 2008. Destabilized fish stocks. **Nature**, 452(7189): 825-826.

Tsikliras, A. C., Stergiou, K. I. & Froese, R. 2013. Editorial note on reproductive biology of fishes. **Acta Ichthyologica Et Piscatoria**, 43(1): 1-5.

Zhou, S., Smith, A. D., Punt, A. E., Richardson, A. J., Gibbs, M., Fulton, E. A., Pascoe, S., Bulman, C., Bayliss, P. & Sainsbury, K. 2010. Ecosystem-based fisheries management requires a change to the selective fishing philosophy. **Proceedings of the National Academy of Sciences of the United States of America,** 107(21): 9485-9489.

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