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Research Article

Tracking the southern Brazilian schools of *Mugil liza* during reproductive migration using VMS of purse seiners

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ABSTRACT. Brazilian mullet *Mugil liza* is a schooling fish that migrates in fall and winter, leaving estuaries and coastal lagoons to spawn in ocean waters. In order to understand the reproductive migration pattern of southern stock along Brazil's coast, we analyzed data collected through the Brazilian Satellite Vessel Tracking Program (Programa Nacional de Rastreamento das Embarcações Pesqueiras por Satélite-PREPS) from 2008 to 2012. The migration period overlaps with the fishing season (May-July) when the licensed purse seine fleet fishes along the southern and southeastern coast of Brazil, motivated to capture mullet by the high value of the roe. During the five fishing seasons the average effort was of 51 active vessels. The average time per season that each vessel navigated in the Speed Compatible with Fishing Operation (SCFO) was 349.3 h, which represented an average of 17% of the total time at sea. From May to July the highest frequency (54%) of SCFO transmissions occurred in June ($P < 0.05$), and in 95% of the SCFO transmissions the vessels were at depths less than 50 m. The temporal and spatial displacement of the fleet in a south-north direction follows the progression of sea surface temperature SST of 19-21°C ($P < 0.05$). Most (60%) SCFO signals occurred in areas with this range of temperature, independent of the month and latitude. The south-north displacement of the fleets through the season was similar among the different years ($P > 0.05$).

Keywords: mullets, PREPS, Vessel Monitoring System (VMS), spawning temperature, southern Brazil.

Seguimiento de cardúmenes de *Mugil liza* en el sur de Brasil durante la migración reproductiva usando VMS de buques cerqueros

RESUMEN. La lisa *Mugil liza*, es una especie que forma cardúmenes, migra en otoño e invierno, saliendo de los estuarios y lagunas costeras para desovar en el océano. Para comprender la migración reproductiva del stock del Sur a lo largo de la costa de Brasil, se analizó los datos obtenidos en el Programa Nacional de Seguimiento de Embarcaciones Pesqueras por Satélite de Brasil (PREPS en portugués). El período de la migración coincide con la temporada de pesca (mayo-julio), cuando los buques cerqueros autorizados pescan a lo largo de la costa sur y sudeste de Brasil, que buscan capturar las hembras de lisas por el alto valor de sus huevos. Durante las cinco temporadas de pesca (2008-2012), el esfuerzo promedio fue de 51 embarcaciones en operación. El tiempo promedio por temporada que cada embarcación navegó de acuerdo con la Velocidad Compatible con la Operación Pesquera (VCOP) fue 349,3 h, con un promedio de 17% del tiempo total en el mar. De mayo a julio la mayor frecuencia (54%) de las transmisiones VCOP ocurrió en junio ($P < 0,05$), y en el 95% de las transmisiones las embarcaciones operaron a profundidades menores de 50 m. El desplazamiento temporal y espacial de la flota cerquera en dirección sur-norte sigue la progresión de la temperatura superficial del mar en el intervalo de 19-21°C ($P < 0,05$). La mayoría de las señales (60%) VCOP ocurrieron en áreas con este rango de temperatura, independiente del mes y la latitud. El desplazamiento sur-norte de la flota durante la temporada fue similar entre los diferentes años analizados ($P > 0,05$).

Palabras clave: lisa, PREPS, flota cerquera, Sistema de Monitoreo de Embarcaciones (VMS), temperatura de desove, sur de Brasil.

INTRODUCTION

The mullet *Mugil liza* is a marine species distributed in the Atlantic along the coast of South America, from the Caribbean Sea to Argentina (Menezes *et al.*, 2010). A population of this species identified as the “southern population” (Mai *et al.*, 2014) is distributed from the coast of the State of São Paulo (23°S) to Argentina (38°S) and more than 95% of the catches occurs between the States of Rio Grande do Sul and Santa Catarina (24-34°S) (Vieira & Scalabrin, 1991; IBAMA/ICMBio/CEPSUL, 2007). *M. liza* has historical and cultural importance to the southern region and part of the southeastern region of Brazil (Miranda *et al.*, 2006). Its harvest has a high economic value for the industrial purse seine fleet in recent years (IBAMA/ICMBio/CEPSUL, 2007).

Mullet use coastal lagoons and estuaries as nursery zones (Vieira & Scalabrin, 1991; Lemos *et al.*, 2014). In southern Brazil (24-34°S), catches of *M. liza* follow the gradual and seasonal shifting of the coastal waters with surface temperatures between 19 and 21°C along the Argentinean, Uruguayan, and southern Brazilian coasts (Vieira & Scalabrin, 1991; Lemos *et al.*, 2014). *M. liza* is a single spawner and in order to complete ovaries maturation (hydration) has to reach saltwater (Lemos *et al.*, 2014). A drop in the water temperature of the Patos Lagoon Estuary after May associated with southwest winds forcing saltwater to enter into the estuary, act as a trigger for large shoals of *M. liza* to leave the estuary and migrate northward and spawn in ocean waters (Vieira & Scalabrin, 1991; Lemos *et al.*, 2014).

Evidences from artisanal and purse seine fisheries, sea surface temperature (SST) analysis and the following of gonad development reveal that peak spawning occurs in June (Vieira & Scalabrin, 1991; Lemos *et al.*, 2014). The exact location of *M. liza* spawning remains uncertain, but seems to occur in one specific oceanographic situation that is reached in June/July between the north of Rio Grande do Sul State and Paraná State (Brazil) in waters temperature between 19 and 21°C (Vieira & Scalabrin, 1991; Herbst & Hanazaki, 2014; Lemos *et al.*, 2014).

The purse seine fleet was introduced in Brazil by Spanish immigrants in the early 20th Century, searching for the Brazilian sardine (*Sardinella brasiliensis*) along the coast of Rio de Janeiro (Diegues, 1983). Its operation remained essentially the same until the 1970s, when technological innovations allowed the use of auxiliary equipment, such as echo sounders, sonar, and power block, which increased its fishing power (Schwingel & Occhialini, 2003). Purse seiners capture more than 20 species but the Brazilian sardine is the

main target fish for this fleet (Cergole & Dias-Neto, 2011).

Until 2000 *M. liza* was considered an accessory resource occupying the 20th position in the list of species catch by purse seiners and represented less than 0.5% of the annual amount of fish landed by purse seiners off Santa Catarina waters (Schwingel & Occhialini, 2003). In Rio Grande do Sul, mullet represented less than 5% of the fish captured by purse seiners between 1990 and 1994 (Haimovici, 1997). As explained above, the collapse of the Brazilian sardine fishery-catches dropped from 117,000 to about 17,000 ton in 1996 (MMA/IBAMA/CEPSUL, 2000; Seckendorff & Azevedo, 2007; Cergole & Dias-Neto, 2011) drove the fleet to target the mullet during two to three months a year interest. The major economic importance of the resource was boosted by the economic potential of mature roe, considered analogous to caviar (IBAMA/ICMBio/CEPSUL 2007). The official (legal) fishing season extended from May 15th to the end of July, a period that coincides with the reproductive migration of the species along the coast of the southern and southeastern states of Brazil (Vieira & Scalabrin, 1991; Lemos *et al.*, 2014).

Initially, every purse seine vessel was authorized to catch Brazilian sardine was also allowed to capture mullet. However, considering the increased fishing effort and the inclusion *M. liza* in the list of Brazilian overexploited species (IN MMA N°5/2004) the federal government, through IN N°171/2008, allowed only 60 purse seine vessels to catch mullet. To receive authorization, each vessel had to demonstrate that it had captured mullet during a minimum period of three years between 2000 and 2007. For the 2009 season the IN IBAMA N°13/2009 annulled article 4 of the IN IBAMA N°171/2008 and determined that the vessels authorized to catch Brazilian sardine could also capture mullet if they had participated in mullet fishing activity in 2008. This rule allowed 115 purse seine vessels to be authorized during the 2009 season. In 2010, the IN N°7/2011, from MPA/MMA, the number of vessels was reduced to 82, but in 2011, another IN (MPA/MMA N°7/2011) determined that no more than 60 vessels should participate in mullet fisheries. The same number of vessels was maintained for the 2012 and 2013 seasons (INs MPA N°5/2004 and N°2/2013) but no consideration was given to the obvious fishing power increase. One of the criteria considered for the concession and renovation of the Complementary Fishing Authorizations for mullet in southern and southeastern Brazil for the 2013 season (IN MPA N°2/2013) was the vessel's historical record in relation to the vessel monitoring systems (VMS) (in portuguese: Programa Nacional de Rastreamento das Embarcações

Pesqueiras por Satélite - PREPS). For example, vessels that did not exceed the time limit for signal transmission and that showed the lowest percentage of transmissions in restricted fishing areas were not penalized.

In this paper we describe and track the southern Brazilian stock of *M. liza* reproductive migration using the PREPS information provided by the purse seine fleet, because the interest of the fleet is to capture individuals before spawning. We also analyzed the relationships between the fleet position and sea surface temperature (SST) in association with the reproductive migration patterns of the species.

MATERIALS AND METHODS

The area of study was delimited by the purse seine fleet activity between 23°-34°S and 53°-44°W covering from Chui, south of Rio Grande do Sul, to the northern coast of São Paulo. PREPS data provided by Ministério da Pesca e Aquicultura (MPA), refer to years of 2008 to 2012 from which the fishing seasons (May 15 to July 31) data were selected. The fishing season is defined between the legal opening of the fishing period up to the moment when no mullet landings at the Port of Itajaí Santa Catarina (SC) are registered (UNIVALI/CTTMar, 2011) in August.

The data consisted of georeferenced signals (Datum WGS84) emitted each hour for each purse seine vessel authorized to catch mullet. Vessels were not identified by name but signed a code that allowed a numerical identification. Each transmission included the position, date, time, average speed in knots, and distance traveled between consecutive transmissions in nautical miles.

In order to use only information related to fishing activities, data were filtered to select Speed Compatible with Fishing Operation (SCFO) that should be between zero and four knots (Bertrand *et al.*, 2005; SEAPPR/MMA/IBAMA/MB, 2006). Signals with transmission failures and signals emitted when the vessels were at port were also excluded from the analysis.

The monthly averages of the sea surface temperature (SST) were obtained from the database at <http://disc.sci.gsfc.nasa.gov/giovanni> (Acker & Lepoukh, 2007). Average monthly data from NASA's Moderate Resolution Imaging Spectroradiometer (MODIS) instrument were used-Aqua 9x9 km from May, June, and July, 2008 to 2012 in the study region (<http://disc.sci.gsfc.nasa.gov/giovanni>). After testing for different temperature intervals we choose a 3°C interval in order to better visualize the ideal thermal range of the fishing activities and to test the hypothesis suggested by Vieira & Scalabrin (1991) and Lemos *et*

al. (2014) that reproduction occurs in the temperature interval of 19-21°C.

The density distribution (number of signals of SCFO) was estimated using 0.125°x0.125° latitude and longitude quadrants. The spatial distribution of the operation signals were correlated with SST and tested using analysis of variance (ANOVA) to estimate the preferential thermal range of the occurrence of mullet during reproductive migration. We used Microsoft Excel, Bioestat 5.3 and ArcMap 10.0 to conduct the analysis.

RESULTS

During the five fishing seasons analyzed (2008 to 2012), 70 different purse seine vessels monitored by PREPS captured *M. liza* in the coastal region of Rio Grande do Sul to São Paulo. Of those vessels, 13% operated for three seasons, 27% operated for four, and 37% were active in all five seasons. About 23% of vessels participated in only one or two fishing seasons.

During the five fishing seasons, in total, 537,344 signals were included in the analysis, and the total fishing effort amounted approximately to 108,000 h, expended by an annual average of 51 active purse seine vessels. An average of 17,945 transmissions was SCFO in each fishing season. The years of 2011 and 2012 represented the smallest (15,631, $P < 0.05$) and the largest (19,488, $P < 0.05$) numbers of SCFO records, respectively. Each vessel transmitted an average of 349.3 SCFO signals per season, which represented an average of 17% of the total time at sea (Table 1).

There were no significant differences in the spatial patterns of the transmissions among the different years ($P > 0.05$). The highest frequency of SCFO transmissions occurred in June ($P < 0.05$), which included about 54% of the signals transmitted during the fishing season (Fig. 1). Fishing activity was most intense in May at Rio Grande do Sul, in June and July at Santa Catarina and Paraná coast, and in late June and early July at São Paulo coast.

In 95% of the SCFO transmissions, the purse seine vessels were at depths of less than 50 m. There was a northward and temporal progression of the density of the SCFO signals from the beginning of the fishing season, in the proximities of the mouth and at south of Patos Lagoon, to the São Paulo coast. This geographic progression was observed in all years, although some interannual temporal variability was observed (Fig. 2). In addition to the temporal and spatial progression, a large concentration of purse seine vessel was observed near the mouths of the three main lagoons of the region: Patos Lagoon (32°09'S, 52°02'W), Tramandaí (29°58'S, 50°06'W), and Laguna (28°28'S, 48°43'W).

Table 1. Summary of data obtained through the PREPS during five fishing seasons (2008-2012) of *Mugil liza* by purse seine fisheries in southern and southeastern Brazil. Speed Compatible with Fishing Operation (SCFO). * $P = 0.038$ ** $P = 0.012$.

Year	2008	2009	2010	2011	2012	Mean
Number of vessel	47	53	53	55	50	51
Number of signals	94032	103033	117986	115265	107028	107468
Number of signals SCFO	17605	18718	18287	15631*	19488**	18203
Signals SCFO/Vessel	374.5	353.1	345.0	284.2	389.8	349.3
Signals SCFO/Day	225.7	240.0	234.4	200.4	249.8	230.1
Signals SCFO/Vessel/Day	4.80	4.53	4.42	3.64	5.00	4.48
Frequency of SCFO	18.7%	18.2%	15.5%	13.6%	18.2%	16.8%
Days at sea/Vessel	83	81	93	87	89	87
Hours at sea/Vessel	2000.7	1944.0	2226.2	2095.7	2140.6	2081.4

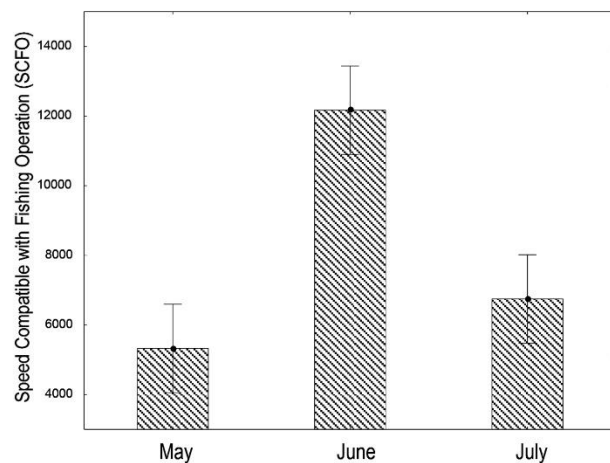


Figure 1. Frequency of monthly average of Speed Compatible with Fishing Operation (SCFO) signals of the purse seine fleet during the fishing seasons between 2008 and 2012.

According to the present data, the mullet catch occurs along the southern coast of Brazil in waters with SST between 15 and 25°C (Fig. 3). Most (60%) of the SCFO signals occurred in areas with a SST of 19-21°C ($P < 0.05$), independent of the month and latitude. The temporal and spatial displacement of the fleet in a south-north direction follows the progression of temperature along the coast.

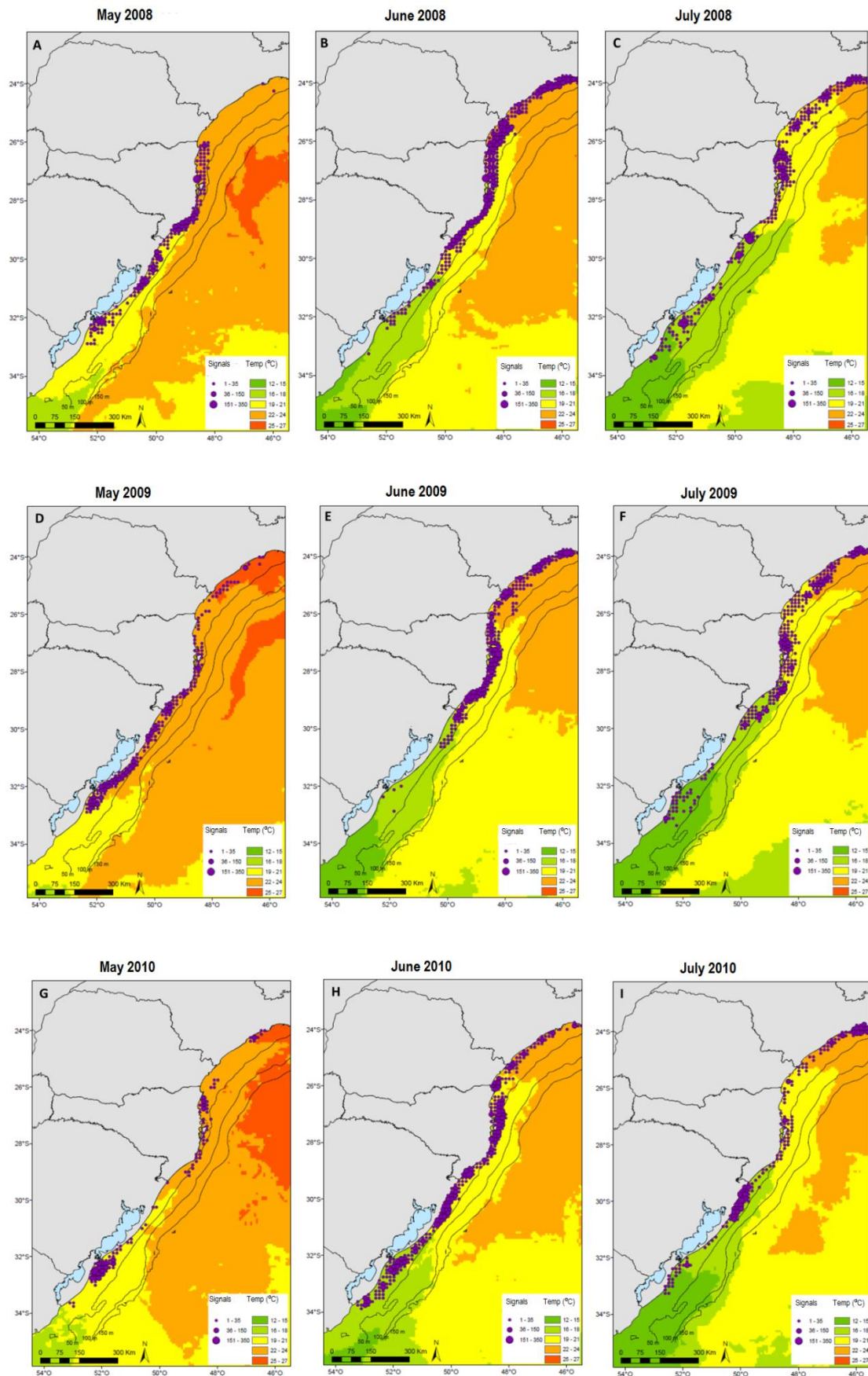
DISCUSSION

From 2008 to 2012, the number of fishing licenses to catch mullet varied widely, although the effective number of purse seine vessels in the period did not change (Table 1). The results suggest that for satellite-tracked vessels the fishing effort (number of vessels and hours at sea) remained constant along the years.

VMS revealed the sequential space and temporal exploration pattern of purse seine vessels fishing operation and thus trace the reproductive migratory behavior of the species. The fleet followed the movement of shoals because fishermen prefer to capture individuals before they spawn because of the high economic value of the roes. According to the technical report of IBAMA/ICMBio/CEPSUL (2007), in 2005, the market price of mullet roe reached thresholds of 40 US\$/kg. Currently, mullet is the third most captured resource by the purse seine fishery in Santa Catarina, a notable change from the late 1990s, when the species was considered an accessory capture (IBAMA/ICMBio/CEPSUL, 2007).

Mullet has been captured by this fleet for about 40 years, but, since 2000, catches increased due to the roe's exportation (IBAMA/ICMBio/CEPSUL, 2007). This trade is now the main motivation for catch mullet by purse seine fisheries, because the value of its roe far exceeds the value of the fish. In 2001, in an attempt to prevent excessive exploitation, the MPA and the MMA published together the INI N°7/2011, forbidding the landings of roe without the mullet carcass.

The migration of the mullet was described by (Vieira & Scalabrin, 1991; Herbst & Hanazaki, 2014; Lemos *et al.*, 2014). The trajectory followed by the purse seine fleet is a good indicator of the reproductive migration of the mullet population. More than 50% of the analyzed SCFO signals for the period originated in areas with a SST of 19-21°C, regardless of the month and latitude. Vieira & Scalabrin (1991) noted the importance of this temperature interval for artisanal fishing in their study area, and Lemos *et al.* (2014) determined that *M. liza* does not spawn in a geographically defined site in southern Brazilian waters but in a specific oceanographic conditions that includes these SST conditions. The PREPS data showed that the purse seine vessels catch the fish from south to the north



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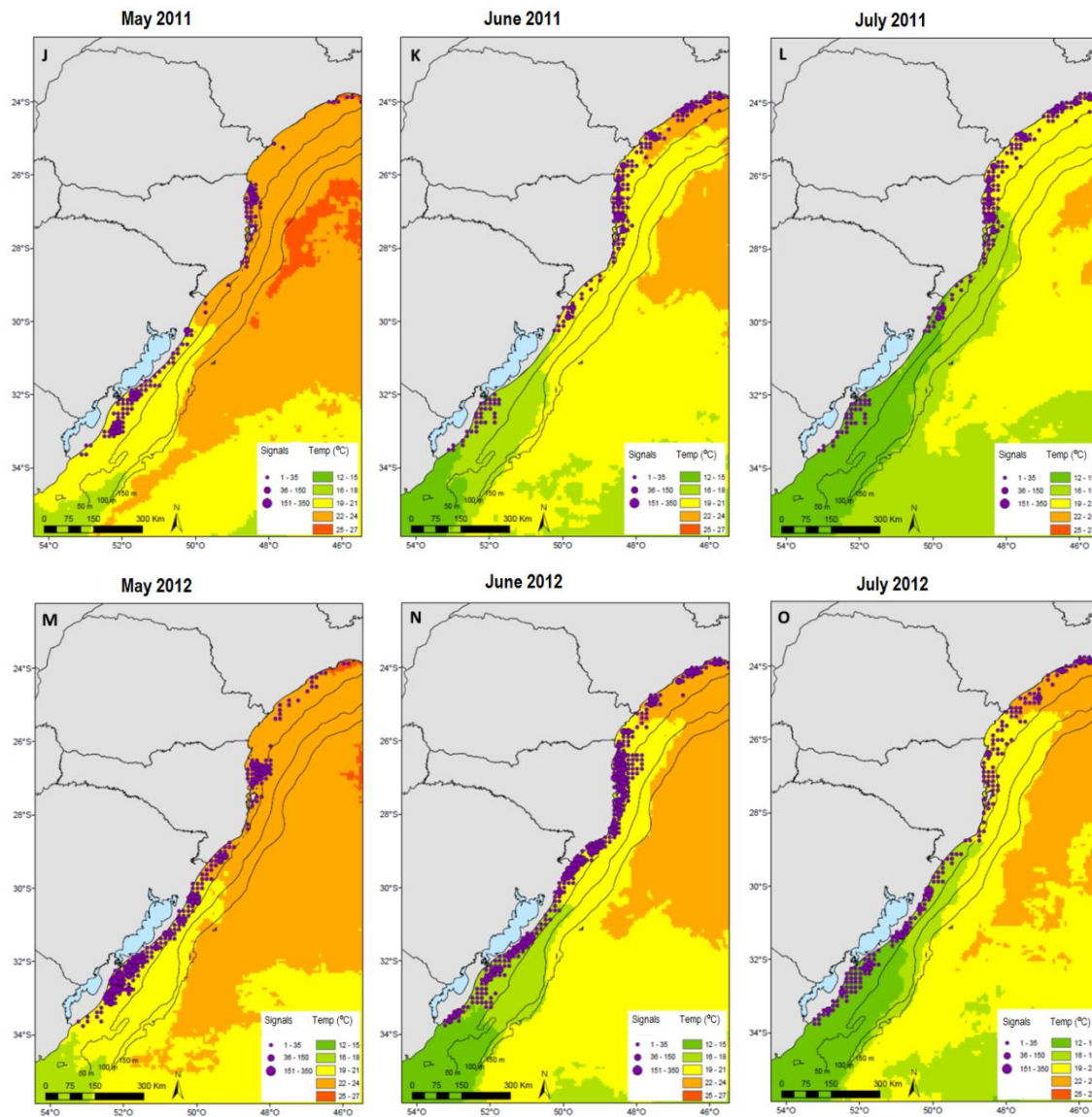


Figure 2. Maps of the density monthly distribution of Speed Compatible with Fishing Operation (SCFO) signals of the purse seine fleet during the study period (2008-2012).

following a SST range of 19-21°C along the coast of Rio Grande do Sul, Santa Catarina, Paraná, and São Paulo (Fig. 2).

In addition to the SST, wind influences the life cycle of mullet. Winds from the southeastern quadrant in May are very common in southern Brazil (Möller *et al.*, 2008). These winds, which mainly occur during the passage of cold fronts (Stech & Lorenzetti, 1992), induced seawater penetration in the Patos Lagoon Estuary (Castello & Möller, 1977). The drop in temperature and the increase in salinity inside the estuary are considered triggers for the beginning of the reproductive migration from this environment, because

they favor the formation of shoals (Vieira & Scalabrin, 1991).

In addition to triggering migration, wind influences the coastal migratory process, as it is directly involved in the dynamics of water masses on the shelf (Rossi-Wongtschowski & Madureira, 2006). The coastal water, which is derived from the mixture of the continental shelf water and freshwater from the continental drainage of the Prata River and Patos Lagoon (Braga & Niencheski, 2006), is affected seasonally by the surface winds (Castro *et al.*, 2006; Möller *et al.*, 2008). During the mullet migration period, this water mass moves toward lower latitudes,

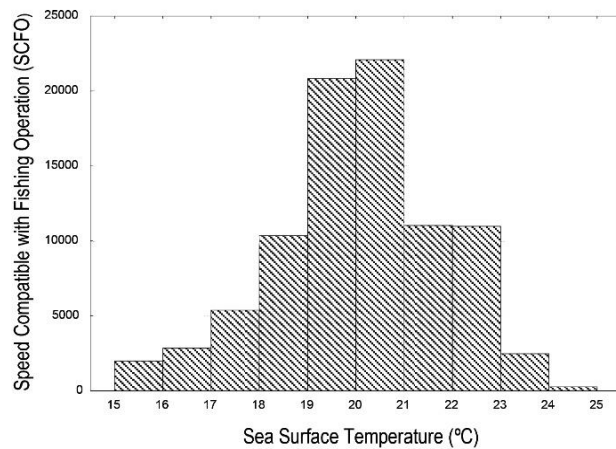


Figure 3. Distribution of frequencies of Speed Compatible with Fishing Operation (SCFO) signs of the purse seine fleet during the fishing seasons between 2008 and 2012 in Sea Surface Temperature.

due to the action of winds from the southern quadrant (Castello *et al.*, 1997; Piola & Romero, 2004). The intrusion of cold waters from the south (Castro *et al.*, 2006) and the progression toward the north of waters with temperature between 19 and 21°C, during the mullet migration, extend to the northern limit of the industrial fishing operations (Fig. 2). In this way, the coastal water dynamic determines the area on which the fleet acts in a scenario of ideal oceanographic conditions for migration, spawning, and, consequently, the fisheries.

Several pelagic species are commercially fished during reproductive aggregations (Fréon & Misund, 1999), which compromises the applicability and precision of stock assessment methods (Aglen, 1994). It is known that fishing during reproductive aggregations can generate the “Illusion of plenty” (hyper-stability) (Hilborn & Walters, 1992; Hanchet *et al.*, 2005; Erisman *et al.*, 2011). In these situations, the abundance index, like the capture per unit effort (CPUE) use to remain high given the illusion that stock is full, whereas the real fish abundance decreases (Hilborn & Walters, 1992). This phenomenon occurs due to the species’ capability to maintain an aggregated formation in shoals, leading to an overestimation of the biomass and underestimation of the fishing mortality (Crecco & Overholtz, 1990). It is important to consider that hyper-stability may be occurring when *M. liza* stock is assessed, and one example could be bring from Taiwan mullets fisheries with describe the failure of the fishing activities. Like the catches of mullet in the southern region of Brazil (Vieira *et al.*, 2008), the catch of mullet in Taiwan varied widely from one year to another, but after an increase in effort and consequent increase in the catches, likewise the mullets purse seine

fisheries in Brazil, the Taiwan resource drop substantial followed by a fishery collapse (Panfili *et al.*, 2006 in Whitfield *et al.*, 2012).

Since 2004, the mullet was integrated into the IN N°05 of 05/21/2004 from the MMA, which ranked her as overexploited. The actual management plan for *M. liza* (MPA/MMA, 2014) is not effective and resent of several basic information such as official landings, stock evaluation, etc. It is imperative to develop such a plan in order to maintain and safeguard the mullet resource for the future. However, so far no policies have been developed that will maintain the use of mullet resources at adequate levels to prevent the stock’s collapse.

Maps of fishery activity may be closely correlated with the distribution of a resource and the marine environment conditions (Williams *et al.*, 2010). As far we know the present paper is the first to use data from the VMS of the Brazilian purse seine fleet authorized to catch mullet. The new information generated by this analysis regarding the species’ migration patterns and the purse seine fishery fleet activities in southern and southeastern Brazil can improve our understanding of the use of this valuable Brazilian fishery resource, suggesting possible management measures and appropriate zones and time that should be closed to fishing. In addition of the use of VMS for the Brazilian purse seine fleet, other measures should be implemented as possible forms of monitoring the mullet fishing in the southeast-south of Brazil, as board observers programs and effective commercial (artisanal and industrial) official landings reports programs.

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