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Modelling Habitat Suitability Index for Chilean Jack mackerel

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Modeling Habitat Suitability Index for Chilean Jack Mackerel in the Southeastern Pacific Based on Fishery and Remote Sensing Data

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Introduction

- Fish habitat is a key ingredient for the ecosystem-based fishery management and sustainable exploitation of fishery resources (Minns, 1997)
- Habitat suitability index (HSI) models describe the relationships between fish abundance and the environmental conditions, and then estimate the level of HS (USFWS, 1981; Tian et al, 2009).
- HSI maps based on GIS can help managers and scientists better understand fish–habitat relationships (Kumari et al, 2009; Druon, 2010)

- This study use the fishery data from Chinese trawling fleets and remote sensing data to develop habitat suitability index model for Chilean jack mackerel in the Southeastern Pacific:

Quantify the relationship between the spatial distribution of CJM and environmental variables;

Estimate the suitable habitat area for CJM;

Improve scientific knowledge, management and harvesting of the CJM resource.

Materials & Methods

- *Fishery and Satellite remote sensing data*

Catch and effort data of Chinese trawl fishery, 2001-2013;

Monthly SST (0.1° resolution), SSH (0.25° resolution) and Chl-*a* (0.05° resolution) 2001-2013, from OceanWatch LAS;

Matched all data with 0.1° resolution in R;

Study area: 25°S -47°S , 74°W - 120°W.

- *Suitability index and HSI modeling*

Fishery and remote-sensing data from 2001 to 2012 were applied for SI and HSI modeling.

Based on the frequency distribution of fishing effort on the environmental valuables, SI values calculated as:

$$SI_{ij}=Effort_{ij}/Max(Effort_{ij}) \qquad (1)$$

$Effort_{ij}$, cumulative efforts in the *ith* interval of the range of environmental valuable j;

$Max(Effort_{ij})$,the maximum $Effort_{ij}$;

SI values 0 and 1 , non-suitable and most suitable habitat conditions, respectively (USFWS, 1981).

Calculated SI values were used as observed values to fit SI models with the midpoints of each class interval of environmental variable. The relationships between SI and environmental variables were defended as follow:

$$SI_{SST} = Exp[a(SST - b)^2]$$

$$SI_{SSH} = Exp[a(SSH - b)^2]$$

$$SI_{Chl-a} = Exp[a(Chl\_a - b)^2]$$

assuming 0.8 is the threshold of the optimal SI value for CJM

- Two common used empirical HSI model, Arithmetic mean model (AMM; Hess and Bay, 2000) and geometric mean model (GMM; USFWS, 1981; Lauver et al., 2002; Chen et al., 2009), were applied to estimate HSI:

$$HSI_{AMM} = \frac{SI_{SST} + SI_{SSH} + SI_{Chl-a}}{3}$$

$$HSI_{GMM} = \sqrt[3]{SI_{SST} \times SI_{SSH} \times SI_{Chl-a}}$$

Seasonal mean HSI values were estimated based on the quarterly available SST, SSH and Chl-a, considering the austral summer (December-February), fall (March-May), winter (June-August) and spring (September-November), because obvious seasonal variation of marine environmental conditions, e.g. SST, was found in the South East Pacific (Núñez Elías et al., 2009).

- *HSI model selection and validation*

Model performances of different HSI models were examined through the percentage of total catch and effort on the range groups of the HSI ([0-0.2]; [0.2-0.4]; [0.4-0.6]; [0.6-0.8]; [0.8-1.0]) and comparing the overlaying AMM-based and GMM-based HSI maps with effort data;

Predicted HSI map based on 2013 environmental data + catch distribution map in 2013, to validate agreement between the HSI and catch.

- *Suitable habitat area*

0.5 is considered as the criteria to distinguish suitable or non-suitable habitat for, so suitable area each season is equate to the total number of 0.1° grid cells that its HSI value greater than or equal to 0.5.

Latitudinal gravity centers of fishing effort were calculated following as:

$$G_i = \frac{\sum (L_i \times E_i)}{\sum E_i}$$

Li is the latitude of cell *i*, *Ei* is the total fishing effort in cell *i*

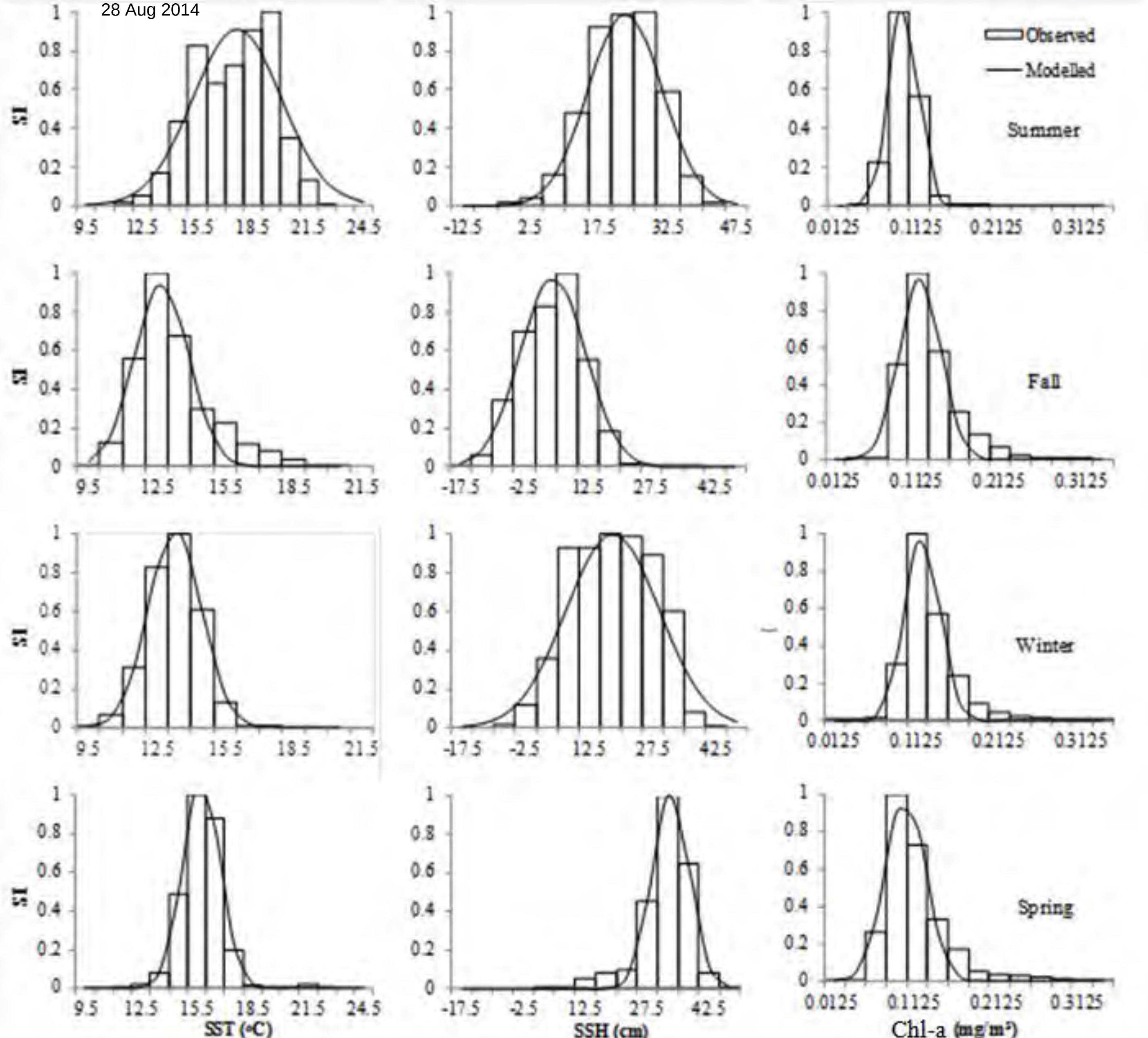
Validating the availability of the best HSI model by comparing the average latitude of suitable HSI area and latitude of gravity centers of fishing effort.

Results & Discussions

- *SI of the environmental variables*

All the SI models of the environmental variables in different seasons are significant with *P* values less than 0.0001.

Season	SI model	a	b	*P*
Summer	SI_{SST}	-0.0871	17.6667	<0.0001
	SI_{SSH}	-0.0077	23.0151	<0.0001
	SI_{Chl-a}	-1634.0	0.0931	<0.0001
Fall	SI_{SST}	-0.3577	12.6885	<0.0001
	SI_{SSH}	-0.0085	4.3505	<0.0001
	SI_{Chl-a}	-817.7	0.1156	<0.0001
Winter	SI_{SST}	-0.3784	13.2774	<0.0001
	SI_{SSH}	-0.0041	18.1521	<0.0001
	SI_{Chl-a}	-1128.0	0.1180	<0.0001
Spring	SI_{SST}	-0.5075	15.7880	<0.0001
	SI_{SSH}	-0.0248	33.1602	<0.0001
	SI_{Chl-a}	-858.8	0.0978	<0.0001



Observed SI (frequency distribution of effort) and predicted SI

SI models (exponential equation) implies a constraint:

the frequency distributions of observed SI (fishing effort) in relation to the environmental variables should be approximately normal or lognormal distribution.

Formula of SI models

$$SI_{SST} = Exp[a(SST - b)^2]$$

$$SI_{SSH} = Exp[a(SSH - b)^2]$$

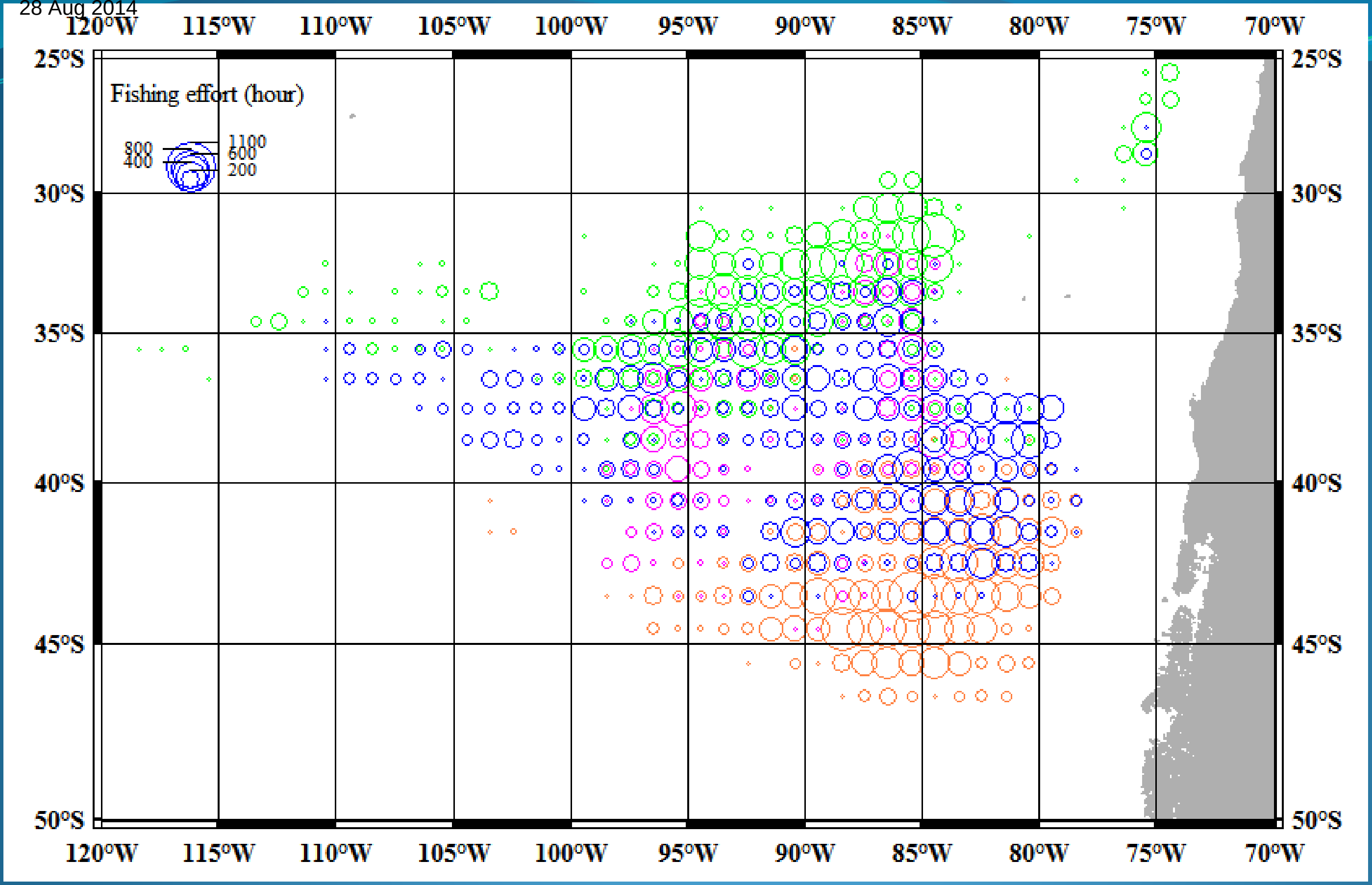
$$SI_{Chl-a} = Exp[a(Chl\_a - b)^2]$$

PDF of the normal distribution

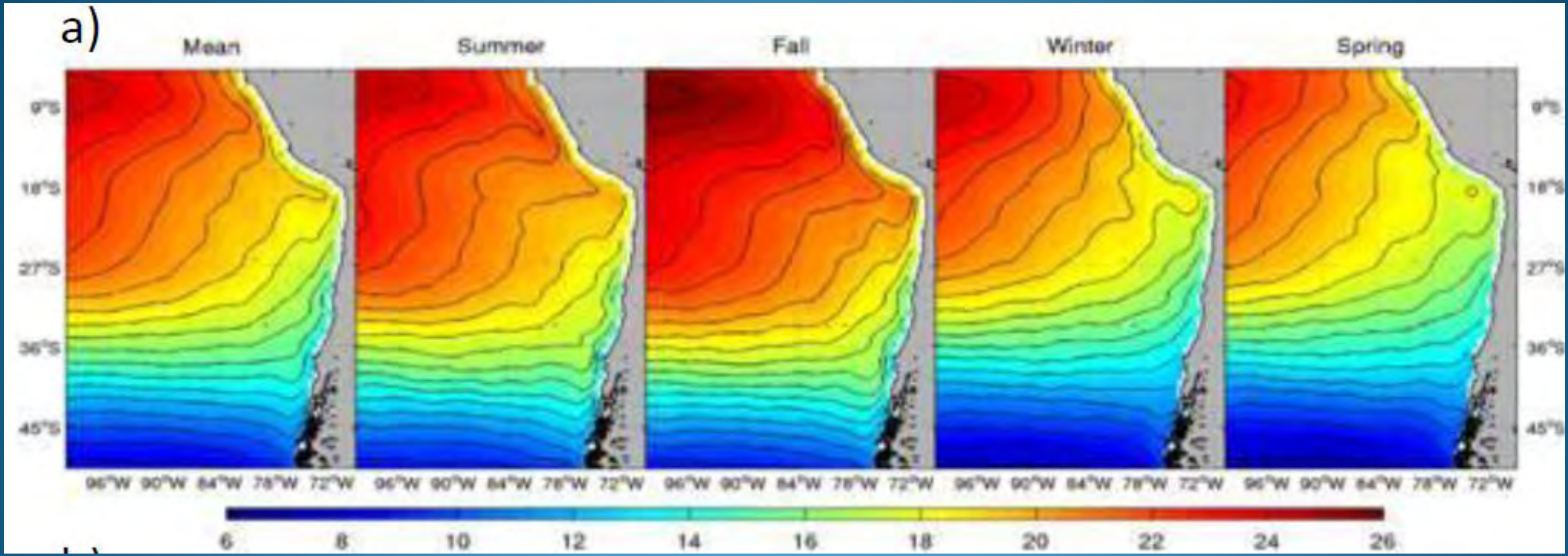
$$f(x) = \frac{1}{\sqrt{2\pi}\sigma} Exp[-\frac{(x-\mu)^2}{2\sigma 2}]$$

Season	Variable	Observed range	Estimated tolerant range	Estimated optimal range	Fishing effort (%)	Catch (%)
Summer	SST (°C)	11.4-22.5	8.8–26.6	16.1–19.3	47.3	44.8
	SSH (m)	-3.2-42.7	-7.0–53.0	17.6–28.4	52.7	54.0
	Chl-a (mg/m3)	0.04-0.19	0.03–0.16	0.08–0.10	52.4	55.2
Fall	SST	9.8–20.8	8.3–17.1	11.9–13.5	46.6	52.5
	SSH	-15.3–35.3	-24.2–32.9	-0.8–9.5	49.9	53.0
	Chl-a	0.04–0.31	0.02–0.21	0.10–0.13	47.3	42.5
Winter	SST	9.1–20.3	9.0–17.6	12.5–14.0	54.1	53.9
	SSH	-6.3–42.8	-22.9–59.2	10.8–25.5	52.3	53.2
	Chl-a	0.01–0.35	0.04–0.20	0.10–0.13	47.1	46.2
Spring	SST	11.9–22.2	12.1–19.5	15.1–16.5	52.0	52.9
	SSH	3.2–46.5	16.5–49.8	30.2–36.2	51.1	58.5
	Chl-a	0.01–0.34	0.01–0.19	0.08–0.11	48.1	48.2

- CJM habitat presented a great tolerance to water temperature (8.3–26.6 ° C) and SSH (-24.2–59.2 cm), but a narrow range to Chl-a (0.01–0.21 mg/m^3)
- HSI values in summer are overestimated because of biased SI model of SST. Larger latitude range of catch distribution (about 15 degree in latitude) with a wider range of SST in summer resulted in a big uncertainty for estimating parameters of the SI_{SST} model and biased optimal SST range.



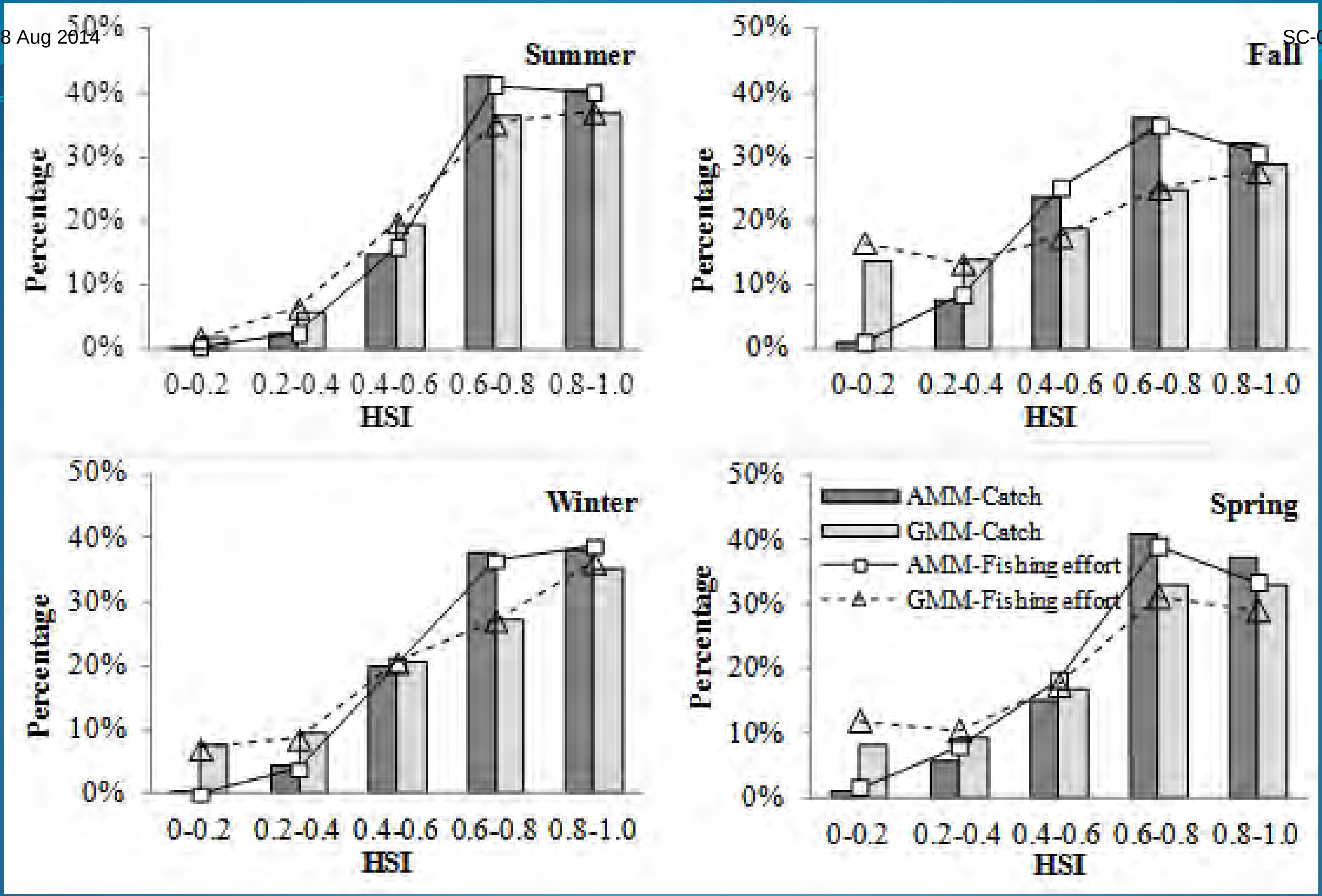
Seasonally fishing effort distribution (1°×1°) of the Chinese fleets in SPRFMO area in 2001-2012 (purple=summer, orange= fall, green=spring, blue=winter)



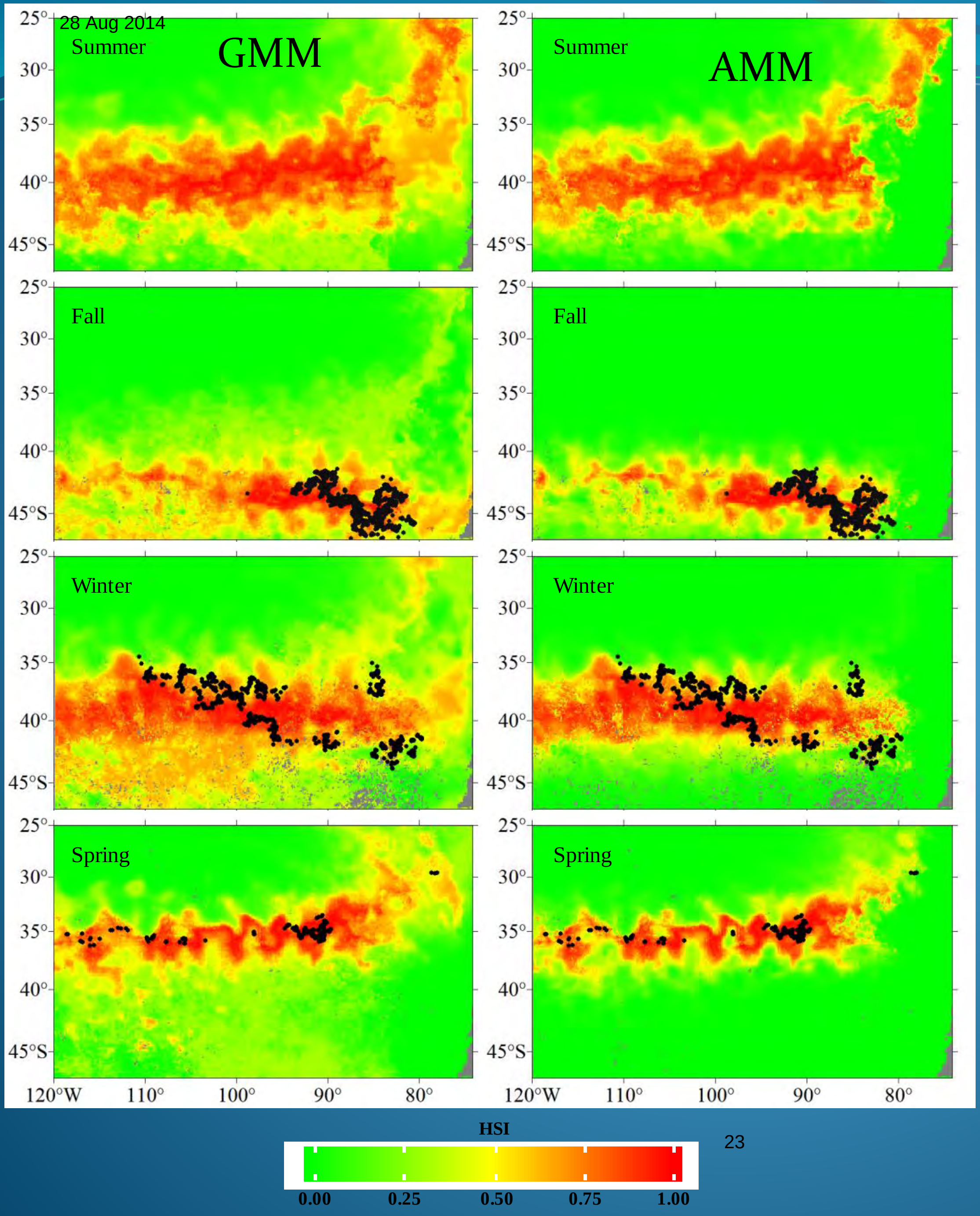
Spatial average distribution of Sea surface temperature (ºC), during 1975-2005 (Núñez Elías et al., 2008)

- *HSI model selection and validation*

We compared the performances of AMM and GMM based HSI models by estimating the percentage of fishing effort and catch according to each grouped HSI values of the two models



The percentages of catch and effort in preferred habitat of CJM (HSI > 0.6) for AMM were higher than those for GMM;
Poor habitat with HSI values less than 0.4 yielded higher percentages of catch and effort for GMM than those for AMM.



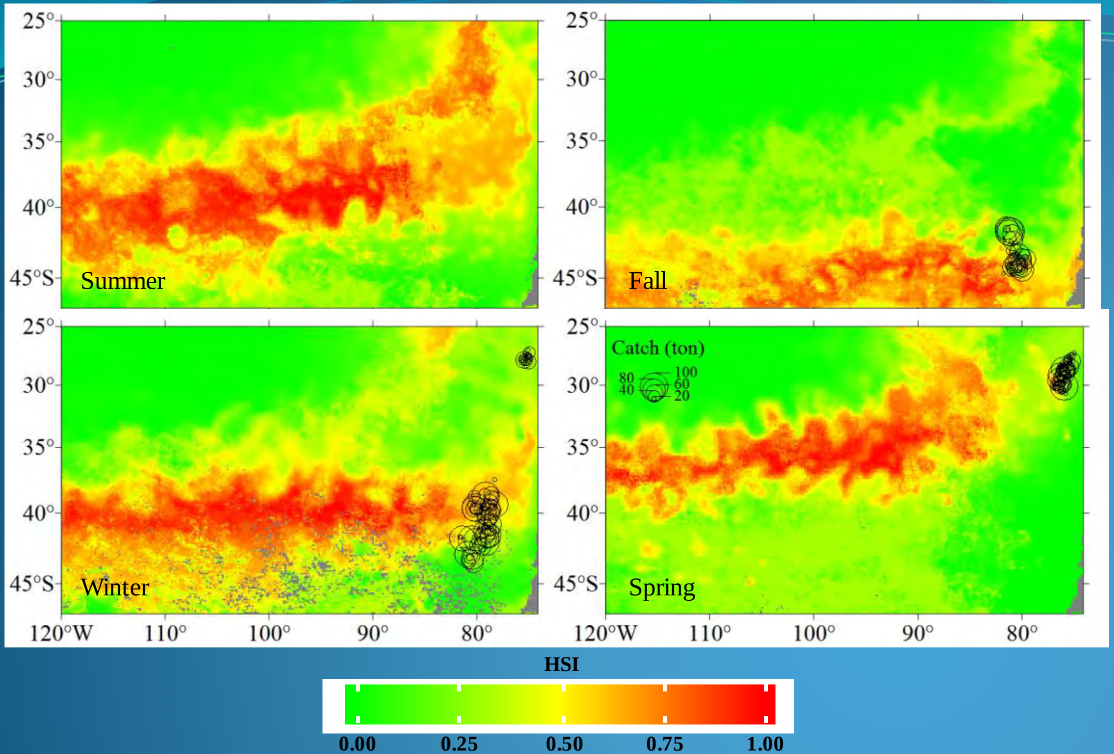
Fishing effort distribution (black dots) overlaid on the predicted HSI maps using the GMM (left) and AMM(right) in 2009

HSI values and suitable habitat areas in 2009 estimated by AMM were larger than those estimated by GMM;

Some catch occur in non-suitable habitat in HSI maps based on GMM, especially in fall and winter of 2009

GMM underestimate HSI and suitable habitat;

AMM performed better than GMM, it was chosen to estimate HSI and the suitable habitat area.



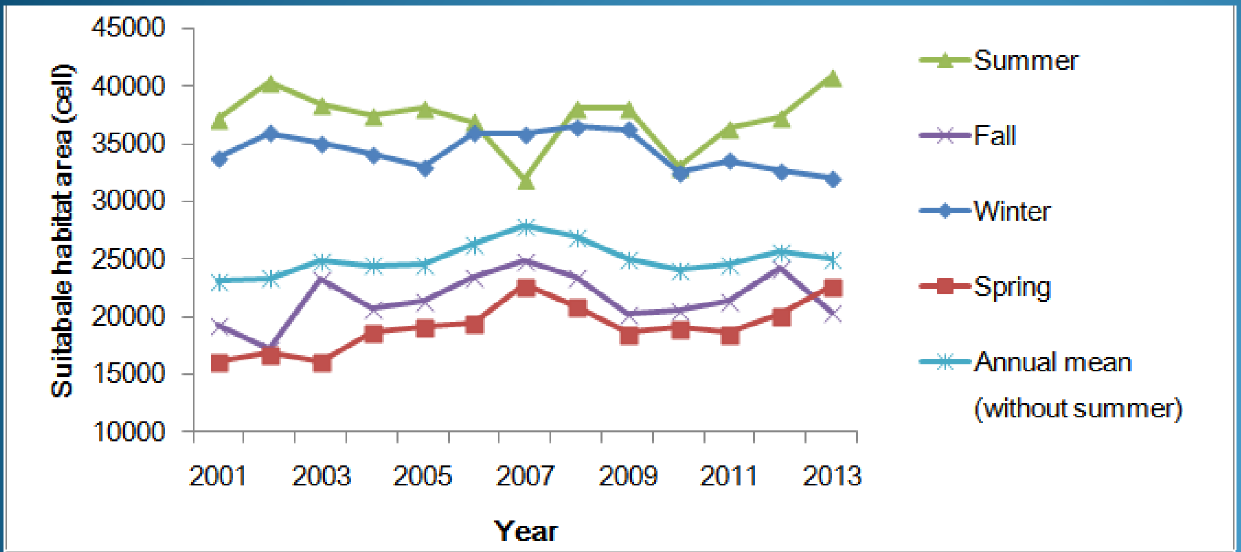
Fishing effort distribution in 2013 overlaid on the predicted HSI maps using AMM

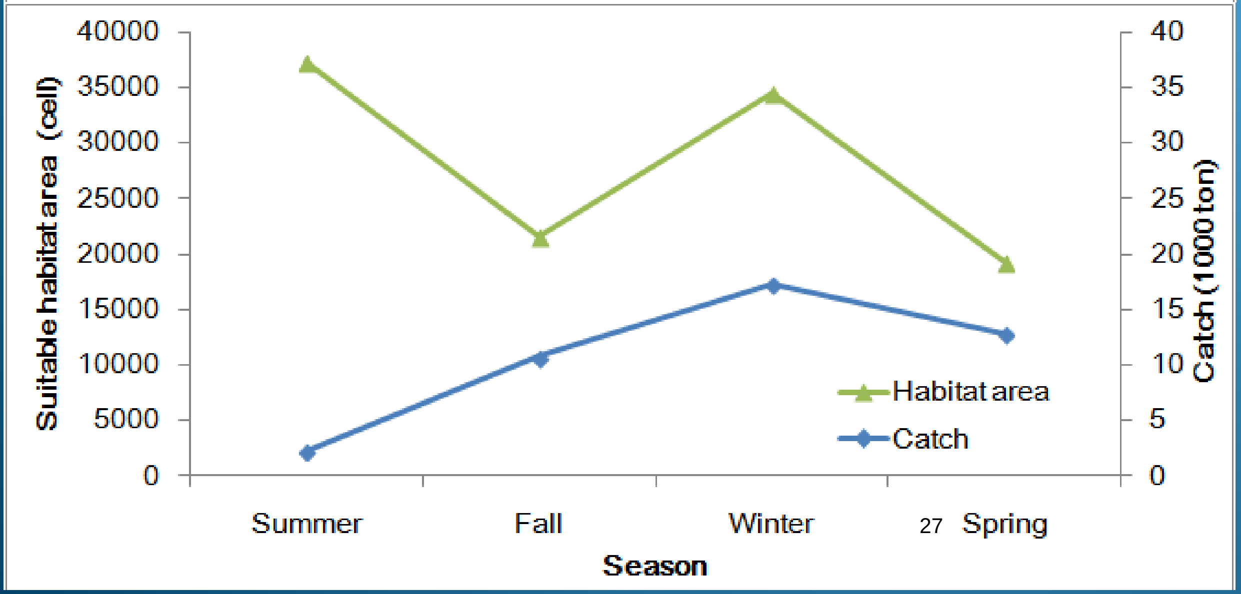
- Most of CJM in fall and winter 2013 were caught in the suitable habitat, but there were still some catch data distributed in some unsuitable areas around the suitable habitat.
- Although the area of suitable habitat peaked in summer, there were no fishing activities

Biggest latitude range, lowest catch and shortest fishing days indicated that high seas off central-southern Chile are not good fish habitat in summer, specially with regard to its spawning behavior.

Spawning occurs during a dispersion phase where schools are almost disappearing should limit the risks of cannibalism (Gerlotto and Dioses, 2013).

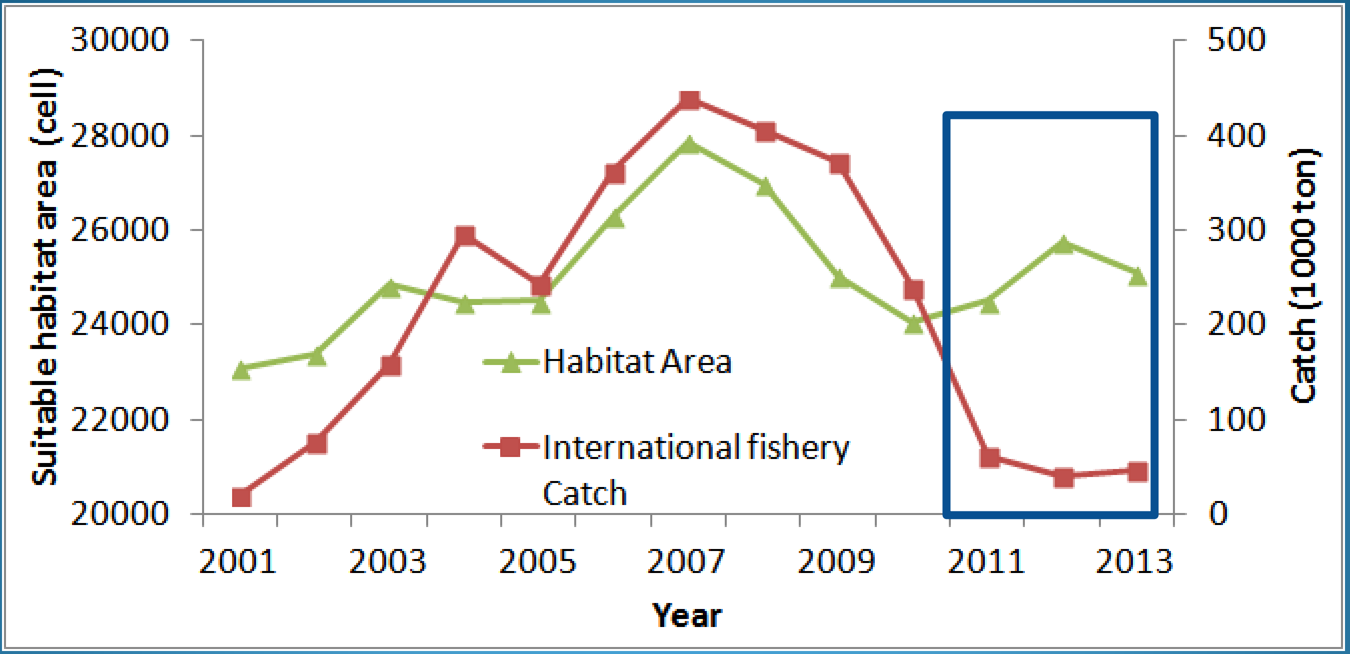
• *Suitable habitat area*



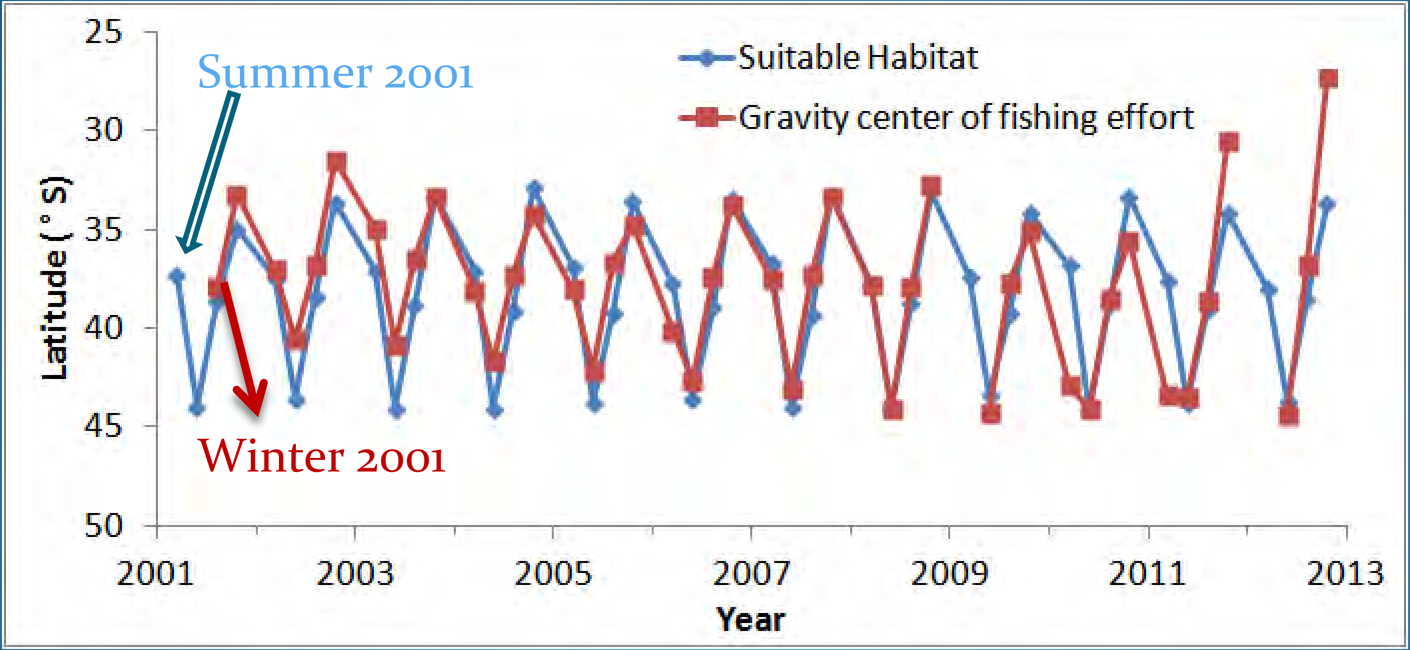


Area of suitable HSI maximum in summer except 2007; average catch was proportional to habitat area except summer.

So HSI in summer was rejected to calculate the annual mean.

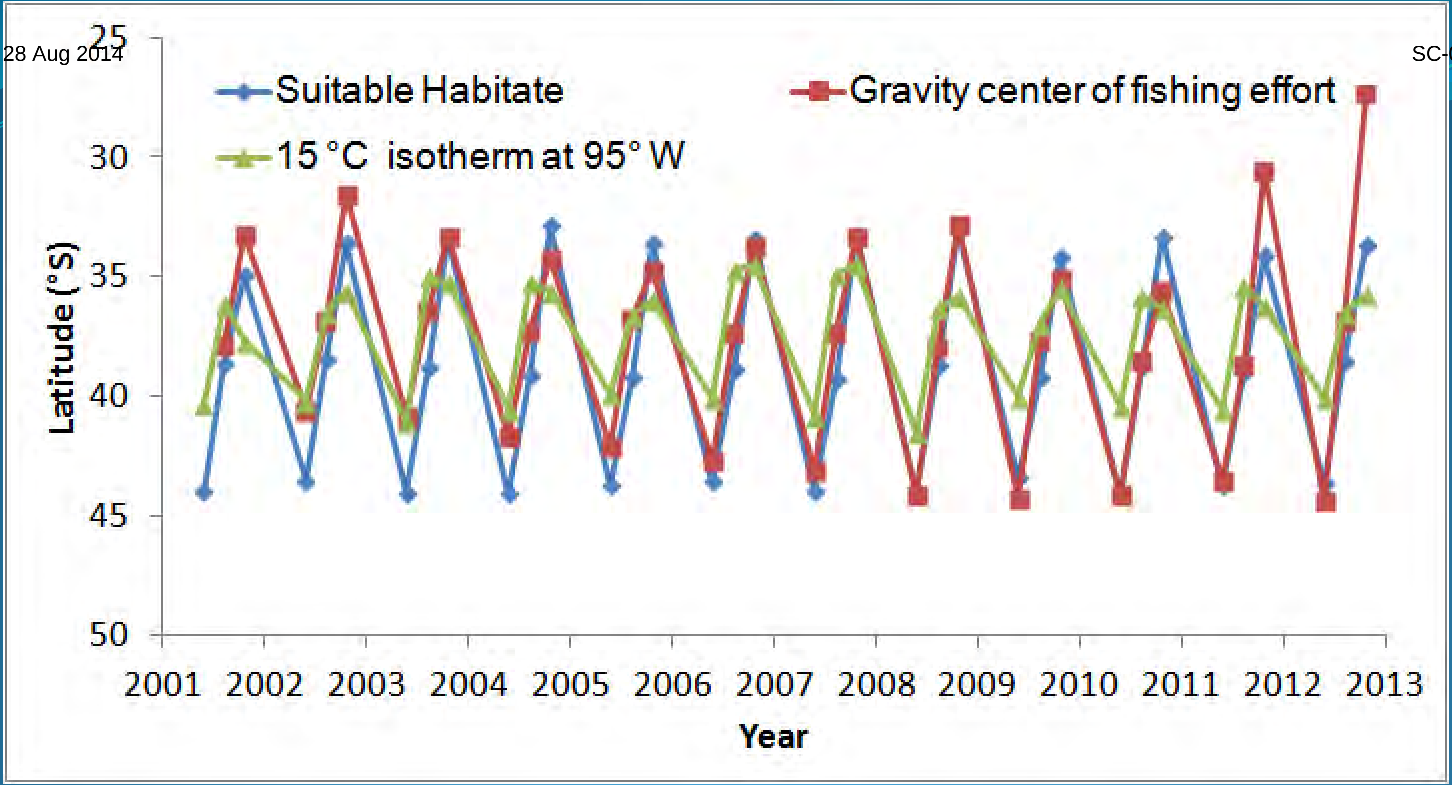


Annual total catch changed in sync with mean habitat area during 2001 to 2010. However, they showed an opposite trend from 2011 to 2013, which might be related to the lowest biomass and interim measures regarding TAC since 2010.



Concentration of suitable habitat have moved northward gradually during fall to spring.

The average latitude of suitable habitat in each season oscillated seasonally from north to south (36-38°S in summer, 43-44°S in fall, 38-39°S in winter, and 33-35°S in spring) consistent with the latitude of fishing effort gravity centres (r=0. 85)



The average latitude of suitable habitat, the latitude of fishing effort gravity centres and 15°C isotherm at 95°W in fall, winter and spring during 2001-2013. Showing similar spatial trend.

$r_{hab.\text{-}effort}$ =0.93; $r_{hab.\text{-}15°C}$ =0.84; $r_{effort\text{-}15°C}$ =0.80.

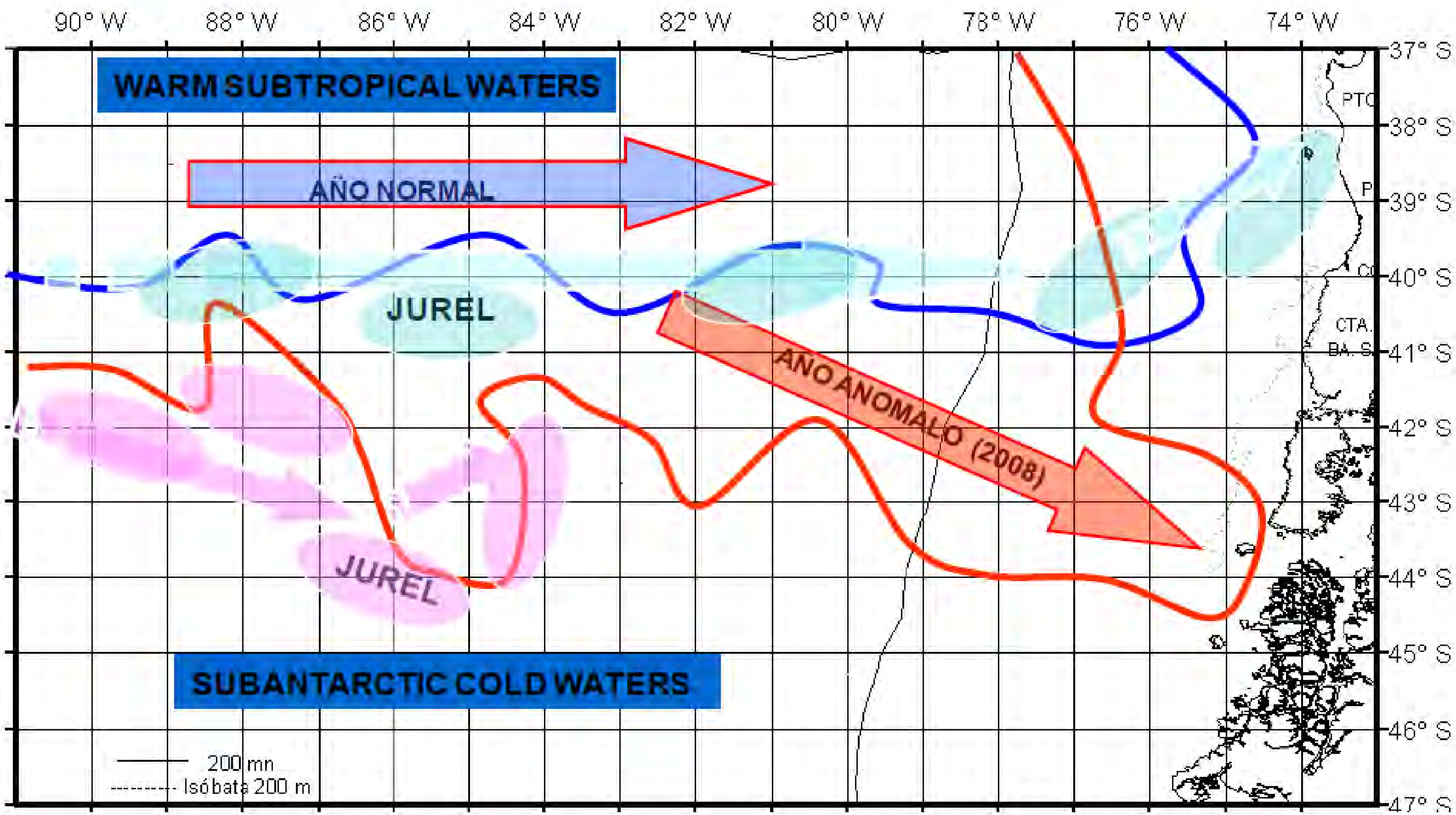


Figure 3. Migrations of the CJM in March-May during normal (year 2006-7) and abnormal (year 2008) oceanographic conditions (from Gretchina, 2009)

From Gerlotto and Dioses 2013(**SC-01-INF-17**)

Two conclusions or inferences:

SST is the key environmental factor for CJM habitat;

Distribution of CJM suitable habitat seems to be determined by the distribution of warm subtropical water mass, which is affected by the *El nino/La nina*.

Thank you !