Impacts of climate change on the distribution of blue marlin (*Makaira nigricans*) as inferred from data for longline fisheries in the Pacific Ocean

Nan-Jay Su[1*], Chi-Lu Sun[1], Andre Punt[2], Su-Zan Yeh[1], and Gerard DiNardo[3]

[1]Institute of Oceanography, National Taiwan University, Taipei, Taiwan

[2]School of Aquatic and Fishery Sciences, University of Washington, Seattle, WA, USA

[3]NOAA Fisheries, Pacific Islands Fisheries Science Center, Honolulu, HI, U.S.A.

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- *Objectives of this study*

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3. RESULTS AND DISCUSSION
- *Model fitting*
- *Annual variation*
- *Regional variation*
- *Conclusions*

1. Introduction

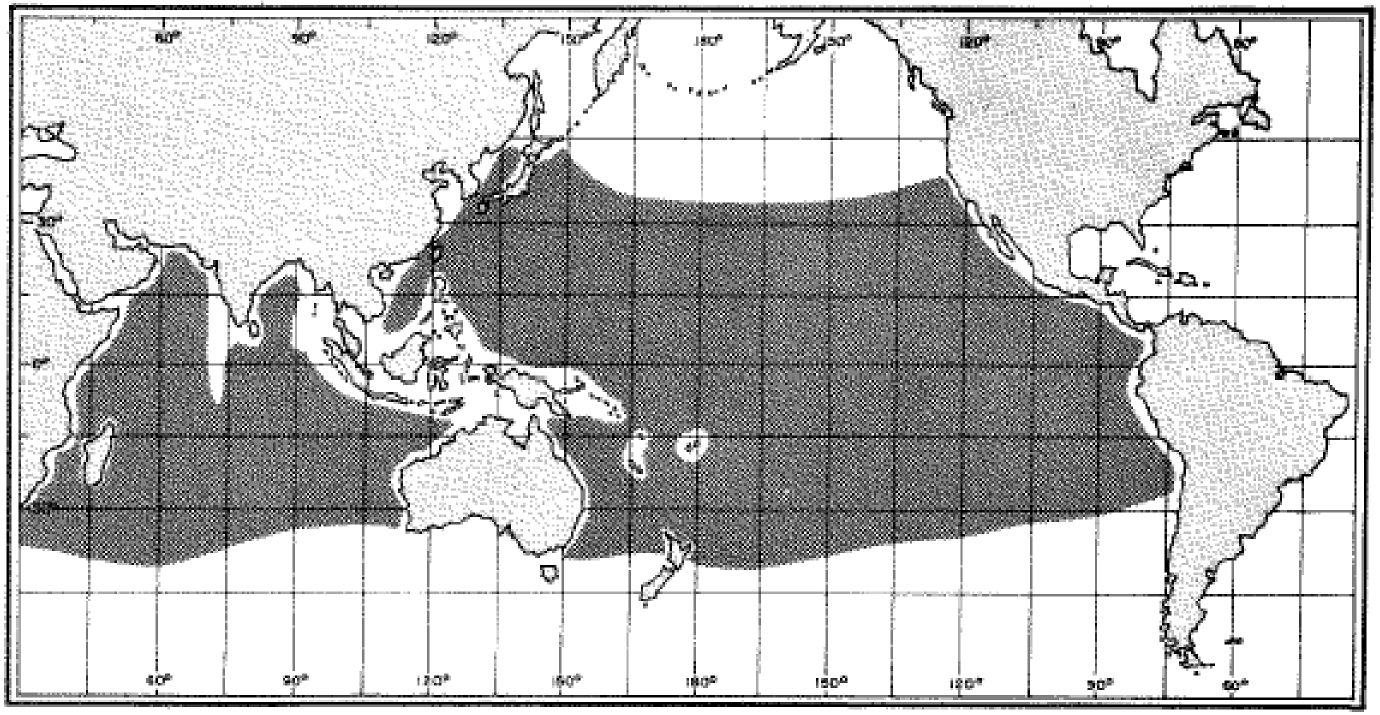
Blue marlin is a large, pelagic species

Source: NOAA

1. Introduction

Distribution

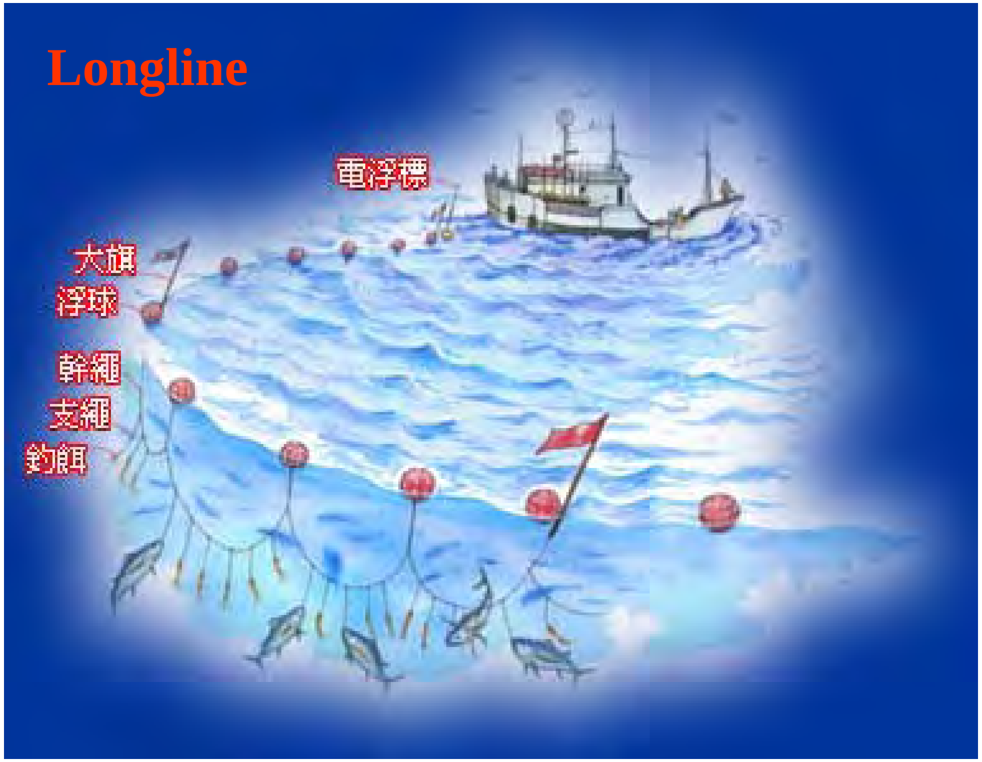
30˚N
0˚
30˚S

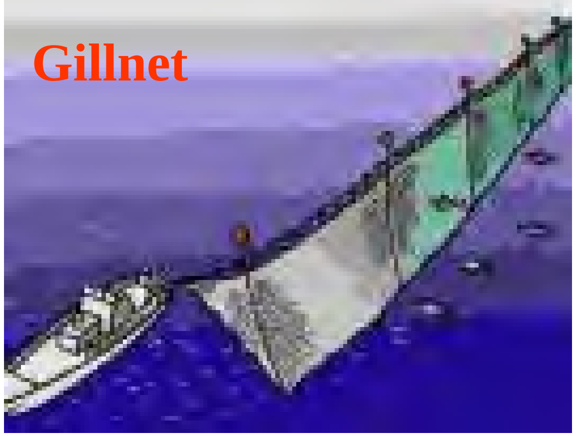


Source: Nakamura (1985)

1. Introduction

Various fisheries

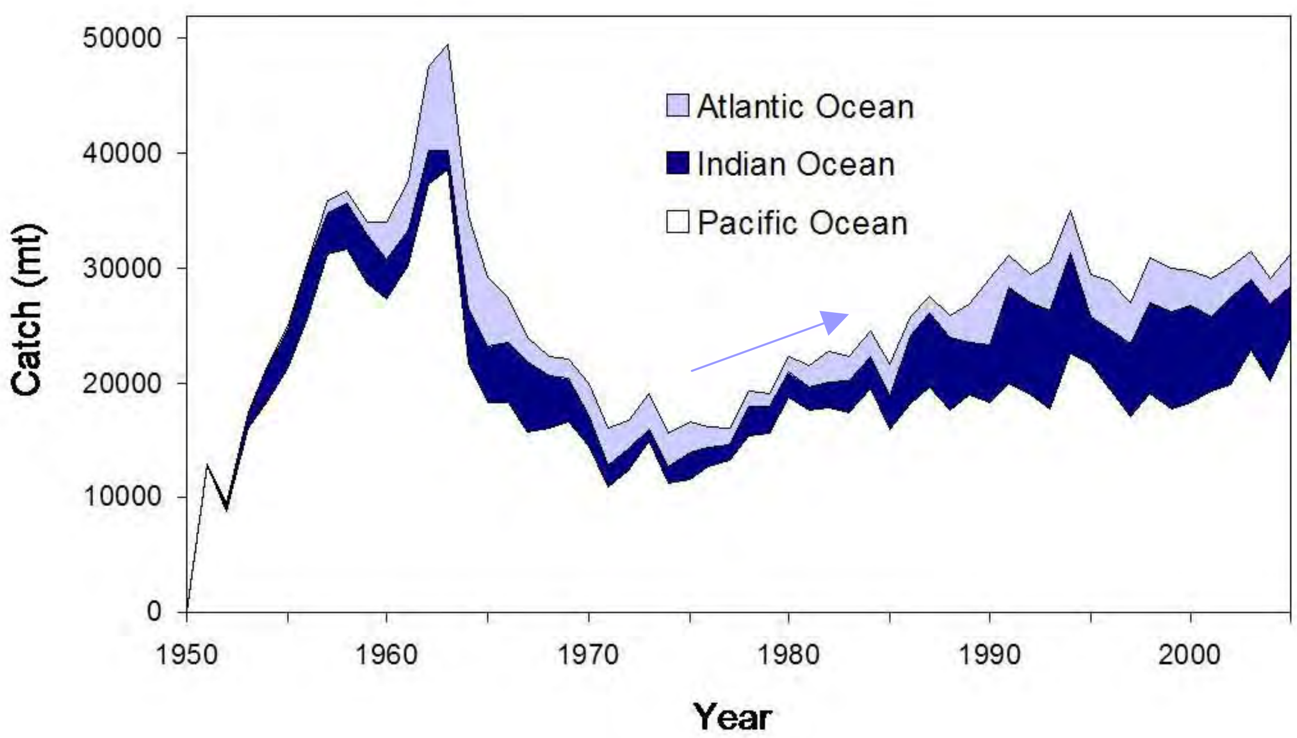




Source: TTA, CTW, MAFF

1. Introduction

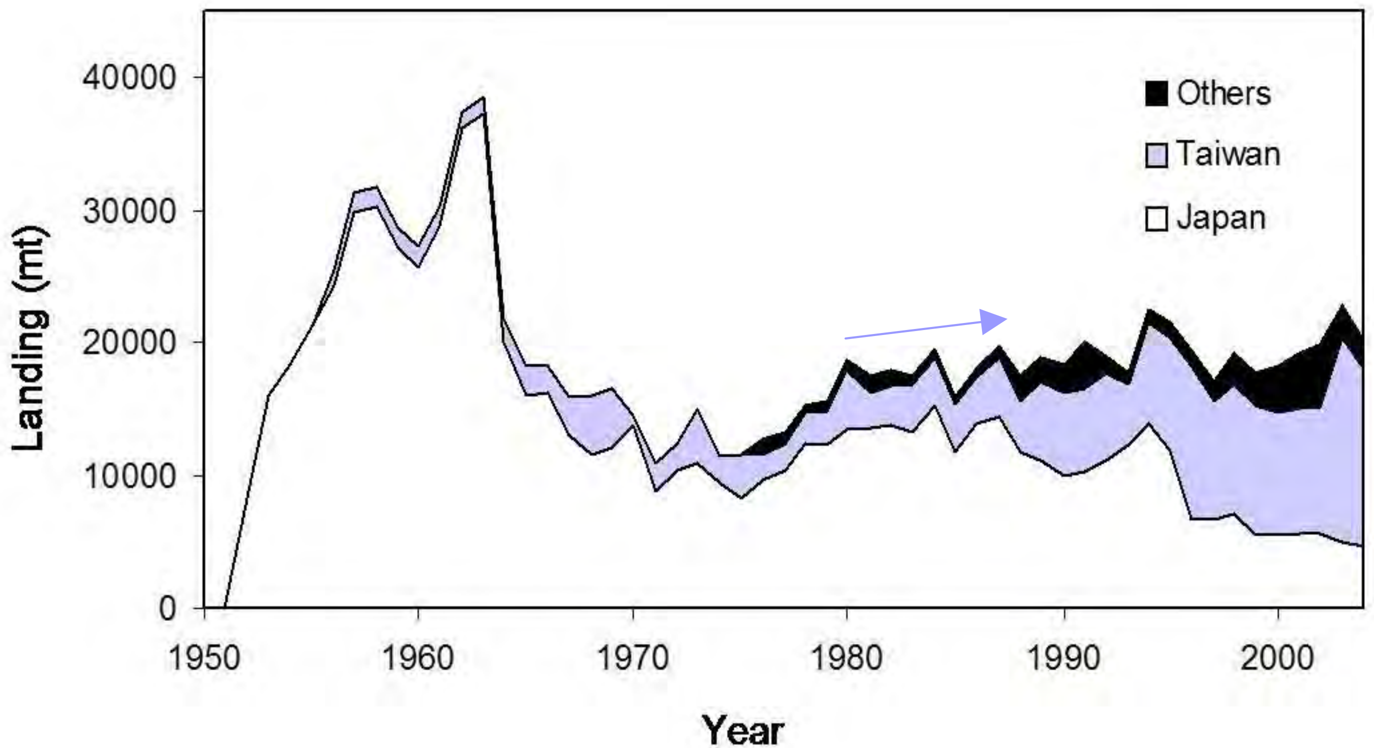
Catch in the three oceans



Source: FAO

1. Introduction

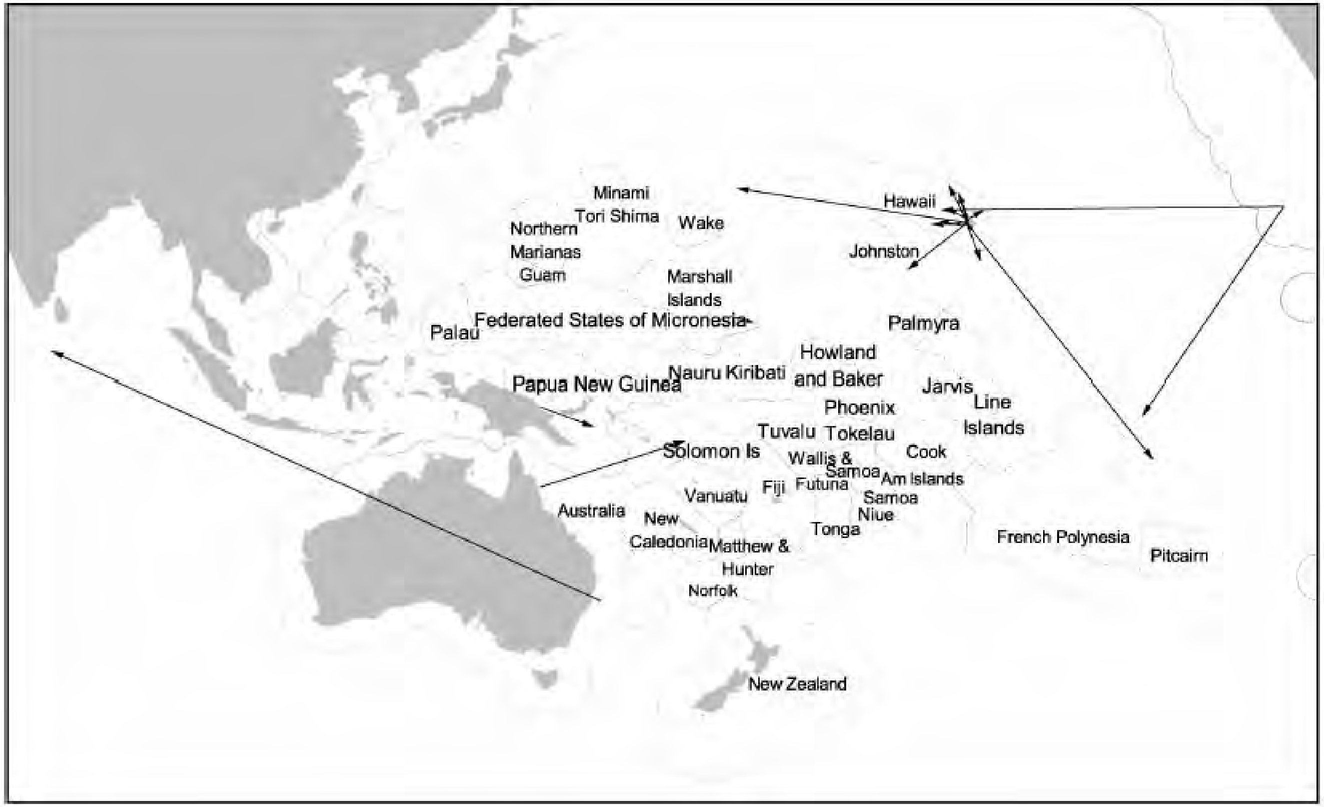
Landing in the Pacific Ocean



Source: FAO

1. Introduction

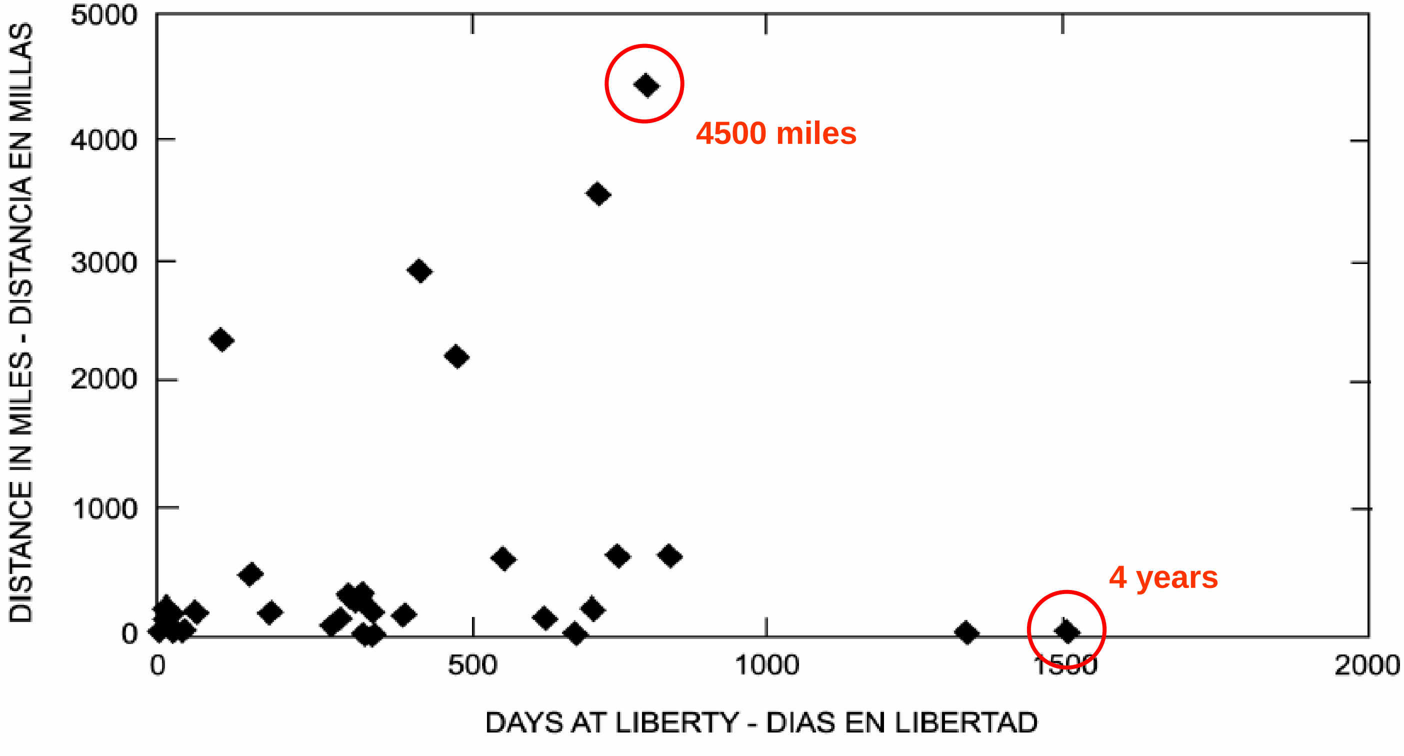
Migration and movement



Source: Hinton (2001)

1. Introduction

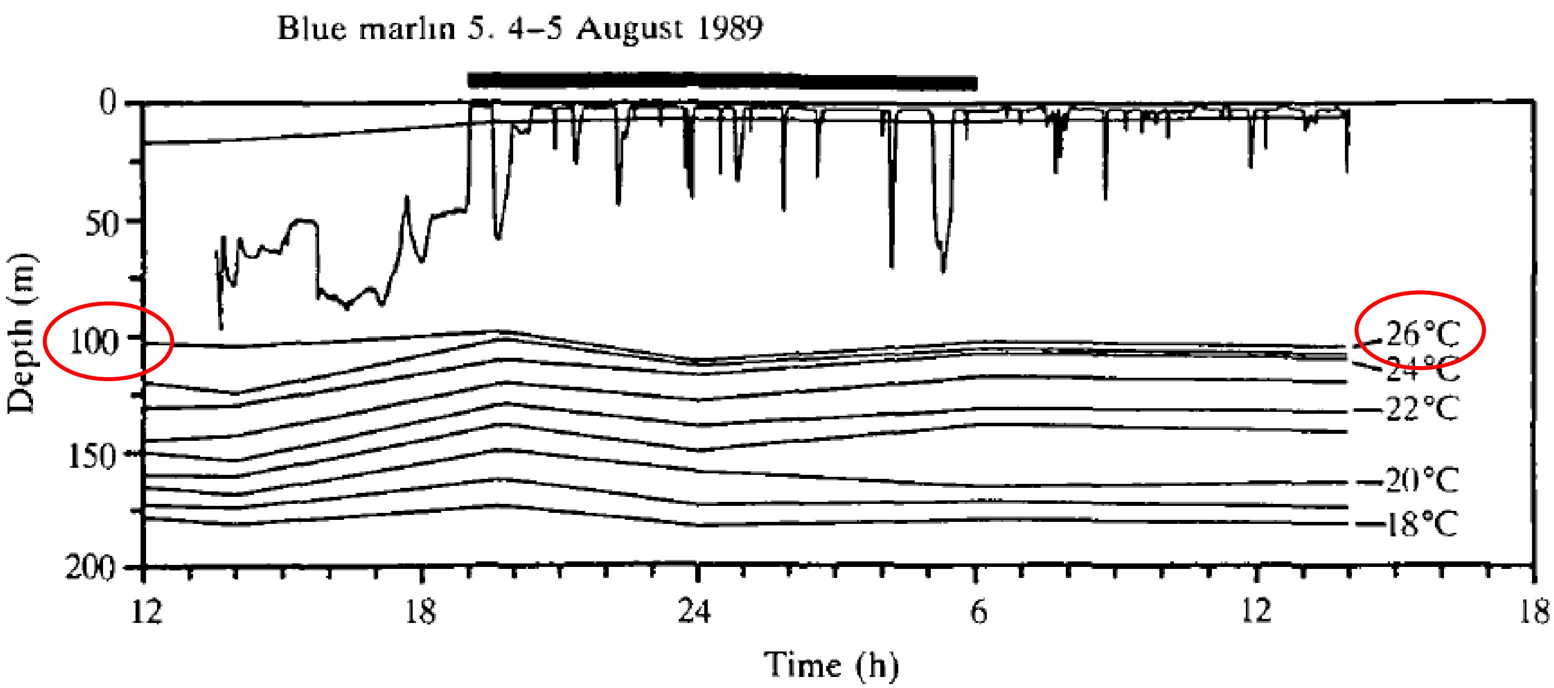
Migration and movement – a single stock in the Pacific



Source: Hinton (2001)

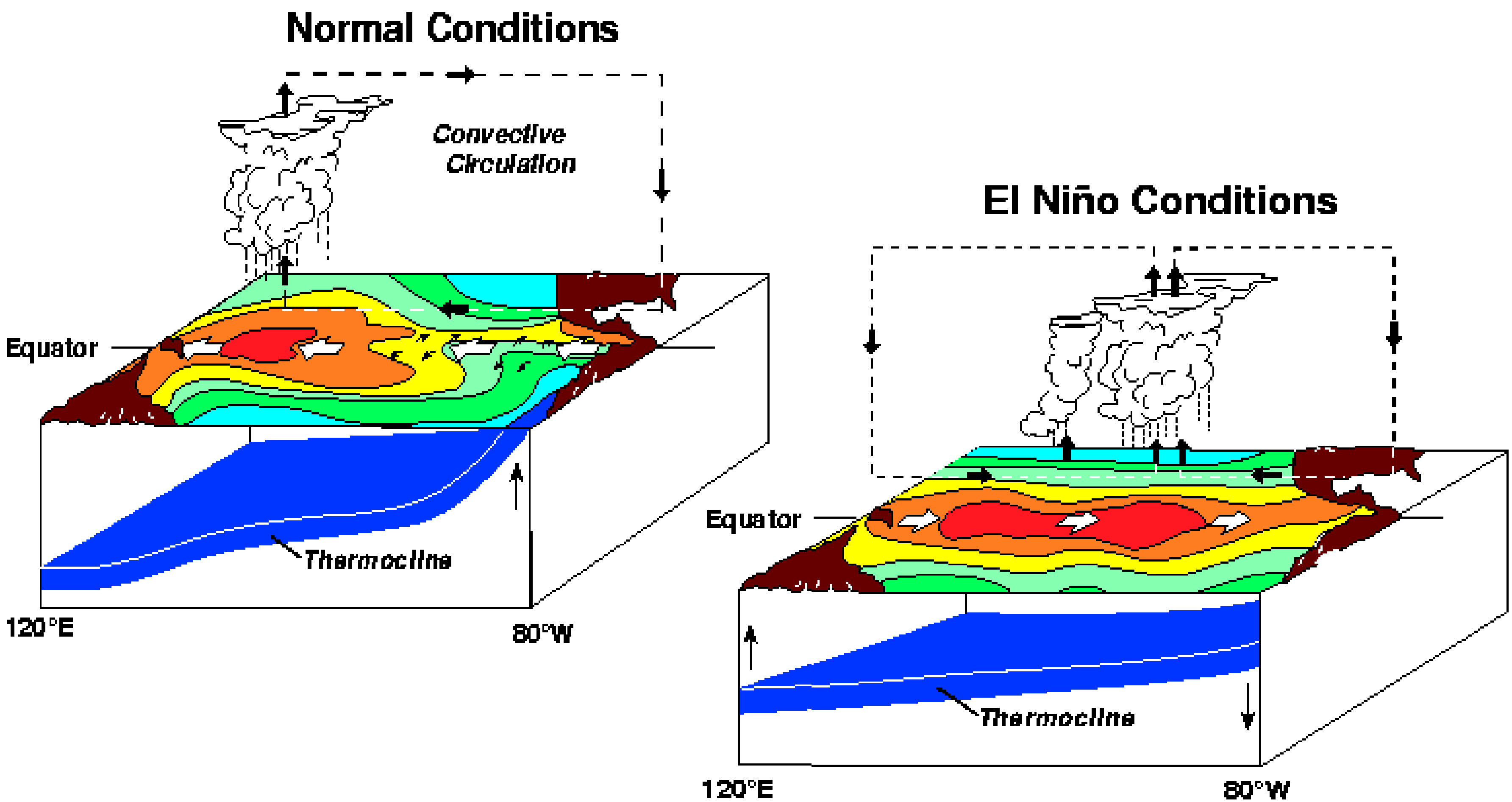
1. Introduction

Tagging experiment



Source: Block et al. (1992)

1. Introduction



Source: Dr. Hsu HH, NTUAS

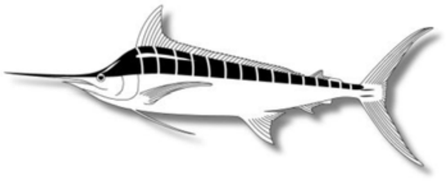
1. Introduction

Blue marlin inhabit certain preferred habitats in the open ocean. The preference of this species for particular habitats may impact its distribution and vulnerability to being caught.

We could infer relative density through catch-rate information.

The objectives of this study

To examine 1) the relationship between spatial patterns of abundance and environmental factors, 2) the impact of climate change on the distribution of blue marlin, and 3) the potential influence on the catch-rates for the longline fisheries.



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- *Regional variation*
- *Conclusions*

2. Materials and Methods

Two fishery data sets of longline 5x5 grids

a) SPC, aggregated over longline fisheries **(PLL)** for 1998-2004

Secretariat of the Pacific Community / Secrétariat de la Communauté du Pacifique (SPC)

OCEANIC FISHERIES PROGRAMME / *PROGRAMME PECHE HAUTURIERE*

b) OFDC, Taiwanese longline fisheries **(TLL)** for 1998-2007

中華民國對外漁業合作發展協會

Overseas Fisheries Development Council of The Republic of China

Covariates: Year, Month, Lat, Lon, Fishing effort in hooks,
and number of blue marlin caught

2. Materials and Methods

Four data sets of environmental factors for 1998-2007

a) chlorophyll a concentration (CHL): SeaWiFS

b) mixed layer depth (MLD): OSU

c) sea surface height anomaly (SSH): AVISO

d) sea surface temperature (SST): PODAAC

- Average to 5x5 grids to match the fishery data

2. Materials and Methods

Statistical modeling

- delta GAM (Generalized additive model) $g(\mu_i) = \mu + \sum_{j=1}^{p} f_j(X_i)$

a) P/A (present/absent) model: 0 or1, assuming binominal

P/A ~ s(Year) + s(Month) + s(CHL) + s(MLD) + s(SSH) + s(SST)
+ s(Year,Latitude) + s(Year,Longitude) + s(Latitude,Longitude)

b) CPUE (abundance) model: catch-rates > 0, assuming lognormal

CPUE ~ s(Year) + s(Month) + s(CHL) + s(MLD) + s(SSH) + s(SST)
+ s(Year,Latitude) + s(Year,Longitude) + s(Latitude,Longitude)

Diagnostic analysis: residual distribution and quantile-quantile plot

2. Materials and Methods

Predict relative density

Consider both information from the P/A and CPUE models

Prediction = probability of present $\times$ relative density given presence

Predict the distribution of relative density

a) temporally: 1998-2007 for each month

b) spatially: 5x5 latitude and longitude grids

Define the hotspot areas, the relative densities in the top 5%

2. Materials and Methods

Impacts of climate change

Track temporal variations of the hotspot areas

- by Latitude and Longitude

Remove yearly variations

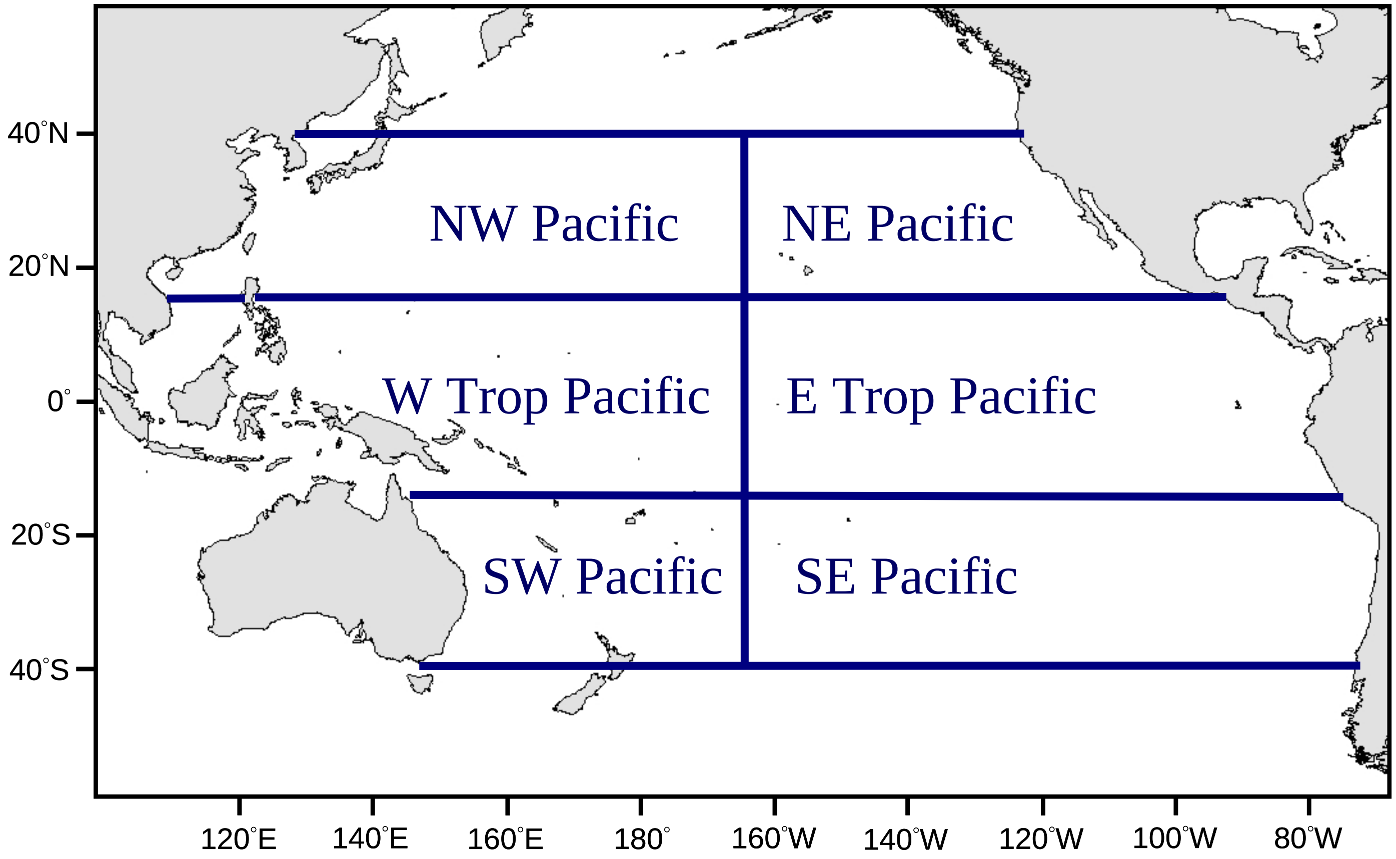
- medians of environment data in 1998-2007
- predict year-invariant relative density distribution

Examine climate impacts, by six regions

- separate the Pacific into temperate and tropical areas

2. Materials and Methods

The six regions of the Pacific Ocean



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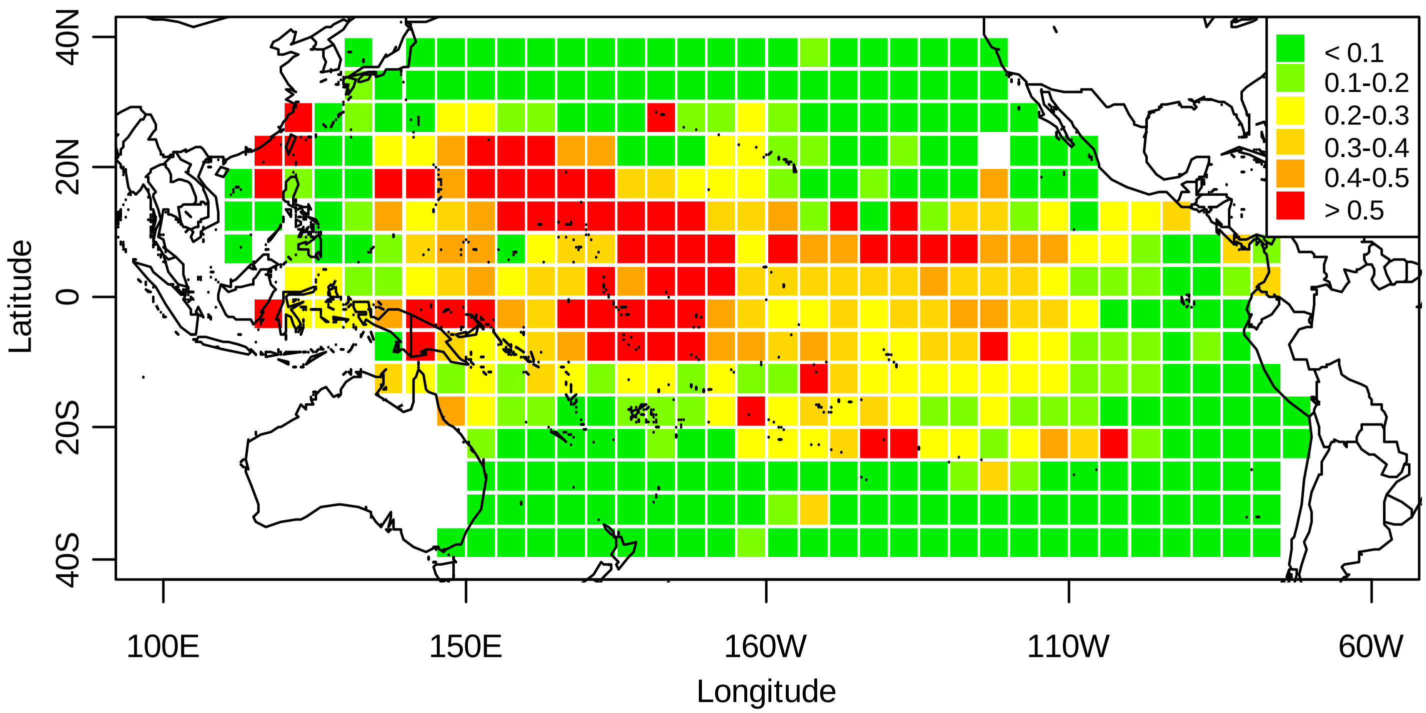
  - ***Regional variation***
  - ***Conclusions***

3. Results and discussion

Nominal CPUE of Pacific longline fisheries (PLL)



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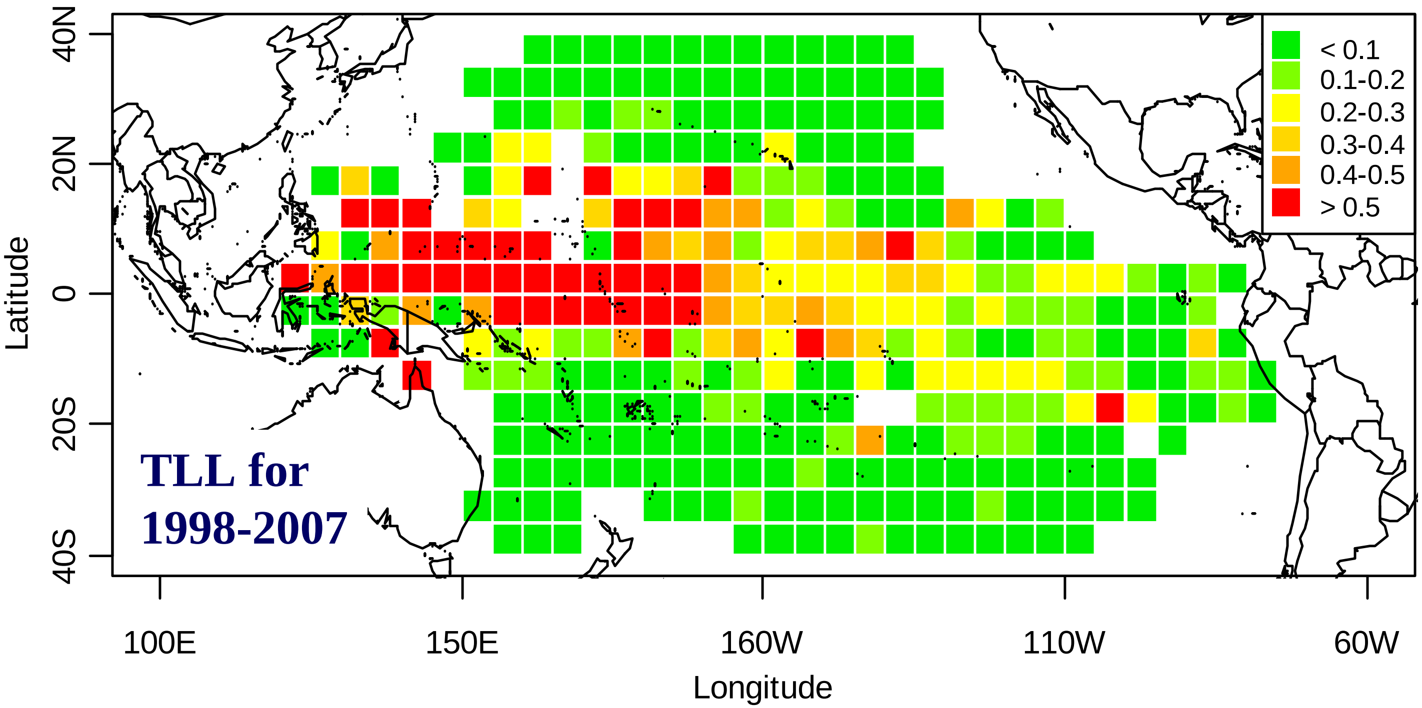
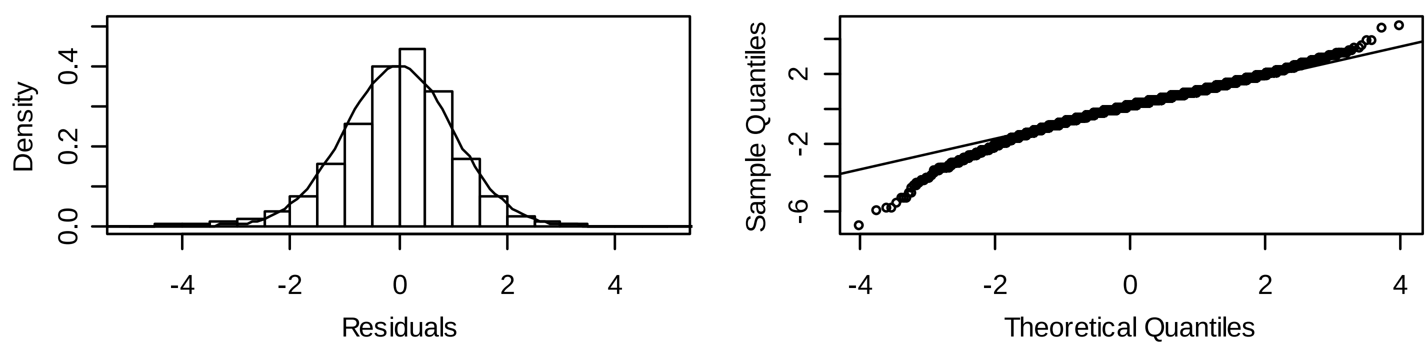
Nominal CPUE of Taiwanese longline fisheries (TLL)



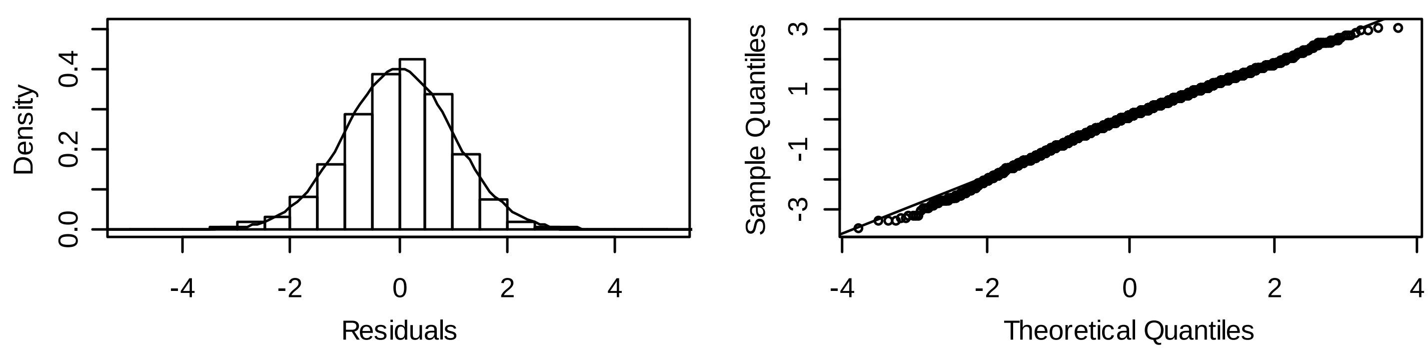
3. Results and discussion

Diagnostic analysis: residual and Q-Q plots

a) PLL for 1998-2004



b) TLL for 1998-2007



3. Results and discussion

ANOVA table of P/A models for PLL and TLL

	PLL for 1998-2004					TLL for 1998-2007				
	Resid dev	% dev explain	AIC	%AIC	P(Chi)	Resid dev	% dev explain	AIC	%AIC	P(Chi)
PA model										
NULL	24477		24479			13816		13818		
+s(Year)	24459	0.2%	24465	0.2%	<0.01	13566	14.8%	13575	15.6%	<0.01
+s(Month)	24415	0.5%	24426	0.5%	<0.01	13516	3.0%	13530	2.9%	<0.01
+s(CHL)	23953	5.6%	23971	5.6%	<0.01	13288	13.5%	13309	14.2%	<0.01
+s(MLD)	22593	16.5%	22622	16.7%	<0.01	13177	6.6%	13206	6.6%	<0.01
+s(SSH)	22448	1.8%	22483	1.7%	<0.01	13104	4.3%	13139	4.2%	<0.01
+s(SST)	18487	48.0%	18526	48.8%	<0.01	12641	27.4%	12682	29.3%	<0.01
+s(Year,Latitude)	17663	10.0%	17737	9.7%	<0.01	12380	15.4%	12454	14.6%	<0.01
+s(Year,Longitude	16878	9.5%	16990	9.2%	<0.01	12243	8.1%	12348	6.7%	<0.01
+s(Latitude,Longitu	16234	7.8%	16376	7.6%	<0.01	12128	6.9%	12255	6.0%	<0.01
Tot dev expl	33.7%					12.2%				

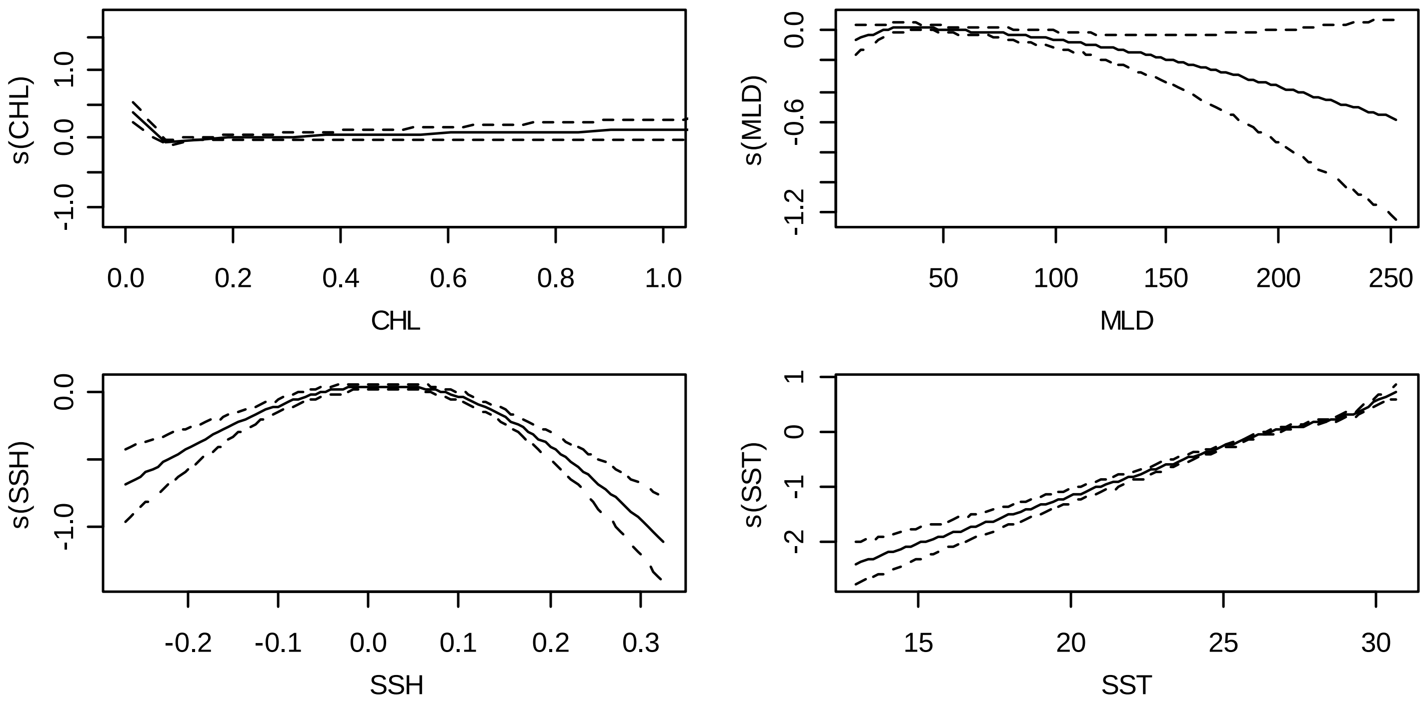
3. Results and discussion

ANOVA table of CPUE models for PLL and TLL

	PLL for 1998-2004					TLL for 1998-2007				
	Resid dev	% dev explain	AIC	%AIC	P(Chi)	Resid dev	% dev explain	AIC	%AIC	P(Chi)
CPUE model										
NULL	27312		53497			6633		16923		
+s(Year)	27098	1.9%	53380	1.4%	<0.01	6529	7.2%	16840	6.5%	<0.01
+s(Month)	27036	0.5%	53349	0.4%	<0.01	6441	6.0%	16771	5.4%	<0.01
+s(CHL)	26469	4.9%	53022	3.9%	<0.01	6414	1.8%	16755	1.3%	<0.01
+s(MLD)	25190	11.2%	52248	9.1%	<0.01	6378	2.5%	16729	2.1%	<0.01
+s(SSH)	24966	2.0%	52114	1.6%	<0.01	6320	3.9%	16684	3.6%	<0.01
+s(SST)	18791	53.8%	47630	53.0%	<0.01	5963	24.5%	16358	25.7%	<0.01
+s(Year,Latitude)	17689	9.6%	46713	10.8%	<0.01	5512	31.0%	15953	31.8%	<0.01
+s(Year,Longitude	17046	5.6%	46166	6.5%	<0.01	5356	10.7%	15822	10.3%	<0.01
+s(Latitude,Longitu	15844	10.5%	45028	13.4%	<0.01	5177	12.3%	15651	13.5%	<0.01
Tot dev expl	42.0%					22.0%				

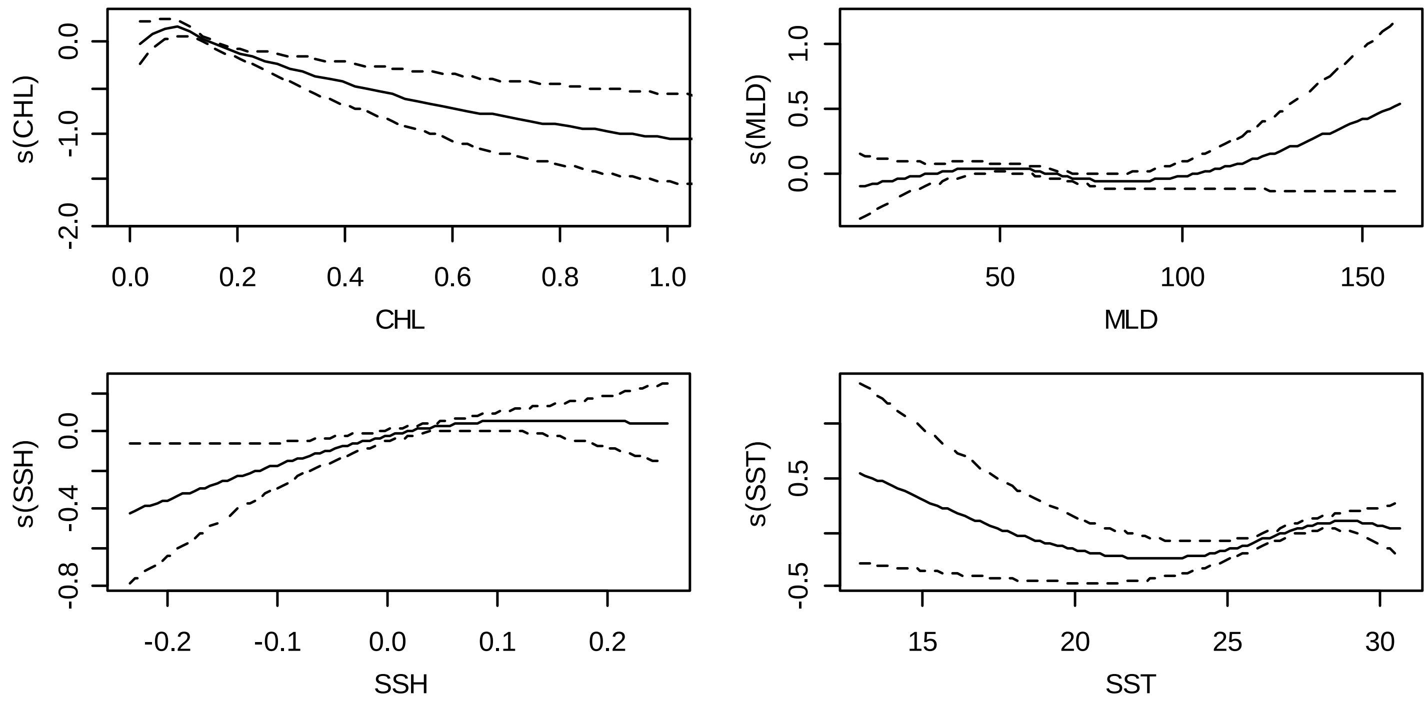
3. Results and discussion

Partial effects of environmental factors for PLL



3. Results and discussion

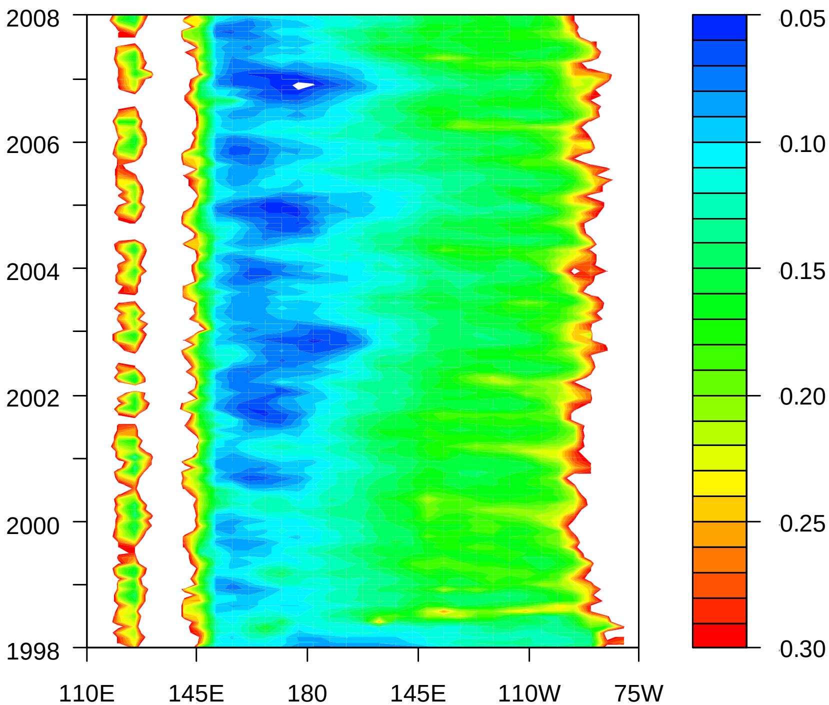
Partial effects of environmental factors for TLL



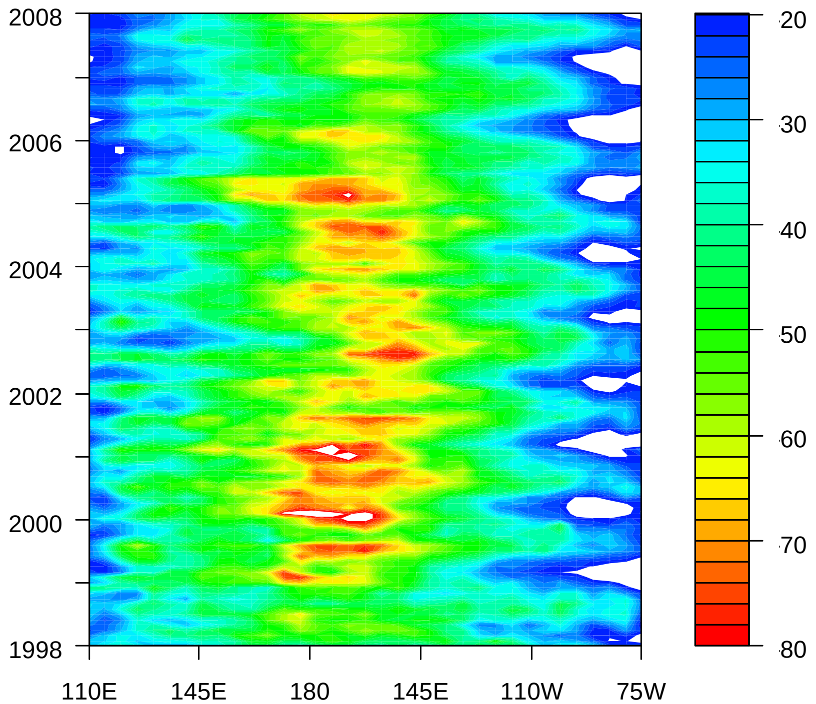
3. Results and discussion

Yearly variation of environmental factors (15˚S-15˚N)

Chlorophyll a concentration



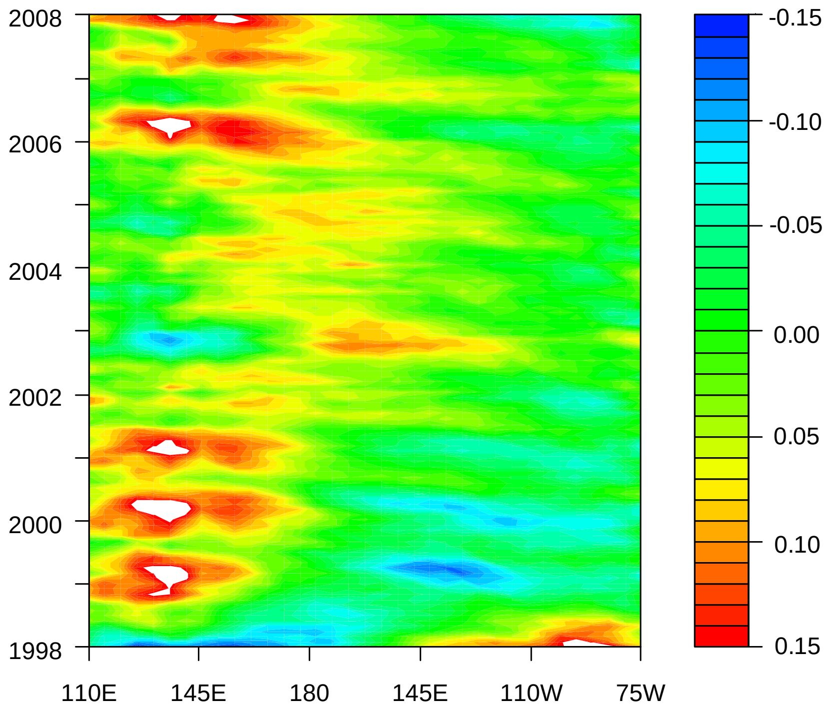
Mixed layer depth



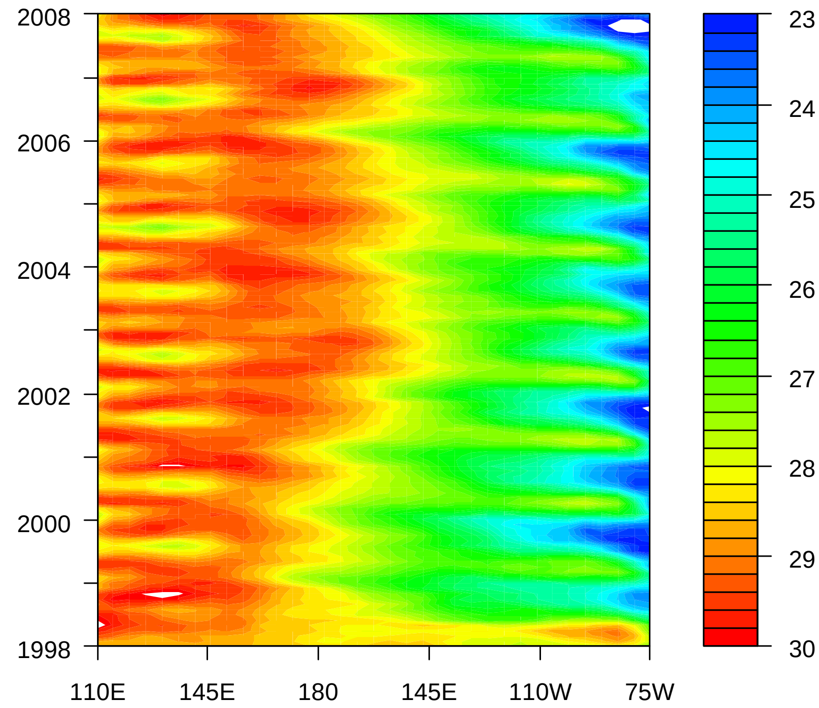
3. Results and discussion

Yearly variation of environmental factors (15°S-15°N)

Sea surface height anomaly



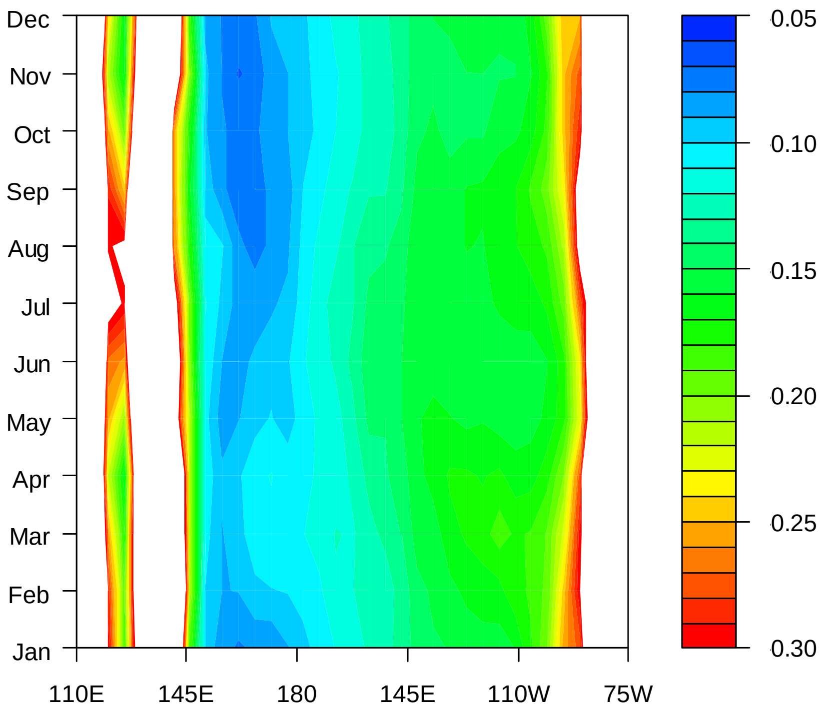
Sea surface temperature



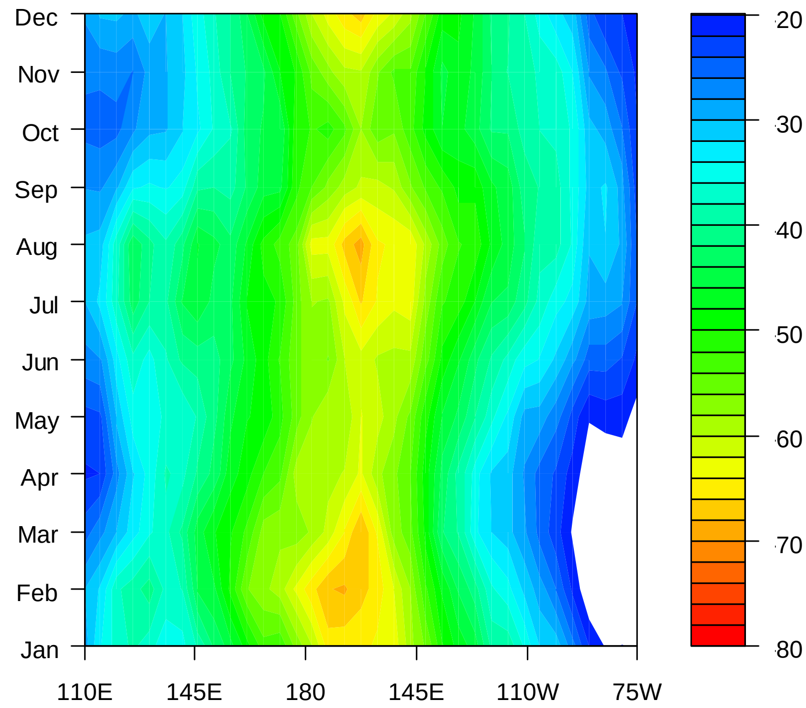
3. Results and discussion

Year-invariant environmental factor (median of 10 years)

Chlorophyll a concentration



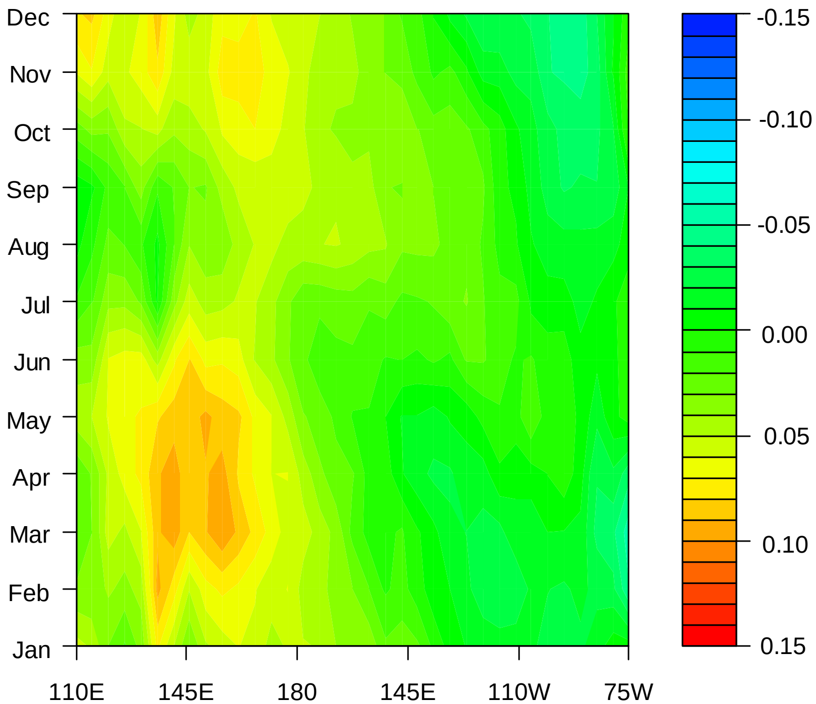
Mixed layer depth



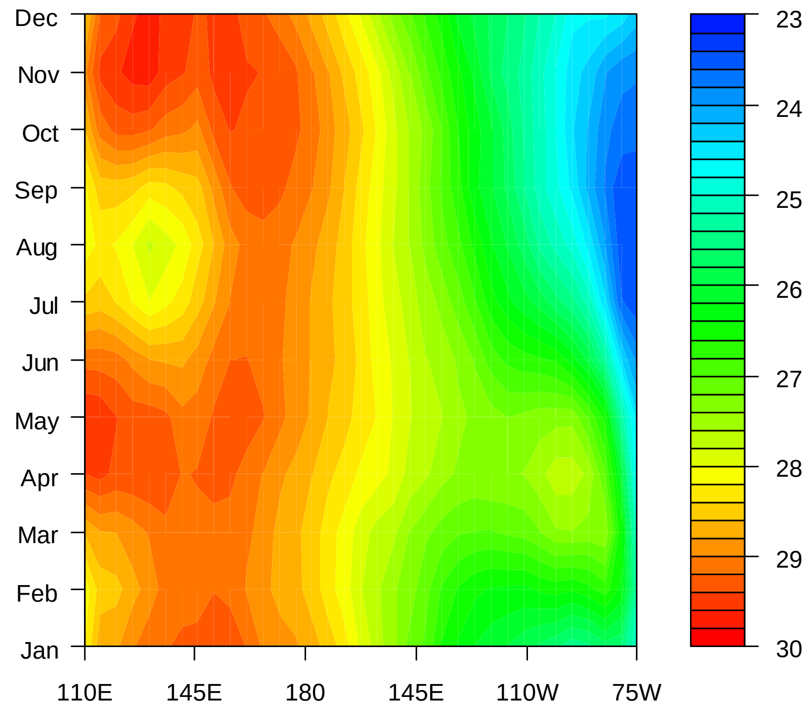
3. Results and discussion

Year-invariant environmental factor (median of 10 years)

Sea surface height anomaly



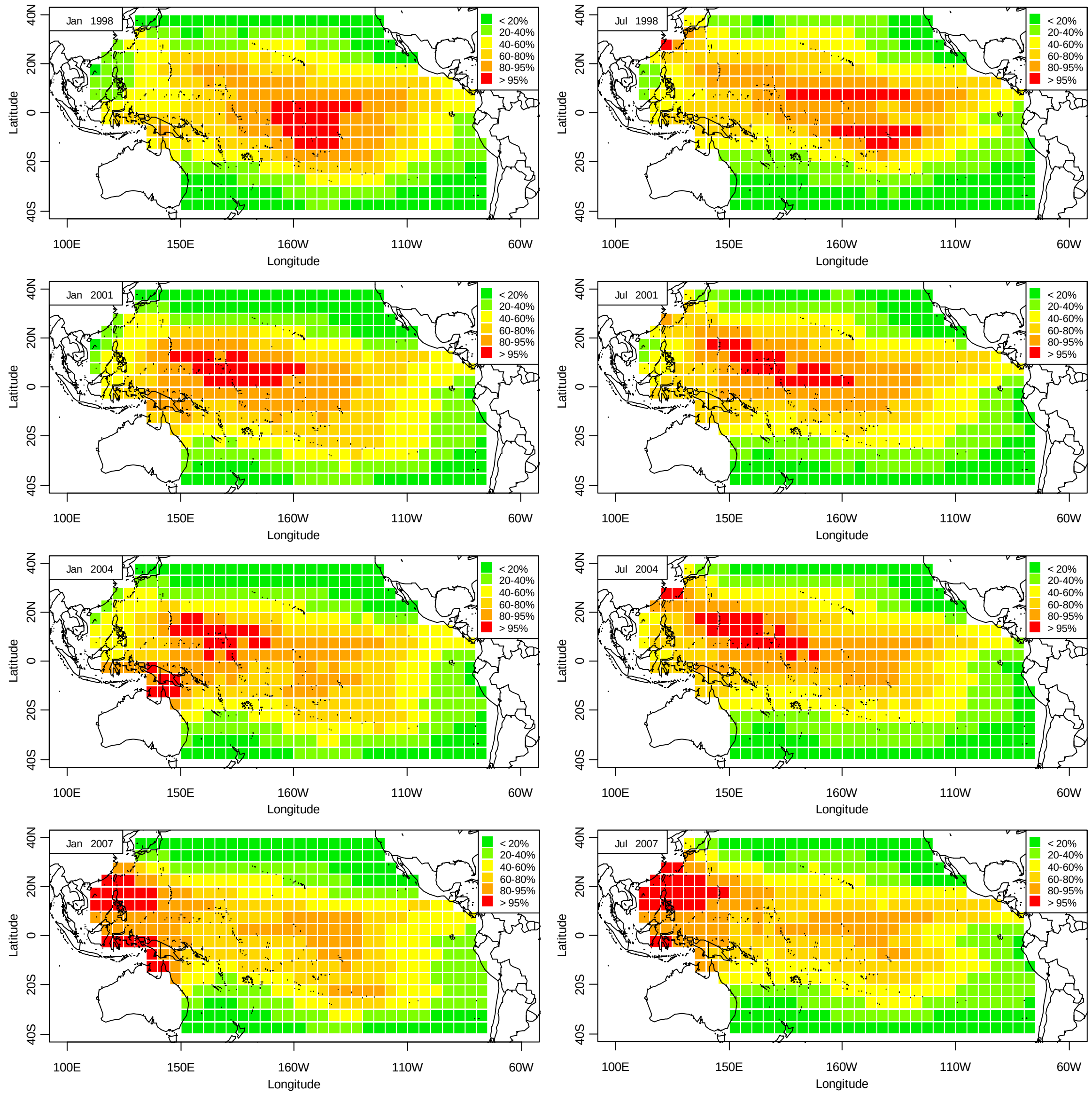
Sea surface temperature



3. Results and discussion

PLL

1998
to
2007



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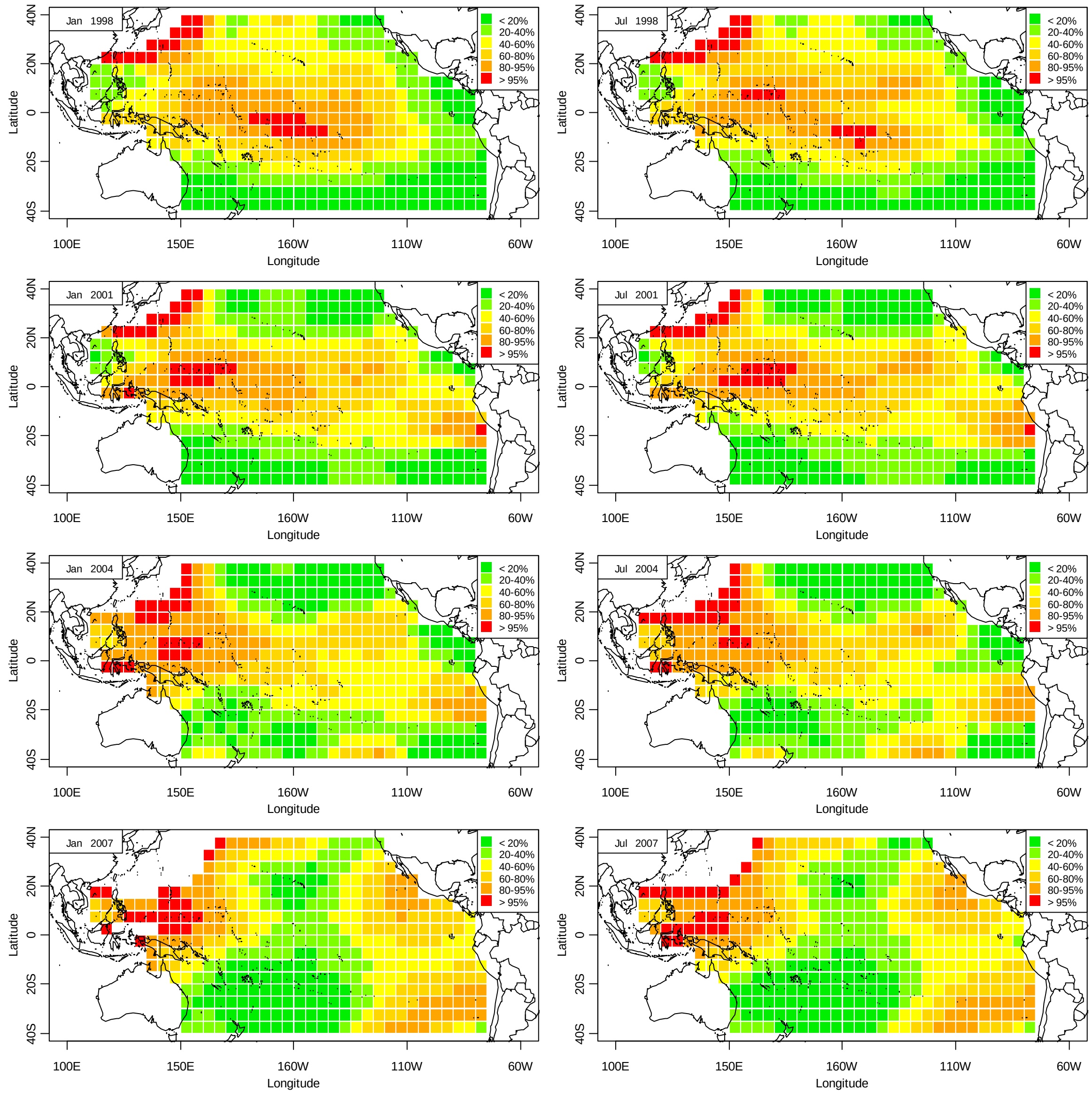
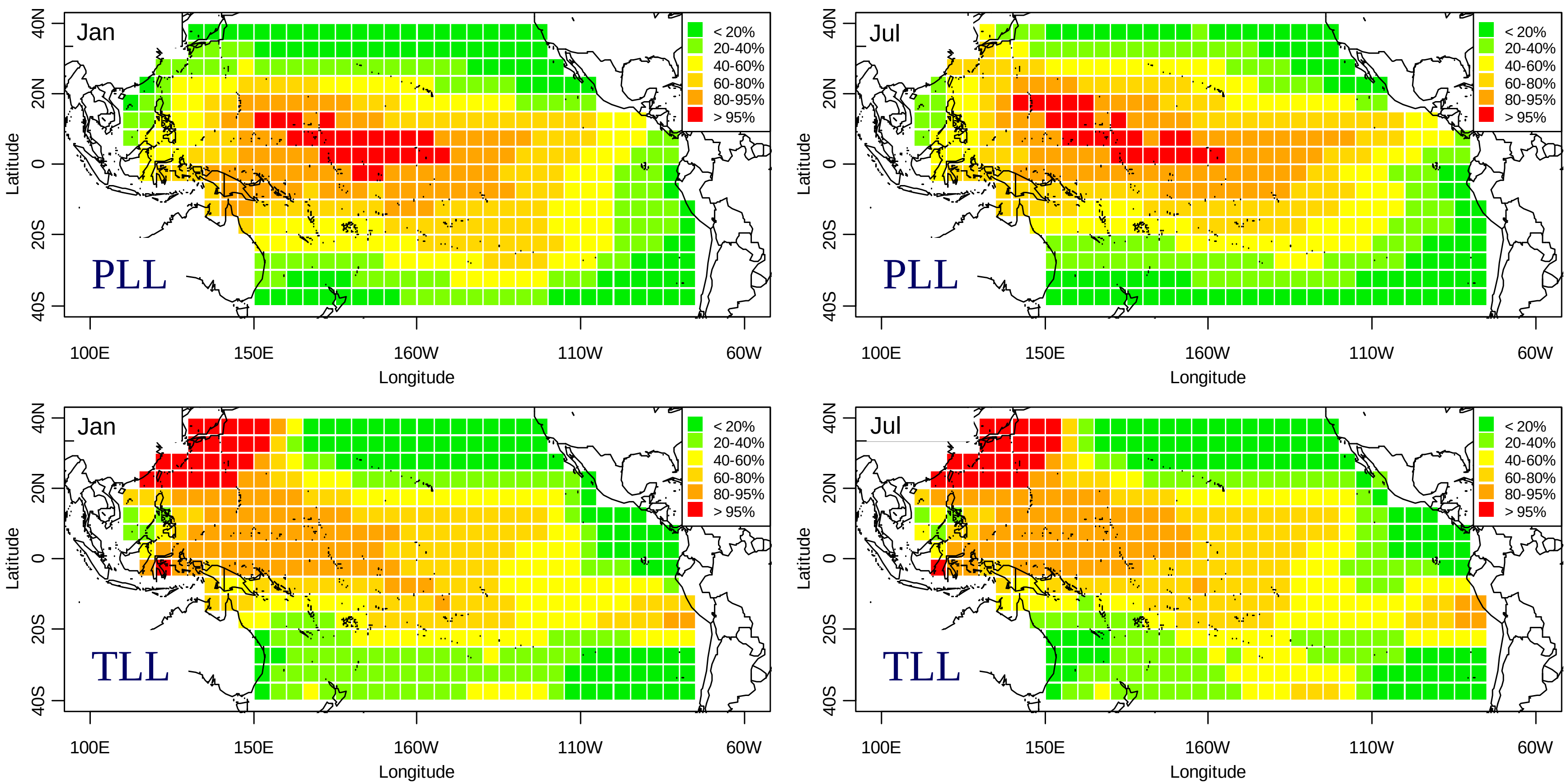
TLL

1998
to
2007



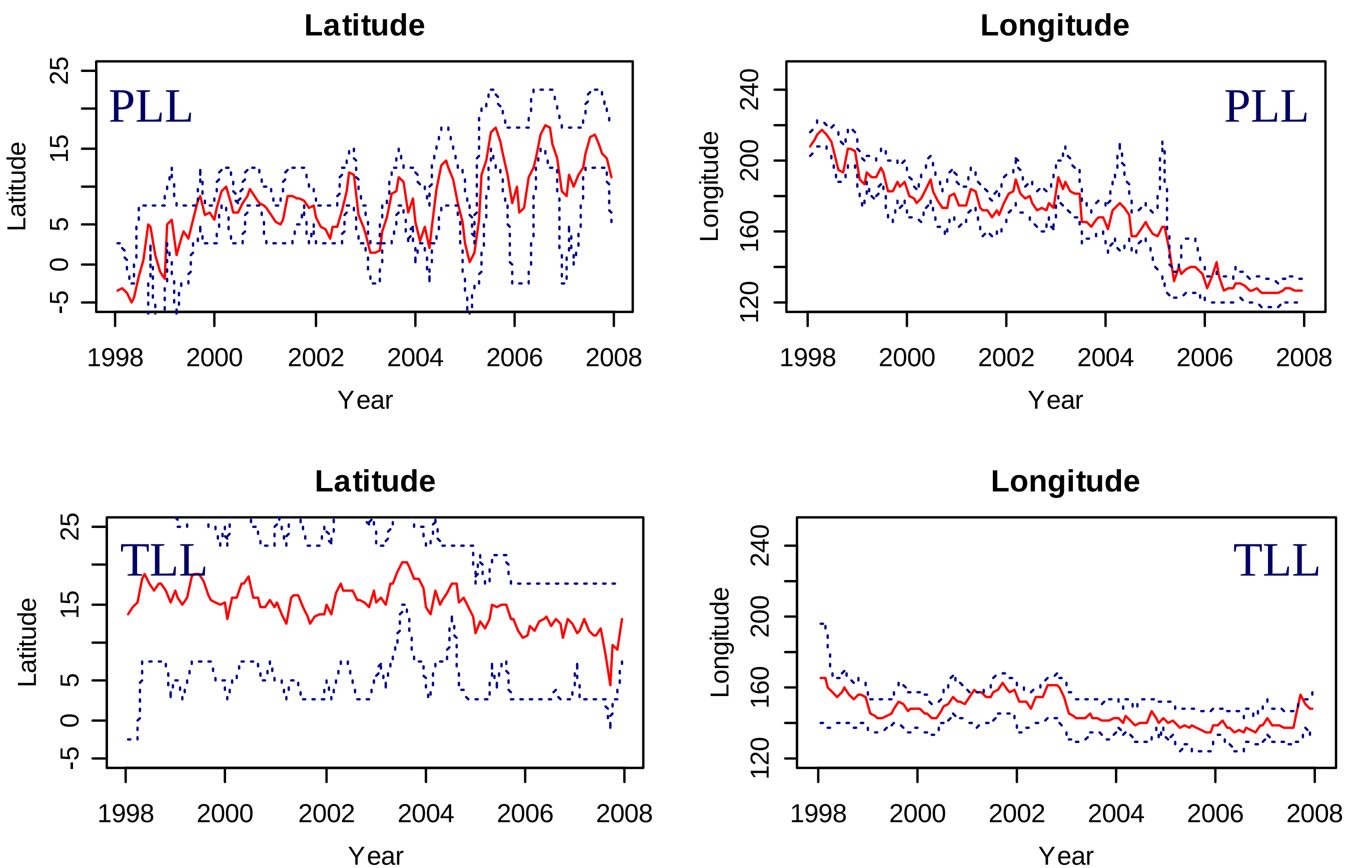
3. Results and discussion

Year-invariant relative density without climate change



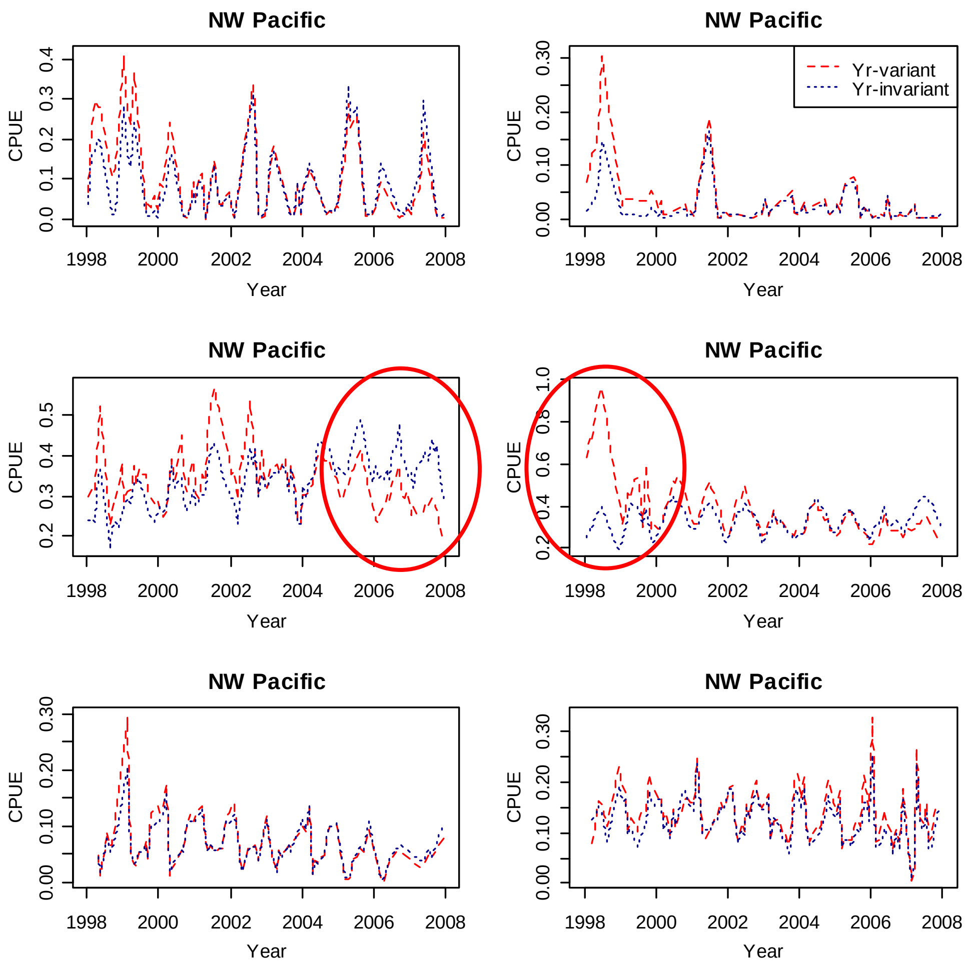
3. Results and discussion

Track the hotspot areas for PLL and TLL



3. Results and discussion

Relative density by region for PLL



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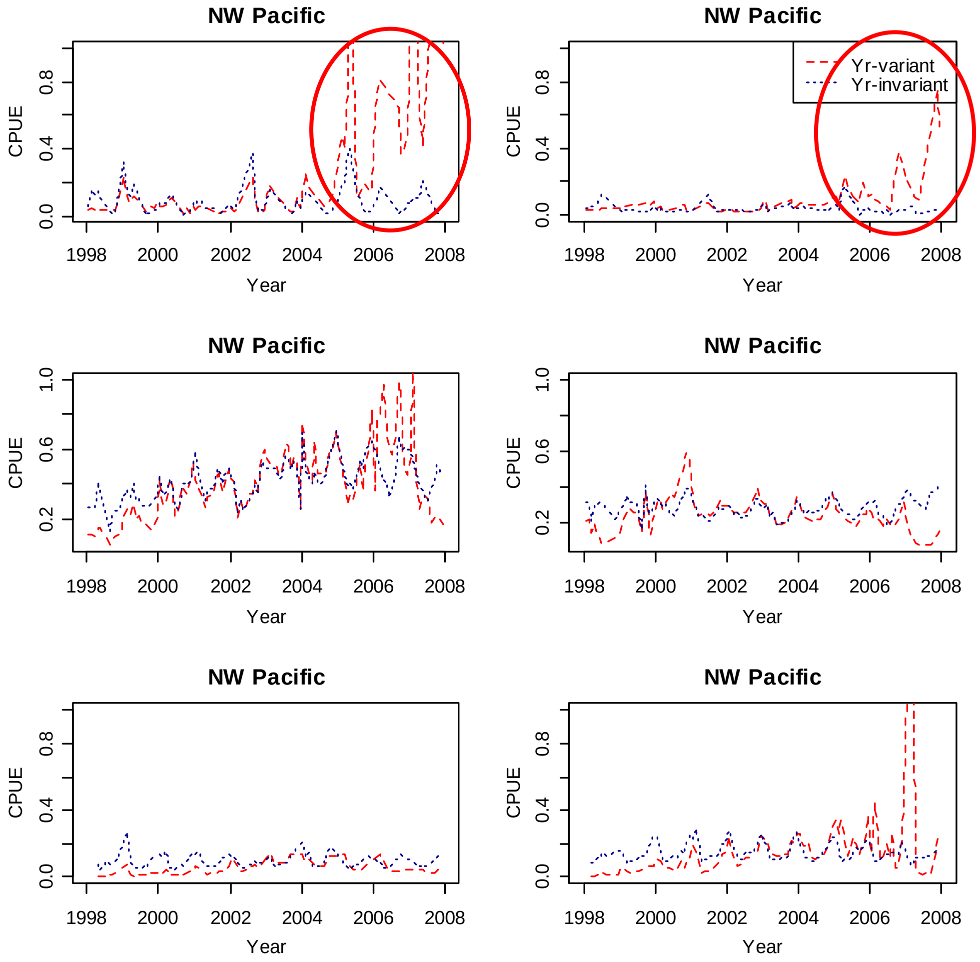
Relative density by region for TLL



3. Results and discussion

Conclusions

- The blue marlin population apparently moved eastwardly during the 1997-1998 El Niño in the tropics
- Yearly patterns in distribution appear to be associated with the El Niño event and related to shifts in SST

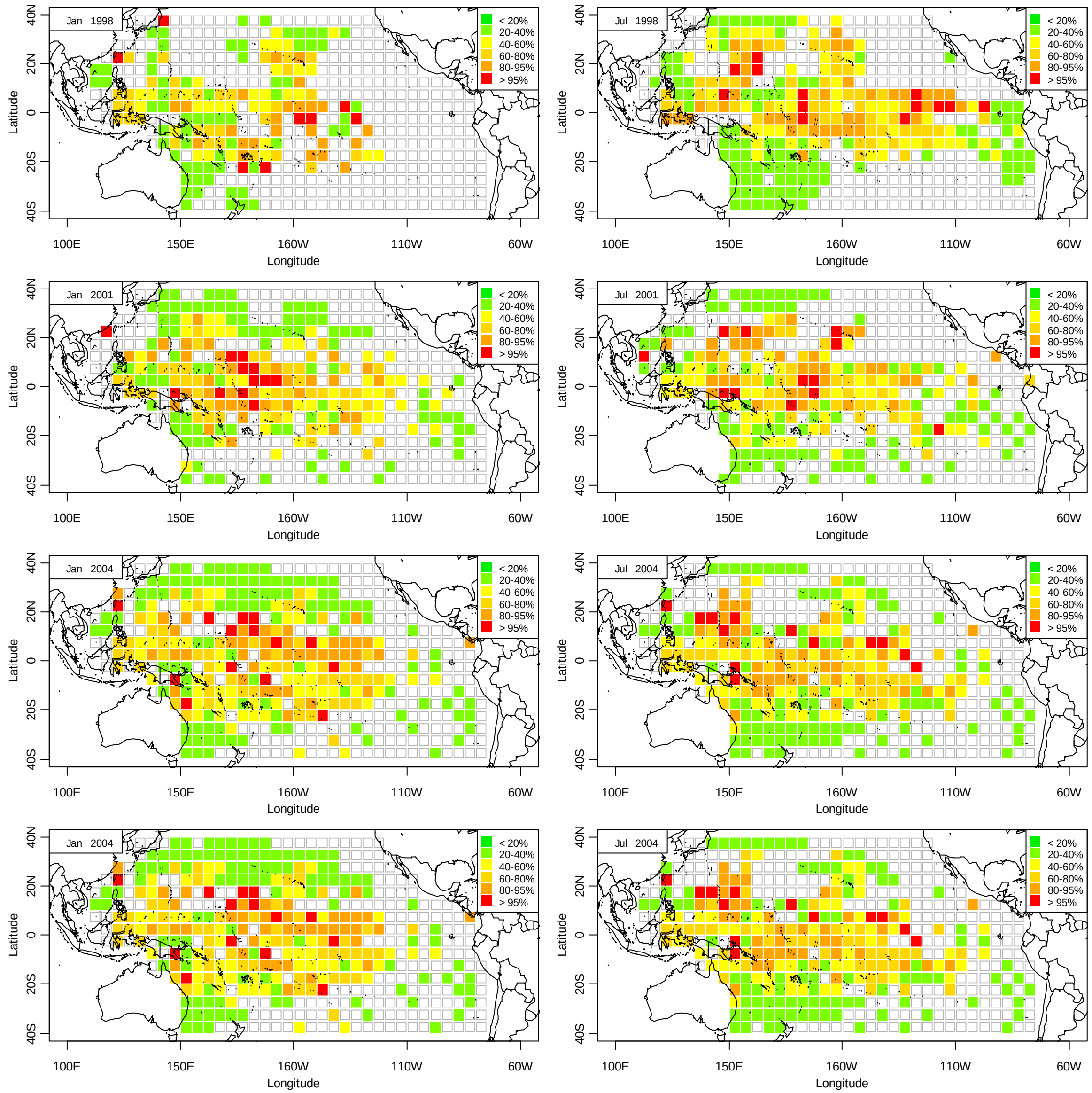
Future directions

- Increase spatial and temporal coverage of data set
- Include more explanatory variables, e.g. fishing gear


Thank you !!

3. Results and discussion

PLL



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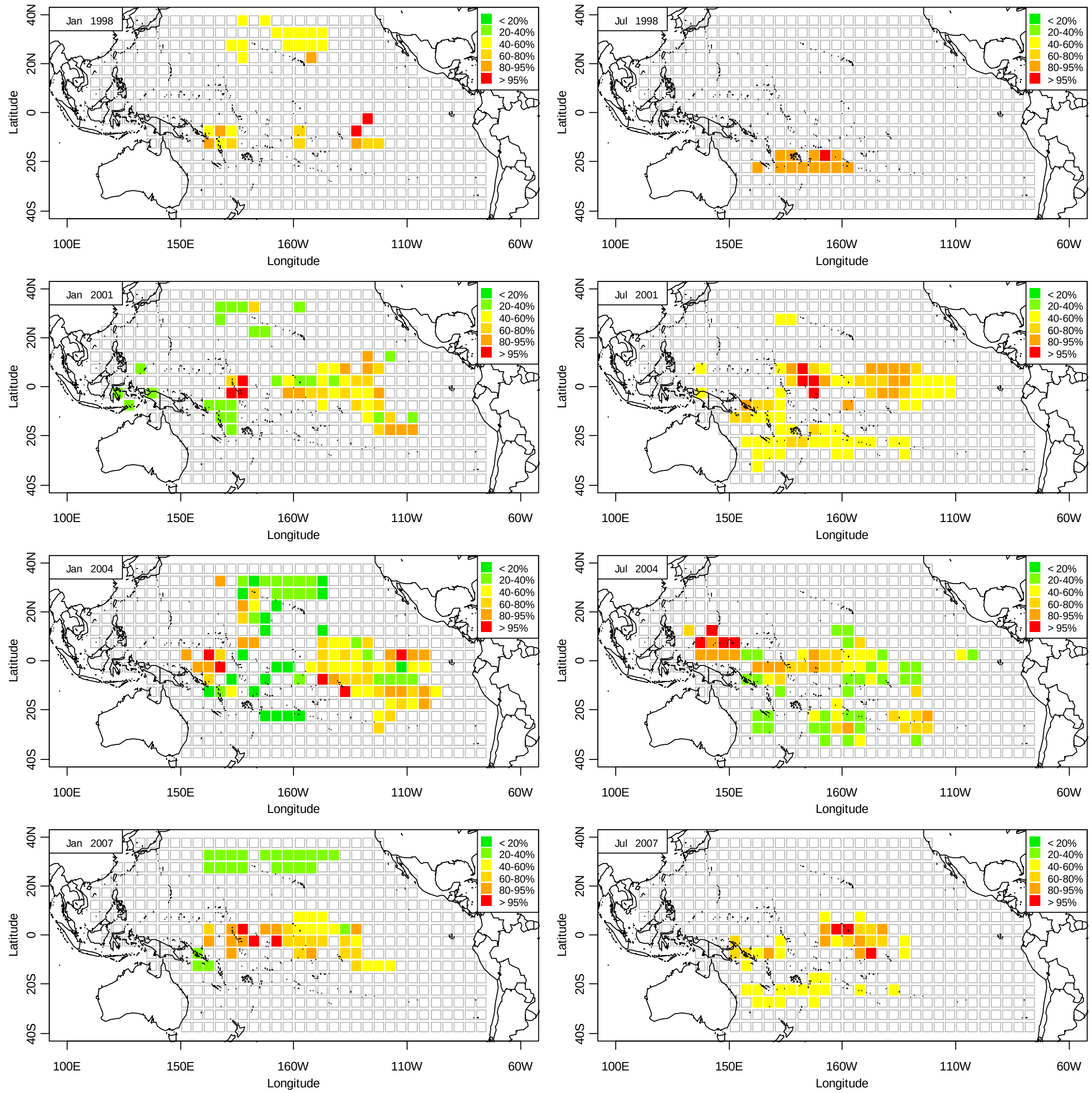
TLL



3. Results and discussion

Predicted catch = predicted CPUE x observed fishing effort