Understanding the spatial habitat distribution of moonfish (*Mene maculata*) in southwestern Taiwan in relation to oceanographic factors

Aratrika Ray[1], Riah Irawati Sihombing[1], Sandipan Mondal[1,2], Ming-An Lee[1,2] & Yi-Chen Wang[1,2]

[1]Department of Environmental Biology & Fisheries Sciences, National Taiwan ocean University

[2]Center of Excellence for Ocean Engineering, National Taiwan Ocean University

No. 2, Beining Rd, Zhongzheng District, Keelung City, 202

Email: aratrikaray25@gmail.com

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Abstract

This study used geometric mean model (GMM) to predict moonfish abundance using ten oceanographic predictors: sea surface chlorophyll-a (SSC), mixed layer depth (MLD), dissolved oxygen (O), pH, sea surface height (SSH), sea surface salinity (SSS), sea surface temperature (SST), northward velocity (V), eastward velocity (U), and eddy kinetic energy (EKE). Southwestern Taiwan's major fishing seasons—October to April from 2014 to 2019—showed higher catch from January to April. Therefore, only these four months were analyzed. SSH had the highest GAM parameter contribution for this species, followed by MLD. The optimal ranges for the parameters are SSC: 0.3-0.5 mg/m³, MLD: 40-44 m, O: 210-215 mmol/m³, pH: 8.08-8.1, SSH: 0.65-0.7 m, SSS: 34-35 PSU, SST: 22°-24°C, U: 0-0.2 m/s, V: -0.1-0.2 m/s, and EKE: 0-0.1 m²/s². Based on these environmental features, predictive moonfish distribution maps are credible. S. CPUE was highest between 22°-24°N and 119°-121°E. Average catch weight was highest at 23.5°N and lowest at 26.5°N. The prediction was the highest in January and the least in April.

Introduction

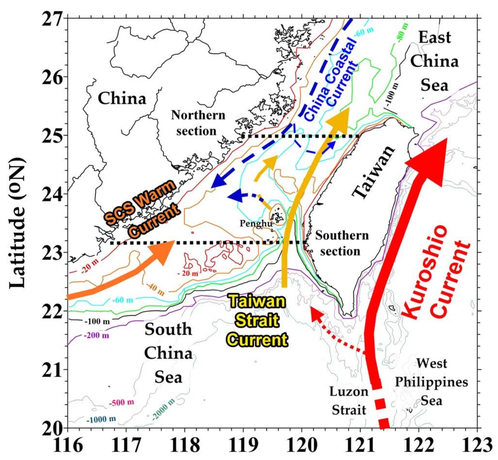


Figure 1: Study area and schematic current. Black dashed lines delineate northern and southern sections in the Taiwan Strait.

Popular commercial fish in Taiwan

Major fishing gear: Taiwanese seine

Common prey for larger pelagic apex predators

Declining catch potential in Central Taiwan and Penghu

Climatic data → Ocean data → Presence-absence data → Habitat/ climatic change projection → Suitability maps → Climatic data

Sustainability Development Goals 13 & 14

Scientific classification	
Kingdom:	Animalia
Phylum:	Chordata
Class:	Actinopterygii
Order:	Carangiformes
Family:	Menidae
Genus:	*Mene*
Species:	***M. maculata***

Methods

Environmental data (Satellite remote-sensing observation data: 0.083° X 0.083°)

Copernicus Marine Services (Level 4 data)

Part 1: Data standardization

2014 - 2019

Nominal catch per unit effort (N. CPUE)

Regression models (General additive model GAM)

1. Year
2. Month
3. Latitude
4. Longitude
5. CT No.
6. Gear ID
7. SST
8. Best interactions

N.CPUE standardization

Standardized CPUE (S.CPUE)

Part 2: Understanding environment - S.CPUE relationship

Management

Climate regimes

Heat maps

Geometric mean model (GMM)

GMM prediction

Moonfish presence data

Predictor variables

Spatiotemporal analysis

GAM standardization

Removing sampling bias

10 data models

Model fitting and quality evaluation
AIC, Deviance explained, GCV

Model selection

Selected model (least AIC and GCV)

GMM prediction

Habitat prediction (mean predicted probability)
Current suitability

Climate change scenarios
Forecasting

Future scope

Predictor variables: Sea surface chlorophyll-a (SSC), Mixed layer depth (MLD), Dissolved oxygen (O), pH, Sea surface height (SSH), Sea surface salinity (SSS), Sea Surface Temperature (SST), Eastward velocity (U), Northward velocity (V), Eddy kinetic energy (EKE)

Results

Monthly catch variation and environmental parameter estimation by GAM

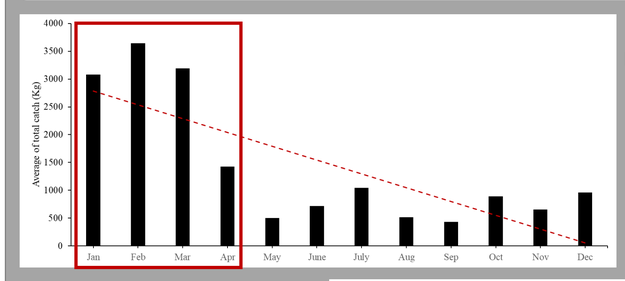
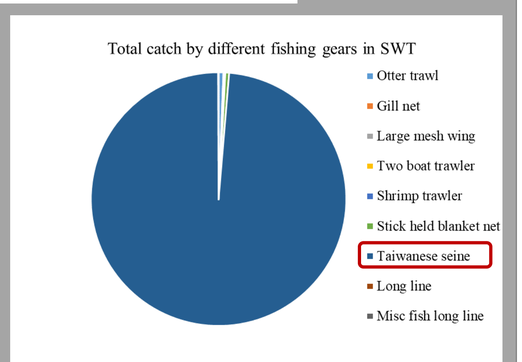


Figure 2: Average of total catch of moonfish from 2014 to 2019 by all types of fishing gears used in SWT.

Figure 3: Contribution of different fishing gears in total moonfish catch in SWT from 2014 to 2019. Taiwanese seine had the highest percentage of fish catch in all the years (~99%).



Parameters	df	AIC	Adj. R^2	R	Deviance explained	GCV
SSH	**10.81693**	**44953.46**	**0.158**	**0.39749**	**15.90%**	**10.739**
MLD	**10.91737**	**45244.81**	**0.129**	**0.35917**	**13%**	**11.108**
pH	**10.91541**	**45599.88**	**0.0922**	**0.30364**	**9.32%**	**11.575**
SST	10.59909	45836.35	0.067	0.25884	6.79%	11.897
O	10.83774	45842.32	0.0663	0.25749	6.73%	11.905
SSC	10.9473	45905.14	0.0595	0.24393	6.05%	11.992
V	10.9426	46070.67	0.0413	0.20322	4.23%	12.224
U	10.25776	46182.87	0.0287	0.16941	2.96%	12.384
SSS	10.55349	46255.77	0.0205	0.14318	2.14%	12.489
EKE	**10.73885**	**46270.38**	**0.0188**	**0.13711**	**1.98%**	**12.511**

Table 1: Environmental parameters contribution through GAM.

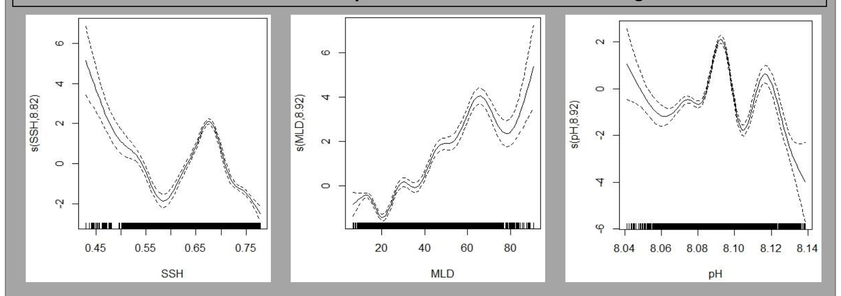


Figure 4: The regression curves of the three chosen environmental parameters in GAM. The dashed line represents the 95% confidence limit.

Standardization of nominal catch per unit effort (N. CPUE) by GAM

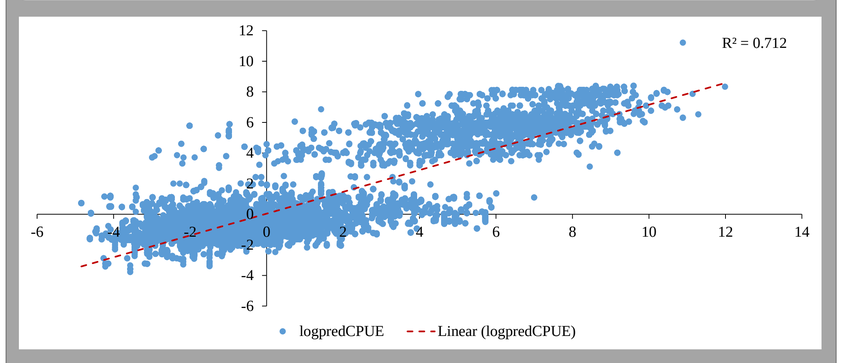
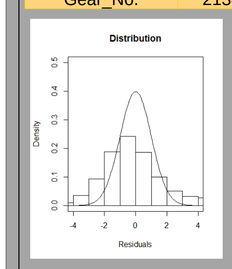


Figure 5: Performance of the final GAM used for standardization with R^2 = 0.712 between nominal and standardized CPUE of moonfish.

Parameter combinations	AIC	BIC	Adjusted R^2	Deviance explained (%)	GCV
Month, Gear_No.	208464.9	208741.2	0.661	66.1	2.5306
Year, Gear_No.	208977.5	209252	0.658	65.8	2.5542
Lat, Gear_No.	209185.1	209457.5	0.656	65.6	2.5637
Lon, Gear_No.	209185.1	209457.5	0.656	65.6	2.5637
CT_No, Gear_No.	210686.2	210960.7	0.647	64.7	2.6342
Gear_No.	213475.5	213573.3	0.628	62.8	2.7704

Table 2 (up): The contribution of variable interactions as tested by GAM.



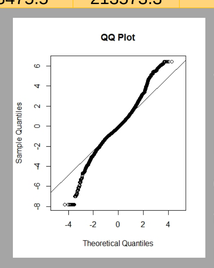


Figure 6 (left): Residual histogram distribution and quantile-quantile plots for the chosen GAM model for moonfish N. CPUE standardization.

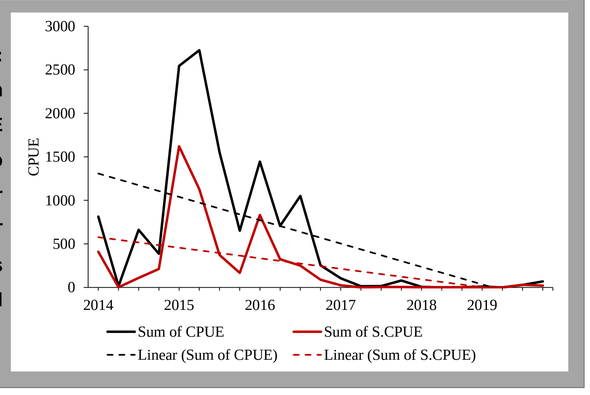


Figure 7: Spatiotemporal variation of N. CPUE and S. CPUE between January to April, 2014 to 2019 for moonfish in SWT waters. Both the CPUEs show a declining trend from 2014 to 2019.

GMM and predicted monthly habitat maps of moonfish (*Mene maculata*)

Model	Parameters	a	b	R squared	df	AIC	BIC
AMM	SSH, MLD	-579.636	4315.542	0.9208597	3	152.2879	153.1957
GMM	**SSH, MLD**	**182.9854**	**3661.611**	**0.8999143**	**3**	**151.5796**	**152.4874**

Table 3: Comparison of the model combinations by AMM and GMM using forward stepwise with the best two remotely-sensed satellite environmental parameters for moonfish in SWT. GMM with SSH and MLD showed the least AIC (151.5796) and BIC scores (152.4874) (highlighted in green) that was further used to predict moonfish habitats.

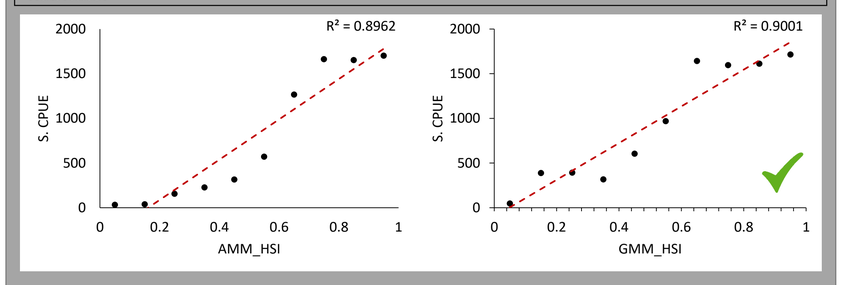


Figure 8: Performances of AMM and GMM with the chosen environmental parameters. GMM was chosen as it had the least AIC and BIC compared to AMM.

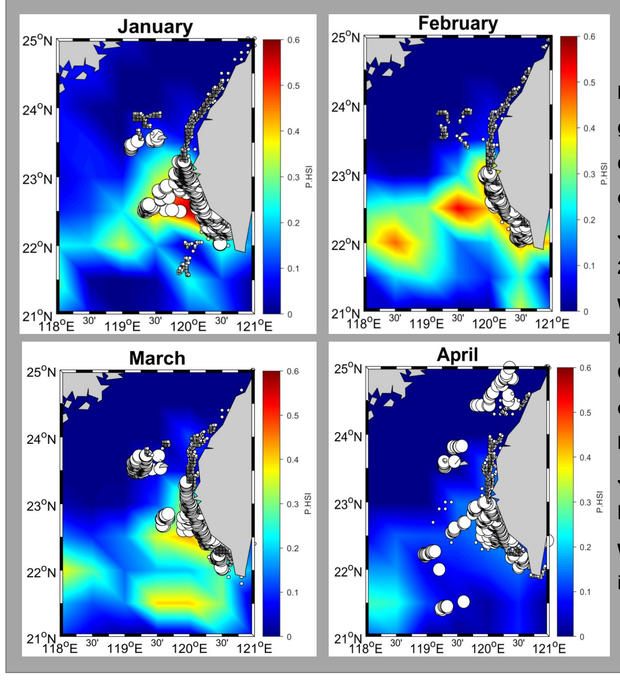


Figure 9: Monthly geographical habitat distribution pattern of moonfish during January to April from 2014 to 2019. The white circles indicate the standardized CPUE in the considered month. Higher HSI is seen in January within the high predicted zone while the last HSI is in April.

Conclusion

- Major fishing season in SWT is from January to April
- Decreasing habitat suitability from January to April as summer begins
- SSH appears to be the most important parameter as it helps in fish spawning
- Fishing gear is significant in analyzing fisheries production
- Reduced moonfish catch may also be due to overfishing as reported previously
- Commercial fishing can be better directed by practical applications

Future recommendations

- To understand the impacts of climate change on fisheries and marine systems using an economic framework
- To forecast projections of future climate scenarios
- Use of higher-resolution catch and effort and ocean data may provide more useful results for fisheries management
- All types of fishing gears to catch moonfish may be considered

Limitations

- Life stages of moonfish were not identified
- The species may have different oceanographic preferences during feeding and spawning times
- Reduced moonfish catch despite high effort may be due to reduced catch of other species