Seasonal Variation of Fish Catches and Fisherman Practices for Sustainable Fishery Management in Songkhla Lake, Thailand

Ha Thi Thu Hue

A Thesis Submitted in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Marine and Coastal Resources Management

Prince of Songkla University

2019

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Major Program	Marine and Coastal Resources Management

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....

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Dean of Graduate School

This is to certify that the work here submitted is the result of the candidate's own investigations. Due to acknowledgement has been made of any assistance received.

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Major Advisor

....Signature

(Assoc. Prof. Dr. Apiradee Lim)

Co-advisor

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Co-advisor

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(Ms. Ha Thi Thu Hue)

Candidate

I hereby certify that this work has not been accepted in substance for any degree and is not being currently submitted in candidature for any degree.

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Thesis Title Seasonal Variation of Fish Catches and Fisherman Practices for Sustainable Fishery Management in Songkhla Lake, Thailand

Author Ha Thi Thu Hue

Major Program Marine and Coastal Resources Management

Academic year 2018

ABSTRACT

The study was conducted in Songkhla lake, Thailand from 2017 to 2018. The data collection was done from primary and secondary sources. The results of an assessment of the relationship among amout of rainfall, air temperature and landings of different commercial species were obtained. The present study showed an effective tool for making accurate forecasts, time series analysis techniques and Seasonal Autoregressive Integrated Moving Average (SARIMA) models were used to analyze monthly fish and shrimp catch landing trends recorded for Songkhla lake during (2003-2016). These models were well-chosen for explaining the time series and forecasting future catch landings. It was found that both fish and shrimp catch landings tend to fluctuate steadily. The fish catch from 2017 to 2020 was steadily increasing at the average catch of 36.06% for the period 2003-2016, while the shrimp catch is decreasing at the average catch of 15.47% for the same period. This study was the first reference on LWR equation parameters of *Pellona ditchella* (Valenciennes, 1847), *Sardinella gibbosa* (Bleeker, 1849) and *Alepes vari* (G. Cuvier, 1833) in the lower Gulf of Thailand. This good document would be used to compare these fish condition with many coastal areas in the world. This work provided a wider size range in FishBase, *Pellona ditchella* (Valenciennes, 1847) and *Sardinella gibbosa* (Bleeker, 1849). There were moderately low but significant correlations between the socio-economic data and total catch. There was a significant difference in the mean catch among three seasons. The highest mean total catches of 1,602 ± 136.4 kgs/year/fisher were found in the light rainy season. The lowest mean total catches of 963.3 ± 104.7 kgs/year/fisher were found in the rainy season. Some important findings from this research were that all the interviewed did not have the alternative occupation and were difficult to find another job. Based on the results, this study pointed out some recommendations for forecasting, managing, planning, aimed to contribute fishery sustainable development in Songkhla lake.

ACKNOWLEDGEMENTS

This dissertation entitles “Seasonal Variation of Fish Catches and Fisherman Practices for Sustainable Fishery Management in Songkhla lake, Thailand” has been completed with the supports from Songkhla province, especially Fishermen Community in Songkhla lake. I am appreciated to express my sincere thanks with a deep sense of gratitude to my supervisors: Asst. Prof. Dr. Siriporn Pradit, Assoc. Prof. Dr. Apiradee Lim and Assoc. Prof. Dr. Thongchai Nitiratsuwan for their suggestions and improvement of this dissertation, scientific help, and academic articles. Further, they have continually provided all my necessary requirement for completing my research. I would like to thank my thesis defense committee members, Assoc. Prof. Dr. Sukree Hajisamae and Assoc. Prof. Dr. Shettapong Meksumpun for their valuable ideas to improve the quality of my thesis.

I would like to extend my gratitude to Prince of Songkla University for giving me an opportunity to study in Thailand through a scholarship under Thailand’s Education Hub for Southern Region of ASEAN countries (Grant No: THE-AC 070/2016). In addition to this, I am also pleasured to Research Fund from Graduate School and COCC for working field that was fantastically supported to all my activities during my studying.

I am grateful to the lectures, academic staff, and students at Marine and Coastal Resources Institute, Prince of Songkla University, where I had lots sharing knowledge for carried out experiments for this study. All people in MACORIN helped me to cover document under administrative formative for University requirements.

By the way, I would like to take this opportunity to express my big thanks to National Institute of Coastal Aquaculture (NICA) leaders and staffs, the fishermen communities in 8 villages, MACORIN research assistance team for supporting, advising the technical terms, giving me golden chances to join field work, providing me accommodations.

I am pleasured to the international environment sharing with international students from other countries, which was not only academic knowledge of research but also cultural behavior among us. That had provided me to go ahead to complete the study and reduce the homesick when I studied far away from my homeland. The sincere thanks to my international and Thai friends in MACORIN.

It is undoubted fact that family is extremely important part of my habitat; I would also like to thank my family, especially my mother, without their supports, I cannot go to Thailand and concentrate on studying, thanks my son, Minh Tung and my daughter, Ha Anh for understanding and sympathizing me because I could not take care them during the time I was studying here, thanks my dear friends from my country for helping me to look after my family when I am far away from Vietnam.

Hopefully, this dissertation will be contributed a part of academic knowledge for readers and brought a usefulness of the society in the future.

Ha Thi Thu Hue

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LIST OF ABBREVIATIONS

Akaike's information criterion	AIC
Analysis of variance	ANOVA
Artificial neural network	ANNs
Autocorrelation	AC
Autoregressive	AR
Biochemical Oxygen Demand	BOD
Dissolved Oxygen	DO
K-nearest neighbor	KNN
Kilogram	Kg
Kilometer	Km
Length Weight Relationship	LWR
Marine and Coastal Resources Institute	MACORIN
Mean Absolute Error	MAE
Mean Squared Error	MSE
Meter	M
Moving Average	MA
Multivariate Adaptive Regression Splines	MARS
National Institute of Coastal Aquaculture	NICA
Partial Autocorrelation	PAC

LIST OF ABBREVIATIONS (CONT.)

Schwartz's Bayesian Criterion	SBC
Seasonal Autoregressive Integrated Moving Average	SARIMA
Smallest of Mean Errors	SME
Southern Oscillation Index	SOI
Statistical Package for Social Sciences	SPSS

LIST OF PAPERS

1. Hue, H. T. T., Pradit, S., Lim, A., Nitiratsuwan, T., Jualaong, S., Kobkeatthawin, T., Azad, S.M.O. and Goncalo, C. 2018. A case study of the correlation between landings and environmental factors in the Songkhla lake, Thailand. EnvironmentalAsia journal. (Submitted).
2. Hue, H. T. T., Pradit, S., Lim, A., Goncalo, C. and Nitiratsuwan, T. 2018. Shrimp and fish catch landing trends in Songkhla lake, Thailand during 2003-2016. Applied Ecology and Environmental Research, 16(3): 3061–3078. doi: 10.15666/aeer/1603_30613078. (ISI)
3. Hue, H. T. T., Pradit, S., Janunee, C., Lim, A., Nitiratsuwan, T. and Goncalo, C. 2018. Physical properties of three Songkhla Lake fish species in the lower gulf of Thailand during and after the monsoon season. Applied Ecology and Environmental Research, 16(5): 6113-6127. doi: 10.15666/aeer/1605_61136127. (ISI)
4. Hue, H. T. T., Pradit, S., Lim, A., Nitiratsuwan, T. and Goncalo, C. 2018. Seasonal aspects and the adaptation of fishermen in the Songkhla Lake, Thailand. Asian Journal of Microbiology, Biotechnology and Environmental Sciences, 20(4): 1349-1355. (Scopus)
5. Hue, H. T. T., Pradit, S., Lim, A., Nitiratsuwan, T., Jualaong, S. and Goncalo, C. A comparative study of Artificial Neural Network, Multiple Adaptive Regression Spline and K-Nearest Neighbors for predicting fish catch landing in Songkhla Lake, Thailand. Proceeding book, 1st International Conference on Climate Change, Biodiversity, Food Security and Local Knowledge, Kupang, East Nusa Tenggara, Indonesia, September 3rd – 4th 2018, pp. 75-90
6. Hue, H. T. T., Pradit, S., Lim, A. and Nitiratsuwan, T. Social Aspects to fish catch in Songkhla Lake, Thailand. International Conference on Energy and Environmental Science on 26th-29th January 2019, South Korea. (Accepted paper).

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Date: 30.9.2018
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Social Aspects to Fish catches in Songkhla Lagoon, Thailand

(International Conference on Energy and Environmental Science on 26th-29th January 2019, South Korea – Accepted paper)

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Title: Social aspects to fish catch in Songkhla Lagoon, Thailand

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We are looking forward to meeting you in **Seoul, Korea.**
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CHAPTER I: INTRODUCTION

1.1.Background and rationale

Songkhla lake is one of the two lakes in the world that has Irrawaddy dolphins (*Orcaella brevirostris*), which are endangered species. The lake is divided into three distinct parts. The southern part of the lake is connected to the Gulf of Thailand through a 380 meter (m) wide strait Songkhla lake. It is very rich regarding biodiversity and provides resources and livelihoods for local fishermen all year around (Pornpinatepong et al., 2010).

Small-scale fisheries is a main source of livelihood for people living in the coastal areas of many places in the world, Mexican state of Baja California Sur (Sievanen, 2014), in the Gulf of Thailand (Satumanatpan and Pollnac, 2017), Coastal areas of Songkhla province (Hue et al., 2018), the livelihood of more than 1.9 million population of the 25 districts located in the three provinces of Southern Thailand rely on this fishery resource (NSO, 2012).

As in many other similar ecosystems elsewhere (Martínez et al., 2007; Satumanatpan and Pollnac, 2017), those resources have been declining sharply over recent decades. Many fishermen in two of these coastal areas are wondering whether they can sustain themselves through fishing or if they must convert to another occupation. Many of them have already moved to other fishing areas or changed profession.

For the effective socio-economic and environmental management and in aiming for sustainable development of fishery resources, it is vital to know the reasons that cause the decline of fish catch, the seasons and the trends of fish catch in the future, the condition of Songkhla fish species in the coastal area for doing the migration of fish, the adaptation of fishers to the changes of fish catch and their future point of view, aims to remain stable livelihood for the local community.

As part of the efforts to create policies for sustainable fishing in Songkhla province and improve the livelihoods of fishing communities dependent on the coastal resources, numerous studies were conducted in the past two decades in Songkhla province, focusing mostly on models of fish catch landing (Chesoh and Lim, 2008; Chesoh, 2009; Chesoh and Choonpradub, 2011); or the effects of chemical contamination (Pradit et al., 2013). Other research has dealt with the government-led shrimp restocking program (Xu et al., 1997; Davenport et al., 1999; Wang et al., 2006; Hamasaki and Kitada, 2013). However, the lack of the information that this study implemented include:

Rainfall and temperature have been shown to have and are expected to continue having an impact on fishing activities in different contexts (Roessig et al., 2004). The decision to fish has been shown to be modulated by the rainfall (George et al., 1962), and there have been studies of the effects of rainfall and temperature on the catch of marine species in large embayment, or gulf ecosystems (Sutcliffe et al., 1977; Vance et al., 1985), as well as in estuaries (Meynecke et al., 2006; Ayub, 2010; Sutcliffe et al., 1977). In contrast, the impacts of rainfall and temperature on fishery landings in lake ecosystems is an area that is relatively underexplored, with only few studies on this subject.

This is what this study intends to address, presenting the results of an assessment of the relationship between rainfall and air temperature, and landings of different commercial species in the Songkhla lake in Southern Thailand.

There is a growing body of literature that recognizes the importance of statistical models in forecasting as well as in analyzing fish catches in Songkhla Lake over the last few decades. Significantly, Chesoh and Lim (2008) used a linear regression model for forecasting fish catches during 1977-2006. The structure of the fish community was analyzed using a clustering model (Chesoh and Choonpradub, 2011), the method for analyzing fish assemblage distribution (Chesoh and Choonpradub, 2009). However, historical time series fish catch data usually cover a long time, which includes seasonal and non-seasonal periods. The seasonal ARIMA model, therefore, is widely used for time series forecasting and resolves the problems of season and non-season of the data by describing the autocorrelations of the data.

Fish catch landing data depends not only on human activities, but also very much on the weather. Normally this data changes over time. Artificial neural network (ANNs) models were used in this study to compare with Seasonal Autoregressive Integrated Moving Average (SARIMA) models because ANNs have some advantage over other forecasting models. ANNs are powerful nonlinear regression techniques (Bishop, 1995; Ripley, 1996; Titterington, 2010). Nowadays, ANNs have been used widely in time series forecasting due to their ability to approximate various nonlinearities in the data (Zhang, 2003). The significant advantage of ANNs is no prior assumption of the model form is required in the model building process; moreover, the network model is mainly determined by the characteristics of the data.

These marine fish species are important commercial fishes that can be found frequently at the local market, however, the information about their living condition is rare. Previous research on these fishes focuses on *S. gibbosa* and includes a study on the genetics and morphology of cryptic species of *S. gibbosa* (Thomas et al., 2014); the confirmation of presence of *S. gibbosa* in the Red sea and documenting its introduction into the Eastern Mediterranean Sea (Stern et al., 2015); heavy metal contamination in *S. gibbosa* in the coast of Balochistan, Pakistan (Ahmed et al., 2015); and stock assessment of *S. gibbosa* in the Gulf of Thailand (Boonjorn et al., 2012). The ecology or the living conditions of these fishes is rare, let alone of monthly or seasonal changes in those two aspects. This study addresses this gap by studying monthly and seasonal changes in the length–weight relationship of these species. It provides an account of investigations carried out in both Songkhla lake and Sathing Pra, in a context of sharp decline in fish catches in Songkhla lake. It concentrates primarily on the populations and general biology of those fishes, growth and related aspects, thereby providing early findings to inform further research on measures to enhance fish populations in Songkhla lake.

Evidently, these social and cultural aspects of marine fisheries are often neglected in developing fishery policy and management, in the efforts of handing out the decline of fish stocks, they only focus on the biological and economic impacts of fishing (Urquhart et al., 2013). To achieve sustainable fishery development, it is vital to integrate environmental, economic and social dimensions.

This study was conducted to find out the direct reasons from fishermen may impact on the decline of fish catch on the social aspects and how the fishermen in Songkhla lake adapt with the descent of fish catch both now and in the future.

1. 2. Objectives

The overall goal of the study is to investigate the fishing activities in Songkhla lake and give out the recommendations for sustainable fishing activities. To do this goal, the details of the objectives of this study are as follows:

1. To investigate the correlation between fish, catch landing with the rainfall and air temperature.

2. To find the suitable model for forecasting fish catch landing in Songkhla lake.
3. To compare the condition of three fish species in rainy and summer season.
4. To describe the seasonal variations and the fishermen practices with the changes of fish catches.

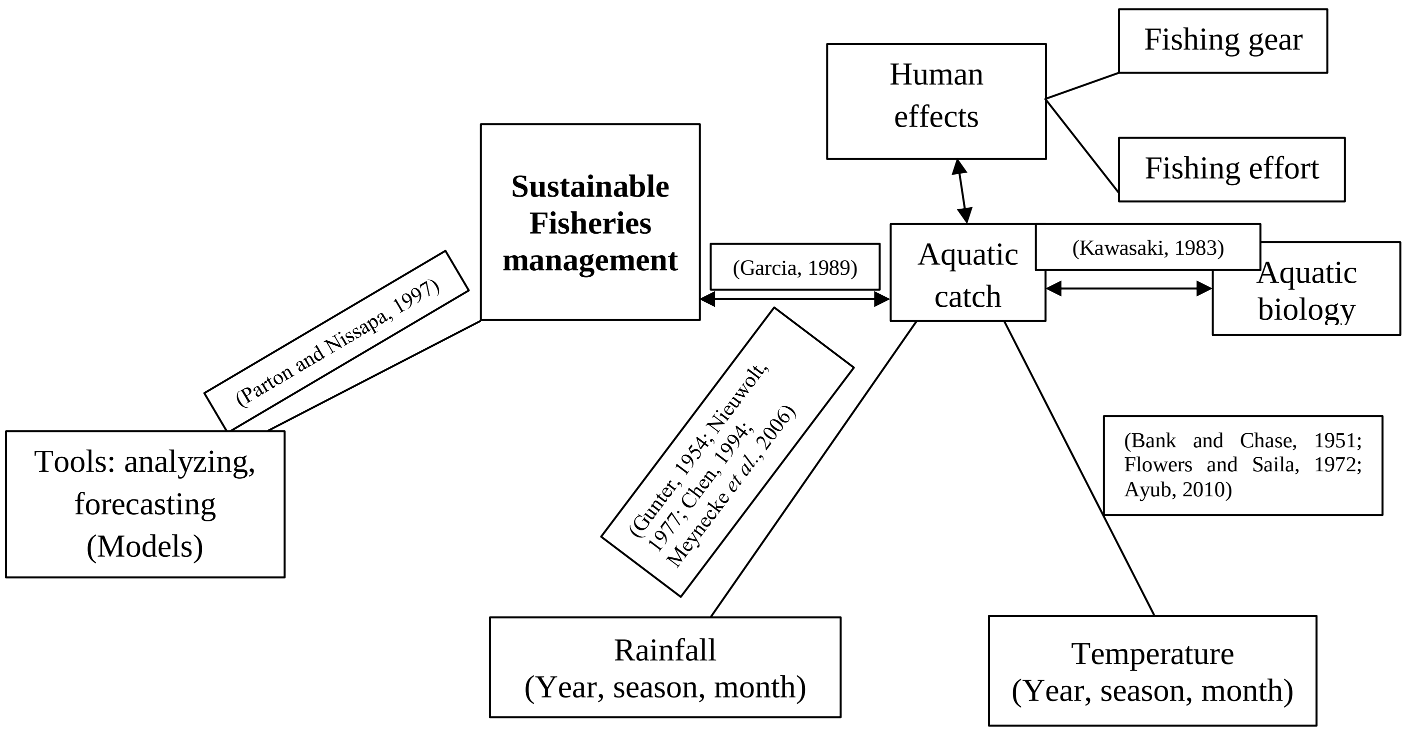
1. 3. Scopes of the study

This study concentrated on fishing activities in Songkhla lake. Mainly, the fish catch landings in Songkhla lake and the condition of three dominant marine fish species that were found frequently in Songkhla lake.

The study focused mainly on amount of rainfall and air temperature.

Interviewing fishermen: the study concentrated on fishermen and the head of village in eight villages in Songkhla lake.

1. 4. Path diagram



CHAPTER II: RESEARCH METHODOLOGY

This chapter explained details of the study area, general procedures and methodology for specific studies on:

a) The correlation between fish catch landing with the rainfall and air temperature
b) Statistical modeling for forecasting fish catches landing
c) The condition of three fish species in rainy and summer season
d) Seasonal variation and fishermen practices in fishing.

2.1. Description of study area

Two different coastal areas of Songkhla province were selected for this study (Figure 1), Songkhla Lake and Sathing Pra district, where many local fishers are staying and doing fishing.

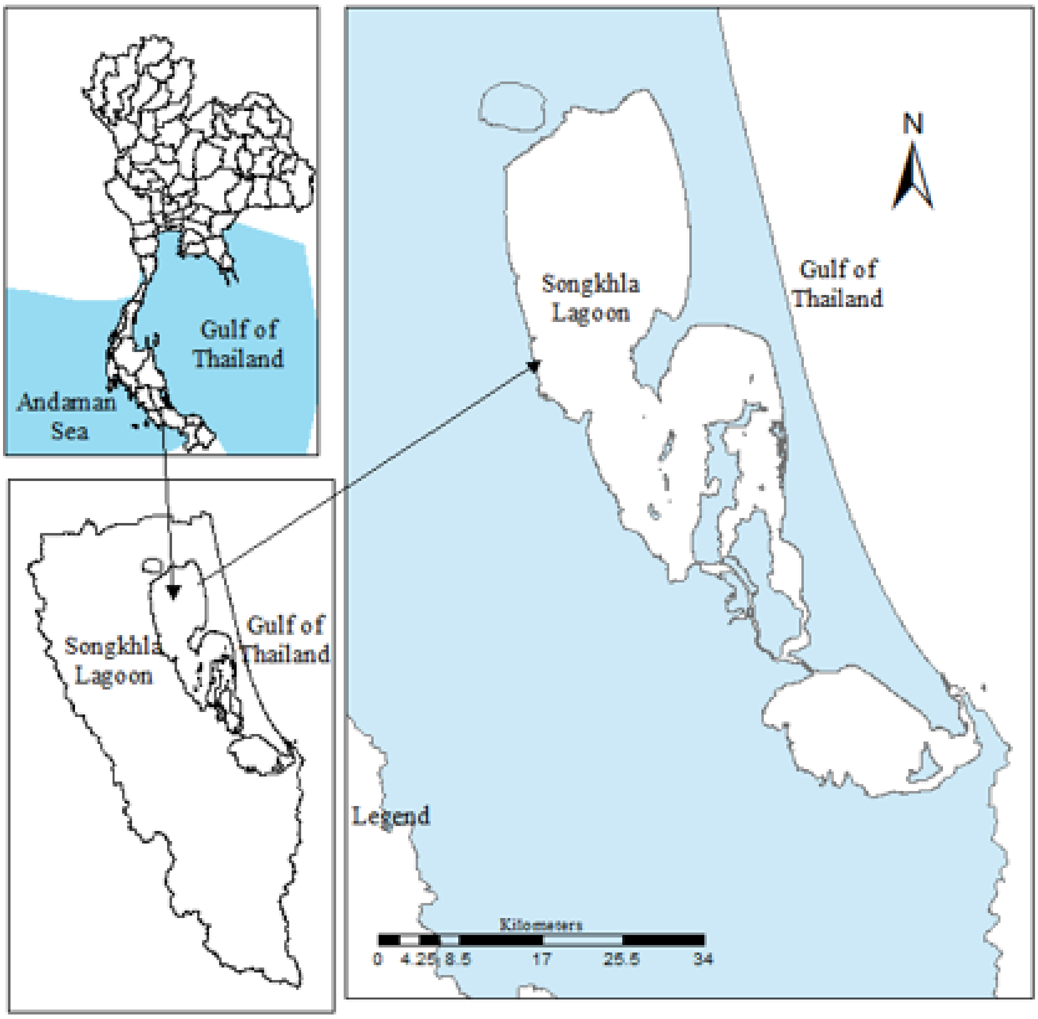


Figure 1. Location of study site

Songkhla lake is a shallow coastal lake, situated in the Southern part of Thailand with the surface of approximately 1,042 km^2 (Ratanachai, 2005). The lake plays important role in supplying natural and economic resource for the people who live in Songkhla Province, Phatthalung Province and some parts of Nakhon Si Thammarat Province, as a major fish stock for local fishermen. The lake is divided into 4 sections: Thale Noi, Inner Section, Middle Section and Outer Section. The deeper in the Inner Section with more than 2 m, and quite shallow in the Middle and Outer Section.

2.2. Methodology for the correlation between fish catch landing, the rainfall, air temperature

2.2.1. Data collection

Secondary data of 14 dominant species of fish, shrimp, and crab were collected from National Institute of Coastal Aquaculture (NICA). This data was collected every month from 37 middle men around Songkhla Lake during 2003-2016.

The rainfall data for this study was collected from 7 stations: Hatyai, Songkhla, Singhanakorn, Sathingpra, Krasaesin, Ranot, Bangkham, these gauging stations were selected due to the weather data was consislift net over a long time and have direct effects on the Songkhla Lake with the high number of fisheries catch records, located near Songkhla Lake. The amount of rainfall every month data at every location was provided by the Songkhla Meteorological Department, Government of Thailand.

The data of air temperature was collected from Meteorological Department, Ministry of Information and Communication Technology, Thailand.

2.2. 2. Data Analysis

For the purpose of this study, data of fish, shrimp and crab catch species, rainfall and temperature were rearranged as monthly, yearly and grouped into 3 seasons every year during the period of 2003-2016 (rainy season – October to January (S1); summer season – February to May (S2); and the interseason – June to September (S3)) (Samphan, Promhom, 2015).

The catch landing of species from the present season was analyzed correlation with the total of rainfall and mean air temperature from the previous season. The fish life cycles, such as feeding and movement are most likely influenced by environmental factors at shorter annual or seasonal period (Meynecke *et al.*, 2006), that is why monthly rainfall, monthly temperature were analyzed with monthly catch data.

2.2.3. Statistical Analysis

Autoregressive Integrated Moving Average (ARIMA) models were used to choose the appreciated models for predicting some missing values for each variable (Preciado et al., 2006). Each data was checked the normal distribution by frequency histogram, boxplot, and Shapiro-Wilk normality test. The null hypothesis of Shapiro-Wilk normality test is data is normally distributed, the study used significant P-value 0.05 to reject or accept the null hypothesis. The Tukey's Ladder of Powers was used to transform unnormal distribution data (Tukey, 1977). This approach uses a power transformation on a data set, which integrated Shapiro-Wilk normality tests. In essence, this finds the power transformation that makes the data fit the normal distribution as closely as possible with this type of transformation. Significant outliers of each data were treated before analyzing data.

To see whether two measurement variables are associated with each other, whether as one variable increase, the other tends to increase or decrease, the study used Pearson correlation coefficient (Sedgwick, 2012; McDonald, 2009). The Pearson correlation coefficient measures the strength of linear association between two variables. The null hypothesis for each test was the correlation between each species catch and rainfall or temperature is zero with the chosen significant level of P-value 0.05 to reject or accept the null hypothesis. The strength of the relationship between two variables was estimated through r correlation coefficient and scatter plot. The formula for r correlation coefficient between two measurement variables was shown:

$$r = \frac{\sum_{i=1}^{n}(x_i = \bar{x})(y_i - \bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i - \bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i - \bar{y})^2}} \qquad \text{(Eq 1)}$$

While: n: sample size

x_i, y_i single samples indexed with i

$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$; $\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$ (the sample mean);

Data was analyzed by using open R software.

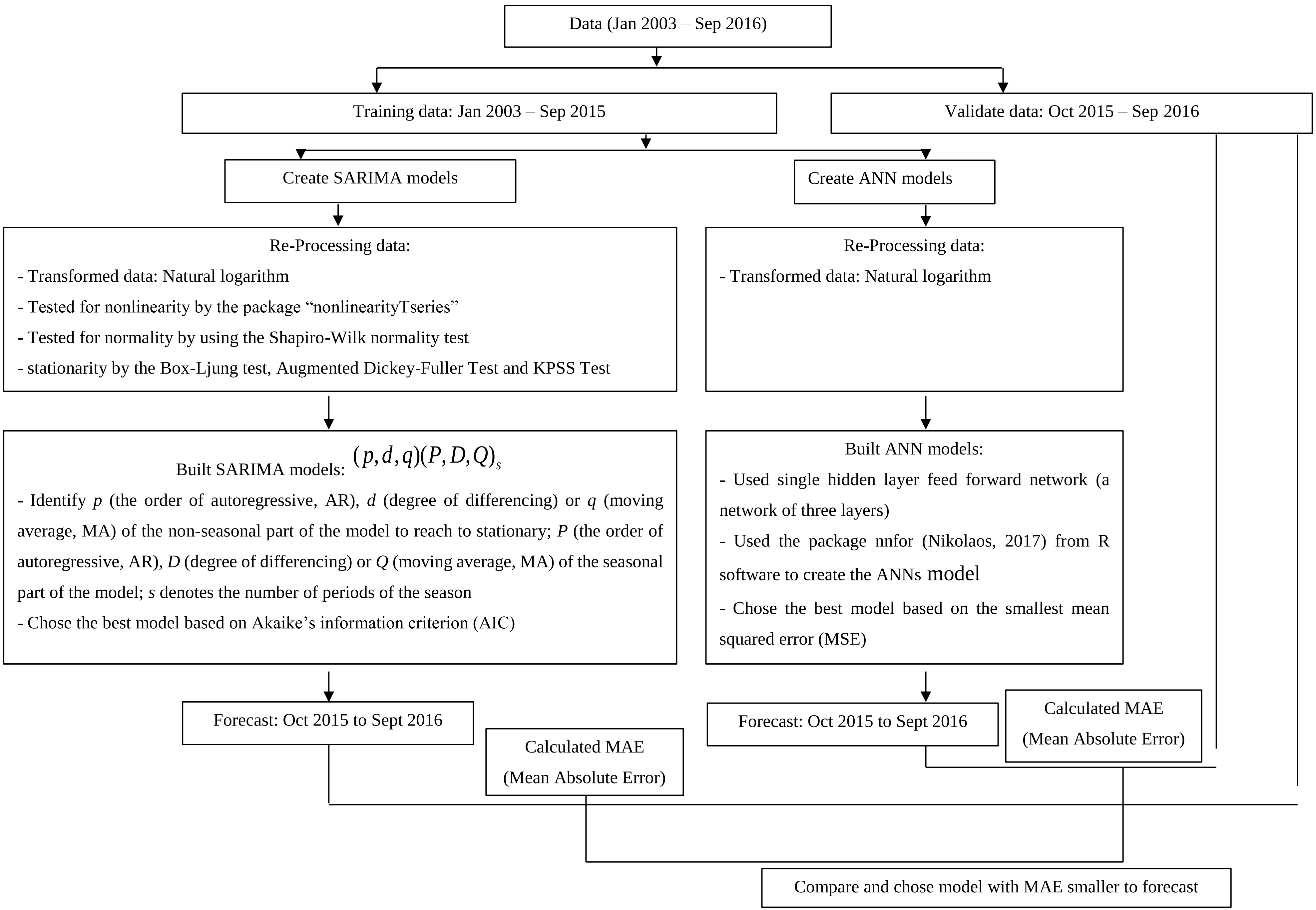
2.3. Methodology for Statistical modeling for forecasting fish catch landing

2.3.1. Data collection

Secondary data of fish and shrimp catch landing was collected from National Institute of Coastal Aquaculture (NICA). This data was collected every month from 37 middle men around Songkhla Lake during 2003-2016.

2.3.2. Data and statistical analysis

The whole data analysis and statistical analysis process to choose the best model for forecasting fish, shrimp catch landing to 2020 is summarized in the flow following chart:


Data (Jan 2003 – Sep 2016)
Training data: Jan 2003 – Sep 2015
Validate data: Oct 2015 – Sep 2016
Create SARIMA models
Create ANN models
Re-Processing data:
- Transformed data: Natural logarithm
- Tested for nonlinearity by the package "nonlinearityTseries"
- Tested for normality by using the Shapiro-Wilk normality test
- stationarity by the Box-Ljung test, Augmented Dickey-Fuller Test and KPSS Test
Re-Processing data:
- Transformed data: Natural logarithm
Built SARIMA models: $(p,d,q)(P,D,Q)_s$
- Identify p (the order of autoregressive, AR), d (degree of differencing) or q (moving average, MA) of the non-seasonal part of the model to reach to stationary; P (the order of autoregressive, AR), D (degree of differencing) or Q (moving average, MA) of the seasonal part of the model; s denotes the number of periods of the season
- Chose the best model based on Akaike's information criterion (AIC)
Built ANN models:
- Used single hidden layer feed forward network (a network of three layers)
- Used the package nnfor (Nikolaos, 2017) from R software to create the ANNs model
- Chose the best model based on the smallest mean squared error (MSE)
Forecast: Oct 2015 to Sept 2016
Calculated MAE (Mean Absolute Error)
Forecast: Oct 2015 to Sept 2016
Calculated MAE (Mean Absolute Error)
Compare and chose model with MAE smaller to forecast

2.4. Methodology for Statistical modeling for forecasting fish catch landing based on other factors

2.4.1. Data collection

32 data sets were recorded every three months for 8 years (2009-2017) by Department of Environment in Songkhla province. Quarterly data for mean temperature, rainfall, water parameters from three stations located in the upper, middle and lower parts of Songkhla lake, mean of these factors were used to be input variables in the models.

The total of fish catch landing was selected from National Institute of Coastal Aquaculture (NICA), Thailand quarterly in February, May, August, and November during 2009-2017, and it was hypothesized to depend on environmental parameters, the depth of the lake, air temperature, water temperature, pH, turbidity, conductivity (CO), Salinity (Sal), Dissolved Oxygen (DO), Biochemical Oxygen Demand (BOD), rainfall.

2.4.2. Data analysis

Pre-processing data was done before building the models to remove the water temperature, CO, BOD that have high correlation with Air temperature, Salinity, DO. This feature extraction technique was done by using principle component analysis (Kuhn and Johnson, 2013). All predictors were normalized and satisfied the qualifications for using to create models.

Multiple Adaptive Regression Splines (MARS)

Multivariate adaptive regression splines (MARS) is a procedure for fitting adaptive non-linear regression that uses piece-wise linear basis functions to define relationships between a response variable and some set of predictors (Friedman, 1991). MARS fundamentally builds optimal models in two steps. In the first step, MARS builds a collection of Basis Functions (BF), which are transformations of independent variables considering nonlinearities and interactions in the model. In the second step, MARS estimates a least-squares model with its Basis Functions as independent variables. MARS's capability to handle nonlinearities and interactions in complex data structures makes it particularly suited to fish catch applications. MARS algorithm is automatically select and evaluate the important levels of predictors in the model. All steps of creating and validating MARS models were implemented by using the package “earth” in R software (Stephen, 2018).

K-nearest neighbor model (KNN)

The KNN approach simply predicts a new sample using the K-closest samples from the training set. Its construction is solely based on the individual samples from the training data. To predict a new sample for regression, KNN identifies that sample’s KNNs in the predictor space. The predicted response for the new sample is then the mean of the K neighbors’ responses (Kuhn and Johnson, 2013). All predictors were centered and scaled prior to performing KNN then selected the distance metric, the next step is to find the optimal number of neighbors. K can be determined by resampling. All steps of creating and validating KNN models were implemented by using the package “caret” in R software (Max, 2018).

Artificial neural network model (ANN)

Artificial neural network (ANN) emulating the biological connections between neurons are known as soft computing techniques. The processing ability of the network is stored in the inter unit connection strengths, or weights, which are tuned in the learning process. The training algorithm (or learning) is defined as a procedure that consists of adjusting the weights and biases of a network that minimize selected function of the error between the actual and desired outputs (Gareta et al., 2006; Kalogirou, 2003; Karataş et al., 2009). ANN models provide an alternative approach to analyze the data, because they can deduce patterns in the data. In this study, a simple process element of the ANN was used which has three layers; the input, hidden, and output layers. The input and output layers are defined as nodes, and the hidden layer provides a relation between the input and output layers.

The depth, Air temperature (AirT), pH, Tur, Salinity (Sal), DO, rainfall (rain) are considered as the process parameters. The input layers of the ANN consist of seven neurons whereas the output layer has a single neuron that represents the predicted value of fish catch landing. Since the input parameters were in different ranges, these parameters were normalized within 0.1–0.9 ranges to prevent the simulated neurons from being driven too far into saturation. All the predictors were scaled and centered prior to modeling (Kuhn and Johnson, 2013). The neuralnet package (Stefan and Frauke, 2016) in R software was used in analyzing data in this study because it is a very flexible package (Günther and Fritsch, 2010).

The used data set consists of 32 patterns, the data is divided into a training data set with 25 patterns and a validation data set (7 patterns) by the percentage (80% and 20%). The models are trained on the training data set. The network calculates the errors on the training data set and the validation data set. Stop training when the validation error is the minimum. This means that the ANN can generalize to unseen data. Cross validation does not apply just to ANN, but it is a way of selecting the best model that produces the best generalization to unseen data. The error during the learning called as mean squared error (MSE).

2.5. Methodology for the condition of three fish species

2.5.1. Data collection

Primary data were collected monthly from fishermen fishing in the coastal are of Sathing Pra district during the period of September 2017 to April 2018, at the sampling sites (07°31’24” N; 100°27’46” E).

The fishing grounds where the specimens were caught are located approximately 3 km from the shores of the Lake. Number Fish specimens were captured with two main fishing gears: fish nets and shrimp nets, at depths of approximately 80, 15 and 20 m, respectively. Fishing usually took place between 3 and 6 am, with some variation between months and seasons. The fishing boats in this coastal area are usually small boats with a length of 7-10 m length and a width of 1.8-2 m.

All specimens were bought from the fishermen, iced and transferred to the laboratory of the Marine and Coastal Resources Institute, Prince of Songkla University (MACORIN), where a verification of the species was carried out, followed by the measurement of the total length and weight. Total length of fish was measured from the tip of the premaxilla to the tip of the longest caudal fin ray stretched out posteriorly. Millimeter was used to be length measurements (Society, 2017). The total weight of fish specimens was recorded with an accuracy of 0.1 g using an Ohaus digital weighing balance (Ajani et al., 2013).

2.5.2. Data and statistical analysis

Length–weight relationship analysis

Linear transformation of fish length and weight was made by using natural logarithm at the observed lengths and weights. The length–weight relationship (LWR) was calculated following Pauly (1983) and used to calculate the regression coefficient (slope of regression line of weight and length). The parameter "β" of the LWR was estimated using Equation 2:

$$W = aL^{\beta} \qquad \text{(Eq 2)}$$

Here: W = the weight of the fish in grams, L = the total length of the fish in millimeters (mm), a = constant, β = growth exponent.

A logarithmic transformation was used to make the relationship linear (Equation 2, (Le Cren, 1951):

$$\text{Log W} = \beta \log \text{L} + \log \text{a} \qquad \text{(Eq 3)}$$

The LWR parameters *a* and β as well as the coefficient of determination (R^2) were derived by least squares regression (Ricker, 1973). The slope (β) also known as the allometry coefficient, has an important biological meaning, indicating the rate of weight gain relative to growth in length or the rate at which weight increases for a given increase in length.

Inferences about slope (β)

If a fish grows without changing its shape or density, then it is said to exhibit isometric growth. In this case, the volume of the fish is proportional to any linear measure of its size and $\beta = 3$. Isometric growth in fish is rare (Mc Gurk, 1985; Bolger and Connolly, 1989). If $\beta > 3$ the fish tends to become "plumper" with an increase in length, a situation called positive allometric growth (Blackwell et al., 2000). If $\beta < 3$ the fish tends to become "thinner" with a decrease in length, a situation called negative allometric growth (R. Froese, 2006).

A test of whether the fish from the lower Gulf of Thailand exhibits allometric growth or not and confidence interval for β can be obtained by fitting the transformed length–weight model. The slope is generically labeled with beta (β) such that the test for allometry can be translated into the following statistical hypotheses:

$$H_0 : \beta = 3 \text{ ("Isometric growth")}$$

$$H_1 : \beta \neq 3 \text{ ("Allometric growth")}$$

Regarding model parameters can be obtained with a t-test using Equation 3*:*

$$t = \frac{\hat{\beta} - \beta_0}{SE_{\hat{\beta}}} \qquad \text{(Eq 4)}$$

where β, SE_β are from the linear regression result and β_0 is the specified value in the H_0. In this study, the hypothesis test that a linear model parameter is equal to a specific value. To test a parameter is equal to a value other than 0, hoCoef meets all the requires and was used to efficiently compute the t and corresponding P-value for non-default hypothesis (for H_0: $\beta = 0$ by default).

Predictions of fish original scale

The study used the result from the length–weight regression to predict the weight of the fishes at the mean length. The result was back – transformed to the original scale by exponentiation. Due to the fact that the geometric mean is always less than the arithmetic means and, thus, the back-transformed mean always underestimates the arithmetic mean from the original scale (Ogle and College, 2013), the final original scale was multiplied with a correction factor derived from analysis of normal and log – normal distribution theory $e^{\frac{(\delta_{Y/X})^2}{2}}$, where $\delta_{Y/X}$ is calculated from summarizing model length–weight regression of fish.

Comparing length–weight regressions (between seasons)

Inter-seasonal variation in the LWR of the fish included in this study was assessed by means of an analysis of variance (ANOVA) of the regression models using the factor season. The statistical significance for the study was set at a P value < 0.05. The full model with indicator and interaction terms was then fit and stored in an object with the ANOVA table. All statistical analysis was performed using the FSA package (Ogle, 2018) from the R software (R Core Team, 2018).

2.6. Methodology for seasonal aspects and the adaptation of fishermen

2.6.1. Data collection

Primary data was collected by conducting survey with 164 fishing households in 8 villages in Songkhla lake and Sathing Pra district, these villages were chosen after doing preliminary research based on the criteria season may affect on fish catch.

To design questionnaires, two preliminary researches were implemented in Songkhla lake and Sathing Pra district to find out background information about fisheries. Themes of questionnaires focused on demographics, information about fishing activities and patterns, perceived changes in fishing and seasons, how do fishers cope with fishing situation, what other kinds of income do they get, do household member engage in, what is the seasonality of these activities, can non-fishing work be alternated with fishing or is it full-time? Does non-fishing work require moving to another location?

Before the interviews took place, 8 studied villages were chosen randomly from 8 districts around Songkhla lake, there was a meeting in the village with a head of the village who was a key-informant, to gain an understanding of the background of fishing. The adaptation of fishermen to response the changes of seasonal and fish catch were explored from two series of structured questionnaires, aimed to know fishermen point of view about their plan in the future. The number of fishermen was interviewed then. The list of households and the number of fishermen in the 8 villages was taken from the head village. In the total of 1608 households, 823 households are doing fishing. 164 fishermen (around 20%) were chosen for interviewing. This sample size is line with the research from (Sievanen, 2014) when they chose 60 household surveys of the approximately 500 households that depend on fishing in the focal communities. At least 15 fishing households from each site was chosen randomly from the list of fishermen by Random and Convenience sample strategies (Robinson, 2014), this sample size is considered sufficient for the goal of describing a shared perception, belief or behavior among a relatively homogeneous group (Guest et al., 2006), and line with the range from 3-16 of (Smith, 2009).

The list of fishing household surveyed was selected from the list of fishermen who have been doing fishing, this list was identified from community leaders, then was selected randomly. The extra list was done in case of the appointed fisher may not be available to be interviewed.

The questionnaires right after that were pretested with 2 fishermen in each area and were revised to suitable with the conlift net and situation.

The data collection via face to face interviews and observations were implemented between February 2018 and June 2018 with the support from interpreter and other investigators. Surveys were conducted using semi-structured questionnaires that facilitated the collection of additional information such as comments from respondents. The questionnaire was formulated in English then translated into Thai and consisted of two parts: the first to the situation of fishing during three seasons in one year, and the second to gain an understanding of the fishermen's perspective relating to the fishing activities, the fishermen's wish or suggestion to improve their situation. All interviews were conducted in Thai. The interviewee will be asked for permission and arrangement of timetable, each interview was taken notes during the interview section. One interview supposes last maximum 1.5 hour to ensure not disturbing to their work. This study did not record interview section to make sure the interviewee feels free to answer all questions and praise up their mind for talking their thinking.

2.6.2. Data and statistical analysis

Data on the total catch in one year was estimated from three seasons. The data were sorted and analyzed using the IBM Statistical Package for Social Sciences (SPSS), version 20 and Microsoft Excel. Both descriptive and statistical data analyses were performed. The calculation of sample means, standard errors, medians, minimum and maximum values, and frequency distributions was conducted.

Inferential statistical analysis was used to discover the relationships among the relevant variables. Because the data was not normally distributed, the Mann–Whitney U test for two variables and the Kruskal–Wallis test for more than two variables were used in SPSS, to analyze the data with any significant differences expressed at the 0.05 level (or higher where indicated in the text). The estimated catch total of fish from two religions in the eight villages was computed based on the data from the questionnaires.

CHAPTER III: RESULTS

3. 1. The correlation between landings and environmental factors

The correlation between fisheries catch landing and rainfall result were very different between species (Table 1).

Table 1**.** Pearson Correlation coefficients (r) between fish catch landings and rainfall during the period 2003-2016 (**P-value<0.05; ***P-value much less than 0.01)

Species	Month		Season		Lag one season		Year	
	r	**n**	**r**	**n**	**r**	**n**	**r**	**n**
Total fish, shrimp and crab catch landing	0.129	163	0.064	39	-0.222	39	0.055	12
Fenneropenaeus merguiensis (De Man, 1888)	0.101	163	-0.228	37	-0.392**	39	0.273	12
Penaeus monodon (Fabricius, 1798)	0.080	163	0.196	39	-0.451***	39	0.063	12
Macrobrachium dacqueti (Sunier, 1925)	-0.016	163	-0.031	39	-0.169	39	0.281	12
Scylla olivacea (Herbst, 1796)	-0.112	163	-0.494***	39	0.091	39	0.068	12
Channa striata (Bloch, 1793)	-0.090	163	-0.073	39	0.071	39	-0.248	12
Penaeus monodon (Fabricius, 1798) (H. Milne- Edward, 1837)	0.160**	163	0.289	39	0.318**	39	0.086	12
Clarias macrocephalus (Gunther, 1864)	-0.131	163	0.005	39	0.274	39	0.039	12
Hampala macrolepidota (Kuhl & van Hasselt, 1823)	-0.016	152	0.279	39	-0.234	39	-0.051	12
Lates Calcarifer (Bloch, 1790)	0.040	163	0.204	39	0.166	39	0.079	12
Valamugil cunnesius (Valenciennes,1836)	0.341***	163	0.608***	39	-0.441**	39	0.535**	12

Species	Month		Season		Lag one season		Year	
	r	n	r	n	r	n	r	n
Platystacus anguillaris (Bloch, 1794)	-0.042	162	0.080	39	-0.057	39	-0.227	12
Notopterus notopterus (Pallas, 1769)	-0.024	163	0.042	39	-0.236	39	0.031	12
Pristolepis fasciata (Bleeker, 1851)	-0.062	163	0.127	39	0.033	39	-0.416	12
Scatophagus argus (Linnaeus, 1766)	-0.053	163	-0.188	39	0.028	39	-0.302	12

In general, the total of fish, shrimp and crab catch were not correlated with rainfall. Other species correlated with rainfall were shown in Figure 2.

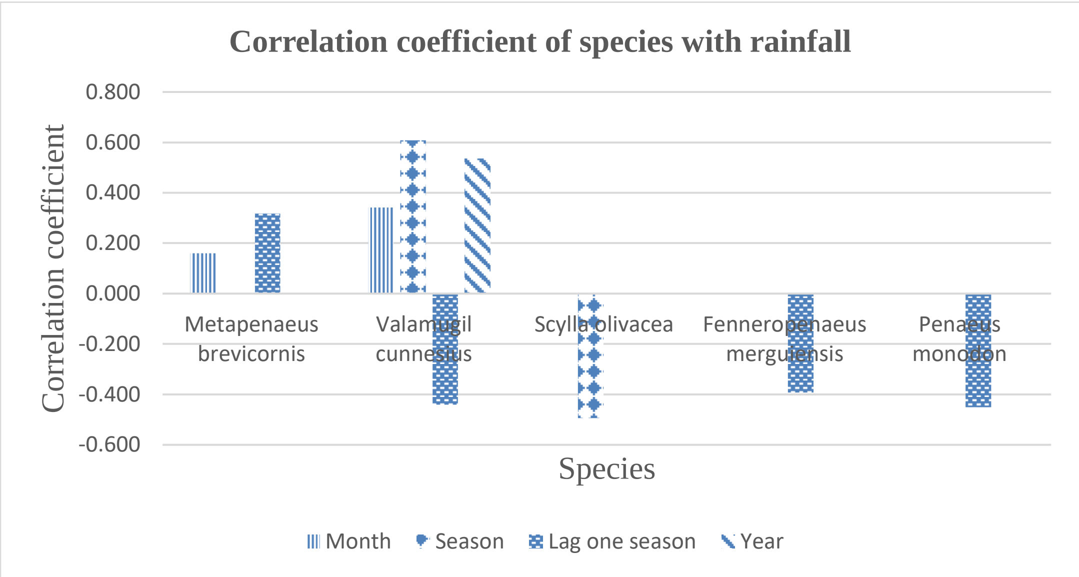


Figure 2. The correlation coefficient of species with rainfall

Among shrimp and crab species selected for analyzing the correlation with the amount of rainfall in this study, *Penaeus monodon* had a strong negative relationship with rainfall lagged one season. *Metapenaeus brevicornis* had a negligible positive correlation with monthly rainfall and positive relationship with lag one season of rainfall. *Fenneropenaeus merguiensis* had a moderate negative with lag one season of rainfall. *Macrobrachium dacqueti* did not have any correlation with rainfall. *Scylla olivacea* had a strong negative correlation with seasonal rainfall.

Along with shrimp and crab species, nine fish species were chosen for this study, only *Valamugil cunnesius* had a strong positive relationship with rainfall in monthly, seasonally and yearly. And it had a strong negative relationship with rainfall in lag one season of rainfall.

These significant correlations are expressed in Figure 3

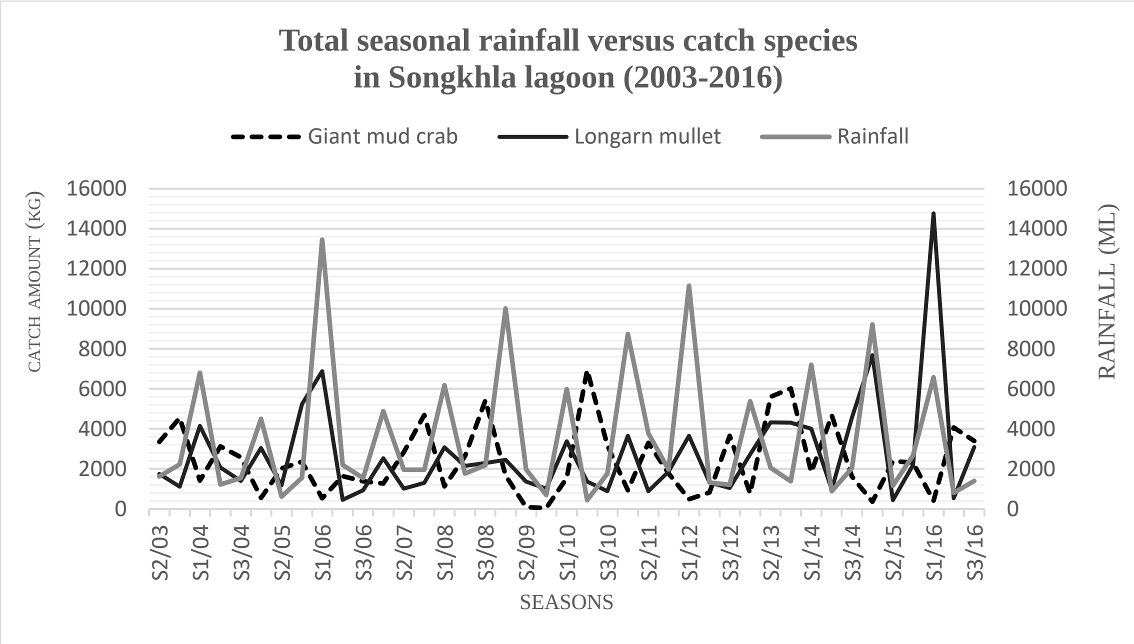


Figure 3. Total seasonal rainfall versus two species catch landings

It can be seen that, the *Valamugil cunnesius* (Longarn mullet) changes the same direction with the amount of rainfall, while *Scylla olivaceawas* (Giant mud crab) change is opposite. In the highest rainy season (S1/2006), the amount of rainfall reached 13,455 milliliter (ml), the catch of *Scylla olivaceawas* was very low, only 540 kilogram (kg), while the *Valamugil cunnesius* catch was moderate around 6,880 kgs. The high catch of *Valamugil cunnesius* almost concentrated in rainy season (S1) while *Scylla olivaceawas* catch was low. When the rainfall was dropped in S2 and S3/2006, the catch amount of *Scylla olivacea* started increasing and *Valamugil cunnesius* catch amount was decreased. In the dry season with the lowest amount of rainfall (S2/2010), the amount of rainfall was only 441 ml, the catch amount of *Scylla olivacea* reached the peak of 6,946 kgs, the *Valamugil cunnesius* catch amount remained at 1,371 kgs. When the *Valamugil cunnesius* catch amount was highest (14,770 kgs) in rainy season 1/2016 and the amount of rainfall was quite high (6,578 ml) (Figure 3). After rainy season, the *Valamugil cunnesius* catch amount had trends to decrease while *Scylla olivacea* catch amount trended to increase.

During the time period relevant to this study, these species had the different correlation with the temperature, this is shown in Table 2.

Table 2. Pearson Correlation coefficients (r) between fish catch landing and mean air temperature (Monthly (during 2012-2016), seasonally (during 2012-2016), and Yearly (during 2003-2016), (**P-value< 0.05; ***P-value much less than 0.01)

Common name	**Monthly**		**Seasonal**		**Yearly**	
	r	**n**	**r**	**n**	**r**	**n**
Total fish, shrimp, and crab catch landing	-0.055	55	-0.611***	12	-0.427	12
Fenneropenaeus merguiensis	0.288**	55	-0.247	12	0.733***	12
Penaeus monodon	0.097	55	0.041	12	0.384	12
Macrobrachium dacquetiprawn	0.111	55	0.176	12	-0.214	12
Scylla olivacea	0.603***	55	0.532***	12	0.10	12
Channa striata	0.248	55	0.266	12	-0.445	12
Metapenaeus Brevicornis	-0.200	55	-0.636**	12	-0.637**	12
Clarias macrocephalus	0.162	55	0.207	12	-0.269	12
Hampala macrolepidota	-0.294**	55	-0.624**	12	-0.294	12
Lates calcarifer	-0.022	55	-0.317	11	0.014	12
Valamugil cunnesius	-0.221	55	-0.468	11	0.182	12
Platystacus anguillaris	0.327**	55	0.381	12	-0.386	12
Notopterus notopterus	-0.043	55	-0.263	12	-0.376	12
Pristolepis fasciata	-0.105	55	-0.059	12	-0.561**	12
Scatophagus argus	0.284**	55	0.267	12	-0.256	12

On the overall, the total of fish, shrimp and crab catch landings had only strong negative correlation with seasonal mean air temperature during the period of 2012-2016 in Songkhla lake. This is shown in Figure 4.

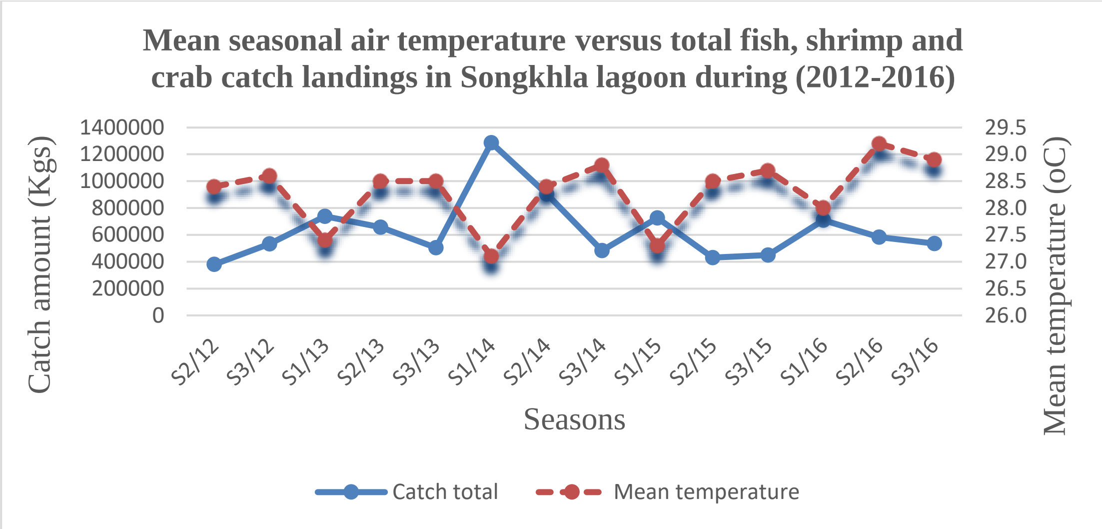


Figure 4. Seasonal mean air temperature versus total fish, shrimp and crab catch landings

The total catch species landing reacted negative with the air temperature, in the heavy rainy season S1/2014, when the mean temperature reached the lowest degree, around 27.1 degrees, the total catch species reached the highest amount, it was estimated up to 1,300,000 kgs. Moreover, the mean temperature touches the highest record in the dry season S2/2016, around 29.3 degree, the catch of fisheries landing fluctuated around 600,000 kgs (Figure 4), the catch of *Scylla olivacea* was quite high (4,072 kgs), the catch of *Hampala macrolepidota* was at low level (17,250 kgs) (Figure 5). The strong positive correlation between *Scylla olivacea* catch and mean seasonal temperature was expressed by the high catch in dry seasons (S2 and S3).

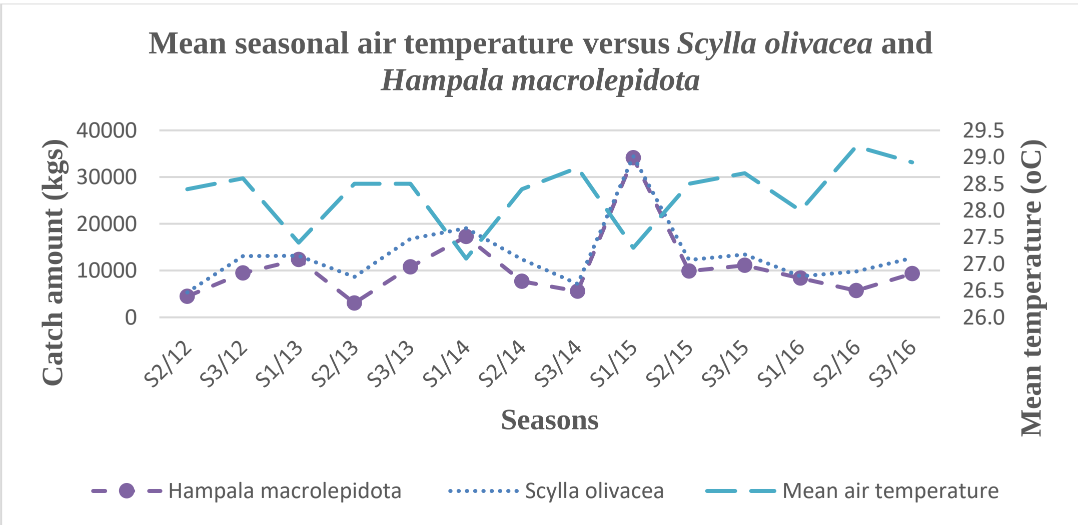


Figure 5. The correlation of species with mean seasonal air temperature

The strong negative correlation between *Hampala macrolepidota* and mean seasonal temperature can be seen clearly that almost high *Hampala macrolepidota* catch was focused in the heavy rainy season (S1) when the temperature is normally lower than other seasons.

The level of correlation between different species with mean temperature was different in monthly, seasonally or yearly, this statement was shown in Figure 6.

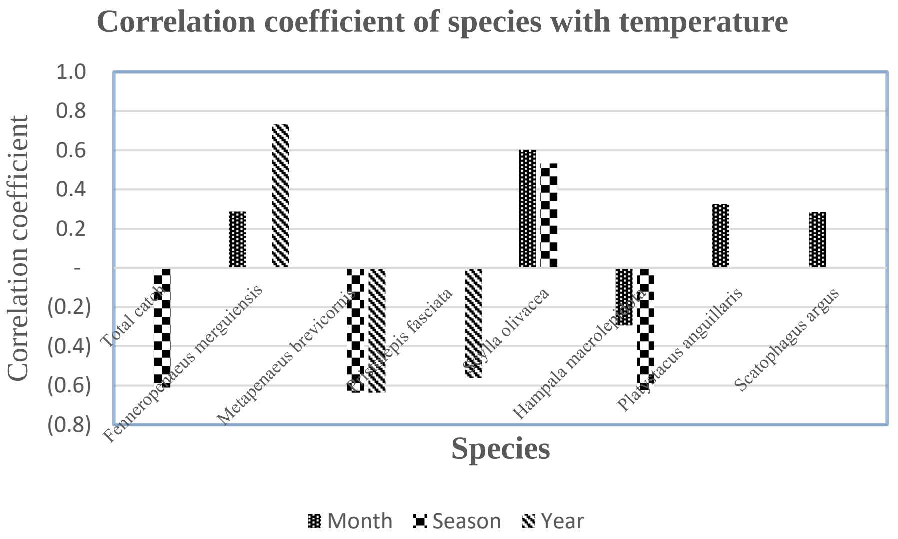


Figure 6. The level correlation coefficient of species with temperature

In Figure 6, among the five kinds of shrimp and crab species were chosen for this study, opposite to the result from rainfall, *Penaeus monodon* and *Macrobrachium dacqueti* had no correlation with mean air temperature. While *Fenneropenaeus merguiensis* catch had a significant positive correlation with yearly mean air temperature and weak positive relationship with monthly mean air temperature. *Metapenaeus brevicornis* had a strong negative correlation with both seasonal and yearly mean temperature. The *Scylla olivacea* had both strong positive correlations with monthly mean air temperature and seasonally.

To nine kinds of fish species. *Hampala macrolepidota* had a weak negative relationship with mean monthly temperature and strong negative relationship with mean seasonal temperature. Both *Platystacus anguillaris* and *Scatophagus argus* had moderate and weak positive correlation with mean air temperature in monthly. *Pristolepis fasciata* had a strong negative with mean temperature in yearly.

3.2. Shrimp and fish catch landing trends during 2003-2016

Comparison between the SARIMA and ANNs models

To estimate the accuracy of the two models, the authors calculated the percentage improvement of SARIMA and ANNs models through Mean Absolute Error (MAE). The percentage MAE was calculated on the average over the validation samples of fish and shrimp catch landings from October 2015 to September 2016. The equation to measure percentage of MAE is as below:

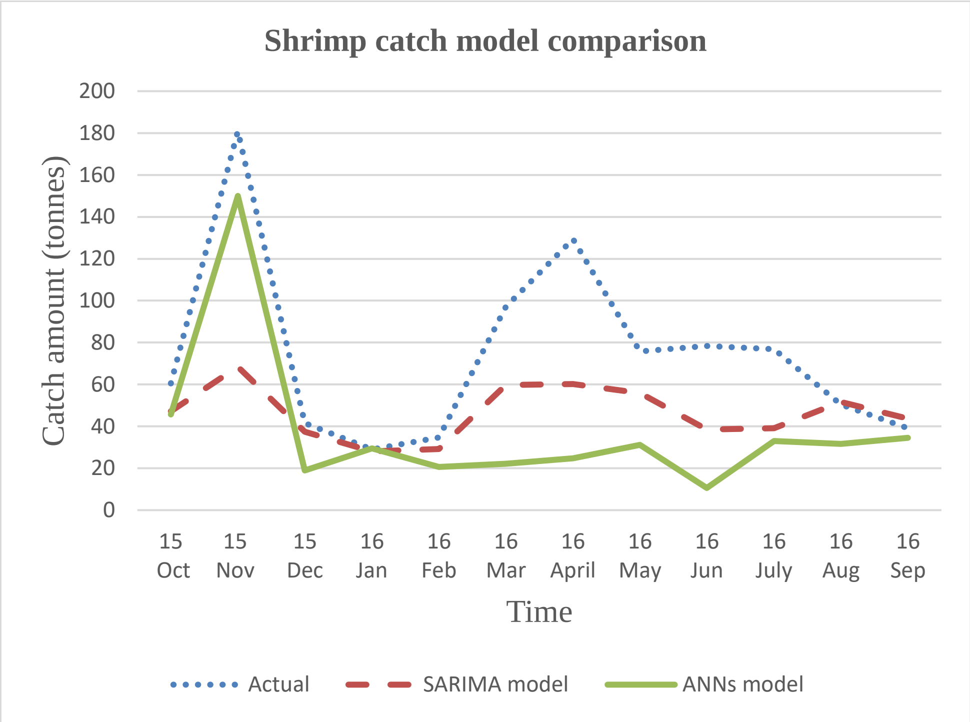
$$MAE(\%) = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{|y_i - \hat{y}_i|}{y_i}\right)\times 100\% \qquad \text{(Eq 5)}$$

where, $|y_i - \hat{y}_i|$ is absolute difference between predicted value in the period October 2015 to September 2016 and its actual observation; n is the number of observations. The optimum model with the smaller percentage of MAE will be chosen for forecasting. The percentage MAE of SARIMA and ANNs models are shown in Table 3.

Table 3. The percentage MAE values of shrimp and fish catch landings from chosen SARIMA models and ANNs during the period October 2015 to September 2016

Months	**Shrimp catches landings (tonnes)**	**SARIMA model prediction (95%CI)-mean**		**Neural Network prediction**		**Fish catches landings (tonnes)**	**SARIMA model prediction (95%CI)-mean**		**Neural Network prediction**	
		Amount (tonnes)	**|% error|**	**Amount (tonnes)**	**|% error|**		**Amount (tonnes)**	**|% error|**	**Amount (tonnes)**	**|% error|**
Oct 2015	60.52	47.22	21.97	45.75	24.41	114.50	76.83	32.90	101.33	11.50
Nov 2015	180.93	68.43	62.18	149.99	17.10	114.50	79.03	30.98	99.77	12.86
Dec 2015	41.5	37.41	9.85	19.00	54.22	63.27	71.54	13.07	66.26	4.73
Jan 2016	29.01	28.07	3.24	29.48	1.62	61.07	73.51	20.37	71.75	17.49
Feb 2016	34.68	29.18	15.85	20.57	40.69	54.19	62.78	15.85	70.31	29.75
Mar 2016	97.09	59.77	38.44	22.19	77.14	49.27	65.96	33.87	63.96	29.82
Apr 2016	129.39	60.17	53.50	24.69	80.92	59.03	64.26	8.86	44.87	5.84
May 2016	75.72	55.97	26.08	31.14	58.87	69.49	69.42	0.10	73.55	19.80
Jun 2016	78.32	38.56	50.77	10.60	86.47	60.29	64.20	6.49	72.23	22.81
Jul 2016	76.79	39.11	49.07	32.93	57.12	63.40	69.02	8.86	77.86	19.66
Aug 2016	50.44	51.59	2.28	31.66	37.23	63.28	69.65	10.07	75.72	5.70
Sep 2016	39.17	43.67	11.49	34.55	11.79	74.96	75.11	0.2	79.23	8.94
MAE (%)			**28.73**		**45.63**	**MAE (%)**		**15.14**		**16.70**

As can be seen from Table 3, the ANNs models used for forecasting shrimp and fish catch have higher percentage of MAE than SARIMA models, especially in the shrimp data set. These results are clearly described by the amount of the fish and shrimp catch in validated data sets. These are shown in Figure 7.



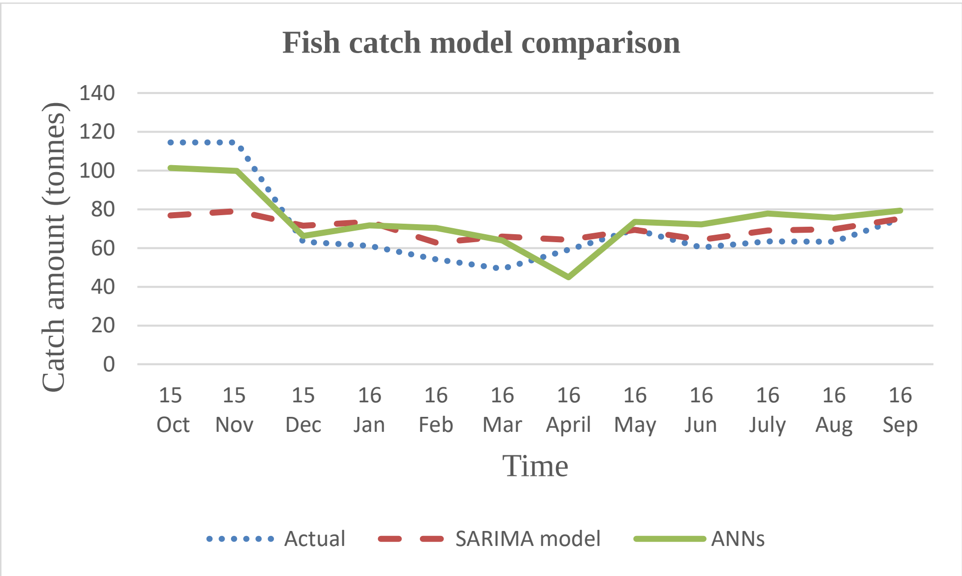


Figure 7. Fish and shrimp model comparisons

In both the shrimp and fish models, generally, the fit line for the SARIMA model had the smaller distance along with the actual line than the ANN model (Figure 7). However, in shrimp catch model, at the point April 2016, the fit line was much wider with both SARIMA and ANNs model, this due to the shrimp catch data was fluctuated sharply in the same month April between years, the range for this was 4.56-175.79 tonnes. The forecast fit line from fish catch model was nearer with the real line than shrimp catch model, this statement can be explained by the stable data of fish catch. Therefore, this study uses SARIMA models for prediction of shrimp and fish catch landings in Songkhla lake until 2020.

Shrimp and fish catch landing trends in Songkhla lake during 2016-2020

The monthly catch landings of fish and shrimp groups during 2003-2016, fits for coming years, that were produced by the best fitting and best seasonal ARIMA forecasting model per group species, are shown in Figure 8. Overall, the amplitude and the duration of the between–month fluctuations are adequately described and forecasted by the model with few exceptions.

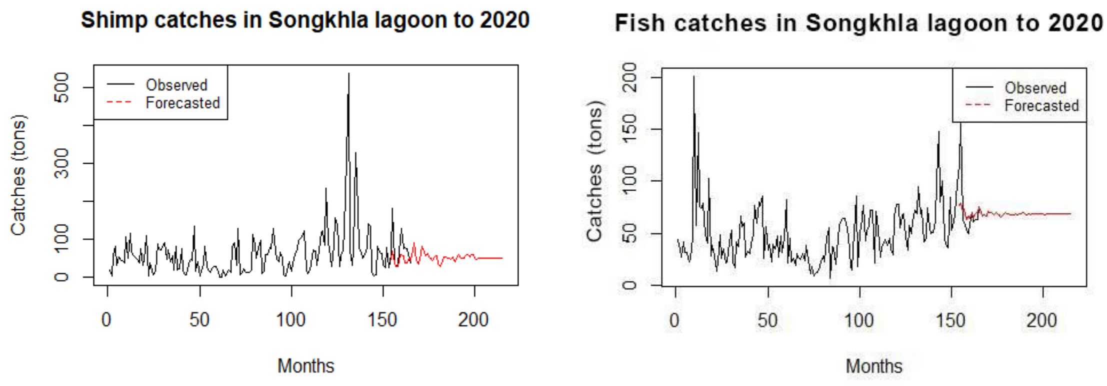


Figure 8. Shrimp and fish catch forecasted in Songkhla lake to 2020

The result of shrimp and fish catch landings to 2020 is shown in the Figure 8. It can be seen clearly that, during the period between 2017 and 2020, the shrimp catch landing in Songkhla lake fluctuates at around 53 tonnes (tonnes) per month, compared with the mean catch (62.5 tonnes per month) during 2003-2016. Moreover, the fish catch will be around 68 tonnes per month, compared with the mean catch of around 49 tonnes during the period

2003-2016. The detailed trends of fish and shrimp catch landings in Songkhla Lake until 2020 are clearly described in Figure 9.

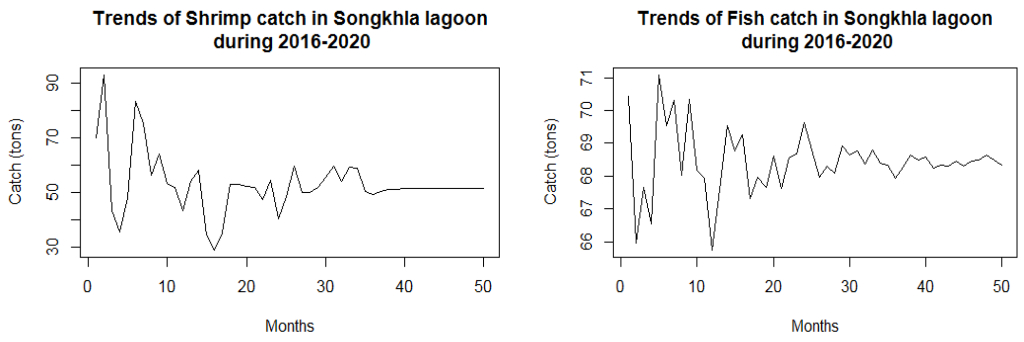


Figure 9. Shrimp and fish catch forecasted for Songkhla lake during 2016- 2020

In Figure 9, the fluctuations of the shrimp and fish catch landings during 50 upcoming months are somehow similar. During the two first years (from month 1 to month 24), the catch amount fluctuated sharply between months; after that, the catch amount was more stable. The difference between the lowest and highest catch amounts of shrimp are significant bigger than for fish. The lowest shrimp catch was January 2018 (28.95 tonnes) and the highest catch in November 2016 (92.94 tonnes), the difference being approximately 64 tonnes. The lowest fish catch was September 2017 (65.75 tonnes) and the highest fish catch was February 2017 (71.08 tonnes), with a difference of only 5.33 tonnes.

Seasonal factor

The overview of monthly shrimp and fish catch landings in Songkhla lake during 2003-2016 are presented in Figure 10.

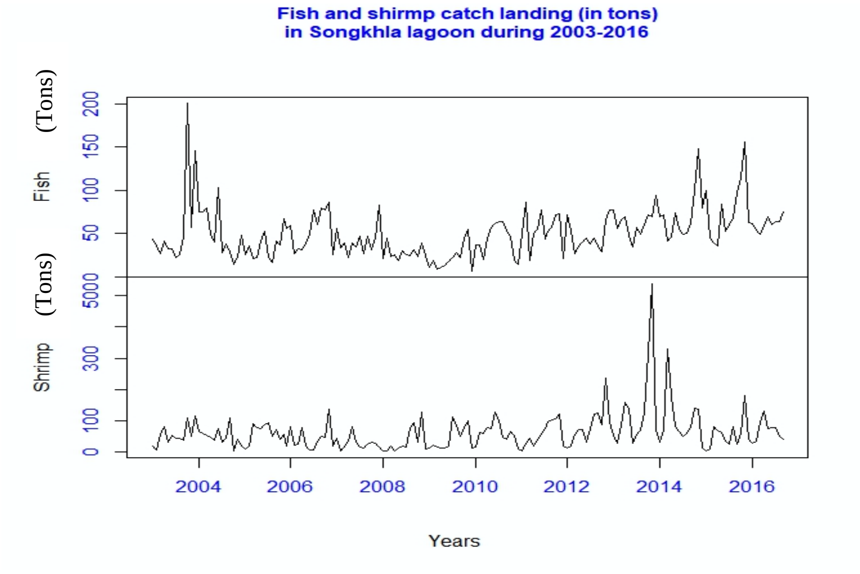


Figure 10. Monthly shrimp and fish catch landings in Songkhla Lake during 2003-2016

As shown in Figure 10, the lowest shrimp catch landing was in January 2008, with only 1.77 tonnes; and the highest catch amount was in November 2013, the shrimp catch reached a peak with 537.41 tonnes. The mean shrimp catch was estimated at around 62.56 tonnes. The results obtained for the monthly fish landings were also shown in Figure 10, when the most significant catch amount topped 200.78 tonnes in October 2003; and the lowest in this 2003-2016 period was in December 2009 (6.96 tonnes). The average monthly catch was around 50.31 tonnes for this period.

Seasonal factors are the way to analyze data to explore usual repeat changes connect with the calendar. A seasonal factor measures the percentage amount when, on average, a month is higher or lower than normal (Austin, 1981). From Figure 10, it can be seen that the size of the seasonal factor fluctuations in both shrimp and fish catch time series data seems to be roughly constant over time, and does not depend on the level of the time series. Thus, to know exactly the seasonal trend of monthly shrimp and fish catches, the study estimated seasonal factors affecting shrimp and fish for the particular month from January to December. These seasonal factors are the same for each particular month, each year. Before rainy season in Southern Thailand, December, is the best season for both shrimp and fish catching, which is shown by the high seasonal factors (from September to November). However, during monsoon season (December to February), the seasonal factors for shrimp catch landings are significant low while the factors for fish catch are really low during the dry season (March to May). The details for these claims are given in

Table 4 and Figure 11. November provides the best seasonal factors for both shrimp catch landings (about 0.88) and fish (about 0.31); while the lowest seasonal factor for shrimp catch (about -0.96) is in January, and for the fish catch (about -0.36) in March, indicating that there seems to be a peak in both shrimp and fish catch landings in November with the bottom for shrimp catch in January, and for the fish catch in March in each year.

Table 4. Seasonal factors for shrimp and fish catch in Songkhla Lake during 2003-2016

Months	Shrimp seasonal factors	Fish seasonal factors
January	-0.96	0.09
February	-0.76	0.03
March	0.20	-0.36
April	0.14	-0.23
May	0.13	-0.03
June	-0.10	0.09
July	-0.005	-0.08
August	0.30	-0.10
September	0.41	0.09
October	0.33	0.19
November	0.88	0.31
December	-0.59	-0.01

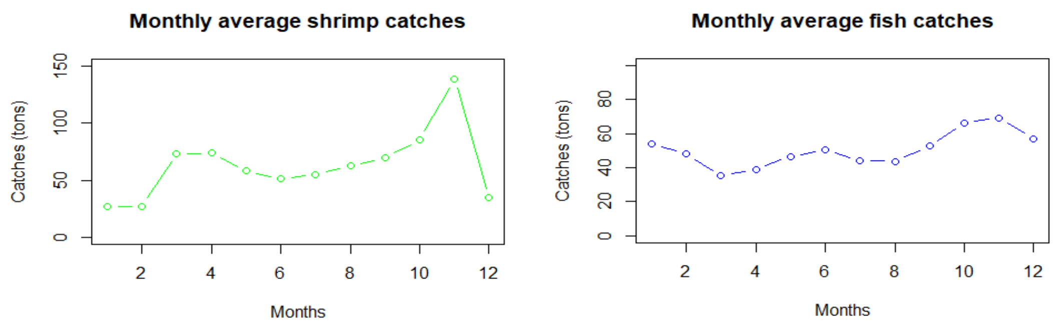
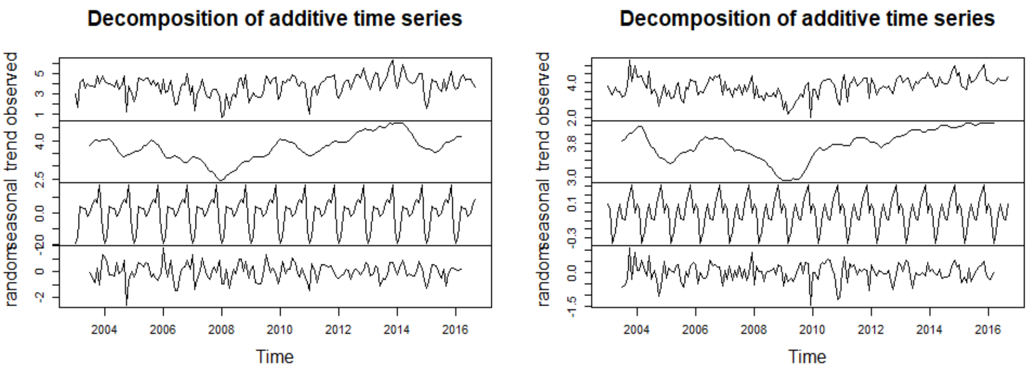


Figure 11. The monthly average catch of fish and shrimp in Songkhla lake during 2003-2016

According to the data for the total fish and shrimp catch from January to December for January 2003 through to the first 9 months of 2016, the total catch in months of the two species was different with reference to both the amount and the time of catch in the year.

The amount of shrimp caught was lowest in January (estimate 27.06 tonnes) and highest in November, up to 138.55 tonnes. The amount of fish caught was lowest in March (only 35.13 tonnes) and highest in November, around 69.36 tonnes. In general, there was a sharp fluctuation in the average catch between months in year, particularly with reference to shrimp catch landings.

The trend and season of monthly shrimp and fish catch landings is shown clearly in Figure 12.



a. Shrimp catches b. Fish catches

Figure 12. Trend and season of monthly shrimp and fish catch landings in Songkhla Lake during 2003-2016

3.3. Modeling for forecasting fish catch landing based on environmental factors

Multiple Adaptive Regression Spline (MARS) model

The MARS model was built. The final equation for forecasting fish catches based on given data is shown as follows:

Fish catch (tonnes) = 87295.64 – 5819.73 x (8.5-Salinity) +33.2 x (Rainfall-275) (Eq 6)

The salinity and rainfall are the most important factors on the fish catch landing in Songkhla lake, the remained factors, such as: depth, pH, turbidity (Tur), Dissolved Oxygen (DO), water temperature were not included in the model as they did not have significant effect on the catch. The significance of the MARS coefficients for the model (R^2, determination coefficient) is 0.8679. It can be explained that the MARS model can explain the variation with accuracy, 86.79%. Figure 13 shows the comparison of measured and predicted data of fish catch by using MARS model.

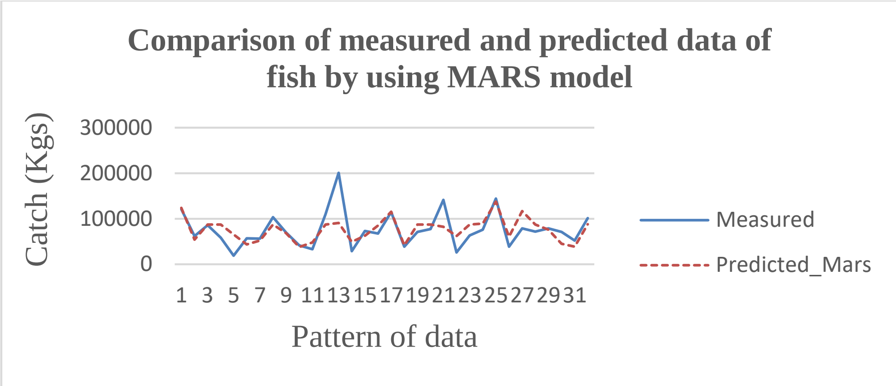


Figure 13. Comparison of measured and predicted data of fish catch by using MARS model

It is seen from Figure 13 that there is a moderate relationship between the predictor variables and response variable. The ANOVA test was used to determine the dependency of fish catch to selected machining parameters. The main effects of these variables were included to the analysis. The results of this test are shown in Table 5**.**

Table 5. The results of ANOVA test for fish catch

Factors	**Df**	**Sum Square error**	**Mean Square error**	**F value**	**Pr(>F)**
Depth	1	281,947,767	281,947,767	0.26	0.61
Air Temperature	1	623,307,735	623,307,735	0.58	0.45
pH	1	963,312,373	963,312,373	0.89	0.35
Turbidity	1	6,664,208,285	6,664,208,285	6.19	0.02*
Salinity	1	4,060,914,712	4,060,914,712	3.77	0.06.
Dissolved Oxygen	1	57,312,826	57,312,826	0.05	0.82
Rainfall	1	8,161,486,369	8,161,486,369	7.58	0.01*

Signif.codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '' 1

From Table 5, regarding the main effects, the greatest influence on the fish catch is exhibited by the rainfall (Rain), followed by the turbidity. ANOVA test was performed at a significance level of 5%, confidence level of 95%. Since P value given in Table 5 is less than 0.05, the developed model is significant. According to the other hypothesis, if at least one of these coefficients is not equal to zero, the model will be accepted. It is seen from Table 5 that this hypothesis is confirmed.

Result of K-nearest neighbor (KNN) model

The significance of the KNN coefficients for the model (R^2, determination coefficient) is 0.8426. KNN model can explain the variation with accuracy, 84.26%. Figure 14 shows the comparison of measured and predicted data of fish catch by using KNN model.

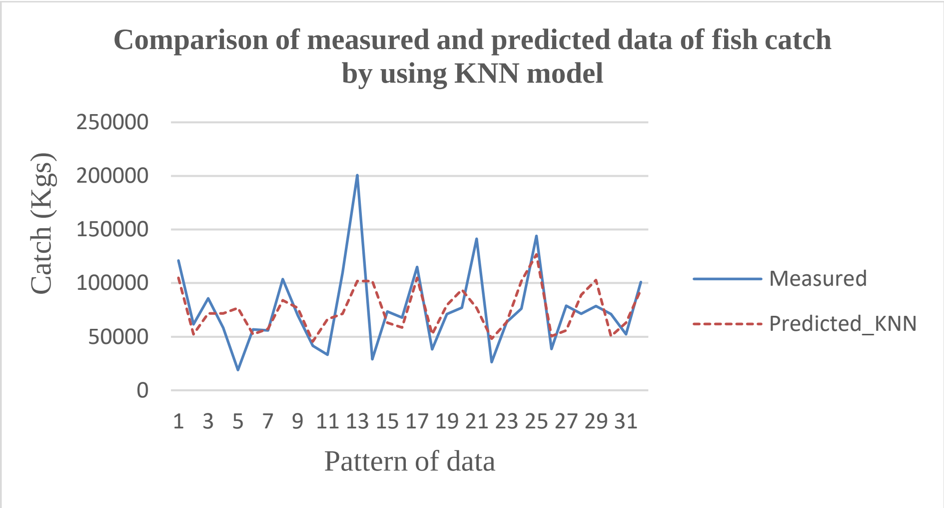


Figure 14. Comparison of measured and predicted data of fish catch by using KNN model

Results of artificial neural networks

The backpropagation and resilient backpropagation training algorithms were used for ANN model training. The best results were obtained with this algorithm compared to other training algorithms. The data set consists of 32 patterns, of which 25 patterns were used for training the network and 7 patterns were chosen randomly for testing the performance of the trained network. After the network has successfully completed the training stage, it was tested with the data set that were not present in the training data set. The results obtained were compared by using statistical methods. The performance criteria considered are the mean absolute percentage error (MAPE) and the determination coefficient (R^2) (Asiltürk and Çunkaş, 2011).

For the fish catch landing, the best approach having the minimum error is achieved by backpropagation algorithm with the training process needed 22,717 steps until all absolute partial derivatives of the error function were smaller than 0.01 (the default threshold). The estimated weights range from -4.53 to 1.7. For instance, the intercepts of the first hidden layer are -0.37 and 7 weights leading to the first hidden neuron are estimated as 0.65, 0.21, -1,84, -4,53, 1.03, 1.25 and 1.79 for the depth, water temperature, pH, turbidity, Salinity, dissolved oxygen and rainfall. The intercept from the first hidden to the output is 0.11 and the weight from the first hidden to the output is 0.7.

Overall evaluation

A full factorial experimentation design is implemented to seek the effects of environmental and water parameters on the fish catch landing. After each turning operation, the measurements of fish catch were recorded. ANN, MARS and KNN models were developed to predict the fish catch using the collected data. Table 6 shows the comparison results according to accuracy values of MARS, KNN and ANN model. The results are generally found to be close to the directly measured. So, the proposed models can be used effectively to predict the fish catch in Songkhla lake. From Table 6, ANN produces the better result compared to MARS and KNN. So, the proposed model predicts the fish catch should be here ANN. The result of mean square error, square coefficient and mean absolute percentage error between the models are compared in Table 6.

Table 6. Comparison of the models

Models		**MSE**	**R^2**	**MAPE**
Multiple Adaptive Regression Splines		844,219,142.3	0.87	0.34
Artificial neural network	Training	18,897.5	0.99	0.59
	Testing	47,392.7	0.93	0.49
K-nearest neighbor		15,497,832	0.84	0.41

However, as can be seen from the performance criterion in Table 6, ANN is very successful at the training stage, but it is not good for the test data. This statement is shown clearly in Figure 15.

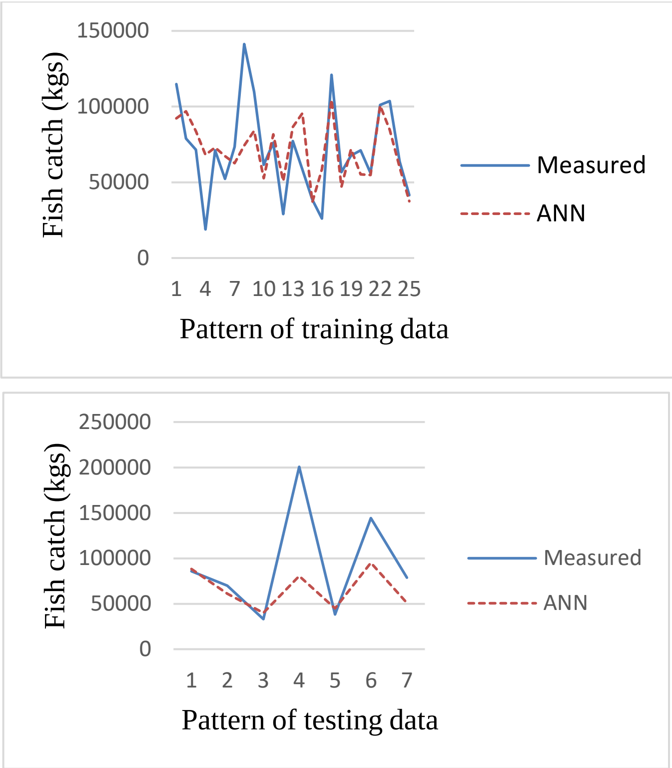


Figure 15. Comparison of measured and predicted data of fish catch by using ANN model

Social economic context, fishing gears, equipment may effect on fish catch landing. Since fish catch landing activities are the huge topic, therefore, this study only focus on main factors as the fishermen said they have huge impacts on their fishing, they may be causing to make the amount of fish decrease these days.

3.4. The Physical Properties of Three Songkhla Lake fish species in the Lower Gulf of Thailand during and after the monsoon season

During the study period, 20 different Songkhla lake species were captured in the coastal area of Sathing Pra, of which two species were crabs, three species were shrimps and 15 species were fish. The number of species varied markedly between months, but the fish species including Indian pellona (*Pellona ditchella*), goldstripe sardinella (*Sardinella gibbosa*) and genus alepes (*Alepes vari*) appeared regularly, with sample sizes of 537, 162 and 49, respectively (Table 7). Among the samples, the total length of *P. ditchella* ranged from 103 to 183 mm, *S. gibbosa* from 102 to 175 mm, and *Alepes vari* from 122 to 216 (Table 7), whereas the ranges of the total body weight were 9 to 59 g, 6 to 43 g, and 11 to 93 g, respectively (Table 7).

Table 7. Total length and weight for *Pellona ditchella*, *Alepes vari* and *Sardinela gibbosa*

Fish species	**Sample size**	**Total length (mm)**		**Total weight (g)**	
		Range	**Mean**	**Range**	**Mean**
Pellona ditchella (Valenciennes, 1847)	537	103-187	143.9	9-59	30.81
Alepes vari (G. Cuvier, 1833)	49	112-216	162.9	11-93	47.71
Sardinella gibbosa (Bleeker, 1849)	162	102-175	130.8	6-43	19.93

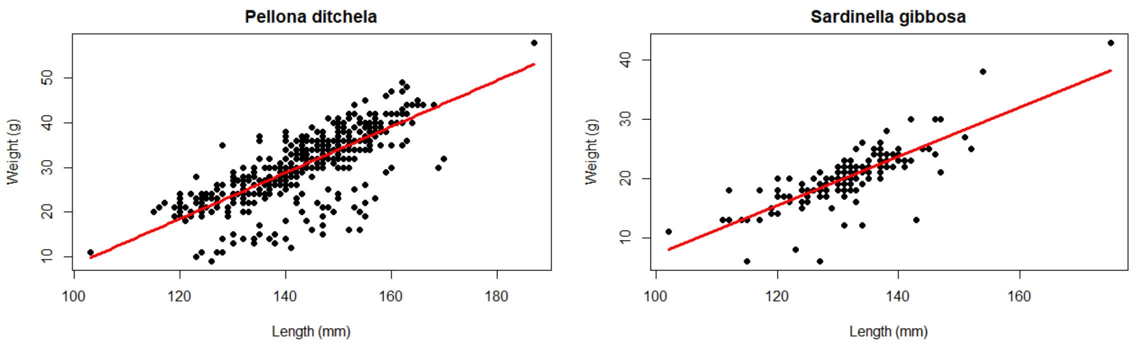
Length–weight model

The relationship between length and weight was used by the equation from (Le Cren, 1951; Ricker, 1973; Froese, 2006) :

$$LogW = \beta \log L + \log a$$

(Eq 7)

where W: the total weight in gram (g), L: the total length in centimeter (cm), a: the intercept and b the slope of the line, Figure 16 depicts the natural log-transformed total length and weight of *P. ditchella*, *Alepes* and *S. gibbosa* captured in the lower gulf of Thailand between September 2017 and April 2018, with the best fit regression line superimposed. Table 8 gives the equations and other parameters of the length weight models for the three fish included in the study by using Equation 7, derived from those regression lines.



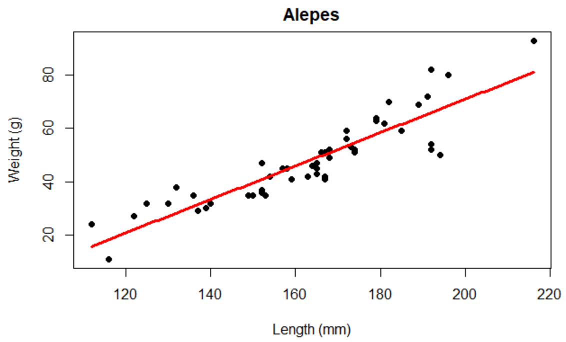


Figure 16. Plot of total length and weight of the three sampled fish

Table 8. Equation of the length weight models for *P. ditchella*, *Alepes vari.* and *S. gibbosa*

Fish species	**Equation (on the transformed scale)**	**Equation (on the original scale)**	R^2	**β range (95% confidence)**	**P value**
P. ditchella	log(W) = -9.19+2.53log(L)	$W = 0.000102*L^{2.53}$	0.51	2.32 - 2.75	P = 0.00002
Alepes vari	Log(W) = -7.64+2.25log(L)	$W=0.000481*L^{2.25}$	0.81	1.93 - 1.93	P = 2.538096e-05
S. gibbosa	Log(W) = -10.25 + 2.71*log(L)	$W = 0.000035*L^{2.71}$	0.55	2.33 - 3.1	P = 0.1432605

With a value of R^2 between 0.5 and 0.6 the models for *P. ditchella* and *S. gibbosa* have a weaker fit to the data than the model for *Alepes vari*, with a value of R^2 of 0.81. The results for the slopes of the equations show that, according to the model, *S. gibbosa* exhibits isometric growth ($p > 0.05$) with an exponent parameter (β) between 2.33 and 3.1, with 95% confidence. The results for the other two fish show that, according to the respective models, both *P. ditchella* and *Alepes vari* exhibit allometric growth ($p < 0.05$) with values of β between 2.32 and 2.75 for *P. ditchella* and 1.93 and 2.27 for *Alepes vari*.

Weight predictions based on original scale

The final original scale was multiplied with a correction factor derived from analysis of normal and log – normal distribution theory, using $e^{\frac{(\delta_{Y/X})^2}{2}}$, where $\delta_{Y/X}$ is calculated from summarizing model length–weight regression of fish.

Table 9 presents the results for the predicted mean weight of the three fish included in the study, using the length–weight models presented in Table 8 and the correction factor. With a mean length of 150 mm, *P. ditchella* was estimated to have a weight between 33.4 and 34.6 grams. For *Alepes vari*, with the mean length is 160 mm, the weight predicted lies between 18.6 to 19.7 grams, whereas for *S. gibbosa* the figures are 130 mm and 42.2 to 46.3 grams.

Table 9. Prediction of weight of *P. ditchella*, *Alepes vari* and *S. gibbosa* based on the mean length

Fish species	**Bias correction factor**	**Predicted weight (grams)**	**Mean length (mm)**
P. ditchella	1.097	33.4 - 34.6	150
Alepes vari	1.01	18.6 - 19.7	160
S. gibbosa	1.015	42.2 – 46.3	130

Monthly variation of length–weight relationship of the fish

The study presents the monthly data for the length and weight of the three fish, for the entire study period (September 2017 to April 2018), and the parameters for the respective length–weight relationships. The value of β could not be determined for certain fish in the months of November 2017 and January, March and April 2018 due to the small size of the sample. No sampling was carried out in December 2017, as the heavy weather prevented all fishing activities.

There is a slight variation in the value of β (slope) between months for the three fish included in the study, with the majority exhibiting negative allometric growth ($\beta < 3$), and only *Alepes vari* exhibiting positive allometric growth during the month of October 2017 ($\beta = 3.14$). This suggests that the majority of the fish sampled experiences poor growth and living conditions. Carlander (1969) showed that the coefficient β in the LWR of fish usually ranged from 2.5 to 3.5. In this study, there were 10 instances in which the value of β was outside this range, as depicted in Figure 17. The same table and figure also show that the lowest value of β was obtained for *S. gibbosa* in October 2017, whereas the highest was for *Alepes vari* in October 2017 (β = 3.14), followed by that for *S. gibbosa* in January 2018 (b = 2.94).

In the majority of instances (76.9%) the value of the coefficient of determination (R^2) was equal or greater than 0.60, which indicates a moderately significant relationship between length and weight of the fish examined in the period of this study (Figure 18).

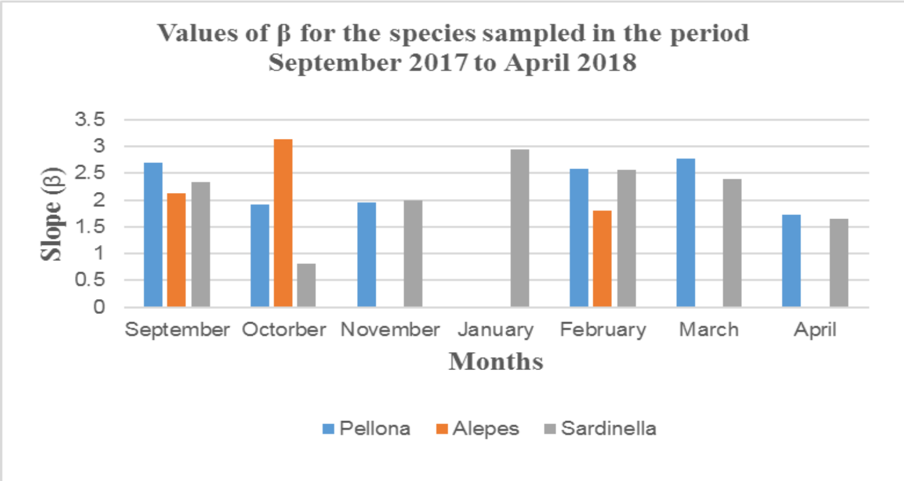


Figure 17. Values of β for the species sampled in the period September 2017 to April 2018

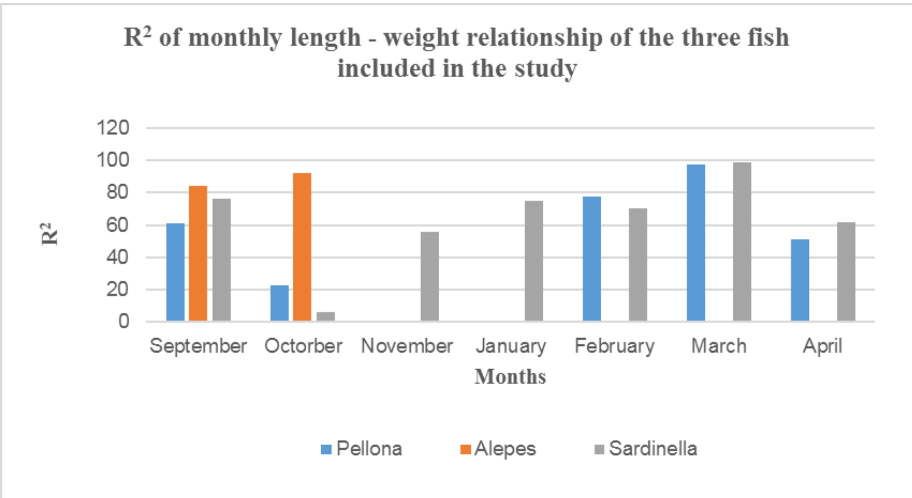


Figure 18. R^2 of monthly length–weight relationship of the three fish included in the study

These results also show that *P. ditchella* and *S. gibbosa* captured during the monsoon season are smaller than those captured after the monsoon (dry) season, with differences in weight of 0.05 - 0.13 g and 0.03 - 0.14 g, respectively. The opposite was found for *Alepes vari*, in which case fish captured during the monsoon season was 0.14 to 0.25 g larger than the fish captured during the dry season. Figure 19 portrays the final models for the length–weight regressions for the monsoon and dry seasons for the three fish, with the respective fit plots.

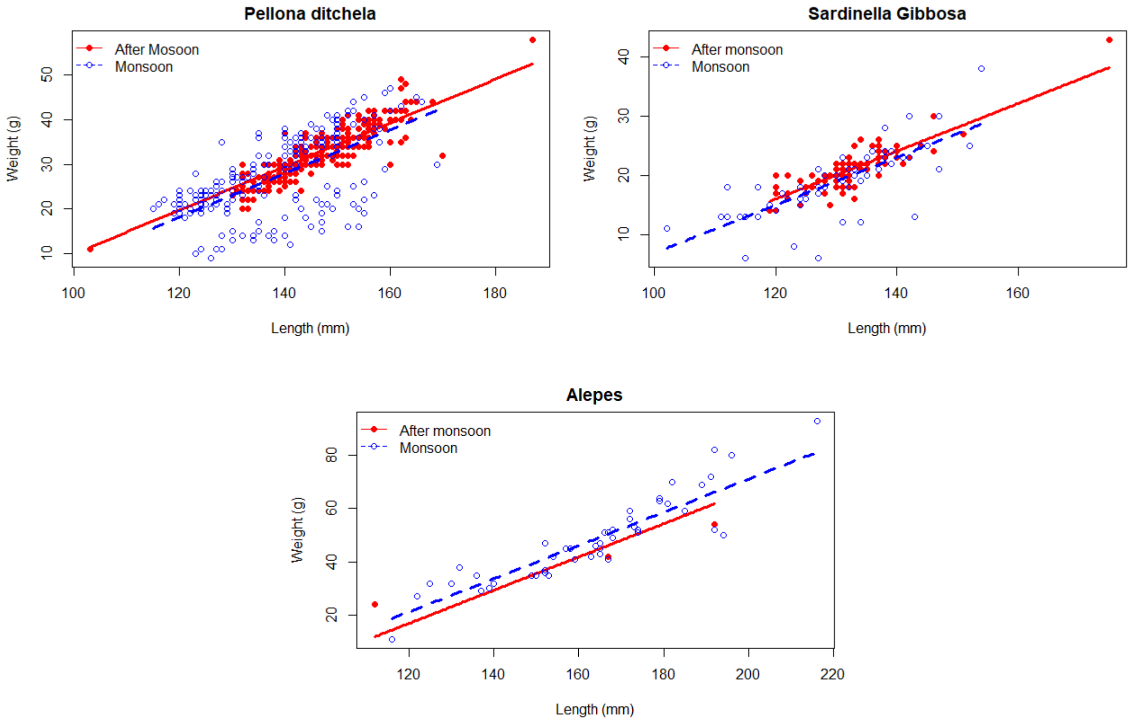


Figure 19. Fit plot of the length–weight relationship for the three fishes during the monsoon and after monsoon (dry) seasons

3. 5. The adaptation of fishermen to the seasonal aspects

Background information established from the survey of fishermen

All 164 interviewees were male, the females in the village does not directly join fishing in these villages and they were not self-confident to answer the questionnaires. The age of the interviewees ranged from 20 to 70 years with the median age, 49 years (Table 10). The largest age group represented was 51 – 60 years with 35.4% of the respondents. This implies that the respondents had experience on various issues relating to fishing activities by themselves and in the community. The number of year fishing of respondents ranged from 2 to 60 years with the median 27 years. The mean number of persons in each household was 5, ranging from 1 to 13 members and more than half of the households (61%) had less than four persons. More than half of the interviewed fishermen (74.4 %)

had primary school level education (first five years school). Based on religions, two main religions in the researched areas are Muslim and Buddhist, in among of that, 56.7 % of the interviewees are Muslim. Regarding to boat types for fishing, long tail boat become dominant in the research sites with 89%. The size of boat ranged from 5 meter (m) to 14m with the median of 11m. The character of long tail boat is motorized with inboard engines have long outboard drive shafts that can be lifted out of shallow water to avoid obstructions. Most frequently used fishing gears in these research areas include gill nets, trap, long line, hook and line fishing.

Table 10. Summary of socio - economic respondents based on the survey

Social-economic situation	Categories	Frequency (n)	Proportion (%)
Gender	Male	164	100
	Female	0	0
Age (years)	≦20	1	0.6
	21 – 30	13	7.9
	31 – 40	30	18.3
	41-50	38	23.2
	51-60	58	35.4
	>60	24	16.4
Number of persons in the family	≤ 4	100	61
	5 – 7	47	29
	≥ 8	17	10
Education level of the fishermen	University	5	3
	Secondary school	19	11.6
	Primary school	122	74.4
	None formal	18	11
Boat types	Cots	6	3.7
	Fiber boat	7	4.3
	Long tail boat	146	89
	Wooden boat	5	3
Religions	Muslim	93	56.7
	Buddhist	71	43.3

There were significant differences in the total catch among the religions in the Songkhla Lake with total catch earned by the two religions different, at the $p < 0.001$ level. The Muslim caught the higher average total catch of 4,291.37 ± 391.76 kgs/fisherman/year, while the lower catch was 3,312.17 ± 295.58 kgs/fisherman/year for the Buddhist. Further, there were moderately low but significant correlations between the socio-economic data and total catch. The total amount of catch for one year was correlated with the number year living of fishermen, number of catching days, and number of catching hours based on Spearman rank order correlations (rs) of 0.23, ($p < 0.01$), 0.38 ($p < 0.01$) and 0.24 ($p < 0.01$), respectively for the fishermen in Songkhla Lake.

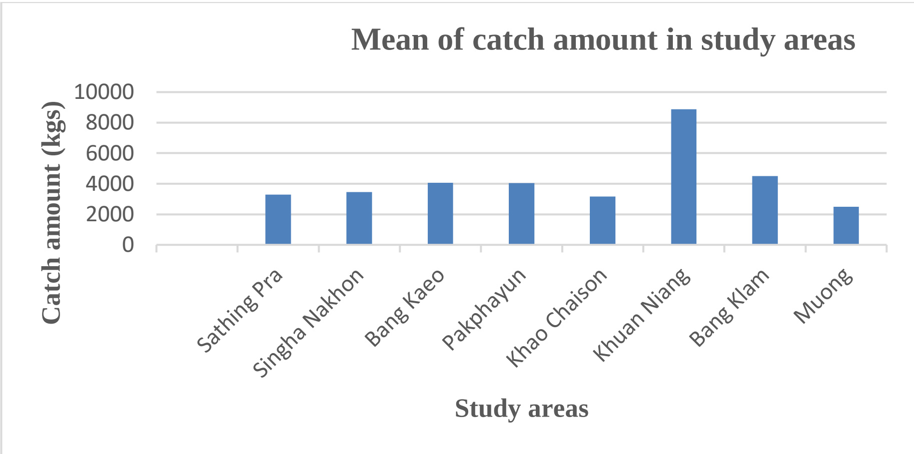


Figure 20. Mean of fish catch in study areas

Statistical result also showed that there was not significant correlations between total catch amount in one year and family size, boat size, years of fishing, fishing distance, boat age, age of fishermen in coastal areas of Songkhla Province.

Multispecies and multigear fisheries which were based on small scale operations can be commonly observed in Songkhla lake. Such diverse fisheries differ spatially according to the availability of fishery resources and condition of each part of the lake. This statement is shown in Figure 21.

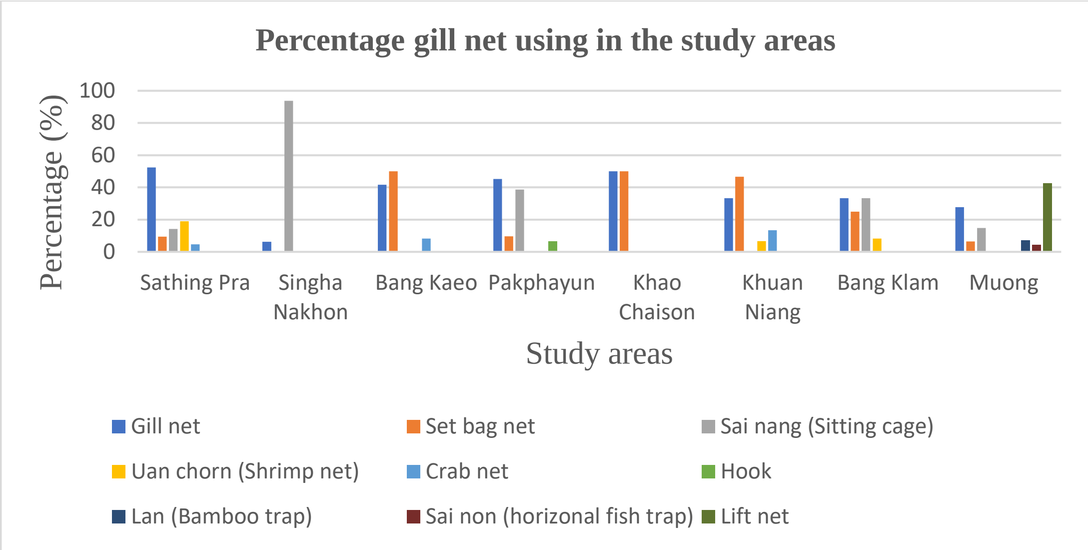


Figure 21. The fishing gear percentage in study areas

Relate to this, during the author's survey, nine main fishing gears were found in Songkhla lake and Sathing Pra, the fishing gear percentage using in each area were different, gill net was used in most areas in the study areas, only in Singha Nakhon, fishermen used mostly Sai nang (sitting cage). According fishermen, the used Sai nang was one of the main reasons make the fish decreases these days, because Sai nang caught all kinds of fish even with the small size.

However, the statistical result showed that, generally, there was no significant different in mean fish catch within one year among fishing gear groups (P value = 0.061), only the lift net had significant different in mean catch with gill net (P value = 0.02), Uan chorn (shrimp net) (P value = 0.012), Set bag net (P value = 0.002) and Sai nang (Pvalue = 0.047). The highest mean total catches of 5,844 ± 5,651.91 kgs/fishing gear/fisherman being found in Uan chorn (shrimp net) gear. The lowest mean total catches of 864 ± 610.94 kgs/fishing gear/fisherman being found in Lan (bamboo trap) gear.

Is the different between catches in the season?

There was a significant difference in the mean catch between three seasons, at the $p < 0.001$ level. The highest mean total catches of 1,602 ± 136.37 kgs/year/fisherman was found in the light rainy season. The lowest mean total catch of 963.29 ± 104.66 kgs/year/fisherman was found in rainy season. The mean amount of total catch caught by all three seasons was 1,280.53 ± 70.31 kgs/year/fisherman. Post Hoc tests also showed the significant difference in the mean catch between rainy season and light rainy season, however, there was no different in fish catch amount between dry season with two remain seasons. These show in (Figure 22).

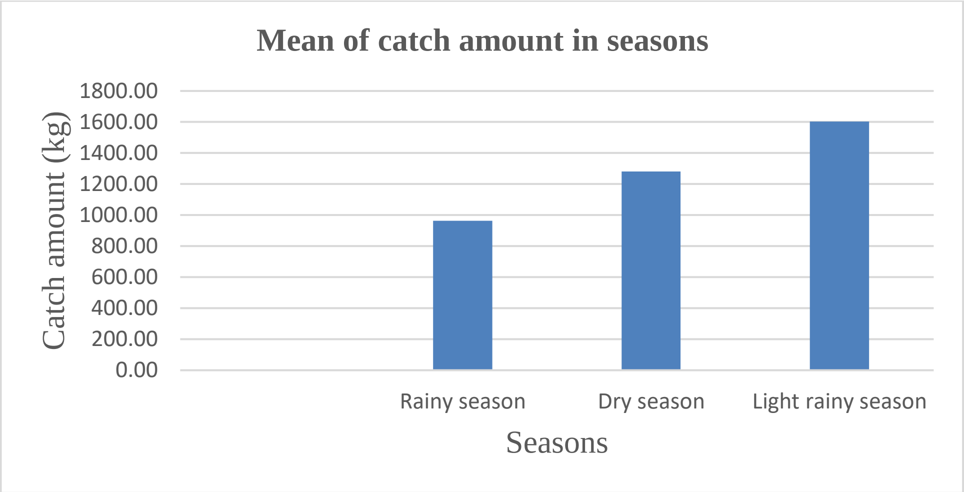


Figure 22. Mean of fish catch in seasons

The different between catches in the season in each research site is shown in Table 11

Table 11. Compare fish catch different between seasons in each study site

Study sites	Significant different (P value)	Mean catch between seasons (kgs)	Highest value (kgs)	Lowest value (kgs)	Seasonal different
Sathing Pra	0.028***	1,099.30 ± 177.26	1,530.50 ± 375.39 (Dry season)	448.38±75.37 (Rainy season)	Rainy season-dry season and Light rainy season
Singha Nakhon	0.01***	1,153 ± 172.81	1,868.75 ± 385.13 (Light rainy season)	708.25±149.92 (Rainy season)	Rainy season – Light rainy season, Dry season – Light rainy season
Bang Kaeo	0.161	1,353 ± 209.35	1,894.67 ± 449.48 (Light rainy season)	935.4±281.84 (Rainy season)	No difference
Pak Phayun	0.026***	1,345.49 ± 153.46	1,925.94 ± 344.54 (Rainy season)	1,027.35±181.30 (Light rainy season)	Rainy season-Dry season and light rainy season
Khao Chaison	0.460	1,278.38 ± 351.57	1,579.64 ± 722.25 (Dry and light rainy season)	615.60±127.44 (Rainy season)	No difference
Khuan Niang	0.064	2,956.32 ± 425.45	4,260 ± 704.89 (Light rainy season)	1,866.29±610.71 (Rainy season)	Rainy – Light rainy season

From the Table 11, it can be seen clearly that, there is a significant difference in fish catch between three seasons in year were found in Sathing Pra, Singha Nakhon, Pak Phayun, Muong.

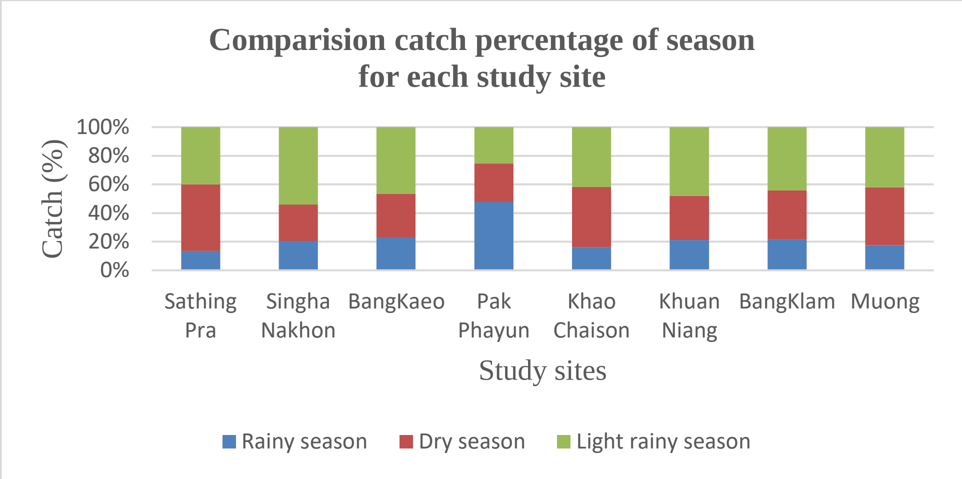


Figure 23. Comparison fish catch percentage between seasons for each study site

The percentage of mean fish catch in each season is different between each study site. While the highest fish catch percentage in the dry season in Sathing Pra, this happened in the rainy season in Pak Phayun or in the Light rainy season in Singha Nakhon (Figure 23).

Alternative work of fishermen in the study sites

Most of fishermen in the study sites indicated that they did not have alternative work, and this high percentage was shown in Figure 24. Some but very small percentage of fishermen worked on animal husbandry, collect debris (plastic material) for selling, shrimp farm, factory, fish trading, rubber cutting or doing fishing tool maintain. However, their livelihood was lift neted to change to semi-agriculture and semi-fishing activities because the fish amount is decreasing, and they can not only live on fishing.

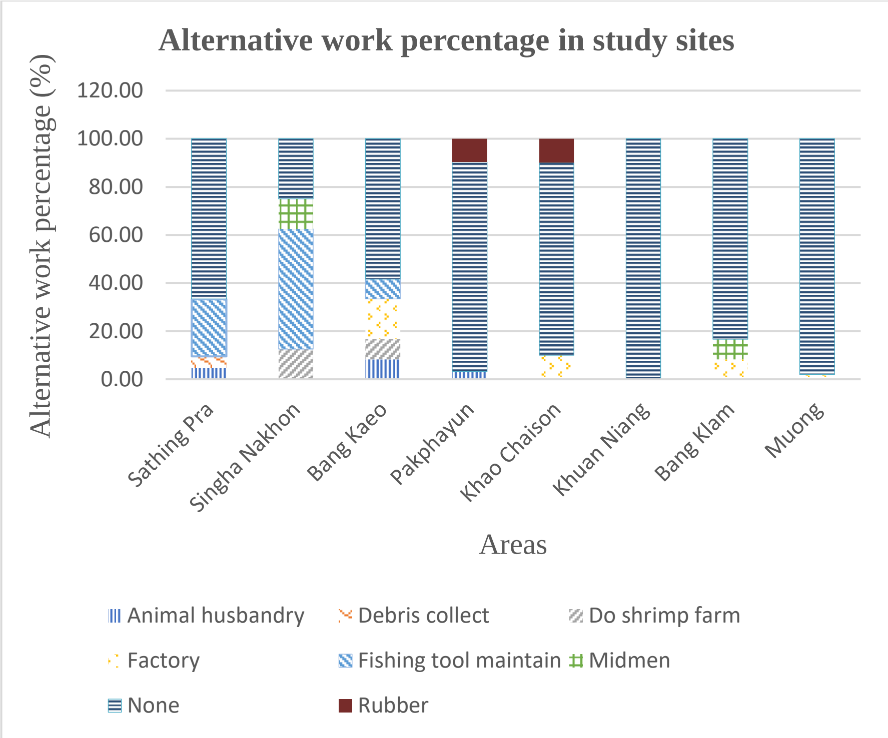


Figure 24. Alternative work percentage in study sites

Fishermen future perception

When asked about the perception of doing fishing, very few fishermen wanted to change to another job (only 10.98%), The main reason was they did not want to change the job as they invested much money on boat and equipment, it is hard for them to change the job because of old age, lack of education. These statements are shown clearly in Figure 25, where 72.56% interviewed fishermen said that they met difficulty to find another job. Especially, one 41-year-old fisherman told “So far, I only do fishing, I have never worked elsewhere, I do know what to do if I do not fish”. The big percentage of interviewed fishermen, 78.05% do not want to change to another job, and most of them said that, they loved this job but these days, less fish, low income, it is difficult for them to support their children.

The perception of fishermen for their children, more than half interviewed fishermen (53.05%) allowed their children to do fishing if they want, or they did not know how to orient job for the next generation, 37.37% (Figure 25) do not allow their children do fishing because they consider this job is not suitable any more, less fish, low income, they want their children to have higher education and earn more money.

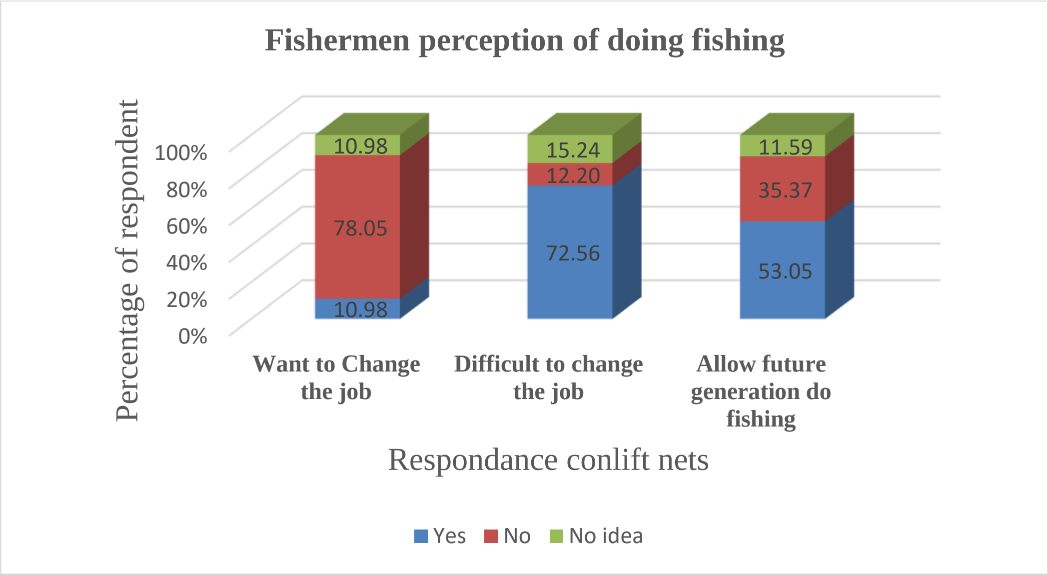


Figure 25. Fishermen perception of doing fishing

CHAPTER IV: DISCUSSION AND CONCLUSION

4.1. The correlation between aquatic catch landing with environmental factors

Reports from Pakistan showed that, the total fish catch increased after rains (Ayub, 2010), and in neighbor country Malaysia showed the fish catch landing was proved to have significant correlation with meteorological parameters, such as rainfall, temperature, wind, the Southern Oscillation Index (SOI) (Jafar-Sidik et al.,2010). However, in this study, the total fish catch was not sensitive with rainfall. Therefore, it is hard to do the forecasting total fish catch landing based on environmental factors, especially rainfall factor.

Shrimp and crab group in this study was proved to be very sensitive with rainfall and air temperature, this was confirmed by Gunter et al., 1954 (white shrimp) in Texas; Ruello, 1973; Glaister, 1978 (school prawn); Vance et al., 1985 (banana prawn); Gammelsrød, 1992 (red-legged banana prawn); Galindo et al., 2000 (blue shrimp). Even though shrimp in Pakistan had no correlation with rainfall (Ayub, 2010). Significantly, *Scylla olivacea* catch was very positive sensitive with temperature, this can be explained by the peak abundance of *Scylla olivace* juvenile during post monsoon season, thanks to the high seagrass and algal bed (Chandrasekaran and Natarajan, 1994). Therefore, in the dry season, when the temperature is high, the high catch of *Scylla olivace.*

Seven dominant fish species in this study showed the different result compare with other country reports. *Valamugil cunnesius* catch landing was sensitive with all rainfall. this result was confirmed in Queensland, Australia (Meynecke et al., 2006). The explanation for this may come from the food feeding, its food are plankton, algae (Mondal and Mitra, 2016). And these foods available depend on condition of the weather, the change of rainfall would change the plankton and algae. However, this species was no any correlation with temperature in this study, this result was different with Ayub (2010) in Pakistan when it had a significant positive correlation with annual mean temperature. *Lates calcarifer* had no correlation with rainfall or temperature in this study, however, *Lates calcarifer* was a negative correlation with temperature in Pakistan (Ayub, 2010) and *Lates calcarifer* in Queensland, Australia had a correlation with rainfall (Meynecke et al., 2006).
Conclusion

a) Not all studied species have correlation with rainfall and temperature

b) Rainfall and temperature normally have correlation with each other, however, some studied species had correlation with rainfall but had not correlation with temperature or vice versa

4.2. Statistical modeling for forecasting aquatic catch landing

Model fitting and forecasting performances

In this study, the percentage improvement figures for SARIMA and the ANN model for shrimp catch were significantly different (16.9%). In contrast with this result, the improvement figures for fish were very little different (1.56%). In the past, the percentage improvement of ARIMA and the ANN model has been different according to the data set and the period of the forecasting, which was confirmed by (Khashei and Bijari, 2011) when they used sunspot, Canadian lynx, and exchange rate data sets to compare percentage improvements of ARIMA and the ANN model. Almost all the results showed the better percentage improvement for ANNs over the ARIMA model at different levels. However, when they forecasted 67 points ahead from sunspot data set, percentage MAE of ANNs model is 3.32% bigger than ARIMA model. Again, this statement was proved by (Tseng et al., 2002), when the SARIMA model of machinery production time series showed the better result compared to the neural network (NN) with 60 historical forecasting items of data, but the SARIMA model's results were not as good as NN when they forecast 36 points ahead.

In the past, Stergiou (1989) found two suitable ARIMA models to forecast pilchard (*sardina pilchardus*) catches up to 12 months ahead with mean errors (ME) of 14.6% and 12% for the two models. Suitable SARIMA models were found in this study for shrimp and fish with mean errors of 4.56% and 1.83%.

SARIMA models provided satisfactory forecasts that were close to the recorded fish and shrimp catch values.

In practice, however, the limitation of sufficient data for model development, univariate time series data for SARIMA and ANN models was 165 months. Multivariate time series for the models were 32 points, therefore, resulting in model uncertainties and not so good model performance.

Seasonal fish and shrimp catch landing

Factors involved in the seasonal variation in fish and shrimp catches may be due to regional climate, especially the effect of the monsoon season in the Southern Thailand, for during these months, the catch in coastal provinces decreases sharply (Komontree et al., 2006), and the catch in the lake tends to increase. Seasonal difference effects on monthly fish catch also have been found in previous studies (Stergiou and Christou, 1996; Komontree et al., 2006). Even though the fish catch was very low during March to May, the shrimp catch tends to increase which may be due to the effect of seasonal difference, as the annual closure of the fishing area of the Gulf of Thailand from February 16 to May 15 did not affect the fish catch in the Lake. The changes of season lead to the changes in zooplankton (Brysiewicz et al., 2006), which would be one of the reasons for the difference in fish and shrimp catch between seasons.

Fish and shrimp catch trends in Songkhla lake

In the monthly fish and shrimp catch landings until 2020, both shrimp and fish catch fluctuated sharply during the two first years of forecasting, then they fluctuated steadily. The shrimp catch reduced to 52.88 tonnes, by around 15.47% of the catch average during 2003-2016. In contrast with the shrimp catch, the fish catch increased to 68.45 tonnes, estimated at a 36.05% increase in comparison with the mean fish for the same period in 2003-2016. This result reflects the reality of fishing activities in Songkhla: the general trends of shrimp catch reduce due to the decrease in the number of juvenile shrimps from the stocking program.

Conclusion

a) SARIMA models are fit for forecasting fish, shrimp catch landing in Songkhla Lake
b) November is high season for both fish and shrimp catch landings. Low season for fish is march and for shrimp is January

4.3. The condition of three fish species

This paper provided the first monthly values for the length–weight relationship of three commercially important fish commonly found in Songkhla lake and captured in the coastal areas of the lower Gulf of Thailand. It contributed with revised values for the maximum length of two of the species studied in the online database FishBase (Froese and

Pauly, 2018): the maximum recorded length for *P. ditchella* **(**Valenciennes, 1847) and *S. gibbosa* (Bleeker, 1849) was previously 160 mm and 170 mm length (Whitehead, 1985), and this study determined new maximums at 187 mm and 175 mm, respectively. The range of length and weight from these fish species were high, it may come from using the difference fishing gear. However, these ranges were smaller than previous published, the distance range of total length (cm) was 82.2 and total weight (g) was 7,785 for Sphyraena afra species (Correia et al., 2018).

With respect to the LWR, a value of 3 (three) for the slope of the regression (β) corresponds to the ideal growth of fish. However, such situation was seldom found (Allen, 1938) due to the changes in the shape of fish during the growth period (Martin, 1949). That coefficient can be affected by factors such as the length and shape of the fish itself and the time of spawning; the fishing gear used (Farran, 1936; Deason and Hile, 1947); or environmental factors such as food supply and season changes in environmental parameters (Brosset et al., 2015). In this study, the average of the monthly values of β for the three fish studied fall below the standard interval of 2.5 to 3.5 as determined by (Carlander, 1969). The average values from this study are 2.28, 2.36 and 2.1 for *P. ditchella,* Alepes vari and *S. gibbosa*, respectively. This indicates that all three fish have negative allometry, which is interpreted as a sign of poor body condition. This was in line with the views of contacted fishermen for this study, most of whom were of the view that the amount and size of fish has decreased in the coastal area of the southern Gulf of Thailand, which they attribute to the oil drilling activities taking place offshore and the illegal fishing gear, such as: sai nang (sitting cage). 14.29% of the fishermen interviewed in this area said they are using sai nang, they knew that this fishing gear catches all small fishes, but they still have to use because the number of fishes was decreasing sharply (Source: Author). The results from this study are insufficient to establish such a causal relationship though, and a broader investigation would be needed to determine the effects of coastal water quality on the condition of fish in the lower Gulf of Thailand.

The study also found that two of the fish captured after the monsoon season (dry season), namely *P. ditchella* and *S. gibbosa* were on average fatter than when captured during the monsoon season. This was in line with the result from the author, only 13.6% amount of fish was caught during monsoon season, 39.98% was before monsoon season and 46.42% was after monsoon season (Source: Author). This may be due to the biology of these two species, as both migrate to the mangroves in the estuarine and freshwater environments of the Lake which affects their growth negatively compared to life in the marine environment of the coastal waters. Eventhough, *Alepes* was found thinner in the dry season, but due to its small sample size (N = 3), it was not appropriate for a correct statistical evaluation, to conclude about Alepes, it requires further study.

Conclusion

a) Fish captured in dry season is fatter than monsoon season
b) Three studied fish species are in poor body condition
c) This study is useful for current and future stock estimation and evaluation studies

4.4. Seasonal variations and the fishermen pratices

Fish catch relate to seasons

The high catch focused on the light rainy season, as this time, there was no monsoon season, the water became brackish water. During monsoon season, the fishermen in Sathing Pra could not do fishing for whole month if it was heavy rain or strong wave. This makes the fisher's life to become difficult when they did not have alternative job, during this time, they used saving money to cover daily life.

While fishers in the studied areas did not have solution to again with the seasonal, somewhere in the world, the fishers in West Java, Indonesia response to seasonal and inter annual variations in fish availability species by switching between rice farming, tree-crop farming. The full time fishers from the North Coast (Java Sea) against seasonal and spatial variations in fish stock availability by migrating long shore and inter island (Allison et al., 2001).

The practices of local fishermen in front of the fish decline

Like the Rayong coast, the fishers in coastal areas of Songkhla province tended to have high vulnerability due to increasing industry and urbanization (Satumanatpan and Pollnac, 2017), which impacts fisher's living. However, the alternative jobs in the study areas were not diversity for fishers, they did not have much choices at the meantime if they did not do fishing. As Satumanatpan and Pollnac (2017) confirmed that, the fishers who perceived more options or a high level of self – adaptation to unexpected changes will expose higher levels of well – being, therefore, the issues of sustainable livelihoods in the study areas became the hot problem for the government. The topic of resilience and vulnerability was likely to become more meaningful in the designing of resource management questions in the future (Adger, 2000; Adger et al., 2005). When the fishers had high levels of satisfaction with features of the occupation, they were difficult to find acceptable alternative job with the same satisfaction (Satumanatpan and Pollnac, 2017). In this study, some interviewed fishers were not satisfied with fishing due to low income, they faced difficulty to change the job because of lack of education, experience, old age barrier, they were not self-confident to work outside, this situation has been happen with fishers in Hokkaido, Japan (Sweke et al., 2016). The consequence of cycling between falling catches – using illegal fishing gear – overfishing – declining catches sharply make a challenge for creating appropriate fishery management plans.

Future perception of fishermen

From interviewed fishermen, it was easy to recognize that the fisher allowed the young to enter fishing if their children are interested, the fishermen wanted to remain the traditional fishing job, however, they were wondering about this uncertain job could not afford to support their life. This result was relevant with the study in Rayong, the Eastern Thai province, on the Gulf of Thailand when advising the young to enter fishing was also related to fisher's well – being, basic needs or earnings (Satumanatpan and Pollnac, 2017). As many parts of the world, the fishers in Uruguay and Brazil wanted to continue fishing in the future, they did many occupations at the same time or considered fishing as a way of life rather than just a job (Urquhart et al., 2013; Sievanen, 2014). The fishers diversed pattern of fishing activities with respect to the species exploited, location of fishing grounds and gear used, increase incomes from seasonal fishing by a range of people cited retired persons, taxi drivers, shopkeepers, the unemployed (Freire and García-Allut, 2000).

The number of 78.05% interviewed fisher would not want to change the job, 72.56% met difficulty to change the job, 53.05% fisher allowed their children to do fishing if the young generations want are significant numbers. It makes sense that, fishers with positive attitudes towards their occupation would not want to change or they would not want to change because of being difficult to find another job. This was an interesting finding that answers the question why attempts to reduce fishing effort have failed in some areas, particularly in those with limited job alternatives (Sweke et al., 2016; Pollnac et al., 2012).

The study areas, except Sathing pra district where the fishermen do fishing in the sea and they hardly have alternative job because the lack of land for doing agriculture. The other villages, the community ecosystem was one of alternating brackish or sea water circulating seasonally, providing the bases to local occupations that include paddy farming, manufacturing of sugar palm, and raising cattle (Chuapram et al., 2012).

Conclusion

a) The seasonal aspects to fish catch in Songkhla Lake and Sathing Pra are different
b) Fishing is not the stable career in Songkhla province anymore
c) Almost fishers in this study do not have alternative livelihoods, the adaptation of fishers to the changes of fish catch is low.

4.5. Further studies

Further studies of similar nature and involving some biological aspects of commercially important species are necessary to support the formulation of policies for sustainable utilization and appropriate management of fisheries resources in the country.

Rainfall in Songkhla lake was related to seasonal temperature, the changes in temperature would change the pH and salinity of the water, therefore, it is necessary to have further studies the effect of temperature on the fish catch for a longer period.

The performance of the models could be improved by additional information about environmental factors (e.g. temperature, salinity…) and other factors (market prices and biological information) put into the multivariate models.

CHAPTER V: RECOMMENDATION FOR FISH CATCH MANAGEMENT

Based on the results of the study, some recommendations were given aimed to contribute on sustainable fisheries management in Songkhla lake:

1) Need to have single species management strategy, list the important order of each species, have more research on each species biology as well as their life cycle to enhance by restocking or aquaculture. The government need to pay more attention to the various types of fishery domains in order to achieve fisheries management.
2) Can apply SARIMA models to forecast fish catch landing in case of budgets for organizing the usual surveys is limited. Using forecasting results in fisheries planning
3) The information of Songkhla lake fish species that found in Sathing Pra may be useful for further research on migrating of fish between lake and Coastal area
4) In practice, these results can be used to suggest some fishery policy based on the variables that were significant correlated with fish catch. Training courses for fishing techniques are not important because the fish catches did not relate to fishing experience, instead of this, strictly control illegal fishing gears is urgent duty for the fisheries managers. The government should cooperate with all stakeholders in fish catch management, organize some workshops to propagate to the fishermen with the slogan “Fish for future”, it means they should catch aquatic species which is line with standard size, they should not catch all aquatic species.
5) The government should have deep market research, identify and provide training for suitable alternative livelihoods.

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APPENDIX

APPENDIX A: FLOW CHART OF THE STUDY

Seasonal Variation of Fish Catches and Fisherman Practices for Sustainable Fishery Management in Songkhla Lake, Thailand

General Research Question: How are the fishing activities in Coastal areas of Songkhla province? What recommendations for sustainable fishing activities?

Research Questions	Do rainfall and air temperature have really correlation with fish catch landings?	Which model is fit for forecasting fish catch landing in Songkhla lake?	How is the condition of fish species in rainy and summer season	Do season effect on fish catch in the coastal areas of Songkhla province and how fishermen point of view about their future?
Objectives	To investigate the correlation between fish, catch landing with the rainfall and air temperature	To find the suitable model for forecasting fish catch landing in Songkhla lake	To compare the condition of three fish species in rainy and summer season	To describe the seasonal variations and the fishermen practices with the changes of fish catches
Methodology	**Secondary data:** - 14 dominant species - Monthly Fish catch landing data from 2003-2016 (NICA) - Rainfall, temperature data (Songkhla Meteorological Department)	**Secondary data:** - Monthly fish catch landing data from 2003-2016	**Primary data:** - Monthly fish collecting from 9/2017 – 4/2018 - Lab work	**Primary data:** - Deep interview: 8 village leaders - Interview 164 fishermen

Data analysis	- Grouped data into 3 seasons: S1: Heavy rainy season: October to January S2: Dry season: February to May S3: Light rainy season: June to September - Used Pearson correlation coefficient - Open R software	- Time series analysis techniques - Open R software, packages: NoneliearityTseries, nnfor	- Length – weight relationship analysis - Inferences about slope - Predictions of fish original scale - ANOVA analysis (Compare LWR between seasons) - Open R software, Package: FSA	- Descriptive and statistical data analysis - Inferential statistical to discover the relationship among the relevant variables - Mann – Whitney U test for two variables and the Kruskal – Wallis test for more than two variables - SPSS
Main results	***Monthly:*** Rainfall: Yellow shrimp (+) Longarm mullet (+) Temperature: Banana shrimp (+) Giant Mud crab (+) ***Seasonal***: Rainfall: Giant Mud crab (-) Longarm mullet (+) Temperature: Total catch (-) Giant mud crab (+) ***Lag one season:*** Rainfall: Banana shrimp (-) Giant tiger prawn (-) Yellow shrimp (+) ***Yearly:*** Rainfall: Longarm mullet (+) Temperature: Banana shrimp (+)	- SARIMA models were chosen for forecasting fish, shrimp catch. This model was proven more accurate than models have been used so far. - Found the seasonal factors for Fish and Shrimp catch - Forecast Fish, shrimp catch until 2020	- First reference on LWR equation parameters of *Pellona ditchella* (Valenciennes, 1847), *Sardinella gibbosa* (Bleeker, 1849) and *Alepes vari* (G. Cuvier, 1833) in the lower gulf of Thailand - Provide wider size range in FishBase, Pellona ditchella (Valenciennes, 1847) and Sardinella gibbosa (Bleeker, 1849) - Compare the fish condition of three fish studied between two seasons	- The highest mean catches in the light rainy season. The lowest mean catches in the rainy season. - Almost studied fishers don't have the alternative occupation and are difficult to find another job. - Illegal fishing gear is the serious cause of fish decline - The total catch for one year was correlated with the number of fisher's year living, number of catching days, and number of catching hours. - No significant correlations between total catch amount in one year and family size, boat size, years of fishing, fishing distance, boat age, age of fishermen

Conclusion

1/ Not all studied species have correlation with rainfall and temperature
2/ Rainfall and temperature normally have correlation with each other, however, some studied species had correlation with rainfall but had not correlation with temperature or vice versa

1/ SARIMA models are fit for forecasting fish catch landing in Songkhla Lagoon
2/ November is high season for both fish and shrimp catch landings. Low season for fish is march and for shrimp is January

1/ Fish captured in dry season is fatter than monsoon season
2/ Three studied fish species are in poor body condition
3/ This study is useful for current and future stock estimation and evaluation studies

1/ The seasonal aspects to fish catch in Songkhla Lagoon and Sathing Pra are different.
2/ Fishing is not the stable career in Songkhla province anymore.
3/ Almost fishers in this study do not have alternative livelihoods, the adaptation of fishers to the changes of fish catch is low

Recommendations for fishing sustainable development

1) Need to have single species management strategy, list the important order of each species, have more research on each species biology as well as their life cycle to enhance by restocking or aquaculture. The government need to pay more attention to the various types of fishery domains in order to achieve fisheries management.
2) Can apply SARIMA models to forecast fish catch landing in case of budgets for organizing the usual surveys is limited. Using forecasting results in fisheries planning
3) The information of Songkhla lake fish species that found in Sathing Pra may be useful for further research on migrating of fish between lake and Coastal area
4) In practice, these results can be used to suggest some fishery policy based on the variables that were significant correlated with fish catch. Training courses for fishing techniques are not important because the fish catches did not relate to fishing experience, instead of this, strictly control illegal fishing gears is urgent duty for the fisheries managers. The government should cooperate with all stakeholders in fish catch management, organize some workshops to propagate to the fishermen with the slogan “Fish for future”, it means they should catch aquatic species which is line with standard size, they should not catch all aquatic species.
5) The government should have deep market research, identify and provide training for suitable alternative livelihoods.

PPENDIX B: PAPER 1

A case study of the correlation between landings and environmental factors in the Songkhla lagoon, Thailand

(This paper was submitted to EnvironmentalAsia journal, it is under reviewers – International journal)

A case study of the correlation between landings and environmental factors in the Songkhla Lagoon, Thailand

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Abstract: The correlation of air temperature and rainfall was analyzed for the total of fish catch landings in Songkhla lagoon, including 14 dominant species. The most species records contained 165 months of data during the period of 2003-2016. Overall, the total catch of species was found had a strong negative correlation with mean seasonal temperature. The study result was different between species. Longarn mullet showed a positive correlation with monthly, seasonally and yearly rainfall and negative correlation with rainfall in lag one season.Hampala barb and Malayan leaffish had a negative correlation with air temperature in monthly and seasonally. Plotosus and Scatophagus were shown to have only positive with monthly temperature. Seminally, yellow shrimp had positive relationship with both monthly and lag-one season of rainfall and negative correlation with seasonal and yearly mean temperature. The giant mud crab had a strong negative correlation with seasonal rainfall, this is reasonable when it showed the strong positive correlation with monthly and seasonal temperature. These results are preliminary inquiries to convince local authorities and researchers to implement further research on the changes in fish catches, in hopes that sustainable fish species strategy management will be established in Songkhla lagoon.
Keywords: Fish catch landing; Songkhla lagoon; rainfall; temperature.

1. Introduction

Environmental factors have been shown to have an influence on different elements of fisheries biology (Lehodey et al., 2006; Ottersen et al., 2001). The productivity, abundance and distribution of fish stocks at both regional and oceanic scales are influenced by temperature, salinity, upwelling, winds, tidal currents, oceanic circulation, rain and river runoff (Baptista et al., 2014; Vânia et al., 2014; Brander, 2007, 2010; Borges et al., 2003; Erzini, 2005; Lehodey et al., 2006; Planque et al., 1999; Santos et al, 2001). Different environmental parameters have a direct effect on commercial species (Brander, 2007, 2010; Lehodey et al., 2006), and climate factors may indirectly affect the early life cycle stages of species by through changes in food supply and other ecosystem functions (Balston, 2009; Brander, 2007, 2010).

Studies of the relationship between environmental factors and fisheries have been conducted on different aspects of fisheries biology, such as recruitment (Solow, 2002), spawning stock biomass (Gröger et al., 2011), fish landing (Erzini, 2005) and catch rates (Baptista et al., 2014). Over the last decade there has been a growing trend towards investigating the impacts of environmental parameters on commercial fisheries, covering pelagic fish species (Lehodey et al., 2006; Santos et al., 2001; Ullah et al., 2012), demersal fish species (Gröger et al., 2011; Planque et al., 1999;Solow, 2002), cephalopods (Ullah et al,, 2012), bivalves (Baptista et al., 2014; Vânia et al., 2014) and crustaceans (Herraiza et al., 2009).

Environmental factors have been shown to have and are expected to continue having an impact on fishing activities in different contexts (Roessig et al., 2004). The decision to fish has been shown to be modulated by environmental factors such as rainfall (George et al., 1962), and there have been studies of the effects of environmental factors on the catch of marine species in large embayment, or gulf ecosystems (Sutcliffe et al., 1977; Vance et al., 1985), as well as in estuaries (Meynecke et al., 2006; Ayub, 2010; Sutcliffe et al., 1977). In contrast, the impacts of rainfall and temperature on fisheries landings in lagoon ecosystems is an area that is relatively underexplored, with only few studies on this subject.

This is what this paper intends to address, presenting the results of an assessment of the relationship between two environmental factors, rainfall and air temperature, and landings of different commercial species in the Songkhla lagoon in southern Thailand. The relevance of this study extends beyond the study area and Thailand, since in many other developing countries lagoons have played an important role for local populations since many generations, not only by providing the main livelihood, but also by constituting a central feature of their cultural identify.

2. Material and methods

This study aims to determine if the rainfall and temperature have the correlation with the fish catch landing of 14 dominant species of fish, shrimp, and crab. Correlation analysis between rainfall and temperature and fish catch landing was implemented by monthly, seasonally, yearly during 2003-2016 to give a comprehensive picture of the effects of climate parameters on fish catch landing in Songkhla lagoon, contributing to fishery sustainable management for each target fish species.

During the period 2003-2016, 14 commercial dominant species was chosen for this study in among 185 species found in Songkhla lagoon, include fishes, crabs, and shrimps, which are lagoon dependent species that brings the regular significant income for fishermen for many years, and fishermen can catch every month, those economic species are easy to find at the local market every day.

Study site and sample collection

Environmental and Fisheries Data Sources

A database of fishing activity for the period 2003–2016 were collected every month from all mid men in Songkhla lagoon by National Institute of Coastal Aquaculture (NICA), Thailand (Figure 1), this database contains information of monthly landings per mid man per month.

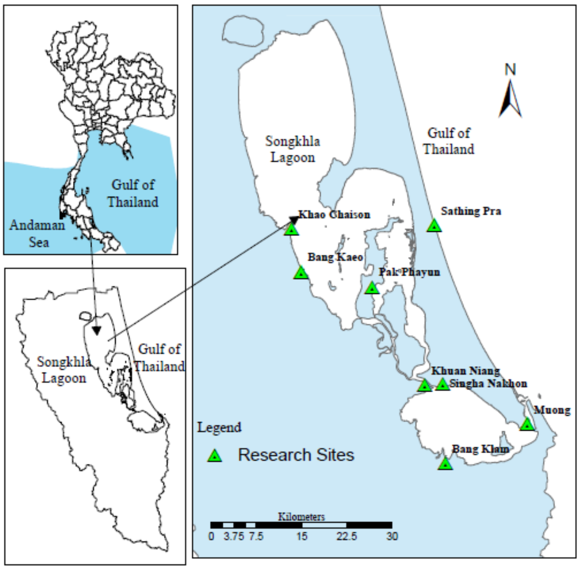


Fig 26. Location and Data collection stations

These sampling stations cover bio-diversity of species, from upper section to the outer section of Songkhla lagoon. The Gulf of Thailand is connected with the outer section through 380m width cannel.

The rainfall data for this study was collected from 7 stations: Hatyai, Songkhla, Singhanakorn, Sathingpra, Krasae, Ranot, Bangkham, these gauging stations were selected due to the weather data was consistent over 14 years and have direct effects on the Songkhla lagoon with the high number of fisheries catch records, located around in the Songkhla lagoon. The amount of rainfall every month data at every location was provided by the Songkhla Meteorological Department, Government of Thailand.

Due to the missing of data, the data of temperature had only the yearly data from 2003-2016 and monthly data from 2012-2016, this data was collected from Meteorological Department, Ministry of Information and Communication Technology, Thailand.

Data Analysis

For the purpose of this study, data for total 185 fish, shrimp and crab catch species, the data for each dominant species, rainfall and temperature were rearranged as monthly, yearly and grouped into 3 seasons every year during the period of 2003-2016 (heavy rainy season – October to January (S1); dry season – February to May (S2); and the light rainy season – June to September (S3)).

The catch landing of species from the present season was analyzed correlation with the total of rainfall and mean temperature from the previous season (Gunter and Hildebrand, 1954).

Statistical Analysis

Autoregressive Integrated Moving Average (ARIMA) models were used to choose the appreciated models for predicting some missing values for each variable (Preciado et al., 2006). Each data was checked the normal distribution by frequency histogram, boxplot, and Shapiro-Wilk normality test. The null hypothesis of Shapiro-Wilk normality test is data is normally distributed, the study used significant P-value 0.05 to reject or accept the null hypothesis. The Tukey's Ladder of Powers was used to transform skewed distribution data(Tukey, 1977). This approach uses a power transformation on a data set, which integrated Shapiro-Wilk normality tests. In essence, this finds the power transformation that makes the data fit the normal distribution as closely as possible with this type of transformation. Significant outliers of each data were treated before analyzing data.

To see whether two measurement variables are associated with each other, whether as one variable increase, the other tends to increase or decrease, the study used Pearson correlation coefficient (Sedgwick, 2012; McDonald, 2009). The null hypothesis for each test was the correlation between each species catch and rainfall or temperature is zero with the chosen significant level of P-value 0.05 to reject or accept the null hypothesis. The strength of the relationship between two variables was estimated through r correlation coefficient and scatter plot. The formula for r correlation coefficient between two measurement variables was shown:

$$r = \frac{\sum_{i=1}^{n}(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum_{i=1}^{n}(x_i-\bar{x})^2}\sqrt{\sum_{i=1}^{n}(y_i-\bar{y})^2}} \qquad \text{(Eq 8)}$$

While: n: sample size

x_i, y_i single samples indexed with i

$\bar{x} = \frac{1}{n}\sum_{i=1}^{n} x_i$; $\bar{y} = \frac{1}{n}\sum_{i=1}^{n} y_i$ (The sample mean);

3. Results

The percentage of 14 dominant species catch in Songkhla Lagoon

During the period of 2003-2016, 185 species of fishes, shrimps, and crabs were found in Songkhla lagoon. Among these species, the scientific name and the catch percentage of 14 dominant species which were used in this study were shown in Table 1.

Table 12. The abundance groups of fish, shrimp and crab catch in Songkhla Lagoon from 2003-2016

Common name	**Scientific name**	**Catch percentages (%)**													
		2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Banana shrimp	*Fenneropenaeus merguiensis* (De Man, 1888)	3.83	8.49	10.66	1.41	5.50	5.21	5.16	10.82	3.13	1.21	2.11	2.81	1.87	2.19
Giant tiger prawn	*Penaeus monodon* (Fabricius, 1798)	3.10	1.94	10.08	1.38	3.68	0.40	1.32	3.84	0.20	0.67	0.31	1.39	1.36	0.55
Giant fresh water prawn	*Macrobrachium dacqueti* (Sunier, 1925)	1.43	1.78	0.89	3.11	3.63	12.60	21.35	4.99	13.46	8.01	4.81	5.35	4.09	4.18
Yellow shrimp	*Metapenaeus brevicornis* (H. Milne-Edward, 1837)	0.89	4.20	3.86	7.82	7.89	5.95	0.94	6.25	12.07	17.14	44.03	32.53	16.53	8.15
Snakehead murrel	*Channa striata* (Bloch, 1793)	5.26	3.94	3.30	5.08	4.30	6.78	6.13	3.74	6.51	3.52	2.42	2.79	5.10	7.32

Table 1 (Cont

Common name	Scientific name	Catch percentages (%)													
		2003	**2004**	**2005**	**2006**	**2007**	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**	**2015**	**2016**
Snakehead murrel	*Channa striata* (Bloch, 1793)	5.26	3.94	3.30	5.08	4.30	6.78	6.13	3.74	6.51	3.52	2.42	2.79	5.10	7.32
Broadhead catfish	*Clarias macrocephalus* (Gunther, 1864)	0.69	0.76	1.04	2.91	1.18	1.41	0.79	0.41	1.55	0.43	0.17	0.10	0.66	0.66
Hampala barb	*Hampala macrolepidota* (Kuhl & van Hasselt, 1823)	2.55	0.85	0.38	0.84	1.70	1.33	1.21	1.33	0.94	1.64	1.14	2.20	1.93	1.44
Barramundi	*Lates calcarifer* (Bloch, 1790)	1.12	0.68	0.34	0.69	0.15	0.31	0.04	0.04	0.17	0.02	0.28	0.03	0.13	0.10
Longarn mullet	*Valamugil cunnesius* (Valenciennes,1836)	0.01	0.44	1.17	0.14	0.18	0.55	0.02	0.02	0.05	0.17	0.52	0.56	1.12	0.39
Plotosus	*Platystacus anguillaris* (Bloch, 1794)	6.60	4.43	3.38	4.00	3.49	4.35	1.72	0.52	4.67	3.81	2.11	2.52	5.09	6.50
Bronze feather back	*Notopterus notopterus* (Pallas, 1769)	3.38	1.97	1.64	3.25	3.32	2.84	1.61	2.44	2.73	2.87	1.82	2.26	2.14	2.26
Malayan leaffish	*Pristolepis fasciata* (Bleeker, 1851)	0.69	1.40	1.15	2.19	1.64	1.15	0.20	1.03	0.95	1.14	0.77	1.45	1.08	1.93
Scatophagus	*Scatophagus argus* (Linnaeus, 1766)	0.77	0.46	0.24	0.29	0.19	0.11	0.22	0.09	0.07	0.33	0.63	0.49	0.49	0.78
Giant mud crab	*Scylla olivacea* (Herbst, 1796)	0.63	0.50	0.42	0.30	1.03	1.10	0.00	0.82	0.35	0.33	0.52	0.31	0.32	0.62

ese dominant species were found every month from middlemen, some shrimp species played the significant role not only for the local people but for Thai exporting by their both high percentage and high economic value, especially banana shrimp and giant tiger prawn. According to FAO (2014), Thailand was the top ten country had biggest catches in important shrimps, this leads Thailand stood the fourth biggest country had the big amount of Giant tiger prawn catch landing, the second biggest country for Banana shrimp catch landings in the world in 2014. Giant mud crab, even though, it had a small percentage of the amount, but we cannot deny the big economic that it brings to the local people.

The correlation between fisheries catch landing and rainfall result are very different between species (Table 2).

Table 13. Pearson Correlation coefficients (r) between fish catch landings and rainfall during the period 2003-2016 (**P-value<0.05; ***P-value much less than 0.01)

Common name	Month		Season		Lag one season		Year	
	r	**n**	**r**	**n**	**r**	**n**	**r**	**n**
Total fish, shrimp and crab catch landing	0.129	163	0.064	39	-0.222	39	0.055	12
Banana shrimp	0.101	163	-0.228	37	-0.392**	39	0.273	12
Giant tiger prawn	0.080	163	0.196	39	-0.451***	39	0.063	12
Giant fresh water prawn	-0.016	163	-0.031	39	-0.169	39	0.281	12
Giant mud crab	-0.112	163	-0.494***	39	0.091	39	0.068	12
Snakehead Murrel	-0.090	163	-0.073	39	0.071	39	-0.248	12
Yellow shrimp	0.160**	163	0.289	39	0.318**	39	0.086	12

Common name	Month		Season		Lag one season		Year	
	r	n	r	n	r	n	r	n
Broadhead catfish	-0.131	163	0.005	39	0.274	39	0.039	12
Hampala Barb	-0.016	152	0.279	39	-0.234	39	-0.051	12
Barramundi	0.040	163	0.204	39	0.166	39	0.079	12
Longarm mullet	0.341***	163	0.608***	39	-0.441**	39	0.535**	12
Plotosus	-0.042	162	0.080	39	-0.057	39	-0.227	12
Bronze feather back	-0.024	163	0.042	39	-0.236	39	0.031	12
Malayan leaffish	-0.062	163	0.127	39	0.033	39	-0.416	12
Scatophagus argus	-0.053	163	-0.188	39	0.028	39	-0.302	12

In general, the total of fish, shrimp and crab catch did not have the correlation with rainfall. Other species had the correlation with rainfall were shown in Figure 2.

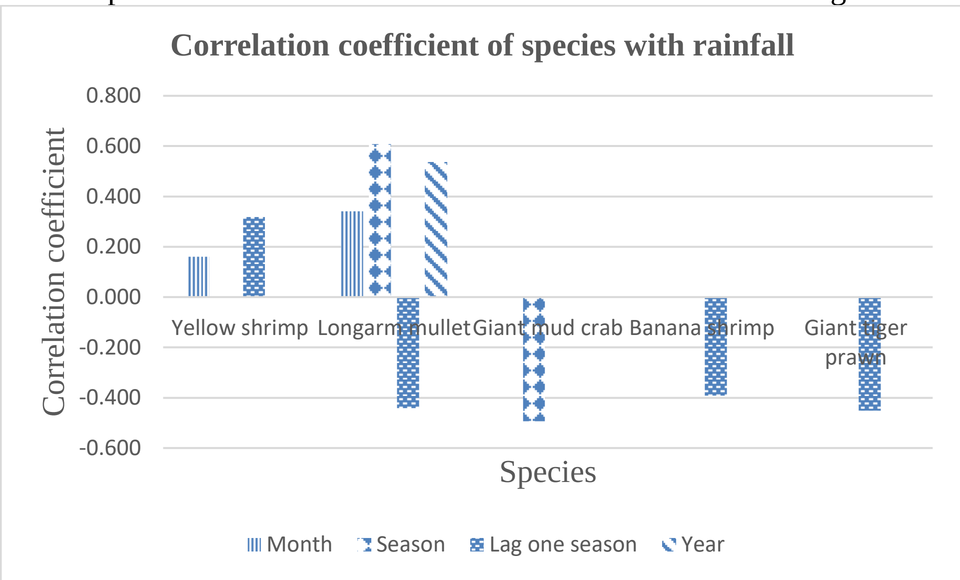


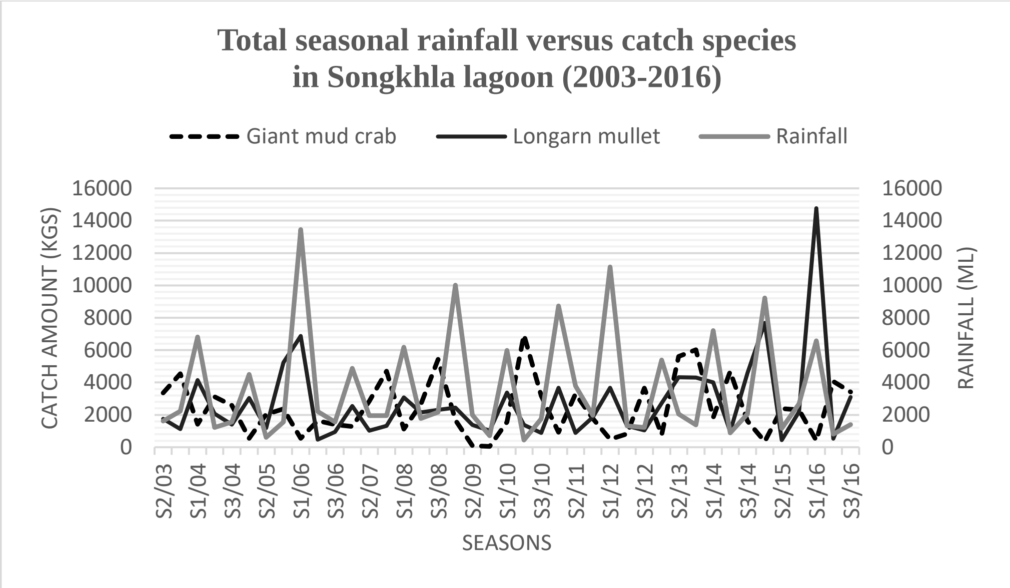
Fig 27. The correlation coefficient of species with rainfall

With five shrimp and crab species were selected for analyzing the correlation with rainfall in this study. Giant tiger prawn had a strong negative relationship with rainfall when rainfall data was lagged one season. Yellow shrimp had a negligible positive correlation with monthly rainfall and moderate positive relationship with lag one season of rainfall. Banana shrimp had a moderate negative with lag one season of rainfall. Giant freshwater did not have any correlation with rainfall. Giant mud crab had a strong negative correlation with rainfall in season.

Along with shrimp and crab species, nine fish species were chosen for this study, only Longarn mullet had a strong positive relationship with rainfall in monthly, seasonally and yearly. And it had a strong negative relationship with rainfall in lag one season of rainfall.

These significant correlations are expressed in Figure 3

Fig 28. Total seasonal rainfall versus two species catch landings



It can be seen that, in the highest rainy season (S1/2006), the amount of rainfall reached 13,455 ml, the catch of Giant mud crab was very lowest, only 540 kilograms, while the Longarn mullet catch was moderate around 6,880 kilograms. In the dry season with the lowest amount of rainfall (S2/2010), the amount of rainfall was only 441 ml, the amount of Giant mud crab reached the peak of 6,946 kilograms, the Longarn mullet catch amount remained at 1,371 kilograms. When the Longarn mullet catch amount was highest (14,770 kilograms) in rainy season 1/2016, the amount of rainfall was quite high (6,578 ml) (Figure 3).

During the time period relevant to this study, these species had the different correlation with temperature, this is shown in Table 3.

Table 14. Pearson Correlation coefficients (r) between fish catch landing and mean temperature (Monthly (during 2012-2016), seasonally (during 2012-2016), and Yearly (during 2003-2016), (**P-value< 0.05; ***P-value much less than 0.01)

Common name	**Monthly**		**Seasonal**		**Yearly**	
	r	**n**	**r**	**n**	**r**	**n**
Total fish, shrimp, and crab catch landing	-0.055	55	-0.611***	12	-0.427	12
Banana shrimp	0.288**	55	-0.247	12	0.733***	12
Giant tiger prawn	0.097	55	0.041	12	0.384	12
Giant freshwater prawn	0.111	55	0.176	12	-0.214	12
Giant mud crab	0.603***	55	0.532***	12	0.10	12
Snakehead murrel	0.248	55	0.266	12	-0.445	12
Yellow shrimp	-0.200	55	-0.636**	12	-0.637**	12
Broadhead catfish	0.162	55	0.207	12	-0.269	12
Hampala barb	-0.294**	55	-0.624**	12	-0.294	12
Barramundi	-0.022	55	-0.317	11	0.014	12
Longarm mullet	-0.221	55	-0.468	11	0.182	12
Plotosus	0.327**	55	0.381	12	-0.386	12
Bronze feather back	-0.043	55	-0.263	12	-0.376	12
Malayan leaffish	-0.105	55	-0.059	12	-0.561**	12
Scatophagus	0.284**	55	0.267	12	-0.256	12

On the overall, the total of fish, shrimp and crab catch landings had only strong negative correlation with seasonal mean temperature during the period of 2012-2016 in Songkhla Lagoon. This is shown in Figure 4

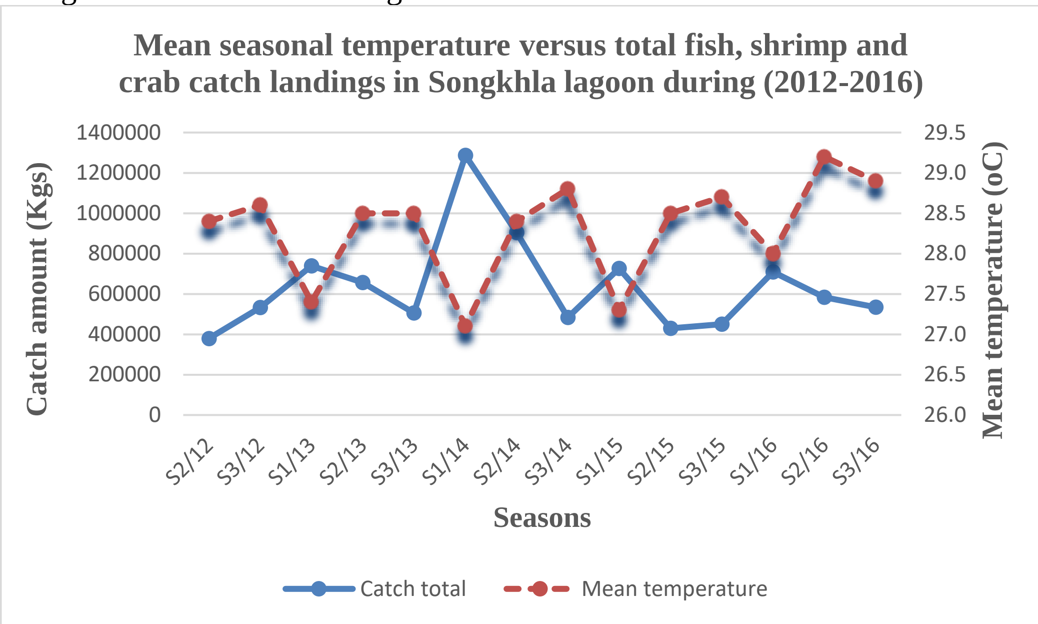


Fig 29. Seasonal mean temperature versus total fish, shrimp and crab catch landings

The total catch species landing had negative correlation with the temperature, in the heavy rainy season 2014 (S1), when the mean temperature reached the lowest degree, around 27.1 degrees, the total catch species reached the highest amount, it was estimated up to 1,300,000 kilograms. Moreover, the mean temperature touches the highest record in the dry season 2016 (S2), around 29.3 degrees, the catch of fisheries landing fluctuated around 600,000 kilograms (Figure 4), the catch of Giant mud crab was quite high (4,072 kilograms), the catch of Hampala barb was at low level (17,250 kilograms) (Figure 5). The strong positive correlation between Giant mud crab catch and mean seasonal temperature was expressed by the high catch in dry seasons (S2 and S3).

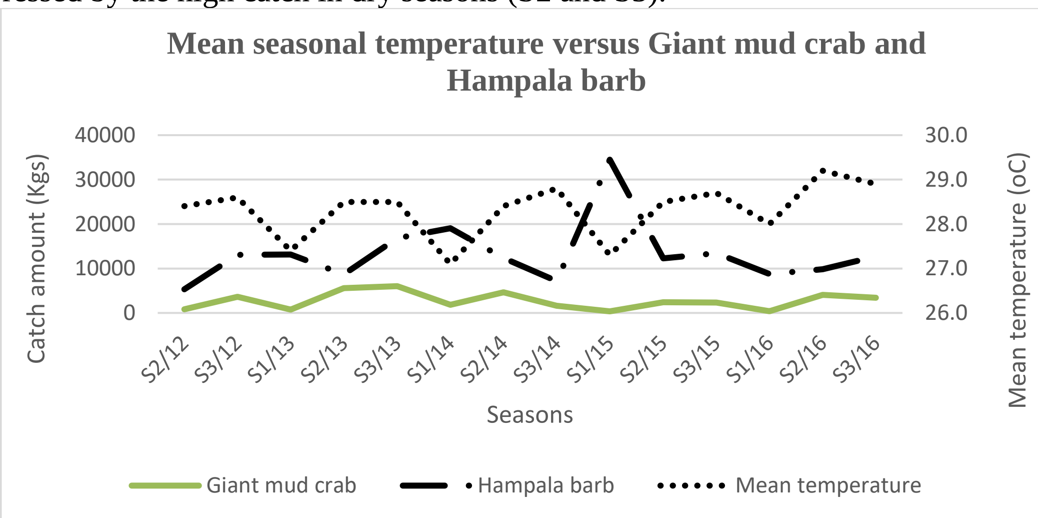


Fig 30. The correlation of species with mean seasonal temperature

The strong negative correlation between Hampala barb and mean seasonal temperature can be seen clearly that almost high Hampala barb catch was focused in the heavy rainy season (S1) when the temperature is normally lower than other seasons.

The level of correlation between different species with mean temperature was different in monthly, seasonally or yearly, this statement was shown in Figure 6.

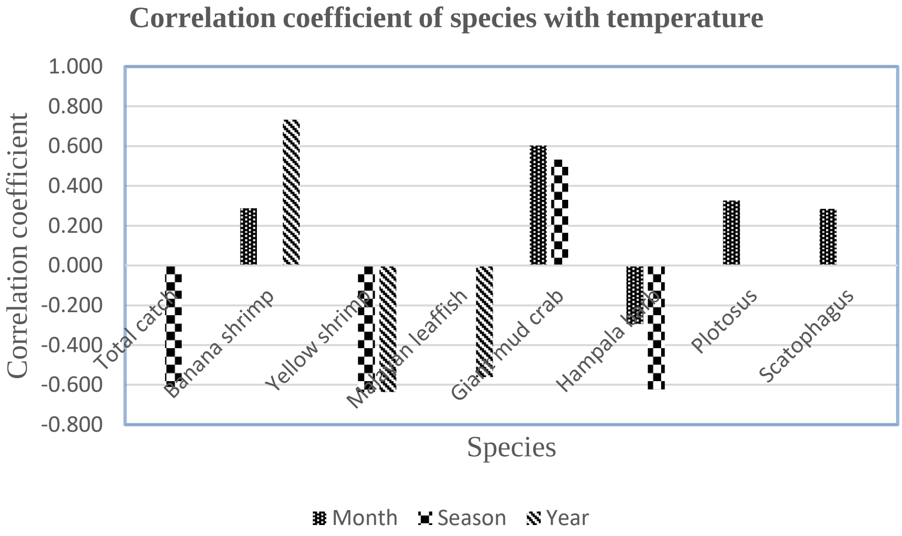


Fig 31. The level correlation coefficient of species with temperature

In Figure 6, among the five kinds of shrimp and crab species were chosen for this study, opposite to the result from rainfall, Giant tiger prawn and Giant fresh water had no correlation with mean temperature. While Banana shrimp catch had a significant positive correlation with yearly mean temperature and weak positive relationship with monthly mean temperature. Yellow shrimp had a strong negative correlation with both seasonal and yearly mean temperature. The giant mud crab had both strong positive correlations with monthly mean temperature and seasonally.

Regarding nine fish species. Hampala barb had a weak negative relationship with mean monthly temperature and strong negative relationship with mean seasonal temperature. Both Plotosus and Scatophagus had moderate and weak positive correlation with mean monthly temperature. Malayan leaffish had a strong negative with mean yearly temperature.

4. Discussion

The total of fish, shrimp and crab catch landing in the Songkhla lagoon during 2003-2016 had only negative correlation with mean seasonal temperature. In the heavy rainy season, while the fishermen from coastal areas in Songkhla province cannot go fishing in the sea, the fishermen around the Songkhla lagoon still continue doing fishing in the lagoon that is a reason to prove why the amount of total fish, shrimp and crab catch landings, keep the highest amount during 2003-2016, doing fishing in Songkhla lagoon is more stable than in some coastal areas in Songkhla province. This result again confirms the statement, fish catch in Songkhla lagoon not only really rely on the environmental factors, it relates to the cultures, religions. Some months in the year, the fishermen will not go for fishing, not because of the weather, but for Songkran festival in April (Thai new year), or in August, many Buddhists fishermen, who comprise the majority of the fishermen in the Songkhla lagoon, refrain from killing animals for religious reasons. Relate to the seasonal, in the dry season, most of the brackish and saltwater fish populations migrate to the open sea whereas the freshwater fish in the upper lake migrate to deeper pools. This phenomenon is consistent with the seasonal migration of some fishermen to find work in the cities. In the rainy season, pollution from wastewater discharge and eutrophication effects are also likely to have damaged the fish stock in the lake. The high seasonal effect in December might be due to the heavy rain during the monsoon season in the southeast of Thailand. During these months, the offshore catch decreases and the freshwater fish living in the deeper pools and the brackish and saltwater fish living in the Gulf of Thailand in the Songkhla Lake basin during the dry season migrate back to the lake for breeding, spawning, and larval nursing. Fishermen can thus catch greater amounts of fish in this flood period. These factors make the fish catch in Songkhla lagoon is different from other areas in the world. Some reports showed that the fish catch is normally increased after rain, it would be related to the biology or life cycle of fish, and therefore, this study conducted the relationship with lag one season of rainfall with the fish catch. Doing research on the correlation between fish catch and monthly, seasonal and yearly environmental data aims to understand the broader implications of the impacts of environmental factors on fish biology.

Reports from Pakistan showed that, the total fish catch increased after rains (Ayub, 2010), and in neighbor country Malaysia also showed the fish catch landing was proved to have significant correlation with meteorological parameters, such as Rainfall, temperature, wind, the Southern Oscillation Index (SOI) (Jafar-Sidik et al.,2010). However, in this study, the total fish catch was not sensitive with rainfall. Therefore, it is hard to do the forecasting total fish catch landing based on environmental factors, especially rainfall factor.

Shrimp and crab group in this study was proved tobe very sensitive with environmental factors (rainfall and temperature), this was confirmed by Gunter and Hildebrand, 1954 (white shrimp) in Texas; Ruello, 1973; Glaister, 1978 (school prawn); Vance et al., 1985 (banana prawn); Gammelsrød, 1992(red-legged banana prawn); Galindo et al., 2000(blue shrimp). Even though shrimp in Pakistan had no correlation with rainfall (Ayub, 2010). It is vital to find out this correlation was real or by chance, it may relate to unseen relations between fish catch landings with other factors, such as the biology of the fishery, the economic cycle, the human impact.

Seven dominant fish species in this study showed the different result compare with other country reports. Longarn mullet catch landing was sensitive with all rainfall, this result was confirmed in Queensland, Australia (Meynecke et al., 2006). However, this species was no any correlation with mean temperature in this study, this result was different with Ayub (2010) in Pakistan when it had a significant positive correlation with annual mean temperature. Barramundi had no correlation with rainfall or mean temperature in this study, while it had negative correlation with mean temperature in Pakistan (Ayub, 2010) and had positive correlation with rainfall in Queensland, Australia (Meynecke et al., 2006).

5. Conclusion

The total of fish catch landing did not have the correlation with rainfall, it was found to have a strong negative correlation with mean seasonal temperature. However, the sample size to analysis the relationship between mean seasonal temperature and fish catch landing was 12, therefore, it is necessary to have further studies the effect of temperature on the fish catch with a longer period. The interesting finding is that the fishermen can catch more longarm mullet and less giant mud crab in the rainy season. As mentioned above, other factors, such as water pollution, overfishing, reduction of fishing time, livelihood changes may also have influenced the fish and shrimp catch. Due to the lack of data for social-economic information as well as water physical parameters, this study only focuses on two environmental factors. However, this research had contributed an important role for local authority and researchers have a new direction in doing further research and have the strategy for sustainable fish species in Songkhla lagoon.

Acknowledgements

This paper has been partly prepared with the support of the Higher Education Research Promotion and the Thailand's Education Hub for the Southern Region of ASEAN Countries Project Office of the Higher Education Commission. Financial support was granted by the Graduate School, Prince of Songkla University, Thailand. The authors would like to thank NICA for agreeing authors to use the data and joining with the field work.

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APPENDIX C: PAPER 2

Shrimp and Fish Catch landing trends in Songkhla Lagoon, Thailand during 2003-2016

(This paper was published in Applied Ecology and Environmental Research - ISI)

SHRIMP AND FISH CATCH LANDING TRENDS IN SONGKHLA LAGOON, THAILAND DURING 2003-2016

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(Received 14th Mar 2018; accepted 21st May 2018)

Abstract. Time series analysis techniques and Seasonal Autoregressive Integrated Moving Average (SARIMA) models were used to analyze monthly fish and shrimp catch landing trends recorded for Songkhla shallow lagoon in Thailand (2003-2016). Autocorrelation (AC) and Partial Autocorrelation (PAC) functions were calculated to build seasonal ARIMA models. These models were well- chosen for explaining the time series and forecasting future catch landings. It is found that both fish and shrimp catch landings tend to fluctuate steadily. The fish catch from 2017 to 2020 is steadily increasing on the average catch for the period 2003-2016 by up to 36.06%, while the shrimp catch is decreasing by around 15.47% for the same period. This study demonstrates the importance of undertaking detailed studies of ecological and economic sustainable development to support the comprehensive fisheries management policy for Songkhla Lagoon. The present study shows an effective tool for making accurate forecasts; it also helps in decision making about, and fisheries management of the Songkhla Lagoon.
Keywords: *seasonal ARIMA models, artificial neural networks, time series forecasting, fishery trend, Songkhla lagoon*

Introduction

Time series analysis of fishery landings plays a vital role in fisheries management and decision making due to its capacity for demonstrating the trends and seasonality patterns of the data (Koutroumanidis et al., 2006; Tsitsika et al., 2007). In the fishery field, time series analysis qualifies for forecasting because it expresses past patterns and projects into the future (Stergiou et al., 1997).

Forecasting has been applied to all sectors of the economy. During the last three decades, forecasting has been rapidly developing in the field of fisheries, in describing fishery units (Murawski et al., 1983) and the state of fisheries' resources and management (Fox, 1970; Pauly, 1989; Sparre et al., 1989; Stergiou and Petrakis, 1993). Various statistical models have been used to analyze trends and to forecast fish catches.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1603_30613078

Significant regression, univariate and multivariate time series models were used to forecast monthly and annual marine fisheries' catches (Stergiou and Christow, 1996; Stergiou et al., 1997) of Loliginid and Ommastrephid (Georgakarakos et al., 2002, 2006).

The forecasting of fisheries' landings has been studied by many researchers using the Autoregressive Integrated Moving Average (ARIMA) methodology. So far, this method has been successful in describing and forecasting fishery dynamics of broadly different species-significantly, demersal and pelagic species (Stergiou, 1990; Stergiou and Christow, 1996; Stergiou et al., 1997; Tsitsika et al., 2007), squid (Pierce and Boyle, 2003), mackerel (Lloret et al., 2000; Punzón et al., 2004), loliginid and ommastrephid (Georgakarakos et al., 2002, 2006).

Songkhla Lagoon is one of the two lagoons in the world that has Irrawaddy dolphins, an endangered species. The lagoon's multitude of flora and fauna species makes it rich in biodiversity and it provides resources for local fisheries' fishermen all year around. The livelihood of the more than 1.9 million people of the 25 districts located in the three provinces of Southern Thailand rely on this fishery resource. The lagoon provides both economic benefits and nutrition for the local people. It is not only an important source of livelihood for men, but also for women, who do fish processing.

Small-scale fishing has been the main livelihood for local fishermen around Songkhla Lagoon for many generations. However, as in many places in the world, the numbers of fish have been declining sharply. Many fishermen of Songkhla Lagoon are wondering whether they can survive in fishing or if they must convert to another occupation. Many of them are moving to other fishing areas or changing their work.

For the effective socio-economic and environmental management of Songkhla Lagoon, and in aiming for sustainable development of fisheries' resources, it is vital to know the seasons and the trends of fish catch in the future, as well as the factors that affect any changes in these. Forecasting fish catch trends in Songkhla Lagoon is necessary.

There is a growing body of literature that recognizes the importance of statistical models in forecasting as well as in analyzing fish catches in Songkhla Lagoon over the last few decades. Significantly, Chesoh and Lim (2008) used a linear regression model for forecasting fish catches during 1977-2006. The structure of the fish community was analyzed using a clustering model (Chesoh and Choonpradub, 2011), the method for analyzing fish assemblage distribution (Chesoh and Choonpradub, 2009). However, historical time series fish catch data usually cover a long time, which includes seasonal and non-seasonal periods. The seasonal ARIMA model, therefore, is widely used for time series forecasting and resolves the problems of season and non-season of the data by describing the autocorrelations of the data.

Fish catch landing data depends not only on human activities, but also very much on the weather. Normally this data changes over time. Artificial neural network (ANNs) models were used in this study to compare with SARIMA models because ANNs have some advantage over other forecasting models. ANNs are powerful nonlinear regression techniques (Bishop, 1995; Ripley, 1996; Titterington, 2010). Nowadays, ANNs have been used widely in time series forecasting due to their ability to approximate various nonlinearities in the data (Zhang, 2003). The significant advantage of ANNs is no prior assumption of the model form is required in the model building process; moreover, the network model is mainly determined by the characteristics of the data.

This study used monthly fish catch landings in Songkhla Lagoon data from 2003 to 2016 to evaluate the accuracy of SARIMA and ANNs models. The better model was chosen to forecast the fish and shrimp catch landing trends in Songkhla Lagoon to 2020.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1603_30613078

Materials and Methods

Study site and sample collection

The total of fish and shrimp catch landings were collected for Songkhla Lagoon every month during 2003-2016 by the National Institute of Coastal Aquaculture (NICA), Thailand *(Fig. 1)*.

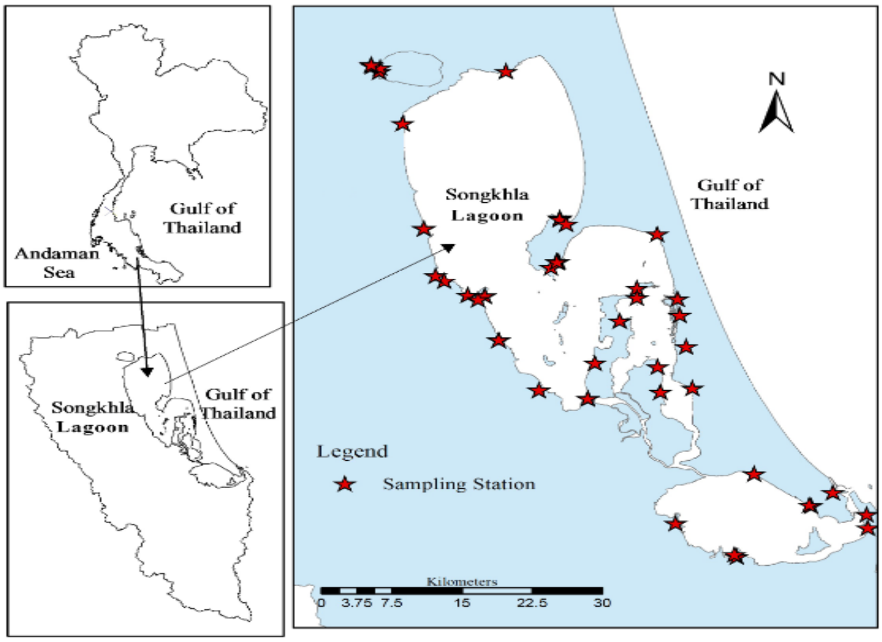

Figure 1. *Sampling stations in Songkhla Lagoon*

During 14 years of data collecting, 21 shrimp species and 158 fish species were collected every month in 37 stations around Songkhla Lagoon. The main types of fishing gear that have been used in Songkhla Lagoon include traps, set-bag nets and gill nets; and fishing activities that use such gear affect fish stock dynamics and the ecosystem (Chesoh and Choonpradub, 2011).

Time series forecasting models

SARIMA models

A time series $\{Z_t \mid t = 1, 2, ..., k\}$ is built using the SARIMA $(p, d, q)(P, D, Q)_s$ process with the mean μ of the Box and Jenkins (1976) time series model if

$$\varphi(B)\phi(B^s)(1-B)^d(1-B^s)^D(Z_t-\mu) = \theta(B)\Theta(B^s)a_t \qquad \text{(Eq.1)}$$

where, Z_t denotes the observed value at time *t*, *t*=1, 2,…, *k* and a_t is the estimated residual at time *t* (*Eq. 1*); *p, d, q* denote the order of autoregressive (AR), degree of differencing or moving average (MA) of the non-seasonal part of the model to reach to stationary; *P, D, Q* are autoregressive (AR), order or moving average (MA) of the seasonal part of the model; *s* denotes the number of periods of the season;

$$\varphi(B) = 1 - \varphi_1 B - \varphi_2 B^2 - ... - \varphi_p B^p, \qquad \phi(B^s) = 1 - \phi_1 B^s - \phi_2 B^{2s} - ... - \phi_p B^{ps},$$

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$\theta(B) = 1 - \theta_1 B - \theta_2 B^2 - ... - \theta_q B^q$, and $\Theta(B^s) = 1 - \Theta_1 B^s - \Theta_2 B^{2s} - ... - \Theta_Q B^{Qs}$
are polynomials in *B* of degree *p, q, P* and *Q; B* is the backward shift operator.
The SARIMA model includes four basic steps:

- Identification of the SARIMA $(p,d,q)(P,D,Q)_s$ structure.
- Estimation of the unknown parameters.
- Goodness-of-fit tests on the estimated residuals (Box and Jenkins, 1976; Makridakis,1990).
- Forecast future outcomes based on the known data.

The a_t should be independently and identically distributed as normal random variables with mean = 0 and variance σ^2. The roots of $\varphi(Z) = 0$ and $\theta(Z) = 0$ should all lie outside the unit circle. The SARIMA model should use at least 50, or preferably 100 observations (Box and Jenkins, 1976). This data includes more than 100 months, which is adequate for a proper time-series analysis (Tsitsika et al., 2007).

The autocorrelation (ACF) and partial autocorrelation functions (PACF) of a series together are the most powerful tool usually applied to reveal the correct values of the model parameters. The ACF gives the autocorrelations calculated at lags 1, 2 and so on, while PACF gives the corresponding partial autocorrelations, controlling for autocorrelations at intervening lags. Parameter estimation of tentative models was determined using maximum-likelihood methods. The results included the parameter estimates, standard errors, estimate of residual variance, standard error of the estimate, natural log likelihood Akaike's information criterion (AIC), and Schwartz's Bayesian criterion (SBC). Model selection was based on the minimization of AIC and SBC. These criteria were descriptors of the model's parsimony as they simultaneously account for the model's fit onto the observed series alongside the number of parameters used in the fit.

Building SARIMA models

Monthly fish and shrimp catch landing data during 2003-2016 in Songkhla Lagoon were divided into two data sets. The training data set was applied for the period (January 2003 to September 2015), and was transformed by taking the natural logarithm. The transformed data sets then were White Neural Network, tested for nonlinearity by the package "nonlinearityTseries" in R (Garcia, 2015). Both transformed shrimp and fish tests had p value >0.05, which means that there is no evidence to reject the null hypothesis of linearity (Varvey and Leybourne, 2007). The transformed training data of both shrimp and fish catch landings were tested for normality by using the Shapiro-Wilk normality test. The shrimp data test results were w=0.95967, p values > 0.05 and the fish data test results were (w= 0.9843, p values >0.05). Therefore, the study had evidence to confirm that both transformed data sets were of normal distribution (Royston, 1995). Then, the data sets were tested the stationarity by the Box-Ljung test, Augmented Dickey-Fuller Test and KPSS Test. All these stationary test results had evidence to confirm that the transformed data of fish and shrimp catch landings were non-stationary time series; therefore, we can apply seasonal ARIMA models for forecasting shrimp and fish catches in the short term.

However, to get forecasts for shrimp and fish catch landings back to the original unit, the forecasted data were back-transformed after using a fitting model by taking exponentiation of the coefficients and the forecast is then the mean of the catches.

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Twelve last months of data (October 2015 to September 2016) were used to validate the models.

The data was strongly seasonal and obviously non-stationary; therefore, seasonal differencing was used. The seasonally differenced monthly shrimp and fish catch landing data are shown in *Fig. 2*.

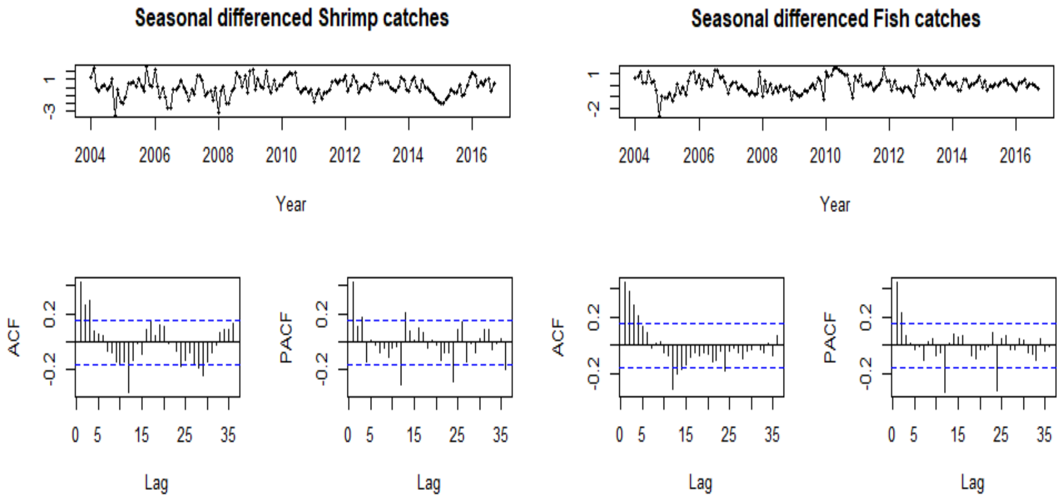

Figure 2. *First differencing log monthly shrimp and fish catches landings data*

The ACF and PACF of the transformed data sets showed spikes at periodic lags 12 and 24 *(Fig. 2)*, which declined slowly, indicating that seasonal differencing was required to achieve stationary. Abrupt fluctuations in the seasonal ACF and PACF had been leveled out.

Based on the first differencing correlograms of autocorrelation (ACF) and partial autocorrelation (PACF) of natural log transformed data of shrimp and fish catch landings, this result was combined with the Akaike information criterion (AIC) to determine the best model. The values for SARIMA $(p,d,q)(P,D,Q)_s$ models were applied as follows:

- Shrimp catch landing, the SARIMA model $(1,1,2)(0,0,3)_{12}$ was considered as the most appropriate, and due to this model passing all required checks (all the spikes are now within the significant limits), the residuals appear to be white noise. A Ljung-Box test also shows that the residuals have no remaining autocorrelations; additionally, this model has the smallest AIC and RMSE and gives the smallest mean error (ME) (0.0456). This statement is shown in *Fig. 3*.

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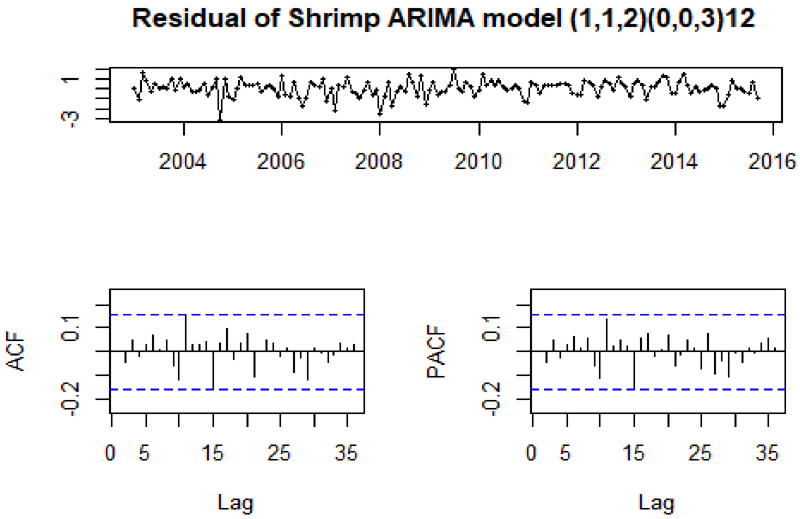

Figure 3. *Residual of shrimp seasonal ARIMA model* $(1,1,2)(0,0,3)_{12}$

- For fish catch landings, the seasonal ARIMA model $(1,1,1)(1,0,1)_{12}$ was considered as the most appropriate, due to this model having passed all requried checks (all the spikes are now within the significant limits, and the residuals appear to be white noise). A Ljung-Box test also shows that the residuals have no remaining autocorrelations. Jarque Bera Test result with X-squared = 4.0196, df = 2, p-value = 0.134 means that the data is consistent with having skewness and excess kurtosis zero; as well as this, this model has the smallest AIC and RMSE and gives the smallest of mean errors (ME) (0.018). This declaration is shown in *Fig. 4*.

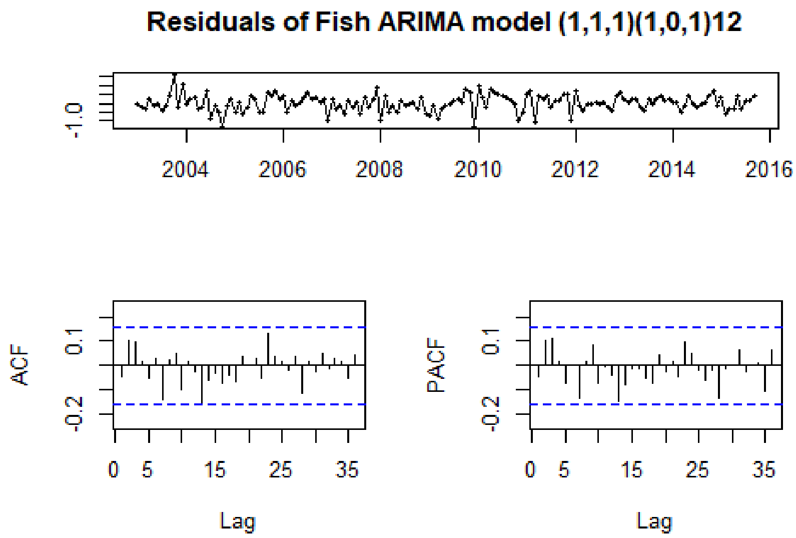

Figure 4. *Residual of fish seasonal ARIMA model* $(1,1,1)(1,0,1)_{12}$

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Artificial neural networks (ANNs)

In this study we used single hidden layer feed forward network, this is the model form that is the most widely used for time series modeling and forecasting (Zhang et al., 1998). The model is described by a network of three layers of simple processing units connected by acyclic links. The relationship between the output (y_t) and the inputs $(y_{t-1}, y_{t-2}, ..., y_{t-p})$ follows the mathematical equation:

$$y_t = \alpha_0 + \sum_{j=1}^{q} \alpha_j g(\beta_{0j} + \sum_{i=1}^{p} \beta_{ij} y_{t-i}) + \varepsilon_t \quad \text{(Eq.2)}$$

where, $\alpha_j (j = 0,1,2,...,q)$ and $\beta_{ij} (i = 0,1,2,..., p; j = 1,2,...,q)$ are the model parameters, often called the connection weights; *p* is the number of input nodes; and *q* is the number of hidden nodes. The logistic function is often used as the hidden layer transfer function:

$$g(x) = \frac{1}{1 + \exp(-x)} \quad \text{(Eq.3)}$$

Thus, the ANN model (2) in fact performs a nonlinear functional capturing from the past observations $(y_{t-1}, y_{t-2}, ..., y_{t-p})$ to the future value y_t ; therefore, y_t can be written:

$$y_t = f(y_{t-1}, y_{t-2}, ..., y_{t-p}, w) + \varepsilon_t \quad \text{(Eq.4)}$$

where, *w* is a vector of all parameters and *f* is a function identified by the network structure and connection weights. Hence, the neural network is equivalent to a nonlinear autoregressive model. The *Eq. 2* implies one output node in the output layer which is typically used for one step ahead forecasting.

Building ANN model

Like SARIMA model building, the training data set was natural logarithm transformed to get the best results and was used to build the ANN model, then the testing data was used to validate the model. While the SARIMA model uses one sample for model identification, estimation and evaluation, the ANNs estimated model is usually evaluated using a separate hold-out sample that is not displayed to the training process (Zhang, 2003). The model with the smallest mean squared error (MSE) will be chosen. The authors used the package nnfor (Nikolaos, 2017) from R software to create the ANNs model. The forecast statistical packages from R software were used to formulate the SARIMA models (Hyndman, 2017). All graphics and statistics were implemented by R software (R Core Team, 2018).

The best ANNs model was chosen to forecast shrimp fit with 5 hidden nodes and 20 repetitions, series modelled in differences: D1, univariate lags: (1,2,3,4,5,6,7,10) due to its smallest MSE (0.0078). The procedure demonstration is expressed in *Fig. 5*.

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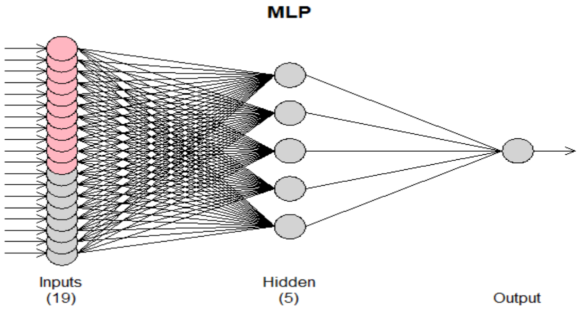

Figure 5. *Structures of the best fitted Artificial neural network model for shrimp*

The best ANNs model was chosen to forecast fish fit with 5 hidden nodes and 20 repetitions. Series modelled in differences: D1, univariate lags: (1, 2, 3, 4, 5, 6, 7, 8, 12) due to its smallest MSE (0.0372) is shown in *Fig. 6*.

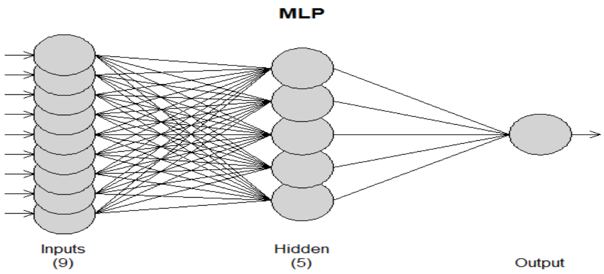

Figure 6. *Structures of the best fitted artificial neural network model for fish*

Results

Comparison between the SARIMA and ANNs models

To estimate the accuracy of the two models, the authors calculated the percentage improvement of SARIMA and ANNs models through Mean Absolute Error (MAE). The percentage MAE was calculated on the average over the validation samples of fish and shrimp catch landings from October 2015 to September 2016. The equation to measure percentage of MAE is as below:

$$MAE(\%) = \frac{1}{n}\sum_{i=1}^{n}\left(\frac{|y_i - \hat{y}_i|}{y_i}\right)x100\% \qquad \text{(Eq.5)}$$

where, $|y_i - \hat{y}_i|$ is absolute difference between prediction and actual observation; n is the number of observations. The optimum model with the smaller percentage of MAE will be chosen for forecasting. The percentage MAE of SARIMA and ANNs models are shown in *Table 1*.

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Table 1. *The percentage MAE values of shrimp and fish catch landings from chosen SARIMA models and ANNs during the period October 2015 to September 2016*

Months	**Shrimp catches landings (tons)**	**SARIMA model prediction (95%CI)-mean**		**Neural Network prediction**		**Fish catches landings (tons)**	**SARIMA model prediction (95%CI)-mean**		**Neural Network prediction**	
		Amount (tons)	**|% error|**	**Amount (tons)**	**|% error|**		**Amount (tons)**	**|% error|**	**Amount (tons)**	**|% error|**
Oct 2015	60.52	47.22	21.97	45.75	24.41	114.50	76.83	32.90	101.33	11.50
Nov 2015	180.93	68.43	62.18	149.99	17.10	114.50	79.03	30.98	99.77	12.86
Dec 2015	41.5	37.41	9.85	19.00	54.22	63.27	71.54	13.07	66.26	4.73
Jan 2016	29.01	28.07	3.24	29.48	1.62	61.07	73.51	20.37	71.75	17.49
Feb 2016	34.68	29.18	15.85	20.57	40.69	54.19	62.78	15.85	70.31	29.75
Mar 2016	97.09	59.77	38.44	22.19	77.14	49.27	65.96	33.87	63.96	29.82
Apr 2016	129.39	60.17	53.50	24.69	80.92	59.03	64.26	8.86	44.87	5.84
May 2016	75.72	55.97	26.08	31.14	58.87	69.49	69.42	0.10	73.55	19.80
Jun 2016	78.32	38.56	50.77	10.60	86.47	60.29	64.20	6.49	72.23	22.81
Jul 2016	76.79	39.11	49.07	32.93	57.12	63.40	69.02	8.86	77.86	19.66
Aug 2016	50.44	51.59	2.28	31.66	37.23	63.28	69.65	10.07	75.72	5.70
Sep 2016	39.17	43.67	11.49	34.55	11.79	74.96	75.11	0.2	79.23	8.94
MAE (%)			**28.73**		**45.63**	**MAE (%)**		**15.14**		**16.70**

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As can be seen from *Table 1*, the ANNs models used for forecasting shrimp and fish catch have higher percentage MAE than SARIMA models, especially in the shrimp data set. These results are clearly described by the amount of the fish and shrimp catch in validated data sets. These are shown in *Fig. 7*.

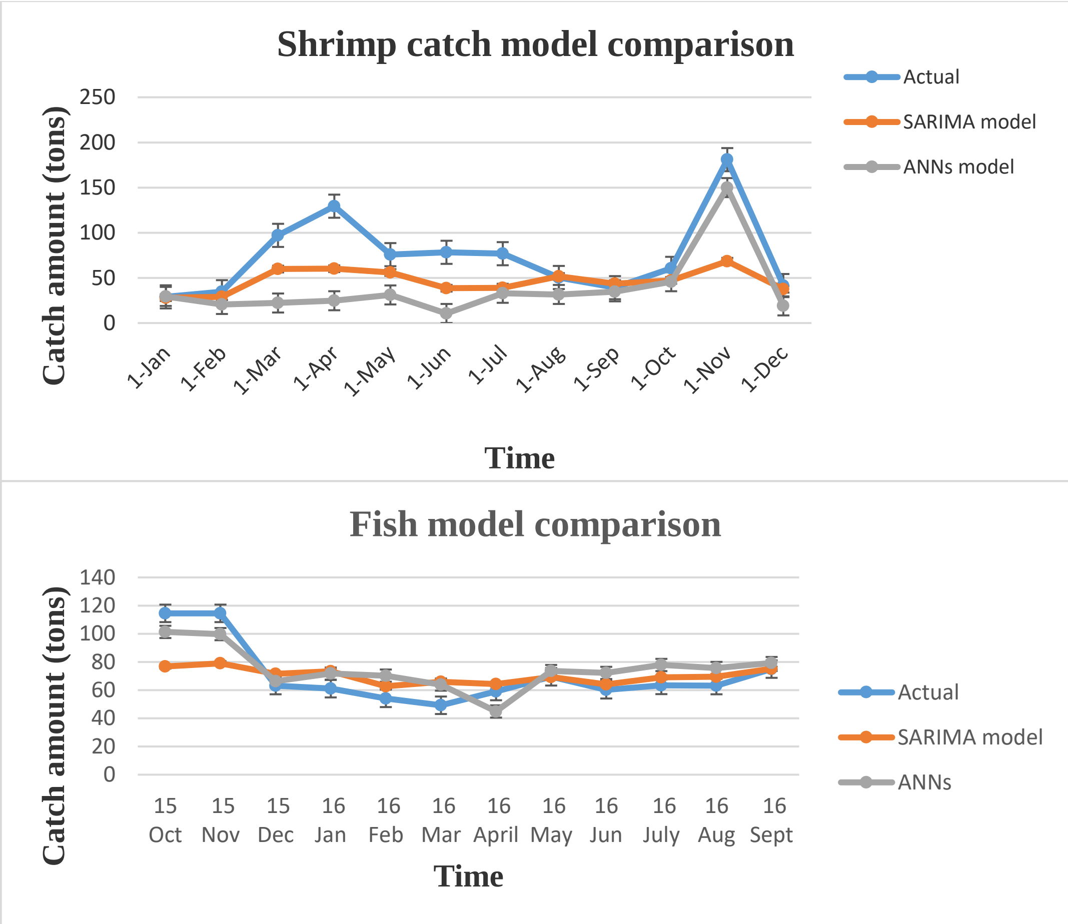

Figure 7. *Fish and shrimp model comparisons*

In both the shrimp and fish models, the ‘forecast’ line for the SARIMA model has the smaller distance, along with the Actual line, than the ANN model *(Fig. 7).* Therefore, this study uses SARIMA models for forecasting shrimp and fish catch landings in Songkhla Lagoon until 2020.

Shrimp and fish catch landing trends in Songkhla Lagoon during 2016-2020

The monthly catch landings of fish and shrimp groups during 2003-2016, fits and forecasts for coming years, that were produced by the best fitting and best seasonal ARIMA forecasting model per group species, are shown in *Fig. 8*. Overall, the amplitude and the duration of the between–month fluctuations are adequately described and forecasted by the model with few exceptions.

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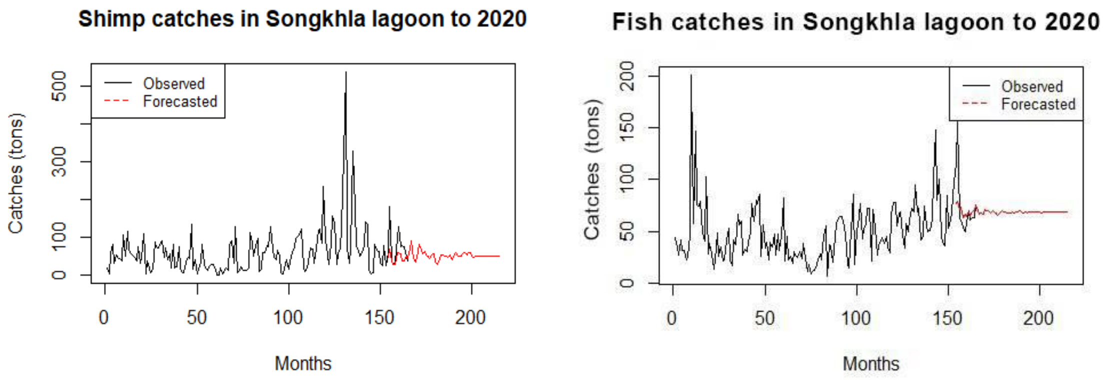

Figure 8. *Shrimp and fish catch forecasted in Songkhla Lagoon to 2020*

The result of shrimp and fish catch landings to 2020 is shown in the *Fig. 8*. It can be seen clearly that, during the period between 2017 and 2020, the shrimp catch landing in Songkhla Lagoon fluctuates at around 53 tons per month, compared with the mean catch (62.5 tons per month) during 2003-2016. Moreover, the fish catch will be around 68 tons per month, compared with the mean catch of around 49 tons during the period 2003-2016. The detailed trends of fish and shrimp catch landings in Songkhla Lagoon until 2020 are clearly described in *Fig. 9*.

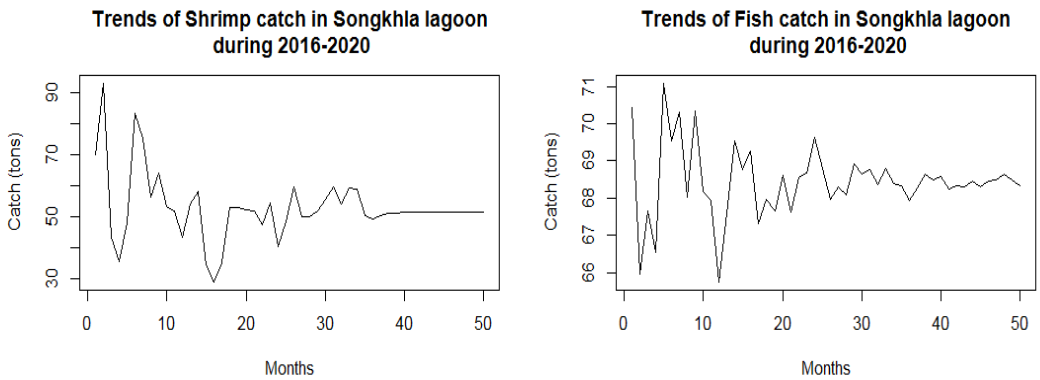

Figure 9. *Shrimp and fish catch forecasted for Songkhla Lagoon during 2016- 2020*

In *Fig. 9*, the fluctuations of the shrimp and fish catch landings during 50 upcoming months are somehow similar. During the two first years (from month 1 to month 24), the catch amount fluctuated sharply between months; after that, the catch amount was more stable. The difference between the lowest and highest catch amounts of shrimp are significant bigger than for fish. The lowest shrimp catch was January 2018 (28.95 tons) and the highest catch in November 2016 (92.94 tons), the difference being approximately 64 tons. The lowest fish catch was September 2017 (65.75 tons) and the highest fish catch was February 2017 (71.08 tons), with a difference of only 5.33 tons.

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Seasonal factor

The overview of monthly shrimp and fish catch landings in Songkhla Lagoon during 2003-2016 are presented in *Fig. 10*.

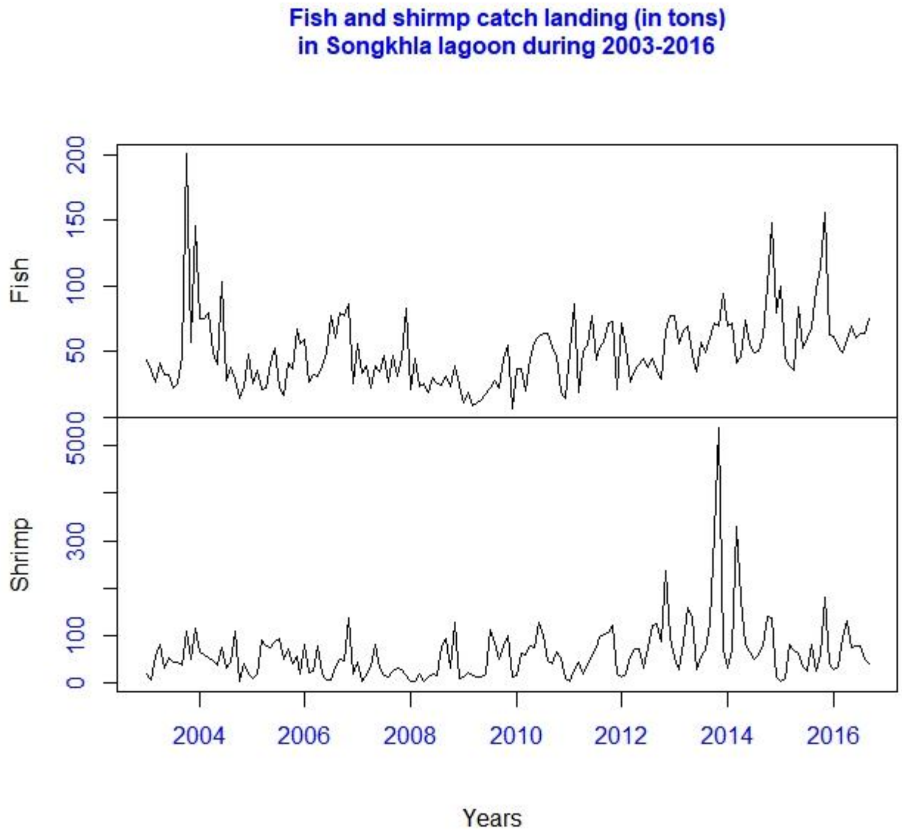

Figure 10. *Monthly shrimp and fish catch landings in Songkhla Lagoon during 2003-2016*

As shown in *Fig. 10*, the lowest shrimp catch landing was in January 2008, with only 1.77 tons; and the highest catch amount was in November 2013, the shrimp catch reached a peak with 537.41 tons. The mean shrimp catch was estimated at around 62.56 tons. The results obtained for the monthly fish landings were also shown in *Fig. 2*, when the most significant catch amount topped 200.78 tons in October 2003; and the lowest in this 2003-2016 period was in December 2009 (6.96 tons). The average monthly catch was around 50.31 tons for this period.

Using Seasonal Factors is the way to analyze data to reveal regular recurring changes associated with the calendar. A seasonal factor measures the percentage amount when, on average, a month is higher or lower than normal (Austin, 1981). From *Fig. 10*, it can be seen that the size of the seasonal fluctuations in both shrimp and fish time series data seems to be roughly constant over time, and does not depend on the level of the time series. Thus, to know exactly the seasonal trend of monthly shrimp and fish catches, the study estimated seasonal factors affecting shrimp and fish for the particular month from January to December. These factors are the same for each particular month, each year. Before monsoon season in Southern Thailand, December, is the best season for both shrimp and

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fish catching, which is shown by the high seasonal factors (from September to November). However, during monsoon season (December to February), the seasonal factors for shrimp catch landings are significant low while the factors for fish catch are really low during the dry season (March to May). The details for these claims are given in *Table 2* and *Fig. 11*. November provides the best seasonal factors for both shrimp catch landings (about 0.88) and fish (about 0.31); while the lowest seasonal factor for shrimp catch (about -0.96) is in January, and for the fish catch (about -0.36) in March, indicating that there seems to be a peak in both shrimp and fish catch landings in November with the bottom for shrimp catch in January, and for the fish catch in March in each year.

Table 2. *Seasonal factors for shrimp and fish catch in Songkhla Lagoon during 2003-2016*

Months	Shrimp seasonal factors	Fish seasonal factors
January	-0.96	0.09
February	-0.76	0.03
March	0.20	-0.36
April	0.14	-0.23
May	0.13	-0.03
June	-0.10	0.09
July	-0.005	-0.08
August	0.30	-0.10
September	0.41	0.09
October	0.33	0.19
November	0.88	0.31
December	-0.59	-0.01

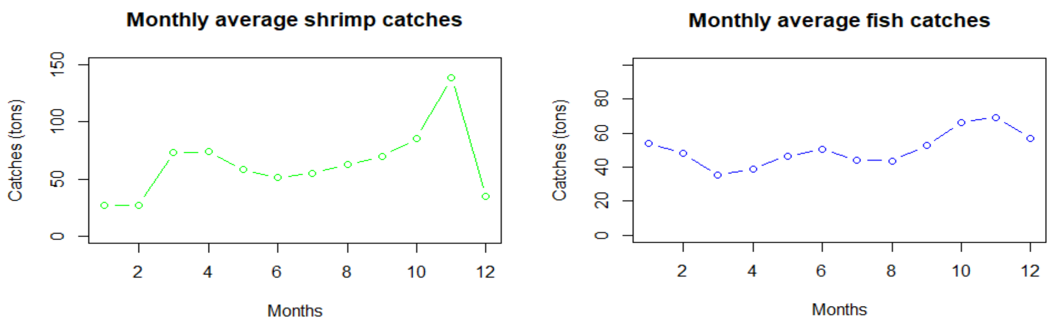

Figure 11. *The average catch of fish and shrimp per month in Songkhla Lagoon during 2003-2016*

According to the data for the total fish and shrimp catch from January to December for January 2003 through to the first 9 months of 2016, the total catch in months of the two species was different with reference to both the amount and the time of catch in the year. The amount of shrimp caught was lowest in January (estimate 27.06 tons) and highest in November, up to 138.55 tons. The amount of fish caught was lowest in March (only 35.13 tons) and highest in November, around 69.36 tons. In general, there was a sharp fluctuation

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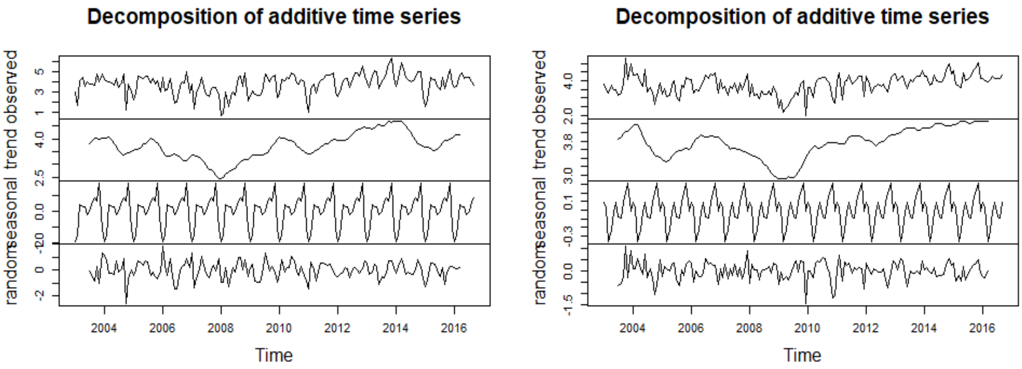
in the average catch between months in year, particularly with reference to shrimp catch landings.

The trend and season of monthly shrimp and fish catch landings is shown clearly in *Fig. 12*.



a.Shrimp catches b.Fish catches

Figure 12. *Trend and season of monthly shrimp and fish catch landings in Songkhla Lagoon during 2003-2016*

Discussion

Model fitting and forecasting performances

In this study, the percentage improvement figures for SARIMA and the ANN model for shrimp catch are significantly different (16.9%). In contrast with this result, the improvement figures for fish are very little different (1.56%). In the past, the percentage improvement of ARIMA and the ANN model has been different according to the data set and the period of the forecasting, which was confirmed by Khashei and Bijari (2011) when they used sunspot, Canadian lynx, and exchange rate data sets to compare percentage improvements of ARIMA and the ANN model. Almost all the results showed the better percentage improvement for ANNs over the ARIMA model at different levels. However, when they forecasted 67 points ahead from sunspot data set, percentage MAE of ANNs model is 3.32% bigger than ARIMA model. Again, this statement was proved by Tseng et al. (2002), when the SARIMA model of machinery production time series showed the better result compared to the neural network (NN) with 60 historical forecasting items of data, but the SARIMA model's results were not as good as NN when they forecast 36 points ahead.

In the past, Stergiow (1989) found two suitable ARIMA models to forecast pilchard (*sardina pilchardus*) catches up to 12 months ahead with mean errors (ME) of 14.6% and 12% for the two models. Suitable SARIMA models were found in this study for shrimp and fish with mean errors of 4.56% and 1.83%.

Univariate SARIMA models satisfactorily predicted the total fish and shrimp catch landings. So far, linear regression models developed for total fish catch in Songkhla Lagoon have illustrated little forecasting power (the percentage improvement was 34.6%) (Chesoh and Lim, 2008). In the present study, the univariate SARIMA models that were built show good performance in terms of explained variability and predicting power. The results demonstrate a strong autoregressive character of the time series, i.e. the fish catch

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landing value at month t depends on the catch at month t-12. SARIMA models provided satisfactory forecasts that were close to the recorded fish and shrimp catch values. The seasonal ARIMA models were found not to be appropriate for both shrimp and fish catch landing, suggesting that the catch landings of fish and shrimp had a different statistical structure. The present findings also imply the clear existence of a seasonal pattern in the monthly fish/shrimp catch landing, which is shown both in the original data and seasonal factor *(Table 2 and Fig. 11).*

Seasonal fish and shrimp catch landing

There are major peaks for seasonal fish and shrimp catch landing in the rainy season (from September to November), however, they quickly reduce in December-January. The seasonal cycle is most likely related to the nature of the lagoon ecosystem. In the monsoon seasons (October-January), there is intrusion of sea water from the Gulf of Thailand into the lagoon through a short narrow channel (about 8m in depth) in the outer section. Where the most intensive fishing activities occur, the average depth is very shallow, 1.0-1.5 m. The dry season in southeast Thailand extends from February to April. Most of the brackish and saltwater fish populations migrate to the open sea, whereas the freshwater fish in the upper lake migrate to deeper pools. This phenomenon is consistent with the seasonal migration of some fishermen to find work in the cities (Chesoh and Lim, 2008). The fishing is more intense during the first months of the monsoon season and decreases in December, due to such heavy rain and flooding that the fishermen cannot go fishing. The seasonal catch of shrimp and fish during 2003-2016 was different: while the shrimp catch decreased sharply from December to February, the fish catch decreased significant in the dry season, mostly concentrated in March to May, and before the rainy season (July and August). During the dry season, the fish from Songkhla Lagoon migrate back to the sea (the Gulf of Thailand) for breeding, spawning and larval nursing (Choonhapran, 1996; Chesoh and Samphantharaga, 2004). This claim is also confirmed by the composition of the first finding species found in both Songkhla Lagoon and Sathing Pra (a coastal area in Songkhla province that the author is studying). The seasonal shrimp catch landing is somehow different from the seasonal fish catch, the explanation coming from the effect of the restocking program during this period.

Factors involved in the seasonal variation in fish and shrimp catches may be due to regional climate, especially the effect of the monsoon season in the Southern Thailand, for during these months, the catch in coastal provinces decreases sharply (Komontree et al., 2006), and the catch in the lagoon tends to increase. Seasonal difference effects on monthly fish catch also have been found in previous studies (Stergiou and Christou, 1996; Komontree et al., 2006). Even though the fish catch is very low during March to May, the shrimp catch tends to increase which may be due to the effect of seasonal difference, as the annual closure of the fishing area of the Gulf of Thailand from February 16 to May 15 does not affect the fish catch in the lagoon. The changes of season lead to the changes in zooplankton (Brysiewicz et al., 2006), which would be one of the reasons for the difference in fish and shrimp catch between seasons.

Fish and shrimp catch trends in Songkhla Lagoon

In the monthly fish and shrimp catch landings until 2020, both shrimp and fish catch fluctuated sharply during the two first years of forecasting, then they fluctuated steadily. The shrimp catch reduced to 52.88 tons, by around 15.47% of the catch average during

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2003-2016. In contrast with the shrimp catch, the fish catch increased to 68.45 tons, estimated at a 36.05% increase in comparison with the mean fish for the same period in 2003-2016. This result reflects the reality of fishing activities in Songkhla: the general trends of shrimp catch reduce due to the decrease in the number of juvenile shrimps from the stocking program.

During the past four decades, only two papers have reported the annual catches in the main Songkhla Lagoon. The first study was conducted during 1984-1986 (Tonkwinas et al., 1986) and the second during 1994-1995 (Choonhapran et al., 1996). These studies reported the total annual fish catch during 1994-1995, a decrease of 22% compared to the catch in 1984-1986. The monthly report of total fish catches during 1977 to 2006 was 219.9 tons (Chesoh and Lim, 2008).

Conclusion

Knowing the seasons and forecasting both play an important role in fisheries' management, as they constitute the first steps of the planning and decision-making process (Stergiou and Christow, 1996; Stergiou et al., 1997). The facts of the good performance of the final ARIMA models applied to shrimp and fish catch landings in this paper in terms of short term forecasting of up to 12 months in advance, as well as the results that the models provided for insight into the seasonal components of the time series, all justify their use in fisheries' management. Accurate forecasts for 1-2 years may provide useful information to fishery policy makers as well as fishermen. For small scale fishing, the conditions for fishing do not seem to change much inside the lagoon and there are limited budgets for organizing the usual surveys, so SARIMA models can be considered as suitable tools to forecast the persistence of fish and shrimp catches. The performance of the models could be improved by additional information about environmental factors (e.g. temperature, salinity…) and other factors (market prices and biological information) put into the multivariate models.

Acknowledgments. This paper has been partly prepared with the support from the Higher Education Research Promotion and the Thailand's Education Hub for the Southern Region of ASEAN Countries Project Office of the Higher Education Commission. Financial support was granted by the Graduate School, Prince of Songkla University, Thailand. The authors would like to thank the National Institute of Coastal Aquaculture (NICA) staff for giving them the chance to join in data collection and for providing data for the research.

Conflict of interest. The authors definitely confirm that there is no conflict of interest concerning this article.

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DOI: http://dx.doi.org/10.15666/aeer/1603_30613078

APPENDIX D: PAPER 3

Physical Properties of Three Songkhla Lagoon Fish Species in the Lower Gulf of Thailand During and After the Monsoon Season

(This paper was published in Applied Ecology and Environmental Research - ISI)

PHYSICAL PROPERTIES OF THREE SONGKHLA LAGOON FISH SPECIES IN THE LOWER GULF OF THAILAND DURING AND AFTER THE MONSOON SEASON

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(Received 3rd Jul 2018; accepted 31st Aug 2018)

Abstract. Length–weight relationships (LWR) were estimated for three main Songkhla Lagoon fish species occurring in the lower gulf of Thailand. Samples were collected monthly during monsoon and after monsoon season (September 2017 to April 2018). Fishes were captured by three methods: fishing gear, crab gear and shrimp gear. This study is the first reference on LWR equation parameters of *Pellona ditchella* (Valenciennes, 1847), *Sardinella gibbosa* (Bleeker, 1849) and *Alepes vari* (G. Cuvier, 1833) in the lower gulf of Thailand, this good document would be used to compare these fish condition with many coastal areas in the world. This work provides the important information of fish migration between lagoon and lower gulf of Thailand as well as for two species from which we present a wider size range in FishBase, *Pellona ditchella* (Valenciennes, 1847) and *Sardinella gibbosa* (Bleeker, 1849).
Keywords: *length–weight relationship, Pellona ditchella, Sardinella gibbosa, Alepes vari, fish migration, fish well-being*

Introduction

Songkhla Lagoon is one of the two lagoons in the world that has Irrawaddy dolphins (*Orcaella brevirostris*), which are endangered species. The lagoon is located in the southern part of Thailand and is divided into three distinct parts. The southern part of the lagoon is connected to the Gulf of Thailand through a 380 m wide strait Songkhla Lagoon. It is very rich regarding biodiversity and provides resources and livelihoods for local fishermen all year around. The livelihood of more than 1.9 million people of the 25 districts located in the three provinces of Southern Thailand rely on the lagoon's fishery resources. However, as in many other similar ecosystems elsewhere (Martínez et al., 2007; Satumanatpan and Pollnac, 2017), those resources have been declining sharply over recent decades. Many fishermen of Songkhla Lagoon are wondering whether they can

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1605_61136127

sustain themselves through fishing or if they must convert to another occupation. Many of them have already moved to other fishing areas or changed profession.

As part of the efforts to create policies for sustainable fishing in Songkhla Lagoon and improve the livelihoods of fishing communities dependent on the lagoon's resources, numerous studies were conducted in the past two decades on Songkhla Lagoon, focusing mostly on models of fish catch landing (e.g. Chesoh and Lim, 2008; Chesoh, 2009; Chesoh and Choonpradub, 2011; Hue et al., 2018) or the effects of chemical contamination (e.g. Pradit et al., 2013). Other research has dealt with the government-led shrimp restocking program (Xu et al., 1997; Davenport et al., 1999; Wang et al., 2006; Hamasaki and Kitada, 2013; Niamaimandi and Zarshenas, 2015).

Fish condition can be a very important parameter to the managers of fisheries. Plump fish may be an indicator of favorable environmental conditions (e.g., habitat, food availability), whereas thin fish may indicate a less favorable environment. Thus, monitoring fish well-being can be extremely useful for the biologists of fisheries to make management recommendations concerning fish populations and their management. There is evidence that length–weight relationships (LWR) plays an important role in estimating fish biomass based on length. These parameters can be compared between seasons, years or different areas using standardized sampling procedures (Correia et al., 2017), and data on the length and weight of fish are currently two of the most common and standardized parameters about the biology of fish (Le Cren, 1951).

Pellona ditchella (Valenciennes, 1847), *Sardinella gibbosa* (Bleeker, 1849) and *Alepes vari* (G. Cuvier, 1833) are present in most of the markets in Southeast Asia. Their current known distribution extends across the Indo-West Pacific: from Madagascar, and Durban, South Africa to the Gulf of Oman and the coasts of India; from the Andaman Sea to Indonesia and the Philippines, southeast to the Arafura Sea, northern and western Australia and Papua New Guinea (Russell et al., 1989). During the period 2003-2017, they were found frequently in the lower Gulf of Thailand, including Songkhla Lagoon. *P. ditchella* is found most often in coastal, marine waters, but also enters mangroves and river estuaries, and tolerates brackish water and freshwater. *S. gibbosa* is commonly found in marine, pelagic-neritic habitats, and forms schools in coastal waters. Alepes scads are marine, coastal predatory fish not found in the open oceans (Pauly et al., 1996; Riede, 2004; Fricke et al., 2011).

Information about the health of these fishes is important in all countries along their range of distribution where they are fished commercially. Previous research on these fishes focuses on *S. gibbosa* and includes a study on the genetics and morphology of cryptic species of *S. gibbosa* (Thomas et al., 2014); the confirmation of presence of *S. gibbosa* in the Red sea and documenting its introduction into the Eastern Mediterranean Sea (Stern et al., 2015); heavy metal contamination in *S. gibbosa* in the coast of Balochistan, Pakistan (Ahmed et al., 2015); and stock assessment of *S. gibbosa* in the Gulf of Thailand (Boonjorn et al., 2012). No studies are known of the ecology or the living conditions of these fishes, let alone of monthly or seasonal changes in those two aspects. This paper addresses this gap by studying monthly and seasonal changes in the length–weight relationship of the two species and one genus of fish. It provides an account of investigations carried out in both Songkhla Lagoon and Sathing Pra, in a context of sharp decline in fish catches in Songkhla Lagoon. This study concentrates primarily on the populations and general biology of those fishes, in particular growth and related aspects, thereby providing early findings to inform further research on measures to enhance fish populations in Songkhla Lagoon.

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Material and methods

Study site

This study was conducted in the lower Gulf of Thailand, in the coastal area of Sathing Pra District, Thailand (*Fig. 1*). The climate of the lower Gulf of Thailand is governed by two monsoons the southwest monsoon from May to September, and the northeast monsoon between October and March. There are two seasons: (a) the rainy season, usually covering the period May to January, with the heaviest rains typically in November; and (b) the dry season, from February to April. April is normally the hottest month (ONEP, 2005).

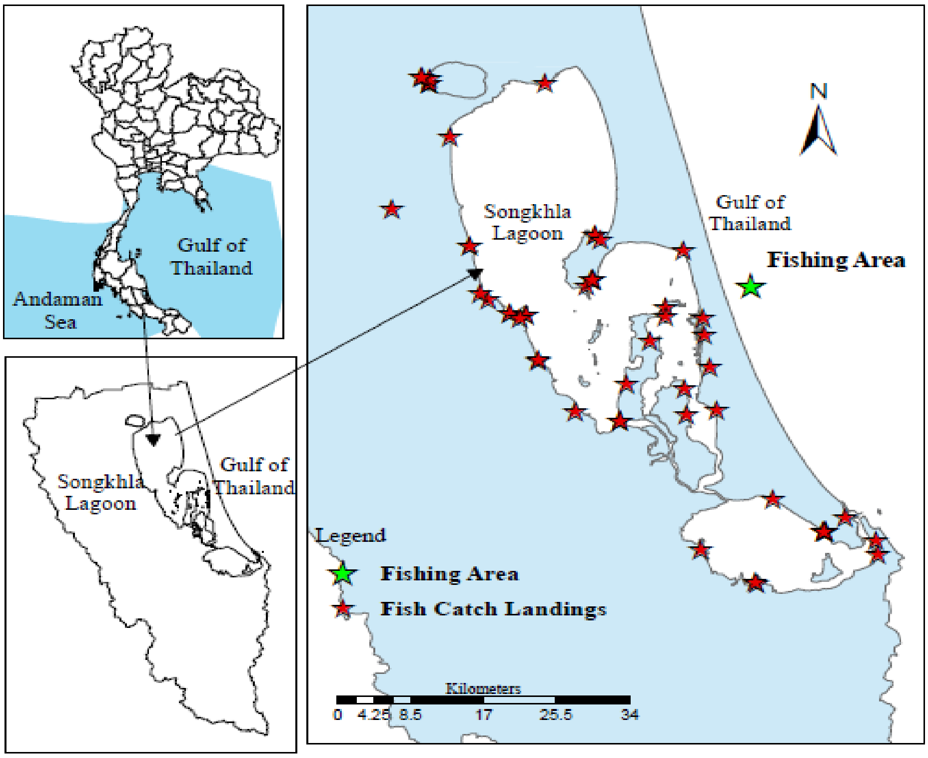

Figure 1. *The locations of sampling*

Data collection

Specimens used in this study were collected on a monthly basis from fishermen fishing in the coastal district of Sathing Pra during the period of September 2017 to April 2018, at the sampling sites indicated in *Figure 1* (07°31’24” N; 100°27’46” E). A list of 185 fish species found in Songkhla Lagoon during 2003-2017 issued by the Thai National Institute of Coastal Aquaculture (NICA) was used to identify the caught fish species. The list was first given to the head of Fisherman Association in Sathing Pra, through whom it was distributed to the fishermen contributing to the study, who did the first species identification themselves.

The fishing grounds where the specimens were caught are located approximately 3 km from the shores of the lagoon. Number Fish specimens were captured with two main fishing gears: fish nets (length: 180 m, mesh size: 4.5 × 4.5 cm) and shrimp nets (length: 30 m, mesh size: 3 × 3 cm), the only one fish specimen Sardinella gibbosa was caught

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with crab nets (length: 180 m, mesh size: 11 × 11 cm), at depths of approximately 80, 15 and 20 m, respectively. Fishing usually took place between 3 and 6 am, with some variation between months and seasons. The fishing boats in this coastal area are usually small boats with a length of 7-10 m length and a width of 1.8-2 m.

All specimens were bought from the fishermen, iced and transferred to the laboratory of the Marine and Coastal Resources Institute, Prince of Songkla University (MACORIN), where a verification of the species was carried out, followed by the measurement of the total length and weight. Total length of fish was measured from the tip of the premaxilla to the tip of the longest caudal fin ray stretched out posteriorly. Millimeter was used to be length measurements (Society, 2017). The total weight of fish specimens was recorded with an accuracy of 0.1 g using an Ohaus digital weighing balance (Ajani et al., 2013).

Data analysis

The purpose of this study is to assess the condition of commercially important fish found in Songkhla Lagoon by investigating their length–weight relationship, and monthly and seasonal changes in this parameter. The monthly data on length and weight was separated into two periods: the monsoon season (from September 2017 to January 2018) and after the monsoon season (dry season) (from February to April 2018).

Length–weight relationship analysis

Linear transformation of fish length and weight was made by using natural logarithm at the observed lengths and weights. The length–weight relationship (LWR) was calculated following Pauly (1983) and used to calculate the regression coefficient (slope of regression line of weight and length). The parameter "β" of the LWR was estimated using *Equation 1:*

$$W = aL^{\beta} \tag{Eq.1}$$

Here: W = the weight of the fish in grams, L = the total length of the fish in millimeters, a = constant, β = growth exponent.

A logarithmic transformation was used to make the relationship linear (*Eq. 2;* Le Cren, 1951):

$$\text{Log W} = \beta \log \text{L} + \log \text{a} \tag{Eq.2}$$

The LWR parameters *a* and β as well as the coefficient of determination (R^2) were derived by least squares regression (Ricker, 1973). The slope (β) also known as the allometry coefficient, has an important biological meaning, indicating the rate of weight gain relative to growth in length or the rate at which weight increases for a given increase in length.

Inferences about slope (β)

If a fish grows without changing its shape or density, then it is said to exhibit isometric growth. In this case, the volume of the fish is proportional to any linear measure of its size and β = 3. Isometric growth in fish is rare (Bolger and Connolly, 1989; McGurk, 1985). If β > 3 the fish tends to become "plumper" with an increase in length, a situation

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called positive allometric growth (Blackwell et al., 2000). If $\beta < 3$ the fish tends to become "thinner" with a decrease in length, a situation called negative allometric growth (Froese, 2006).

A test of whether the fish from the lower Gulf of Thailand exhibits allometric growth or not and confidence interval for β can be obtained by fitting the transformed length–weight model. The slope is generically labeled with beta (β) such that the test for allometry can be translated into the following statistical hypotheses:

$$H_0 : \beta = 3 \text{ ("Isometric growth")}$$

$$H_1 : \beta \neq 3 \text{ ("Allometric growth")}$$

Regarding model parameters can be obtained with a t-test using *Equation 3:*

$$t = \frac{\hat{\beta} - \beta_0}{SE_{\hat{\beta}}} \quad \text{(Eq.3)}$$

where β, SE_{β} are from the linear regression result and β_0 is the specified value in the H_0. In this study, the hypothesis test that a linear model parameter is equal to a specific value. To test a parameter is equal to a value other than 0, hoCoef meets all the requires and was used to efficiently compute the t and corresponding P-value for non-default hypothesis (for H_0: $\beta = 0$ by default).

Predictions of fish original scale

The study used the result from the length–weight regression to predict the weight of the fishes at the mean length. The result was back – transformed to the original scale by exponentiation. Due to the fact that the geometric mean is always less than the arithmetic means and, thus, the back-transformed mean always underestimates the arithmetic mean from the original scale (Ogle and College, 2013), the final original scale was multiplied with a correction factor derived from analysis of normal and log – normal distribution theory, using *Equation 4:*

$$e^{\frac{(\delta_{Y/X})^2}{2}} \quad \text{(Eq.4)}$$

where $\delta_{Y/X}$ is calculated from summarizing model length–weight regression of fish.

Comparing length–weight regressions (between seasons)

Inter-seasonal variation in the LWR of the fish included in this study was assessed by means of an analysis of variance (ANOVA) of the regression models using the factor season. The statistical significance for the study was set at a P value < 0.05. The full model with indicator and interaction terms was then fit and stored in an object with the ANOVA table. All statistical analysis was performed using the FSA package (Ogle, 2018) from the R software (R Core Team, 2018).

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Results

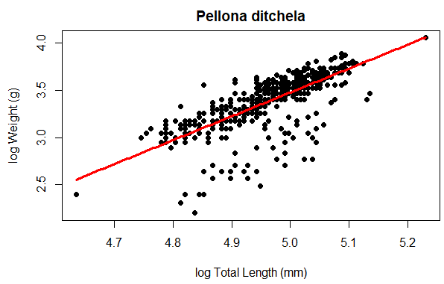
During the study period, 20 different Songkhla Lagoon species were captured in the coastal area of Sathing Pra, of which two species were crabs, three species were shrimps and 15 species were fish. The number of species varied markedly between months, but the fish species Indian pellona (*Pellona ditchella*), goldstripe sardinella (*Sardinella gibbosa*) and genus alepes (*Alepes vari*) appeared regularly, with sample sizes of 537, 162 and 49, respectively *(Table 1).* Among the samples, the total length of *P. ditchella* ranged from 103 to 183 mm, *S. gibbosa* from 102 to 175 mm, and *Alepes vari* from 122 to 216 (*Table 1*), whereas the ranges of the total body weight were 9 to 59 g, 6 to 43 g, and 11 to 93 g, respectively (*Table 1*).

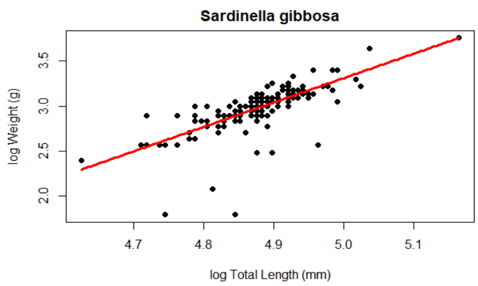
Table 1. *Total length and weight for Pellona ditchella, Alepes vari and Sardineela gibbosa*

Common name	Scientific name	Sample size	Total length (mm)		Total weight (g)	
			Range	Mean	Range	Mean
Pellona ditchella	*Pellona ditchella* (Valenciennes, 1847)	537	103-187	143.9	9-59	30.81
Alepes vari	*Alepes vari* (G. Cuvier, 1833)	49	112-216	162.9	11-93	47.71
Sardinella gibbosa	*Sardinella gibbosa* (Bleeker, 1849)	162	102-175	130.8	6-43	19.93

Length–weight model

Figure 2 depicts the natural log-transformed total length and weight of *P. ditchella*, Alepes and *S. gibbosa* captured in the lower gulf of Thailand between September 2017 and April 2018, with the best fit regression line superimposed. *Table 2* gives the equations and other parameters of the length weight models for the three fish included in the study by using *Equation 2*, derived from those regression lines.





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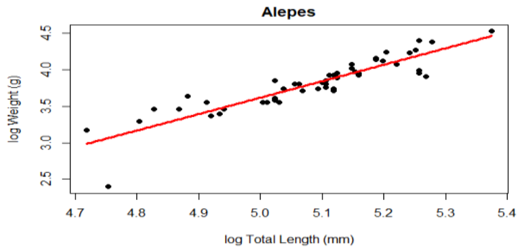

Figure 2. *Plot of natural log total length and weight of the three sampled fish*

Table 2. *Equation of the length weight models for P. ditchella, Alepes vari. and S. gibbosa*

Fish species	Equation (on the transformed scale)	Equation (on the original scale)	R^2	b range (95% confidence)	P value
P. ditchella	log(W) = -9.19+2.53log(L)	W = 0.000102*$L^{2.53}$	0.51	2.32 - 2.75	P = 0.00002
Alepes vari	Log(W) = -7.64+2.25log(L)	W=0.000481*$L^{2.25}$	0.81	1.93 - 1.93	P = 2.538096e-05
S. gibbosa	Log(W) = -10.25 + 2.71*log(L)	W = 0.000035*$L^{2.71}$	0.55	2.33 - 3.1	P = 0.1432605

With a value of R^2 between 0.5 and 0.6 the models for *P. ditchella* and *S. gibbosa* have a weaker fit to the data than the model for Alepes vari, with a value of R^2 of 0.81. The results for the slopes of the equations show that, according to the model, *S. gibbosa* exhibits isometric growth ($p > 0.05$) with an exponent parameter (β) between 2.33 and 3.1, with 95% confidence. The results for the other two fish show that, according to the respective models, both *P. ditchella* and Alepes vari exhibit allometric growth ($p < 0.05$) with values of β between 2.32 and 2.75 for *P. ditchella* and 1.93 and 2.27 for Alepes vari.

Predictions based on original scale

Table 3 presents the results for the predicted mean weight of the three fish included in the study, using the length–weight models presented in *Table 2* and *Equation 4*. With a mean length of 150 mm, *P. ditchella* was estimated to have a weight between 33.4 and 34.6 g. For *Alepes vari*, with the mean length is 160 mm, the weight predicted lies between 18.6 to 19.7, whereas for *S. gibbosa* the figures are 130 mm and 42.2 to 46.3 g.

Table 3. *Prediction of weight of P. ditchella, Alepes vari and S. gibbosa based on the mean length*

Fish species	Bias correction factor	Predicted weight (g)	Mean length (mm)
P. ditchella	1.097	33.4 - 34.6	150
Alepes vari	1.01	18.6 - 19.7	160
S. gibbosa	1.015	42.2 – 46.3	130

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DOI: http://dx.doi.org/10.15666/aeer/1605_61136127

Monthly variation of length–weight relationship of the fish

Monthly length–weight relationship of the fish was calculated by using *Equation 1*, where a = constant, β = slope (or allometry coefficient or growth exponent), n = number of fish sampled, R^2 = Coefficient of determination. The results are shown in *Table 4*.

Table 4 presents the monthly data for the length and weight of the three fish, for the entire study period (September 2017 to April 2018), and the parameters for the respective length–weight relationships. The value of β could not be determined for certain fish in the months of November 2017 and January, March and April 2018 due to the small size of the sample. No sampling was carried out in December 2017, as the heavy weather prevented all fishing activities.

There is a slight variation in the value of β (slope) between months for the three fish included in the study, with the majority exhibiting negative allometric growth ($\beta < 3$), and only Alepes vari exhibiting positive allometric growth during the month of October 2017 ($\beta = 3.14$). This suggests that the majority of the fish sampled experiences poor growth and living conditions. Carlander (1969) showed that the coefficient β in the LWR of fish usually ranged from 2.5 to 3.5. In this study, there were 10 instances in which the value of β was outside this range, as depicted in *Table 4* and *Figure 3*. The same table and figure also show that the lowest value of β was obtained for *S. gibbosa* in October 2017, whereas the highest was for Alepes vari in October 2017 ($\beta = 3.14$), followed by that for *S. gibbosa* in January 2018 ($b = 2.94$).

In the majority of instances (76.9%) the value of the coefficient of determination (R^2) was equal or greater than 0.60, which indicates a moderately significant relationship between length and weight of the fish examined in the period of this study *(Fig. 4)*.

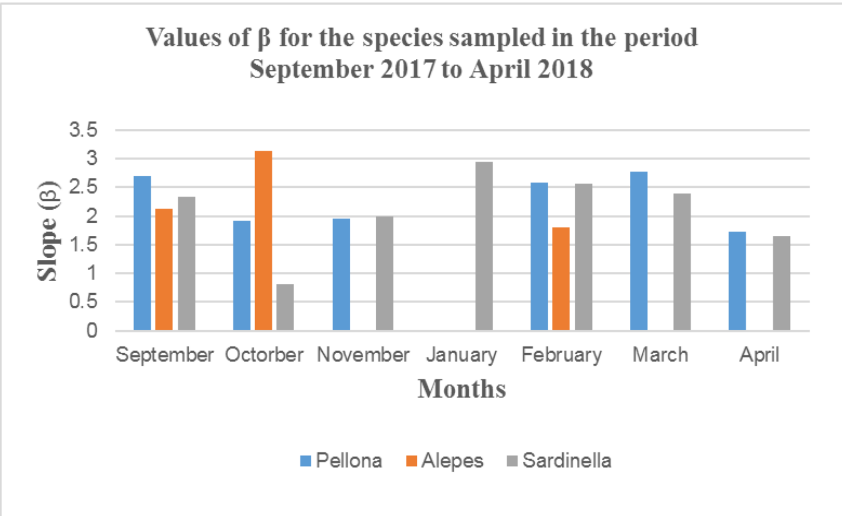

Figure 3. *Values of β for the species sampled in the period September 2017 to April 2018*

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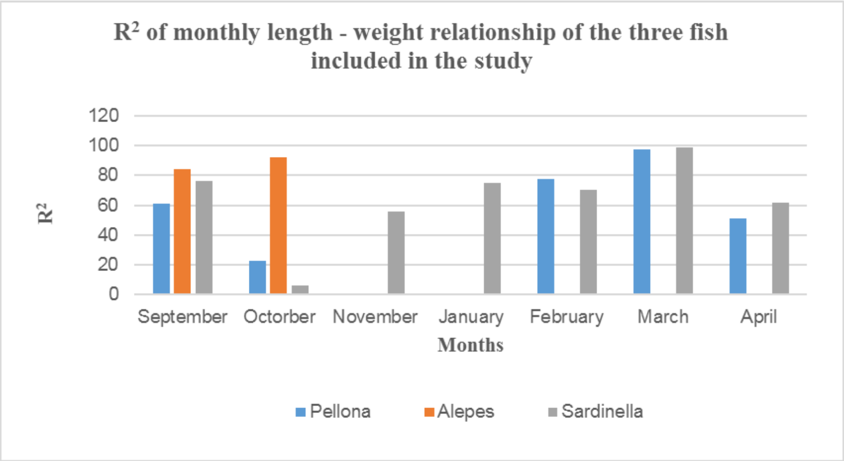

Figure 4. *R^2 of monthly length–weight relationship of the three fish included in the study*

Comparing length–weight regressions during and after the monsoon season

Table 5 presents the values of the ANOVA of the length–weight relationship for the three fish in two distinct periods, namely during and after the monsoon season.

http://www.aloki.hu ● ISSN 1589 1623 (Print) ● ISSN 1785 0037 (Online)
DOI: http://dx.doi.org/10.15666/aeer/1605_61136127

Table 4. *Monthly values of length and weight for P. ditchella, Alepes vari. and S. gibbosa, and respective length–weight model parameters, September 2017–April 2018*

Month	P. ditchella							Alepes vari							S. gibbosa						
	n	LWR			Length			n	LWR			Length			n	LWR			Length		
		a	β	R^2	Min	Max	Mean		a	β	R^2	Min	Max	Mean		a	β	R^2	Min	Max	Mean
September	9	0.000099	2.69	61^{**}	147	165	154.8	42	0.000942	2.13	84.15^{***}	122	196	162.4	16	0.000232	2.33	76.53^{***}	117	147	132.4
Octerber	189	0.00197	1.92	23^{***}	115	169	137.4	3	0.0000041	3.14	92.02^{***}	167	216	191.7	18	0.25	0.81	6.12	102	152	120.4
November	2	0.00181	1.96		132	142	137	1				116	116	116	9	0.00119	1.995	55.53^{**}	124	138	132.7
January	1				147	147	147								23	0.0000122	2.94	74.89^{***}	112	154	131.7
February	305	0.0000808	2.59	77.93^{**}	130	170	147.4	2	0.00416	1.802		167	192	179.5	75	0.0000727	2.57	70.4^{***}	119	175	132
March	16	0.0000302	2.78	97.46^{***}											3	0.000169	2.4	99.14^{*}	128	144	137.3
April	15	0.0059	1.72	51.39^{**}	134	160	144.3	1				112	112	112	18	0.0066609	1.65	62.06^{***}	122	146	131.6

*P-value < 0.1; **P-value < 0.05; ***P-value much less than 0.01

Table 5. *ANOVA of fish species in monsoon and after monsoon season*

Variables	Df	SS	MS	F value	P value	Confidence interval (2.5 And 97.5%)		
						Intercept	Log (L)	fSeason Monsoon

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P. ditchella								
Log (L)	1	21.4152	21.4152	576.7773	< 2.2e-16 ***	-3.3-(-2.1)	2.08-2.53	-0.12-(-0.055)
fSeason	1	0.8866	0.8866	23.8779	1.36e-06 ***			
Log(L)$fSeason	1	0.1973	0.1973	5.3127	0.02155 *			
Alepes vari								
Log (L)	1	5.0864	5.0864	210.0341	<2e-16 ***	-9.30-(-9.30)	1.92-2.57	-0.13-0.25
fSeason	1	0.0098	0.0098	0.4032	0.5286			
Log(L)$fSeason	1	0.1078	0.1078	4.4501	0.0405 *			
S. gibbosa								
Log (L)	1	5.9244	5.9244	205.2222	< 2e-16 ***	-11.53-(-7.82)	2.22 - 2.98	-0.14- (-0.033)
fSeason	1	0.2904	0.2904	10.0608	0.00182 **			
Log(L)$fSeason	1	0.0110	0.0110	0.3808	0.53806			

*P-value < 0.1; **P-value < 0.05; ***P-value much less than 0.01

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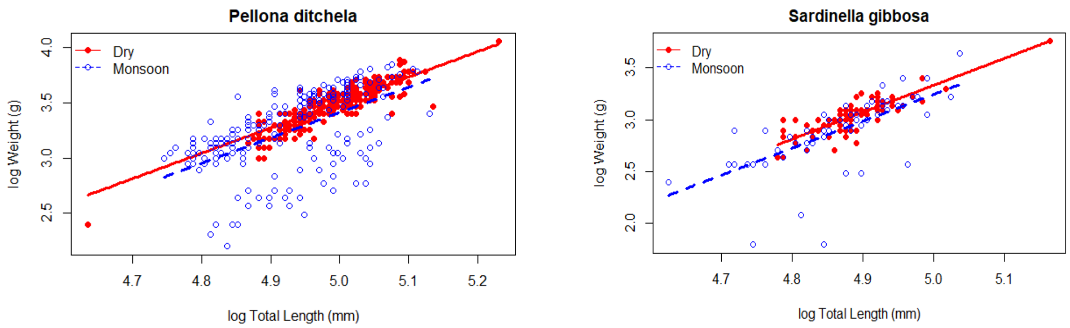
These results show that for *P. ditchella* the interaction terms are significant (p = 0.02), which indicates that there is enough evidence of the difference in the slope in the length–weight relationship between the monsoon and after monsoon seasons. The p-value for the indicator variable also suggests that there is a difference in the intercepts between seasons (p < 0.05). There are statistically significant differences between the slopes and intercepts of the regressions for the two different seasons, and there is a constant difference between the log-transformed weights of fish from the two seasons regardless of the log-transformed lengths of the fish. This is confirmed by the plots *(Fig. 5)* and confidence intervals. This result states that, the growth of *P. ditchella* during monsoon and after monsoon seasons is different.

For *S. gibbosa Table 5* shows that the difference in the length–weight regression between seasons is not significant (p = 0.538), hence there is not enough evidence to draw any conclusions about inter seasonal differences in the length–weight relationship of this fish species. The p-value for the indicator variable suggests that there is a difference in the intercepts between the two seasons (p < 0.05).

The interaction term for Alepes vari is slightly significant (p = 0.04), suggesting that there is enough evidence to conclude that there is difference in the slopes in the length–weight relationship between the monsoon and after monsoon seasons. The p-value for the indicator variable suggests that there is no difference in the intercepts of the regressions for each of the two seasons (p = 0.53).

These results also show that *P. ditchella* and *S. gibbosa* captured during the monsoon season are smaller than those captured after the monsoon (dry) season, with differences in weight of 0.05 - 0.13 g and 0.03 - 0.14 g, respectively. The opposite was found for Alepes vari, in which case fish captured during the monsoon season was 0.14 to 0.25 g larger than the fish captured during the dry season. *Figure 5* portrays the final models for the length–weight regressions for the monsoon and dry seasons for the three fish, with the respective fit plots.



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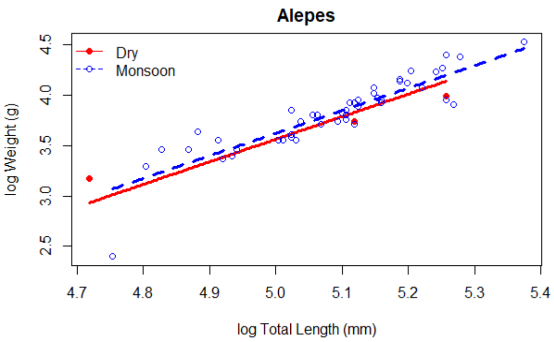

Figure 5. *Fit plot of the length–weight relationship for the three fish during the monsoon and after monsoon (dry) seasons*

Discussion

This paper provides the first monthly values for the length–weight relationship of three commercially important fish commonly found in Songkhla Lagoon and captured in the coastal areas of the lower Gulf of Thailand. It also contributes with revised values for the maximum length of two of the species studied in the online database FishBase (Froese and Pauly, 2018, *Table 1*): the maximum recorded length for *P. ditchella* **(**Valenciennes, 1847) and *S. gibbosa* (Bleeker, 1849) was previously 160 mm and 170 mm length (Whitehead, 1985), and this study determined new maximums at 187 mm and 175 mm, respectively.

With respect to the LWR, a value of 3 (three) for the slope of the regression (β) corresponds to the ideal growth of fish. However, such situation is seldom found (Allen, 1938) due to changes in the shape of fish during the growth period (Martin, 1949). That coefficient can be affected by factors such as the length and shape of the fish itself and the time of spawning; the fishing gear used (Farran, 1936; Deason and Hile, 1947); or environmental factors such as food supply and season changes in environmental parameters (Brosset et al., 2015). In this study, the average of the monthly values of β for the three fish studied fall below the standard interval of 2.5 to 3.5 as determined by Carlander (1969). The average values from this study are 2.277, 2.357 and 2.099 for *P. ditchella*, Alepes vari and *S. gibbosa*, respectively. This indicates that all three fish have negative allometry, which is interpreted as a sign of poor body condition. This is in line with the views of fishermen contacted for this study, most of whom were of the view that the amount and size of fish has decreased in the coastal area of the southern Gulf of Thailand, which they attribute to the oil drilling activities taking place offshore and the illegal fishing gear, such as: sai nang (sitting cage). 14.29% of the fishermen interviewed in this area said they are using sai nang, they knew that this fishing gear catches all small fishes, but they still have to use because the number of fishes is decreasing sharply (Source: Author). The results from this study are insufficient to establish such a causal relationship though, and a broader investigation would be needed to determine the effects of coastal water quality on the condition of fish in the lower Gulf of Thailand.

The study also found that two of the fish captured after the monsoon season (dry season), namely *P. ditchella* and *S. gibbosa* were on average fatter than when captured during the monsoon season. This is in line with the result from the author, only 13.6% amount of fish was caught during monsoon season, 39.98% was before monsoon season and 46.42% was after monsoon season (Source: Author). This may be due to the biology of these two

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species, as both migrate to the mangroves in the estuarine and freshwater environments of the lagoon (Hue et al., 2018), which affects their growth negatively compared to life in the marine environment of the coastal waters. Even though, Alepes was found thinner in the dry season, but due to its small sample size (N = 3), it is not appropriate for a correct statistical evaluation, to conclude about Alepes, it requires further study.

The main limitation of this study is the relatively short study period of seven months, which is insufficient for studying the biology of the fish included in the assessment. Despite this limitation, it has unveiled statistically significant differences in selected growth parameters between two seasons in the lower Gulf of Thailand. The fish studied are all of high commercial importance, yet are subject to increasing anthropogenic pressure from fishing, including the use of illegal gear such as sitting cage (Source: Author), offshore drilling for oil and habitat destruction (Satumanatpan and Pollnac, 2017). In view of these pressures and the need to improve the management of commercial fish stocks, the findings of this study are potentially very useful for current and future stock estimation and evaluation studies. Moreover, these findings could be useful for comparing the body condition of fish over time and between different regions. Further studies of similar nature and involving some elements of the biology of commercially important species are necessary to support the formulation of policies for the sustainable utilization and appropriate management of fisheries resources in the southern Gulf of Thailand and in the whole the country.

Conclusion

Seven months for studying the biology of fish may not be a long time but this is enough time to see the difference of growth parameters between two typical seasons in the lower gulf of Thailand for some fish species. In the investigated area, these species have high commercial value, however, high pressure on population caused by fishing, illegal fishing gear (trawl), oil drilling from human activities are destroying fish habitat. Findings of present research are very important for stock estimation and evaluation studies in the future. Moreover, they will give an opportunity to compare fish conditional living over the time and between regions.

Further studies of similar nature and involving some biological aspects of commercially important species are necessary to support the formulation of policies for sustainable utilization and appropriate management of fisheries resources in the country.

Acknowledgements. This paper has been partly prepared with the support of the Higher Education Research Promotion and the Thailand’s Education Hub for the Southern Region of ASEAN Countries Project Office of the Higher Education Commission. Financial support was granted by the Graduate School, Prince of Songkla University, Thailand. The authors would like to thank the Fishermen Association in Sathing Pra district for giving us the chance to go fishing with, thanks to the MACORIN research team for helping authors to do the lab works. Thanks NICA for agreeing authors to use the data.

Conflict of interest. The authors confirm that this article content has no conflict of interest.

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APPENDIX E: PAPER 4

Seasonal Aspects and The Adaptation of Fishermen in the Songkhla Lagoon, Thailand

(This paper was Published in Asean Journal of Microbiology, Biotechnology and Environmental Sciences - Scopus)

Asian Jr. of Microbiol. Biotech. Env. Sc. Vol. 20, No. (4) : 2018 : 1349-1355

ISSN-0972-3005

SEASONAL ASPECTS AND THE ADAPTATION OF FISHERMEN IN THE SONGKHLA LAGOON, THAILAND

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Abstract: Small-scale fisheries are very important in the coastal areas as the main livelihood in Thailand. However, as many places in the world, the fishers are facing the decline of fish catch and worrying about their future. The study was conducted to obtain an understanding of fishing activity and fisher's future perception in Songkhla Lagoon. The methodology included questionnaires, observing fishing practices, and in-depth interviews with village leaders. A survey of 164 fishers was conducted in eight villages in the area, who were found to engage in fishing. There was a significant difference in the mean catch between three seasons. The highest mean total catches of 1602 ± 136.369 kg/year/fisher were found in the light rainy season. The lowest mean total catch of 963.29 ± 104.660 kg/year/Fisher was found in the rainy season. Some important findings from this research were that almost studied fishers don't have the alternative occupation and are difficult to find another job, illegal fishing gear is the serious cause of fish decline. A well-managed fishing activity and alternative sustainable livelihood need to be urgent acted in the Songkhla Lagoon.

Keywords: Fish catch, Songkhla Lagoon, Small-scale fisheries, livelihood.

INTRODUCTION

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ISSN-0972-3005

Small-scale fisheries is a main source of livelihood for people living in Songkhla Lagoon, where is a major area of interest within the field of fish catch landing forecasting (Chesoh and Lim, 2008; Chesoh, 2009; Chesoh and Choonpradub, 2011; Hue *et al.*, 2018a), water quality (Pradit *et al.*, 2013; Pornpinatepong *et al.*, 2010;), policy and management (Parton and Nissapa, 1997; Doungsuwan, 2013), fish condition (Hue *et al.*, 2018b), local culture relate to their houses (Chuapram *et al.*, 2012) and social aspects of water governance (Cookey *et al.*, 2016).

Evidently, these social and cultural aspects of marine fisheries are often neglected in developing fishery policy and management, in the efforts of handing out the decline of fish stocks, they only focus on the biological and economic impacts of fishing (Urquhart *et al.*, 2013). To achieve sustainable fishery development, it is vital to integrate environmental, economic and social dimensions.

This study was conducted to find out the seasonal aspects to fish catch and how the fishermen adapt with that condition both now and in the future.

METHODOLOGY

Study areas

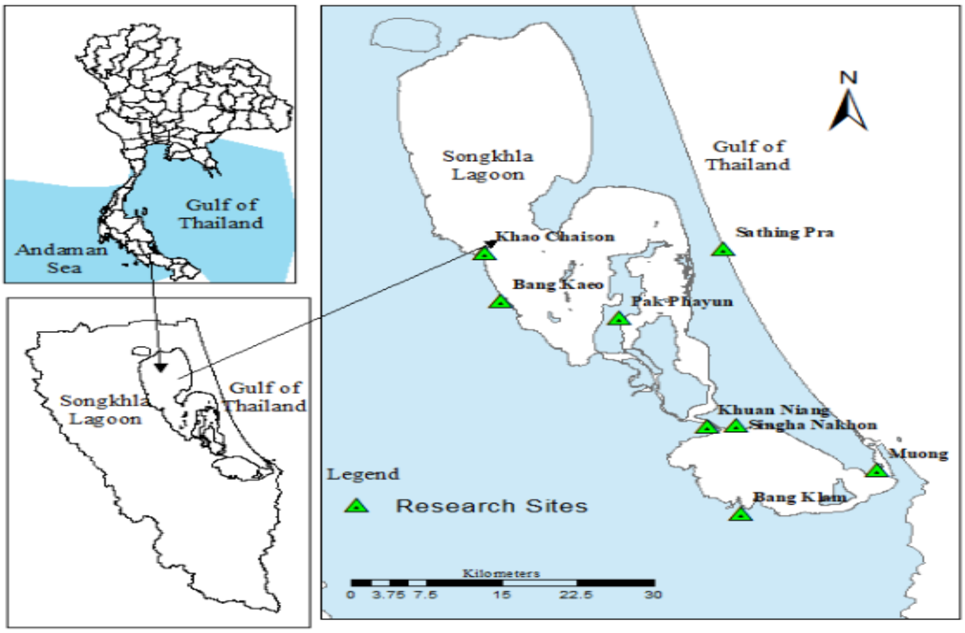

Fig. 32. Location of Sampling

The study was conducted with 164 fishing households in 8 villages in Songkhla Lagoon and Sathing Pra district, these villages were chosen after doing preliminary research based on the criteria season may effect on fish catch.

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Data collection

To design questionnaires, two preliminary researches were implemented in Songkhla Lagoon and Sathing Pra district to find out background information about fisheries. Themes of questionnaires focused on demographics, information about fishing activities and patterns, perceived changes in fishing and seasons, how do fishers cope with fishing situation, what other kinds of income do they get, do household member engage in, what is the seasonality of these activities, can non-fishing work be alternated with fishing or is it full-time? Does non-fishing work require moving to another location?

Before the interviews took place, 8 studied villages were chosen randomly from 8 districts around Songkhla Lagoon, there was a meeting in the village with a head of the village who was a key-informant, to gain an understanding of the background of fishing. The adaptation of fishermen to response the changes of seasonal and fish catch were explored from two series of structured questionnaires, aimed to know fishermen point of view about their plan in the future. The number of fishermen was interviewed then. The list of households and the number of fishermen in the 8 villages was taken from the head village. In the total of 1608 households, 823 households are doing fishing. 164 fishermen (around 20%) were chosen for interviewing. This sample size is line with the research from (Sievanen, 2014) when they chose 60 household surveys of the approximately 500 households that depend on fishing in the focal communities. At least 15 fishing households from each site was chosen randomly from the list of fishermen by Random and Convenience sample strategies (Robinson, 2014), this sample size is considered sufficient for the goal of describing a shared perception, belief or behavior among a relatively homogeneous group (Guest *et al.*, 2006), and line with the range from 3-16 of (Smith, 2009).

The list of fishing household surveyed was selected from the list of fishermen who have been doing fishing, this list was identified from community leaders, then was selected randomly. The extra list was done in case of the appointed fisher may not be available to be interviewed.

The questionnaires right after that were pretested with 2 fishermen in each area and were revised to suitable with the content and situation.

The data collection via face to face interviews and observations were implemented between February 2018 and June 2018 with the support from interpreter and other

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investigators. Surveys were conducted using semi-structured questionnaires that facilitated the collection of additional information such as comments from respondents. The questionnaire was formulated in English then translated into Thai and consisted of two parts: the first to the situation of fishing during three seasons in one year, and the second to gain an understanding of the fishermen's perspective relating to the fishing activities, the fishermen's wish or suggestion to improve their situation. All interviews were conducted in Thai. The interviewee will be asked for permission and arrangement of timetable, each interview was taken notes during the interview section. One interview supposes last maximum 1.5 hour to ensure not disturbing to their work. This study did not record interview section to make sure the interviewee feels free to answer all questions and praise up their mind for talking their thinking.

Data analysis

Data on the total catch in one year was estimated from three seasons. The data were sorted and analyzed using the IBM Statistical Package for Social Sciences (SPSS), version 20 and Microsoft Excel. Both descriptive and statistical data analyses were performed. The calculation of sample means, standard errors, medians, minimum and maximum values, and frequency distributions was conducted.

Inferential statistical analysis was used to discover the relationships among the relevant variables. Because the data was not normally distributed, the Mann–Whitney U test for two variables and the Kruskal–Wallis test for more than two variables were used in SPSS, to analyze the data with any significant differences expressed at the 0.05 level (or higher where indicated in the text). The estimated catch total of fish from two religions in the eight villages was computed based on the data from the questionnaires.

Ethical considerations

Participation of the survey respondents solely depended upon their willingness. Generally, most of the encountered respondents were welcoming and willing to participate in the surveys. However, a few fishers declined to be surveyed. We removed questions that seemed sensitive and that could have precluded respondents from answering other questions. Such questions included income earned from respondents' occupations or the details of illegal fishing activities.

RESULTS

Is the different between catches in the seasons?

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There was a significant difference in the mean catch between three seasons, at the $p < 0.001$ level. The highest mean total catches of 1602 ± 136.369 kg/year/fishermen being found in the light rainy season. The lowest mean total catch of 963.29 ± 104.660 kg/year/fishermen was found in rainy season. The mean amount of total catch caught by all three seasons was 1280.53 ± 70.310 kg/year/fishermen. Post Hoc Tests also showed the significant different in the mean catch between rainy season and light rainy season, however, there was no different in fish catch amount between dry seasons with two remain seasons. These shown in (*Fig. 2*).

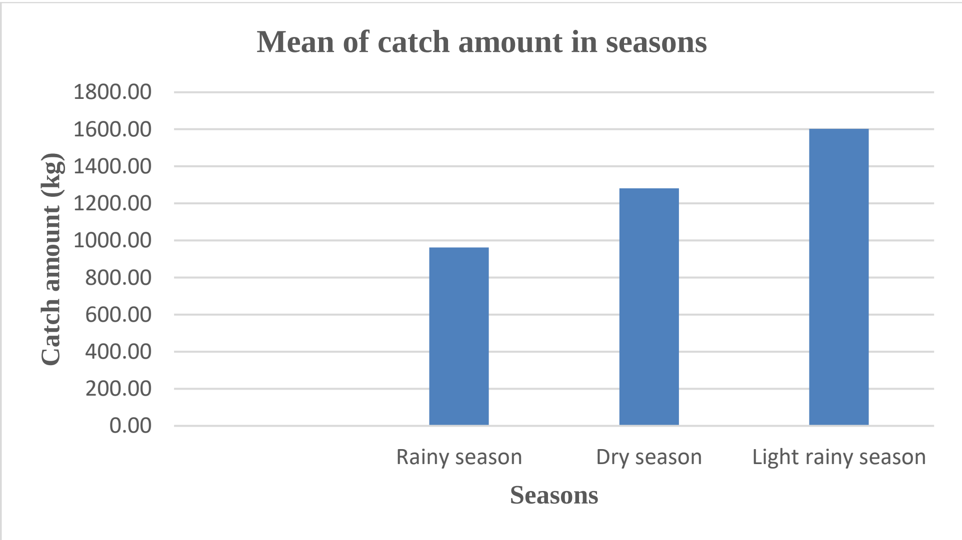

Fig. 2. Mean of fish catch in seasons

The different between catches in the season in each research site is shown in *Table 1*

Table 15. Compare fish catch different between seasons in each study site

Study sites	Significant different (P value)	Mean catch between seasons	Highest value	Lowest value	Seasonal different
Sathing Pra	0.028***	1099.3 ± 177.261	1530.5 ± 375.389 (Dry season)	448.38±75.371 (Rainy season)	Rainy season-dry season and Light rainy season
Singha Nakhon	0.01***	1153 ± 172.813	1868.75 ± 385.125	708.25±149.918 (Rainy season)	Rainy season – Light rainy season, Dry

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			(Light rainy season)		season – Light rainy season
Bang Kaeo	0.161	1353 ± 209.345	1894.67 ± 449.484 (Light rainy season)	935.4±281.837 (Rainy season)	No difference
Pak Phayun	0.026***	1345.49 ± 153.463	1925.94 ± 344.535 (Rainy season)	1027.35±181.297 (Light rainy season)	Rainy season- Dry season and light rainy season
Khao Chaison	0.460	1278.38 ± 351.572	1579.64 ± 722.254 (Dry and light rainy season)	615.6±127.442 (Rainy season)	No difference
Khuan Niang	0.064	2956.32 ± 425.449	4260 ± 704.889 (Light rainy season)	1866.29±610.714 (Rainy season)	Rainy – Light rainy season

From the *Table 1*, it can be seen clearly that, there is a significant difference in fish catch between three seasons in year were found in Sathing Pra, Singha Nakhon, Pak Phayun, Muong.

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ISSN-0972-3005

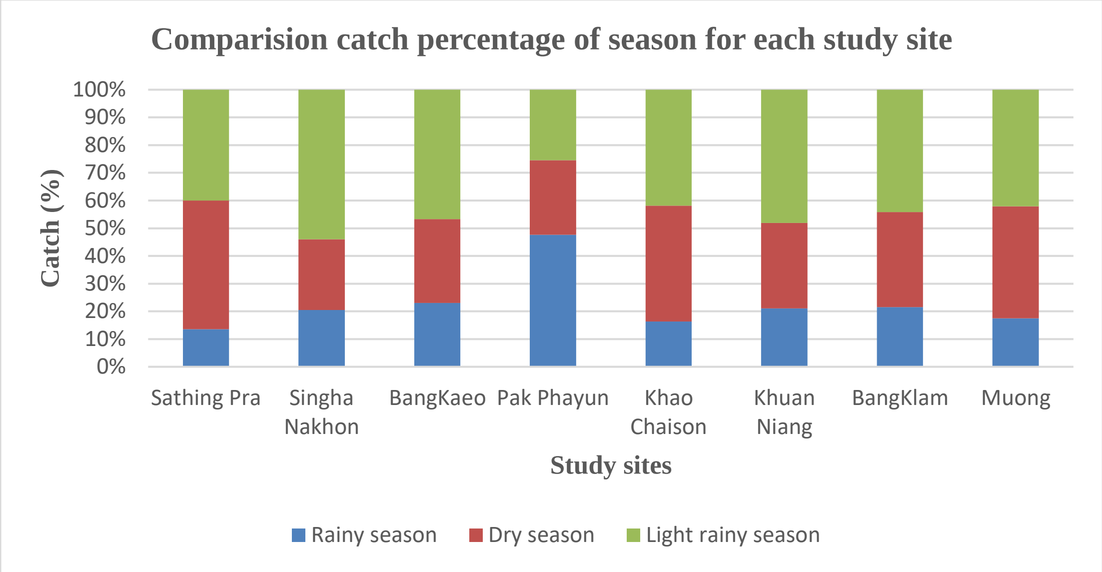

Fig. 3. Comparison fish catch percentage between seasons for each study site.

The percentage of mean fish catch in each season is different between each study site. While the highest fish catch percentage in the dry season in Sathing Pra, this happens in the rainy season in Pak Phayun or in the Light rainy season in Singha Nakhon (*Fig. 3*).

Alternative work of fishermen in the study sites

Almost fishermen in the study sites said that they do not have alternative work, during the time they do not do fishing, they only stay at home and do nothing, and this high percentage is shown in *Fig. 4*. Some but very small percentage of fishermen do animal husbandry, collect debris (plastic material) for selling, do shrimp farm, factory, fish trading, rubber cutting or doing fishing tool maintain. However, their livelihood was tented to change to semi-agriculture and semi-fishing activities because the fish amount is decreasing, and they can not only live on fishing.

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ISSN-0972-3005

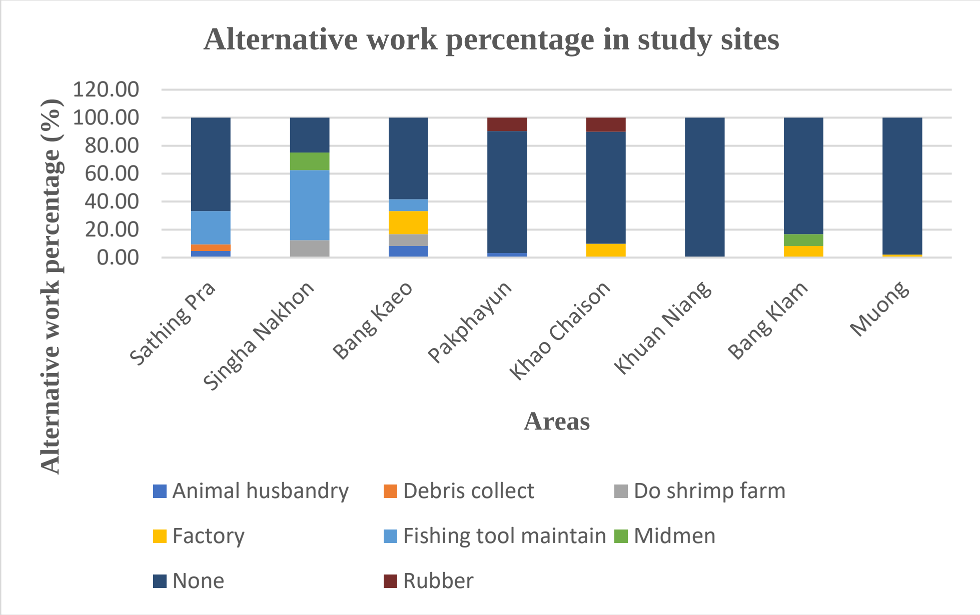

Fig. 4. Alternative work percentage in study sites.

Fishermen future perception

When asked about the perception of doing fishing, very few fishermen interviewed want to change to another job (only 10.98%), In among of them, the main reasons they do not want to change the job because they love fishing, they invested much money on boat and equipment, it is hard for them to change the job because of old age, lack of education, "I want to change the job because of low income, but without knowledge, I do not know what job I can do" – One 42-year-old fisherman said. These statements are shown clearly in *Fig. 5*, where 72.56% interviewed fishermen said that they met difficult to find another job. Especially, one 41-year-old fisherman confident "So far, I only do fishing, I have never worked elsewhere, I do know what to do if I do not fish". The big percentage of fishermen interviewed, 78.05% do not want to change to another job, and most of them said that, they love this job but these days, less fish, low income, it is so difficult for them to support their children.

The perception of fishermen for their children, more than a half interviewed fishermen (53.05%) will allow their children do fishing if they want, or they do not know how to orient job for the next generation, 37.37% (*Fig. 5*) do not allow their children do fishing because they consider this job is not stable any more, less fish, low income, they want their children to have higher education and earn more money.

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ISSN-0972-3005

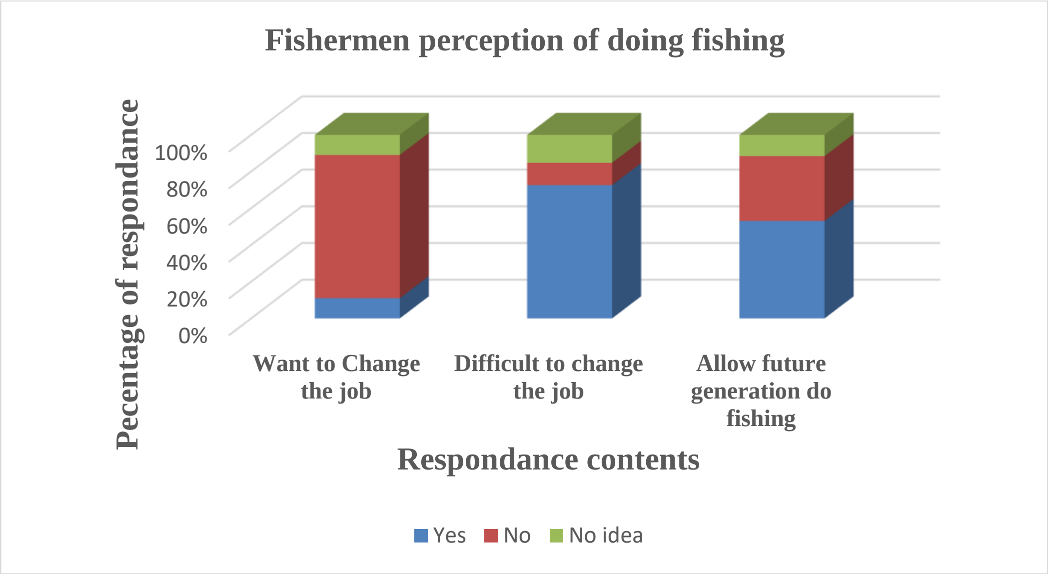

Fig. 5. Fishermen perception of doing fishing

DISCUSSION

Fish catch relate to seasons

The climate of the Songkhla Lagoon is governed by two monsoons; the southwest monsoon and the northeast monsoon. There are two seasons: (a) the rainy season, from May to January, under the influence of the southwest monsoon from May to September and the northeast monsoon from October to January. The heaviest rains usually occur in November; and (b) the dry season, from February to April. The hottest month is normally April. During this dry season, the amount of freshwater flowing into Songkhla Lake is substantially lower than the rest of the year. The local people living in Songkhla Lagoon and Sathing Pra have traditionally adapted to seasonal changes in resource availability. The temperature also varies seasonally between rainy season and dried season in the Gulf of Thailand. While some species are available to fish year-round, others migrate seasonally. The catch data confirms seasonal variation. To adapt with the fish catch change due to the seasons, somewhere in the world, fishers travel to a different fishing spot, such as Pacific for days to even several months at a time (Allison *et al.*, 2001).

The high catch focus on the light rainy season, because this time, there is no monsoon season, the water become brackish water. During monsoon season, the fishermen in Sathing Pra even cannot fishing for whole month if it is heavy rain or strong wave. This makes the fisher's life difficult when they do not have alternative job, during this time, they use saving money to cover daily life.

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While fishers in the studied areas have not found the solution to again with the seasonal, somewhere in the world, the fishers in West Java, Indonesia response to seasonal and inter annual variations in fish availability species by switching between rice farming, tree-crop farming. The full time fishers from the North Coast (Java Sea) against seasonal and spatial variations in fish stock availability by migrating long shore and inter island (Allison *et al.,* 2001).

The adaptation of local fishermen in front of the fish decline

Like the Rayong coast, the fishers in coastal areas of Songkhla province tend to have high vulnerability due to increasing industry and urbanization (Satumanatpan and Pollnac, 2017), which impacts fisher's living. However, the alternative jobs in the study areas are not diversity for fishers, they do not have much choices at the meantime if they do not fish. As Satumanatpan and Pollnac (2017) confirmed that, the fishers who perceived more options or a high level of self – adaptation to unexpected changes will expose higher levels of well – being, therefore, the issues of sustainable livelihoods in the study areas becomes the hot problem for the government. The topic of resilience and vulnerability are likely to become more meaningful in the designing of resource management questions in the future (Adger, 2000; Adger *et al.,* 2005). When the fishers have high levels of satisfaction with features of the occupation, they are difficult to find acceptable alternative job with the same satisfaction (Satumanatpan and Pollnac, 2017). In this study, some interviewed fishers are not satisfied with fishing due to low income, they face difficulty to change the job because of lack of education, experience, old age barrier, they are not confident to work outside, this situation has been happen with fishers in Hokkaido, Japan (Sweke *et al.,* 2016). The consequence of cycling between falling catches – using illegal fishing gear – overfishing – declining catches sharply make a challenge for creating appropriate fishery management plans.

Future perception of fishermen

From interviewed fishermen, it is significant to recognize that allowing the young to enter fishing is encouraged if they are interested, the fishermen want to remain the traditional fishing job, however, they are wondering about this uncertain job cannot afford to support their life. This result is relevant with the study in Rayong, the Eastern Thai province, on the Gulf of Thailand when advising the young to enter fishing is also related to fisher's well – being, basic needs or earnings (Satumanatpan and Pollnac, 2017). As many parts of the world, the fishers in Uruguay and Brazil want to continue fishing in the future, they do many occupations at the same time or consider fishing as a way of life rather than just a job (Urquhart, Acott and Zhao, 2013; Sievanen, 2014). The fishers diverse pattern of fishing activities with respect to the species exploited, location of fishing grounds and gear used, increase incomes from seasonal fishing by a range of people cited retired persons, taxi drivers, shopkeepers, the unemployed (Freire and García-Allut, 2000).

78.05% interviewed fisher would not want to change the job, 72.56% meet difficult to change the job, 53.05% fisher allow their children to do fishing if the young generations want are significant numbers. It makes sense that, fishers with positive attitudes towards their occupation would not want to change or they would not want to change because of being difficult to find another job. This is an interesting finding that answers the question why attempts to reduce fishing effort have failed in some areas, particularly in those with limited job alternatives (Sweke *et al.*, 2016; Pollnac *et al.*, 2012).

The study areas, except Sathing pra district where the fishermen fishing in the sea and they hardly have alternative job because the lack of land for doing agriculture. The other villages, the community ecosystem is one of alternating brackish or sea water circulating seasonally, providing the bases to local occupations that include paddy farming, manufacturing of sugar palm, and raising cattle (Chuapram *et al.*, 2012).

CONCLUSION

The results draw a picture of fishing activities in the study areas. The adaptation of fishers in the studied areas is very limited, because lack of alternative jobs, lack of knowledge to do another work. The government should identify and provide training for suitable alternative livelihoods that same satisfactions as fishing such as becoming recreational fishery guides or providing boat transport for tourist activities, this requires to have deep market research for these new pursuits (Pollnac and Poggie, 2006; Satumanatpan and Pollnac, 2017). Such policy could apply to sustainable fisheries in Thailand and in similar fishery contexts around the world.

ACKNOWLEDGEMENTS

This paper has been partly prepared with the support from the Higher Education Research Promotion and the Thailand's Education Hub for the Southern Region of ASEAN Countries Project Office of the Higher Education Commission. Financial support was granted by the Graduate School, Prince of Songkla University, Thailand. We are grateful

Asian Jr. of Microbiol. Biotech. Env. Sc. Vol. 20, No. (4) : 2018 : 1349-1355

ISSN-0972-3005

to the local people in the households of the study areas for assistance in the field and for contributing and sharing their knowledge about fishing activities.

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APPENDIX F: CONFERENCE PAPER 1

A comparative study of Artificial Neural Network, Multiple Adaptive Regression Spline and *K* – Nearest Neighbors for Predicting Fish Catch Landing in Songkhla Lagoon, Thailand

(This Conference paper was published on the 1st International Conference on Climate change, Biodiversity, Food Security and Local Knowledge proceeding in Kupang, Indonesia)

A COMPARATIVE STUDY OF ARTIFICIAL NEURAL NETWORK, MULTIPLE ADAPTIVE REGRESSION SPLINE AND *K*-NEAREST NEIGHBORS FOR PREDICTING FISH CATCH LANDING IN SONGKHLA LAGOON, THAILAND

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Abstract

Artificial Neural Network (ANN) model was chosen from three high appreciated models to predict the fish catch landing in Songkhla Lagoon based on environmental factors gathered with the water parameters. Quarterly data for fish catches landing and environmental factor, water parameters during the period 2009-2017 were used for this study. The performance of the model was validated by comparing the predicted data sets with the measured data. The results showed that, the proposed ANN model provided the best result can be used effectively to predict the fish catch landing. The determination coefficient (R^2) was 99.99% for training data and 93.12% for the testing data in ANN model. Again, this study also confirmed rainfall, turbidity and salinity were the most important factors effect on fish catch through Multivariate Adaptive Regression Splines (MARS) model. This research plays important role in choosing the suitable model for forecasting fish catch in the fisheries, this is a very necessary tool for fishery sustainable development management.

Keywords: *Fish catch landing, Forecasting, Nonlinear Regression models, Prediction, Songkhla Lagoon*

Introduction

Songkhla Lagoon is one of the two Lagoons in the world that has Irrawaddy dolphins, an endangered species. The Lagoon's multitude of flora and fauna species makes it rich in biodiversity and it provides resources for local fisheries' fishermen all year around. The livelihood of the more than 1.9 million people of the 25 districts located in the three provinces of Southern Thailand rely on this fishery resource.

During the last three decades, forecasting has been rapidly developing in the field of fisheries, Significant regression, univariate and multivariate time series models were used to forecast monthly and annual marine fisheries' catches (Stergiou and Christow 1996; Stergiou *et al.*, 1997; Hue *at al.*, 2018). Fisheries data is normally nonlinear, it depends on the seasons and many external factors (McDonald, 2009). Artificial neural network (ANN), *K*-nearest neighbor (KNN), Multiple Adaptive Regression Spline (MARS) are powerful nonlinear regression techniques that we no need to do exact form of the nonlinearity prior to model training (Kuhn and Johnson, 2013). Especially ANN was confirmed its advantages compared with ARIMA models (Tseng *et al.*, 2002; Khashei and Bijari, 2011) or multiple regression (Asiltürk and Çunkaş, 2011). In contrast, these models are applied popular in the engineering, soil components. In the fisheries forecasting, these models have not been paid attention. This is what this paper intends to address, presenting the results of an effective approach based on ANN, KNN and MARS to predict the fish catch landing in Songkhla Lagoon in the context of environmental factor and water parameters. The performances of proposed models are compared by means of statistical methods. The proposed models can be used to predict the fish catch landing in Songkhla Lagoon. The results obtained show that ANN produces the better results compared to two remain models.

Methodology

Study site and sample collection

32 data sets were recorded every three months for 8 years (2009-2017) by Department of Environment in Songkhla province. Quarterly data for mean temperature, rainfall, water parameters from three stations located in the upper, middle and lower parts of Songkhla Lagoon, mean these factors were used to be input variables in the models, the locations of these stations are shown in Figure 1.

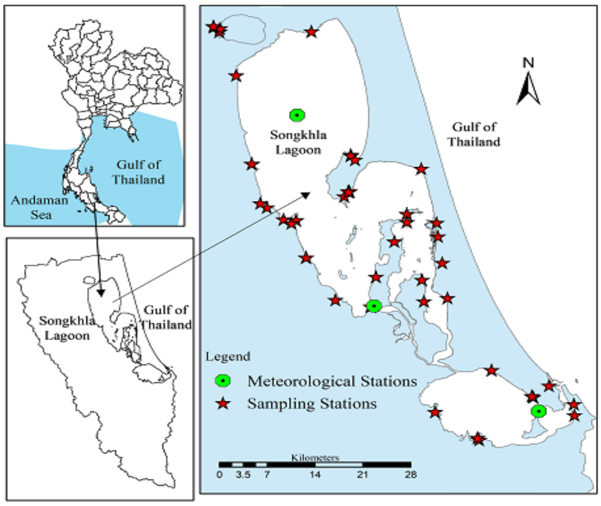

Fig. 33 Locations of fish catch landings and meteorological stations in Songkhla Lagoon

The total of fish catch landing was selected from National Institute of Coastal Aquaculture (NICA), Thailand quarterly in February, May, August, and November during 2009-2017 (Figure1), and it was hypothesized to depend on environmental parameters, the depth of Lagoon, air temperature, water temperature, pH, turbidity, conductivity, Salinity, Dissolved Oxygen **(**DO), Biochemical Oxygen Demand (BOD), rainfall. Pre-processing data was done before building the models to remove the water temperature, conductivity, BOD that have high correlation with Air temperature, Salinity, DO. This feature extraction technique was done by using principle component analysis (Kuhn and Johnson, 2013). All predictors were normalized and satisfied the qualifications for using to create models.

Multiple Adaptive Regression Splines (MARS)

Multivariate adaptive regression splines (MARS) is a procedure for fitting adaptive non-linear regression that uses piece-wise linear basis functions to define relationships between a response variable and some set of predictors (Friedman, 1991). MARS fundamentally builds optimal models in two steps. In the first step, MARS builds a collection of Basis Functions (BF), which are transformations of independent variables considering nonlinearities and interactions in the model. In the second step, MARS estimates a least-squares model with its Basis Functions as independent variables. MARS's capability to handle nonlinearities and interactions in complex data structures makes it particularly suited to fish catch applications. MARS algorithm is automatically select and evaluate the important levels of predictors in the model. All steps of creating and validating

MARS models were implemented by using the package "earth" in R software (Stephen, 2018).

K-nearest neighbor model (KNN)

The KNN approach simply predicts a new sample using the K-closest samples from the training set. Its construction is solely based on the individual samples from the training data. To predict a new sample for regression, KNN identifies that sample's KNNs in the predictor space. The predicted response for the new sample is then the mean of the K neighbors' responses (Kuhn and Johnson, 2013). All predictors were centered and scaled prior to performing KNN then selected the distance metric, the next step is to find the optimal number of neighbors. K can be determined by resampling. All steps of creating and validating KNN models were implemented by using the package "caret" in R software (Max, 2018).

Artificial neural network model

Artificial neural network (ANN) emulating the biological connections between neurons are known as soft computing techniques. The processing ability of the network is stored in the inter unit connection strengths, or weights, which are tuned in the learning process. The training algorithm (or learning) is defined as a procedure that consists of adjusting the weights and biases of a network that minimize selected function of the error between the actual and desired outputs (Gareta *et al.*, 2006; Kalogirou, 2003; *Karataş et al.*, 2009). ANN models provide an alternative approach to analyze the data, because they can deduce patterns in the data. In this study, a simple process element of the ANN was used which has three layers; the input, hidden, and output layers. The input and output layers are defined as nodes, and the hidden layer provides a relation between the input and output layers.

The depth, Air temperature (AirT), pH, Tur, Salinity (Sal), DO, rainfall (rain) are considered as the process parameters. The input layers of the ANN consist of seven neurons whereas the output layer has a single neuron that represents the predicted value of fish catch landing. Since the input parameters were in different ranges, these parameters were normalized within 0.1–0.9 ranges to prevent the simulated neurons from being driven too far into saturation. All the predictors were scaled and centered prior to modeling (Kuhn and Johnson, 2013). The neuralnet package (Stefan and Frauke, 2016) in R software was used in analyzing data in this study because it is a very flexible package (Günther and Fritsch, 2010).

The used data set consists of 32 patterns, the data is divided into a training data set with 25 patterns and a validation data set (7 patterns) by the percentage (80% and 20%). The models are trained on the training data set. The network calculates the errors on the training data set and the validation data set. Stop training when the validation error is the minimum. This means that the ANN can generalize to unseen data. Cross validation does not apply just to ANN, but it is a way of selecting the best model that produces the best generalization to unseen data. The error during the learning called as mean squared error (MSE).

Result and discussion

MARS model

The MARS model was built. The final equation for forecasting fish catches based on given data is shown as follows:

$$\text{Fish Catch} = 87295.64 - 5819.73 \times (8.5\text{-Sal}) + 33.2 \times (\text{Rain-275}) \quad (1)$$

The salinity and rainfall are the most important factors on the fish catch landing in Songkhla Lagoon, the remained factors, such as: Depth, pH, Tur, DO, Temperature are unused from the model because they do not effect on the catch. The significance of the MARS coefficients for the model (R^2, determination coefficient) is 0.8679. It can be said that the MARS model can explain the variation with accuracy, 86.79%. *Fig. 2* shows the comparison of measured and predicted data of fish catch by using MARS model.

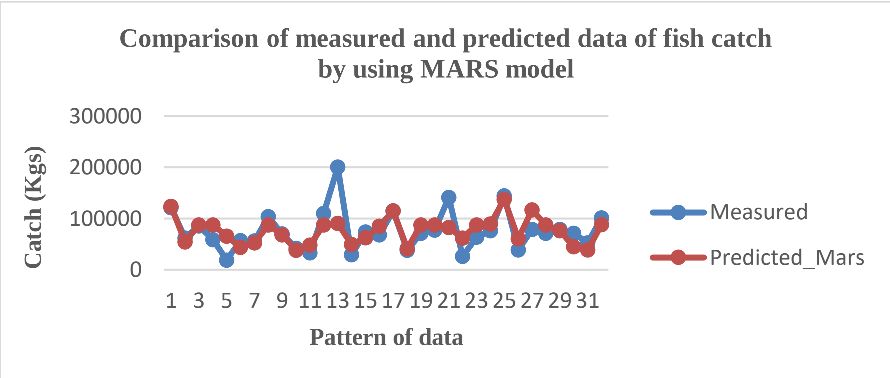

Fig. 2 Comparison of measured and predicted data of fish catch by using MARS model

It is seen from Figure 2 that there is a moderate relationship between the predictor variables and response variable. The ANOVA test was used to determine the dependency of fish catch to selected machining parameters. The main effects of these variables were included to the analysis. The results of this test are shown in *Table 1.*

Table 1 The results of ANOVA test for fish catch

Factors	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Depth	1	281947767	281947767	0.26179	0.61356
AirT	1	623307735	623307735	0.57875	0.454212
pH	1	963312373	963312373	0.89445	0.353699
Tur	1	6664208285	6664208285	6.18783	0.020207*
Sal	1	4060914712	4060914712	3.77063	0.063987.
DO	1	57312826	57312826	0.05322	0.819514
Rain	1	8161486369	8161486369	7.57808	0.011075*

Signif.codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 '' 1

It can be said from Table 1 that, regarding the main effects, the greatest influence on the fish catch is exhibited by the Rainfall (Rain), followed by the Tur. The ANOVA test was performed at a significance level of 5%, confidence level of 95%. Since P value given in Table 1 is less than 0.05, the developed model is significant. According to the other hypothesis, if at least one of these coefficients is not equal to zero, the model will be accepted. It is seen from Table 1 that this hypothesis is confirmed.

Result of KNN model

The significance of the KNN coefficients for the model (R^2, determination coefficient) is 0.8426. It can be said that the KNN model can explain the variation with accuracy, 84.26%. Figure 3 shows the comparison of measured and predicted data of fish catch by using KNN model

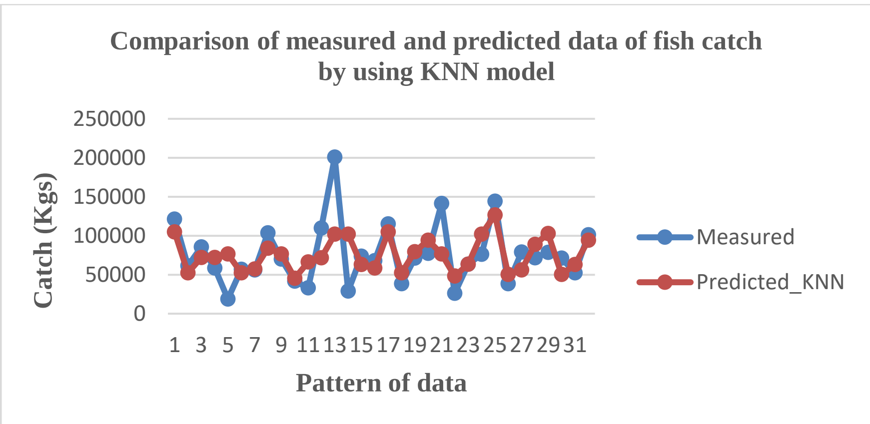

Fig. 3 Comparison of measured and predicted data of fish catch by using KNN model

Results of artificial neural networks

The backpropagation and resilient backpropagation training algorithms were used for ANN training. The best results were obtained with this algorithm compared to other training algorithms. The data set consists of 32 patterns, of which 25 patterns were used for training the network and 7 patterns were chosen randomly for testing the performance of the trained network. After the network has successfully completed the training stage, it was tested with the data set that were not present in the training data set. The results obtained were compared by using statistical methods. The performance criteria considered are the mean absolute percentage error (MAPE) and the determination coefficient (R^2) (Asiltürk and Çunkaş, 2011).

For the fish catch landing, the best approach having the minimum error is achieved by backpropagation algorithm with the training process needed 22717 steps until all absolute partial derivatives of the error function were smaller than 0.01 (the default threshold). The estimated weights range from -4.53 to 1.7. For instance, the intercepts of the first hidden layer are -0.37 and 7 weights leading to the first hidden neuron are estimated as 0.65, 0.21, -1,84, -4,53, 1.03, 1.25 and 1.79 for the depth, Air, pH, Tur, Sal, Do and Rain. The intercept from the first hidden to the output is 0.11 and the weight from the first hidden to the output is 0.7. Whole this process is shown in Figure 4

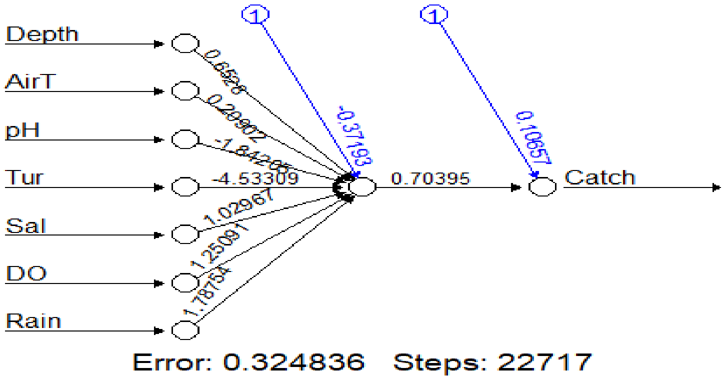

Fig. 4 Plot of a trained ANN information

Overall evaluation

A full factorial experimentation design is implemented to seek the effects of environmental and water parameters on the fish catch landing. After each turning operation, the measurements of fish catch were recorded. ANN, MARS and KNN models were developed to predict the fish catch using the collected data. *Table 3* shows the comparison results according to accuracy values of MARS, KNN and ANN model. The results are generally found to be close to the directly measured. So, the proposed models can be used effectively to predict the fish catch in Songkhla Lagoon. From Table 2, ANN produces the better result compared to MARS and KNN. So, the proposed model predicts the fish catch should be here ANN.

Table 2. Comparison of the models

Models		**MSE**	**R^2**	**MAPE**
Multiple Adaptive Regression Splines		844219142.3	0.867870543	0.3387634021
Artificial neural network	Training	18897.5	0.9999995539	0.5864077360
	Testing	47392.66	0.9311691863	0.4887889367
K-nearest neighbor		15497832	0.8425913	0.4101339

However, as can be seen from the performance criterion in Table 2, ANN is very successful at the training stage, but it is not good enough at the test data. This statement is shown clearly in Figure 5

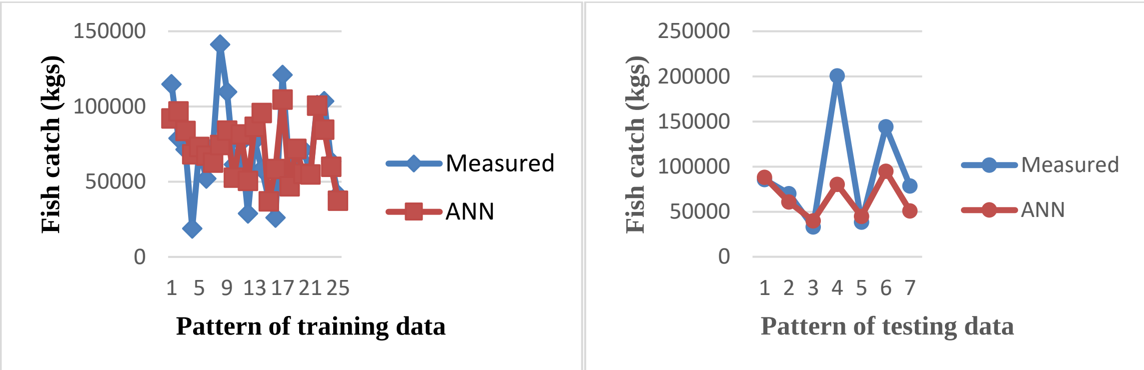

Fig. 5 Comparison of measured and predicted data of fish catch by using ANN model

Social economic context, fishing gears, equipment also effect on fish catch landing. Since fish catch landing activities are the huge topic, therefore, this study only focusses on main factors as the fishermen said they have huge impacts on their fishing, they may be causing to make the amount of fish decrease these days.

Conclusion

In this study, MARS and ANN approaches were used to predict the fish catch in Songkhla Lagoon. The parameters such as the depth of Lagoon, the air temperature, pH, tur, DO, salinity, rainfall were measured by means of full factorial experimental design. The data obtained were used to develop the fish catch models. The following conclusions can be drawn from the present study. The rainfall is the dominant factor affecting the fish catch in Songkhla Lagoon, followed salinity, the remain factors does not effects on fish catch from statistical result. The back-propagation training algorithms, the resilient back propagation, were used for ANNs training. The best result having the minimum error was obtained by the traditional back propagation algorithm. The developed models were evaluated for their prediction capability with measured values. The predicted values were found to be close to the measured values. The proposed model can be used effectively to predict the fish catch landing. The determination coefficient (R2) is 99.99% for training data and 93.12% for the testing data in ANN model, while it is only achieved as 86.78% for MARS and 84.26% for KNN model. Considering that advantages of the ANN compared to other nonlinear regression models, the ANN is a powerful tool in predicting fish catch landing.

Acknowledgement

This paper has been partly prepared with the support from the Higher Education Research Promotion and the Thailand's Education Hub for the Southern Region of ASEAN Countries Project Office of the Higher Education Commission. Financial support was granted by the Graduate School, Coastal Oceanography and Climate Change Research Center, Prince of Songkla University, Thailand. The authors would like to thank the National Institute of Coastal Aquaculture (NICA), Songkhla Department of Environment for giving us the chance to join in data collection and for providing data for the research.

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APPENDIX G: CONFERENCE PAPER 2

Social Aspects to Fish catch in Songkhla Lgoon, Thailand

(This Conference paper was accepted to present at The International Conference on Management, Economics and Social Sicences, will be held on 8^{th}-9^{th} January, 2019, in Osaka, Japan)

Social aspects to fish catch in Songkhla Lagoon, Thailand

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Abstract – Fishing plays an important role as a main livelihood for the local people in Thailand. However, as many coastal areas in the world, the fishers are facing with the decrease of fish catch. This study was implemented to find out if the social aspects effect on the fish catch in Songkhla Lagoon. The method covered questionnaires and in-depth interview with the village leaders. A survey of 164 fishers was conducted in eight villages in this area. There were moderately low but significant correlations between the socio-economic data and total catch. The total catch for one year was correlated with the number of fisher's year living, number of catching days, and number of catching hours based on Spearman rank order correlations (rs) of 0.23, ($p < 0.01$), 0.38 ($p < 0.01$) and 0.24 ($p < 0.01$) respectively for the fishermen in Songkhla Lagoon. Illegal fishing gear causes seriously to fish decline. A well-managed fishing activity need to be urgent acted in the Songkhla Lagoon.

Key words: - Small - scale fisheries, Sociology, sustainable livelihood, socio-economic

I. INTRODUCTION

Small-scale fisheries is a main source of livelihood for people living in the coastal areas of many places in the world, such as, Mexican state of Baja California Sur (Sievanen, 2014), in the Gulf of Thailand (Satumanatpan and Pollnac, 2017), Coastal areas of Songkhla province (Hue *et al.*, 2018), the livelihood of more than 1.9 million population of the 25 districts located in the three provinces of Southern Thailand rely on this fishery resource.

Notwithstanding, as other countries in the world, small-scale fishers have faced to many problems that lead to decline sharply of fish, the competition with the coastal tourism and other fishing sectors (Sievanen, 2014; Abunge *et al.*, 2013), changes of marine ecosystem from polluted industrial plants (Satumanatpan and Pollnac, 2017), more people fishing, environmental pollution, seagrass bed loss (Abunge et al., 2013).

Obviously, in the attempts of solving out the decline of fish catch, the social aspects of marine fisheries are often neglected in developing fishery policy. They only concentrate on the biological and economic impacts of fishing (Urquhart et al., 2013). To achieve sustainable fishery development, it is vital to integrate environmental, economic and social dimensions.

That's what this study tried to find out the direct reasons from fishermen may impact on the decline of fish catch on the social dimensions.

II. METHODOLOGY

A. Study site

Songkhla Lagoon and Sathing Pra are coastal areas in Songkhla province. However, these two areas are different about ecosystem. Songkhla Lagoon is the biggest natural Lagoon in Thailand, the Lagoon concludes four different ecosystems: Thale Noi (around 27 km^2), this marsh is the first Ramsar site of Thailand in 1997. Others are Thale Luang (approximately 473 km2), Thale Sap (approximately 360 km2), and Thale Sap Songkhla (approximately 182 km2). Songkhla Lagoon composes fresh water (in Thale Noi and upper section), brackish water (middle section) and saline water (outer section, this area is connected with the Gulf of Thailand by cannel), this is the unique Lagoon features. Therefore, the ecosystem in Songkhla Lagoon is diversity, range from fresh water ecosystem to marine ecosystem. Sathing Pra totally composes coastal marine ecosystem. Therefore, the effect of social factors and seasonal is also different in these two areas.

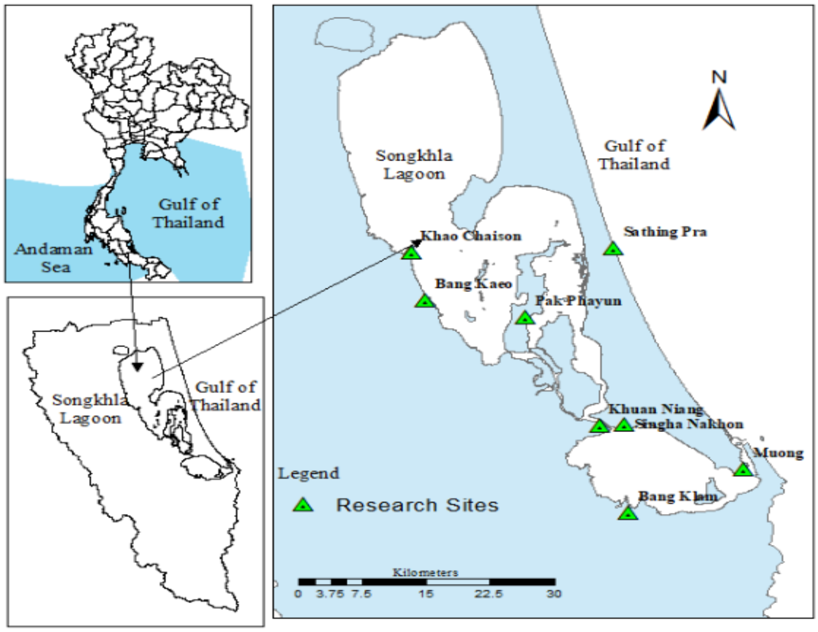

Fig. 34. Location of Sampling

B. Data collection

The data was collected from interviewing 164 fishers in eight villages around Songkhla Lagoon and in-depth interview with 8 head villages to obtain the background information on socio-economic conditions, the number of households, the main livelihood, the number of fishing household, the number of fishermen, the main method of fishing, the rule or the regulations relate to the fishing in the village, the list of fishermen was obtained. The questionnaires mainly focus on the respondent's socio-economic situation and their fishing activities. The age categorize in this study was divided by scale 10 years as previous social researches had done (Cookey *et al.*, 2016; Sweke *et al.*, 2016)

C. Data analysis

Data on the total catch in one year was estimated from three seasons. The data were sorted and analyzed using the IBM Statistical Package for Social Sciences (SPSS), version 20 and Microsoft Excel. Both descriptive and statistical data analyses were performed. The calculation of sample means, standard errors, medians, minimum and maximum values, and frequency distributions was conducted.

Inferential statistical analysis was used to discover the relationships among the relevant variables. Because the data was not normally distributed, the Mann–Whitney U test for two variables and the Kruskal–Wallis test for more than two variables were used in SPSS, to analyze the data with any significant differences expressed at the 0.05 level (or higher where indicated in the text). The estimated catch total of fish from two religions in the eight villages was computed based on the data from the questionnaires.

III. RESULTS

A. Background information established from the survey of fishermen

All 164 interviewees are male, the females in the village does not directly join fishing in these villages and they are ashamed to answer the questionnaires. The age of the interviewees ranged from 20 to 70 years with the median age, 49 years (*Table 1*). The largest age group represented was 51 – 60 years with 35.4% of the respondents. This implies that the respondents had experience on various issues relating to fishing activities by themselves and in the community. The number of year fishing of respondents ranged from 2 to 60 years with the median 27 years. The mean number of persons in each household was 5, ranging from 1 to 13 members and more than half of the households (61%) had less than four persons. More than half of the interviewed fishermen (74.4 %) had primary school level education (first five years school). Based on religions, two main religions in the researched areas are Muslim and Buddhist, in among of that, 56.7 % of the interviewees are Muslim. Regarding to boat types for fishing, long tail boat become dominant in the research sites with 89%. The size of boat ranged from 5m to 14m with the median of 11m. The character of long tail boat is motorized with inboard engines have long outboard drive shafts that can be lifted out of shallow water to avoid obstructions. Most frequently used fishing gears in these research areas include gill nets, trap, long line, hook and line fishing.

Table 16. Summary of socio - economic respondents based on the survey

Social-economic situation	Categories	Frequency (n)	Proportion (%)
Gender	Male	164	100
	Female	0	0
Age (years)	≤20	1	0.6
	21 – 30	13	7.9
	31 – 40	30	18.3

	41-50	38	23.2
	51-60	58	35.4
	>60	24	16.4
Number of persons in the family	≤ 4	100	61
	5 – 7	47	29
	≥ 8	17	10
Education level of the fishermen	University	5	3
	Secondary school	19	11.6
	Primary school	122	74.4
	None formal	18	11
Boat types	Cots	6	3.7
	Fiber boat	7	4.3
	Long tail boat	146	89
	Wooden boat	5	3
Religions	Muslim	93	56.7
	Buddhist	71	43.3

There were significant differences in the total catch among the religions in the Songkhla Lagoon with total catch earned by the two religions different, at the $p < 0.001$ level. The Muslim caught the higher average total catch of 4291.37 ± 391.759 kg/fishermen/year, while the lower catch was 3312.17 ± 295.578 kg/fishermen/year for the Buddhist. Further, there were moderately low but significant correlations between the socio-economic data and total catch. The total amount of catch for one year was correlated with the number year living of fishermen, number of catching days, and number of catching hours based on Spearman rank order correlations (rs) of 0.23, ($p < 0.01$), 0.38 ($p < 0.01$) and 0.24 ($p < 0.01$) respectively for the fishermen in Songkhla Lagoon.

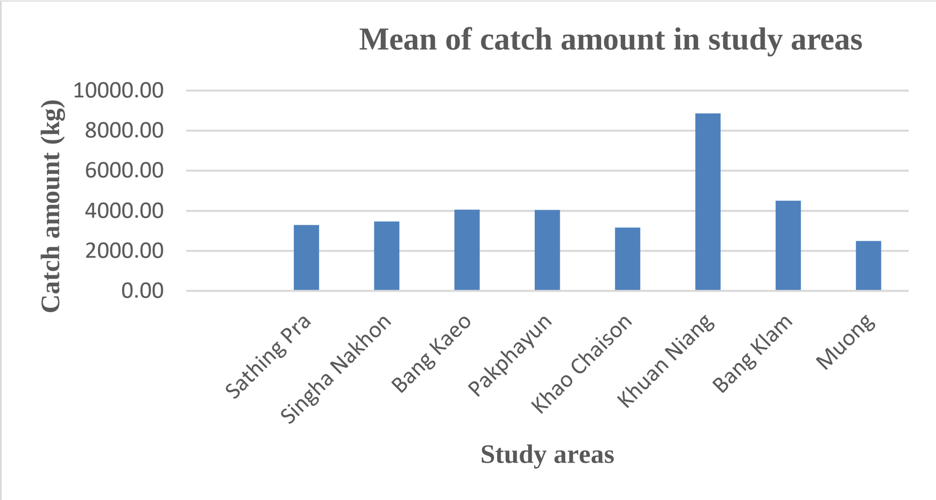

Fig. 35. Mean of fish catch in study areas.

Statistical result also showed that there are no significant correlations between total catch amount in one year and family size, boat size, years of fishing, fishing distance, boat age, age of fishermen in coastal areas of Songkhla Province.

Multispecies and multigear fisheries which are based on small scale operations can be commonly observed in Songkhla Lagoon. Such diverse fisheries differ spatially according to the availability of fishery resources and condition of each part of the lake. This statement is shown in *Fig. 3*.

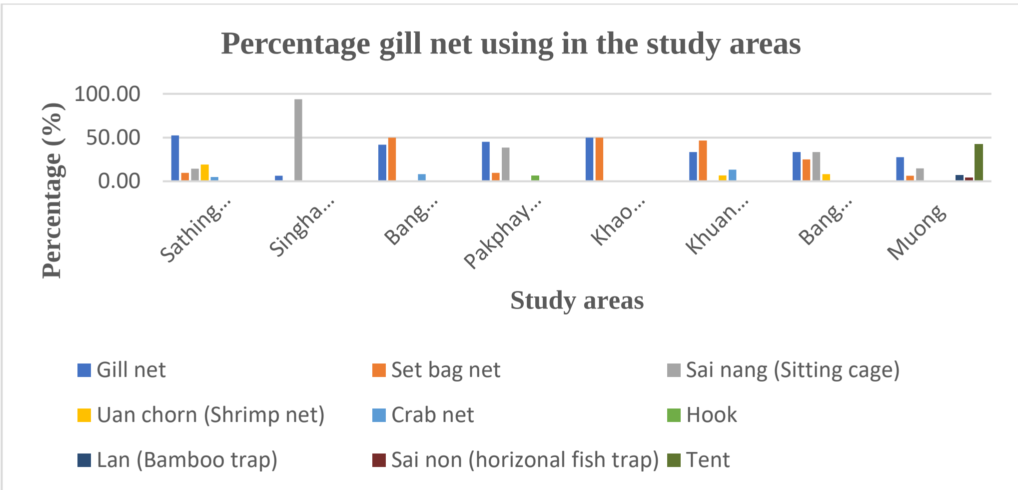

Fig. 36. The fishing gear percentage in study areas

Relate to this, during the author's survey, nine main fishing gears are found in Songkhla Lagoon and Sathing Pra, the fishing gear percentage using in each area are different, gill net is used in almost areas in the study areas, only in Singha Nakhon, fishermen used most Sai nang (sitting cage). According fishermen, the using Sai nang is one of the main reasons make the fish decreases these days, because Sai nang will catch all kinds of fish even with the small size.

However, the statistical result showed that, generally, there is no significant different in mean fish catch within one year among fishing gear groups (P value = 0.061), only tent has significant different in mean catch with gill net (P value = 0.02), Uan chorn (shrimp net) (P value = 0.012), Set bag net (P value = 0.002) and Sai nang (Pvalue = 0.047). The highest mean total catches of 5844 ± 5651.91 kg/fishing gear/fishermen being found in Uan chorn (shrimp net) gear. The lowest mean total catches of 864 ± 610.94 kg/fishing gear/fishermen being found in Lan (bamboo trap) gear.

IV. DISCUSSION

Livelihood of fishing villages largely depend on the fisheries from Songkhla Lagoon, according questionnaire survey (N=164), interestingly, those who are engaged in the fishing only men, they normally go fishing by using small scale boats which are capable of navigating to their fishing grounds, instead of normal boats not being feasible to sail due to shallowness in water depth. Members of fishing boats are limited to single or family with various fishing gears, therefore, the household size does not influence fish catch. However, household size might suggest that families with young people are guaranteed of future workforce and the passing of fishing traditions to the next generations (Sweke *et al.*, 2016). The fish catches have significant positive correlation with the time of catching (catching hour, catching day), this reflect the reality fish decrease nowadays.

V. CONCLUSION

The study showed that, the fluctuation in catches does not have significant correlation with the social aspects, in practice, our results can be used to suggest some fishery policy based on the variables that are significant correlated with fish catch. Training courses for fishing techniques are not important because the fish catches do not relate to fishing experience, instead of this, strictly control illegal fishing gears is urgent duty for the fisheries managers.

ACKNOWLEDGEMENTS

This paper has been partly prepared with the support from the Higher Education Research Promotion and the Thailand's Education Hub for the Southern Region of ASEAN Countries Project Office of the Higher Education Commission. Financial support was granted by the Graduate School, Prince of Songkla University, Thailand. We are grateful to the local people in the households of the study areas for assistance in the field and for contributing and sharing their knowledge about fishing activities.

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APPENDIX H: QUESTIONNAIR SURVEY

FISHERMAN No: …………………………

ADDRESS: ………………………………

PRINCE OF SONGKLA UNIVERSITY

Marine and Coastal Resources Management

FISHING HOUSEHOLD INTERVIEW

PART 1: GENERAL INFORMATION

1. Name: ………………………………………………………………………...
2. Age:
3. Education: ☐ Primary ☐ Secondary ☐ Technical ☐ University ☐ Other
4. Ethnic Composition: ☐ Muslim ☐ Budish ☐ Other
5. Basic information

Contents	Answer
1. Size of boat	
2. Type of boat	
3. Age of boat	
4. Type of fishing gear	
5. What were the traditional practices in the past you have used for catching fish, are they still same?	
6. Number of members in the family?	
7. Duties of each member in the family?	-What grandparents do?.................. - What husband does?................ - What wife does………… - What children does?.......................... Other notes:
8. Years of living this community	
9. Years of fishing	

PART 2: FISHING ACTIVITIES

1. In your community, among people who fish, which are the HIGH season months? **(H)**
   Which months are the LOW season months? **(L)**
   And in which months is there almost no fishing? **(N)**

Jan	**Feb**	**Mar**	**April**	**May**	**Jun**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**

2. Season for fishing, if no fishing, what do you do?

Contents	**Heavy rainy season**				**Dry season**				**Light rainy season**			**Remarks**	
	10	**11**	**12**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	
Days of fishing													
Day without fishing, what do you do?													
Number hours fishing per day													
Species dominant													
Fish amount estimate (kgs)/trip: - Fish - Shrimp - Crab													
Average Size of: - Fish - Shrimp - Crab													
The best month for fishing, why													

Notes:

…………………………………………………………………………………………………

…………………………………………………………………………………………………

………
……………………………………………………………………………………………..

- Do the storms often happen in here? Yes ☐ No ☐
(If yes, which month storm often happen? ……………………………………………………)
- Which year do you remember most about the uncertain weather? ……………………………
- What was happen in that year? how did it effects on your family? What did your family do to improve that situation?
………
……………………….………………………………………………………………………..…………
……………………………………………………………………………………………………..
- Do fishermen have any story/experience about the fishing relate to the weather? ……………
If yes, please tell me about that story/experience …………………………………………….
…………………………………………………………………………………………………….
Note (why increase/decrease), other reasons:
………
………
………
…………………………………………………………………………………
- Is there any impact on developments/restrictions near the lake has any influence in fish catch? (If yes, what is that? How is it effect?
………
……………………………………………………………………………………………
………
……………………………………………………………………………………………
3. What have you done with the changes of fish catches?
- Do you have alternative work? (Yes/no):
+ If yes, what is that work (Industrial farm, cultivation (food), livestock, rural trade, worker part time) or other (give the name of work) ……………………………………...………
…………………………………………………………………………………………………….
+ If no, how can your family afford to cover monthly expenditure?.......................................
…………………………………………………………………………………………………….
- Do you have any difficulties in finding a new job? ……………………………………….
…………………………………………………………………………………………………….
- Do you have intention to change to another work? ……………………………………….

……

4. Are you a member of Fishing Cooperative Association?

Yes ☐ No ☐

(If "yes", what is the benefit when you join Fishing Cooperative Association?)

……

……………………………………………………………………………………………

. ……………………………………………………………………………………………………..

5. Location for fishing (Show the map)

- Mark the location and name of the location of fishing
- Which area in the Lagoon that the best fish catch was found? (Show on the map, and why?)

  ……………………………………………………………………………………….

  ……………………………………………………………………………………….

- How long is the distance from the coast to the fishing ground location that you usually visit?

  ……………………………………………………………………………………….

  ……………………………………………………………………………………….

- Do you have any additional comments?

  ……………………………………………………………………………………………

  ………………………………………………………………………………………

  ………………………………………………………………………………………

6. What threats do fishermen perceive to their continued ability to adapt?

……

……

…………………………………………………………………………………………

7. How about the interest of new generation for fishing?

……

……………………………………………………………………………………………

8. Will you continue or allow your children to do fishing in the future?..................................

Why (yes), why (no)?

……

……

Thank you very much!

END OF INTERVIEW

VITAE

Name **Ha Thi Thu Hue**

Student ID **5910033001**

Educational Attainment

Degree	Name of Institution	Year of Graduation
Master of Economics	Viet Nam University of Commerce	2008
Bachelor of Economics	National Economic University	2003

Scholarship Awards during Enrolment

1. Thailand's Education Hub for Southern Region of ASEAN countries, Prince of Songkla University, 2016-2019 (Grant No: THE-AC 070/2016).
2. Graduate School Dessertation Funding for thesis, Prince of Songkla University, for Doctor of Philosophy 2017.
3. Coastal Oceanography and Climate Change Research Center, Prince of Songkla University 2018

Work – Position and Address

1. Researcher, Institute of Centre for Natural Resource and Environmental Studies, Vietnam National University, Ha Noi, Vietnam, 19 Le Thanh Tong street, Ha Noi, Vietnam

List of Publication and Proceeding

Publications

1. Hue, H. T. T., Pradit, S., Lim, A., Goncalo, C. and Nitiratsuwan. T. 2018. Shrimp and fish catch landing trends in Songkhla lagoon, Thailand during 2003-2016. Applied Ecology and Environmental Research, 16(3): 3061–3078. doi: 10.15666/aeer/1603_30613078.
2. Hue, H. T. T., Pradit, S., Janunee, C., Lim, A., Nitiratsuwan, T. and Goncalo, C. 2018. Physical properties of three Songkhla Lagoon fish species in the lower gulf

of Thailand during and after the monsoon season. Applied Ecology and Environmental Research, 16(5): 6113-6127. doi: 10.15666/aeer/1605_61136127

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Proceeding

1. Hue, H. T. T., Pradit, S., Lim, A., Nitiratsuwan, T., Jualaong, S. and Gocalo. C. A comparative study of Artificial Neural Network, Multiple Adaptive Regression Spline and K-Nearest Neighbors for predicting fish catch landing in Songkhla Lagoon, Thailand. International Conference on Climate Change, Biodiversity, Food Security and Local Knowledge on September 5th, 2018 in Kupang, Indonesia.