Statistical Model for Predicting Fish Fingerling Abundance in the Na Thap River of Southern Thailand

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ชื่อวิทยานิพนธ์ ตัวแบบทางสถิติสำหรับทำนายความอุดมสมบูรณ์ของสัตว์น้ำขนาดนิ้ว ในคลองนาทับ ภาคใต้ของประเทศไทย

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บทคัดย่อ

การศึกษาครั้งนี้มีวัตถุประสงค์เพื่อศึกษารูปแบบการเปลี่ยนแปลงเชิงปริมาณ และหาความสัมพันธ์ระหว่างความอุดมสมบูรณ์ของสัตว์น้ำขนาดนิ้ว กับสถานที่ ฤดูกาล ปริมาณกำลังผลิตสัตว์น้ำ และคุณภาพน้ำบางประการ โดยเก็บรวบรวมตัวอย่าง และตรวจวัดข้อมูลเป็นรายเดือน 10 สถานี ตลอดลำคลองนาทับ ตั้งแต่เดือนมิถุนายน พ.ศ. 2548 จนถึงเดือนตุลาคม พ.ศ. 2558 ทำการแปลงข้อมูลความอุดมสมบูรณ์ของสัตว์น้ำด้วยรากที่สอง เพื่อให้ข้อมูลมีการแจกแจงแบบปรกติ วิเคราะห์ปัจจัยเพื่อแบ่งกลุ่มสัตว์น้ำจำนวน 58 ชนิด และวิเคราะห์สมการถดถอยเชิงเส้นเพื่อหาความสัมพันธ์ระหว่างความอุดมสมบูรณ์ของสัตว์น้ำขนาดนิ้ว กับฤดูกาล สถานที่ ปริมาณกำลังผลิตสัตว์น้ำและคุณภาพน้ำบางชนิด

ผลการวิเคราะห์พบว่าชนิดของสัตว์น้ำขนาดนิ้ว สามารถแบ่งได้เป็น 3 กลุ่ม ตามพื้นที่อยู่อาศัย คือ สัตว์น้ำเค็ม สัตว์น้ำจืดและสัตว์น้ำที่พบได้แพร่หลายทั่วทั้งลำคลอง สัตว์น้ำทั้ง 3 กลุ่มมีความสัมพันธ์กับฤดูกาล สถานที่ ปริมาณกำลังผลิตสัตว์น้ำ และคุณภาพน้ำ ได้แก่ ความเค็ม ปริมาณออกซิเจนที่ละลายน้ำ และความโปร่งแสงอย่างมีนัยสำคัญทางสถิติ และพบว่าช่วงฤดูแล้งกลุ่มสัตว์น้ำเค็ม มีปริมาณเพิ่มขึ้นในช่วงเดือนมกราคมถึงเดือนพฤษภาคม ขณะที่กลุ่มสัตว์น้ำจืดพบมากที่สุดในช่วงฤดูฝน ระหว่างดือนมิถุนายนจนถึงเดือนธันวาคม การค้นพบครั้งนี้ยืนยันได้ว่าการวิเคราะห์ปัจจัยและการวิเคราะห์สมการถดถอยเชิงเส้น สามารถประมาณความอุดมสมบูรณ์ของสัตว์น้ำขนาดนิ้วซึ่งใช้ในการจำแนกและตรวจสอบความอุดมสมบูรณ์ของสัตว์น้ำในคลองนาทับได้ อันจักเป็นองค์ความรู้พื้นฐานที่นำไปประยุกต์ให้มีการจัดการทรัพยากรสัตว์น้ำ และระบบนิเวศทางน้ำได้อย่างมีประสิทธิภาพต่อไป

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Major Program Research Methodology

ABSTRACT

This study aimed to examine pattern variation and find out the association between fish fingerling abundance and season, location, standing crop and some water quality parameters. Data were collected monthly from 10 sampling sites along the Na Thap River from June 2005 to October 2015. Fish fingerling abundance was transformed using square root to maintain normality distribution. Factor analysis was applied to group 58 species of fish. Multiple regression model was used for investigating the association between fish fingerling and month, year, sampling site, standing crop and some water quality parameters. Fish fingerlings were classified by factor analysis into 3 interpretable factors: saltwater, freshwater and ubiquitous species. The results show that month, year, sampling site, standing crop, salinity, dissolved oxygen and transparency were statistically significant associated with fish fingerling abundance. During dry season, the saltwater fish fingerling showed significantly increased from January to May, whereas freshwater fish presented a maximum peak in rainy season from June to December. This finding confirmed that factor analysis and multiple regression analysis can be used for classifying and clustering fish fingerling abundance in established regulation measures for sustaining fish population management.

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Chapter 1

Introduction

1.1 Background

Fish and aquatic animals are valuable sources of protein. Since, the last five decades (1950-2000), the global fish production has grown steadily with the average annual increment rate of food fish supply to 3.2 percent, outpacing world population growth at 1.6 percent. In 1960, the world average per capita apparent fish consumption increased from 9.9 kilograms (kg) to 19.2 kg in the year 2012 (FAO, 2014).

Thailand is one of the top fish producing nations in the world. Fish is the primary source of animal protein for most of Thailand's population, particularly in the coastal and near coastal provinces. During the period 1980-2006, the per capita consumption of fish ranged from 17 kg to 34 kg. In 2006, per capita fish consumption was 33.6 kg, which is relatively high compared to other main animal protein sources such as pork, beef and chicken (FAO, 2009). This reflects the high demand of fish consumption in Thailand. Therefore, management in ecosystem field and monitoring quality and quantity of fish is important for fisheries which add in the multiplication of biodiversity and resource sustainable development.

Fish fingerling defined as a small juvenile stage of fish life cycle that can swim freely and feed themselves (Serns, 1982; Garren *et al*., 2008). The number and quality of fish fingerling are vital component and play important role in the aquatic ecosystem. Hilborn and Walter (1992) reported that number of fish depend on fish birth rate and survival rate. Also, the population of fish can be forecasted which depends on natural migration and fishing rate. Since, the life cycle of fish in each stage such as spawning, growth and mortality occur according to the habitat and period of time. The distribution of fingerling depends on the characteristics of habitat and living environment (Bruno *et al*., 2013). While mortality rate of fingerling is useful parameter for evaluating fish population dynamics in aquatic ecosystem. In addition, the seasonal fluctuation also has an effect on number of fish population (Anderson *et al*., 2004). Moreover, Bruno *et al.* (2013) mentioned that biological and physical factors like water quality, water depth and nutrient content are important factors for determining fish abundance and distribution.

The Na Thap River was selected as the area of this study. Due to there are three aquatic ecosystems including saltwater, brackish and freshwater, and connects the Gulf of Thailand. This river has high biodiversity of fish fingerling. There are many local communities and fishery activities engaging along the Na Thap River such as shrimp farm, fish cage rearing and industrial factories. Those activities may impact life circle of fish abundance for example fishing in spawning season, using small mesh size of fishing net and fishing in sanctuary areas.

Normally, linear regression models, analysis of variance (ANOVA), canonical correlation analysis and ARIMA models are most popular for statistical method used to predict fish fingerling abundance (Green *et al*., 2006; Preciado *et al*., 2006; Bruno *et al*., 2013; Paighambari *et al*., 2017).

This study aimed to investigate the pattern variation and to find out the relationship between fingerling abundance and season, location, standing crop and some water quality of the tropical tidal river.

1.2 Objectives

1.2.1 To investigate the variation of spatial and temporal of fingerling abundance and their distribution in the Na Thap River from 2005 to 2015.
1.2.2 To apply statistical model for identifying and predicting the relationship between fingerling abundance and location, season, standing crop and some water quality parameters.

1.3 Literature review

1.3.1 Effect of standing crop on fish fingerling

Fingerling abundance is the number of fingerlings in juvenile stage that complete free swimmers and can feed themselves in a water column. It does not only describe the number of fingerlings but also explains the size and growth rates (Serns, 1982; Garren *et al.*, 2008). Standing crop usually is a total number of biomass of aquatic animals per unit area at a particular time in weight. Moreover, it is calculated from total catch weight per water area (Fausch *et al.*, 1988).

In the ecosystem, there are many biological and physical factors can be used to estimate fish fingerling abundance. One of such important factors is standing crop (Kerr and Lasenby, 2000). Several studies found that fish fingerling density was positively associated with standing crop (Henderson and Hamilton, 1995; Saheem, *et al.,* 2014). This indicates that there is a corresponding increase in fish fingerling abundance with the increasing of standing crop. In addition, the number of fingerling in aquatic ecosystem in a particular year depends on the matured fish population in the previous year (Hilborn and Walter, 1992).

1.3.2 Effect of environmental factors on fingerling distribution

Investigating the distribution pattern of organism based on habitat characteristics of their living environments were studied worldwide (Roberts and Ormond, 1987). Generally, there are many factors that affect the variation of fish fingerling abundance in number of individuals. These factors include habitat, nutrient content and seasonal variations. Saheem *et al*. (2014) and Olukolajo and Oluwaseun (2008), documented that standing crop and fingerling abundance in tropical freshwater were higher during rainy seasons whereas saltwater fish fingerlings was abundant in the dry season. Moreover, environmental variables and seasonal fluctuations have effects on community distribution and diversity species of fish fingerling (Bruno *et al.*, 2013; Mohanty *et al*., 2015). This implied that fish fingerlings can live and survive in a particularly area that supports their environments. In addition, different species at different stages of fish life cycle live in different habitats (Oyugi *et al.*, 2014). For example in case of mangrove forest area known as a high nutrient rich area, it contains a numerous of zooplankton and phytoplankton. Therefore, it is appropriate habitat for fish larvae to be a nursery and spawning ground.

1.3.3 Effect of water qualities on fingerling distribution

One of the most important environmental factors for fish fingerlings to survive is water quality. These parameters include dissolved oxygen, carbon-dioxide, ammonia, nitrate, nitrite, pH, chlorine, and other characteristics. These water quality parameters cannot be ignored for maintaining quality of water for other living organisms to produce sufficient food for fish (Bhatnagar, 2013). In tropical zone, the optimal water temperature for fish ranges between 25°C and 35°C. High water temperature has strong association with feeding rates and metabolism of fish, while low water temperature maybe a cause of decreasing of metabolism and growth of fish (Lessard and Hayes, 2003). Salinity is important for indicating saline concentration of a water body. Fish assemblage can be classified by wide range of salinity. In addition, salinity has an effect on growth, survival and pattern distribution of fish (Love *et al*., 2008; Abowei, 2010; Emmanuel and Chukwu, 2010). Dissolved oxygen is amount of free oxygen in natural water body. The optimal dissolved oxygen for aquatic animals ranges between 4-5 mg/L. A low level of dissolved oxygen is the most common water quality problem. Even though the fish may not die directly from low oxygen condition, stress from such conditions often lowers resistance to diseases (Clark, 1996; Abowei, 2010). The optimal pH (6-8) is suitable for living organisms and pH can control the activity of living organisms in the water (Duangsawasdi and Somsiri, 1985; Kochasaney, 1993). The level of turbidity has effect on feeding and migration of fish fingerling (Kaweeka, 1980). Nitrogen and phosphorus are essential nutrients and have effects on living organisms (Clark, 1996).

1.3.4 Statistical methods

Many statistical methods are available for classifying and estimating fish fingerling abundance. Tondoto *et al.* (2010), used log (x+1) transformed for fish fingerling abundance, then the principal component analysis (PCA) was used to reduce the multi-dimensionality of fish fingerling species based on the ecological characteristics.

Factor analysis not only can be used for categorizing fish fingerling species but it also can be used to grouped water qualities in natural water bodies. (Lueangthuwapranit, *et* *al.*, 2011). However, the result from these methods should be related to the principle of ecology.

For time series ecological data set, dynamic factor analysis is used to evaluate these type of data (Zuur *et al.*, 2003). Jorgensen (2016) employed autocorrelation to fit the time series model to characterize diversity among fingerling abundance.

Transformed data were used to adjust normality distribution of the data. There are many methods of transforming fish fingerling data such as arcsin-square root or log (x+1) or square-root transformation, it depends on the ability to reduce the skewness of data by each method (Zar, 1984; Tondoto *et al.*, 2010; Saheem *et al.*, 2014). Moreover, correlation and regression analysis were carried out to find the relationship between fish fingerling abundance and environmental conditions (abiotic including water temperature, dissolved oxygen, pH and transparency and biotic is zooplankton factors) (Tondoto *et al.*, 2010). Whereas, Paighambari *et al.* (2017) used canonical correlation analysis (CCA) to investigate the association between fish fingerling abundance with temperature, salinity, dissolved oxygen and water transparency including 19 families in all sampling sites of 4 seasons. Since, CCA is used when dependent and independent variables are more than 1, this method is similar to multivariate analysis (Thomson, 1984). It can be concluded that each method is appropriate for each type of data set (Venugopalan and Srinath, 1998).

1.4 Scope of the research

This study applied the appropriate statistical method to analyze the pattern variation of fish fingerling abundance. Data were obtained from Electricity Generation Authority of Thailand (EGAT). Samples were collected from June 2005 to October 2015. The information on fish fingerling abundance, month, year, sampling site, standing crop and water quality parameters were acquired. There were 10 sampling sites along the Na Thap River. Total observed record was 1,220. Factor analysis was used to group the different species of fish fingerling. The multiple regression analysis method was used to find out the relationship between fish fingerling abundance and season, location, standing crop and some water qualities parameters.

Chapter 2

Methodology

2.1 Study site

The study area is located in the Na Thap River at Chana district in Songkhla province, Southern Thailand. The river originates from the mountain bordered between Thailand and Malaysia and flows into the Gulf of Thailand. The length of the river is around 26.5 kilometers.

There are three aquatic ecosystems in the Na Thap River, the first is downstream, this part is saltwater which covered 10 kilometers in length and connects the Gulf of Thailand. This area is the main source for fishing by the villagers, settlement, fisheries processing activities, shrimp farms and fish cage. The middle part of the river is brackish water ecosystem which is 9 kilometers in length, surrounded by mangrove forest, cajuput forest and several agro processing factories. The upstream of the river is freshwater with a length of 7.5 kilometers. Apart from households use, this freshwater has been utilized in many activities such as the Chana thermal power plant, rice field and other agricultural projects. The area for this study is shown in Figure 2.1 and the data were collected from 10 sampling sites along the river as shown in Table 2.1.

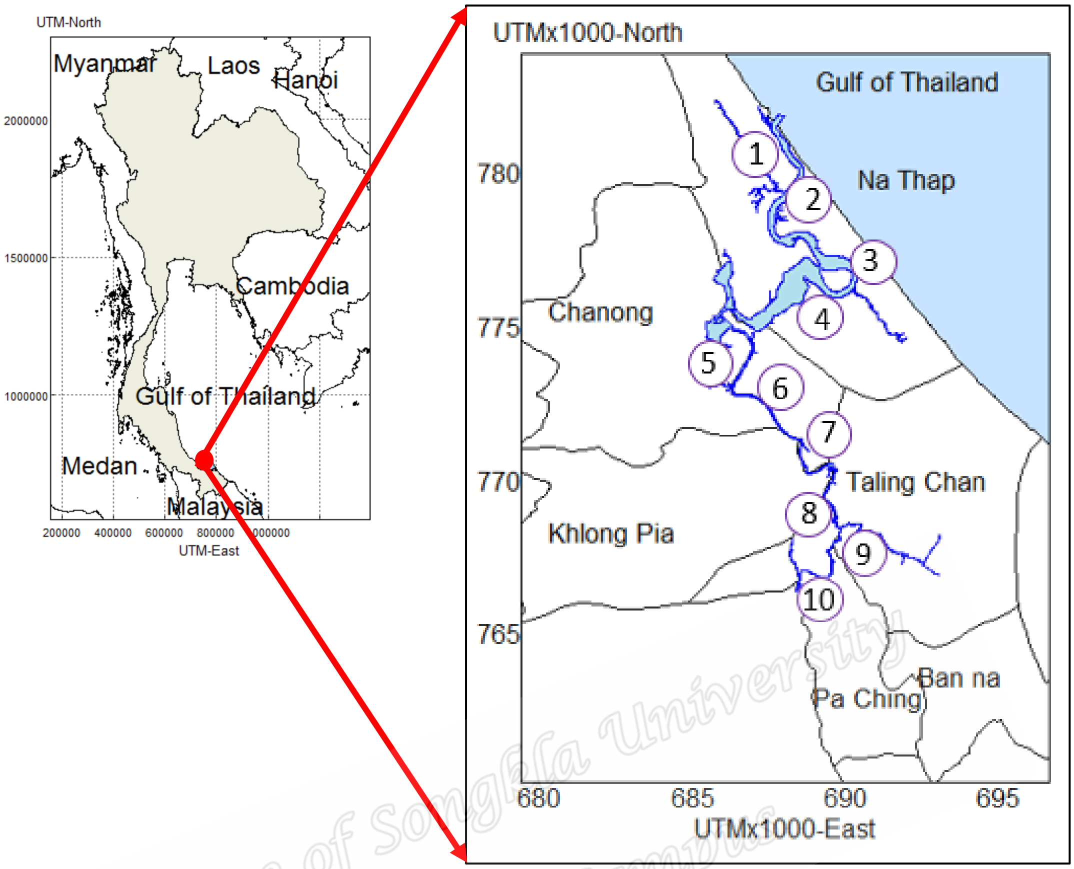

Figure 2.1 Map of the Na Thap River and 10 sampling sites

Table 2.1 Ten sampling sites along the Na Thap River

Station	UTM (East, North)	Location
1. Ban Pak Bang	687333.34, 781940.43	M.2, Ban Pak Bang, Na Thap, Na Thap sub-district.
2. Ban Khlong Kha	687698.98, 779581.09	M.1, Ban Khlong Kla, Na Thap sub-district.
3. Ban Tha Khlong	688715.59, 777913.24	M.4, Ban Tha Khlong, Na Thap sub-district.
4. Ban Ma Ngon	688958.14, 777393.73	M.5, Ban Ma Ngon, Na Thap sub-district.
5. Ban Thung Kruat	685296.28, 774982.39	M.7, Ban Thung Kruat, Chanong sub-district.
6. Ban Tha Khlong Chanong	687386.30, 772124. 37	M.6, Ban Tha Khlong, Chanong sub-district.
7. Ban Kuan Kao Chang	688652.55, 770549.55	M.6, Ban Khuan Hua Chang, Khlong Pia sub-district.
8. Khlong Bang Ped (Outflow pump)	688978.82, 769621.85	M.6, Ban Kuan Hua Chang, Khlong Pia sub-district.
9. Khlong Bang Ped (Inflow pump)	688293.97, 767327.67	M.1, Ban Kok Muang, Pa Ching sub-district.
10. Khlong Pho Ma	689085.82,769537.35	M.1, Ban Pa Ching, Pa Ching sub-district.

2.2 Study design and data source

Data were collected from June 2005 to October 2015. Details of 58 different species of fish are shown in Table 2.3. Ten sampling sites were set up along the Na Thap River which covers three aquatic ecosystems: saltwater, brackish and freshwater. Monthly data were collected including fish fingerling abundance by month, year, sampling site, standing crop and quality of water. The surrounding net was used to collect fish fingerling. The sampling area was calculated per 200 square meters (m^2) by 1-meter depth of water. Fish fingerling in each species were classified in taxa following Rainboth (1996) and Taki (1974) and recorded in terms of individuals per cubic meter (individuals/m^3).

Standing crop samples were collected by purse seine nets. Furthermore, crop weight was calculated in grams/1,000 m^2 for each species. Standard methods (APHA, AWWA and WEF, 1998) were used to analyze the water qualities.

2.3 Variables

The outcome of this study is fish fingerling abundance (individuals/m^3).

Determinants of this study are month, year, sampling site, standing crop and water quality parameters namely salinity, transparency, total suspended solids (TSS), dissolved oxygen (DO), pH, nitrate-nitrogen (NO_3), water temperature, turbidity, phosphate-phosphorus (PO_4) and ammonia-nitrogen (NH_3).

Table 2.2 Fish species commonly found in Na Thap River during study period

Common Name	Scientific Name	Family
Sumatran tiger barb	*Puntius Partipentazona*	Cyprinidae
Minnow	*Trigonostigma spp.*	Cyprinidae
Black spotted long tom	*Strongylurus strongylura*	Belonidae
Shortnose ponyfish	*Leiognathus spp.*	Leiognathidae
Common glassfish	*Ambassis ambassis*	Ambassidae
Anchovy	*Stolephorus indicus*	Engraulidae
Dwarf goby	*Brachygobius sp.*	Gobiidae
Green pufferfish	*Tetraodon fluviatilis*	Tetraodon
Small-eye silverside	*Rasbora argyrotaenia*	Cyprinidae
Giant freshwater prawn	*Macrobrachium rosenbergii*	Palaemonidae
Lanchester's freshwater prawn	*Macrobrachium lanchesteri*	Palaemonoidae
Bagrid catfish	*Bagridae*	Catfish
Silver Sillago	*Sillago sihama*	Sillaginidae
Mullet	*Liza sp.*	Mugilidae
White-spotted spinefoot	*Siganus canaliculatus*	Siganidae
Spotted scat	*Scatophagus argus*	Scatophagidae
Silver biddy	*Gerres filamentosus*	Gerreidae
Java tilapia	*Oreochromis mossambicus*	Cichlidae
White sardine	*Sardinella sp.*	Clupeidae
Johns snapper	*Lutjanus johnii*	Lutjanidae
Crescent grunter	*Therapon jarbua*	Teraponidae
Yellow pike-conger	*Congresox talabon*	Muraenesocidae
Mud skipper	*Periophthalmus sp.*	Gobiidae
Tongue sole	*Cynoglossus sp.*	Cynoglossidae
Indo pacific mackerel	*Rastrelliger brachysoma*	Scombridae
Greasy grouper	*Epinephelus sp.*	Serranidae
Caragobiopsis geomys	*Parapocryptes sp.*	Gobiidae
Tiger-toothed croaker	*Otolithes ruber*	Sciaenidae
Yellow stripe trevally	*Selaroides leptolepis*	Carangidae
Starry triggerfish	*Triacanthus*	Balistidae
Black tiger shrimp	*Penaeus monodon*	Penaeidae
Green tiger prawn	*Penaeus semisulcatus*	Penaeidae
Banana prawn	*Penaeus merguiensis*	Penaeidae
Stork shrimp	*Metapenaeus tenuipes*	Penaeidae
Greasy-back shrimp	*Metapenaeus ensis*	Aristeidae
Acetes	*Acetes sp.*	Sergestidae
Mantis shrimp	*Cloridopsis dubia*	Squillidae
Indian squid	*Photololigo duvauceli*	Ocypodidae

Common Name	Scientific Name	Family
Octopus	*Octopus sp.*	Octopodidae
Painted stone crab	*Matuta planipes*	Grapsidae
Blue swimming crab	*Portunus pelagicus*	Portunidae
Mud crab	*Scylla serrata*	Portunidae
Oceanic paddler crab	*Neodorippe callida*	Dorippidae
Snakehead fish	*Channa striata*	Channidae
Snakeskin gourami	*Trichogaster pectoralis*	Osphronemidae
Three spot gourami	*Trichogaster sp.*	Osphronemidae
Common climbing perch	*Anabas testudineus*	Anabantidae
Walking catfish	*Clarias batrachus*	Clariidae
Common silver barb	*Barbonymus gonionotus*	Cyprinidae
Schwanenfeld's tinfoil barb	*Barbonymus schwanenfeldii*	Cyprinidae
Hard-lipped barb	*Osteochilus hasseltii*	Cyprinidae
Grey featherback	*Notopterus notopterus*	Notopteridae
Jellyfish	*Aurelia spp.*	Ulmaridae
Croaking gourami	*Trichopsis vittata*	Osphronemidae
Transverse-bar barb	*Hampala macrolepidota*	Cyprinidae
Siamese glassfish	*Parambassis siamensis*	Ambassidae
Catopra	*Pristolepis fasciata*	Pristolepididae
Marine shrimp larvae	-	

2.4 Statistical analysis

The monthly data from June 2005 to October 2015 consist of 12 months, 10 sampling sites and 11 years, the total are 1,220 observations. All of water quality parameters were changed from continuous variables to the categorical variables. The numbers of categories of each parameters are shown in Table 2.3. Fifty eight different species of fish fingerling were classified into 3 factors based on habitat characteristics by using factor analysis. Standing crop were classified into 3 factors the same as fish fingerling species. High loading scores were grouped into the same factor. Sum of fingerlings in each factor of fingerling species was 36, 14 for freshwater and 8 for ubiquitous fingerling, respectively. The range of standing crop and water quality parameters were created and calculated by distribution of each parameter.

This study focused on abundance of fish fingerling only. Fingerling with zero count was omitted before fitting the model by using multiple regression analysis. All steps of data analysis are shown in Figure 2.2. Figure 2.3 shows the path diagram of this study. Each statistical method used in this study is described below.

The square root transformation was used to transform fish fingerling to follow the normality distribution to reduce the positive skewness. Pearson's correlation was calculated to measure the correlation between each pair of fish fingerling species.

Factor analysis was used to reduce the number of variables into smaller groups. The high association within group must be greater than association between other groups. For this study, factor analysis was used to classify number of species of fish fingerling from 58 different species to 3 factors based on maximum likelihood method. The Promax rotation method was applied to allow for the correlation between factors. Factor analysis provided the factor loading scores in each species of fingerling abundance. High loading scores were grouped into the same factor. After the appropriate numbers of factor were obtained, sum of each species of fish fingerling in each factor were calculated according to month, year and sampling site.

Multiple regression was used to determine the relationship between fingerling abundance and determinants. The multiple regression model expressed as

$$\sqrt{y} = b_0 + \sum_{i=1}^{k} b_i x_i + \varepsilon$$

Where $\sqrt{y}$ the outcome of the study with square root transformation, b_0 is the intercept, b_i are the regression coefficient in each independent variable, x_i are independent variables (month, year, sampling site, standing crop and some water quality) from 1, 2, 3,…..,*k* and ε is error term. After fitting the linear model, the normality assumption of residuals was examined. The goodness of fit was determined by r-square. The seasonal effect was adjusted by subtracting fitted values with observed values and then the mean of fingerling abundance was added back to reduce the residuals autocorrelation. The model was refitted again.

Sum contrasts (Venables and Ripley, 2002; Tongkumchum and McNeil, 2009) was used and confidence intervals were calculated for comparing the adjusted fingerling abundance within each factor with the overall mean. All of the statistical analysis and graphs were created by using R program (The R Foundation, 2009).

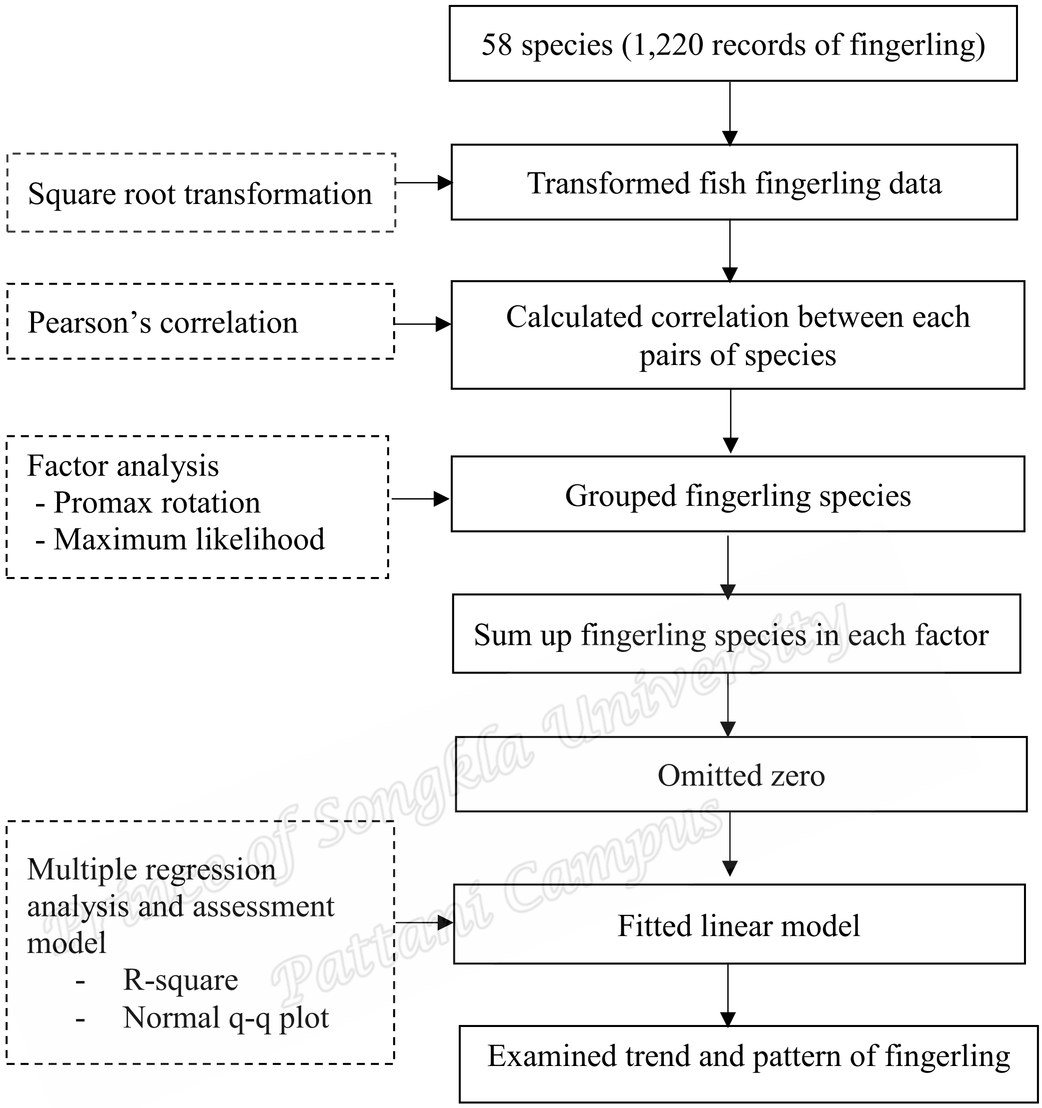

Figure 2.2 Data analysis process for this study

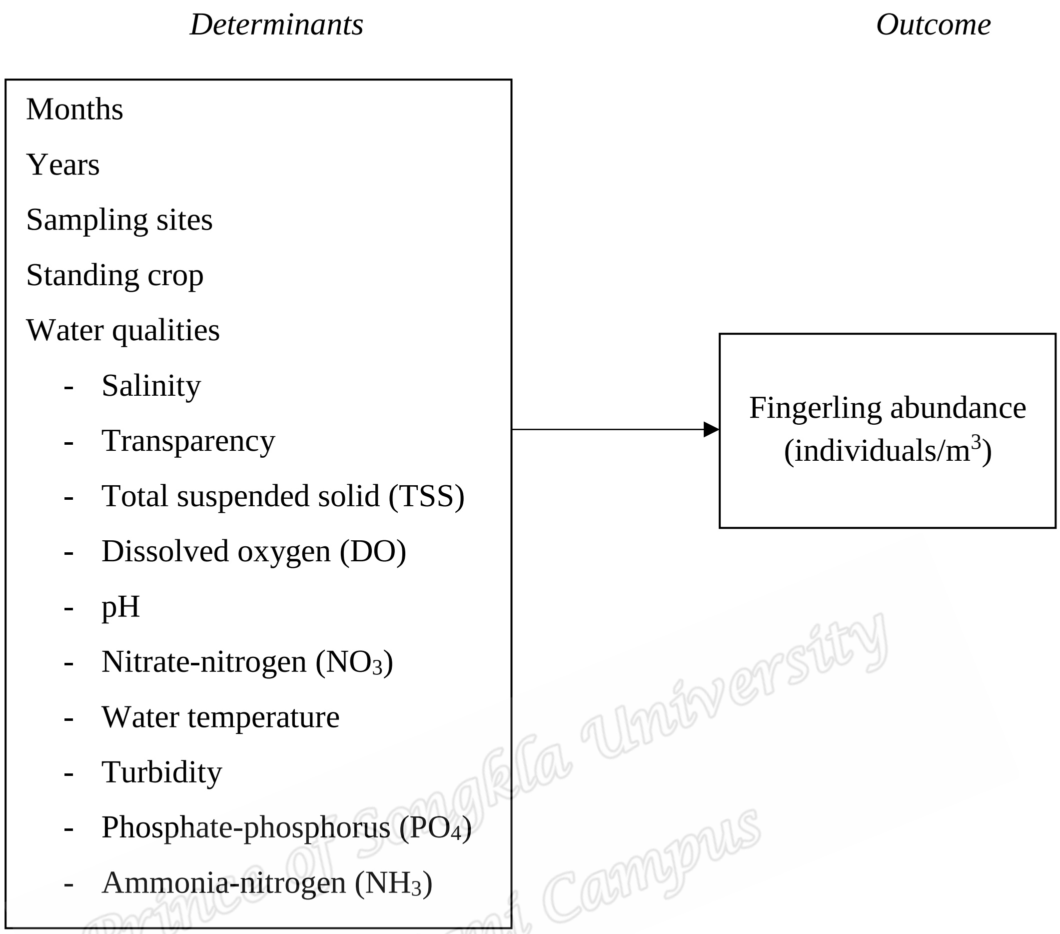

Figure 2.3 Path diagram for this study

Table 2.3 Data structure

Variables	Unit	Description
Fish fingerling	Individuals/m^3	-
Month	-	January, February,…, December
Year	-	2005, 2006,…2015
Sampling site	-	1, 2,…, 10
Standing crop	Gram/1,000 m^2	
Saltwater fish		1) 0-3,400 2) 3,401-6,800, 3) 6,801-10,200 4) 10,201-13,600 5) 13,600+
Ubiquitous fish		1) 0-1,400 2) 1,401-2,800, 3) 2,801-4,200 4) 4,201-5,600 5) 5,601+
Freshwater fish		1) 0-720 2) 721-1,440 3) 1,441-2,160 4) 2,161-2,880 5) 2,881+
Salinity	Parts per thousand (ppt)	1) 0-13 2) 14-26 3) 27+
TSS	Milligram per liter (mg/L)	1) 0-61.9 2) 62-123.9 3) 124+
Trans	Centimeter (cm)	1) 0-74 2) 75-149 3) 150-223 4) 224+
DO	(mg/L)	1) 0-3 2) 4-7 3) 8+
pH	-	1) 0-4.9 2) 5+
NO_3	(mg/L)	1) 0-0.49 2) 0.5+
Water Temperature	Celsius	1) 0-11.9 2) 12-23.9 3) 24+
Turbidity	Nephelometric turbidity unit (NTU)	1) 0-31.5 2) 31.6-63 3) 64+
PO_4	(mg/L)	1) 0-0.179 2) 0.18+
NH_3	(mg/L)	1) 0-0.369 2) 0.37-0.739 3) 0.74+

Chapter 3

Results

3.1 Preliminary results

The normal Q-Q plots of fish fingerling abundance of each species after square root transformation are shown in Figure 3.1. The circle with several colors shows the different species with different groups. Brown, blue and yellow colors represent fingerling abundance in saltwater, freshwater and ubiquitous respectively. The size of circles shows the average abundance of each species. The Q-Q plot (diagonal line) denotes normality distribution. The blue bar plot shows the prevalence in each species based on its common name. Last two sub-figures explain the symbol of graph. Figure 3.1 suggests that more than half of the species of fingerling have normal distribution after using square root transformation.

Figure 3.2 shows the correlation matrix of 58 difference species of fish fingerling abundance. Grey, red and yellow color represent positive correlation, negative correlation and correlation of itself based on its common name, respectively. This figure shows three groups by the size of square; biggest, medium and smallest group which represent the saltwater, freshwater and ubiquitous fingerling abundance.

The loading scores greater than 0.1 from factor analysis are shown in Table 3.1. The different factors have been highlighted; the first factor included 36 species prefer to saltwater, the second include 14 species prefer to freshwater and the last one included 8 species of fish prefer to ubiquitous fingerling. Finally, the species of the fingerling were grouped into factors.

The boxplot in Figure 3.3 shows the distribution of fingerling abundance before and after transformation by taking square root transformation.

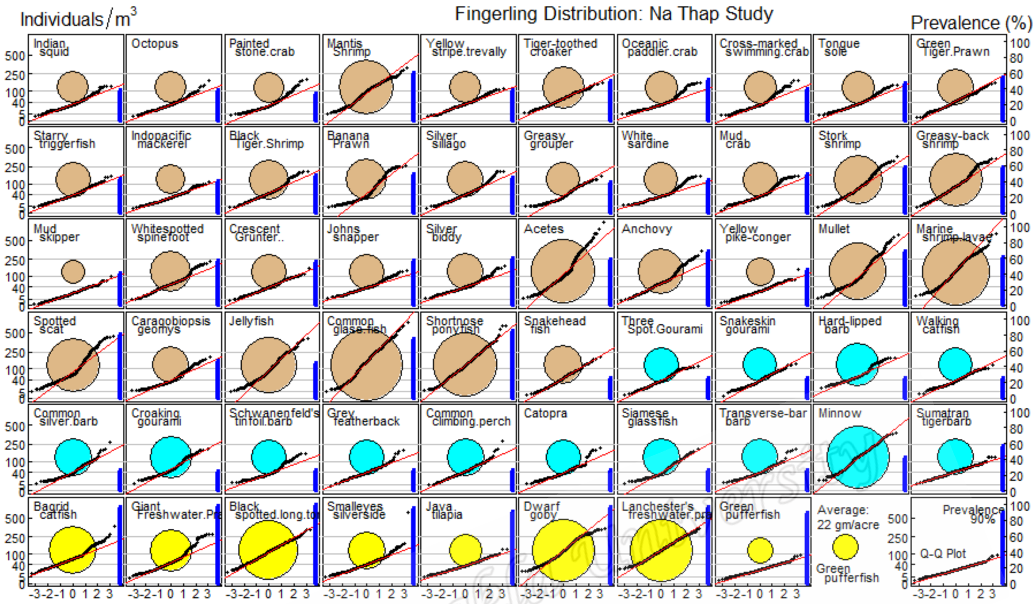

Figure 3.1 The abundance and distribution of fingerling during study period

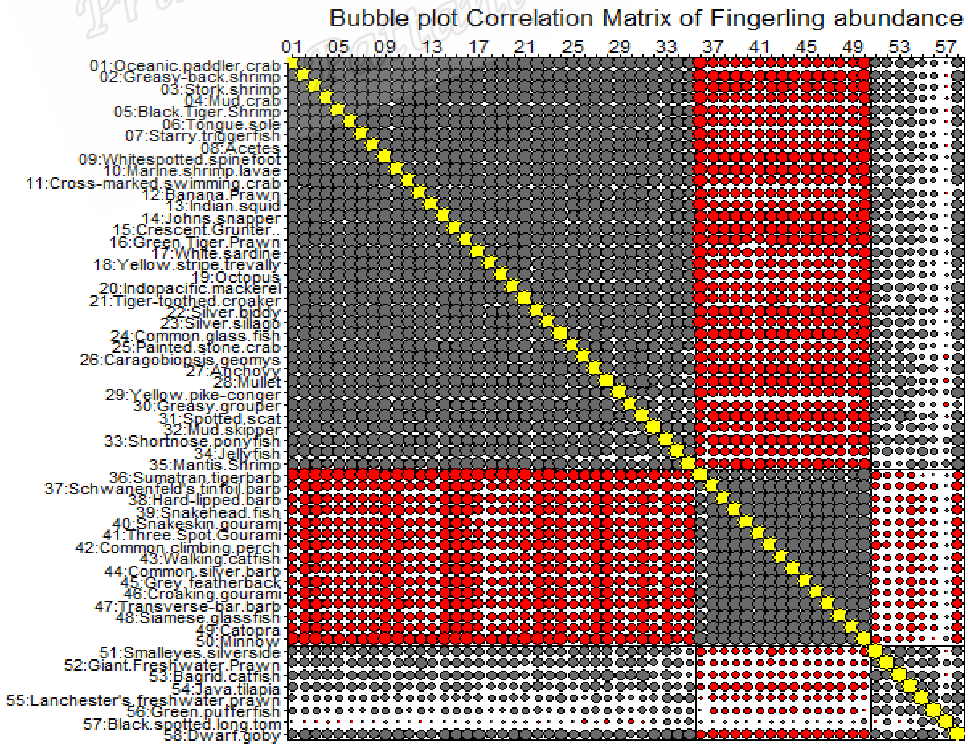

Figure 3.2 Bubble plot correlation matrix of fish fingerling abundance

Table 3.1 Loading score greater than 0.1 by using factor analysis including 58 species

Common name	Factor 1	Factor 2	Factor 3
Sumatran tiger barb	-0.883		0.282
Short nose pony fish	0.377	-0.267	0.327
Common glass fish	0.630	-0.265	0.110
Anchovy	0.593	-0.170	0.221
Spotted.scat	0.519	-0.223	0.185
Silver sillago	0.938		-0.103
Mullet	0.647	-0.190	
White spotted spine foot	0.807	-0.126	
Silver biddy	0.697	-0.211	
White sardine	0.972	0.106	
Johns snapper	0.788	-0.134	
Crescent Grunter	0.825	-0.121	
Yellow pike conger	0.817		
Mud skipper	0.727		
Tongue sole	0.994		
Indo-pacific mackerel	0.957		
Greasy grouper	0.877		
Caragobiopsis geomys	0.854		
Tiger toothed croaker	0.834		
Yellow stripe trevally	1.012	0.124	
Starry triggerfish	0.986		
Black tiger shrimp	0.969		
Green tiger prawn	0.845		
Banana prawn	0.931		
Stork shrimp	0.898		
Greasy back shrimp	0.881		
Acetes	0.861		
Indian squid	1.020	0.151	
Mantis shrimp	0.479		
Painted stone crab	0.992	0.180	
Cross-marked swimming crab	1.014	0.141	
Mud crab	0.973		
Oceanic paddler crab	0.945		
Jellyfish	0.695		
Marine shrimp larvae	0.800	-0.122	

Common name	Factor 1	Factor 2	Factor 3
Snakehead fish		0.948	
Snakeskin gourami		0.976	
Three Spot Gourami		0.980	
Common climbing perch		0.973	
Walking catfish		0.981	
Common silver barb		0.981	
Schwanenfeld’s tinfoil barb		0.984	
Hard-lipped barb		0.986	
Grey featherback		0.978	
Croaking gourami		0.982	
Transverse-bar barb		0.977	
Siamese glassfish		0.973	
Catopra		0.972	
Minnow	-0.527	0.561	0.215
Black spotted long tom	-0.154	0.191	0.491
Dwarf goby	0.141	-0.105	0.627
Smalleye silverside	0.175		0.511
Giant Freshwater Prawn	0.277	0.193	0.539
Lanchester's freshwater prawn	-0.226		0.834
Bagrid catfish	0.188		0.545
Green pufferfish	-0.250		0.876
Java tilapia		-0.15	0.598

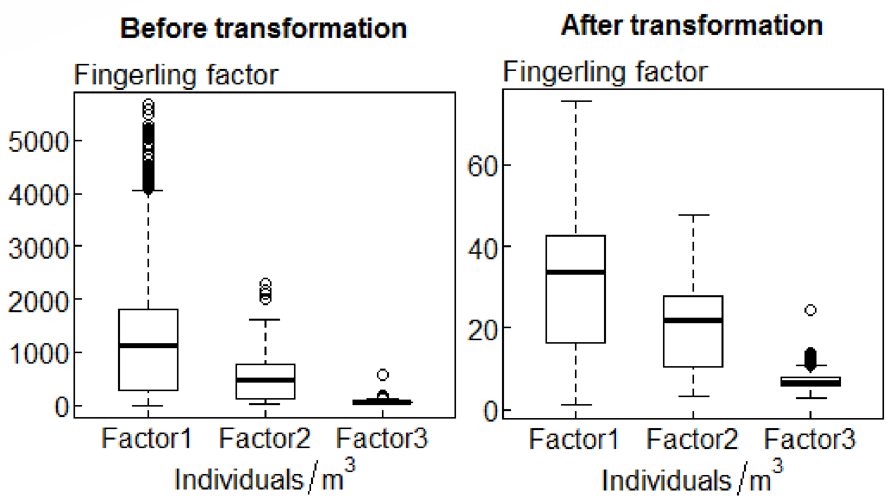

Figure 3.3 Boxplot showing fingerling abundance before and after transformation

3.2 Model fitting

In this study, linear regression analysis was used to find the association between fish fingerling and determinants. Backward elimination method was applied to select the best model. The seasonal adjustment was used to reduce the residuals autocorrelation for saltwater and ubiquitous fingerling model. The coefficients, standard errors and p-values were obtained from the multiple regression analysis. Table 3.2, Table 3.3 and Table 3.4 show the results from multiple linear regression model using sum contrasts from saltwater, freshwater and ubiquitous fingerling abundance, respectively.

The results (Table 3.2, Table 3.3 and Table 3.4) show the positive constants for saltwater, freshwater and ubiquitous fingerling. Table 3.2 indicates that the first half of the year had a positive relationship with fingerling abundance compare to other months of the year except in January. These results contrast with those occurred in freshwater fingerling abundance, which the first half of the year had a negative relationship with fingerling abundance. Negative coefficient means negatively relationship with the fingerling abundance. The highest negative relationship of ubiquitous fingerling was found in December follow by October, November, June, July and May.

Coefficients, standard errors and p-values of those three groups of fish fingerling abundance had a negative relationship from 2005 to 2011 whereas a positive relationship presented from 2012 to 2015. Apart from 2005, there was positive relationship in the ubiquitous fingerling.

The coefficients of saltwater and ubiquitous fingerling have the same pattern based on sampling sites with a negative relationship from site 6 until site 10. Hence, it denotes that fingerling at site 6 to site 10 had negative relationship with fingerling abundance. Freshwater fingerling had the highest negative relationship with fingerling abundance at site 5. In contrast, site 7 had the lowest fingerling abundance.

The results show negative relationship for saltwater fingerling abundance with standing crop where the abundance was higher than 6,801 grams/m^2, whereas the abundance was lower than those hold a positive relationship. Salinity ranged between 0-13 ppt showed negative relationship with saltwater fish fingerling, while the salinity more than 13 ppt hold a positive.

The water transparency that ranging lower than 150 cm showed positive relationship for freshwater fingerling abundance, but when water transparency was higher than 149 cm showed negative relationship presented. Likewise, the ubiquitous fingerling, standing crop showed negative relationship with fingerling abundance except standing crop which ranged between 2,161-2,880 grams/m^2 with positive relationship occurred. Dissolved oxygen greater than 4 mg/L had negative relationship with ubiquitous fingerling whereas lower than 3 mg/L had positive relationship with fingerling abundance.

Table 3.2 Coefficients, standard errors and p-values of saltwater fingerling from multiple linear regression model based on sum contrasts

Characteristics	Coefficients	Standard errors	P-values
Constant	7.54	0.02	0.00
Months			
January	-0.03	0.02	0.10
February	0.11	0.02	0.00
March	0.17	0.02	0.00
April	0.22	0.02	0.00
May	0.17	0.02	0.00
June	0.04	0.01	0.00
July	-0.01	0.02	0.62
August	-0.05	0.01	0.00
September	-0.09	0.02	0.00
October	-0.10	0.02	0.00
November	-0.19	0.02	0.00
December	-0.25	0.02	0.00
Years			
2005	-0.02	0.03	0.50
2006	-0.08	0.02	0.00
2007	-0.05	0.02	0.00
2008	-0.06	0.01	0.00
2009	-0.03	0.01	0.03
2010	-0.16	0.01	0.00
2011	-0.21	0.02	0.00
2012	0.04	0.02	0.02
2013	0.14	0.02	0.00
2014	0.19	0.02	0.00
2015	0.25	0.02	0.00
Sites			
Site 1	0.37	0.02	0.00
Site 2	0.37	0.02	0.00
Site 3	0.35	0.02	0.00
Site 4	0.29	0.02	0.00
Site 5	0.10	0.01	0.00
Site 6	-0.10	0.02	0.00
Site 7	-0.23	0.02	0.00
Site 8	-0.34	0.02	0.00

Characteristics	Coefficients	Standard errors	P-values
Site 9	-0.35	0.02	0.00
Site 10	-0.46	0.06	0.00
Standing crop (grams/m^2)			
1) 0-3,400	0.17	0.03	0.00
2) 3,401-6,800	0.12	0.02	0.00
3) 6,801-10,200	-0.09	0.02	0.00
4) 10,201-13,600	-0.06	0.04	0.17
5) 13,601+	-0.14	0.07	0.07
Salinity (ppt)			
1) 0-13	-0.03	0.07	0.00
2) 14-26	0.01	0.01	0.03
3) 27+	0.02	0.01	0.07

Table 3.3 Coefficients, standard errors and p-values of freshwater fingerling from multiple linear regression model based on sum contrasts

Characteristics	Coefficients	Standard errors	P-values
Constant	14.51	0.49	0.00
Months			
January	-1.75	0.57	0.00
February	-1.63	0.57	0.00
March	-2.88	0.58	0.00
April	-4.60	0.57	0.00
May	-2.04	0.56	0.00
June	-0.02	0.51	0.96
July	0.91	0.52	0.08
August	1.66	0.51	0.00
September	2.31	0.50	0.00
October	1.94	0.50	0.00
November	2.68	0.58	0.00
December	3.42	0.56	0.00
Years			
2005	-1.45	0.78	0.06
2006	-2.37	0.59	0.00
2007	-2.10	0.53	0.00
2008	-3.46	0.51	0.00

Characteristics	Coefficients	Standard errors	P-values
2009	-3.40	0.52	0.00
2010	-4.91	0.52	0.00
2011	-4.05	0.51	0.00
2012	2.47	0.49	0.00
2013	4.92	0.47	0.00
2014	6.05	0.51	0.00
2015	8.29	0.54	0.00
Sites			
Site 5	-13.81	0.82	0.00
Site 6	-10.64	0.64	0.00
Site 7	-6.06	0.38	0.00
Site 8	11.14	0.37	0.00
Site 9	6.53	0.36	0.00
Site 10	12.85	0.36	0.00
Transparency (cm)			
1) 0-74	1.32	0.51	0.01
2) 75-149	0.15	0.50	0.76
3) 150-223	-1.19	0.56	0.04
4) 224+	-0.29	1.27	0.82

Table 3.4 Coefficients, standard errors and p-values of ubiquitous fingerling from multiple linear regression model based on sum contrasts

Characteristics	Coefficients	Standard errors	P-values
Constant	6.13	0.04	0.00
Months			
January	0.01	0.02	0.75
February	0.05	0.02	0.01
March	0.07	0.02	0.00
April	0.03	0.02	0.11
May	-0.01	0.02	0.96
June	-0.04	0.02	0.03
July	-0.04	0.02	0.04
August	0.05	0.02	0.00
September	0.03	0.02	0.09
October	-0.05	0.02	0.00
November	-0.05	0.02	0.00
December	-0.06	0.02	0.00

Characteristics	Coefficients	Coefficients	P-values
Years			
2005	0.01	0.03	0.87
2006	-0.13	0.02	0.00
2007	-0.08	0.02	0.00
2008	-0.10	0.02	0.00
2009	-0.02	0.02	0.14
2010	-0.17	0.02	0.00
2011	-0.15		
2012	0.08		
2013	0.16	0.02	0.00
2014	0.23	0.02	0.00
2015	0.18	0.02	0.00
Sites			
Site 1	0.10	0.02	0.00
Site 2	0.08	0.02	0.00
Site 3	0.13	0.02	0.00
Site 4	0.09	0.02	0.00
Site 5	0.04	0.02	0.02
Site 6	-0.04	0.02	0.01
Site 7	-0.07	0.02	0.00
Site 8	-0.02	0.02	0.13
Site 9	-0.11	0.02	0.00
Site 10	-0.19	0.02	0.00
Standing crop (grams/m^2)			
1) 0-720	-0.13	0.03	0.00
2) 721-1440	-0.05	0.03	0.13
3) 1441-2160	-0.13	0.04	0.00
4) 2161-2880	0.40	0.12	0.00
5) 2881+	-0.09	0.05	0.06
Dissolved oxygen (mg/L)			
1) 0-3	0.04	0.01	0.00
2) 4-7	-0.02	0.01	0.77
3) 8+	-0.04	0.02	0.02

After the linear regression model was fitted, normal Q-Q plot of residuals was checked for the normality assumption. The normal Q-Q plot of studentized residuals in different aquatic ecosystem and adjusted r-square are shown in the Figure 3.4. The results suggest that the Q-Q plot of saltwater and freshwater have better fit than ubiquitous fingerling. Most of the residuals lie on the diagonal line except some values at the extremes of the distribution especially, for ubiquitous fingerling has long tailed residuals. Since the normal distribution of residuals of ubiquitous fingerling was not satisfied, 2 species of fish fingerling were omitted as shown in bottom-right panel of Figure 3.4. The model of saltwater fingerling has the highest adjusted r-square while the model of ubiquitous fingerling abundance had the lowest adjusted r-square.

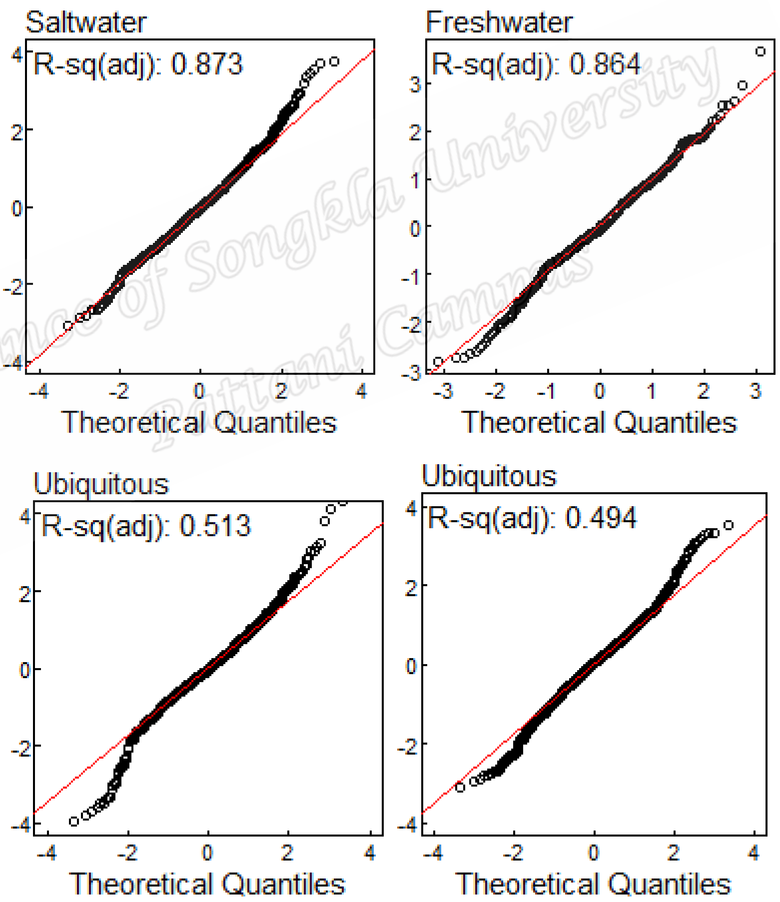

Figure 3.4 Normal Q-Q plots of studentized residuals for saltwater, freshwater and ubiquitous fingerling before and after omitting two species from the linear regression model

After model diagnosis, 95% confidence intervals of fish fingerling abundance of three aquatic ecosystems are shown in Figure 3.6. X-axis shows the variables which were significant with fish fingerling abundance including month referring as J = January, F = February, ..., D = December, year starting from 2005 to 2015, ten sampling sites from 1, 2, 3,..., 10, standing crop, salinity, dissolved oxygen and transparency including 5, 3, 3, 4 groups, respectively. Y-axis shows the fish fingerling abundance in each three aquatic ecosystems. Month, year and sampling site were significantly associated with all three aquatic ecosystems, whereas, standing crop and salinity shows statistically significant with saltwater fish fingerling abundance. Standing crop and DO (dissolved oxygen) has significant effect to ubiquitous fingerling abundance. Meanwhile, only transparency was significantly associated with freshwater fingerling abundance.

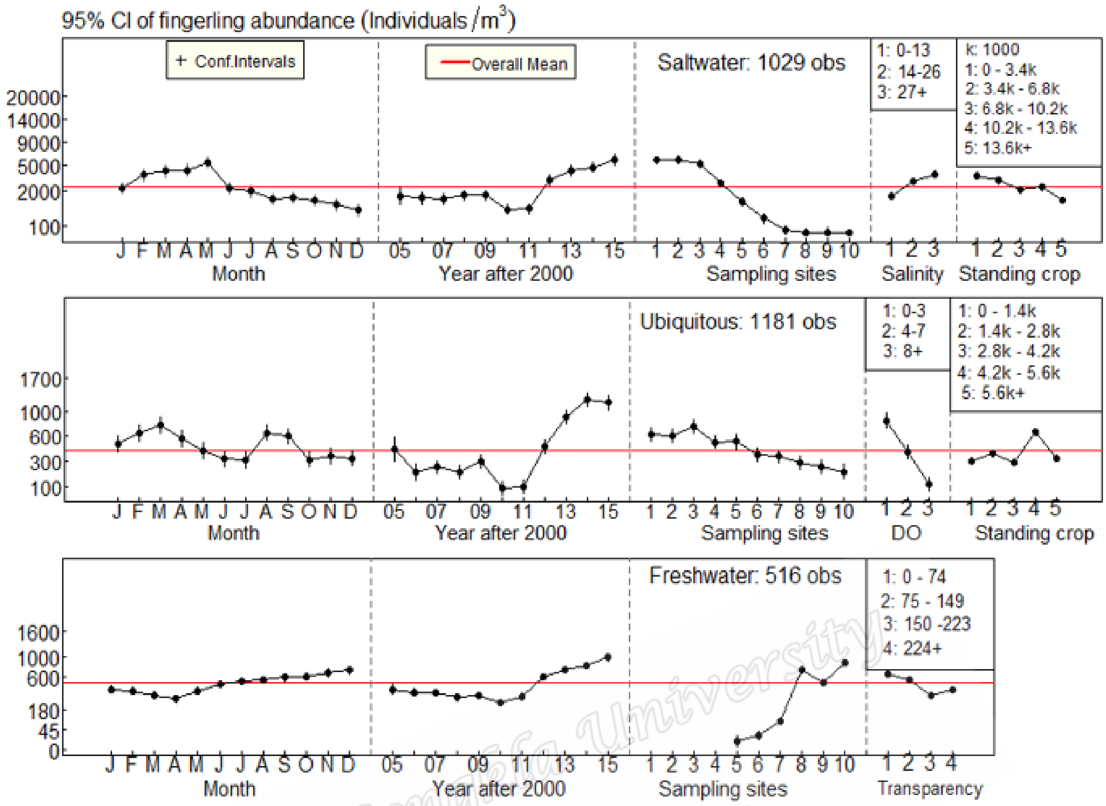

Figure 3.5 95% shows confidence intervals of fish fingerling abundance in Na Thap River

Fish fingerling abundance in three aquatic ecosystems showed the similar pattern. Fish fingerling abundance from 2005 to 2011 was lower than the overall mean, which sharply increased to higher than the overall mean until 2015. Except for ubiquitous fingerling abundance on 2005 was not difference with the overall mean.

The saltwater fingerling abundance was higher than the overall mean from February until May and gradually decreased until December. In contrast, the freshwater fingerling abundance was lower than the overall mean from January to May after that it increased until December. On the other hand, ubiquitous fingerling abundance fluctuated throughout the year.

For saltwater, maximum peak occurred in estuarine zone at site 1 to site 3, then decreased slowly until site 9 in the upstream. Ubiquitous fingerling abundance were higher than the overall mean at site 1 to site 5 then decreased less than overall mean until site 10. Fish fingerling for freshwater were not found at saltwater area, therefore, found from site 5 to site 10 and the highest were found at site 10.

Saltwater fish fingerling abundance was found higher than the overall mean where standing crop lower than 6,800 grams/m^2 and usually found at salinity was higher than 27 ppt, whereas freshwater fish fingerling abundance was found at salinity ranged from 0-13 ppt. Ubiquitous fish fingerling abundance showed the highest at standing crop ranged between 4,201-5,600 grams/m^2. Ubiquitous fish fingerling abundance was highest where dissolved oxygen ranged between 0-3 mg/L. Moreover, freshwater fish fingerling abundance was found the higher than overall mean when water transparency was lower than 149 cm.

Chapter 4

Discussion and Conclusion

4.1 Discussion

This study used factor analysis to reduce the 58-different species of fish fingerling into 3 interpretable groups based on habitat characteristic preference particularly saltwater, freshwater and ubiquitous fish.

After 3 factors were obtained, the number of fish fingerling abundance was summed up. Multiple regression analysis was used to find the association between fish fingerling abundance and season, location, standing crop and some water quality. The pattern variations were examined after the seasonal adjusted was checked to reduce the residuals autocorrelation which may arise while collecting data at the same area in different times.

Two species of ubiquitous fish namely green pufferfish (*Tetraodon fluviatilis*) and java tilapia (*Oreochromis mossambicus*) were omitted when modeled for satisfied normality. These 2-species had the lowest mean when compared to the other fish species. Since, java tilapia and green pufferfish fingerling usually conceal and spend most of their lives in mangrove forest, this may be unavailability of equipment to catch the fingerling.

It clearly revealed that the number of saltwater and ubiquitous fingerling increased in dry season, starting from January to May, while, it decreased during rainy season, which was opposite freshwater fingerling, which high abundance in rainy season from June to December. Our findings are consistent with several previous studies (Saheem *et al*., 2014; Olukolajo and Oluwaseun, 2008; Bruno *et al*., 2013), where standing crop in weight and fingerling densities for freshwater were found maximum in the rainy season (Saheem *et al*., 2014). Abundance of saltwater species of fish increased as water temperature increased in dry season. While, freshwater species of fish increased with high rainfall (Olukolajo and Oluwaseun, 2008, Bruno *et al*., 2013). Moreover, the number of individuals, aquatic animal's diversity and species distribution depend on the seasonal variation (Fisher and Eckmann, 1997).

All of the three aquatic ecosystems showed the same abundance pattern of fingerling species. The fish fingerling abundance from 2005-2011 was less than the overall mean and from 2012-2015 it was higher than the overall mean. These occurrence during 2009-2011 was due to reopening of the sand-chocked mouth of the Na Thap River, may facilitated the convenient movement of fish fingerling to the open sea.

This research revealed the association between standing crop with saltwater and ubiquitous fish fingerling abundance. And saltwater fish fingerling abundance was associated with salinity. This finding was supported by Chowdhury *et al*., (2010), identified that salinity has a major influence on the fish abundance and distribution. Ubiquitous fingerling abundance was found the highest peak at lower level of dissolved oxygen, which may be occurred in some fish fingerling species such as fish in Gobiidae (goby) family and Cichlidae (tilapia) family are tolerable to less or large dissolved oxygen ranged (Breitburg, 1994). Transparency was associated and also had an effect on the fish fingerling abundance. These results were supported by Ziober *et al*., (2012), mentioned that the characteristics of the water such as transparency, pH, conductivity and NO_3 were associated with freshwater fish fingerling abundance, which control the abundance and distribution of fish in the river.

During rainy season, increasing of water level in the river leads to the low value of water salinity and high level of nutrition (Kazungu, 1989; Offem *et al*., 2011). This event was associated with much larger amounts of aquatic animal. As there is variation in the salinity level among most of marine fish species or migratory, their preference to salinity also differs from the higher salinity to the lower salinity. Some of these species survive under wide range of salinity. Moreover, some marine species even though spend their life in the sea, they return to freshwater to spawn such as Hilsa loli, hagfish and lamprey (Maes *et al*., 2007). In the summer season, due to a high temperature, the water level decreases which cause changes of water quality.

4.2 Conclusion

The finding from this study can be used to suggest the regulatory authorities to manage better fisheries enhancement to maintain the fish fingerling from destructive catching activities such as using smaller net or catching fish in spawning season, when dry season for saltwater fish fingerling and when rainy season for freshwater fish fingerling. These can be applied to construct measures of the fisheries management for maintaining fish fingerling and balancing aquatic ecosystem to survive and grow up to be a large number fish stock in the future.

4.3 Limitation of study

This study has some limitations. Fish fingerling in the Na Thap River were not only originated from the natural river as the Chana thermal power plant annually has released much larger number of fish fingerling into the river since 2005 until present.

Even if most of the selected determinants show relationship and effect on fish fingerling abundance, there are other several factors for example nutrient contents, prey-predator relation, human activities or nature phenomena may effect on the number of fingerling abundance. These factors have not been included in this study.

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