Chapter 1

Introduction

1.1 Rationale for study

The commercial capture fisheries and fish farming sectors are of fundamental importance worldwide in terms of food security, revenue source and employment. Moreover, fish play an important role in both the food security and nutritional security of many rural and coastal populations which people can utilize all sizes and types of fish for catering (Sugiyama et al 2004).

Time-series data on global fish catches indicate that in the late 1980s the world passed the maximum sustainable yield of marine fish resources. Since then, although there have been regional variations, the global fish production has gradually declined, even as fishing efforts have increased. There has also been a loss of marine biodiversity, mainly due to over-fishing and destruction of fish habitats (Pauly et al 2003; FAO Fisheries Department 2005).

In 2004, of the 600 marine fish stocks worldwide, monitoring found that 72% were exploited, 17% were over-exploited, 7% were depleted, 3% were under-exploited, and 1% was recovering from depletion (Garibaldi and Caddy 2004). Similarly, a world review of fisheries in 2006 by FAO (2008) reported that fisheries and aquaculture supplied the world with about 110 million tonnes of consumption fish in 2006 while about 52% of fish stocks were fully exploited and 20% were moderately exploited. Therefore, fish catch productions reached their maximum sustainable limits with no space for further expansion. Areas showing the highest proportions of fully-exploited stocks include the Northeast Atlantic, the Western Indian Ocean and the Northwest Pacific. Asian countries accounted for 52 percent of the global capture production. China has remained the global leader with more than 17.1 million tonnes of capture production. Thailand ranks among the top ten countries for fish capture production. Analysis of survey information for the southeast Asia region have shown considerable degradation and overfishing of coastal stocks, most dramatically in the Gulf of Thailand and along the east coast of Malaysia.

In Thailand, the fisheries sector constitutes an important source of export earnings, livelihoods and domestic food supply (Department of Fisheries of Thailand 2008). However, since 1960 capture volumes have increased after the demersal trawl was introduced resulting in over–fishing and conflicts in resource use (Tokrisna et al 1997). The Gulf of Thailand contributes about 70% of the total national marine catch while the Andaman Sea accounts for the remaining 30%. The fishery structure is characterized by small scale and commercial fisheries. Demersal fish are caught mainly by otter-board trawls, pair trawls, beam trawls and push nets. The demersal fish resources in coastal waters have been severely depleted. Trash fish currently constitute about 60% of the total trawl catch. Between 18% and 32% of trash fish are juveniles of commercially important fish species. Several factors may have contributed to overfishing, notably increasing human population, increased pressure from Thai trawlers who have lost access to foreign fishing grounds after neighboring countries declared exclusive economic zones, development of processing techniques for turning low-priced demersal fish into human food, and increasing numbers of animal feed plants that utilize trash fish. Nevertheless the fisheries products have long played a vital role in the Thai economy. In terms of exports, fisheries products reached 4,864.7 million USD in 2005, up from 2,154.7 million USD in 1994. This rise represents an average of 4.6 % annual increase in terms of value (Department of Fisheries, Thailand 2008).

Biodiversity is most often understood as the number of different species of plants, animals and microorganisms in existence in an ecosystem. Conflicting issues of utilization against conservation of aquatic resources and environment has become more and more critical, and often developed into serious social and community conflicts (Cooney et al 2004). The marine fish biodiversity of four north-temperate oceanic regions (Northeast Atlantic and Pacific, Northwest Atlantic, North mid-Atlantic) was assessed in one study using Sequential or Virtual Population Analysis (SPA or VPA) and found that 81% of the populations in decline prior to 1992 were predominantly top predators, such as Atlantic cod (*Gadus morhua*), sole (*Solea solea*) and pelagic sharks (Hutchings and Baum 2005). Tropical Asia–Pacific protection areas support a rich but incompletely known biota, including fish, a diverse array of benthic invertebrates, and an assemblage of mammals adapted to wetland ecosystems.

Aquatic biodiversity is threatened by habitat degradation, such as pollution, deforestation, dams and flow regulation, as well as over–harvesting (Braatz and Davis 1992). Presently, at least 570 species of freshwater fish are known, of which 56 are endemic to Thailand. A total of 1,160 fish species have been found to exist in estuarine and sea water. An additional 30 species are deep-sea fish. Of all marine fish species, 78 species are cartilaginous fish and 1,664 species are bony fish. However, five species of freshwater fish are now not found in Thai waters and there are approximately 30 endangered species of freshwater fish that are captured for food or to supply aquarium businesses (ONEP 2009). Large areas of wetlands in Thailand have been converted to rice fields and urban sprawl which suffer from pollution and various other problems. Thailand's abundant and diverse marine biodiversity has suffered from destructive fishing gear in the open sea and coastal areas (Khunkitti and Porter 2009). A study on the macro–invertebrate community structure of the coastal mangrove forest ecosystem on the Andaman Sea coast of southern Thailand suggested that some of these representative families of mangrove macro-invertebrate species could be used as indicators of ecological change for environmental monitoring programmes (Macintosh et al 2002).

As mentioned above, global fisheries are currently over-exploited or have not been adequately managed and catches are in decline. Similarly, the key problems of tropical shallow aquatic systems are related to upstream modifications of river discharges, to changes in water quality, in particular related to sedimentation, nutrient loading and salinity regime fluctuation causing shallowness, euthophication and depletion of fish stocks. Furthermore, the use of destructive fishing gear has destroyed the natural migration patterns for fish and damaged habitats (Chufamanee et al 2003; Chesoh et al 2008). The occurrence of fish death, both in natural waters and in cage culture, has been increased due to diseases and pollution problems (Pimentel et al 2007). Over-exploitation of species affects the loss of biodiversity in aquatic systems. These problems are a major issue and are difficult to manage in today's competitive world (Clausena, and York 2008).

Fish numbers have long been used as indicators of environmental change because of their generally large size and relative ease of identification. Fish stock and fishing pressure indicators are also used in state of the environment reporting for coastal and oceanic competency (Caddy 2000). The fishing industry in Songkhla Lake, the largest tropical lagoonal ecosystem of Thailand, is a classic example case study for distribution of commercial fish catch and fish community clustering by species. The lake's fisheries use various types of fishing gear and account for a large component of the economic activity of the region (Ratanachai and Kanchanasuwan 2005).

1.2 Scope of study, variables and target population

This thesis is concerned with the distribution of fish catch landing weights of commercial fisheries with a particular focus on species clustering. We investigated and analyzed available data and identified existing fish assemblages. This study developed appropriate statistical models that can be used generally to describe the magnitude and distribution of fish catch weights in aquatic systems. These models describe the fish catch weight distribution and how this outcome variable depends on location, season, period of fishing, and type of fishing gear. In this thesis the term "fish" includes both invertebrates and vertebrates and "catch" is defined as the fish caught commercially.

The need to access reliable information for effective management and involvement of stakeholders is widely recognized. Therefore, it is important to know how the fish catch has changed over the years and how fish assemblages depend on the season and other factors within an aquatic system.

The target population in this study is commercial fish catches from tropical lagoonal lakes over the last three decades. Actually, this population is not very large. Because of the unique or specific intrinsic characteristics and linkage effects between oceanic and continental inputs (Lassere and Marzollo, 2000), there are only a small number of tropical coastal lagoons in the world with substantial fishing production. In addition to Songkhla Lake, these comprise Tonlé Sap (Great Lake) of Cambodia, the Laguna de Bay Lake of Philippines, and Lake Chilka (the largest lagoon of India), as shown in Table 1.1, (ILEC, 2009; LakeNet, 2009).

Table 1.1 Tropical lakes with characteristics similar to Songkhla Lake

Name of lake	**Surface area** (km^2)	**Maximum depth** (m)	**Catchment area** (km^2)	**Country**
Songkhla Lake	1,082	2.0	8,020	Thailand
Lake Chilka	1,100	2.4	4,300	India
Laguna de Bay	900	7.3	3,820	Philippines
Tonlé Sap (Great Lake)	13,000	10.0	70,000	Cambodia

1.3 Background information for study sample

Songkhla Lake is the largest tropical lagoonal ecosystem of Thailand. Fishermen have claimed that the catch now is lower than in the past and the fish being caught are smaller in size. Furthermore, the proportion of higher valued shrimp in the overall catch has decreased, thus decreasing fishermen's income (Choonhapran 1996; Sirimontraporn and Choosrirat 2001). It is therefore reasonable to use Songkhla Lake as a sampling site for data collection of this study. Since the lake is rich in biodiversity, various types of fishing gear are used and thousands of fishermen are involved.

Songkhla Lake basin covers approximately 8,729 square kilometers, consisting of approximately 7,687 square kilometers of land area and approximately 1,042 square kilometers of the lake's water body area. The basin spans approximately 150 kilometers from north to south, and approximately 65 kilometers from east to west.

Songkhla Lake is a shallow coastal lake formed by an interaction of land and ocean over a long period of time. A sand dune, about 75 kilometers long and 5 kilometers wide, on the western coast of the Gulf of Thailand separates the Lake from the sea on the eastern side. The western and the southern borders of the lake constitute a vast drainage area in Phattalung and Songkhla provinces where many freshwater streams drain into the lake (Ratanachai and Kanchanasuwan 2005). The basin extends into three provinces, namely Songkhla, Phattalung and Nakhon Si Thammarat, as shown in Figure 1.1.

Generally, the Lake is classified into three distinctive zones from north to south, as follows:

1) The upper lake ("Thale Luang") which comprises an area of 491 square kilometers of area. It is a turbid windswept lake, generally fresh, but occasionally too brackish for irrigation.

2) The middle lake ("Thale Sap" or "Inner Lake" or "Middle lake") has an area of 336 square kilometers of brackish water containing many islands. This is a contact zone between fresh and saline waters, leading to sedimentation that has been significantly changed by a salinity barrier separating it from the outer lake.

3) The lower lake ("Outer Lake") is a marine ecosystem with an area of 190 square kilometers containing intensive fishing gear (set bag nets and sitting traps), fish

cage culture, and surrounded by shrimp ponds, livestock, agricultural farms, agro-processing factories, restaurants, and housing development. This area is also a regionally significant wildlife resource being developed for tourism.

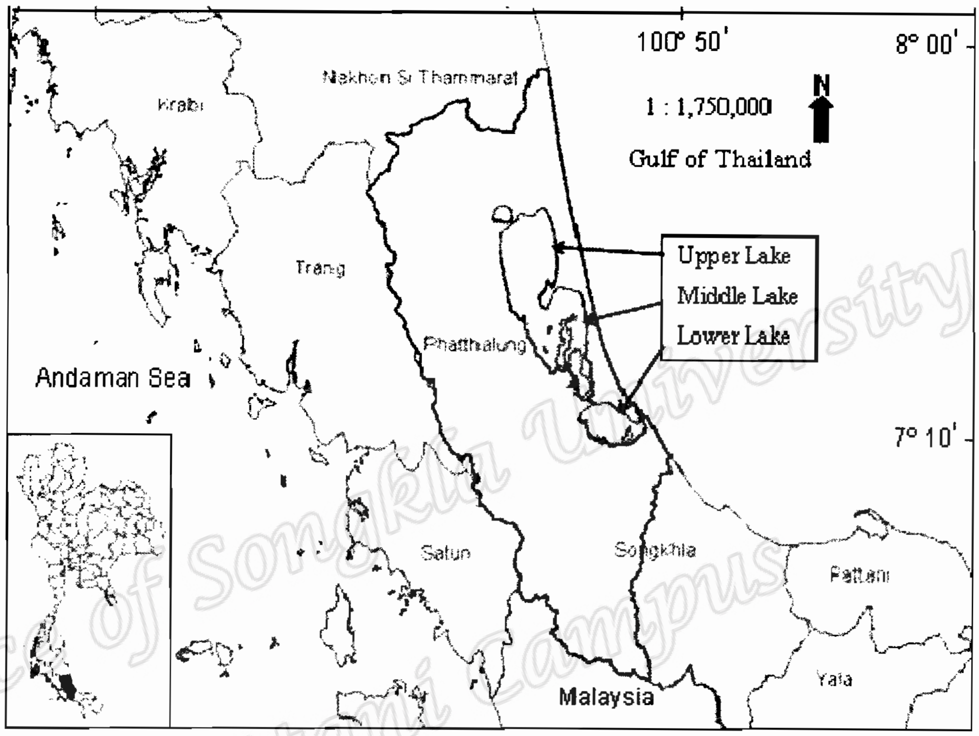

Figure 1.1 Map of Songkhla Lake and the three main zones of the lake

1.4 Literature review

Most research concerning the distribution of fish catch weights and species clustering has been conducted outside the tropical zone of the Asia–Pacific region. Much of this research describes only catch fluctuations and patterns of fish assemblages without regard to fishing period or type of gear used in aquatic systems. However, some of these studies and the methods they use are relevant to our study, and are reviewed below.

Fish catch assessment

A study of empirical predictions of fish yields of North American lakes found that the most significant predictive relationships only involved average dry weight of bottom fauna standing crop, which explained 83% of the variation of catch per unit water area in a semi-logarithm relationship, and 80% of the variation of catch per unit area (Matuszek 1978).

Data from a 17–year period (1964–1980) of monthly catches of pilchard (*Sardina pilchardus*) from Greek waters was analyzed using auto-regressive integrated moving average (ARIMA) techniques. Forecasts using two models were compared with actual data for 1981 that were not used in the estimation of the parameters of either model. The mean errors of the two models were 14.6% and 12%, respectively. This suggests that ARIMA procedures are capable of describing and forecasting the complex dynamics of the Greek pilchard fishery, which have hitherto been regarded as difficult to predict owing to the strong influence of year–to–year changes in oceanographic and biological conditions and socio-economic factors (Stergiou 1989).

A seasonal catchability model for the rock lobster, *Jasus edwardsii*, was conducted in northern and southern fishing regions off the Australian island state of Tasmania. The full models were constructed from commercial catch, effort data, fishery–independent estimates of exploitation rates, and some environmental parameters. These models described 72% of the total variation in catchability over 6 years in the south and 80% of the total variation over 4 years in the north (Wallace et al 1998).

The South Pacific Commission's Deep Sea Fisheries Development Project operated in Truk State, Federated States of Micronesia, reported the landing of saleable and unsalable fish. The overall catch rate was 4.0 kg/reel-hour and suggested that one or two fishing vessels could make a reasonable living by using hand reels as the major fishing technique (Chapman 1999).

Univariate seasonal ARIMA and intervention models were developed to forecast monthly catches of 53 commercial species in the northwestern part of the Mediterranean Sea. The models showed good agreement between forecasts and observed catches of target demersal species. By contrast, models fitted to non–target demersal species and pelagic species were unsatisfactory in terms of explained variability and predicting power. Large commercial size classes were better explained than the small size classes (Lloret et al 2000).

Dynamic factor analysis, a technique used to detect common patterns in a set of time series and relationships between these series and explanatory variables, was applied to estimate common trends in 13 landings per unit of effort time for lobster *(Nephrops)* in waters around northern Europe. The model could identify three common trends for 12 of the series, with one series being poorly fitted, but no relationships with the North Atlantic Oscillation (NAO) or sea surface temperature were found (Zuur et al 2003).

Quantitative analyses of the catch structure by age or length classes of pink shrimp fisheries from trawling in southeastern Brazil were analyzed based on the classical models (Schaefer and Fox's global production models, Beverton and Holt's model, and the predictive cohort analysis based on the length structure). The results showed that this fishery had reached its maximum sustainable yield and suggested that reduction of the fishing effort and adequate season and area closures seem to be the best management actions for the pink shrimp fishery (Leite and Petrere 2005).

Monthly catch forecasting of anchovy, *Engraulis ringens*, in the north of Chile based on non-linear univariate approach of hybrid ARIMA model was conducted. The variance in the external validation fluctuated between 84% and 87%, the standard error of prediction was lower than 31% and the mean absolute error was around 18,000 tonnes. The strong correlation among estimated and observed anchovy catches in the external validation phases suggest that calibrated models captured the general trend of the historical data and therefore these models can be used to carry out an accuracy forecast in the context of a short to medium term time period (Gutiérrez-Estrada et al 20007).

Fish community clustering

An ecological classification of Minnesota Lakes with associated fish communities using principal components analysis classified the variables into three types and found that these variables were associated with lake size, lake depth, the chemical fertility of the lakes, and length of the growing season. Gill and trap net catch indices within lake classes were used to characterize fish communities for each lake class (Schupp 1992).

Spatial patterns and temporal trends in the fishery landings of the coastal lagoons in western Greece coast were investigated by principal components analysis and showed two seasonal patterns linking fish spawning behaviour (Katselis et al 2003).

A study of the effect of fishing on community structure of demersal fish assemblage was carried out in the Mediterranean Sea (Labropoulou and Papaconstantinou 2005). The results revealed 157 different fish species were caught. The effect of depth on the diversity patterns was significant but no seasonal trends were detected. Commercially important species were dominant in the shallowest zone, while non-commercial species predominated at depths below 200 meters and between 30-200 meters of water depth almost 50% of the total catches were non-commercially important fish.

Economic response to harvest and effort control in fisheries of European waters was applied by two dynamic bio-economic models based on the economic development of a number of fishing fleets, given the influence of different management procedures on the fish stocks. The model presented was a simplification of the actual dynamics between fish stocks and fishery management plans, and could provide a plausible tool for development of a depleted fish stock under a recovery scheme. However, these models may be unrealistic as the fleet size varied by more than 150% during a period of 15 years (Hoff and Frost 2006).

A study exploring the linkages between poverty, marine protected area management, and the use of destructive fishing gear in Tanzania found that the livelihoods of coastal communities directly depend on these resources that are consequently under increasing threat and vulnerability. Some aspects of poverty increase the likelihood of using destructive fishing gear (Silva 2006).

A study of habitat utilization by fish in a shallow, semi-enclosed estuarine bay in the southern Gulf of Thailand was evaluated by multivariate methods and a multi-dimensional scaling. Significant differences were found in relative abundance and species richness between both sampling sites and months and fish community presented four different habitats. The most dominant fish species were clustered into six different seasonal groups, with preference for specific months, although many recruited and occurred throughout the year (Hajisamae et al 2006).

A comparison of the composition and abundance of fish species caught with experimental gill net with that of artisanal fishermen at Oyan Lake, South West Nigeria found the commercial fish catch (weight and number) compared with that of the experimental gill net gave a positive correlation ($r = 0.2$) showing that one can be extrapolated to get the other (Ikenweiwe et al 2007).

Monitoring temporal and spatial variations in fish size-at-age data of cod (*Gadus morhua*) in the northwest Atlantic using robust principal components analysis enabled the development of a size indicator for fish populations (Chen et al 2008).

In an attempt to extend our literature review of fish catch weights, most studies reviewed here have been conducted for marine systems in temperate zones and few studies have been conducted for aquatic systems. Moreover, few studies have been carried out for tropical aquatic systems and only one contemporary study has investigated fish assemblages and some ecological characteristics of fish in Southeast Asia. Two main factors influencing the quantity of fish catch in particular tropical aquatic systems are gear type (fishing technology) and fishing season. Unfortunately, only two studies (Tsehaye 2007; Mahévas et al 2008) have investigated these significant factors for fish clustering.

1.5 Plan of thesis

This thesis contains five chapters, including this introductory chapter. It proceeds with the background of the importance of fish catch assessment and their problems. This chapter also includes objectives, background information of Songkhla Lake, and literature review.

Chapter 2 provides a description of data and overview of the statistical methods used, including data transformation, linear regression model on time series, the additive model for variation in catch weights of species over time and its extensions to allow for different time series patterns for different species, and goodness-of-fit tests.

Chapter 3 includes the preliminary data analysis for the fish catch weights over the period of 1977-2006. This involves using graphical and statistical methods, described in Chapter 2.

Chapter 4 comprises the preliminary data analysis for the fish catch weights over the period of 2003-2006 using the methods described in Chapter 2. This model takes the season and type of gear into account.

Chapter 5 gives overall conclusions, limitations and suggestions for the further study.