SHORT REPORT
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Forecasting fish catches in the Songkhla Lake basin

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ABSTRACT: This study aims to develop statistical models for forecasting the quantity of fish catches in the Songkhla Lake basin in southern Thailand. Data comprise a total monthly fish catch in tonnes from January 1977 to December 2006. We fitted an observation-driven model to the logarithm of the total monthly fish catch. The model contains seasonal effects and time-lagged terms for the preceding two months. We obtained an r-squared of 51% with both the seasonal and time-lagged coefficients which was statistically significant. Although the catch has decreased substantially in the last ten years, no long-term trend is evident. This model can be used for short-term and possibly medium-term fish catch forecasting. The catch in the Songkhla Lake basin may have exceeded the sustainable capacity due to over-exploitation and illegal fishing. Strengthening the political will to develop enforceable and sustainable fishing practices is therefore desirable.

KEYWORDS: trends, regression model, fisheries assessment, tropical lake management

INTRODUCTION

In many parts of the world, fisheries are currently overexploited or have not been adequately managed and catches are in decline[1,2]. An essential component of successful fisheries management is an ongoing assessment programme to monitor the condition of the fish stock in the context of the aquatic ecosystem and the fishing activities that are sustained by the fishing community[3]. Trends in the size of fish catches can be important indicators of the status of the fishing industry[4]. In Thailand, fish products have long played a vital role in the economy as export commodities and protein sources for residents[5].

Songkhla Lake, the largest lagoon in Thailand, is located in the south, approximately 900 km from Bangkok (Fig. 1). The Songkhla Lake basin has an area of 8,729 km^2 including 1,017 km^2 of main lake water body, and extends into three provinces (Songkhla, Phatthalung, and Nakhon Si Thammarat). It is usually classified into three distinct zones from north to south. The upper lake covers an area of 491 km^2 of turbid and windswept fresh to brackish water. The middle lake has an area of 336 km^2 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 lower lake. The lower lake is a marine ecosystem with an area of 190 km^2 containing extensive fixed fishing gear and fish cage culture, surrounded by shrimp ponds, agricultural and pastoral farms, factories processing their products, tourist resorts, and housing developments.

Fishermen have reported that the present catch is lower than in the past and that the fish being caught are smaller. Furthermore, the proportion of higher-valued shrimp in the overall catch has decreased, resulting in a drop in fishermen's income[6]. Due to illegal fishing, the environment has been degraded and the lake is suffering from eutrophication. These effects may slowly spoil the lake on which more than 1.6 million people depend for their livelihood. The Songkhla Lake basin is a classic example of a link between the watershed area and the coastal ecosystems where all factors need to be considered.

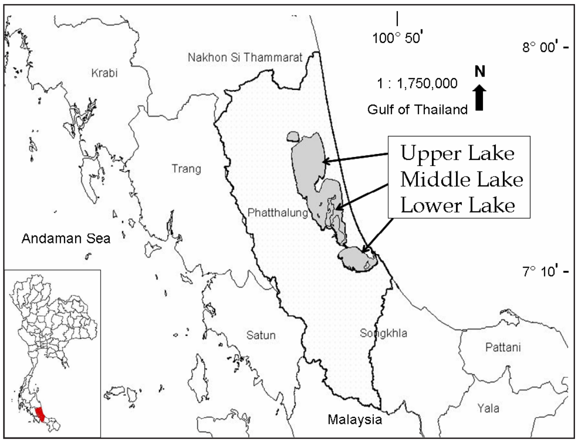

Fig. 1 Songkhla Lake basin comprising the upper, middle, and lower lakes.

Fishing in Songkhla Lake differs spatially according to the resources and conditions of each part of the lake. Climatic factors and water quality affect the biotic and abiotic elements that influence the quantity and distribution of fish species. The relationship between climatic factors and the fish-carrying capacity of the aquatic environment is clearly complicated. Nevertheless, water temperature and rainfall can be used as a basis for forecasting the abundance and distribution of many species[7,8]. All activities of fishermen in the lake have affected fish stock dynamics.

For effective management of the Songkhla Lake environment and planning for sustainable development in the future, it is important to know how the fish catch has changed over the years and how it depends on the season and other factors routinely measured by authorities. Such knowledge will facilitate the development of statistical forecasting models that predict fish catches, allowing for trend, seasonality, and other aspects of the catch including species composition and location. As a consequence, it will be possible to develop strategies for strengthening and consolidating fishing management regulations and land-use practices to ensure sustainable yields in the fishing industry.

METHODS

The time series of monthly total fish catch tonnage from the Songkhla Lake basin from January 1977 to December 2006 was obtained from three regional fisheries offices within the Department of Fisheries, Ministry of Agriculture and Co-operatives, Thailand, namely, the Songkhla Provincial Fisheries Office, the Phattalung Provincial Fisheries Office, and the National Institute of Coastal Aquaculture (NICA).

We fitted a linear regression model (see, for example, Ref. 9) to the data after transforming using natural logarithms to ensure that statistical assumptions of normality and constant variance were satisfied. The predictor variables were the month of the year, the linear trend, and the (log-transformed) catches in the preceding two months. If y_t is the catch in tonnes in elapsed month t, s is the "season-month" coded as January = 1, February = 2, and so on, and ε_t is a series of independent normally distributed errors with mean 0, we write

$$\ln y_t = \alpha + \beta t + \gamma_s + \delta_1 \ln y_{t-1} + \delta_2 \ln y_{t-2} + \varepsilon_t \qquad (1)$$

where α, β and (δ_1, δ_2) are parameters in the model denoting an initial value, a trend, and two further coefficients denoting the influence of the catch in the previous two months, respectively, and $\gamma_1 = 0$, $\gamma_2, \ldots, \gamma_{12}$ is a set of seasonal effects indicating how the catch varied with month of the year. Forecasts for $\ln y_{t+k}$ (k months in the future) are obtained by substituting the estimated values for the coefficients into the right-hand side of (1), using the forecast values themselves for values of $k > 1$. However, to obtain forecasts for y_{t+k}, (1) must be transformed back by exponentiation and the forecast is then the mean of y_t, which has a log-normal distribution with expected value

$$E[y_t] = \exp\left(\mu + \tfrac{1}{2}\sigma^2\right)$$

where μ and σ are the mean and standard deviation, respectively, of $\ln y_t$ (see Komontree et al[10]). Thus if σ is the standard deviation of the errors in the fitted regression model, the forecast of y_{t+k} is

$$E[y_{t+k}] = \exp\Big(\alpha + \beta(t+k) + \gamma_s + \delta_1 \ln y_{t+k-1} + \delta_2 \ln y_{t+k-2} + \tfrac{1}{2}\sigma^2\Big) \qquad (2)$$

All analysis was undertaken using the R program[11].

RESULTS

Table 1 shows the estimates of the parameters in (1) together with their standard errors, z-values and p-values. The month t was coded so that $t = 1$ corresponds to January 1977, and thus t ranges from 1 to 360. Given that the first two months were needed to accommodate the two time-lagged observations, the sample size was 358. Note that both the time-lagged variables (δ_1, δ_2) were statistically significant, but the trend (β) was not (Table 1). The seasonal effect was statistically significant overall ($p < 0.0001$). However, the seasonal effects vary from large negative values in February, April, and August to a large positive value in December. This model provided an r-squared of 0.51, implying that it accounted for 51% of the variation in the data, and the correlation between observed values and the values fitted by the model is $\sqrt{0.51} = 0.714$.

Fig. 2 shows a scatter plot of the observed total fish catch with the natural log transformed and fitted values in the left panel and residual plot in the right panel. The normality assumption for the errors is plausible because the points in this plot follow the line corresponding to normality with no extreme outliers. Fig. 3 shows a plot of the time series of data with the forecasts based on the model given by (2). The monthly forecasts of fish catches in the Songkhla

Table 1 Results from fitting linear regression model to logarithms of monthly catches.

Determinant	Coefficient	Std error	*z*-value	*p*-value
Constant α	1.9303	0.2805	6.88	< 0.0001
Lag 1 δ_1	0.4955	0.0536	9.25	< 0.0001
Lag 2 δ_2	0.1511	0.0536	2.82	0.0051
Season:				< 0.0001
Jan γ_1	0	-	-	-
Feb γ_2	-0.4147	0.0984	-4.21	< 0.0001
Mar γ_3	0.0871	0.1020	0.85	0.3938
Apr γ_4	-0.3907	0.0925	-4.23	< 0.0001
May γ_5	-0.0111	0.1027	-0.11	0.9137
Jun γ_6	0.0715	0.0943	0.76	0.4491
Jul γ_7	-0.2274	0.0937	-2.43	0.0157
Aug γ_8	-0.4081	0.0985	-4.14	< 0.0001
Sept γ_9	-0.0890	0.1018	-0.87	0.3825
Oct γ_{10}	0.1869	0.0968	1.93	0.0545
Nov γ_{11}	-0.0861	0.0929	-0.93	0.3549
Dec γ_{12}	0.4330	0.0963	4.50	< 0.0001

r^2: 0.5119 df: 344 Residual Sum of Squares: 41.7690 σ : 0.3485

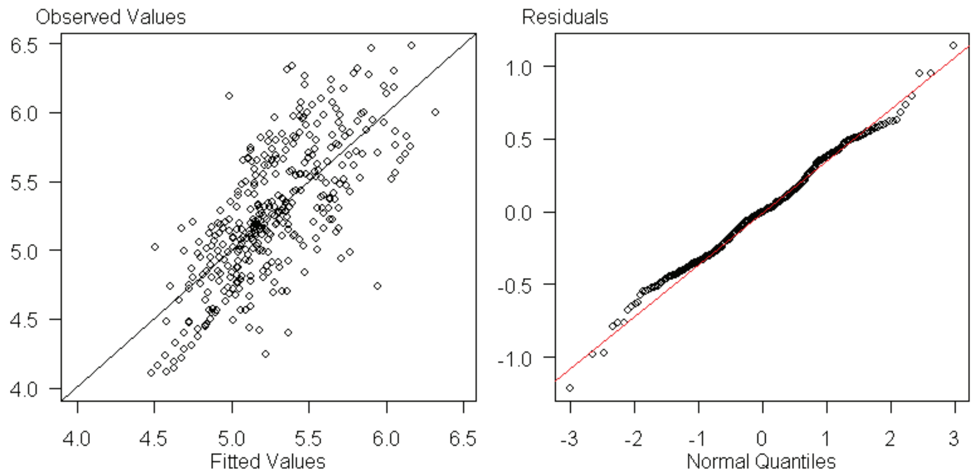

Fig. 2 Scatter plot of observed values and fitted values and residuals plot.

Lake during the twelve months of 2007 were 167.87, 127.29, 191.26, 139.19, 184.83, 220.21, 185.92, 146.52, 174.64, 242.16, 222.54, and 376.81 tonnes. Table 2 shows the forecast and actual values of fish catches (tonnes) and percentage errors in 2006. The average percentage error of predicted fish catches was moderate.

DISCUSSION

Although the fisheries sector in the Songkhla Lake basin accounts for a large part of the economic activities, it is a small-scale operation with poor fishing practices. Most of the 8,400 families of the fishermen are local native people. The majority of intensive fishing activities are found in the lower lake and many of these extend to other areas in the basin. Moreover, a lot of inland fishing in surrounding riparian, stream, swamp, and lowland areas takes place during and after annual floods.

The time series of monthly total fish catch tonnage from January 1977 to December 2006 revealed that the fish catches varied between 1,622 and 4,817 tonnes (average value for 1977–2006, is 2,639 tonnes). The catch slightly increased over the preceding decade to peak at 3,639 tonnes in 1980, gradually declined to 1,817 tonnes in 1986, then dramatically increased to a second peak at 4,817 tonnes in 1996, before entering a steady decline to 1,622 tonnes in 2006. During the past three decades,

Table 2 Forecast and actual values of fish catches (tonnes) in 2006.

Month	Forecast (95% CI)	Actual	% error
January	204.3 (180.9 - 227.7)	135.2	51.2
February	119.5 (96.1 - 142.9)	115.6	3.4
March	176.5 (153.1 - 199.9)	137.0	28.9
April	116.3 (92.8 - 139.7)	147.9	21.4
May	181.1 (157.7 - 204.5)	150.6	20.3
June	200.8 (177.4 - 224.2)	146.4	37.2
July	147.2 (123.8 - 170.7)	178.6	17.5
August	135.0 (111.6 - 158.4)	109.4	23.4
September	150.2 (126.8 - 173.6)	138.0	8.8
October	206.2 (182.8 - 229.6)	109.1	89.1
November	144.7 (121.2 - 168.1)	127.9	13.1
December	253.8 (230.4 - 277.3)	126.7	100.4
Average	169.6	135.2	34.6

only two scientific papers reported the catches in the main Songkhla Lake water body. The first was conducted during 1984–1986[12] and the second during 1994–1995[13]. These studies reported the total fish catch during 1994–1995 to be 9,634 tonnes/year, which is a decrease of 22% compared to the 12,290 tonnes/year reported during 1984–1986.

The statistically significant seasonal effects found in our study could be related both to regional climatic changes and human activities. Monsoon seasons and the intrusion of sea water are the two natural phenomena that seem to drive the lake ecosystem and are the major causes of hydro–biological change in the absence of any massive regime shift. The dry season in southeast Thailand extends from February to April. The lower lake, where the most intensive fishing activities occur, has an average depth of 1.0–1.5 m and connects Songkhla Lake basin to the Gulf of Thailand through a short narrow channel (about 8 m in depth). 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 August, many Buddhists fishermen, who comprise the majority of the fishermen in the Lake basin, refrain from killing animals for religious reasons. In addition, pollution from waste water discharge and eutrophication effects is also likely to have damaged the fish stock in the lake[14–17]. The high seasonal effect in December might be due to the heavy rain during the monsoon season in the southeast. 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[18,19]. Fishermen can thus catch greater amounts of fish in this flood period. Significant causes of the decreased catches could be destructive fishing gear (push–net boats, small trawl boats, and set bag nets), illegal fishing practices (cyanide, electric, and dynamite fishing), or weak law enforcement. Various statistical models have been used to analyse fish catch data in previous studies[20–27]. Mathematical or bio-socio-economic modelling has also been used as an approach to assess the environmental carrying capacity of the coastal community[28,29].

According to the fitted model, the trend is not significant but both the time-lagged variables are statistically significant ($p < 0.001$) and the model can be used for short-term and possibly medium-term fish catch forecasting (Fig. 3). However, species composition, fishing effort and correlation of the environmental parameters were not taken into account

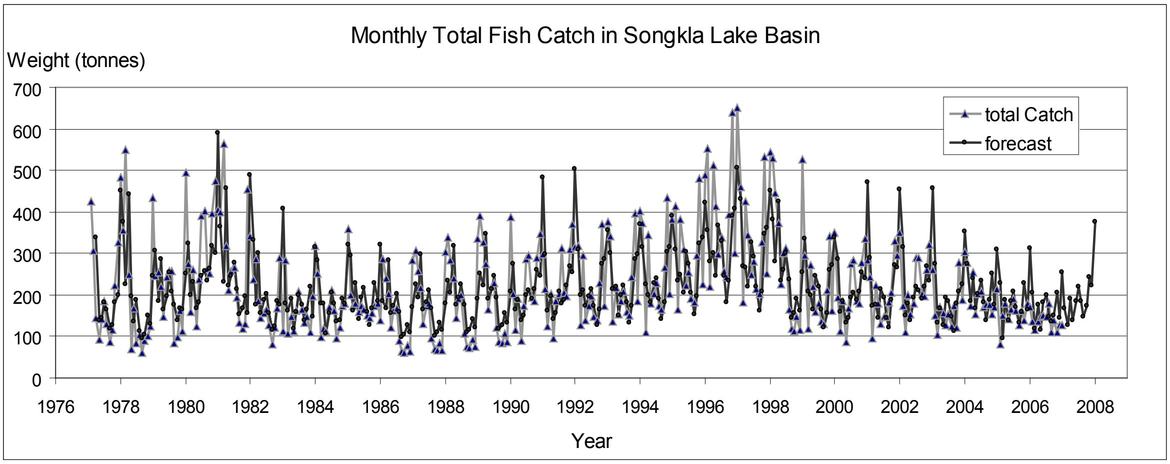

Fig. 3 Monthly total fish catches in Songkhla Lake basin with forecasts based on model.

and that is a major limitation of the study. This study revealed that the average monthly catch was 219.9 tonnes (range 60.8–651.9), and since 2000 there seems to be a breakdown of cycles indicating an irregular seasonal periodic fluctuation. This could reinforce the study by Choonhapran et al[13,18] reporting that the catches per household have decreased sharply, the fish are smaller, and the proportion of higher-value shrimp has decreased. Moreover, studies of fish caught by fish traps in the Lake[30,31] suggest that the size of fish catches has steadily decreased about four–fold from 1996 to 2002. The average catch per unit effort has decreased significantly from 3.6 kg/day in 1996 to 0.9 kg/day in 2002, suggesting that the number of fish traps should be reduced to sustain fisheries production. It is possible that the catch in the Songkhla Lake basin may have reached the limit of sustainable exploitation and thus strengthening the political will to enforce fisheries regulation is desirable.

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