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Study of Water Level-Discharge Relationship Using Artificial Neural Network (ANN) in Sungai Gumum, Tasik Chini Pahang Malaysia

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Abstract: The prediction of discharge (Q) and its variability in a river and lake are an essential component of hydrological regime studies. For the purpose, two tasks were developed to study the relationship in the Sungai Gumum and Tasik Chini Pahang. First, using simple functional relationship between water level and Q and expressed as a rating curve. Second, using complex non-linear Artificial Neural Network (ANN) method to train and validate the Q data of Sungai Gumum and its relationship to Tasik Chini water level fluctuation. The rating curve indicates that maximum Q was calculated at 0.09 m^3 sec^{-1} at 0.64 m depth and the minimum of 0.02 m^3 sec^{-1} at 0.1 m depth. Meanwhile, the ANN model explains 65.9% of the validation data set yielded result within 5% of error in predicting the stream Q. The relationship between ANN prediction of Q and the mean water level of Tasik Chini show highly positive correlation (R^2 = 0.89). This indicates that Sungai Gumum plays a vital role in supplying fresh water into Tasik Chini. Restoration of the hydrological aspects through regulating the water level in Tasik Chini is essential to ensure prolongs water-based activities.

Key words: Artificial neural network, water level, river discharge, Sungai Gumum, Tasik Chini

INTRODUCTION

Tasik Chini is one of well-known place for the water based recreation and tourism in Peninsular Malaysia. For over 30 years, people have visited Tasik Chini for fishing, kayaking, camping, visited the Orang Asli settlements and jungle tracking. Since 2003, The State of Pahang Government promoted Tasik Chini as one of the main tourism attractions in the state by providing more organized cultural activities.

In the line with the objective of enhancing the water based activities, the Pahang State government in 1995 constructed the gateway near Chini River mouth, located at 300 m from Sungai Pahang. The main idea was to retain the water level for year round navigability for tourists and visitors in the Tasik Chini. As a result, the lake's water level was increased causing imbalance on hydrological regime as well as ecosystem within the lake. Despite the local Orang Asli's warning that it would bring ecological disaster to the unique flora and fauna of Lake Chini, 9 years after the control structure was complete, the 12 of opened lakes of Tasik Chini have quickly shown it to have an effect not only an the Chini and Pahang Rivers but also on its tributaries the Melai, Perapuk, Datang and Gumum Rivers. Studied by the Malaysian Wetland International revealed that the damming of Chini River has created negative impacts on the general health of the ecosystem and surrounding water bodies (Mohamad and Toriman, 2006).

These impacts include disruption on fish biodiversity, deterioration of water quality and degradation of swamp forest. While they have a suggestion to restructure the gateway, very little information was gathered on how severe the water level fluctuation could effects the hydrological balance, particularly the inflow discharge and sediment accumulation on the lake's floor. This research on the effects of the Sungai Chini gateway to the wetland hydrology was carried out in order to devise stage-discharge characteristics for Tasik Chini restoration, where river flow from the tributary need

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to be considered as holistic restoration approach. The main objectives of the study can be enumerated as below:

- To design a rating curve of stage-discharge hydrograph for Gumum River
- To model stage-discharge data from River Gumum in relation to Tasik Chini water level fluctuation using ANN modeling

The use of Artificial Neural Network (ANN) in water related research is widely used particularly to predict the relationships between discharge and river stage, rainfall and runoff modeling and discharge vs. ecological parameters. This simulation model is a non-linear method of data description and is very useful, when the area lacking of field data.

Normally running by MATLAB, the ANN's software computing technique composed of densely interconnected processing nodes, which has the ability to extract and store the information from the few pattern data in training through learning (Limin, 1996). The merit in using the ANN is easy to develope, yields satisfactory results especially when applied to complex systems poorly implicitly understood.

For examples, Juahir *et al.* (2003) proposed feed-forward error back propagation ANN models for runoff forecasting using fixed stopping criterion and independent variables, respectively and compared them for performance with the available conceptual models. Sivakumar *et al.* (2002) used the ANN for real time forecasting of rainfall and discharge, while Juahir *et al.* (2004) were able to interpret the internal behaviour of an ANN based rainfall runoff model in Langat River.

ANN training and validation model can be carried out using two approaches. In a feed-forward back propagation ANN scheme, nodes of the input receive the normalized data set (input). The weighted sum corresponding to each node of the next layer is calculated and passed to the next layer through a sigmoid activation function. The error calculated at the output is propagated back to hidden layers and finally to input layer by updating the weights of interconnection. In this approach, the error is defines as:

$$E = \frac{1}{2}\sum_{1}^{K}\left[D_{(K)} - O_{(K)}\right]^2 \quad (1)$$

Where:

$D_{(K)}$ = Observed output at the kth node of the output layer

$O_{(K)}$ = Estimated output at the kth node of the output layer (Avinash *et al.*, 2005)

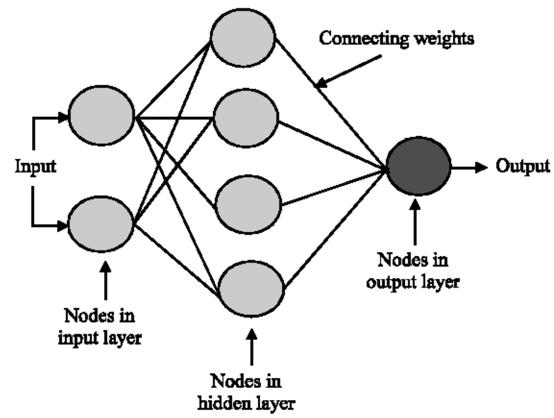

Fig. 1: Structure 2, 4, 1 and notations of a multilayer back propagation ANN

In a multilayer back propagation ANN, the nodes of input layer receive the input data, process it and pass the output of the nodes of subsequent hidden layer (s) and from last hidden layer to the output layer (Fig. 1).

Study area: Tasik Chini or Chini Lake, which is famous for its legend of Chini monster is the second largest natural freshwater inland lake in Peninsular Malaysia with a total catchment area of 4,980 ha (Fig. 2). The lake system lies at 3°15'40"N and 102°45'40"E and comprises of 12 open water bodies, known to the local people as Laut (sea) (Mohamad and Toriman, 2006). Based on Toriman *et al.* (2009a), the lake covers an area of about 202 ha of open water and 700 ha of freshwater swamp and swamp forest. However, it was estimated that the open water area has expanded greatly since the completion of the Sungai Chini barrage in 1995.

Topographically, the lake is surrounded by low hills and undulating land which constitute the catchment of the region. The highest hill is Bukit Ketaya rising to 209 m. The lake system is fed by waters from Sungai Datang in the North-West, Sungai Gumum in the North-East, Sungai Perupok in the west and Sungai Melai in the South. Tasik Chini is connected by a single of Sungai Chini, which meanders for 4.8 km before it meets the Sungai Pahang, the longest water-course in the Peninsula. Within the catchment, Sungai Gumum is among the major river, which supplies >45% of the total inflow (Gasim *et al.*, 2009). The geomorphological characteristics of the river are presented in Table 1. Based on the topographical map, Sheet 4258 (1992), most of the lowland areas have been converted to agricultural land such as rubber and soil palm plantation and mix crops. Logging activity is still active in the North-East from the upstream

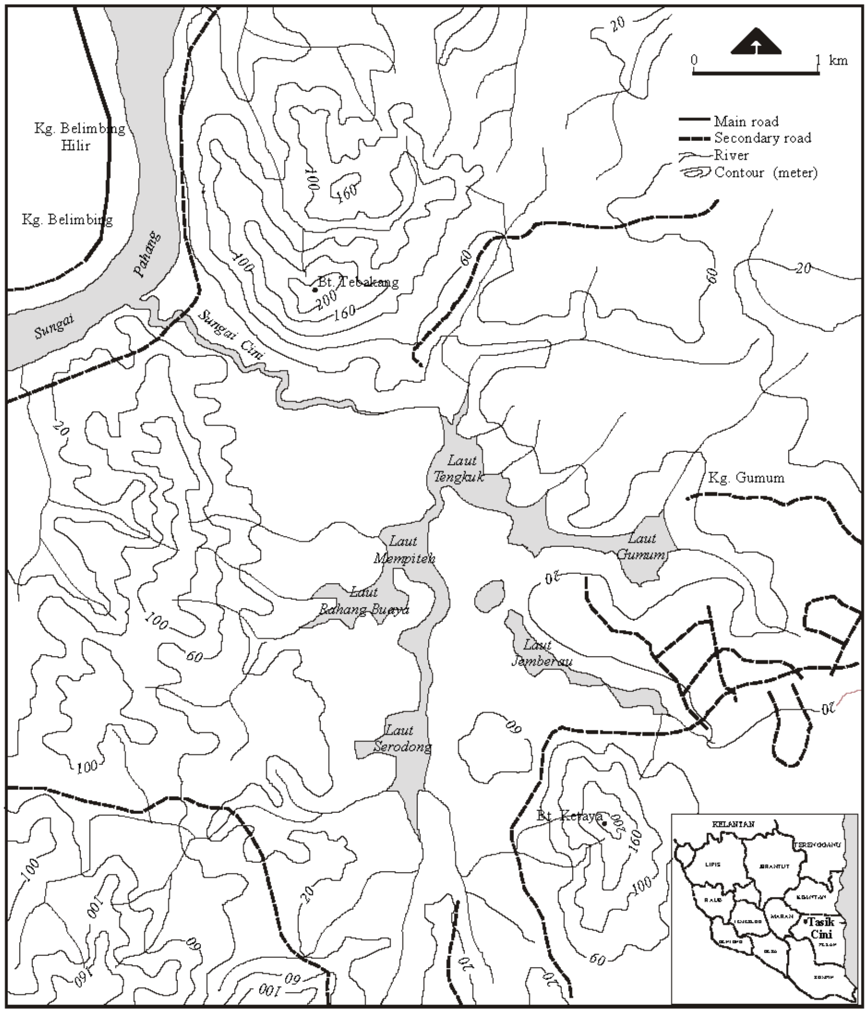

Fig. 2: Tasik chini catchment

Table 1: The characteristic of Sungai Gumum

Hydrological characteristics	Values
Area catchment (km^2)	5.2
Catchment length (km)	4.7
Catchment width (km)	2.4
Drainage density	0.33
No of tributary	4
River stage (m)	0.5-1.48

Topographical Map sheet 4258, 1992

reach of Sungai Gumum. Hydrologically, Tasik Chini catchment is representative of the upstream site of Pahang River in Pekan. This region as categorized by the hydrological Procedure No 12 (Drainage and Irrigation Department) as L_3W_2 (Regions with massive rocks predominantly of sandstones with precipitation (P) Potential Evapotranspiration (PE) is between 500-1000 mm. The soil consists of Segamat/Katong series derived from andesite andesitic and shale. The climate of Tasik Chini is typical of the equatorial climate of Peninsular Malaysia, which is characteristic by moderate average annual rainfall, temperature and humidity. The computed rainfall (P), Runoff (r) and Temperature (T) measured at Muazam Shah Climatological station is presented in Table 2. This station, which located some 56 km toward the southern part of Tasik Chini was considered as the most completed climatic records available. Although, there is the one at Rancangan Chini 2, the station is lacking in hourly rainfall and relative humidity records. In this study, the runoff was calculated determined using the Modified Rational Formula method (Toriman, 2004).

Compared with the nearest climatological stations (i.e., Kuantan: 2919 mm, Bahau: 2477 mm and Anak Keroh: 2266 mm), the Chini catchment received less rainfall as they situated in the rainshadow area, being sheltered by the Pahang mountain ranges. The wettest months stretch from September to December with maximum P occurs in

Table 2: Mean monthly and annual temperature (°C), rainfall (mm) and runoff (mm) for Tasik Chini catchment (1990-1999)

Parameters	Months												
	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Annual
P	85	51	115	164	146	88	98	108	186	258	296	466	2088
Temp	21	22	21	23	23	23	22	23	22	21	21	21	-
Runoff	35	25	38	23	19	12	18	22	27	50	51	72	392

Muazam Shah climatological station, 1990-1999, Runoff was calculated using P-PE. The PE is obtained using the Thornwaithe equation

December, while the minimum was recorded on February, which considered as the driest month. These seasonal variations influence the water level fluctuations in Tasik Chini. Prior to construction, the increase in water level of Sungai Pahang during flood season could cause a backflow into Tasik Chini. Many low-lying areas were inundated during the wet spell, which can extend for several weeks. Based on the survey carried out on the 4th April 2004, the water depth is shallow, between 0.5-5.8 m deep in the middle of Laut Gumum. Thus, it can be categorized as wetlands (Gasim *et al*., 2009). With a scenic open lake surrounded by rainforest clad hills and large beds of flowering lotus, Tasik Chini attracts many visitors, both local and international. Since 2003, the Chini National Service Camp was opened to recruit trainers from among Malaysian teenagers. This makes Tasik Chini dense with people all years round. According to Gasim *et al.* (2008), about 8400 tourists visited Tasik Chini every year with most of them originated from Europe, Australia, North America and Japan. They are attracted to this place because of peace, tranquility and availability of organized recreational activities (Mohamad and Toriman, 2006) together with the cultural attraction of the indigenous Orang Asli, who lives around the lake margins.

MATERIALS AND METHODS

In a situation, where there is insufficient data on stage-discharge, the use of traditional method like rating curve may hardly be justified. However, with the recent advancement in artificial intelligence, data mining and soft computing, there is a choice of better techniques that may help to solve the problem. Besides regression and auto-correlation statistical methods, the use of data driven non linear method such as the ANN provides solution to prediction analysis.

Technically speaking, ANN is an information processing system that roughly replicates the behaviour of a human brain by emulating the operations and connectivity of biological neurons (Bhattaacharya and Solomatine, 2000; Dawson and Wilby, 2001). From the mathematical point of view, ANN is a complex non-linear function with many parameters that are adjusted (calibrated or trained) in such a way that the ANN output becomes similar to the measured output on known data set. This method has been used widely in hydrology research, particularly in small catchment scale (<1000 km^2), i.e., discharge (Q) characteristics related to flow regulation (Dawson and Wilby, 1998; Thirumalaiah and Doe, 1998; Juahir *et al*., 2004), river water quality and sediment analyses (Najah *et al*., 2009; Avinash *et al*., 2005), replicating behaviour of hydrodynamic modeling systems (Solomatine and Torres, 1996) and variation of Q and ecological parameters vs. climate change (Clair and Ehrman, 1996; Toriman *et al*., 2009b). Although, ANN can be applied in many hydrological related fields (simulation, prediction, identification and classification), in this study, it was used to predict and quantify the relationships between time series of Q at Gumum River and Water Level (WL) recorded at Tasik Chini. Mathematically, this relationship can be describe as follows:

$$h = h(t) \text{ and } Q = Q(h)$$

Therefore,

$$Q = Q[h(t)] = Q(t) \quad (2)$$

Where stage, discharge and time are expressed as h, Q and t, respectively.

Due to unavailability of historical record of stage and Q at Gumum River, on the 4th April 2004, a temporary gauging station was constructed at the downstream site of the river, 130 m before it meets the lake. The location was selected to ensure that total Q from the river can be measured as well as to minimize potentially inundation from backflows during flood seasons. The Q (stage) through the river is measured every day for two weeks, depending on the rate of change of surface-water level (for the last five days data were used for validation of the model). For example, stage was measured thrice a day on the 6th April 2004, when prolong rainfall was recorded. The width of the river's cross section at this location is in order of 1.03 m and the maximum depth 0.57 m.

RESULTS AND DISCUSSION

A rating curve (functional relationship between stage and Q) was developed in order to design stage Q hydrograph (Fig. 3). It is pairs of measured values of stage (m) and discharge (Q m^3 sec^{-1}) obtained from temporary gauging station using velocity-area method. The result

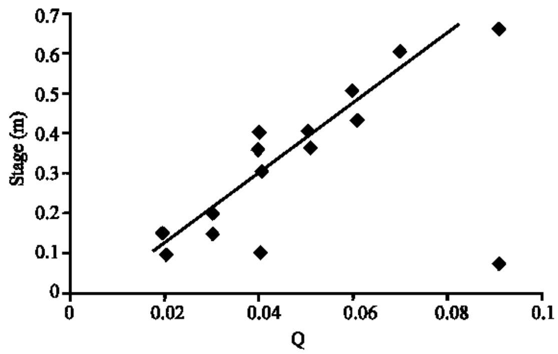

Fig. 3: Rating curve model developed for Sungai Gumum

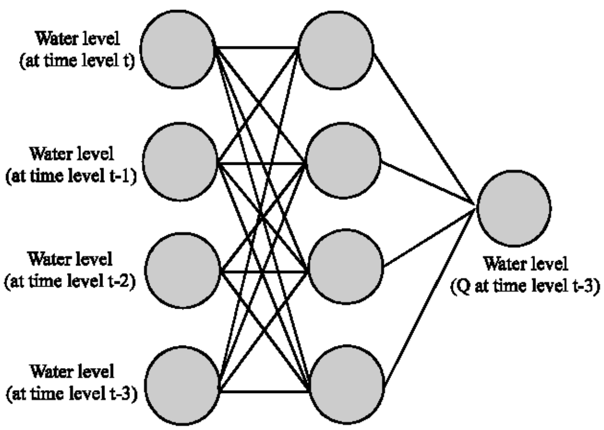

Fig. 4: Network diagram of stage-Q relationship

indicates that maximum Q was calculated at 0.09 m^3 sec^{-1} at 0.64 m depth and the minimum of 0.02 m^3 sec^{-1} at 0.1 m depth. It is generally observed that the estimated Q, most of the times remained within the reasonable proximity of the measured data. However, the stage Q model fails in establishing a definitive stage Q relationship particularly due to change in upland flow to Sungai Gumum. It can be seen clearly on the 0.092 m^3 sec^{-1}, when the water level at staff gauge showing unrealistic value (<0.1 m). Therefore, the ANN was applied to train and validate the data. All simulation programming works carried out using the MATLAB™ 6.5 software.

For training neural network, water level data at two times steps behind were considered at the principle input to the network, while Q at the previous time level as another input to the network. The output of the network remains the Q at the current time step. Hence, the neural network model consists of four input nodes, four hidden nodes and one output nodes (Fig. 4).

The validation output of ANN model is presented in Fig. 5. The Q hydrograph as estimated from the ANN model vis-á-vis the measured Q hydrograph obtained from

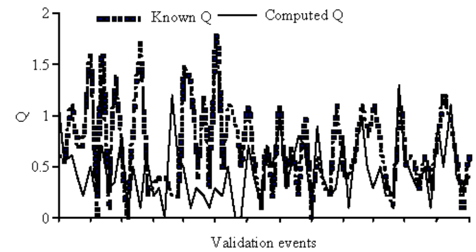

Fig. 5: Validation output of ANN model

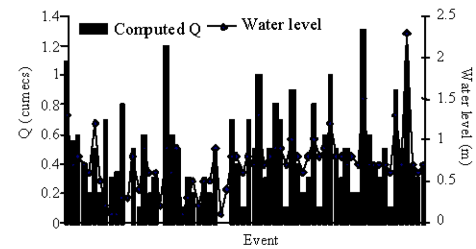

Fig. 6: The relationships between ANN prediction of Q and water level at Sungai Chini gateway

the measure data. However, in some cases, the estimated Q from the rating curve showed some variation with the measured data.

Based on the validation output, the ANN model explains 65.9% of the validation data set yielded result within 5% of error in predicting the stream Q. Meanwhile for conventional rating curve model, this is only 47.3%. The Fig. 6 confirms to the general conclusion that the percentage error of ANN output for the data set was observed to be less compared to that the conventional rating-curve model.

In order to relate with Tasik Chini water level fluctuation, the data measured from Sungai Chini were used. The relationship between ANN prediction of Q and the mean water level is presented in Fig. 6. In general, the water level fluctuation follows the Q trend. The highest mean water level was recorded during the rainy day on 6th April 2004 (2.3 m). For obvious reasons, the increase Q will be followed with higher water level. A linear regression statistical analysis was carried out to explain the relationship. Figure 7 presents the scatter plot with highly positive correlation between both parameters. The linear regression produces a coefficient of determination (R^2) of 0.89, indicating that approximately 89% of the water level fluctuation is explained by the ANN prediction of Q for Sungai Gumum and that only approximately 11% of the variability is caused by other factors such as surface run off and direct rainfall. The percentage can be the measure rating-curve. The result indicates that the estimated Q remained within the reasonable proximity of

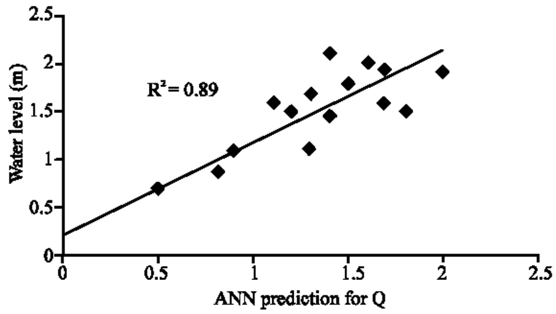

Fig. 7: Scatter plot of ANN prediction for Q and water level and least-square regression line

considerably important particularly during the study period, which subjected to fairy wet season (Table 2). The results obtained from this study indicate that during the wet period, Gumum River is the one of the main river supply of Q into the Tasik Chini. However, for water based recreation, the amount is far from enough. Although, there are other tributaries, the volume of Q is still in adequate. The scenario became problematic during the dry season.

In some places, the boats had to be dragged over the shallowest parts of the riverbed. The government provided funding for a concrete gateway to maintain the water level above the dry season flow. This was completed in June 1995 but 1.35 m higher than designed (Mohamad and Toriman, 2006). As a result, the riparian forests as well as the fringe vegetation of the lake were subjected to permanent inundation and the water depth was higher than the expected value. The impacts of this error reached crisis points in early 1997, when large tracts of the swamp forest and the Tembusu trees around the lake were apparently dead and stagnation of the water caused fish disease and mortality, especially in the Sungai Chini.

Although, the state government took action to reduce the water level by siphoning and then cutting the height of the gateway to its original design level, they are frequent suggestions from the tourism boat operators and Orang Asli, who live around to reduce the height of the gateway.

In facts, they are also extreme recommendations by completely remove of the Sungai Chini gateway. While some engineering works has been done by constructing the lock gate to control water level, further measures on the range of water level fluctuation during drought and wet seasons are still continued.

In order to restore the water balance of the Tasik Chini, restoration of the hyrological aspects of the water levels is essential. It can be carried out by removal of dead trees along the riverside and replanting of trees. This restoration approaches probably the best long-term solution as it should allow natural water fluctuations to occur in all but the driest periods, permit fish and shrimp movements between Tasik Chini and Sungai Pahang and allow boats to navigate uninterrupted up to Sungai and Tasik Chini from Sungai Pahang.

CONCLUSION

As briefly presented, the Tasik Chini is investigated. After studying the hydrological aspects including the river flow and water level characteristics, a general picture on the Sungai Gumum flows to Tasik Chini was developed. Summing up, Tasik Chini is located within the slightly less precipitation with mean monthly rainfall and runoff is 2088 and 392 mm, respectively.

Among major water supply into the lake is fed by the Sungai Gumum. In this study, the relationship between water level-discharge of Sungai Gumum was developed. Based on stage Q hydrograph, the maximum Q was calculated at 0.09 m^3 sec^{-1} at 0.64 m depth and the minimum of 0.02 m^3 sec^{-1} at 0.1 m depth.

Due to demerit of the model, the ANN modeling was applied and found promising to train and validate the data. The ANN capable to explain 65.9% of the validation data set in predicting the stream Q. Meanwhile, the linear regression analysis produces a coefficient of determination (R^2) of 0.89, indicating that approximately 89% of the water level fluctuation is explained by the ANN prediction for Q.

In the context of water use for recreation, the present water level of Tasik Chini apparently cannot support the activities. As a result, the gateway was constructed. The miscalculation of the gateway at about 1.35 m above the recommended level resulted prolonged inundation and result in the death of non flood tolerant tree species. Therefore, most of the freshwater swamp and swamp forest die-off and these continue to affect the biodiversity of tree species.

Restoration approach perhaps could return back the lake into their original functions. That's mean not only for environmental purpose but also for recreational activities. This preliminary study perhaps provides a general view on hydrological factors in relation to water level fluctuation in the Tasik Chini.

A further monitoring programme is urgently required, including forest vegetation plots, swamp forest rehabilitation experiment and remote sensing imagery interpretation, as well as assessment of the gateway's effects on fish and shrimps.

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