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WORKING PAPER

No. 29-08

Evaluating Gains from De-Eutrophication of the Dutch Canal in Sri Lanka: A Cost Benefit Analysis

W.R. Rohitha

South Asian Network for Development and Environmental Economics

February 2008

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PO Box 8975, EPC 1056
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SANDEE Working Paper No. 29-08

Published by the South Asian Network for Development and Environmental Economics (SANDEE)
PO Box 8975, EPC 1056 Kathmandu, Nepal.
Telephone: 977-1-552 8761, 552 6391 Fax: 977-1-553 6786

SANDEE research reports are the output of research projects supported by the South Asian Network for Development and Environmental Economics. The reports have been peer reviewed and edited. A summary of the findings of SANDEE reports are also available as SANDEE Policy Briefs.

National Library of Nepal Catalogue Service:

W.R. Rohita
Evaluating Gains from De-Eutrophication of the Dutch Canal in Sri Lanka: A Cost Benefit Analysis
(SANDEE Working Papers, ISSN 1893-1891; 2008- WP 29)

ISBN: **978 - 9937 - 8015 - 6 - 0**

Key words:

1. Wetland
2. Water quality
3. Sri Lanka

The South Asian Network for Development and Environmental Economics

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SANDEE is financially supported by International Development Research Centre (IDRC), Swedish International Development Cooperation Agency (SIDA) and Norwegian Agency for Development Cooperation (NORAD).

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Abstract

The Dutch canal wetland system in Sri Lanka is an important wetland area for shrimp farming and has become a promising foreign exchange earner. However, shrimp farming in the Dutch Canal is largely unplanned and un-coordinated with more than 1,300 farms working in an area of 3,750 hectares. The lack of controls has resulted in eutrophication of the lagoon system high enough to cause a decline not only in the shrimp industry's output but also in the lagoon's fish harvest. There is a plan to rehabilitate the Dutch Canal to its original water quality status at an estimated cost (in 1999) of LKR 180 million. In this study, we estimate the increase in shrimp productivity that is likely to occur if the Canal is cleaned. We find that the gains from reducing pollution in the Dutch Canal would far outweigh the cost of clean-up and the government could potentially recover the costs within two years.

Key words: Wetland, water quality, Sri Lanka

Evaluating Gains from De-Eutrophication of the Dutch Canal in Sri Lanka: A Cost Benefit Analysis

W.R. Rohitha

1. Introduction

Global shrimp production has grown at a phenomenal rate of 20-30 % per year in the last two decades. Cultured shrimp accounted for only 177,000 metric tons or 9 % of the world shrimp production in 1984. By 1994 this share had increased to about 30 %. Asia is the largest producer of cultured shrimp contributing 70 per cent of world production in 1998, of which South Asia's share was about 13 %. In the same year Sri Lanka's contribution was 0.2 % of world production (Jayasinghe 2001).

The shrimp industry in Sri Lanka has become a promising foreign exchange earner. The industry has grown rapidly thanks to the initiative of the private sector (in fact without any government support) and is concentrated in the North Western Province of Sri Lanka (Rohitha, 1997). The increasing importance of shrimp as a component of total fisheries exports can be gauged by Department of Customs reports. These show that shrimp exports accounted for half of all fisheries exports in the late 1990s.

In Puttalam district, the wetlands associated with the Dutch Canal have emerged as one of the most economically important in Sri Lanka due to an explosion of shrimp farming. Farmed shrimp is a cash crop that is mainly exported to developed countries. Since the 1980s, shrimp farming in the Dutch Canal wetlands developed rapidly without any planning or coordination (Rohitha, 1997). More than 1,300 farms are worked in this wetlands system in an area of 3,750 ha. (Siriwardena,1999). 48 % of the farms covering 40 % of the developed area are supposedly illegal and unauthorised.

The haphazard development of the industry in the Dutch canal has resulted in high eutrophication of the lagoon system. This has contributed to a decline in the shrimp industry's output as well as a decrease in the lagoon's fish harvest. In 1996 and 1998-1999, the industry faced a severe outbreak of the Whitespot virus disease, which left 75 % of the farming area fallow. The shrimp industry frequently faces such disease outbreaks resulting in low productivity and much of this problem is attributable to the self-imposed pollution of its main water source.

The financial implications of not cleaning up the Canal and the wetlands are daunting. The shrimp industry in Sri Lanka is today indebted to financial institutions by over LKR 1 billion due to capital investments and LKR 700 million of accumulated loan interest[1]. Any further disease outbreaks will jeopardise these investments. They will also endanger the employment of over 40,000 people connected directly or indirectly to the industry, apart from lagoon fishermen who are also badly affected by the eutrophication.

In 1999 the Government of Sri Lanka listened to the representations made by the shrimp farmers and prepared a proposal for cleaning up the Dutch Canal, its main objectives being ridding the canal of eutrophication and returning the lagoon to normal conditions. The total cost of this project was estimated at the time to be LKR 180 million. However, the project has yet to

[1] The conversion rate is approximately US $ 1 equals to LKR 100.

commence because the benefits of the Dutch Canal clean-up have remained unexplored. In particular, the current output losses that the shrimp farmers experience need to be linked to the high pollution level, with the potential benefits from restoring and reviving the Canal-wetlands system being made clear.

Although seemingly viable for individual farms, shrimp farming is creating significant negative externalities at the overall system level. It is important to analyse the extent of losses incurred as a result of such externalities. This would help develop guidelines for coastal aquaculture elsewhere in Sri Lanka. For example, such a study would be useful if the shrimp industry expands to the North Eastern Coast which is considered a "high potential" area for commercial shrimp farming. If the political peace process is successful, then this area may witness large scale development in coastal aquaculture.

The shrimp industry of the Dutch Canal wetlands is plagued by pollution because:
1. Individual producers do not treat their emissions into the canal
2. Planning authorities have not analysed the aggregate impact of untreated effluents emission by many ponds/farms in the same area (Neiland et.al. (2001).

While techniques to study impact analysis are available, few such studies appear in the shrimp culture literature (Neiland et.al. 2001) and the environmental effects of wetland use in Sri Lanka are also not adequately studied (2001). Our study attempts to fill this gap by valuing the environmental services of improved water quality in the Dutch canal wetland system.

To establish how the shrimp industry would benefit from reduced water pollution, we assess the value of clean water as an input to shrimp farming. The economic value of water quality in the Dutch Canal is estimated by using the Productivity Change Method (PCM). This technique estimates the value of non-market goods ----- such as environmental quality ----- when they are an input for the production of a marketable commodity by valuing its physical contribution to the marketed output. PCM is widely used to estimate the impact of deforestation, soil erosion, wetlands and reef destruction, air and water pollution etc, on productive activities such as crop cultivation, fishing, hunting etc. (Freeman 1993, Barbier et.al. 2002,). PCM has also been used to value the impact of environmental changes on the agricultural sector (Kopp et.al. 1985) which qualifies the method for our needs on shrimp farming study.

The rest of the paper is organised as follows: Section 2 describes the study area, its specificity as a wetland and the methodology, Section 3 presents the details of data collection and description. Section 4 discusses the results and Section 5 identifies the policy implications of this study.

2. Study Area and Data

The Dutch canal is a brackish water wetland that connects three lagoons in the Puttalam district in the north-western coastal region of Sri Lanka. The Dutch Canal wetland covers a strip that is 30 km at its widest and 172 km in length. Figure 1 shows the geographical location of the study area in Sri Lanka. The climate here is tropical with low variation in temperature and high variation in rainfall.[2] The Dutch Canal can be divided into three distinct sections: Wattala/Modera to Negambo lagoon; Negambo lagoon to Madampe; and Madampe to Puttalam lagoon (our study area). The length of the Dutch Canal studied is 61 kilometres and the depth of the canal varies considerably.

[2] The majority of the study area south of Mundel lagoon is in the Intermediate Zone has an annual rainfall of 1,000 to 1,500 mm and the area north of Mundel lagoon is in the Dry Zone rest with an annual rainfall less than 1,000 mm.

This canal was constructed during the Dutch colonial period (between 1658 and 1795) to transport goods. The canal connects the capital, Colombo, to Puttalam and was constructed to link different water bodies. During the Dutch and British colonial periods, the canal served as an important transport route.However, after the construction of a railway line from Colombo to Puttalam in 1926, this water route was abandoned. When shrimp farming began here in the early 1980s, this area rapidly grew into an economically vibrant region.

2.1 Study Area

Mangroves, salt marshes and sea grass beds are ecologically important ecosystems associated with the Dutch Canal wetlands (Rohitha, 1991 & 1997). Before shrimp farming developed in this zone as a commercial activity, the vegetation as reported in the topographic maps of 1984 was mainly aquatic with mangrove habitats, both marshy and barren lands, sand dunes and shores.

The expansion of shrimp farming has altered the land use completely. An estimated 1,500 hectares of mangroves have been cleared to construct shrimp farms, and this loss has upset the natural balance of the ecosystem. While shrimp farming is the premier commercial activity in this wetlands system, lagoon fishery and cattle rearing are other traditional economic activities that provide substantial income.

Most of the land along the canal is Crown land, and is leased out by private companies and individuals to run shrimp farms. At the time of leasing, the government imposed conditions aimed at protecting the natural ecosystem. Taking advantage of poor supervision and monitoring, shrimp farms began to flout these conditions. Their supernormal profits during the 1980s attracted many investors and led to the rapid expansion of the industry.

Shrimp farms use the Dutch Canal and associated water bodies as their principal water source. A very high concentration of shrimp farms is found along the Dutch Canal especially from Thoduwawa to Mundel lagoon since the water salinity and soil conditions of this area are conducive to shrimp farming.

The farms in this area can be categorised as industrial or backyard. Industrial shrimp farms usually cover a large area and comprise individual ponds of equal size arranged in an orderly way, rectangular in shape with average dimensions of 30 x 50 meters. Industrial shrimp farms are usually surrounded by high walls or fences. Backyard farms cover smaller areas with their ponds varying in size and shape, bounded by dykes smaller and ruder than those used in industrial farms. The shapes of these farms derive from natural contours along creeks and canals.

2.2 Survey Design and Data collection

We used both primary and secondary data for our study. Pollution data was collected from the National Aquatic Resources Research and Development Agency (NARA) which has been collecting water quality data (such as P^H, Dissolved Oxygen, Ammonia, Nitrate, Nitrite, Biological Oxygen Demand (BOD), Total Suspended Solid (TSS), salinity etc.) at ten monitoring points along the Dutch Canal since 1990. Five of these monitoring points, Ambakandawila, Bangadeniya, Chilaw, Karukupone, and Palavi, were chosen for this study as at least five shrimp farms around each of these monitoring stations keep written records of feed and production.

We also limited our selection of farms to those which operate as a company or partnership since they keep records for administrative and accounting purposes. This restricted our sample size to 25 farms, even though there are a number of working shrimp farms in Puttalam District. During the field survey we found that approximately two-thirds of the shrimp farms in the district are quite small (with three to five ponds each) and operate illegally. These farms usually do not keep any kind of written records and we did not collect data from them.

The primary survey collected data on production and feed from 25 shrimp farms. These farms typically have 15 to 20 ponds (although some were as large as 40 ponds). Records are maintained separately for each pond. For this study, each pond in a farm is considered a sub-farm and our sample includes 700 observed ponds. We obtained pond-wise data such as shrimp yield or harvest, feed used, and number of post-larvae (PL) seed used per pond per hectare.

To determine levels of pollution in the water of Dutch Canal, ammonia content was used as a proxy for water quality (see detailed discussion in Section 3.2). Data on ammonia concentration for the period 1995 to 2003 across the five monitoring points (mentioned above) was taken from NARA, Sri Lanka, and Aquaculture Service Centre of Provincial Fisheries Ministry, North Western Province, Sri Lanka.

3. Water Quality Valuation

In this study, the economic value of water quality in the Dutch Canal is estimated using the Productivity Change Method (PCM). This technique estimates the value of non-market goods such as environmental quality when it is an input into the production of a marketable commodity such as shrimp.

PCM involves two steps:
1. Estimating the physical relationship between the cause (environmental change) and the effect on productivity. This relationship is referred as the Damage Function.
2. Imputing a monetary value to this change. The monetary value of environmental change is obtained by multiplying the market price of the produced by the change in physical quantity of the input (Kotagama 1998).

We present below in section 3.1 the production function for shrimp farming from which we estimate the Damage function. In section 3.2 we use an econometric model with data obtained from farms in the Puttalam district to estimate the decline in shrimp output caused by eutrophication.

3.1 Methodology

A generalised neoclassical production function is used for estimating the productivity changes in shrimp farming due to pollution. This production function includes the lagoon water quality as an input, representing levels of pollution along with the other conventional inputs like capital and labour. Assuming that there are "N" numbers of shrimp farms in the Dutch Canal area the production function of i^{th} farm is given as:

$$Y_i = f_i(K_i, L_i, S_i, M_i, Q) \qquad \text{.......... } 1$$

where:

$$Q = \sum_{i=1}^{N-1} q_i \qquad \text{.......... } 2$$

and

Y_i : *Shrimp production by* i^{th} *farm*
K_i : *Capital investment of* i^{th} *farm*
L_i : *Labour of* i^{th} *farm*
S_i : *Seeds used by* i^{th} *farm*
M_i : *Material inputs of* i^{th} *farm including feed*
Q : *Aggregate pollution level of the canal*
q_i : *Pollution (effluents) released by the* i^{th} *farm*

Typically, each farm is affected by the water pollution due to effluent discharge from other farms. Typically, one would anticipate in a Nash type equilibrium, to have an interactive pollution component between the i^{th} farm and the other farms. However, we assume here that the individual pond's own emission is very small in comparison to the aggregate emission of other ponds and farms in the neighbourhood and is therefore inconsequential for its own production. The farm behaves as a pollution-taker. It is affected by the aggregate pollution of all other farms since that affects the water quality it receives at the pond gate and is therefore relevant for its own production. The i^{th} farm cannot however influence the j^{th} farm's pollution decision by its individual action. The j^{th} farm would not change its own pollution strategy based on what the i^{th} farm does in this period.

As a first step to estimating the impact of pollution on yield, we derive the marginal product (partial derivative of Yield) with respect to pollution (Q) which has a negative effect on the production of i^{th} farm:

$$\frac{\partial Y_i}{\partial Q}\left(K_i^*, L_i^*, S_i^*, M_i^*, Q\right) \leq 0 \qquad \text{.......... 3}$$

Given the level of pollution (Q) in the lagoon at the point where the farm draws the water, the shrimp farmer chooses other inputs so that the farm's profits are maximised. A decline in water quality of the lagoon adversely affects the farm's productivity and profits. If the market price of shrimps is "P", then the monetary value of environmental quality is the product of P and the marginal productivity of lagoon water quality. This is estimated as below:

$$\text{Marginal value of Clean Water} = P\frac{\partial Y_i}{\partial Q}\left(K_i^*, L_i^*, S_i^*, M_i^*, Q\right) \qquad \text{.......... 4}$$

3.2 Estimation of Shrimp Yield Function

We estimate the Yield Function of shrimp farms in line with the mathematical model set up above. In our empirical model, yield of shrimp farms depends on variable inputs such as feed, seeds (post-larvae), and quality of the water intake (pollution level). According to De Silva and Jayasinghe (1993), the shares of production cost associated with various inputs in shrimp farming are 55 % for feed, 25 % for fuel, 12.5 % for seed, 4.3 % for labour, 1 % for fertilizer, 1 % for harvesting effort and the rest are miscellaneous expenses. Most of the shrimp farms in Sri Lanka operate as cottage enterprises and maintain proper pond-specific records only for feeding and stocking, which are useful for them to determine the harvesting schedule. The records for labour and fuel expenses are unreliable since they are not recorded systematically and that is why they are excluded from the empirical yield function. As the fertilizer and harvesting effort constituted less than 1 % of production cost, they were also excluded from the empirical yield function.

The quality (pollution level) of water intake in different seasons is added to the yield function as an exogenous variable. We consider two seasons – the first six months (January to June) are labelled Season 1 and the next six (July to December) are labelled Season 2 The concentration of toxic ammonia, hydrogen sulphide, nitrates and nitrites, and biological oxygen demand (BOD) are the common measures used to assess the pollution level of water bodies. Ideally, a pollution index representing the level of pollution in the lagoon could be constructed but there is no accepted way to determine the weights for each pollutant in such an index. Further, since shrimp is most sensitive to the concentration of toxic ammonia, we take the ammonia to be representative of the pollution level. As the concentration of ammonia varies along the Dutch Canal, we use a series of dummy variables in our model to pick up the effects of pond location on the shrimp yield. Thus, our final model is presented below:

$$Y_i = f_i(F_i, S_i, Q, T, D) \quad \text{.........} \quad 5$$

Y_i : Shrimp production by i_{th} farm
F_i : Feed used by i_{th} farm
S_i : Seeds/post-larvae used by i_{th} farm
Q : Pollution level (water quality) in the Dutch Canal
T: Season (Dummy variable)
D: Location (Dummy variable)

The production function given in equation (5) is estimated empirically as equation (6) below. This is a modified version of the standard Cobb Douglas production function. It considers the possibility of non-linear relationships between seed and shrimp production on the one hand and between pollution and shrimp production on the other. It presumes that shrimp production is exponentially related to water pollution.

$$LnY_i = \alpha_0 + \alpha_1 LnF_i + \alpha_2 LnS_i + \alpha_3 LnS_i^{\,2} + \alpha_4 Q + \alpha_5 T + \beta_1 D_1 + \beta_2 D_2 + \beta_3 D_3 + \beta_4 D_4 \quad \text{.........} \quad 6$$

Table 1 describes the variables used in the estimation, the expected signs of their coefficients and also mentions the sources of data. Table 2 presents the descriptive statistics of the variables used in the production function analyses: the yield, stocking density and feeding intensity (and level of pollution) at each monitoring site.

In our set of surveyed shrimp farms, the highest average yield was recorded at Palavi (2,293 kilogrammes per hectare) and the lowest yield was recorded at Ambakandawila (1,569 kg/ha). However, the highest and lowest stocking densities were recorded at Bangadeniya (110,237 PL/ha) and Karukapone (68,716.46 PL/ha). The highest and lowest feed used were at Bangadeniya (3,517 kg/ha) and Ambakandawila (2,454 kg/ha). Our findings are within the ranges recorded in other studies (see e.g. Corea et al. 1995).

4. Analysis of Results

We present the regression estimation of the production function in Table 4 below. As expected, seed and feed have a positive effect and water pollution has a negative effect on shrimp yield. The coefficients of seed, feed, and water pollution are statistically significant at the 1 % level. The coefficient of seed - the number of post larvae (PL) introduced into a square meter of a given pond (stocking density) - is positive while that of its square is negative and both are statistically significant. This suggests that the shrimp yield (yield per hectare) is increasing at a decreasing rate as stocking density increases. It also confirms the well-known observation in the shrimp farming industry: that increasing stocking densities increases the yield but at a decreasing rate.

Feed, the most important factor of production in the shrimp industry, has a coefficient that is significant at 0.01 level. The elasticity of shrimp yield with respect to feed is 0.83 and the estimated Feed Conversion Ratio (FCR) of the shrimp industry in the study area is 1.6[3]. Though the shrimps are not efficient feed converters (Csavas 1994), the FCR recorded here are high which suggests that there is unutilised amount of feed in the pond. This is the main cause of water pollution. Thus, for every kilogram of shrimp produced, more than a matching amount of organic matter is released to the environment as dry matter content[4]. If we assume that 50 % of this effluent is solid waste, then more than 500 grams of organic matter in dissolved form is released into the environment. According to Edirisinghe et.al (1997), the crude protein content of the shrimp feed is generally 35-40 %. This suggests that for every kilogram of shrimp produced, a minimum of 30g of

[3] Feed Conversion Ratio is defined as amount of feed required (kg) to gain 1kg weight of bio mass.

[4] In the shrimp farms, 1.6 kg of feed is used to produce 1 kg of shrimp. The dry matter content of 1kg shrimp is approximately 300 grams. Shrimp feed has about 95 % of dry matter. Thus approximately 1.2 kg of dry matter is released when 1 kg of shrimp is produced.

nitrogen (according to standard calculations, nitrogen content of crude protein is 16 %) is released into the Dutch Canal and is the main cause of its eutrophication.

Our results suggest that season does not have any impact on a shrimp farm's output despite some seasonal variation in ambient temperature and rainfall. Four intercept dummy variables were used to distinguish between the five monitoring stations: Ambakandawila, Bangadeniya, Chilaw, Karukapone and Palavi (control dummy). The shrimp yield at the first four locations is significantly lower than at Palavi. While Palavi records the highest yield, Ambakandawila had the lowest yield, everything else remaining the same. The results suggest that locational differences such as soil type, salinity levels of the canal, water flow-rate of the canal and more importantly the concentration of the farms in the particular areas do matter. Bangadeniya area has the highest farm density among the five locations while Palavi has the lowest density.

A key result is the statistically significant negative relationship between water pollution and yield. Thus, the incremental per hectare yield from improving the water quality of canal can be estimated by comparing yields at varying levels of water pollution. Before the shrimp industry started operating, the water quality of the Dutch Canal can be assumed to have been at the safe level – 0.075 ppm. The current average water quality of the canal is 0.125 ppm. The predicted per hectare yields at pollution levels of 0.125 ppm and 0.075 ppm are 1,874.1 kg and 2,001.5 kg respectively (see Table 5). Therefore, farm productivity per hectare is likely to increase by 127.4 kg if water quality improves from the current level to the safe level.

4.1 Monetary Estimates of gains from Water Quality improvement

We now use the estimates of physical improvement in yield as obtained above and combine it with financial data to get monetary estimates of damages due to pollution in the Dutch Canal. This would enable us to do a cost-benefit analysis of the proposed de-eutrophication programme being considered by the government.

As a first step, we obtained the average annual market price, cost of production of shrimp and average of annual shrimp production in Puttalam District, from published and unpublished data on the shrimp industry for the period 1990 to 2003. The average market price of shrimp was LKR 640 per kg, while the average cost of shrimp production was LKR 410 per kg. About 2,000 hectares of pond area is annually used for shrimp culture in Puttalam District (this is the aggregate area cultivated in the first and second season). The current production per hectare stands at 1874.1 kg and the predicted output under clean conditions is 2001.5 kg. This would mean an increase in output per hectare of 127 kgs. Using this data, the incremental farm revenue per hectare from water quality improvement of canal is estimated at LKR 81,532. The extrapolation of incremental revenue from the pollution reduction to all ponds covering 2000 hectares in the study area provides an estimate of annual benefits equal to LKR 163 million (see Table 4).

As discussed earlier, the estimated project cost of de-eutrophication of the Dutch Canal is LKR 180 million. The above findings clearly show that resuscitation of the Dutch canal is economically feasible and the benefits that the cleaning project would generate could be recovered within 2 years even at a 10 % discount rate without affecting the present profitability of the farmers.

Our data and findings point to direct financial benefits for individual farms, and the Dutch Canal wetlands economy, from the cleaning project. Employment to the more than 40,000 workers in these farms would be further assured, and the other related trading activities could encourage additional job creation. Furthermore, since canal pollution in this study is mainly attributed to excessive (more than optimal) use of feed, an awareness programme that incentivises farmers to use optimal level of feed could in fact result in additional profits (cost saving) to the farmers.

5. Conclusions and Policy Implications

Untreated effluent emission from shrimp farms in the Dutch canal has increased the level of water pollution and adversely affected the survival of the shrimp industry in Puttalm district of Sri Lanka. Over a period of time the profits of the shrimp industry have declined due to the eutrophication of the Dutch canal system.

There is a proposal to rehabilitate (clean up) the Dutch canal which is expected to cost LKR 180 million. Our study finds that the enhanced production from cleaning the Dutch Canal would be sufficient to recover the costs of clean up in a short period (less than 2 years) without affecting current profitability of shrimp farmers. This would create opportunities for increased profits in future and would also ensure the survival and growth of the shrimp farms. The workers employed there would continue to find employment in addition to the ecological benefits that would accrue from rehabilitating the Dutch Canal.

In order to control further pollution the government needs to regulate effluent discharge into Dutch canal. Earlier attempts by Government have been unsuccessful due to insufficient resources and authority vested in the regulating institutions. The monitoring and implementation framework needs to be strengthened. The production area could be limited by keeping in mind the absorption capacity of the lagoon and the externality that each farm creates by polluting the lagoon. Planning authorities could play an important role by (a) demarcating shrimp production areas, (b) limiting effluent emission to the environmental absorption capacity of the canal, and (c) educating the shrimp farmers about the effects of lagoon pollution on their productivity.

A well-managed shrimp industry can bring much needed infrastructure to rural areas of Sri Lanka. The government recently announced that shrimp farming will be introduced to southern areas of the country. Therefore, there is a pressing need for creating a coherent national policy agreeable to all stakeholders. There are many stake holders of Dutch canal — shrimp farmers, labourers, general public with concerns for bio-diversity, and government. The conservation of Dutch canal is likely to result in a win-win situation for all the stakeholders.

6. Acknowledgements

Financial support for this study is acknowledged to the South Asian Network for Development and Environmental Economics (SANDEE). I am grateful to Priya Shyamsundar, Herath Gunatilake, Hemasiri Kotagama, Partha Dasgupta, Karl-Goran Maler and M. N Murty for valuable comments and guidance and to S. Madheswaran for advice on the econometric analysis.

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TABLES

Table 1: Description of Variables

Variables	Description	Expected sign	Source
	Dependent Variable		
Yield	Harvest from each pond in Kg/ha		Farm Records
	Independent Variables		
Feed	Feed used for entire culture cycle, Kg/ha	Positive	Farm Records
Seeds	Number of Post larvae/seed stocked in the pond per hectare	Positive	Farm Records
Water Quality (pollution level)	Concentration of toxic ammonia at the referral sampling point (ppm)	Negative	NARA and Aquaculture Services Centre -NWP
Season	Dummy variable, T= 1 for the second half of the year (July-December), = 0 otherwise	Unknown	Farm records
Location	Four dummy variables were used to capture location effect on shrimp production. D1 = 1 if Ambakandawila (Amb), = 0 otherwise; D2 = 1 if Bangadeniya (Ban), = 0 otherwise; D3 =1 if Chilaw (Chi), = 0 otherwise; D4 = 1 if Karukapone (Kar) = 0, otherwise; Palavi (Pal) is the default dummy.	Unknown	

Table 2: Descriptive Statistics of Variables

Mean and Standard Deviation (in brackets) for all variables

MONITORING STATION	YIELD Kg / ha)	SEED (Pl/ha)	FEED (kg/ha)	AREA (Hectare)	WQ (ppm)	Number of Obs. (N)
Amb	1569.2 (1107.6)	104948 (20432.9)	2454.6 (1559.3)	6658.3 (1139.2)	.19 (.16)	50
Ban	2152.11 (1548.6)	110237.2 (43776.4)	3517.9 (2284.9)	5659.7 (2752.27)	.12 (8.25E-02)	242
Chi	1796.9 (788.6)	91666.7 (24870.9)	2686.1 (1091.7)	5243.8 (1404.9)	.14 (.10284)	90
Kar	1667.1 (916.3)	68716.5 (30534.2)	2751.5 (1719.9)	5940.8 (9990.08)	9.40E-02 (.11714)	286
Pal	2293.5 (664.4)	90272.7 (23894.7)	3288.8 (1238.4)	5281.8 (1413.65)	.28 (5.18E-02)	33
Total	1873.7 (1188.5)	89595.9 (38937.9)	3011.8 (1884.02)	5774.4 (6617.7)	.12 (.1)	701

Table 3: Estimated Shrimp Yield Function

Dependent variable = log (yield per hectare)

Independent Variable	Coefficient	t-Values
Log (seed)	0.1478068***	4.01
Log (seed square)	-0.048780***	-3.24
Log (feed)	0.8343413***	38.45
Water quality	-0.6375154***	-4.16
Season	-0.0139276	-0.57
Ambakandawila (*monitoring point 1)*	-0.2493378***	-3.28
Bangadeniya (*monitoring point 2)*	-0.3068635***	-4.92
Chilaw (*monitoring point 3*)	-0.2329436***	-3.50
Karukapone (*monitoring point 4)*	-0.2584816***	-4.00
Constant	-0.2287412	-0.62
R-square	0.7389	
Adjusted R-square	0.7145	
F (9, 659)	381.25	
Number of Observations	668	

***** Significant at 1% level*

Table 4: Gains from improving water quality to a safe level in the Dutch Canal

	Amount
Predicted value of yield per hectare based on current level of pollution (Y_1 hat)	1874.135 Kg
Predicted value of yield per hectare based on safe level of pollution (Y_2 hat)	2001.529 Kg
Incremental output per hectare due to water quality improvement from current level to safe level (Y_2 hat - Y_1 hat)	127.394 Kg
Incremental revenue per hectare (price x incremental output)	LKR 81,532.16
Incremental profit of water quality improvement for the total extent of shrimp farms in the Puttalam District (incremental profit x total area under shrimp farming, which is 2,000 hectares for both seasons)	LKR 163,064,320

FIGURES

Figure 1: Study Area Map