MALAYSIAN SITE SYNTHESIS REPORT

1. Introduction

1.1. Background

Although mangroves constitute only about 2 percent of the total tropical land area, they are a dominant tropical coastal ecosystem. This strip of vegetation between land and sea is thus a rare and therefore precious natural resource. In the ever-wet tropics, mangroves may be one of the most productive of natural ecosystems. They are believed to be important in coastal protection, maintaining coastal fisheries production, producing timber as well as sequestering carbon. Much of how the mangrove ecosystem function is however still not clear. Unfortunately, many of the world's tropical mangroves have been and are still being rapidly destroyed or degraded in the past half century.

The Malaysian team selected the Sungai (=River, abbreviated as Sg.) Merbok mangroves because some members of the team have been working on the ecology of mangroves since the mid-70s and through international collaboration (Australia, Japan, UNESCO-UNDP, United Kingdom and the United States) on the Sg. Merbok mangroves since the 1980s. Apart from acquiring considerable technical expertise and experience, the Malaysian team has also accumulated, from a number of grants (mainly AUSAID, IDRC and the Government of Malaysia's IRPA grant), an almost complete range of relevant field and laboratory equipment worth about US $1,000,000. This SWOL Project is thus based on extremely solid mangrove experience and infrastructural support.

The overall aim of the Universiti Sains Malaysia Mangrove Ecosystems Group is to try to close the carbon and nutrient budgets of a mangrove ecosystem. This may sound simple but, especially with a very open (horizontally to the land and sea, and vertically to the atmosphere and mud) mangrove ecosystem, is in fact an extremely ambitious task. So that we do not lose our focus, any project that the group undertakes must be in one way or another related to this overall aim. Also, any collaboration we undertake must be on a more or less equal partnership basis.

Focus 4 of LOICZ and Objective 2 of SARCS are thus related to our group's overall aim but has an additional element, the socioeconomic aspect. We are in agreement with the importance of the socioeconomic element and an economic budget is a logical extension of the carbon and nutrient (ecological) budgets. We have thus specifically recruited an economist and a sociologist into our team for the SWOL Project.

This is a report of the results of this 4-year WOTRO funded SARCS and LOICZ sponsored USM study.

1.2. Objectives

The main objective of this report is to document the experience of trying to integrate biogeochemical with socioeconomic studies on a mangrove ecosystem and its water catchment.

There are 3 sections in the substantive part of the report. The first section describes the types of biogeochemical studies that have been undertaken, the second, the socioeconomic studies and the third, which is the bottom line of this project, illustrates our attempt to integrate or at least link the biogeochemical studies with the socioeconomic studies.

1.3. Site description

1.3.1. The sg. Merbok mangroves

The Sg. Merbok mangroves (5° 40 N, 100° 25 W - Map 1), in the northwestern Peninsular Malaysian state of Kedah has been described by Ong *et al.* (1991). It comprises an area of approximately 45 km^2 of mangroves and waterways. The main river is approximately 35 km long, being tidal for about 30 km and varies in depth from 3 m to 15 m. The freshwater part of the river is only a few metres wide. Many small tributaries feed freshwater into the estuary, which is not gauged. The waterways, at low tide, covers approximately 10 km^2 and approximately 45 km^2 (of mainly mangroves) is inundated at high tide (Simpson *et al.*, 1997).

The Sg. Merbok is a tidally energetic estuary with a 1.7 m semidiurnal tide, peak currents of 1.3 m s^{-1} and a mean freshwater discharge of 20 m^3 s^{-1}. The estuary displays a pronounced fortnightly neap-spring stratification-destratification cycle. Various physical aspects of the estuary have been described in Uncles *et al* (1990 and 1992), Dyer *et al.* (1992), Ong *et al.* (1994) and Nakatsuji *et al.* (1998).

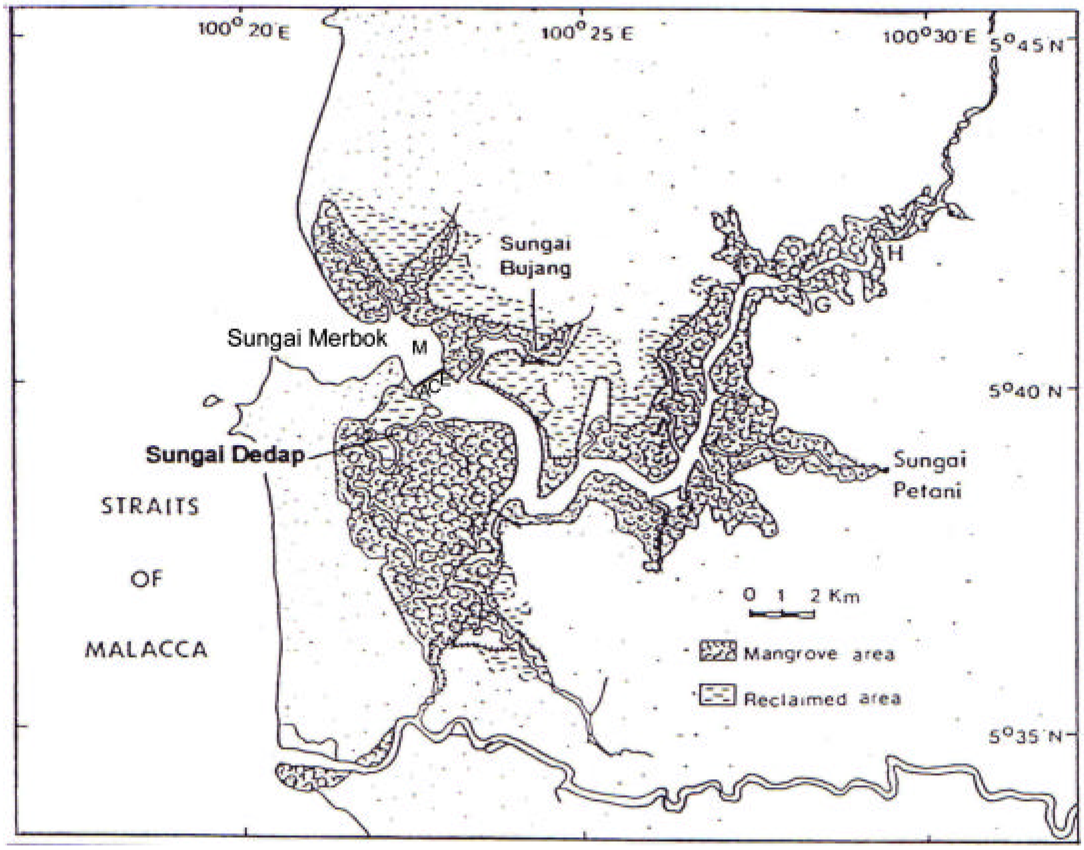
The mangroves are luxuriant, growing to about 30 m high and highly species diverse (Ong *et al.*, 1980 and Ong, 1995), although dominated by *Rhizophora apiculata* and *Bruguiera parviflora.* They are being rapidly depleted (conversion to aquaculture ponds and, more recently to housing estates). The mangroves have been harvested on a sustainable yield basis on a 30-year rotation.

There is a meteorological station situated in Sg. Petani. Daily temperature ranges from about 24°C to 34°C and is almost constant through the year. The region is dominated by the northeasterly monsoon from November to March and the southwesterly monsoon from May to September. The monsoons are very mild because of shielding by the peninsular mountain range and the island of Sumatra. The strongest winds rarely exceed 5 m s^{-1} (from the northwest) and there is no wind 60% of the time. There is no really dry month and the heaviest rains are inter-monsoonal (Figure 1). The annual rainfall is just over 2000 mm.

Geologically, the water catchment, which measures some 550 km^2, is made up of alluvium deposits overlying an extensive span of ferruginous shale and mudstone with a few scattered outcrops of granite and ferruginous sandstone/quartzite.

Most of the catchment is rice fields (some of which, mainly on the north, are reclaimed mangroves) but there are small patches (on higher ground) of rubber and oil palm. The main town is Sg. Petani, a typical medium size Malaysian town, with a human population of about 150,000. The total human population for the mangroves and catchment is around 300,000. There are no human dwellings within the mangroves but there are a number of villages on the fringes whose population rely on mangrove and its related resources (mainly mangrove timber and fish).

Map 1. The Sg. Merbok Mangroves and its water catchment.



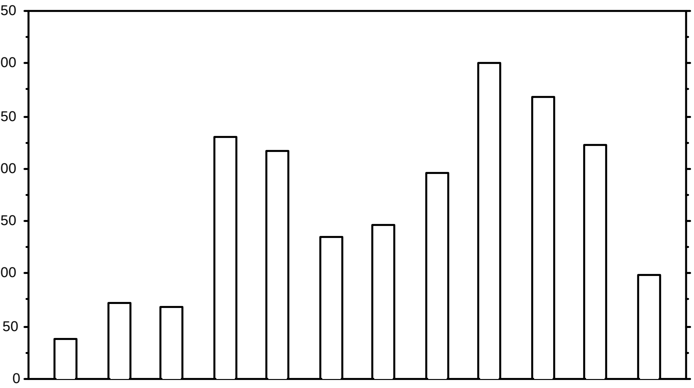


Figure 1. Monthly rainfall (10-year mean from 1976-1985) for Sg. Petani. Data from the Malaysian Meteorological Service.

1.3.2. Brief socioeconomic profile of the Merbok

The following is an outline of the main pressures that operate in the Merbok system.

1.3.2.1. Human population

Based on the 1991 population census (Malaysia, Department of Statistics, 1991), the study area experienced an increase in population from 137,115 in 1980 to 193,991 in 1990, with an annual growth rate of 3.8 percent. This growth rate is equivalent to the growth for the state of Kedah and slightly higher than the national average. However, to be able to gauge the population pressure, the population distribution and the growth rate is analysed (Table 1). The highest population growth occurs in the middle reaches of Sg. Merbok, mainly concentrated around the mukims (=sub-districts) of Sg. Petani and Sg. Pasir. The major tributaries of Sg. Merbok, Sg. Pasir and Sg. Petani and its branches Sg. Bakar, Sg. Gelugor and Sg. Mendideh pass through these mukims. The mukims population in 1980 was 65.2% of the total population of the study area whilst in 1991 the population was 74.2% of the total population. There is an increase from 89,449 in 1980 to 144,073 in 1991. The growth rates for the two mukims are 3.7 and 8.1 percent per annum respectively: these effectively show the rapid growing population and concentration in these two mukims. This is evidence of population pressure at the upper reaches of the Sg. Merbok Basin.

Table 1. Population distribution of the Merbok and its catchment. Population by sub-district (Mukim) 1980 and1991 percentage population growth rate.

Mukim	1980	1991	%
Merbok	12,562	12,433	-0.01
Bujang	5,204	5,897	1.3
Semeling	13,489	13,656	0.1
Sg. Petani	68,917	99,445	3.7
Sg. Pasir	20,532	44,628	8.1
Simpor	4,116	4,694	1.3
Bukit Meriam	4,766	4,977	0.4
Kota	2,643	2,974	1.2
Kuala	2,322	2,603	1.1
Rantau Panjang	2,564	2,684	0.4

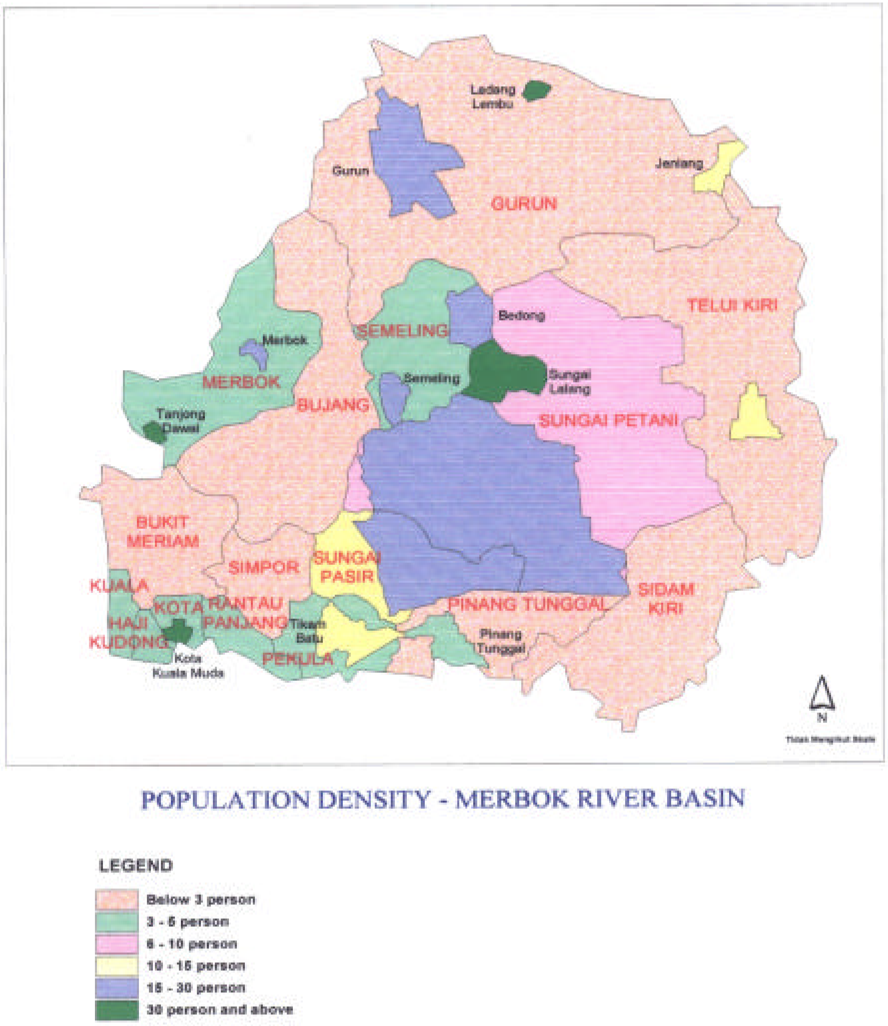
[Source : Malaysia, Department of Statistics (1980 and 1991); Malaysian Housing Population Census 1980 and 1991]

Further upstream, the river passes through the mukims of Semeling and Gurun. The 1980 population in Semeling was 13,489 and in Gurun 27,509, whilst in 1991 it was 13,656 and 31,929 respectively. Semeling experienced a minimal increase in population (growth rate of 0.1%) whilst Gurun’s growth rate was 1.5%. This is the second area of population concentration centred in the town of Semeling, Bedong and further north in the town of Gurun. Although presently the growth rate is low, these areas are part of the linear conurbation of commercial-industrial-residential area which is expected to attract migrants. The Structure Plan Study projects the mukim (Semeling, Bedong and Gurun) growth rate between 2000-2006 to be 4.0% to 6.0% per annum. This trend suggests further population pressures.

The lower reaches of Sg. Merbok receive from the northwest side the tributaries of Sg. Bujang and Sg. Merbok Kechil which flow through the mukim of Merbok and Bujang. In 1980 the Merbok mukim population was 12,565 and in 1991, was 12,433 compared to the Bujang mukim’s smaller population of 5,204 in 1980 and 5,897 in 1991. The Merbok mukim experienced a decline in growth rate of - 0.1% per annum whilst Bujang had a minimal increase of 1.3 percent which was much below the national average. This trend suggests that the rural mukims were experiencing out migration.

On the southern bank, is the Sg. Terus tributary which links the Muda with the Merbok and flows through the mukims of Simpor and Bukit Meriam and the upper reaches of the tributaries flowing through the mukims of Kota, Kuala and Rantau Panjang on the border of the the state of Penang. The population of Simpor and Bukit Meriam was 4,116 and 4,766, respectively, in 1980 whilst in 1991, the population was 4,694 and 4,977. The population growth rate is low: 1.3 percent for Simpor and 0.4 percent for Bukit Meriam. Here again, the low growth rates indicate that the rural mukims are currently experiencing out migration.

In terms of population density (see Map 2), the highest density (above 30 persons per hectare) was at Sg. Lalang at the conurbation of Sg. Petani and Bedong; and the smaller urban centres of Kota Kuala Muda bordering Penang and the fishing town of Tanjung Dawai at the mouth of Sg. Merbok. The whole conurbation of Sg. Petani and Bedong (which also include the towns of Semeling, Merbok and Bedong) has a population density of between 15-30 persons per hectare.
The future population is expected to concentrate in the conurbation area of Sg. Petani, Sg. Lalang, Bedong and extending further north to Gurun.



Map 2. Population density (per ha) of the various mukims in the the Kuala Muda District, Kedah within which lies a major part of the Sg. Merbok Mangroves and its water catchment.

1.3.2.2. Land-Use Change

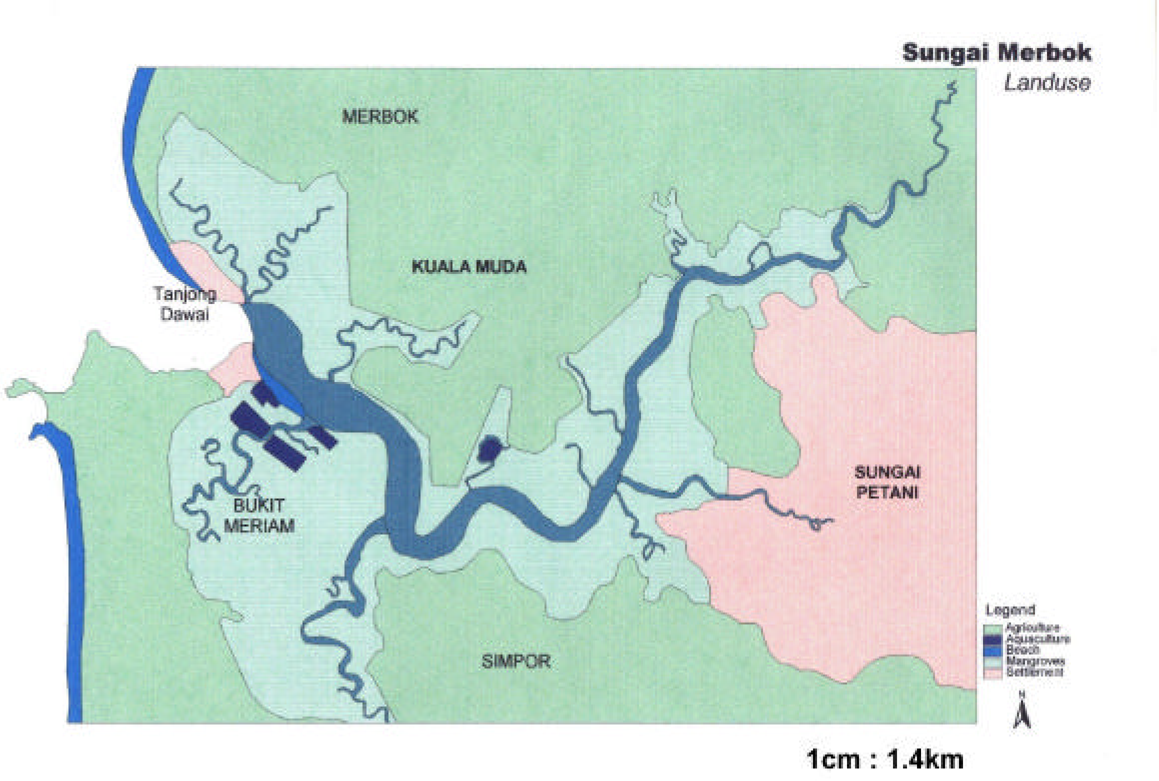
Based on the Kuala Muda Structure Plan Report 1991 for the whole district of Kuala Muda (acreage 9,268.4 ha), the largest land-use activity is agriculture (58.2%), followed by forest land (14.0%), mangroves (7.3%), housing (6.3%) and others - industry, commercial, open space (5%) (Map 3). In 1991, 2,418.7 ha of land have been approved for development out of which 91.3% is located in the existing urban settlement of Sg. Petani, Gurun, Sg. Lalang. The largest acreage is approved for housing (1,265.8 ha), followed by industrial development (720.4 ha), education (335.0 ha), institutional-government (227.8 ha), commercial (39.0 ha) and recreational (20.2 ha).

Nearer the middle reaches of Sg. Merbok, centred around the tributary of Sg. Petani and the branches of Sg. Petani and Sg. Pasir, the urban land-use is predominantly housing and industrial type. There were 39,932 living quarters in 1990 compared to 17,077 in 1980 for the two mukims. Included in the figure are units located in 20 squatters settlement in Sg. Petani. Further upstream at Semeling, Bedong and Sg. Lalang, the river flows through urban areas which are part of the Bedong /Sg.Petani conurbation. The industrial land-use acreage of 513.7 ha are found in three industrial estates of Bakar Arang, Tikam Batu and Sg. Petani , and about 449.8 ha are located outside the industrial estate mostly located linearly along major roads. Domestic discharge and industrial effluents affect Sg. Petani and Sg. Pasir.

The Sg. Merbok and its tributaries also flow through agricultural areas. At the lower reaches northwest of Sg. Merbok, rice is cultivated on the landward side along the Sg. Merbok Kechil and Sg. Bujang. On the northwest side, the irrigation system is dependent on the Sg. Merbok. There are three irrigation systems here, namely Ban Merbok (1,567 ha), Sg. Gelam (155 ha) and Tandop Pekan Merbok (77 ha). On the southwest landward side of Sg. Merbok, rice is cultivated in mukim Bukit Meriam, Kuala, Haji Kudong, Kota, Rantau Panjang and Simpor. The irrigation system here is supported by Sg. Muda. Paddy cultivation is also found further upstream especially at Sg. Petani and Sg. Pasir, bordering the urban landuse.

The land-use changes described earlier indicate that development is spreading eastward from Sg. Petani to the new town of Bandar Muadzam Shah and also westward into the mangrove areas in the middle reaches of Sg. Merbok. Expansion is also occurring linearly along the Federal road to Bedong, forming a massive urban conurbation. This encroachment affects mainly rubber estates which are converted into land for housing, commercial areas and industry.

Map 3. Pattern of land use in the Kuala Muda District of the state of Kedah, within which lies a major part of the Sg. Merbok mangroves and its water catchment.



2. BIOGEOCHEMICAL CYCLES and PROCESSES

2.1. APPROACHES

The main aim of the biogeochemical part of this exercise is to determine the flux of carbon and nutrients from the mangrove estuary into the surrounding sea as well as to try to understand the main processes involved. We are thus looking at the horizontal flows of water and the change in concentrations of carbon and nutrients accompanying these flows. Due to tidal influence many of the flows are bi-directional, greatly complicating computations. On top of this, salinity stratification during neap tides, leads to even more complications.

This is a complex task and Nixon (1980), in his lengthy and critical review on outwelling from salt marshes, had this to say:

> "The end result is that while the past 4 or 5 years have provided us with a number of studies which have attempted to obtain direct measurements of annual flux of material between coastal marshes and coastal waters, most, if not all, of these efforts did not attend closely enough to the problem of **water exchange** and did not provide us with the data needed to place any sort of **confidence estimate** on the results. We are left with a very large amount of information which we must admit is of very uncertain quality."

There are a number of methods that can be used to estimate water discharge and material fluxes from estuaries. For this exercise, the method used was the stoichiometrically linked water, carbon and nutrient budgets described in the LOICZ Guidelines (Gordon *et al.*, 1996). For comparison of this method in the mangrove ecosystem, the estuarine cross-section method was also applied. Mixing diagrams were also used.

It would be too unwieldy to present all the results here but rather the gist of what was obtained during the course of this study.

2.2. STOICHIOMETRICALLY LINKED WATER, CARBON AND NUTRIENT BUDGETS

We present here results of "BUJANG 98" which was carried out on the Sg. Bujang, a tributary of the Sg. Merbok Estuary (Map 1). The method has been described in detail in Gordon *et al.* (1996).

Water samples were collected along the entire estuary, from the sluice gate at the upper reaches of the estuary to the mouth, where the Bujang enters the Merbok.

Duplicate samples were taken at the surface and at mid-depth during a spring slack low tide and the following slack high tide, providing 4 duplicated data sets.

2.2.1. SALINITY DISTRIBUTION / MIXING

The salinity distribution during slack low tide and slack high tide for the Bujang are shown in Figure 2. For the slack low tide, a difference between surface and mid-depth salinity of up to about 7 psu can be seen with a mean difference of just less than 3 psu, indicating a partially mixed condition. During slack high tide the freshwater end of the estuary is stratified (maximum difference of about 8 psu and mean difference of about 5 psu) whilst the seawater end is almost well mixed (mean difference of less than 1 psu). Salinities ranged from about 1 to 26 psu during the slack low tide and from about 5 to 30 psu during the slack high tide.

It is obvious that it is very difficult to fulfil the well-mixed condition necessary for what is essentially a 1-dimensional model. Some sort of depth averaging may be necessary when the not too well-mixed condition occurs, or a multiple box model may be applicable (See Webster *et. al.* 2000, for relevant discussion).

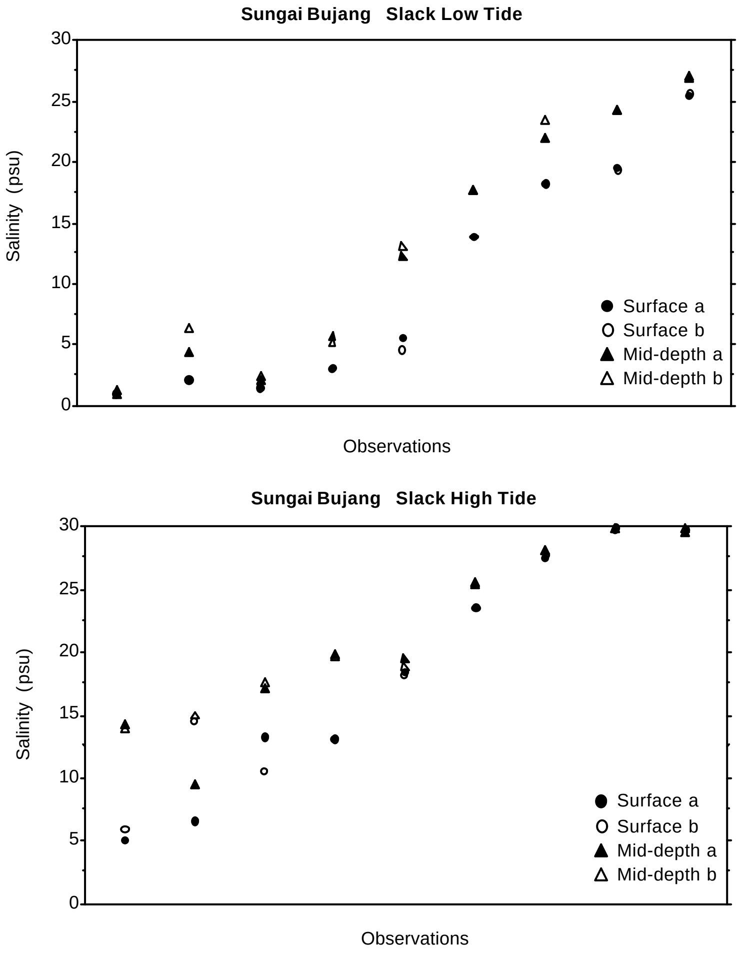


Figure 2. Surface and mid-depth salinities of the Bujang at slack high tide and slack low tide on 22 September, 1998.

2.2.2 WATER BUDGET

The estimate given here (Figure 3) is based on rainfall (2,068 mm per year) over an estimated catchment of 22 km^2 so the the amount of freshwater (V_Q) flowing into the Bujang mangrove estuary is an estimated 56% of the precipitation (i.e. an estimated 44% of precipitation is lost as evapotranspiration). This amounts to a mean (taken over a year) of $70X10^3$ m^3 d^{-1} (i.e. 0.8 m^3 s^{-1}). The amount of freshwater that goes directly into the mangrove estuary from the atmosphere (V_P -V_E) is smaller, $10X10^3$ m^3 d^{-1} (i.e. 0.1 m^3 s^{-1}). It must be emphasised that these are average numbers and are not the numbers at times of sampling and it may make a big difference whether sampling took place during the wet season or the drier season.

During our sampling periods for example, there was no rain so V_P would actually be zero and with evapotranspiration, the mangrove estuary would be losing a small (but perhaps not insignificant) amount of water to the atmosphere.

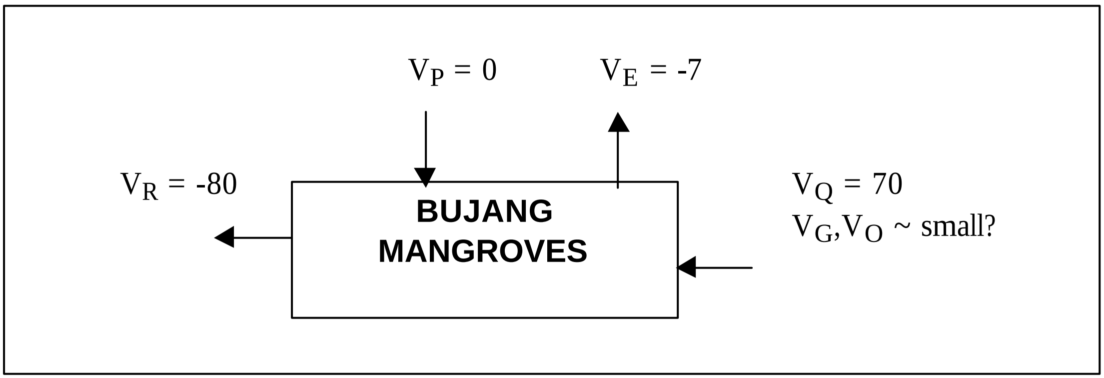


Figure 3. Water Budget (fluxes in 10^3 m^3 d^{-1}) where, V_P = precipitation;
V_E = evaporation; V_Q = stream runoff; V_G = groundwater;
-V_O = other inflows (e.g. sewage) and
-V_R = residual flow = - (70+17-7) X 10^3 m^3 d^{-1} = - $80x10^3$ m^3 d^{-1}
(Negative sign indicates out from the mangroves).

The use of mean flows has a major problem in the Bujang because of the sluice gate and the way it is operated. The sluice gate is opened (except during the dryer season when stream flow is very small or absent) when the tidal level reaches the stream level (on an ebbing tide) and is closed before the flooding tide can intrude so freshwater flow into the mangrove estuary is restricted mainly to the second half of an ebbing tide and the first half of a flooding tide. In our case, we would likely have more freshwater during the first sampling at slack low tide than the mid-day sampling at slack high tide.

The ability to accurately measure the amount of water that gets into and out of the system is perhaps by far the most important aspect of carbon and nutrient flux measurements. But, as can be seen above, this appears to be the weakest link. The ability to measure the error involved in this step would at least allow us to state the confidence of our estimation of the fluxes of the other parameters.

We use mean data for our water estimate but ”instantaneous” data for salt and nutrients. Perhaps we could improve the estimate if we are also able to provide mean data for the constituents. This would mean many more samples and over a time series. The question then would be how often do we need to sample? Quarterly, monthly or weekly? Our present exercise involved just a day of sampling but there was at least 2 weeks of preparation and another 2 weeks of analyses; with some dozen people involved. Logistically it would not be possible to cover shorter than monthly sampling.

2.2.3. SALT BUDGET

An example for calculating the salt budget is given in Figure 4.

Figure 4. Salt Budget (fluxes in 10^3 kg d^{-1}) where S_1 = salinity of estuary (9.1 psu); S_2 = salinity of sea (25.5 psu); S_Q = salinity of stream runoff (0 psu); S_R = (S_2+S_1) / 2 = (25.5+9.1)/2 = 17.3 psu; $V_R.S_R$ = advective salt delivery = -80x17.3 = -1384; V_X = exchange of estuary water with ocean water needed to replace salt export, and V_X.(S_2 - S_1) = 1384. Therefore, V_X = 1384/(25.5-9.1) = $84x10^3$ m^3 d^{-1}. Surface sample, slack low tide.

The calculation of the salinity of the estuary (S_1) can be problematic. More often than not, only a single sample is taken in the estuary (where the water sample is collected for nutrient determinations); then this will be take as the salinity of the estuary. If, on the other hand, a number of samples are taken, then the mean of the salinities can be taken as the estuarine salinity. It would be even better if the bathymetry of the estuary is known and the mean salinity can then be averaged on a volume-weighted basis. In this case we use the average of 7 salinity determinations with no volume-weighted correction.

Another problem is that the salt budget relies on the water budget and thus can only be as accurate as the weakest link. Nonetheless, balancing the salt budget allows for some correction of the water budget.

2.2.4. DISSOLVED PHOSPHORUS BUDGET

Figure 5 is an example for the calculations of the phosphorus budget. DIP_P and DOP_P, dissolved inorganic and organic phosphorus that enters the estuary as rainfall, are taken as approximately zero. The budget was calculated using the single-box model for water and salt budgets. Our measurements (Foong, unpublished) indicated that DIP was negligible but the DOP input from precipitation was about 7 mol d^{-1}. The Δ(DOP and DIP) terms (known as the nonconservative nutrient flux) indicate whether the estuary is a source (-ve) or a sink (+ve) for that nutrient. This budget does not include any exchange that may occur at the water-sediment interface i.e. the exchange is assumed to be zero or close to zero

The concentrations of the different forms of dissolved phosphorus in the Bujang are extremely low (DIP ranging from 0.02 to 0.70 µM and DOP ranging from 0 to 0.79 µM). Robertson and Phillips (1995) reported PO_4 (we assume this is dissolved PO_4) ranging from 0.53 to 4.21µM in intensive shrimp ponds and 0 to 5.26 µM for pristine mangrove waterways. We had a mean total dissolve phosphorus (TDP) of 0.42 µM with a range from 0.2 to 1.14 µM. These values are comparable with the PO_4 values reported by Nixon *et al.* (1984) for the Sangga River and the Selangor River (also on the west coast of Peninsular Malaysia).

There is high variability (some 5 times difference between the lowest and the highest) and this may be in part due to our measuring accuracy at these low concentrations.

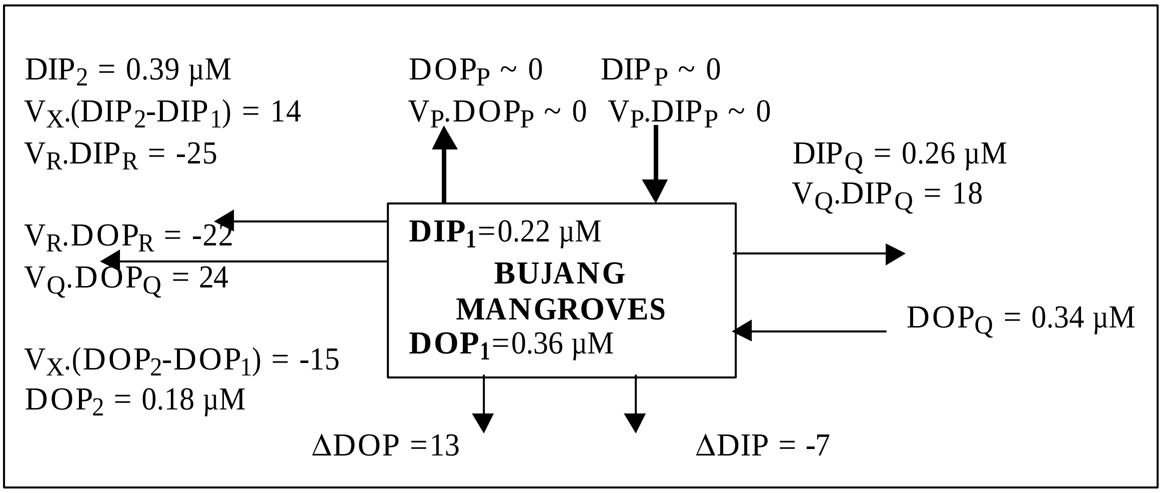


Figure 5. **Dissolved P Budget** (fluxes in mol d^{-1}) where: $DIP_R = (DIP_1+DIP_2)/2$ = 0.31 µM; $V_Q.DIP_Q$ = stream inflow of DIP (18 mol d^{-1}); $V_R.DIP_R$ = residual outflow of DIP (-25 mol d^{-1}) and $V_X.(DIP_2 - DIP_1)$ = DIP added by mixing (14 mol d^{-1}). Surface sample, slack low tide.

2.2.5. DISSOLVED NITROGEN BUDGET

Figure 6 is an example of the calculations of the nitrogen budget. DIN_P and DON_P, dissolved nitrogen that enters the estuary as rainfall, are taken as zero. The budget was calculated using the single-box model for water and salt budgets. The Δ (DON and DIN) terms (known as the nonconservative nutrient flux) indicate whether the estuary is a source (-ve) or a sink for that nutrient. This budget does not include any exchange that may occur at the water-sediment interface (i.e. exchange is assumed to be zero or close to zero). While there is no or negligible loss of phosphorus through gaseous exchange, this is not true for nitrogen, where denitrification can yield loss to the atmosphere of gaseous nitrogen or gaseous nitrogen can be can be nitrified (fixed) from atmospheric nitrogen to nitrite. Of course dissolved forms of inorganic nitrogen, as is the case with dissolved forms of inorganic phosphorus, could be also be converted to the particulate form in the water column (e.g., inorganic nutrient uptake by phytoplankton which could be significant during a phytoplankton bloom). Conversely, declining population phases of phytoplankton populations could release dissolved inorganic as well as organic nutrients.

Robertson and Phillips (1995) reported a range of 1.97 to 73.15 µM for ammonia in intensive shrimp ponds and 0.10 to 1.42 µM for pristine mangrove waterways. Our ammonia values ranged from 2 to 19 µM in the Bujang. These are similar to values reported by Nixon *et al.* (1984) for the Sangga River in the Matang mangrove forests of Malaysia.

In the Bujang, there are shrimp ponds at the head of the estuary. These ponds discharge when the tidal level is low and effluent water is likely high in ammonia and other nutrients.

Robertson and Phillips (1995) quoted nitrate concentrations ranging from 0.05 to 1.54 µM for intensive shrimp ponds and 0 to 11.75 µM for pristine mangrove waterways. Our values for nitrite+nitrate, ranging from 1.0 to 43.0 µM in the Bujang, are thus high for mangrove waterways. These are similar to a high of just over 13 µM of (nitrite+nitrate) in the rather disturbed Selangor River in Malaysia (Nixon *et al.*, 1984).

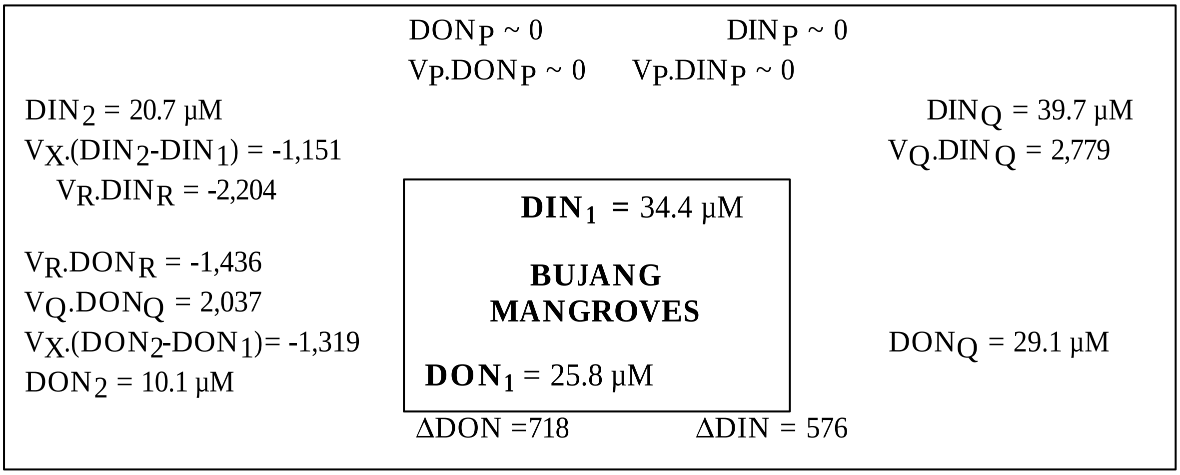


Figure 6. Dissolved N Budget (fluxes in mol d^{-1}) where:
$DIN_R = (DIN_1 + DIN_2)/2 = 28$ µM; $V_Q.DIN_Q$ = stream inflow of DIN (2,779 mol d^{-1}); $V_R.DIN_R$ = residual outflow of DIN (-2,204 mol d^{-1}) and $V_X.(DIN_2 - DIN_1)$ = DIN added by mixing (-1,151 mol d^{-1}). Surface sample, slack low tide.

The final dissolved nitrogen constituent is dissolved organic nitrogen (DON). The observed concentrations are similar to those reported by Nixon *et al.* (1984) for the Sangga River and Selangor River.

2.2.6. NONCONSERVATIVE FLUXES OF NUTRIENTS

The Δ terms in the phosphorus and nitrogen budgets, in the two examples above, refer to the nonconservative fluxes of DIP, DOP, DIN ($NH_4^+ + NO_2^- + NO_3^-$) and DON. Eight sets of data were collected and the calculated nonconservative fluxes are summarised in Table 2.

On the low spring tide (LoS and LoM), Δ phosphorus values are around zero, and consistently positive during high spring tide. ΔDIN values are positive and of similar order at both tidal extremes, with ΔDON being strongly negative on the high spring tidal phase.

Table 2. Summary of nonconservative fluxes of dissolved phosphorus and nitrogen fluxes (mol d^{-1}) for duplicate samples taken at the surface and at mid-depth during the slack low spring tide and slack high spring tide of 22 Sept., 1998.

Sample	DDIP	DDOP	DDIN	DDON
LoS1	- 8	13	586	724
LoS2	3	-11	3374	303
LoM1	- 2	2	3638	- 543
LoM2	-13	-11	3792	-3125
HiS1	37	51	1101	-3595
HiS2	35	31	3692	-2282
HiM1	46	46	4413	474
HiM2	68	75	5116	-6981
Mean	**21**	**25**	**3215**	**-1878**

[LoS=low tide, surface; LoM=low tide, mid-depth; HiS=high tide, surface;HiM=high tide, mid-depth; 1 and 2 are duplicate samples]

2.2.7. C:N:P RATIO

This is the molar ratio in particulate matter. Particulate or suspended organic matter (SOM) was measured after combustion (at 500°C) of material retained on GFC glass filters. The carbon content was taken as 50% of the SOM. Particulate nitrogen was the difference between total nitrogen (TN) and total dissolved nitrogen (TDN) and particulate phosphorus was the difference between total phosphorus (TP) and total dissolved phosphorus (TDP). It is seen (Table 3) that the particulate C:N:P is variable and the mean $C:N:P_{part}$ ratio of about 1,400:9:1 is not very different from the value 1,300:11:1 quoted for mangrove litter by Gordon *et al.* (1996).

Table 3. Summary of the C:N:P ratios and stoichiometrically derived "p-r" (mmol C m^{-2} d^{-1}) and "nfix-denit" (mmol N m^{-2} d^{-1}) for duplicate samples taken at the surface and at mid-depth during the slack low spring tide and slack high spring tide of 22 Sept., 1998.

Sample	C:N:P	***p - r***	***nfix - denit***
LoS1	1,221:7:1	3.3	2.9
LoS2	564:9:1	- 0.6	11.0
LoM1	1,414:8:1	1.0	8.7
LoM2	1,667:5:1	7.1	1.1
HiS1	1,444:15:1	-17.8	-12.8
HiS2	935:1:1	-10.9	5.1
HiM1	1,343:2:1	-20.6	2.9
HiM2	2,838:11:1	-64.2	- 7.1
Mean	**1429:8.5:1**	**-12.8**	**1.5**

2.2.8. PRODUCTIVITY MINUS RESPIRATION (*p-r*)

The stoichiometric linkage of C:N:P ratio to nonconservative fluxes is discussed in Gordon *et al.* (1996). For the phosphorus-carbon stoichiometry:

> "the ratio of C:P in the particulate material $(C:P)_{part}$, multiplied by the nonconservative flux of DIP, becomes an estimate of organic matter (p-r):
>
> $$\Delta DIC_o = \Delta DIP \, . \, (C:P)_{part}$$
>
> That is, ΔDIP scaled by $(C:P)_{part}$ ratio becomes a measure of net ecosystem metabolism. A system with $\Delta DIP>0$ is interpreted to be producing DIC via net respiration ($p-r<0$), while a system with $\Delta DIP<0$ is interpreted to be consuming DIC via net organic production ($p-r>0$). This assumption is most likely not to work with systems with an anaerobic water column, or with sediments anaerobic to the sediment-water interface. Under either of these conditions, redox-mediated phosphorus desorption from organic particles is likely to occur."

The water column is not anaerobic in the Bujang system. Also, it is not likely that conditions are anaerobic at the immediate sediment-water interface, although anaerobic conditions would likely prevail within the sediment.

The (p-r) calculated for the 8 sets of data are shown in Table 3. These ranged from -64.2 to 7.1 mmol C m^{-2} d^{-1} (i.e., heterotrophic) on the high spring tide and around zero on the low spring tide, with a tidal cycle mean value of -12.8 mmol C m^{-2} d^{-1} (mildly heterotrophic but little different from zero).

Primary productivity in a mangrove estuary, like the Bujang, consists of 2 main components: the mangrove trees (mainly mangrove litter contributes to the C, N and P in the particulates, from which the C:N:P ratios are determined) and of phytoplankton. We do not know what proportion of the particulate C, N and P is contributed by mangrove litter, but it appears to dominate. Phytoplankton production in the mangrove estuaries tends to be very low (especially during the spring tides when the estuary is mixed and the light photosynthetic compensation depth is no more than a metre). Respiration in mangrove estuarine waters, on the other hand, tends to be very high due to the high organic carbon load (some 50% of organic matter is leached from mangrove leaf litter within a few days in the water).

2.2.9. NITROGEN FIXATION MINUS DENITRIFICATION

According to Gordon *et al.* (1996),

> "Assuming that the N:P ratio of particulate material in the system $(N:P)_{part}$ is known, the dissolved nitrogen flux associated with production and decomposition of particulate material is the dissolved phosphorus flux (ΔDIP + ΔDOP) multiplied by $(N:P)_{part}$. It follows, that (nfix - denit) is the difference between the measured dissolved nitrogen flux ($\Delta N = \Delta NO_3 + \Delta NH_4 + \Delta DON$) and that expected from production and decomposition of organic matter:
>
> $$(nfix - denit) = \Delta N - \Delta P . (N:P)_{part}$$
>
> ΔDON, ΔNH_4^+ and ΔDOP tend to be small relative to ΔNO_3^-."

For the Bujang, DON and NH_4^+ occur in about the same concentration as NO_3^- so these components cannot be ignored. ΔDOP is also found to be in the same range as ΔDIP so DOP must also be in corporated in estimation of N poise.

Malaysia

The (*Nfix - denit*) calculated for the 8 sets of data are shown in Table 3. These ranged from -12.8 to 11.0 mmol N m^{-2} d^{-1} with a mean of 1.5 mmol N m^{-2} d^{-1} (i.e. notionally N fixing, but little different from zero).

On the basis of this simple single-box model approach, a first-order assessment indicates that the system (while notionally net heterotrophic) is poised around zero for net C and N fluxes. Further assessment of data with multi-box models and comparison with other model approaches (see Section 2.3) may help elucidate the sensitivity of these estimates to changes in the various system parameters and, thus refine the estimates of the net C and N metabolism of the system.

2.2.10. DISCUSSION

Measuring nutrient fluxes from wetlands and estuaries is extremely difficult. Nixon (1980) in his comprehensive review of nutrient fluxes from salt marshes showed that although many measurements have been made, he was of the opinion that less than a handful may actually be reliable.

Perhaps there are methods that will work under a particular situation but it appears that there is no single method that works under all conditions.

The “LOICZ method” that we have applied to the Bujang mangrove estuary is a relatively simple one and has the advantage of being widely used and thus providing a global picture of nutrient flux from land to ocean (one primary objective of the LOICZ programme). This method has been described in detail (with many examples of different coastal ecosystems) and the numerous assumptions and caveats for the method to be applied also have been clearly stated (Gordon *et al.*,1996). It is thus inevitable that there will be systems where these conditions cannot be met and the method should not be used. However, it provides a basis for an initial first-order assessment of the performance and measurement of changes in estuarine net metabolism of C and N.

Nutrient distribution is unlikely to be homogeneous so variability between replicates is to be expected. This brings into question the number of replicates needed and sampling strategy. While a sensitivity analysis could assist in better describing the variability, it should be noted that some of the nonconservative flux estimates for the system are around zero. Here, neither small changes in sign nor small variation in values is of concern, recognising the potentially different biogeochemical “environment” that may be induced during the different tidal states.

These data can be compared with the metabolic performance of other mangrove systems. One example (Gordon *et al.* 1996), is the mangrove estuary (Klong Lad Khao Khao in Phuket, Thailand). This was a case study on the application of the “LOICZ method”. A comparison of the Bujang mangroves with the Klong Lad Khao Khao mangroves (Table 4) may provide some insight into the suitability of the method applied to mangrove estuaries.

The area of the Thai mangroves ($6X10^6$ m^2) is twice that of the Malaysian mangroves ($3X10^6$ m^2) so, for comparison purposes, the Malaysian figure must be multiplied by 2 where rates are not given as per unit area.

It can be seen that the phosphorus concentrations of the two systems are about the same but the nonconservative flux of DIP in the Thai system is 30 times higher and that of DOP is 6 times higher. For nitrogen, both the concentrations and the nonconservative fluxes differ greatly between the two systems. The concentration of DIN is some 15 times higher in the Bujang but the concentration of DON is some 10 times lower. The Bujang exports DON but the Klong Lad Khao Khao is a comparatively massive sink. Both systems are sinks for DIN but the figure for the Bujang is 13 times higher.

Both the Bujang and Klong Lad Khao Khao can be viewed as heterotrophic systems but the Klong Lad Khao Khao is markedly so.

Table 4. Comparison of nutrient concentrations, nonconservative fluxes, C:N:P ratio, *p-r* and nfix-denit between the Bujang (this study) and the Klong Lad Khao Khao mangroves (Gordon *et al.* 1996). The area of the Thai mangrove is about twice that of the Malaysian mangrove.

Nutrient/Flux	Bujang			Klong Lad Khao Khao		
	Sea	System	Fresh	Sea	System	Fresh
DIP (µM)	0.2	0.3	0.3	0.3	1.5	0.4
DOP (µM)	0.2	0.4	0.7	0.3	0.6	0.7
DIN (µM)	11.2	30.0	33.1	1.1	1.9	4.3
DON (µM)	21.8	16.5	28.6	97.0	170.0	220.0
ΔDIP	21 mol d^{-1}			1,299 mol d^{-1}		
ΔDOP	25 mol d^{-1}			282 mol d^{-1}		
ΔDIN	3,215mol d^{-1}			500 mol d^{-1}		
ΔDON	-1,878mol d^{-1}			65,901 mol d^{-1}		
C:N:P	1,400:9:1			1,300:11:1		
p-r	-13 mmol m^{-2} d^{-1}			-230 mmol m^{-2} d^{-1}		
nfix-denit	1.5 mmol m^{-2} d^{-1}			8 mmol m^{-2} d^{-1}		

[**Note:** The figures for the Bujang were based on a mean of 8 separately measured/calculated data sets]

Overall both systems may be considered as net nitrogen fixers, although the number for the Klong Lad Khao Khao provides an unexplainedly high nitrogen-fixing environment.

For two mangrove systems that are apparently very similar, the results obtained are remarkably different. For the Bujang, only the combination of 8 different data sets appear to make some sense (but may not do so when taken individually). Comparison with other estuaries (mangrove–dominated and others in Mexico, South America, Australia and South East Asia), shows the metabolic performance of the Bujang system (around zero poise for net C and N metabolism) fits the central tendency of global data (see http://www.nioz.nl/loicz/) and is "low" compared with other mangrove systems. The "moderate" heterotrophic values for net C metabolism in the Klong Lad Khao Khao system are more representative of low latitude mangrove ecosystems.

2.3. MIXING DIAGRAMS

This approach was succinctly described by Officer (1983) as follows:

> "At some distance away from the source and providing that the waters are well mixed in the vertical and lateral directions, the conservative quantity, *c*, will mix, or dilute, in the same manner as the fresh-water fraction, *f*, in a down-estuary direction from its source, and will mix in the same manner as the salt, *s*, in an up-estuary direction. In either case the quantity dc / ds is a constant. This, then, provides a simple means for ascertaining whether a given quantity remains conservative during its passage through an estuary."

We use the same "BUJANG 98" data set for the mixing diagrams as that used previously in the stoichiometrically linked analysis.

2.3.1. SALINITY DISTRIBUTION / MIXING

This is shown in Figure 2 in the previous section. As stated earlier, mixing is good in certain parts of the estuary but not in others. Here again, the approach was basically a 1-dimensional model, so a well-mixed condition is a prerequisite for mixing diagrams

2.3.2. AMMONIA

Ammonia appeared to act conservatively (i.e. a straight line against salinity) in the Bujang at slack low tide (Figure 7). The source of ammonia is at the top end of the estuary where the water runs through hardly used rice fields (but with cattle and some human habitation) as well as a few shrimp ponds (which discharge prior to and during the slack low tide).

At slack low tide, ammonia levels dropped linearly with salinity, until it reaches the Merbok, where it levelled off. This would imply that ammonia is conservative in the Bujang.

These observations can be explained. In the Bujang, there are shrimp ponds at the head of the estuary. These ponds discharge (effluent water is possibly high in ammonia and other nutrients) when the tidal level is low and would appear to be the main source of ammonia in the slack low tide mixing diagram. Seemingly, the ammonia from the ponds is diluted as the tide ebbs. During the slack high tide (when no discharge from the shrimp ponds is expected) the ammonia concentration at the top of the estuary is similar (at the same salinities) to that seen during slack low tide which means that there was no flushing between the slack low tide and the slack high tide. This is logical since this is the flood period. So during this period, water moved into the estuary and mangroves, and little ammonia may have been absorbed (bearing in mind that the picture may have been complicated by the lack of complete mixing).

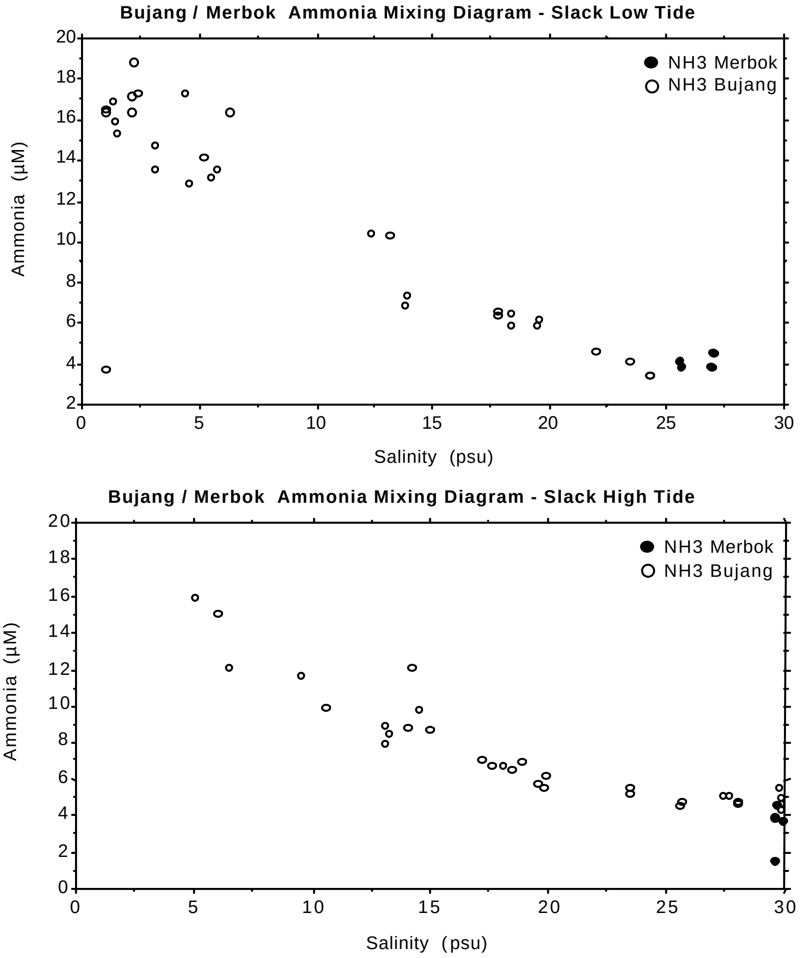


Figure 7. Distribution of ammonia with salinity along the Sg. Bujang on the spring tide of 22 September, 1998.

During the slack high tide, there is a concavity in the curve suggesting that the mangroves act as a weak sink for ammonia.

From the above, it would appear that different outcomes can result from different stages of the tide in a mixing diagram.

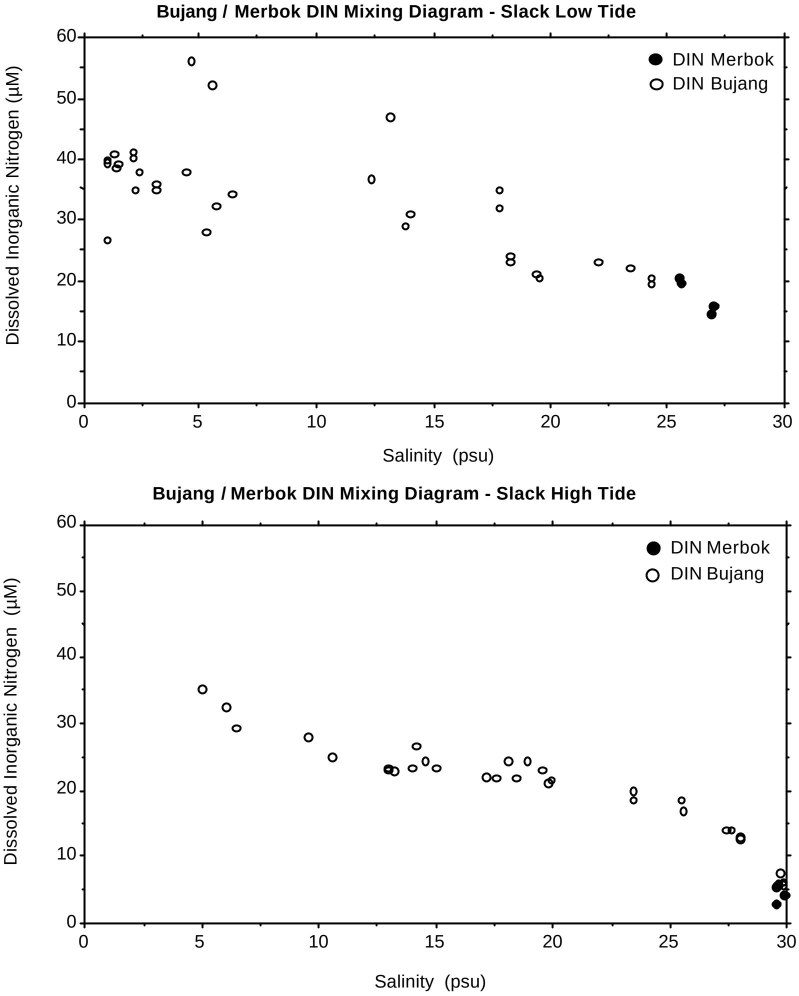


Figure 8. Distribution of dissolved inorganic nitrogen with salinity along the Sg. Bujang on the spring tide of 22 September, 1998.

2.3.3. DISSOLVED INORGANIC NITROGEN (DIN)

The dissolved inorganic nitrogen (DIN) curves show the sum of the ammonia plus nitrite+nitrate characteristics. The distribution of dissolved inorganic nitrogen (DIN) along the Bujang at slack low tide and slack high tide is shown in Figure 8. During slack low tide, the DIN concentrations ranged from 14 to 56 µM, the highest concentrations being at the freshwater end, indicating a source in the freshwater. A straight line may be drawn through the points, indicating conservative behaviour. During the slack high tide the DIN concentrations ranged from 3 to 35 µM, again with the highest concentrations in the freshwater end and lowest concentrations in the seawater end. There is a suggestion of slight concavity in the fresher waters and a slight convexity in the saltier waters, suggesting that the top part of the estuary acts as a weak sink and the bottom end of the estuary behaved as a weak source of DIN. It must be cautioned that these interpretations are under partially mixed (and not well-mixed) conditions and that data are limited.

Malaysia

DIN concentrations are highest in the fresher water and we suspect that shrimp ponds may be the source. The concentrations observed here are up to about 3 times that reported by Nixon *et al.* (1984) for the Sangga River and Selangor River.

2.3.4. DISSOLVED ORGANIC NITROGEN (DON)

There is a rather pronounced discontinuity in the DON mixing diagram for slack low tide (Figure 9), indicating that the estuary may be a sink of DON. The high concentration of DON in the Merbok waters as well as the high concentration at the top end of the estuary would suggest that the estuary is a strong sink for DON. It would be interesting to find out what is sequestering this DON. During the slack high tide, the mixing diagram shows a linear trend from freshwater to about 20 psu salinity, indicating the DON may be conservative for most of the upper end of the estuary during the incoming tide. Again, as during the low tide, the DON concentrations are higher in the Merbok. Thus there are DON sources from the top of the estuary and from the Merbok.

2.3.5. DISCUSSION (Nitrogen)

We have good confidence in the nitrogen data. Dissolved organic nitrogen is obtained by the difference between total dissolved nitrogen and dissolved inorganic nitrogen. The fact that there were only two (low) negative points was reassuring.

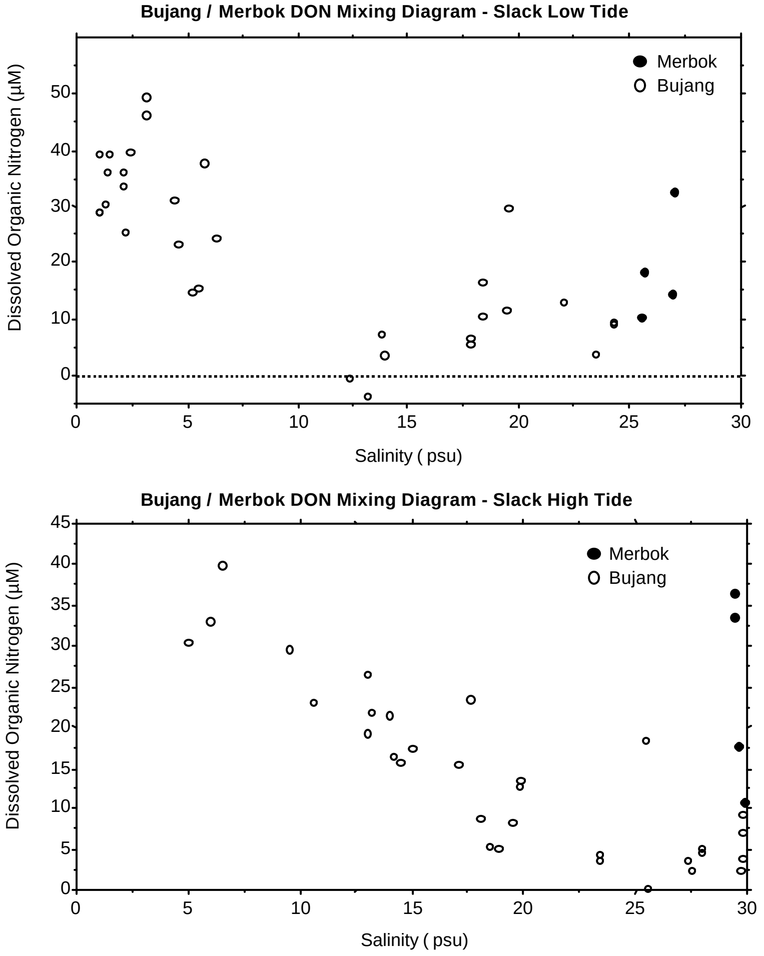


Figure 9. Distribution of dissolved organic nitrogen with salinity along the Sg. Bujang on the spring tide of 22 September, 1998.

Overall it would appear that most forms of dissolved nitrogen, except DON behaved more or less conservatively in their passage through the mangrove estuary. The mangrove estuary may be a relatively strong sink for DON. It would be most interesting to find out the mechanisms involved in the uptake of DON by the mangrove estuary, and the temporal constants.

2.3.6. DISSOLVED INORGANIC PHOSPHORUS (DIP)

The concentrations of DIP in the Bujang are low and ranged from 0.1 to 0.4 µM during slack low tide and 0.02 to 0.58 µM during slack high tide (Figure 10). DIP concentrations did not appear to change with salinity except at around 30 psu salinity during slack high tide where the DIP concentration is lower. However, many high salinity samples at slack low tide, and the 30 psu salinity samples at slack high tide, are near the limits of DIP analysis.

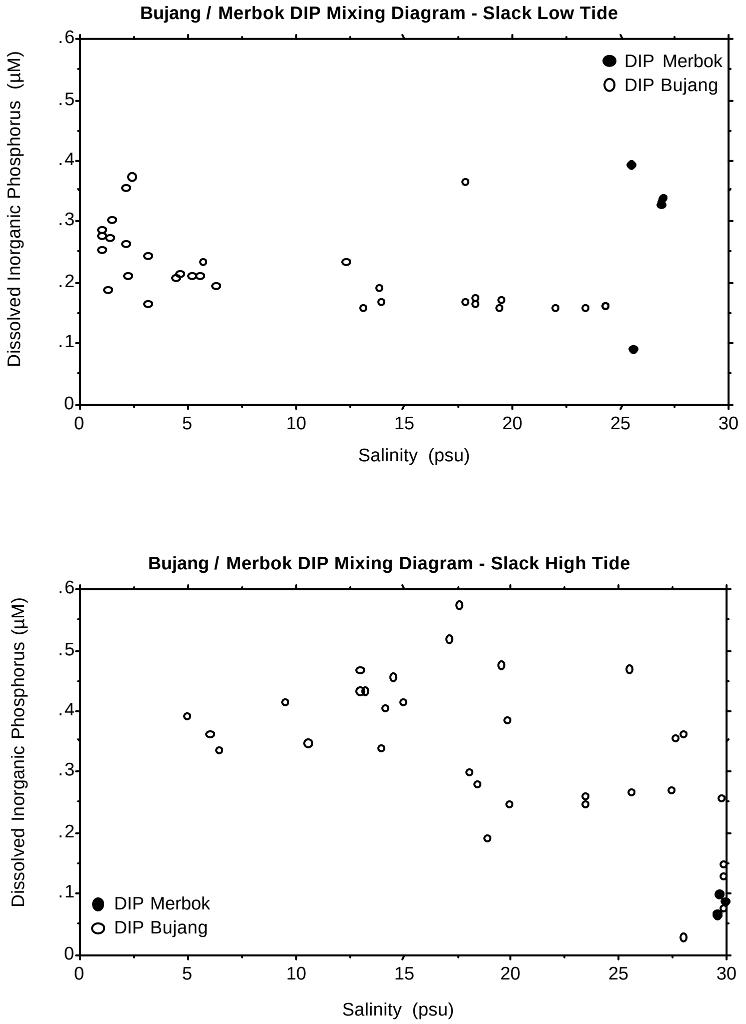


Figure 10. Distribution of dissolved inorganic phosphorus with salinity along the Sg. Bujang on the spring tide of 22 September, 1998.

2.3.7. DISSOLVED ORGANIC PHOSPHORUS (DOP)

As with DIP, the concentrations of DOP in the Bujang are low and ranged from 0.02 to 0.79 µM during slack low tide and 0 to 0.65 during slack high tide (Figure 11). DOP concentrations showed no pattern of change with salinity and exhibited a high scatter of values.

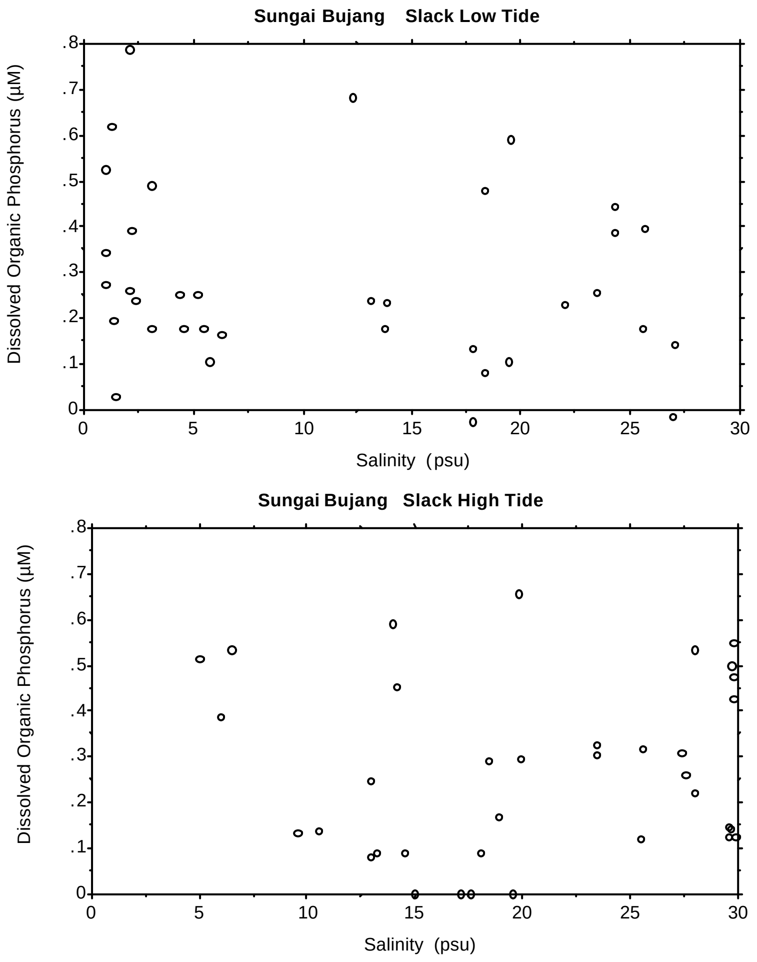


Figure 11. Distribution of dissolved organic phosphorus with salinity along the Sg. Bujang on the spring tide of 22 September, 1998.

2.3.8. DISCUSSION (Phosphorus)

The concentrations of the dissolved inorganic (ranging from 0.02 to 0.70 µM) and organic (0 to 0.79 µM) phosphorus are low in the Bujang. Robertson and Phillips (1995) gave PO_4 (we assume this to be dissolved PO_4) values ranging from 0 to 5.26 for pristine mangrove waterways in Australia, putting our values on the low side. Our values are however comparable to those reported by Nixon *et al.* (1984) for the Sangga River and Selangor River in Malaysia.

2.4. WATER DISCHARGE AND MATERIAL FLUXES FROM AN ESTUARINE MOUTH CROSS-SECTION

This method is that described by Kjerfve *et al.* (1981). It involves the establishment of a number of stations across an estuarine mouth cross-section and sampling (current speed, current direction, salinity and material whose flux is to be determined) at a number of depths over a few tidal cycles. The currents are vectorised and interpolated (spline fitted) over depth and with the sub-cross-sectional area, the water discharge can be calculated. The computation takes into account the change in depth over each tidal cycle - what is known as StokeÕs drift (this correction is more important the shallower the cross-section). The material flux is then the covariance of the water discharge and the concentration of the (strictly speaking dissolved) material in the water. The entire computation procedure was obtained from Kjerfve as a number of FORTRAN programmes that ran on a mainframe computer. We have just completed converting the programmes so that they will run on a WINDOWS OS personal computer.

We use “MERBOK 97” as an example of this approach. “MERBOK 97” was a massive exercise with very intensive measurements covering a neap-spring tidal period. Some 50 people were involved in the 2 weeks of field work.

2.4.1. DATA FROM “MERBOK 97”

The main aim is to determine the fluxes of carbon and nutrients from the estuarine - marine coastal interface of the mangrove ecosystem. The Sg. Merbok mangrove estuary was selected because the estuary has a single opening with most of the mangrove forests located behind this opening. The study involves the establishment of a number of stations to monitor and collect water samples for salt, carbon and nitrogen and phosphorus. By measuring over an entire neap-spring tidal cycle, it should be possible, in theory at least, to determine the water discharge, carbon and nutrient fluxes. Salt is measured as a conservative element so that achieving a salt balance would lend confidence to the method.

In practice, despite having carefully made many of these time-series measurements (some for as long as 31 continuous tidal cycles) on the Sg. Merbok estuary over the years, a satisfactory solution is still not in sight. The problem was summed up in Simpson *et al.*, (1997) as follows:

> “Perhaps the most serious and intractable problem we have encountered in attempting to deduce fluxes in the Merbok system is associated with the large variability of the system. The amplitude of the tidal transport (~3,000 m^3 s^{-1}) is more than two orders of magnitude greater than the estimated river input. Combined with the considerable variations observed in nitrogen levels, this leads to high variability in the daily mean total nitrogen flux and limits our ability to determine a useful average as in the present case, where our conclusion is a near-zero net flux but with wide error bounds.”

This essentially means that we need to make more accurate current speed and direction measurements.

Our previous attempt with deflected-vane current meters has uncertainties and their low resolution resulted in error bands too wide to be useful (Simpson *et al.* 1997). This time we rely primarily on the better accuracy and sampling intensity of an RDI Broad-Band Acoustic Doppler-effect Current Profiler (BB ADCP) as well as 6 moored vector-averaged recording current meters.

Four water sampling stations were established: A, C and E along the main transect and M, about a kilometre downstream (this was mainly to facilitate potential numerical modelling studies) - Map 1. A NISKIN current meter was deployed at Station A. At Station C, 3 current meters were deployed (an AANDERAA RCM7 near the surface, a General Oceanics NISKIN at about mid-depth and another RCM7 near the bottom). All 3 meters were fitted with temperature and conductivity sensors. An AANDERAA DL7 conductivity-temperature chain with five sets of sensors at 2-metre intervals (starting 2 metres from the bottom) was also deployed at Station C. An RCM7 was also deployed at about mid-depth at both Station E and Station M. All these meters were set to record vector averaged measurements at 10-

minute intervals. 2 tide gauges (ENDECO) were also deployed on the north bank of the estuary, near the stations. These were also set to record at 10 minute intervals.

Despite biofouling (resulting in having to discard about a third of the collected data) and late deployment of 2 of the current meters (RCM7s at Station E and M which had last minute problems with their data storage units) the deployed instruments yielded over 50,000 usable individual data points. This does not take into account the enormous amount of data from the ADCP (which in itself will require many months of data analyses). The data are being processed and will be compared and merged with the processed ADCP data when they become available. These will then be used to compute water discharge and checked for salt balance. They will then be used, with the carbon and nutrient data to compute the residual fluxes of carbon and the various nutrients.

Water samples were also collected continuously (every other hour at 3 depths and at mid-depth) from Station C at lunar hourly intervals over 29 tidal cycles and from all 4 stations (3 depths) lunar-hourly over the 36-hours Intensive Neap and the 24-lunar hours Intensive Spring periods. In all, over 2,000 samples of water (filtered and unfiltered) and 5,000 filters with suspended matter were collected during the field exercise. These were returned to the laboratory and analysed for salinity, total suspended solids, dissolved organic matter, total nitrogen, dissolved inorganic nitrogen, total phosphorus and dissolved inorganic phosphorus, and will result in over 12,000 data points, when all the samples are analysed. It took over a month to complete the nutrient analyses (total nitrogen and total phosphorus) and at least twice that time to complete the particulate organic matter (POM) analyses. POM analysis is done by combusting individual filters in a muffle furnace at 500°C for 3 hours.

The following are examples of some of the instrument tracings obtained during MERBOK 97. The main problem was rapid biofouling which affected the rotor type current meters as well as the conductivity sensors. For future studies, it would be advisable to recover, clean and re-deploy all these instruments after a week in the water. Only the tide gauges were not affected by biofouling.

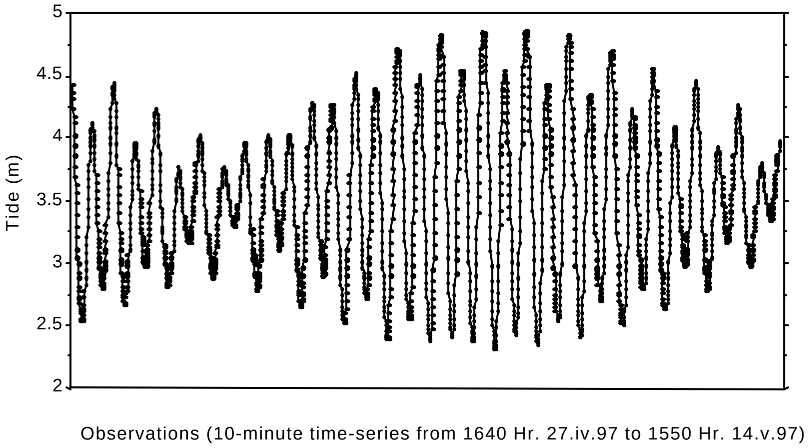


Figure 12. A perfect 17 days record of tides near the mouth cross-section of the Sg. Merbok, during MERBOK 97. A second, back-up meter, worked almost as well.

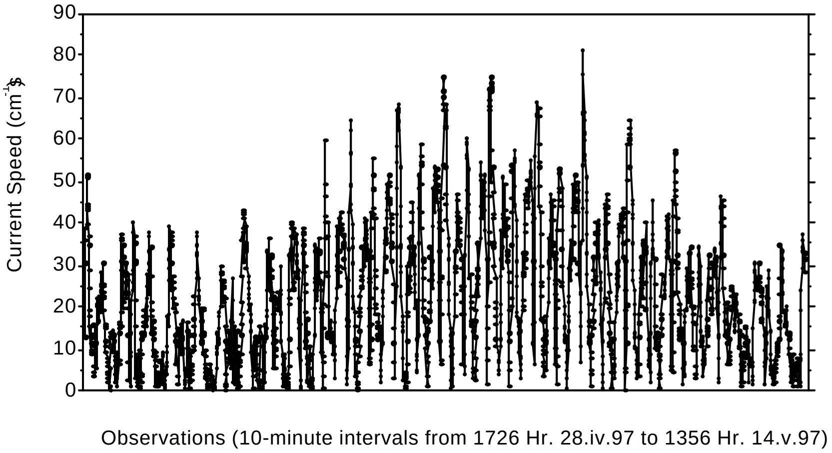


Figure 13. Current speed tracing from a General Oceanics NISKIN 6011 MK II placed at mid-depth at Station C. The winged current meter worked well for the just over 2 weeks of deployment despite biofouling. Current speed reflects the tidal amplitude.

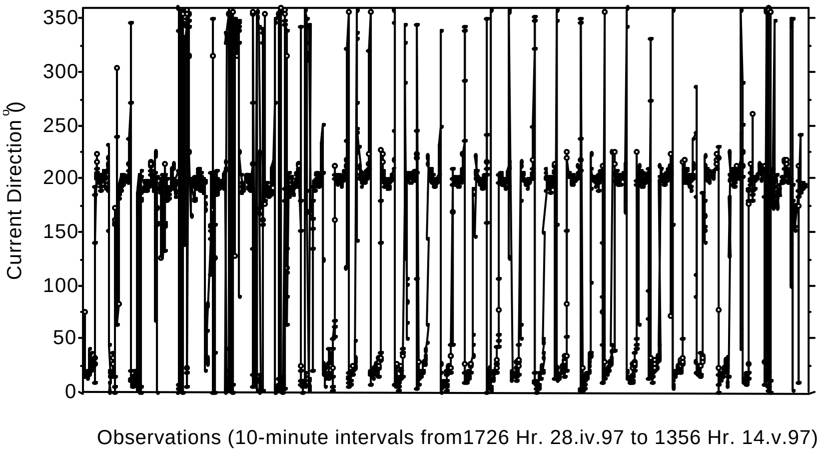


Figure 14. Current direction tracing from a General Oceanics NISKIN 6011 MK II placed at mid-depth at Station C. The winged current meter worked well for the just over 2 weeks of deployment despite heavy biofouling.

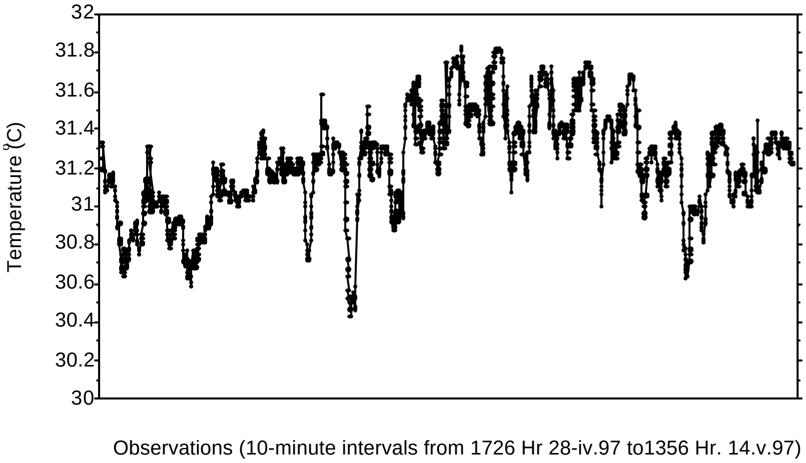


Figure 15. Temperature tracing on a General Oceanics NISKIN 6011 MK II placed at mid-depth at Station C. There was no problem with the sensor, which worked well for the just over 2 weeks of deployment despite biofouling.

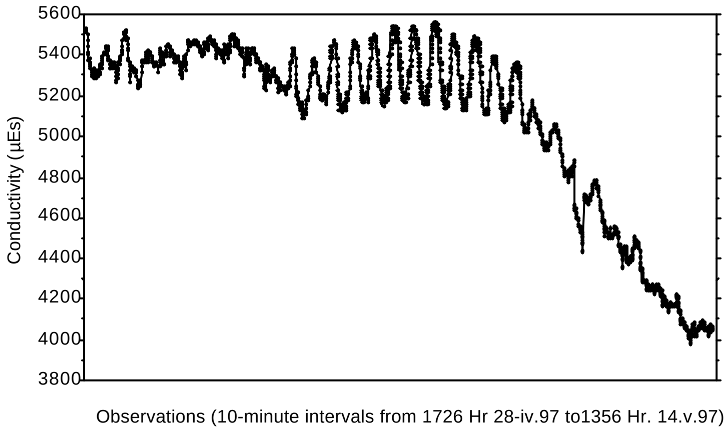


Figure 16. Tracing from the conductivity sensor on the General Oceanics NISKIN 6011 MK II placed at mid-depth at Station C. The conductivity sensor was affected by biofouling just over a week after deployment.

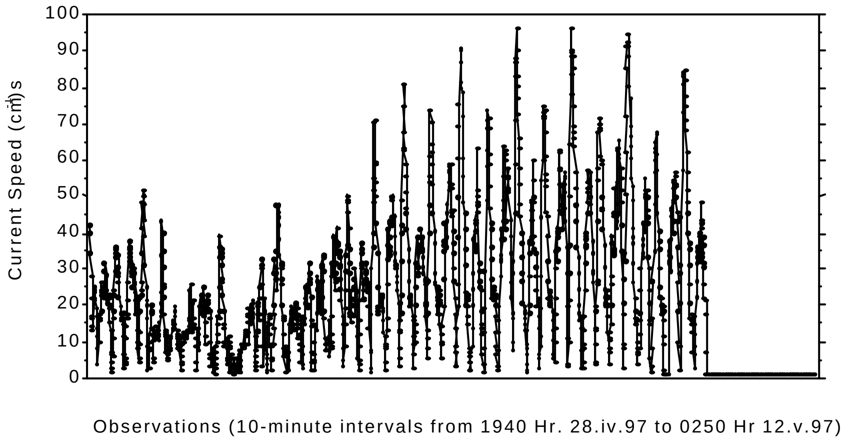


Figure 17. Current speed tracing from an AANDERAA RCM7 placed near the surface at Station C. The rotor impelled current meter failed completely after about 10 days due to rapid biofouling.

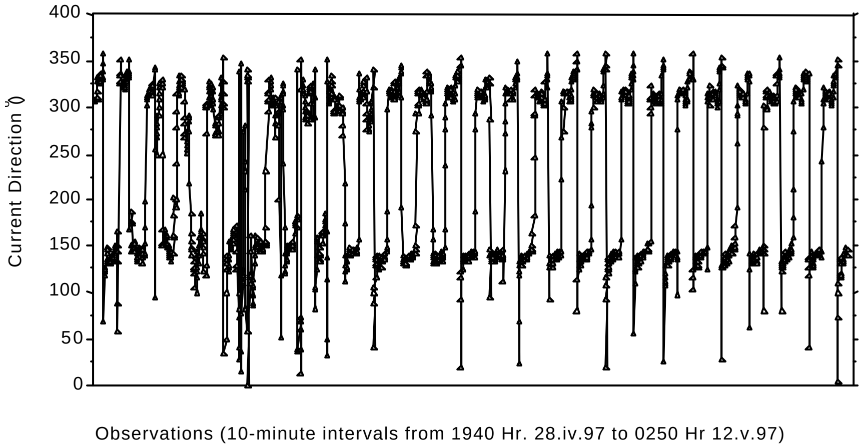


Figure 18. Current direction tracing from an AANDERAA RCM7 placed near the surface at Station C. The direction sensor was not affected by biofouling.

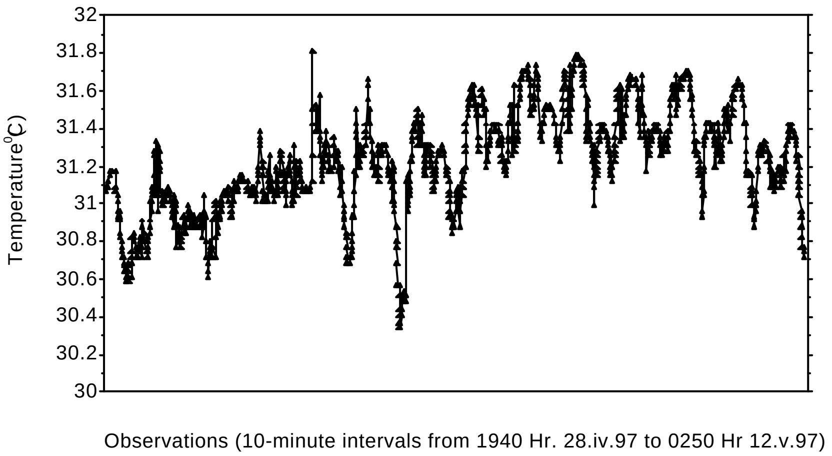


Figure 19. Temperature tracing from an AANDERAA RCM7 placed near the surface at Station C. The temperature sensor does not seem be affected by biofouling in the two weeks of deployment.

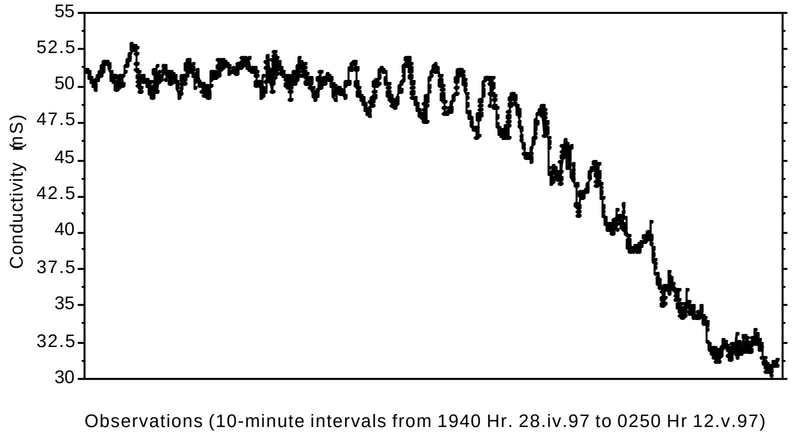


Figure 20. Conductivity tracing from an AANDERAA RCM7 placed near the surface at Station C. The conductivity sensor is affected by biofouling after only about a week in the water.

2.4.2. DISCUSSION ("MERBOK 97" FLUXES)

One of the major aims of "MERBOK 97" was to use an acoustic Doppler-effect current profiler (ADCP) for more accurate current profiling. The RDI ADCP is a 1200 kHz model (selected for its particular suitability for high resolution work in waters no more than about 30 metres deep) that can either be moored in a self-contained mode or can be mounted on a boat and operated moving along a transect. The instrument also has bottom-tracking capability so it is possible to know the velocity of the boat as well as obtain a bathymetry of the track. One problem we faced was to accurately determine the position of the ADCP at any particular time. For this we had to interface a Global Positioning System (GPS) to the ADCP via a notebook computer. Unfortunately there are no position transmitting beacons within receiving distance so we could not use the GPS in differential mode and had to accept an accuracy of no better than 50 metres.

We decided to run the ADCP on a rectangular transect continuously for 36 lunar hours during neap tide (Neap Intensive) and 24 continuous lunar hours during spring tide (Spring Intensive). The reason for running longer during neap tide is that the water stratifies during neap and there are more structures to resolve. During these periods the ADCP (which is mounted "looking down" on our boat) is continuously moved (at a constant speed) across the mouth of the estuary in a rectangular pattern. Data on current speed and direction (amongst others) are continuously collected at 1.0 metre depth intervals. During other periods the boat with the mounted ADCP is moored at Station C and set to record at 10-minute intervals (also collecting at 1.0 m depth intervals). Preparing and deploying the ADCP has been a relatively easy task but the data management and analyses are a different story. Ross Vennell has done the initial processing but, unfortunately, the group (Ross Vennell, John Simpson, Gong Wooi Khoon and Ong Jin Eong) have not yet been able to get together to get the final verdict out.

We have not been able to do the usual computations (as per Kjerfve *et al.* 1981) because (without the ADCP data) there is not enough current data as a result of the failures of some of the deployed current meters. In the meantime we are looking into improving the interpolation used in the original computations.

2.5. GENERAL DISCUSSION

In this section we compare and discuss the three methods illustrated in the previous sections, providing opportunity to evaluate the standard LOICZ method against more data-intensive methods for description of the hydrodynamics. Since we used the same data set ("BUJANG 98") for the LOICZ stoichiometric budget (LSB) method and the mixing diagram (MD) method, it is possible to compare the results of the two methods. Both rely on assumptions (eg., well-mixed conditions) that are not met by the system and the sampling regime; a multiple box model may be a more relevant compartmentation for the LOICZ approach, and potentially obviate this caveat. The comparison is shown in Table 5.

Table 5. Comparison of the "LOICZ Stoichiometric Budget" (LSB) method with the "Mixing Diagram" (MD) method: source, sink or conservative. Figures in ( ) are in mol d^{-1}.

NUTRIENT		**DIP**	**DOP**	**NH_4^+**	**DIN**	**DON**
Tidal State	**Method**					
Low Slack	LSB	Source (-5)	Source (-2)	-	Sink (2848)	Source (-660)
	MD	?	?	Conserv.	Conserv.	Sink
High Slack	LSB	Sink (47)	Sink (51)	-	Sink (3581)	Source (-3096)
	MD	Sink	?	Conserv.	Conserv.	W. sink

Unfortunately, even with the intensive sampling and analyses available for the system, the mixing diagram method provides only qualitative, not quantitative, results. This hampers a detailed comparison of the approaches but does provide for a comparative indication of trends that are insightful, especially in terms of the broad metabolic balance of the system.

While there is little apparent agreement between the methods for nitrogen assessment, it should be noted that the LSB methods yielded assessment values for net flux of N little different from zero. Hence, the inter-methodological analyses are likely to yield sign (+ or -) and small values of net N metabolism, and thus to be qualitatively variable around zero –as reflected in Table 5. The MD results for phosphorus are insufficient to compare methods, noting that the LSB method estimated a low net heterotrophy for the system. Use of a multiple box model may provide further insights and a greater understanding of the hydrodynamics and yield a more ready interpretation of net fluxes.

We had previously encountered problems with the mouth cross-sectional measurement method. One problem was in the inability to obtain a salt balance. What this means is that the amount of salt entering the estuary should be equal or almost equal to the amount of salt coming out of the estuary over a reasonable period of time (and we have time series measurements stretching to just over two weeks, covering a whole neap-spring tidal cycle). In one of our exercises (Simpson *et al.* 1995), we had forced a salt balance to compute the nitrogen flux but the error band for this estimate was large, suggesting that it would be necessary to measure the currents more accurately. This was the reason for the ADCP exercise described in the previous section. To date we have not been able to extract the necessary data. Also, during the ADCP measuring exercise, we may not have covered enough of the northern part of the cross-section so the whole exercise may have to be repeated at a future date.

The conclusion at this stage is that we do not have reliable cross-sectional measurements to compare with the LSB and MD methods. The flux measurement question should be further addressed with supporting sensitivity analysis on the components of the assessment in an effort to understand controlling processes and the effects of their variability; thus, a second phase of this project is needed.

3. ECONOMIC ACTIVITIES AND PROCESSES

3.1. APPROACHES

The overall objective of this project is to develop one or more integrated biogeochemical and economic models to understand and predict how changes in the coastal ecosystems will impact on the deeper (oceanic) waters. For this project two main interacting processes, biogeochemical and economical, are considered but it is realised that sociological processes are also important and will eventually have to be taken into consideration.

Basically, what needs to be considered are the biogeochemical, economical and sociological suites of processes. These are represented as three processes circles in Figure 21. The processes in each of the circles can be (and most of the time are) studied independently by natural scientists, economists and sociologists. In any system where humans are involved the processes from the different circles influence and interact (i.e., provide positive and negative feedback loops) with each other. So, in order to fully understand any system where humans are involved, it is not enough just to understand only one of the three aspects, or even to understand, separately, all three aspects. It is necessary to understand all three aspects (processes within each of the circles) as well as the interactions (arrows between the circles).

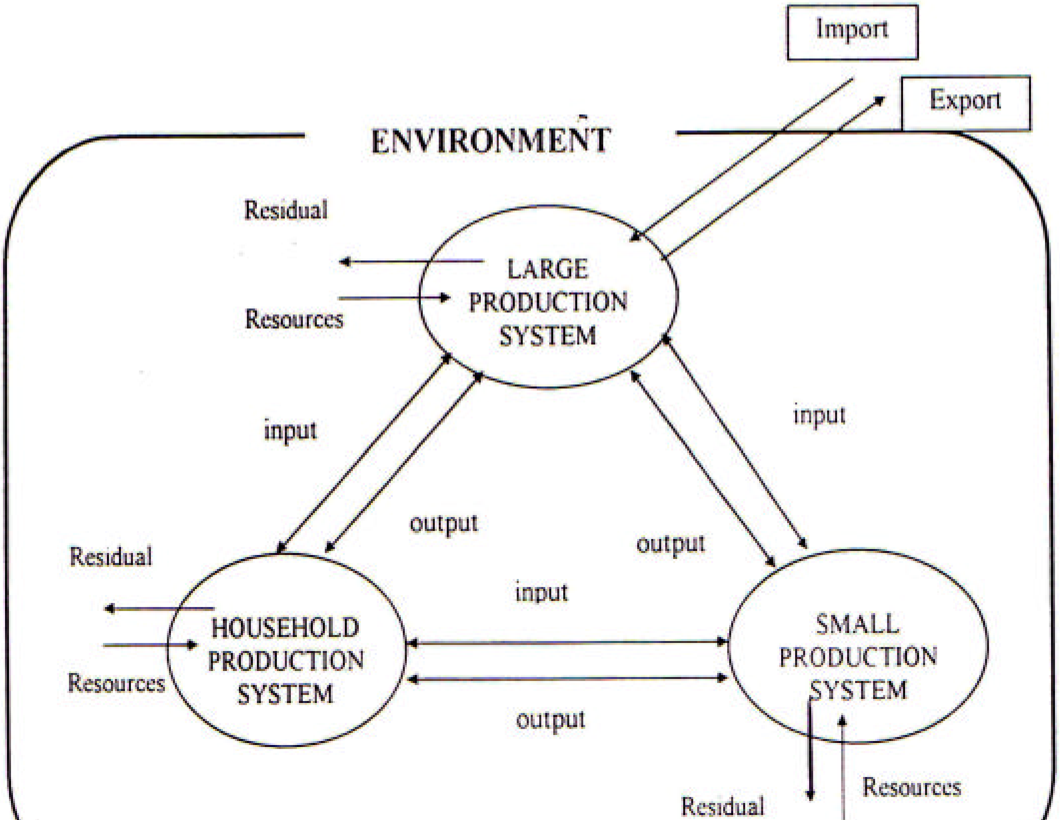


Figure 21. The biogeochemical, economical and sociological suite of processes in an ecosystem.

Malaysia

For this initial exercise, we will consider mainly the biogeochemical circle and the economic circle. The theme (decided by the natural scientists) is essentially the C, N, P fluxes between land and sea. In pristine systems, these fluxes are affected solely by various biogeochemical and physical process but in systems where humans intervene, the economical and sociological aspects have also to be considered. It is thus possible for natural scientists to work on their own to understand pristine systems but as soon as there is human intervention they need to work with economists and sociologists.

For this project, the natural scientists have basically started off working independently with the hope that the economists (and later on sociologists) will be able to fit in, and therein lies the problem of integration. The current paradigm is one based on pressure state response (psr) such that the socioeconomics is merely considered as the pressure on the system. This may be too simplistic and does not consider interaction between the different processes, much less encourage the interaction between natural scientists and socioeconomists. The paradigm shift that is needed is to consider the 3 circles of processes with equal weightage so that it will be easier to build bridges (these can be seen as feedback loops) between these circles. This is essentially what the Malaysian team has tried to do since the beginning of the project.

Whilst LOICZ provided adequate guidance for the biogeophysical model in the form of a "recipe book" as well as committed resource personnel, the same cannot be said for the economic model arena. The original suggestion (LOICZ 1996) was a pressure-state-response model but after much uncertainty, the teams eventually settled on the I/O Model. The I/O model provided one approach that could be adopted across a variety of sites and settings; it has use for short-term scenario analysis and could meet the overall project goals for inter-site comparisons.

The I/O model approach, which is a static method (top-down, using the National I/O Tables), was discussed and recommended at the Manila SWOL project meeting (LOICZ 1997). At the Surat Thani meeting (LOICZ 1998) it became clear that there were problems with the top-down approach. Vietnam was able to fulfil their objective but with a bottom-up approach. Malaysia was able to do likewise (although using only three instead of the stipulated 11 sectors).

3.2. BRIEF SOCIOECONOMIC PROFILE OF MERBOK

The mangrove ecosystem of Merbok sustains several types of production systems which are linked to each other and also externally, and these linkages are shown schematically in Figure 22. The internal structure of the production system i.e., the organisation of production and its operation as well as linkages between the production systems have implications on the socioeconomic activities of the population. The production systems are:

1. Large-scale production systems using modern methods such as large scale prawn and fish culture which are operated by private companies both local and foreign owned and also by government agencies - the Malaysian Fisheries Department and the Malaysian Fisheries Development Authority.

2. Small-scale production systems including cage fish-culture and pond prawn-culture owned by individual fishermen assisted by less than four workers. This type of production system also includes the production of charcoal from mangrove timber.

3. Household production systems based on household labour such as the lucrative bag-nets (pompang), bamboo traps (bubu) and stake-nets (tangkul).

3.2.1. MANGROVES

The Sg. Merbok mangroves were gazetted as a forest reserve in 1951 when some 2,600 hectare were classified as productive forest and another 1,400 hectare as unproductive forest, a total of just over 4,000 hectares. Some 25% of these forests has since be alienated (mainly for aquaculture ponds but more recently, near Sg. Petani, for housing). The forest is harvested for charcoal on a 30-year rotation and thinned for poles. The annual coupe was 100 hectares but it is not known if this has been reduced as a result of the alienation. There was enough timber to sustain 20 licensed charcoal kilns that produced a total of some 10,000 tonnes of charcoal annually. We suspect that the present annual production could be down to about 7,000 tonnes. At RM 500 per tonne the annual revenue from charcoal will still be in the region of RM 3,500,000 and at least that amount from poles giving a conservative total estimate of at least RM 7 million per annum from mangrove timber products alone.

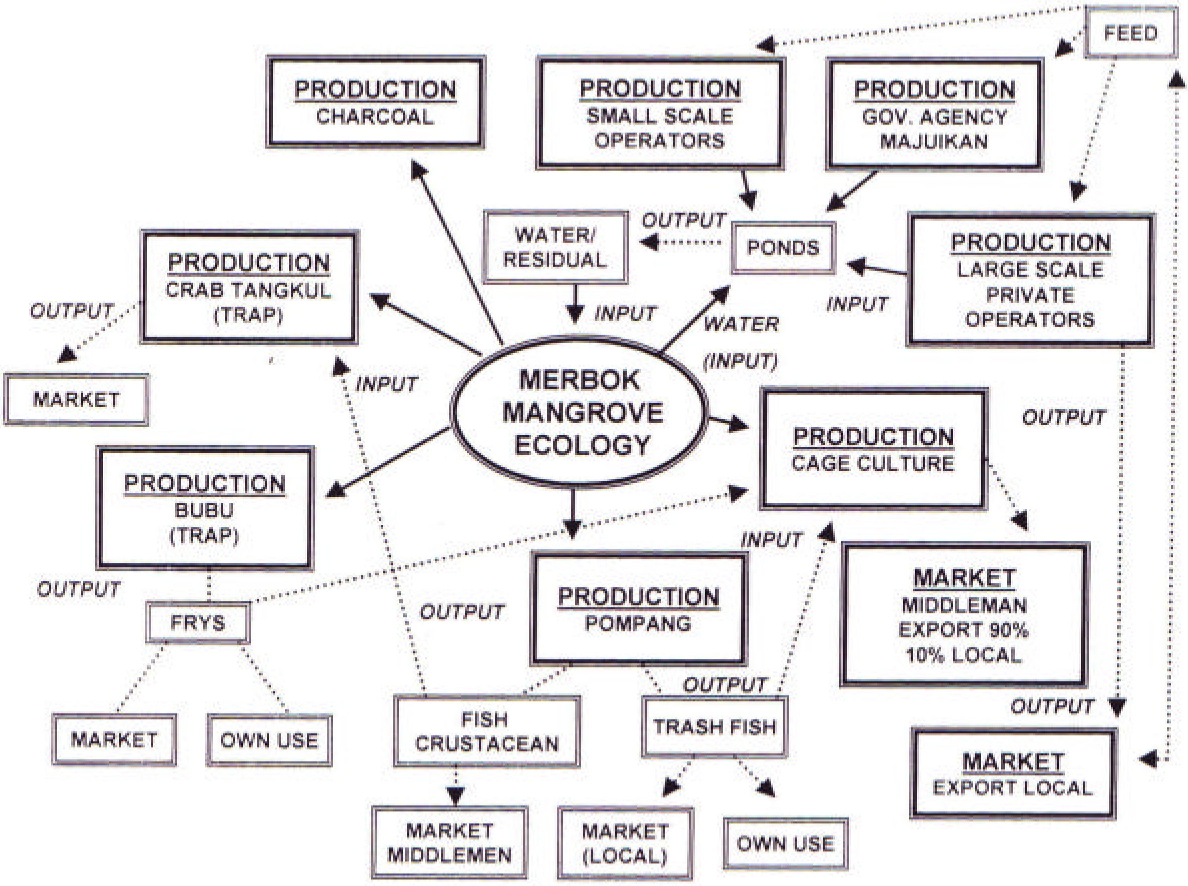


Figure 22. Production systems of the Merbok system and their linkages.

Based on 1996 data, 15 licenses were issued to charcoal kiln owners and these owners have to compete for the timber. Lim (1996) indicated that 13 of the licensees were operating at 30 percent capacity and the remaining two have sold their land and ceased operations. This trend indicates the increasing decline of the industry and based on estimates, some 600 workers were affected. The main reason for the decline of this industry is the loss of some 25% of the mangroves in the past 20 years (most of which were converted to prawn ponds) so that there was not enough mangrove timber to keep all the charcoal kilns operating at full capacity.

3.2.2. FISHERIES

As in most mangrove estuaries, fishing is a major activity here. The capture fisheries in the Merbok have been described by Khoo (1989), who listed the species composition of the bag-net ("pompang") fisheries (Table 6). Much of the catch consists of very small fish but there is a significant biomass of highly valued commercial species like pomfrets (*Pampus chinensis*), prawns (*Penaeus merguiensis* and *P. monodon*) and squid (*Loligo* spp.), making this type of fishing very lucrative. Apart from the bag-net fisheries there are other artisanal activities like push net for the shrimp *Acetes*, trapping crabs (*Scylla serrata*), trapping fish fingerlings (*Epinephalus* spp. and *Lutianus* spp.) for floating cage aquaculture and harvest of various shellfish.

The pompang fishery is based on household labour. For example, the whole village of Bakar Arang is dependent on the pompang fisheries, supplemented by small-scale cage culture, bubu and tangkul fishing. The major and most productive pompangs are at the mouth of the Sg. Merbok, which is controlled by villagers of Bakar Arang. The owners are related to each other along family lines. Pompang stakes have spread upstream at most of the major tributaries of Sg. Merbok but it appears that the pompangs here are less productive.

A pompang gate comprises two coconut trunks planted five metres apart in the river-bed and the bag-net harnessed to them. The total construction cost in 1999 was estimated to be approximately RM 1,500. The net is replaced every one and a half years. Each household owns a maximum of two gates mainly because they are constrained by the time needed to operate the net when harvesting and to clean the net after harvesting. During harvesting the operation of the net requires two people, one to manoeuvre the boat and the other to operate the net.

Pompang fishing is carried out for only 14 fishing days each month (7 days spring tide at the beginning of the lunar month and another 7 days of spring tide around the middle of the lunar month). The bag-net is set twice daily (during the day and night high tides). In order to supplement their income, the households also undertake fish cage culture. The fries for their cage culture are obtained from local fishermen or are captured from the mangrove estuary using bubu (fish trap). Feed for the fish cage culture is trash fish from pompang fishing.

The catch from pompang during each haul is estimated to average about 2 kg of pomfret (*Pampus chinensis*), 2 kg of other edible fishes, 7 kg of small prawns, 3 kg of big white prawns (*Peneaus merguiensis*) and 500 g of tiger prawns (*P. monodon*), 4 kg of squid and 10 kg of trash fish. Pomfrets fetch RM 30 per kg, large prawns fetch RM 10 per kg and tiger prawns, RM 30 per kg. A rough estimate of income from the more productive areas is between RM100-200 per fishing day. The pompang catch are sorted out by women, mainly wives and daughters of the fishermen.

The prawns and fish are sent to the local market by three local level wholesalers. The wholesalers are also related to the local fishermen.

The pompang fishing method is directly linked to the mangrove ecosystem and it is dependent on the mangrove ecosystem for its survival. Whole villages will be affected if the mangrove ecosystem is not able to function to sustain the fisheries. However, the organisation of production suggests that, at present, the system has no significant adverse impact on the mangrove system but may have adverse impact on the fisheries and mangrove system if allowed to grow unchecked.

The estuary is also the base of a very large anchovy (*Stolephorus* spp.) fishery fleet. Shoals are caught using purse seine nets and the fish are cooked on board the mother ship before being taken back to the land base to be sun-dried. This is one of Malaysia's largest mangrove-linked fisheries, in terms of biomass. The quantitative link between these tiny fish and the mangroves is not known but may be significant. Based on 1996 data, there are 40 purse seine anchovy boats employing about 800 workers. This fishing method generates seven anchovy industries employing 175 workers.

Table 6. Species composition of bagnet fisheries, Sg. Merbok. [from Khoo 1989]

Species	Count	Weight		Species		Count	Weight
Ambassis spp.	334	973		*Setipinna taty*		15	312
Arius venosus	20	528		*Stolephorus andhraensis*			
Caranx malabaricus	1	2		*S. heterolobus*			1,200
Chorinemus lysan	1	8		*S. indicus* ?			
Gobiidae	8	43		*Thrissocles dussumeieri*		5	56
Johnius sina	225	240		*T. hamiltoni*		3	109
J. solado	1	78		*T. mystax*		1	19
Kowala spp.	1	7		*Triacanthus* spp.		13	1
Lagocephalidae	13	614		*Trichiurus glossodon*		20	79
Leiognathus brevivostris	6	13		Tripauchenidae		1	11
Liza spp.	38	435		Other species			547
Lobotes surinamensis	1	23		Alpheids		24 70	24
Mugil spp.	6	125		*Penaeus merguiensis*		358	3,073
Opistroptherus tardoore	12	400		*P. monodon*		8	137
Osteogeniosis miltaris	5	388		*Parapeneopsis sculptilis*		7	10
Pampus chinensis	4	3,238		*Metapenaeus lysianassa*		194	139
Pellona elongata	401	568		*M. brevicornis*		24	94
P. pelagicus	?	730		*M. ensis*		178	303
Platycephalus spp.	1	4		*M. dobsoni*		104	82
Pomadasy hasta	2	97		*P. masterisis*		8	4
Rastrelliger spp.	4	7		Other prawns (juveniles)		164	15
Sardinella fimbriata	3	17	.	*Squilla* spp		1	10
Scatophagus argus	4	88		Spider crab		4	8
Sciaena russeli	1	25		*Loligo* spp.		468	1,039
Secutor ruconis	2,116	2,627		*Sepia* spp.		91	1,166
Selar kalla	27	98		Others (mixed species)		460	

3.2.3. MARICULTURE

There are different methods of aquaculture in mangrove estuaries, ranging from those that cause minimal environmental impact on the ecosystem to those that completely replace the ecosystem. The former include floating cage culture in the mangrove waterways and the seeding of mangrove mudflats with cockles (*Anadara granosa*). The latter involves the removal of mangroves and conversion to ponds.

Mangrove estuaries provide excellent shelter for the establishment of floating cages for the culture of both finfish and shellfish. Estuaries are also ideal in that water flow is good and wastes are easily flushed from the site. Like most mangrove estuaries in this region, the Merbok is used extensively for floating cage aquaculture. Most of the operations are for the culture of grouper (*Epinephalus* spp.), sea bass (*Lates calcarifer*) and snapper (*Lutianus* spp.) but there are also operations for mussels (*Perna viridis*) and oysters (*Crassostrea* spp.).

Based on 1995 figures, there were 83 floating cage culture operators in Sg. Merbok. Mukim Bukit Meriam and Merbok account for 80 percent of the total cage culture of about 8,310 m^2. Fish cage culture was started by the government through the Fishermen Association and the Regional Farmers Association. The activity then spread to individuals, for example, the pompang operators described earlier. The pompang operators mainly grew groupers (*Epinephelus* spp.) whose fry are caught in Sg. Merbok.

Fish are reared for 8-12 months. In the first month, the survival rate is about 80 % and for the next 4-5 months, it is about 90%. Fry of sea bass (*Lates calcarifer*) are imported from Thailand and cost RM 4.00-RM 4.50 per fry. These fry are fed trash fish obtained from trawlers or pompang operators.

Each operator employs an average of four workers who are paid RM20 per day and provided free food and cigarettes. The fish cage culture operators are mainly locals and employ local workers. The number of cage culture operators is increasing because of the availability of cheap feeds from trash fish at Tanjung Dawai and the suitability of Sg. Merbok for cage culture (sheltered and well flushed). Although the initial capital is high at RM 10,000 for a frame consisting of 12 sections (one section is equivalent to a 10 feet x 10 feet cage), the return is lucrative, given the high survival rate. A mature fish weighing 1200 grams fetches RM38 and a fish between 700-800 grams, between RM30-RM33. The fish is marketed locally to restaurants or exported to Taiwan and Singapore. Cage culture is an economically viable activity and has become one of the main projects for the government to increase food production and to raise the economic level of the fishers. From the environmental point, cage culture activity is presently not a threat to the Sg. Merbok mangrove ecosystem.

Ponds, dug after mangroves are felled and cleared, are used mainly for the culture of the tiger prawn (*Penaeus monodon*) and most of these are large-scale developments. They are potentially lucrative but the risks are also high (see Chan *et al.*, 1993). Initially, 307 hectares of the Merbok mangroves was excised (to the Malaysian Fisheries Developmental Authority) for aquaculture, but this has burgeoned and it is now estimated that some 25% of the mangroves in the Merbok has been converted to aquaculture ponds over the past 20 years.

Pond prawn culture is mainly organised under large-scale production systems. The first large-scale production system was carried out by government agencies: the Fisheries Department and the Fisheries Development Authority. The first project was undertaken in 1982 with 33 ponds and pond size between 0.5-2.5 hectare, with an allocation of RM 2.3 million. The second project was undertaken in 1989 with 25 operators selected from locals who were each allocated a 0.7 hectare pond. The project provided an average monthly income of RM 2,000 per participant.

In 1995, there were 24 operators operating 127 ponds but, according to the Fisheries Department, there are also illegal operators.

The other large-scale production system is undertaken by large companies from outside the area, and foreign owners. There are altogether 12 companies operating 618 hectares of ponds. The companies are given Temporary Occupational Licences by the State. The cost of starting pond prawn culture per hectare is estimated to be about RM 30,000-35,000. The companies employ one worker per one hectare of pond with a basic pay of RM 400 per month. The workers prepare the ponds, feed the prawns, check water quality and ensure security of the area. The prawns are usually grown for 4 months before harvest. The survival rate is estimated to be about 80%. A one-hectare pond produces five tonnes of prawns at a market price of RM 20-25 per kg. The gross income per hectare is estimated to be about RM 100,000.

3.2.4. RUBBER AND OIL PALM

The area for rubber in 1990 was 34,761 hectare from 47,000 hectare in 1980. Most of these are in the upper reaches of the main river (Sg. Lalang). There are only small patches of oil palm in the Merbok catchment. These are almost insignificant, compared to the total area of catchment. Only about 26,000 hectare of rubber are in the catchment.

3.2.5. RICE

Almost all the rice fields are adjacent to mangroves. In fact many of the rice fields were originally reclaimed from mangroves (mainly in the northern part or the Ban Merbok area). Many of the rice fields originally reclaimed from mangroves are however not very productive and are left idle. In 1990, for the whole district of Kuala Muda, rice acreage was 10,392 hectares from 9,796 hectares in 1980. Only about 7,500 hectares fall within the Sg. Merbok catchment. Most of the rice fields carry two crops per year.

3.3. ECONOMIC (INPUT / OUTPUT) MODEL

Every five years, Malaysia's government publishes a five-year development plan and the current phase of development planning is the Seventh Malaysia Plan, 1996-2000. Much of the work connected with its preparation is carried out by the Economic Planning Unit (EPU) of the Prime Minister's Department. To coordinate development planning with the respective state governments, branch offices are maintained throughout the country by the EPU. The five year plan contains policies and strategies for guiding development following which budgetary allocations that target development of the different sectors of the economy are made. A balanced growth strategy has always been a central feature of the country's development plan. But targeting sectors will inevitably lead to a transformation of the structure of the economy as some sectors expand at higher rates over others and become dominant over time.

Input-output analysis is a useful tool for assessing the impacts that will likely result from sectoral development targets. The model works in the following way.

The basic framework of the input-output model is given by

$$AX+Y = X$$

where AX is the input-output table. This is an n by n matrix that captures inter-industry sales in dollars among n number of industry-sectors of a given economy. The matrix records sales of only intermediate products since outputs by one industry-sector are redirected and used as inputs by another sector. The remaining output not used as intermediates are sales to satisfy final demand. Private consumption, private investment, government spending and imports together make up total final demand which is denoted in the above equation by the n by 1 vector Y. The final demand is equivalent to the gross domestic output or GDP of the economy. Thus gross output X for n industries are the dollar values for both intermediate and final sales. The technical coefficients matrix A is obtained by dividing the matrix elements by the gross output values for the respective industries. These coefficients represent inputs per dollar of gross output.

The input-output calculates the total output requirements by industries for a policy target of final demand. Since gross output is the sum of intermediate demand requirements (described by the structure of the economy AX) and final demand requirements (Y, equivalent to the GDP) which is targeted by policy, the inter-industry structure AX will eventually spin indirect and induced impacts after the following sequence of interactions,

$$AY+A_2Y+A_3Y+A_4Y+.... = X$$

which when infinitely summed mathematically converges on

$$(I-A)^{-1} Y=X$$

The last equation is known in input-output literature as the Leontief inverse (Leontief 1951).

Input-output models are static in the coefficient values contained in the matrix A referred to as the model parameters. The values of final sales given in the vector Y is externally prescribed by way of policy inputs. The vector of gross output X is the resulting impacts generated conditional on the prescribed values of Y.

Thus input-output analysis attempts two things. Firstly, the Leontief inverse attempts to incorporate subsequent rounds of interactions beyond the initial direct impact stage. Time is not an element in the occurrence of the various rounds of impacts. Secondly, the working of the model requires the prescription of a set of policy inputs. In this sense, the input-output model as it is designed is used to compare the total (direct, indirect, induced) impacts arising from different policy inputs in terms of final demand targets.

Thus while the results are quantitative, interpretation is only qualitative in terms of the relative impacts from the different policy targets.

3.3.1. ECONOMIC PLANNING IN THE MERBOK

Consider the economic planning of the Muda District in which the Merbok and its hinterland is situated (Kuala Muda District Council 1991). The gross regional product (GRP), which is the sub national equivalent of the country's GDP, of the basin is about RM 1 billion in 1995 (based on 1978 prices). The sectoral composition in 1995 of the basin's economy is shown in Table 7. The GRP targeted for 2000 is also shown which will result in a number of changes to the sectoral composition.

During the five year period, the two manufacturing sectors combined are expected to expand from 39% to 49% of the total economy of Merbok. On the other hand, the various sectors in agriculture are likely to shrink from a share of 17% to only about 11% of the total economy. Changes in the contributions by the other sectors are only marginal.

To assess the impact on the local economy of the Merbok basin, the change in GRP shown in Table 7, is fed as the Y matrix into the input-output model. The resulting impacts on total output is shown in Table 8 which comprises the direct, indirect and induced impacts resulting from the sector targets contained in the Y vector specified when running the input-output model.

In developing economies such as that of Malaysia (and for that matter the Merbok basin), a portion of the flows among industries is comprised of imported intermediate products used as inputs by local industries. This means that part of the intermediate inputs used by industries in the Merbok river basin is obtained without the input-output interactions occurring in the local economy.

Table 7. Sectoral composition of the Merbok basin (RM x 1000) in 1978 constant dollars).

SECTOR	**1995**	**%**	**2000**	**%**	**Change**
agriculture	166,263	16.63	131,457	10.30	-34,806
fishing	29,464	2.95	2,297	0.18	-27,167
forestry	316	0.03	153	0.012	-163
mining	2,105	0.21	1,276	0.10	-828
manufac 1	38,935	3.89	61,262	4.8	22,326
manufac 2	351,468	35.15	561,564	44.00	210,096
electricity	6,314	0.63	7,147	0.56	833
water	8,418	0.84	9,572	0.75	1,154
construction	72,609	7.26	103,379	8.10	30,770
transport	28,412	2.84	31,269	2.45	2,857
other services	295,696	29.57	366,293	28.70	70,597
TOTAL	**1,000,000**	**100.00**	**1,275,669**	**100.00**	**275,669**

Thus, any input-output impacts that might occur from the imported intermediate goods should be set aside, because they do not actually occur locally. To obtain a more reasonable estimate of local impacts, therefore, it would be better to restrict running of the input-output model based only on domestic flows. The necessary adjustments are also shown in Table 8 alongside the difference which tells how much the impact on the economy has been overestimated should we neglect setting aside the imported inter-industry interactions.

From the input-output analysis, the projected increase in final demand (i.e., GRP level) by RM276 million (in 1978 constant dollars) for Merbok during the five year period will lead to an increase in gross output by RM324 million brought about by direct, indirect and induced effects. As much as RM226 million will occur within the manufacturing sectors, with smaller increases occurring among the other sectors. But these changes will also lead to significant contractions in agriculture and fishing as indicated by the negative numbers. Forestry will, however, expand by RM23 million.

Since a fair proportion of the intermediate inputs and outputs among the many industries located in Merbok are sourced from overseas, it will be necessary to net out the impacts on gross outputs which are not expected to occur locally. Taking imported inputs into consideration, the total impacts on gross output amount to RM271 million with RM205 million occurring in the manufacturing sectors. Thus there will be an over-estimate of the impacts by RM53 million had we failed to consider imports. Nearly 40% of the overestimate amounting to RM21 million is attributed to the manufacturing sector.

Table 8: Direct, indirect and induced impacts generated by I/0 model (1995-2000), (RM thousands in 1978 constant RM)

SECTOR	**Total impacts**	**Total domestic impacts**	**Difference (overestimate)**
agriculture	-35,762	-37,142	1,380
fishing	-25,606	-25,741	134
forestry	23,408	21,208	2,200
mining	23,849	4,715	19,134
manufacturing 1	38,812	21,134	17,678
manufacturing 2	187,294	184,306	2,989
electricity	10,935	8,251	2,684
water	1,653	1,426	227
construction	29,240	28,254	985
transport	14,236	8,322	5,914
other services	56,412	56,410	2
TOTAL	**324,471**	**271,144**	**53,327**

The indirect and induced impacts are caused by inter-industry sector linkage effects present in the production structure of the economy embedded in the input-output framework. When final demand of a particular sector is targeted to grow at a high rate, production in the sector will increase and therefore its demand for intermediate inputs from the other sectors supplying to it will also increase. Thus depending on how strong the linkages are between sectors there will also be such indirect and induced effects brought about by a targeted change in final demand.

This notion of a lead sector spinning off additional effects across the rest of the production structure prompts further investigation into the identification of likely lead sectors in the economy. The first involves looking at multipliers. Imagine if the input-output run had been based on a final demand vector Y containing the value 1 representing one dollar change for a particular sector and zero elsewhere. By pre-multiplying the $(I-A)^{-1}$ matrix with this Y vector we will obtain the resulting X matrix identical to the column representing that sector in the $(I-A)^{-1}$ matrix. This feature is caused by the procedure in matrix multiplication and the 1 in the Y vector with zero values elsewhere.

Thus the individual column sums of the $(I-A)^{-1}$ provides an indication of the strength of the sector multipliers, as if we have run over and over again the Leontief inverse with Y matrices containing a 1 in each of the sectors and zero elsewhere. The multiplier value of a sector is interpreted as the total impact on the economy that is generated as a result of a one dollar change in final demand occurring in that sector. The sector multipliers are as shown in Table 9.

A one ringgit increase in final demand (such as investment) will result in an average of RM1.37 impact on the production structure after incorporating direct, indirect and induced effects. But only RM1.14 of this amount will impact on the local economy as the rest of the impact will be felt abroad due to the import content of the inputs into local industries. The use of the multiplier figure, that is the resulting impacts from a unit increase in final demand, may be useful for picking sectors for expansion. For example manufacturing I or heavy industries have a multiplier figure of 2.02 which is well above the average. Therefore, not taking care to consider imports will result in identifying this as the sector to expand. After adjusting for imports, the local multiplier in this sector is only 1.1 which is even lower than the average.

Table 9: Sector multipliers generated from imported and domestic sectoral linkages.

Sector	Imported+domestic	Domestic only
agriculture	1.067109	1.058200
fishing	1.101060	1.060286
forestry	1.204061	1.108849
mining	1.139463	1.105261
manufac 1	2.016227	1.100567
manufac 2	1.348354	1.212876
electricity	1.544451	1.181612
water	1.593237	1.309142
construction	1.473655	1.194479
transport	1.475220	1.131054
other services	1.136830	1.069438
	1.372697	1.139251

Another useful analysis of the Leontief inverse is to calculate the values of Rasmussen's (1952) power of dispersion and sensitivity of dispersion indices. The dispersion indices are the ratios between the sector average and overall average. When backward linkages of a particular sector are strong, the sector is a large buyer of inputs from the other sectors in the economy. Thus the sector is a power sector, because should the sector expand or contract it will affect many other sectors that supply it with intermediate inputs. When forward linkages are strong, the sector is a sensitive sector because this sector sells its components to a wide variety of sectors. Thus anything that happens to any of the other sectors will indirectly affect this sensitive sector as well. The Rasmussen indices are shown in Table 10.

Figure 23 shows the index values in terms of the power of dispersion and the sensitivity of dispersion among the various sectors. Sectors located near the 45 degree line are generally well balanced in power and sensitivity. Curiously, water utilities appears to be a lead sector in the analysis. This is explained by the possibility of an expansion in water-works projects in the region during the period which must have sourced a significant amount of inputs from the rest of the economy.

The other sectors which appear high on the power index, such as manufacturing and construction are within expectation as these tend to source much inputs from other sectors. On the other hand, sectors such as electricity, transport, forestry and mining appear as sensitive sectors as these sectors tend to sell to other sectors rather than buy from them.

Table 10: Rasmussen power and sensitivity of dispersion indices.

	Power index	**Sensitivity index**
other agriculture	0.928856	0.898817
fishing	0.930687	0.892918
forestry	0.973314	1.020553
mining	0.970164	1.201100
electronics man	0.966044	0.964872
manufac 1	1.064626	0.886640
manufac 2	1.037183	1.151621
water	1.149125	0.899572
construction	1.048477	1.024178
transport	0.992805	1.179279
other services	0.938720	0.880450

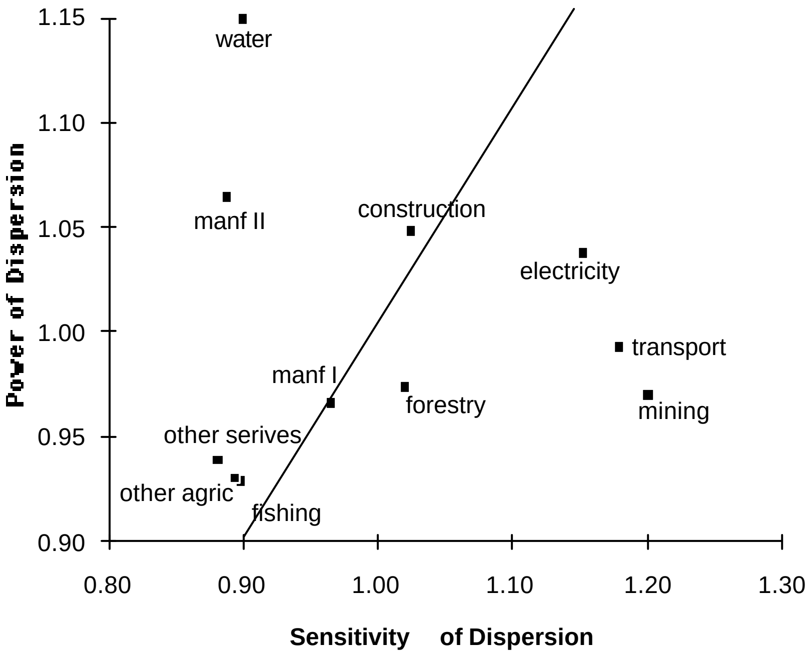


Figure 23. Power and sensitivity of dispersion plot of Table 10.

3.4. ALTERNATIVE ECONOMIC APPROACHES

The input-output model is popularly used for allocating development towards target sectors with high multiplier effects. However, many of the changes that occur to particular sectors will be the result of private sector investments in response to government incentives and other signals, that favour the expansion of some sectors in favour over others. More timely monitoring of economic changes will be necessary to gauge the extent to which the private sector is following such government leads. Typically regular interventions are made by the government to alter various economic signals to further influence the private sector towards established development priorities.

3.4.1. TRACKING OF ECONOMIC INDICATORS/INDICES

Various techniques used in monitoring the economy are discussed in Chan (1997). Tracking indicators is an effective way to closely monitor changes in the economy. These changes usually follow business cycles which have attracted much study over the timing of their turning points that occur after an expanding economy has peaked or an economy in recession has bottomed out (see Lahari and Moore 1991). A large number of variables routinely compiled as government statistics may be monitored. These variables are grouped into three different categories by performing regression analysis between each of them and the status of the economy. From the results obtained, it is possible to identify which variables form leading, coincidental or lagging indicators. All the variables in each group can then be aggregated with different weights to produce a composite index for each of the three groups.

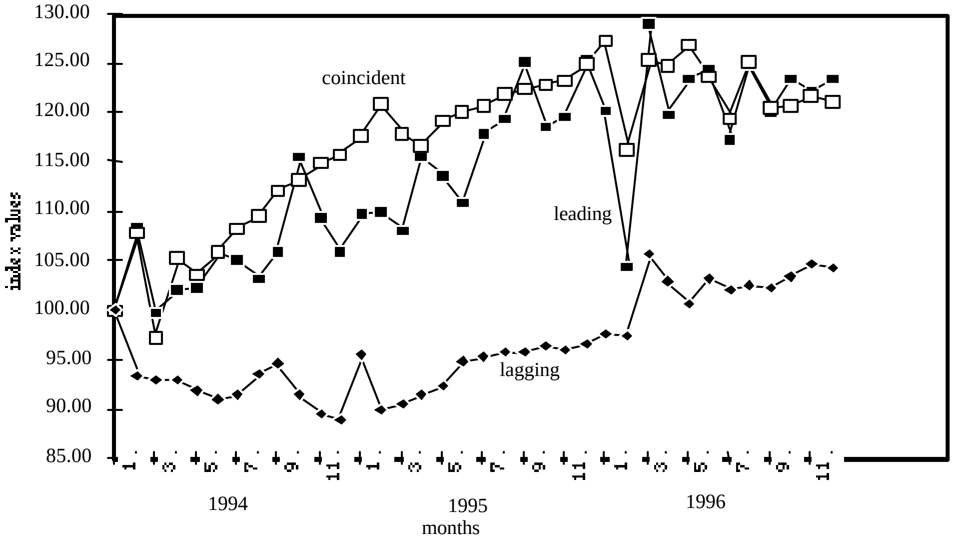


Fig.24: Leading, coincident and Lagging indices, Malaysia, 1994-1996.
Source: Produced from data in Economic Indicators, 4th. Quarter 1996, MIER

The leading index will track changes to the economy several months ahead of time and warn of possible changes at the horizon. The coincidental index will indicate changes as they occur in the economy. The lagging index will only show changes several months after they have occurred in the economy and acts to confirm that the changes experienced are real. In Figure 24, the three indices are plotted over a three-year period after their respective values are rebased to 100 in January 1994 so that they could be compared side by side. The general upward trend in all three indices could be observed for the period but seasonal and cyclical variations are clearly apparent.

During planning it is also necessary to predict the different outcomes of various plan options such that the plan that produces the best outcome could then be selected for implementation. To do so, the features of the various plans considered could be formally introduced into a causal model of the economy.

3.4.2. ECONOMETRIC MODEL

Many causal models of different sizes reflective of Malaysia's economy have been built according to a survey by the Malaysian Institute of Economic Research (MIER) (Imaoka *et al.* 1990). For example, Figure 25 shows part of MIER's annual model. In the figure the causal linkages between variables are shown, each link being represented by an equation for which parameters are to be estimated from data on Malaysia's economy. The actual model is fairly large comprising 38 exogenous variables and 58 endogenous variables which are linked together by 28 equations and 29 identities. The values of exogenous variables are data items obtained elsewhere and entered into the model so that the values of endogenous variables could be computed by the model. Identities are equations without parameters to estimate. Space does not permit a full description of the model here. Suffice that as an example we examine the causative linkage between exports and national income.

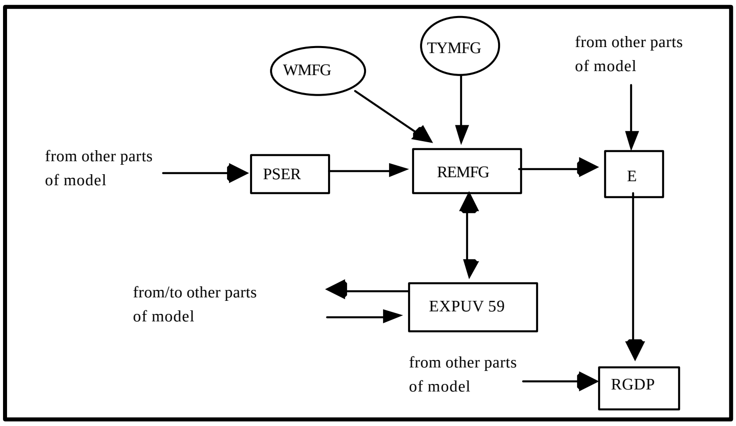


Figure 25. Forecasting national income from exports of manufactures.
Source: Adapted from MIER (1990)

According to the way the model has been specified, real exports of manufactures (REMFG), depend on their export values (EXPUV59), the nominal wage index for manufactures (WMFG), the price index for services (PSER) and the trend index for production in manufacturing (TYMFG). Data on wages and the trend index are directly fed into the model because they are exogenous. Export values and service price index, being endogenous, are computed elsewhere inside the model. Formally, according to the causal relationship established above, a regression equation is specified which links the dependent variable REMFG with the four independent variables.

$$\begin{aligned}\log \text{REMFG} = {} & b_0 + b_1 \log\text{EXPUV59} - b_2 \log\text{WMFG} - \\ & b_3 \log\text{PSER} + b_4 \text{TYMFG}\end{aligned}$$

In this equation, values of five parameters, b_0 to b_4, have to be estimated based on the values of the four independent variables either computed elsewhere or exogenously obtained. The variables were transformed into their logarithmic equivalents because a better fit was achieved by the model when logarithmic values were used. Generally, with n number of data points there are n-1 ways of drawing a regression line across these points. This means that there are that many possible parameter values to choose from. If it is possible to assume that the observations are independent of one another, a method called ordinary least squares may be used as a criterion to select, among the n-1 possibilities, the best parameter values. Another word for such estimation is econometrics. It is because of this process of estimating parameters that causal models are called econometric models.

In the model above, the resulting estimated values of the five parameters b_0 to b_4 that link the various variables together are as follows (Imaoka 1990, p.70):

$$\begin{aligned}\log \text{REMFG} = {} & 4.7257 + 0.0268 \log\text{EXPUV59} - 0.4881 \log\text{WMFG} - \\ & 1.7535 \log\text{PSER} + 0.0353\ \text{TYMFG}\end{aligned}$$

Apart from computation of parameter values, regression analysis is accompanied by some test statistics. The fit of this equation is 98.4 per cent. This means that values of the four independent variables specified in the regression equation explains 98.4 per cent of the value of real exports of manufactures, REMFG. The remaining 1.6 per cent is explained by other factors not accounted for by the model. Also, the relationship between the dependent and various independent variables have t-statistics ranging from 0.24 to 6.67. This is a test of the hypothesis that the true value of each b parameter is actually zero which means to say that there is actually no relationship between REMFG and the independent variable. For the regression to make sense, therefore, this hypothesis must be rejected on the basis of the t-statistics values, which it is in this case. The Durbin-Watson statistics for testing independence was 1.832. Observations used as data in regression analysis must be independent of one another which is achieved when the data sequence is not serially correlated. In this case, independence is achieved. The value of REMFG could now be calculated by simply multiplying the values of each of the four independent variables by their parameter values and then summing these four results.

The value of real exports of manufactures computed from the above equation forms part of total exports of goods and services in $million (E in Figure 25) along with other export items. E in turn forms part of real GDP in $million, RGDP along with other items. The example used above thus demonstrates how export earnings in real terms could be estimated and incorporated in the overall forecast of Malaysia's GDP.

The approach just described is a simplified form of econometric analysis in which each equation from the overall model of many equations is estimated separately from one another. A more comprehensive approach is for all the equations to be simultaneously estimated to allow interactions among the different equations to occur.

3.4.3. DISCUSSION (ALTERNATIVE ECONOMIC MODELS)

The above two are pure economic models that are popularly used in economic planning. There was little need to address environmental issues which are usually not factored in when decisions are made. A more comprehensive approach would be to deal with both economics and the environment simultaneously using a common framework. There are versions of input-output models that contain environment coefficients embedded in them. In the next chapter an example of this is given. However, tracking environmental variables on a day to day basics alongside economic indicators to look for peaks and troughs of business cycles has never been done. Does environmental changes affect business cycles? They should, especially when an economy is dependent on agriculture of other climate sensitive sectors such as tourism. This should be interesting analysis but unfortunately difficult to carry out.

If time series environmental data are available, then causal links might be explored by linking them to relevant economic variables within an existing econometric model. This would be the ultimate model built, because many of the econometric models built are simultaneous equation models containing directional as well as feedback links. By introducing environmental variables into such a model we are actually saying that economics affect the environment the environment affects the economics. But this is still a long way off because most econometric models, even before environmental integration, suffer from statistical discrepancies. With the inclusion of environmental variables it is unlikely that a model that passes all statistical test could be quickly achieved.

“Economists were invented to make weather forecasters look good.” Anon.

4. INTEGRATED MODELS

4.1. APPROACH AND BACKGROUND THEORIES

Environmental impact assessments or EIAs involve the quantification and/or qualification of possible environmental degradation of the environment resulting from interruptions by anthropogenic activities. Many perceive such interruptions by way of a pressure-state-response relationship between anthropogenic impact and the environment. The central focus is the environmental model which is popularly developed as a biogeochemical cycling system. Then analysis is extended to consider perturbations to the natural cycling phenomenon when anthropogenic impacts occur.

From a somewhat different direction, some studies consider ways by which the environment could be valued and costed as an integral part of economic accounting. The motivation here is to internalise the environment which is typically regarded as an externality, because conventional accounting has been able only to incorporate elements of the market economy within its framework. The reason is values are a function of prices which exist only when there are markets for the commodity concerned. Standing stocks of forest, clean air, river water and the sea are not traded by any formal market and thus elude valuation. Nevertheless, realising the serious oversight, many studies have sought ways to estimate economic values for such environmental aspects.

However, true ecologic-economic integration is more than merely adding a component to an existing framework. Adding economic impacts to an ecological model relegates economics to a secondary role in the analytical framework. Similarly, attempting to cost environmental variables for inclusion into an economic model plays down the environmental component. Instead true ecologic-economic integration unites two complete sets of processes that could very well stand on their own. Thus, both the ecologic and the economic processes must first be independently modelled before they can be integrated. Integration is then achieved by developing two-way feedback mechanisms that interconnect both sets of processes.

In the following, a number of possible integration approaches are explored.

Most ecologic-economic input-output frameworks do not provide true integration, because only economic input-output flows are captured in the inter-sector transaction matrix. The environment is usually introduced by way of a set of residual generation coefficients that indicate ecological impacts for each of the sectors.

However, fully integrated ecologic-economic frameworks have been suggested. These have both ecological as well as economic sectors that make up the intersectoral transaction matrix. The only problem with such an arrangement is what units of measurement to use? Input-output transactions are measured by dollar inputs per dollar output. But ecological sectors have no such money equivalents. The suggestion to measure transaction flows instead by weight in place of money values could not be accommodated as weights become totally meaningless for many economic sectors. Electronics for example fetch high values despite their light weight compared to the steel industry, and services sectors such as finance and banking have no weight equivalents.

To circumvent the measurement unit problem, some studies have attempted to adopt hybrid inter-industry transaction tables. This means that the ecologic sector to ecologic sector transactions will be measured by weight, the ecologic to economic sectors flows will be in weight per dollar, the economic to ecologic sector flows in dollars per unit weight and the traditional inter-economic sector flows measured completely in dollars.

No matter how the input-output flows are organised, one must, however, be mindful of what such models are useful for. To begin with, the input-output framework is an efficient way to capture interactions among various components, i.e. sectors, that make up a system. The cell by cell entries of the input-output matrix reveal the degree of interdependence among the sectors. This has prompted studies that examine input-output relationships to identify which are power sectors as opposed to sensitive sectors. Power sectors are those that draw large inputs from many other sectors. They are important in that any change affecting them will create indirect and induced effects throughout the other sectors that make up the system. In contrast, sensitive sectors supply large inputs to many other sectors. Thus such sectors are easily affected by changes that occur elsewhere in the other sectors.

The possible close interactions among sectors of an input-output framework have also prompted several studies that attempt to measure matrices according to their degree of connectedness. Such measures allow different input-output matrices to be compared. Matrices representing different locations could be classified according to similarities and differences in connectedness. Alternatively matrices for the same location but representing different time periods could be examined to see if there is a movement towards greater connectivity over time.

However, input-output analysis is traditionally an impact assessment tool. The Leontief inverse computed from the inter-sectoral flows captures the direct, indirect and induced impacts resulting from changes to an externally defined final demand vector normally introduced as policy instruments to assess their likely impacts.

But input-output models have one serious limitation that makes its ecologic-economic integration less worthwhile. Input-output models are static. By this is meant that the coefficients that define the inter-sectoral flows are constants. Even dynamic input-output models are static in these coefficients. The difference with dynamic input-output models is they use a set of capital coefficients to generate the impacts. On the contrary, the ecology is regarded to be highly dynamic, ever changing from hour to hour and from day to day. Energy is continuously converted as is measured by carbon fluxes, leading to biological growth through carbon uptake.

In summary, input-output models provide a convenient and efficient accounting framework. Their usefulness is limited to the ability to analyse intersectoral linkages for their connectedness and, with the introduction of a final demand vector to drive the model, the total as opposed to first round impacts could also be assessed. Input-output inter linkages are static and the model contains no internal processes.

4.1.1. THE ECOLOGIC-ECONOMIC RESIDUALS GENERATION I/O FRAMEWORK (Isard)

Based on ecological extensions of standard input-output analysis (after Victor, 1972; Cumberland and Korbach, 1973; and Isard, 1971), the direct, indirect and induced impacts of C,N,P residual outputs resulting from economic final demand (i.e., income) changes are estimated as follows:

$$V' = \{V (I-A)^{-1}\} Y$$

where Y is a 11x1 column vector indicating final demand changes by the eleven sectors and V' the 11x1 column vector of C, N, P residual generation.

The mathematics (involving matrix algebra) of this is as described by de Kok (1998).

There are thus two ways of attempting to integrate ecology into the standard input-output framework. The more straightforward approach (as described by de Kok 1998), is by pre-multiplying an ecological "residuals" vector (V), with the original Leontief inverse $(I-A)^{-1}$ Y. The product indicates ecological impacts resulting from pure economic interactions embedded in the technical coefficients matrix A and policy driven changes to the economy found in the vector Y.

The limitation with this straightforward approach is that the interactive components, given as coefficients, in the model are purely economic. Ecology is crudely brought in as a transformation device that converts standard economic impacts (i.e., the Leontief inverse) into ecological impacts.

4.1.2 SIMULTANEOUS DYNAMIC I/O MODEL (Johansen)

Johansen (1974) described an interesting way of devising rates of change in an elaborate intersectoral framework. The dynamics which drive the changes are modelled based on economic theory. Conditions such as profit maximisation, depreciation, technological production functions, input-output relationships and resource allocations among sectors are imposed as a system of simultaneous equations to form the model. Dynamics are achieved by specifying each variable as a change response with respect to another variable - in other words, as derivatives. The different variables are carefully divided between their right hand and left hand sides of the equations in such a way that the number of endogenous ones are exactly equal to the number of equations in the system. The system could then be uniquely solved by exogenously providing values for the remaining variables (see Chan 1996).

Johansen's framework, like the traditional Leontief-type input-output model, presents itself as a useful planning tool. Certain variables are externally defined policy instruments which are introduced into the model to simulate outcomes, or impacts, on a variety of variables. The implications of several policy options considered for possible implementation could then be assessed. The framework could be extended to incorporate the environment by introducing equations which deal with the economic-ecologic interactions. The notion of ecological inputs used by economic production is a convenient way to meet this aim. For example, the Cobb-Douglas (1928) type production function specified as part of the equation system could be divided between ecological and economic inputs instead of the more typical division between labour and capital inputs. Comparison of an I/O model (see Section 4.1.1) and the Johansen model for the same site would be an interesting exercise.

4.1.3. THE INTERACTIVE ECOLOGIC- ECONOMIC I/O MODEL (Miller and Blair)

There are many versions of economic-cum-energy variation of this model. The one which was built for analysis in this paper is based on Miller and Blair (1985) (see also Pearce and Turner 1990). It uses revised form of matrices we will call Z*, Y* and X* in which are contained energy flows in energy units alongside industry flows in ringgit. In addition a diagonal matrix of total energy consumption, F* is established.

The following are defined:

$$\delta = F^* (X^*)^{-1} A^*$$

$$\alpha = F^* (X^*)^{-1} (I - A)^{-1} {}^*$$

Here, X* is a diagonalised matrix of the otherwise n x 1 vector containing both energy and non-energy sectors to facilitate matrix multiplication. The resulting matrix indicated by δ shows the direct energy intensities by sectors. The matrix α shows the total energy intensities which incorporate secondary impacts made up of indirect and induced effects.

The matrices α and δ contain values identical to the A* and $(I-A^*)^{-1}$ matrices respectively except that pre-multiplication by F* and $(X^*)^{-1}$ removes the inter-industry money flows. Such flows are irrelevant here because they should be analysed under standard input-output analysis.

Regional tables expands on the national table by recording flows between sectors and between regions in the country as well (see Miller and Blair 1985). To simplify the regional table concern is only given to flows inside the region and flows with the rest of the country as another composite region.

Incorporating the environment into the input-output framework is complicated by the need to introduce an elaborate set of environmental sectors that have indicated flows among themselves and among these environmental sectors with the various economic sectors. Furthermore there is the need to resolve the units of measurement for the environmental sectors.

With the eMergy concept, the environmental component needed on the input-output table is reduced to one sector flowing out as eMergy, E_A^+ and becomes energy, E_B^-. A sketch of the input output framework is shown in Figure 26.

	local economic sectors	$E^-_{B\ local}$	economic sectors in rest of country	$E^-_{B\ rest}$
local economic sectors	A	B	C	D
cal	E	F	G	H
economic sectors in rest of country	I	J	K	L
$E^+_{A\ rest}$	M	N	O	P

Figure 26. Economic-eMergetic input-output table framework.

In Figure 26, the usual inter-industry flows within the locality are entered into A and the economic investments into the energy transformation process of the local environment goes into B. In C and D are entered economic inputs affecting the rest of the country. E contains data on eMergy inputs into economic production in the locality while F records transformation losses involved from E_A^+ to E_B^-. Again G and H are meant for interactions from the locality to the rest of the country. The remaining parts of the table contain similar inputs but this time dealing either with flows within the rest of the country or from the rest of the country into the locality.

The first step to input-output analysis is to transform the above table format into what is called a technical coefficients table by dividing the column entries by gross economic output in dollar terms. The resulting entries become input-output flows per dollar of gross output. Notice that wherever the nominators are in dollars, we obtain the usual input-output coefficients. Wherever the nominators are in eMergy terms, the coefficients become monergy values. Thus from equations described above, environmental prices of the local ecosystem can be expressed as its total eMergy divided by monergy values on the coefficients table.

Beyond such descriptive indicators, standard input-output analysis procedures can be introduced from which we obtain secondary and induced impacts based on the Leontief inverse and the inter-connectedness between input and output sectors based on Rasmussen's power and sensitivity indices.

We are currently quite far from being able to implement the above framework largely because inter industry flows of any local region is unavailable and may have to be built from scratch. But once this is done, flows for the rest of the region is a matter of subtracting out the locality from data on the national input-output table. The other problem, of course, deals with data units between market dollars and environmental measurement units which should be in eMergy or monergy terms.

4.1.4. ODUM'S "EMBODIED ENERGY" (I/O) MODEL

The survey by Faucheux and Pillet (1994) indicated three main views on energy valuation. The first involves estimating the ratio of energy to money (see Odum and Odum 1981, p.44) so that we can measure money in energy terms or vice-versa. This view is a misconception because energy does not have the same properties that money has. It will be a mistake to think that energy and money are convertible from one to the other. Money can be transformed from one form of asset into another and back again. Fluctuations in money values encountered in the conversion process is not due to transformation losses (the way it happens for energy due to thermodynamic laws) but according to changing market demand and supply conditions.

The second view concerns energy theories of value which attempts to convert labour, materials, capital and all other production factors into energy terms. The limitation of this approach is that when we lose sight of the money values for these items, we also lose sight of whatever price signals that affect how these items are brought into play within the production process. Thus while an accounting of energy within the ecosystem is a useful inventory exercise it will not help us very far when we wish to incorporate economic considerations that impact on the ecosystem.

The third view leaves energy and money as distinct entities and does not attempt to replace one by the other, but attempts to relate them. Economic activities are seen as a continuous transformation of low entropy energy sources into high entropy and in the process emit irreversible waste. Responding to this transformation of energy, composite indicators are developed that show to what extent a threshold is drawing near beyond which the ecosystem will undergo a major change. The next section will discuss details of this view.

The most effective way to make an assessment of the energy fluxes found in various forms within a local ecosystem is in terms of the solar energy that was used to produce them. All energy forms found are thus standardised in relation to solar energy, which is the embodied energy denoted as eMergy contained in the various forms of energy. The principle of this approach initiated by Odum (1983) is illustrated by Figure 27.

As E_A^+, which is the embodied energy (or eMergy), is transformed through the process of economic activities into another form of energy (E_B^-) we obtain an eMergetic balance by the ratio E_B^-/E_A^+ expressed in joules by solar joules or emjoules. This ratio defines the solar transformity of E_B^- telling us the amount of E_A^+ incorporated in E_B^-. Both the first and second laws of thermodynamics are thus taken into account with respect to energy transformation and losses. The degree of solar transformity thus serves as a qualitative description of the ecosystem being assessed. The biomass of the local ecosystem expressed in E_A^+ emjoules indicates the amount of solar energy that had gone into generating this ecosystem.

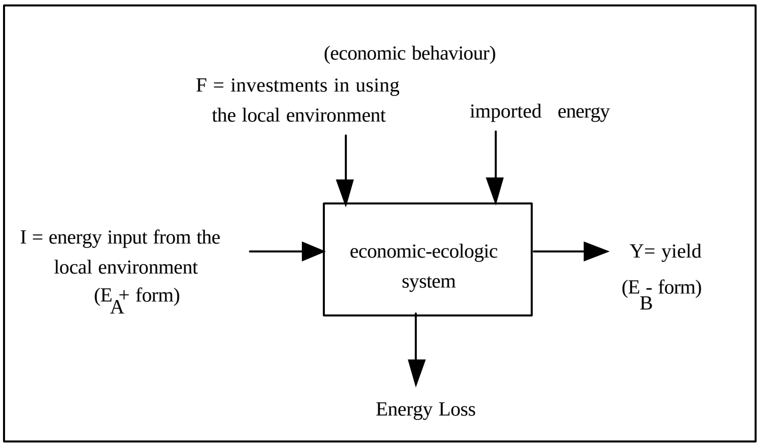


Figure 27. eMergy-energy relationship.

To attempt bridging what we know of the energy state of the ecosystem, in terms of the degree of transformity, with economic production, another term called monergy is introduced (see Pillet 1994).

$$\text{monergy} = [\text{ eMergy}^{\text{nation}} \text{ (emjoule) }] \;/\; \text{GDP}(\$)$$

This is a macroeconomic indicator which relates the total energy state of the country i.e., eMergy in emjoules against the total economic production of the country in dollars.

Our intention is to estimate the unknown ecological price for a given hectare of land, say located within our study area, for a given year. If we assert that this price, P_I($), in proportion to the country's total income, GDP($), is exactly equal to the proportion of the energy inventory of that hectare of land to the total energy state of the country, that is:

$$P_I(\$) / GDP(\$) = eMergy^{local}(emjoule) / eMergy^{nation}(emjoule)$$

then, we can obtain an estimate of P_I($) as follows:

$$P_I(\$) = GDP(\$) . eMergy^{local}(emjoule) / eMergy^{nation}(emjoule)$$

$$P_I(\$) = eMergylocal(emjoule) . GDP(\$) / Mergy^{nation}(emjoule)$$

$$P_I(\$) = eMergy^{local}(emjoule) . 1 / monergy$$

In other words, if we can separately estimate the monergy of the country and if we perform an energy inventory of the local ecosystem in eMergy terms, we will be able to estimate the price of the local ecosystem, P_I($).

4.1.5. BIOECONOMIC RENEWABLE RESOURCE MODEL (Wilen)

It is the formal introduction of economic principles that makes a model an economic model. Essentially, an economic system like its biogeochemical counterpart, is a process that occurs through time as a result of the behaviour of various components that interact within the system. "Bioeconomic" models have been applied in various settings, notably in fisheries and forestry economics.

Take, for instance, the extraction of natural resources for economic purposes (Wilen 1985). Two systems, the economics and the environment collide, each forced to take the other into account. The Merbok mangroves form an example. The mangrove trees would have grown naturally undisturbed if they were not of economic value. But once some of the trees are unnaturally removed, the remaining standing stocks of mangrove will see very different biogeochemical dynamics. Thus, when modelling the mangrove ecology, this anthropogenic disturbance factor cannot be ignored.

From the purely economic perspective, mangrove extraction has to yield maximum revenues. But this cannot be achieved without taking the natural growth rates of mangroves into account. In other words, the economic model that analyses revenue maximisation has to make a reference link to the biogeochemical model of mangrove growth. Thus, as far as the Merbok mangroves are concerned, ecology and economics are not two but one system as they are interdependent on one another.

4.1.6. INTEGRATED MODEL COMPARISON

The models discussed above are essentially "weak" integration models for linking elemental ecological and economic modelling approaches. Five approaches to integrated ecologic-economic modelling have been suggested and their applicability is summarised in Table 11.

The first (here called the Isard) model is essentially the Victor-Cumberland-Isard I/O framework model which was popularly applied during the late sixties and early seventies. It was presented by Douglas McGlone at the 1997 Open Science Meeting and subsequently discussed in Bolinao for application in this SWOL project (LOICZ 1997). It uses standard input-output technology coefficients (or economic interactions) that describe flows among economic sectors but imposing a matrix containing ecologic residuals (pollutants per dollar output) to estimate direct, indirect and induced ecological impacts resulting from changes in future economic demands or incomes.

In the second (Johansen) model, the equations that establish interactions among the relevant variables are differentiated with respect to time to produce rates of change relationships. These form the simultaneous system of equations which is solved by matrix algebra because the system is specified (the number of equations exactly match the unknown variables).

Table 11. Comparison of the five integrated ecologic-economic models.

Suggested ecologic-economic model	Ecol-econ. residuals generation model (Isard)	Simultaneous ecol.-Econ. Model (Johansen)	Interactive ecol.Econ. model (Miller and Blair)	Odum's "embodied energy" model	Bioeconomic renewable resource model (Wilen)
1. Capture processes and interactions	Yes	Yes	Yes	Yes	Yes
2. Address changes through time	No	Yes	No	No	Yes
3. Ecological behaviour mechanism	Yes/No	No	Yes	Yes	Yes
4. Economic behaviour mechanism	Yes	Yes	Yes	Yes	Yes

In the third (Miller and Blair) model, the ecological aspect is incorporated in an interactive manner.

The Isard and the Miller and Blair models attempt to incorporate the ecological aspects into the I/O model. There are two ways of attempting to integrate ecology into the standard input-output framework. The more straightforward approach (as described by de Kok), is by premultiplying an ecological "residuals" vector by the original Leontief inverse $(I-A)^{-1}Y$. The product indicates ecological impacts resulting from pure economic interactions embedded in the technical coefficients matrix and policy driven changes to the economy.

The limitation with this straightforward approach is that the interactive components, given as coefficients, in the model are purely economic. Ecology is crudely brought in as a transformation device that converts standard economic impacts (i.e., the Leontief inverse) into ecological impacts.

A more complete extension of the input-output framework to incorporate ecological variables would be to expand the interactions matrix to contain both economic as well as ecological components (as in the Miller and Blair model). This way there will be coefficients that will relate economic sectors with other economic sectors, economic sectors with ecological sectors in the form of residuals production, ecological sectors with economic sectors in the form of resource utilisation, and pure ecological interactions. The problem that has to be overcome if such an interaction matrix is to be built concerns the units of measurements from which input-output coefficients will be calculated. Traditional input-output tables record dollar flows among economic sectors which is not possible with ecological sectors. Pure ecological interactions can be described using mass but what about interactions between economy and ecology? Hybrid measurements may be required.

Both the Isard and the Miller and Blair models do not capture the time component (i.e. they are static models). The second (Johansen) model captures the time component but does not capture the ecological behaviour.

Isard's model also does not formally incorporate ecological behaviour. Ecological components are introduced merely as coefficients relating economics and the ecology.

The fourth (Odum's) model, attempts to capture the flow of energy in the opposite direction each time money is made through the transformation of materials from one stage of production to the next. Thus energy and money are two sides of the same coin, any one cannot be obtained without affecting the other. Unfortunately this model is static.

The fifth (Wilen bioeconomic renewable resource) model, is a function of time. Economic returns are also timed and these are adjusted to their present values (because they are received at different points in time under different harvest scenarios) so that they can be compared for their maximum values. Here, the trade-off is faced by either (a) increasing each harvest by waiting for biomass to grow (but in the process achieving fewer harvests throughout) or (b) increasing the number of achievable harvests by harvesting frequently (but the value of each harvest is reduced accordingly).

Presently we have only been able to implement the Isard model (Sections 4.1.1 and 4.2) and one aspect of the Wilen bioeconomic renewable resource model (Sections 4.1.5 and 4.3).

4.2. IMPLEMENTATION OF THE ECOLOGIC-ECONOMIC I/O MODEL (ISARD) IN THE MERBOK MANGROVE CATCHMENT

The Input-Output Tables for Malaysia in 1978 (Malaysia, Department of Statistics 1978) and 1983 (Malaysia, Department of Statistics 1983) were used. The latest available was for the year 1987 but this table had a different format rendering it incompatable with the earlier tabulated information. Malaysia's input-output tables were based on 60 sector commodities as well as 60 sector industries, and broken down into domestic and imported inter-sectoral flows. For our evaluations, the sectors have been reduced to 11 (see Section 3).

The corresponding entries of the Leontief inverse matrix, i.e. $(I-A)^{-1}$, found in the national table were extracted to form the 11x11 inverse matrix representing the Merbok estuary. Estimations of the values making up the 11x3 V matrix (comprising carbon, nitrogen and phosphorus residuals) resulting from per ringgit output of mangrove extraction, rice cultivation, and prawn aquaculture are outlined below.

4.2.1. ESTIMATION OF C, N and P RESIDUALS

The C, N and P residuals obtained here are order of magnitude estimates (or perhaps more correctly, "best guesstimates") based on limited knowledge, assumptions and data, where available. Details of the calculations involved are shown for only some of the more important sectors.

4.2.1.1. Agriculture

Agricultural crops includes rice, rubber, oil palm and some fruit orchards. Rice is the main crop and is used here as representative of agriculture. According to the World Health Organization (1993), for one tonne of rice produced, 800 kg of putrescible material result. Presumably, the remaining 200 kgs consist of rice grains. Thus, 1 kg of rice grain produced has an accompanying 4 kg of putrescible material. We assume the same C, N, P concentrations as for mangrove litter.

Rice costs RM 2.00 per kg. Therefore, for a one ringgit output of rice, the C, N and P produced are 1.018 kg, 0.012 kg and 0.0014 kg respectively. This is an underestimate because the N and P contained in fertilisers are not included, but this may be compensated by the lower residuals from rubber and oil palm cultivation.

4.2.1.2. Fishing

Fishing include capture fisheries and cultured fisheries. At least 20% of the mangroves in the Merbok has been converted to prawn culture ponds. There is input of fish from outside the estuary (in the form of trash fish) used for feeding fish in the cage culture system within the estuary. The prawn pond activity is used as indicative of the residuals from the fishing industry.

Only the feed is considered here - an underestimate as fertilisers would contribute to the C, N, P. Twenty tonnes of dry feed would result in 10 tonnes of prawn wet weight. "Guesstimates" of the composition of the feed is 70% C, 10% N and 0.5% P.

1 kg of prawns costs RM 30. Therefore, for a ringgit output of prawns, the C, N, P produced are 0.0462 kg, 0.0066 kg and 0.00033 kg respectively. (This assumes that all the food supplied is eaten by the prawns but if there is excess food then this is an underestimate of the residuals).

4.2.1.3. Forestry

Forest harvests include those from inland forests (mainly on the lower slopes of Gunung Jerai) as well as from mangrove forests. The residuals are estimated based on the mangrove forest litter.

The C, N, P concentrations of mangrove leaf litter (Gong *et al*., 1984) were used, namely C = 50%, N = 0.6% and P = 0.07% of dry weight. 2 tons of dry trunk converts to 1 ton of charcoal; and 0.8 ton of slash (about one-third of the tree biomass) is left behind in the forest.

1 kg of charcoal cost RM 0.50. Therefore, for a ringgit output of charcoal, the C, N, P produced is: 0.8 kg C, 0.0096 kg N and 0.0011 kg P.

4.2.1.4. Other Sectors

The other sectors are:
mining (there is very little mining activity: practically all of the mining is for sand), **manufacturing 1** (there is a relatively new light industrial estate situated at Tikam Batu which is dominated by the electronics industry so the residuals are based on this)
manufacturing 2 (this is a mainly wood-based furniture manufacturing industry so the residuals would be mainly derived from wood waste)
electricity generation (electricity comes from the national grid and relatively little is generated locally)
water supply (most of the potable and industrial water come from the Muda River which is more than enough to supply the whole of the State of Kedah)
construction (most of the construction is related to the housing industry and is concentrated around the main town of Sg. Petani)
transport (much of the public transport is serviced by buses; material transport is also mainly via roads rather than via rail), and
other services (this being small scale enterprises like stalls, eating places, vehicle servicing and cottage industries).

The C, N and P residuals are guesstimates based on the labour force contribution of each sector (Table 12) and the three sectors where better estimated are available. It is thus noted that these values are preliminary “order of magnitude” estimates.

Table 12. Allocation based on labour force, Kuala Muda District Council (1991) Structure Plan 1990 -2000.

	1995	2000
Agriculture	15.80	10.30
Fishery/Aquaculture	2.80	0.18
Forestry and Hunting	0.03	0.01
Mining and Quarrying	0.20	0.01
Manufacturing 1	3.70	4.80
Manufacturing 2	33.40	44.00
Electricity and Gas	0.60	0.56
Water Supply	0.80	0.75
Construction	6.90	8.10
Transport	2.70	2.45
Others	28.10	28.70

The C, N and P residuals for all the 11 sectors for the Sg. Merbok are shown in Table 13.

Table 13. C, N and P residuals for the Sg. Merbok by economic sectors.

kg/RM1 output	C	N	P
Agriculture	1.01819	0.01200	0.00140
Fishing	0.04620	0.00660	0.00033
Forestry	0.80000	0.09600	0.00112
Mining	0.00100	0.00010	0.00001
Manufact. 1	0.01000	0.00150	0.00070
Manufact. 2	0.08000	0.00090	0.00030
Electricity	0.00300	0.00030	0.00003
Water	0.00600	0.00060	0.00006
Construction	0.01000	0.00100	0.00010
Transport	0.00300	0.00030	0.00030
Other services	0.06000	0.00900	0.00050

4.2.2. RESULTS

As stated in Section 4.1.1, the direct, indirect and induced impacts of C,N,P residual outputs resulting from economic final demand (i.e., income) changes are estimated as follows:

$$V' = \{V\,(I-A)^{-1}\}\,Y$$

where, Y is a 11x1 column vector indicating final demand changes by the eleven sectors, and V' the 11x3 column vector of C,N,P residual generation.

Three sets of calculations were made. The first was based on the total flows between sectors using the 1983 National I/O table and the second taking into account only domestic flows (i.e., subtracting out inter-sectoral flows of imported items), also using the 1983 table (Table 14). The difference in multipliers between these two sets of calculations (Table 16) show impacts that will occur externally as opposed to impacts occurring locally. A third set of calculations was conducted based on domestic flows and an updated 1987 National I/O table. The difference in multipliers between this and the second run (shown in Table 14) shows the technological/cultural shifts which indicate whether impacts have become more or less intense for each ringgit change in the respective sectors (Table 16).

For convenience, Y was defined iteratively in the form (1,0,...,0)', (0,1,...,0)' and (0,0,1,...,0)' and signifying one ringgit change in the final demand for each sector one at a time, with no changes elsewhere. By specifying the Y vectors in this fashion, the resulting impacts (V') are called multipliers or total impacts per ringgit change in the respective sectors.

Table 14. The total and domestic generated C, N and P residuals for 1983 for the Sg. Merbok system.

	C,83(Total)	N,83(Total)	P,83(Total)	C,83Dom	N,83Dom	P,83Dom
Agriculture	1.037635	0.012253	0.001433	1.033846	0.012208	0.001431
Fishing	0.050483	0.006709	0.000341	0.048290	0.006682	0.000343
Forestry	0.820620	0.009944	0.001181	0.814166	0.009815	0.001155
Mining	0.003172	0.000179	0.000030	0.002544	0.000180	0.000025
Manufact. 1	0.026431	0.002833	0.001281	0.012390	0.001605	0.000740
Manufact. 1	0.188484	0.002261	0.000477	0.172330	0.002044	0.000443
Electricity	0.006867	0.000444	0.000066	0.004726	0.000363	0.000045
Water	0.014326	0.000963	0.000155	0.009818	0.000774	0.000094
Construction	0.038971	0.001565	0.000239	0.032441	0.001340	0.000164
Transport	0.008916	0.000488	0.000382	0.005194	0.000371	0.000329
Other services	0.070726	0.009190	0.000528	0.063125	0.009082	0.000511

Table 15. The domestic generated C, N and P residuals for 1987 for the Sg. Merbok system.

	C,87Dom	N,87Dom	P,87Dom
Agriculture	1.040822	0.012278	0.001435
Fishing	0.050483	0.006709	0.000341
Forestry	0.048915	0.006667	0.000337
Mining	0.002601	0.000187	0.000074
Manufact. 1	0.011973	0.001560	0.000720
Manufact. 1	0.174553	0.002063	0.000448
Electricity	0.004775	0.000352	0.000041
Water	0.009532	0.000746	0.000082
Construction	0.045997	0.001490	0.000176
Transport	0.006219	0.000415	0.000336
Other serv.	0.064020	0.009091	0.000514

Table 16. The difference between total and domestic generated C, N and P residuals for 1983 and the difference between the 1987 and 1983 domestic generated C, N and P residuals for the Sg. Merbok system.

	C,83Tot-Dom	N,83Tot-Dom	P,83Tot-Dom	C,87-83 Dom	N,87-83 Dom	P,87-83 Dom
Agriculture	0.003789	0.000046	0.000002	0.006976	0.000070	0.000004
Fishing	0.002194	0.000028	-0.000002	0.002194	0.000028	-0.000002
Forestry	0.006454	0.000129	0.000027	-0.765251	-0.003148	-0.000818
Mining	0.000628	-0.000001	0.000005	0.000056	0.000007	0.000049
Manufact. 1	0.014041	0.001228	0.000541	-0.000416	-0.000046	-0.000019
Manufact. 1	0.016155	0.000216	0.000035	0.002224	0.000019	0.000005
Electricity	0.002141	0.000081	0.000021	0.000049	-0.000011	-0.000005
Water	0.004508	0.000189	0.000060	-0.000286	-0.000028	-0.000012
Construction	0.006530	0.000225	0.000075	0.013556	0.000151	0.000012
Transport	0.003722	0.000117	0.000053	0.001025	0.000045	0.000007
Other services	0.007601	0.000108	0.000017	0.000895	0.000009	0.000003

In the above tables (Tables 14, 15, 16), each row shows the C, N and P impacts for a one ringgit change of final demand in the respective sectors. The various columns show results from using data based on: the 1983 total technological inverse incorporating both domestic and imported flows; the 1983 domestic flows only (Table 14); and differences between the two (Table 16). The differences show the likely over-estimation of impacts if imported flows were not to be set aside, because the inter-sectoral interactions that generate impacts by imported flows do not occur within the local vicinity. The differences between the 1987 and 1983 domestic impacts have also been included in Table 16. This shows impact changes resulting from technological transitions that occurred between 1987 and 1983. Further understanding of the characteristics of such technological transitions will help us model changes to the matrix and help overcome the inherent static nature of input-output models.

Returning to the economic planning application of input-output model described in Section 3.3.1, a Y matrix was introduced as a policy variable to assess the economic impacts on gross-output, X. By introducing the V residuals vector, the economic impacts is translated to indicate ecological impacts. Based on the same policy vector that was used, the C, N, P residual generation was produced (Table 17). Here, the Y vector that drives the impacts X may be specified as a one-sector-one-ringgit change in final demand or as an externally defined set of sector by sector final demand changes in actual ringgit. Whether one or the other is used, it is important to take note that the inter-sectoral interactions (contained in the A matrix) as well as the sectoral final demand changes (in the Y matrix) are entirely defined in pure economic terms. In other words, no ecological interactions are captured by the current model nor is the model driven by any ecological factors. The only ecological components which are found in the V vector is a set of coefficients that translates pure economic impacts into anticipated ecological impacts based on the coefficient values of V.

Table 17. The all sectors (total inverse and domestic inverse) and the difference between total inverse and domestic inverse of generated C, N and P residuals for the Sg. Merbok system.

	C	**N**	**P**
All Sectors (Total inverse)	8806	2957	115
All Sectors (domestic inverse)	4536	2649	92
Difference	4270	307	23

4.3. BIOECONOMIC RENEWABLE RESOURCE MODEL

In terms of real output, the Malaysian team was able to take a positive first step with a simple integrated economic and biological growth model. This is described in our paper “An ecologic-economic model for more optimal management of mangrove timber extraction.” submitted to *Ecological Economics* (Chan *et al.* submitted).

4.4. DISCUSSION

Five integrated models were considered (see Section 4.1.6) and the first four of these can be run on the I/O framework. Unfortunately, none of these satisfies all the conditions for a good model. So far, only the first (Isard) model has been implemented but this suffers from the fact that the C, N and P residuals of each of the 11 economic sectors are at best, order of magnitude guesstimates, with limited confidence in the estimates. The model also suffers in that the ecological component is not interactive. The next logical step would be to proceed to the interactive ecologic-economic model (Miller and Blair). There is still the short-coming of it being a static model which can only be overcome if this can be combined with the Johansen simultaneous model. There is thus much conceptualising to be done.

The fifth model (Bioeconomic Renewable Resource Model) satisfies all the modelling conditions but is not based on the I/O framework. The problem with the fifth model is that it does not include the entire ecosystem; only subsections of the ecosystem. It is necessary to eventually integrate the sub-systems into a model that includes the whole ecosystem. Presently, one sub-system (mangrove charcoal production) has been implemented and it would be logical to follow this up with pond prawn production, fish cage culture production, bag-net fishery production and other production sub-systems in the Sg. Merbok. The difficult part will be to link up the various sub-systems to represent the whole ecosystem.

5. CONCLUSIONS and RECOMMENDATIONS

Mangrove and salt marsh workers have long known that determining material fluxes from coastal ecosystems is an extremely difficult task (e.g., Nixon, 1980). For this SWOL project the approach agreed between the groups was the LOICZ stoichiometric budget method. This is basically a "first-order estimation" method and whilst it may be useful in providing a first global picture (once there is data from enough sites, globally), it must be borne in mind that the method may not be universally applicable. Our group has been working on the flux problem (as part of our long term objective of closing the carbon and nutrient budgets for a mangrove ecosystem) and will continue to explore other methods and approaches that will bring increased confidence in flux estimates.

The present integrated model that has been implemented by all four SWOL project groups is the Isard Ecologic-Economic I/O Framework Model (the first of the models in our comparison Table 11). There are two major limitations to using this model; first, it does not address changes through time (i.e., it is a static model) and second, it is not interactive in terms of ecological behaviour.

Although C, N and P residuals are "guesstimated" and fed into the model (V), the output has very limited ecological significance. The second limitation may be overcome by using the Interactive Ecologic-Economic I/O Framework Model (the Miller and Blair model in our comparison Table 11) but the model will remain static and thus have little predictive value.

The Simultaneous Dynamic Model (Johansen) (the second of the models in our comparison Table 11) overcomes the static nature of the I/O approach but cannot capture the ecological behaviour. If we still want to pursue the I/O approach, we should look into the possibility of combining the Interactive Ecologic-Economic I/O Framework Model with the Simultaneous Dynamic Model, if this is possible. It should also be possible to incorporate Odum's Embodied Energy Model especially when dealing with energy and carbon. However, data for this may be difficult to obtain and both the monitoring and energy units will not remain fixed, but change through time.

The only model that fulfils all four attributes is the Bioeconomic Renewable Resource model (the fifth of the models in our comparison Table 11). We have started pursuing this line and have submitted a paper (modelling charcoal production) to Ecological Economics. We are continuing along this line to model pond prawn production, floating fish cage production, bag-net fishery production with the goal of perhaps bring all these various sub-components of the ecosystem together into an integrated ecologic-economic model of the entire ecosystem.

The biogeochemical aspect formed a major part of this project. All four SWOL groups have expended considerable effort in obtaining C, N and P budgets using the LOICZ Stoichiometric Model. One major concern about the present project is that data (which is at least a good order of magnitude more reliable than those guesstimated as C, N and P residuals for each of the economic sectors) from this aspect has not been used in the (Isard) integrated ecologic-economic model.

Finally, we note that the sociological aspect is at present almost completely lacking. The weakness in current government statistics on economic production compiled for measuring gross domestic products (GDP) of national economies is that they fail to incorporate households and informal (petty trading) sectors which are also involved in production. In certain developing economies, both of these neglected sectors can be many times larger than the formal production sectors. When attempting to address the anthropogenic activities in more pristine ecosystems that make up SWOL study sites, this absence of the informal and household sectors becomes a more critical issue, because only a small proportion of the economic activities is captured and compiled in the national accounts statistics.

Thus, when putting together input-output tables to represent anthropogenic activities in the individual SWOL sites, some effort must go into dealing with the above inherent weakness. It may amount to adjusting available data obtained from government statistical sources or through ground-up field evaluation. When doing this, be mindful that economic production in money terms that is meant to be captured and entered into the input-output table is but an outcome of social and cultural processes that interplay in the respective study sites. Figure 21 describes how the different processes connect. Religious beliefs, local traditions and preferences, among other factors, factor in through these processes and result in the quantity and quality of economic production that are observed in these study sites. We refer to these as local dynamics that work in different ways for the formal, informal and household sectors. Such dynamics also lead to not only flows within and among these three divisions of sectors in input-output fashion, but also between all these sectors collectively with economic activities and ecological processes occurring outside the ecosystems of these sites. Such interactions between the site location and the outside represent import and export flows. These external flows become critical when we begin to address the issue of long term sustainability, questioning whether the study site is actually a net contributor or net consumer of both ecological and economic resources used for production.

For the next phase of this project, the recommendations are as follows:

1. The biogeochemical study, using additional approaches, should be continued with the aim of developing a robust set of C, N and P budgets for the ecosystem. This is a vital exercise on its own (for system understanding and for management of changes due to anthropogenic external forcing), even if it cannot be integrated in the integrated models.

2. The integrated biogeochemical-socioeconomic modelling study should also be continued, first by making the ecological behaviour more interactive (using the Miller and Blair model) and then by combining with the Johansen model to add the time component. This would provide vital comparisons for assessment approaches (and additional cost-benefit of the research). It may not be possible to implement all the models but this will be a very useful conceptualisation exercise.

3. The Bioeconomic Renewable Resource Model should also be pursued by adding more sub-production systems, and eventually an attempt should be made to integrate the sub-systems into a whole ecosystem model. Here, socio economic changes and “residuals” can be linked as drivers to the biogeochemical models for system response description and scenario-building to assess land-use practices and land-use changes.

4. The sociological aspect should be very much part of any integrated model. The next phase of the study would therefore explore the social dimension identifying local social institutions and local social organisation that shapes the use of resources.

8. REFERENCES

Chan H.C. (1996). A model framework for simultaneous ecologic-economic analysis. pp. 20-24, *in*: LOICZ. 1996. Report of the SARCS/WOTRO/LOICZ Workshop on Integrated Natural and Socio-economic Modelling. LOICZ Meeting Report No. 20.

Chan, H.C. (1997). Forecasting the structure of an industrialising economy. Pages 12-41 *in*: B.N. Ghosh, Y. W. Lai and S. Narayanan (eds): *Industrialisation in Malaysia: Some Contemporary Issues.* Utusan Publications, Kuala Lumpur.

Chan, H.C, and Alip Rahim (1997). The carbon in our money. Page 155 *In*: LOICZ. Report of LOICZ Open Science Meeting 1997: Global Change Science in the Coastal Zone. *LOICZ Meeting Report* No. **29**, 244 pages, LOICZ International Project Office, Texel, The Netherlands.

Chan, H.C., Gong, W.K., Ong, J.E. and Alip, R. (submitted). An ecologic-economic model for more optimal management of mangrove timber extraction. submitted to *Ecological Economics*

Chan, H.T., Ong, J.E., Gong, W. K. and Sasekumar, A. (1993). The socioeconomic, ecological and environmental values of mangrove ecosystems in Malaysia and their present state of conservation. pp 41-81, *in*: Clough, B.F. (ed.) Technical Report of the Project *The Economic and Environmental Values of Mangrove Forests and their Present State of Conservation in the South-East Asia/Pacific Region.* International Society for Mangrove Ecosystems / International Tropical Timber Organization/ Japan International Association for Mangroves.

Cobb, C.W. and Douglas, P.H. (1928). A theory of production. *American Economic Review* 1928 (suppl.): 139-165.

Cumberland, J.H. and Korbach, B.J.(1973). A regional inter-industry environmental model. In: *Regional Science Association Papers*, Vol. 30.

de Kok, J.-L. (1998). On the integration of economic input-output and dynamic process modelling. pp 34-39, *in*: Report of the SARCS/WOTRO/LOICZ Workshop on Linking Coastal Zone Change Regimes to Input/Output Modelling in Southeast Asia. *LOICZ Meeting Report* No. 32.

Dyer K.R., Gong, W.K. and Ong, J.E. (1992). The cross-sectional salt balance in a tropical estuary during a lunar tide and a discharge event. *Estuarine, Coastal and Shelf Science* **34**: 579-591.

Faucheux, S. and Pillet, G. (1994). Energy Metrics: On Various Valuation Properties of Energy. in Pethig R (ed.) *Valuing the Environment: Methodological and Measurement Issues.* Kluwer Academic Publishers. Dordrecht.

Gong, W.K., Ong, J.E., Wong, C.H. and Dhanarajan, G. (1984). Productivity of mangroves trees and its significance in a managed mangrove ecosystem in Malaysia. pp. 216-225 *in*: Soepadmo, E., Rao, A.N. and Macintosh, D.J. (eds.). *Proceedings of the UNESCO Asian Symposium on "Mangrove Environment: Research and Management* , Universiti Malaya.

Gordon, D.C., Jr., Boudreau, P.R., Mann, K.H., Ong, J.E., Silvert, W.L., Smith, S.V., Wattayakorn, G., Wulff, F. and Yanagi, T. (1996). LOICZ Biogeochemical Modelling Guidelines. *LOICZ R and S* **95-5**, vi + 96 pages. LOICZ, Texel, The Netherlands.

Imaoka, H., Semudram, M., Meyanathan, S. and Chew, K. (1990). *Models of the Malaysian Economy: A Survey.* Malaysian Institute of Economic Research, Kuala Lumpur.

Isard, W. (1971). *Economic-Ecological Analysis for Regional Planning.* The Free Press, New York.

Johansen, L. (1974). *A Multi-sectoral Study of Economic Growth.* North Holland Publishing Company, Amsterdam.

Khoo, K.H. (1989). The mangrove fisheries in Matang, Perak and Merbok, Kedah mangrove ecosystem. Final Report of the ASEAN-Australia Cooperative Program on Marine Science: Coastal Living Resources. Universiti Sains Malaysia, Malaysia.

Kjerfve, B., Stevenson, L.H. ,Proehl, J.A., Chrzanowski, T.H. and Kitchens, W.M. (1981). Estimation of material fluxes in an estuarine cross-section: A critical analysis of spatial measurement density and errors. *Limnology and Oceanography* **26**: 325-335.

Kuala Muda District Council (1991). Kuala Muda Structure Plan Report 1990-2000 (1991). *Laporan Pemeriksaan Rancangan Struktur Kuala Muda 1990 - 2000* (Report in Malay).

Lahari, K. and Moore, G.H. (1991). *Leading Economic Indicators: New Approaches and Forecasting Records.* Cambridge University Press.

Leontief, W. W. (1951). *The Structure of the American Economy, 1919-1939.* Harvard University Press, Cambridge, Mass.

Lim, H. F. (1996). Socio-economic impacts of Merbok mangrove ecosystem utilisation. In: Shigeo Hayase (ed.) *Productivity and Sustainable utilisation of brackish Water Mangrove Ecosystems.* Japan International

Research Centre for Agricultural Science (JIRCAS), Ministry of Agriculture, Forestry and Fisheries, Japan.

LOICZ (1996). Report of the SARCS/WOTRO/LOICZ Workshop on Integrated Natural and Socio-economic Modelling. *LOICZ Meeting Report* No. **20**.

LOICZ (1997). Report of the SARCS/WOTRO/LOICZ Workshop on Coastal Zone Science in Southeast Asia. *LOICZ Meeting Report* No. **28**.

LOICZ (1998). Report of the SARCS/WOTRO/LOICZ Workshop on Linking Coastal Zone Change Regimes to Input/Output Modelling in Southeast Asia. *LOICZ Meeting Report* No. **32**.

Malaysia, Department of Statistics (1980). Malaysian Housing Population Census 1980.

Malaysia, Department of Statistics (1991). Malaysian Housing Population Census 1991.

Malaysia, Department of Statistics (1978). Malaysian Input-Output Tables 1978.

Malaysia, Department of Statistics (1983). Malaysian Input-Output Tables 1983.

Miller, R.E.and Blair, D. (1985). *Input-Output Analysis: Foundation and Extensions.* Prentice Hall, Englewood Cliffs, N.J.

Nakatsuji, K., Ohya, Y, Ong, J.E. and Gong, W.K. (1998). Coupling of 2-D and 3-D modelling of creek and swamp system in mangrove estuaries. *Proceedings IAHR-APD Congress* Vol. **11:** 395-403.

Nixon, S.W. (1980). Between coastal marshes and coastal waters - a review of twenty years of speculation and research on the role of salt marshes and estuarine productivity. pp. 437-520, *in*: P. Hamilton and K.B MacDonald (eds), *Estuarine Wetland Processes.* Plenum Publishing Corporation, New York.

Nixon, S.W., Furnas, B.N., Lee, V., Marshall, N., Ong, J.E., Wong, C.H., Gong, W.K. and Sasekumar, A. (1984). The role of mangrove in the carbon and nutrient dynamics of Malaysian Estuaries. pp. 534-544, *in*: Soepadmo, E., Rao, A.N. and Macintosh, D.J. (eds), *Proceedings of the Asian Symposium on Mangrove Environment: Research and Management.* University of Malaya / UNESCO.

Odum, H.T. (1983). *Systems Ecology.* Wiley Interscience, New York.

Odum H.T and Odum E.C. (1981). *Energy Basis for Man and Nature.* McGraw Hill, N.Y.

Officer, C.B. (1983). Physics of estuarine circulation. pp. 15-41, *in*: Ketchum, B.H. (ed.) *Estuaries and Enclosed Seas.* Ecosystems of the World Series **26**, Elsevier Scientific, Amsterdam.

Ong, J.E. (1995). The ecology of mangrove management and conservation. *Hydrobiologia* **295:** 343-351.

Ong, J.E., Gong, W.K. and Wong, C.H. (1980). *Ecological Survey of the Sungai Merbok Estuarine Mangrove Ecosystem.* 83pp. Report to MAJUIKAN (Malaysian Fisheries Development Authority).

Ong, J.E., Gong, W.K., Wong, C.H., Din Zubir, Hj. and Kjerfve, B. (1991). Characterisation of a Malaysian mangrove estuary. *Estuaries* **14**: 38-48.

Ong, J.E., Gong, W.K.and Uncles, R.J., (1994). Transverse structure of semidiurnal currents over a cross-section of the Merbok Estuary, Malaysia. *Estuarine, Coastal and Shelf Science* **38**: 283-290.

Pearce, D. and Turner, K. (1990). *Economics of Natural Resources and Environment.* Harvester Wheatsheaf, Herfordshire.

Pillet, G. (1994). Applying eMergy analysis to vineyard cultivation and wine production. In: Pethig, R. (ed.) *Valuing the Environment: Methodological and Measurement Issues.* Kluwer Academic Publishers, Dordrecht.

Rasmussen, P. (1952). *Studies in Intersectorial Relations.* North Holland, Amsterdam.

Robertson, A.I. and Phillips, M.J. (1995). Mangroves as filters of shrimp pond effluent: predictions and biogeochemical research needs. *Hydrobiologia* **295**: 311-321.

Simpson, J.H., Gong, W.K. and Ong, J.E. (1997). The determination of net fluxes from a mangrove estuary system. *Estuaries* **20**:103-109.

Uncles, R.J., Ong, J.E. and Gong, W.K. (1990). Observations and Analysis of a Stratification-Destratification Event in a Tropical Estuary. *Estuarine, Coastal and Shelf Science* **31**: 651-66.

Uncles, R.J., Gong, W.K. and Ong, J.E. (1992). Intratidal fluctuations in stratification within a mangrove estuary. *Hydrobiologia* **247**: 163-171.

Victor, P.A. (1972). *Pollution: Economy and Environment.* George Allen and Unwin Ltd., London.

Webster, I.T., Parslow, J.S. and Smith, S.V. (2000). Implications of spatial and temporal variation for biogeochemical budgets of estuaries. *Estuaries* 23 (3): 341-350.

Wilen, J.E. (1985). Bioeconomics of renewable resource use. pp. 61-124 *in*:. Kneese, A. and Sweeney, J.L. (eds) *Handbook of Natural Resource and Energy Economics,* vol. 1.,Elsevier Science Publishers B.V.

World Health Organization (1993). *Rapid Assessment of Sources of Air, Water and Land Pollution.*. Geneva, Switzerland.