Acknowledgement

This collaborative project was funded and supported by the Ministry of Agriculture & Fisheries (MAF), Government of Timor Leste and ATSEF Australia partners, the Australian Institute of Marine Science (AIMS), Charles Darwin University (CDU) and the Australian National University (ANU), and undertaken by the following researchers:

Dan Alongi (AIMS), Alexio Leonito Amaral (MAF-Fisheries), Narciso Almeida de Carvalho (MAF-Fisheries), Andrew McWilliam (ANU), Juno Rouwenhorst (CDU), Francesco Tirendi (AIMS), Lindsay Trott (AIMS), Robert Wasson (CDU)

This project is a recognised project under the Arafura Timor Seas Experts Forum (ATSEF).

Citation

This document should be cited as:


Printed by Uniprint NT, Charles Darwin University, Northern Territory, Australia.
Permission to copy is granted provided the source is acknowledged.

ISBN
978-1-74350-016-3 (Australia)
978-989-8635-10-5 (Timor Leste) (paper)
978-989-8635-11-2 (Timor Leste) (pdf)

Copyright of Photographs

Cover Photographs:
Main: Juno Rouwenhorst
Central photographs left to right: Juno Rouwenhorst, Juno Rouwenhorst, Lindsay Trott, Lindsay Trott, Juno Rouwenhorst
Acknowledgements

A great many Timorese aided this study, particularly at community meetings, on roadsides, in forests, on riverbeds, in mangrove forests and in the offices of the Ministry of Agriculture, Forestry and Fisheries (Timor Leste). In particular we wish to thank the following people for their assistance on fieldtrips: Carlos Alexandre Jesus, Manuel da Silva, Horacio dos Santos Geterres, Lino de Jesus Martins, Oscar da Silva, Francisco Inacio Castro de Araujo, Francisco da Silva (Francisco 500), Sebastino da Costa, Alcino Sarmento, Manuel Soares, Joao Amaral, Angelino Jose Amaral, Francisco Xavier, Francisco de Jesus Alves, Acacio da Costa.

We acknowledge funding from the Government of Timor Leste.

Dr Dan Alongi (Australian Institute of Marine Science),
Professor Bob Wasson (Charles Darwin University),
Narciso Almeida de Carvalho (Ministry of Agriculture, Forestry & Fisheries, Timor Leste).

5 November 2012.
Executive Summary (English)

Project Title: River Catchments and Marine Productivity in Timor Leste: Caraulun and Laclo Catchments; South and North Coasts

Project Leaders: Dan Alongi (AIMS), Robert Wasson (CDU), Narciso de Carvalho (MAF-Fisheries)


Summary:

The study team has used the views of local people in the two catchments, the evidence of natural science, and the analytical techniques of social science. From these sources of knowledge and their comparisons, the following conclusions have been reached.

- Catchment-wide erosion (denudation) is now up to 20 times higher than it has been over the last few thousand years. The most likely cause of the increase is land-use, particularly removal of vegetation from riverbanks (riparian zones), which has caused widespread erosion, and the removal of vegetation from hillslopes thereby promoting landslides. Gully and sheet erosion are minor sources of sediment.
- Increased erosion of catchments has increased the sediment load of rivers which has led to them shallowing and widening, and thereby increasing riverbank erosion. Bank erosion has also severely impacted on transport in the southern coastal zone resulting in bridge collapse and road damage. These changes have also increased flooding, and river flows have become more erratic as channels have widened and braided.
- More sediment has been supplied to the coast, resulting in more rapid seaward growth of the Caraulun delta. The effect on the north coast at the Laclo River mouth has been in deep water offshore, and is unknown.
- Mangroves have been partially buried by the increased sediment load on the Caraulun delta, but there has been no such impact at the Laclo River mouth.
- Revegetation of critical sediment sources is essential if erosion, river sedimentation, flooding and deposition of sediment in the coastal zone are to be reduced.
- The mangroves are less productive than elsewhere in the tropics, as a result of dry climate. Nonetheless, the mangroves are healthy and are an important supplementary source of wood and food.
- The number of large fish in the two rivers and in the nearshore has declined, possibly as a result of habitat change by sedimentation, less nutrients being released from sandier sediment deposited offshore, and fishing pressure.
- The development of joint management between the institutions of local people and government is the most likely way to improve natural resource management of both river catchments and the coast.

Following a Workshop in Dili 4-5 June 2009, the following recommendations are made:

- Revegetate critical sediment sources in catchments, taking account of benefits to local people, land tenure, and customary institutions.
- Understand the existing guidelines for prioritising catchments for management (10 critical catchments out of 27 catchments in Timor-Leste).
- Identify and map sediment source areas in the critical catchments.
• Survey information on socio-economic (energy and material audit at village level) and natural condition in each critical catchment
• Develop guidelines for integrated catchment management, including reforestation. This will involve joint management of catchments and coasts involving government and the institutions of local people to ensure local ownership/engagement.
• Build on existing capacity through training in catchment inventory and data compilation, data analysis and catchment management.
• Develop local capacity in catchment management in communities, through public awareness and training.

• Develop a national joint management plan for mangroves
  • Important across Environment, Culture, Fisheries and Tourism Ministries.
  • Consideration be given to local knowledge and values in mangrove management
  • Survey and map species/communities of mangroves, particularly on the south coast (as data are available for north coast).
  • Prioritise mangrove forests for management.
  • Education and public awareness raising of the importance of mangroves.

• Gain greater understanding of:
  1. The contribution to river sediments and coastal landforms (eg deltas, beaches) of landslides and riverbank erosion.
  • Ongoing exercise, with management responding to new information.
  • Identify soil conservation priorities, (for example hill slope terracing, fire management, riparian zone management and rehabilitation etc)
  2. Identify options for joint management of catchments and coasts (eg legislation & policy – central level; and Tarabandu – local level)
  • Understand why some joint management succeeds and why some fails
  • Strengthen existing relationships and links between regulation and Tarabandu.
  3. Understand the relationship between river flows and nutrient release to the coastal zone and impacts on marine food chains, including fish stocks and sources of food for marine mega fauna. This is to improve management of coastal resources, with an emphasis on food security
  • Spatial and temporal sampling of food chains and nutrient fluxes.

• Develop adaptive strategies and monitoring protocols for the management of the likely impact of climate change on catchment and coastal resources.
Sumário (Tetum)

Titulu Projeto: River Catchments and Marine Productivity in Timor Leste: Caraulun and Laclo Catchments; South and North Coasts

Lider Sira Projetu Nian: Dan Alongi (AIMS), Robert Wasson (CDU), Narciso de Carvalho (MAF-Fisheries)


Sumário:

Grupu estudu ne’e uza ideia/vizaun husi komunidade lokál kona-ba mota-dalan (catchment) rua, evidênsia husi siénsia naturál no téknika análize husi siénsia sosiál. Husi fonte koñesimentu hirak ne’e, no sira-nia komparasaun, mak nia to’o iha konkluzaun no halo rekomendasauaun sira tuir mai ne’e:

- Erozaun catchment-wide (desnudação, Pt) aumenta dala ruanulu liu tinan rehun hira liu ba. Kauza provavel liu ba aumentu ida-ne’e mak uza-rai, liüu bainhira ita hasai ai-oan moris sira husi mota-ninin (zona sira iha mota-ninin), ne’ebé halo erozaun sai boot liu tan, no hasai ai-oan moris husi foho lolon sira, ne’ebé aumenta rai-halai. Erozaun rai-so’uk (gully) no sheet (lençol, Pt) ne’e fonte ki’ik oan sedimento ninian.
- Aumentu erozaun iha mota-dalan (catchment) aumenta mota sira-nia karga sedimentu no halo mota hirak ne’e sai badak no luan, nune’e erozaun iha mota ninin sira sai boot. Erozaun iha mota-ninin sira iha impaktu makaas ba transporte iha zona tasi-mane nian (sul), ne’ebé ponte sira munu no lurón sira sai aat. Mudansa hirak ne’e halo mós mota-tun no halai arbiru, tanba bee-liman sira sai luan no bobar malu.
- Sedimento barak tan mak tun ba zona sira iha tasi-ibun, ne’ebé halo delta (delta, Pt) Caraulun nian ba tasi sai laalais liu. Ita la hatene impaktu ba zona tasi-ibun iha norte (tasi-feto) ne’ebé akontese iha bee-kle’an iha Mota Laclo nia ibun.
- Aumentu karga sedimento iha delta Caraulun nian hakoi tiha ai-oan moris balun, maibé impaktu ida-ne’e la akontese iha Mota Laclo ibun.
- Se ita hanoí atu hamenus erozaun, sedimentasaun mota sira nian, bee-sa’e no sedimento nia depozisaun iha zona tasi-ibun sira, entaun esensiál ita hamoris hikas fonte importante sira sedimento nian.
- Ai-oan moris iha tasi-ibun sira ladun produtivu hanesan iha fatin sira seluk área tropikál ninian, ida-ne’e akontese tanba klima maran. Maiske nune’e, ai-oan sira iha tasi-ibun iha saúde d’ak no sai hanesan fonte suplementár ida importante ba ai no ai-han.
- Númeru ikan boot sira nian iha mota rua ne’e no iha besik tasi-ibun sira sai menus, posivelmente tanba mudansa habitat husi sedimentasaun, nutritivu alimentár husi sedimentu rahun iha rai-maran menus no presauaun husi peska.
- Dezenvolvimentu ba jestaun konjunta entre instituisaun sira komunidade lokál ninian no governu mak dalan ida ne’ebé bele uza atu hadi’a jestaun ba rekursu naturál sira iha mota rua ne’e nia dalan (catchment) no iha tasi-ibun.
Liu tiha workshop ne’ebé hala’o iha Dili iha loron 4-5 Juñu 2009, sai lia-menon hirak ne’e:

- Kuda fali fonte sedimentu importante sira iha *bacia hidrográfica*, maibé lebele haluha benefisiu ba populasun lokál, titulu rai nian no instituisaun tradisionál sira.

  - Hatene no komprendes matadalan ne’ebé iha hodi bele fó prioridade ba *bacia hidrográfica* ne’ebé maka atu halo jestaun ba (*bacia hidrográfica* 10 ne’ebé importante liu husi *bacia hidrográfica* 27 iha Timor-Leste)
  - Identifika no halo mapa ka trasa area sira iha *bacia hidrográfica* sira ne’ebé importante liu.
  - Halo peskiza hodi bele hetan informasaun kona-ba kondisaun sosial no ekonomiku (halo auditoria kona-ba energia no materiál sira iha vila) no kondisaun natural iha *bacia hidrográfica* importante idaidak.
  - Dezenvolve matadalan ida hodi halo jestaun integral ba *bacia hidrográfica* sira, inklui programa atu kuda hikas ai. Ida-ne’e envolve jestaun konjuntu ba *bacia hidrográfica* no zona sira iha tasi-ibun, no envolve mós governu no comunidade lokál nia instituisaun sira, atugarante populasun lokál nia partisipasaun no nia titularidade ba rai.
  - Liu husi formasun kona-ba oinsá atu halibur dadas no halo inventáriu kona-ba *bacia hidrográfica*, dezenvolve kapasidade ne’ebé iha.
  - Liu husi sensibilizasaun públíku no formasun, dezenvolve kapasidade local kona-ba oinsá atu halo jestaun ba *bacia hidrográfica*.

- Dezenvolve planu jestaun nasionál konjuntu ba ai-tasi (mangrove Eng.)

  - Importante iha Ministériu Meiu-Ambiente, Kultura, Peska no Turizmu
  - Fó konsiderasaun ba koñesimentu no valor lokál sira kona-ba jestaun ba ai-tasi
  - Halo peskiza no mapa kona-ba animal oan sira (species Eng.) no comunidade ai-tasi sira, liliu iha zona sira tasi-mane nian (tanba iha ona dadas kona-ba zona sira iha tasi-feto).
  - Fó prioridade ba comunidade ai-tasi ne’ebé atu halo jestaun ba.
  - Has’e educasaun no koñesimentu kona-ba ai-tasi nia importánsia.

- Hetan kompreensaun boot liu kona-ba:

  1. Kontribuisaun ba sedimentu mota nian no *hidrografia costeira* (Pt.) (exemplu, delta, tasi-ibun) husi rai-halai no erozaun iha mota-ibun.

  - Hala’o nafatín servisu, ne’ebé diresaun (management Eng.) sei hatán ba informasaun foun ne’ebé mosu.
  - Identifika prioridade kona-ba konservasaun ba rai, (exemplu *terracemento* (Pt.) iha fohololon sira, jestaun ba ahi-sunu rai, jestaun no reabilitasaun ba zona sira iha mota ninin, no seluk tan).

  2. Identifika opsaun hodi halo jestaun konjuntu ba *bacia hidrográfica* no zona sira iha tasi-ibun (exemplu, lejislasaun & planu no programa sira – nivel nasionál; tarabandu – nivel lokál)

  - Komprende tanbasá mak jestaun konjuntu balu hetan suxesu no balu la hetan
  - Hametin relasaun no ligasaun ne’ebé iha entre regulamentu no Tarabandu.

  3. Komprende relasaun entre mota-tun no nutrisaun ne’ebé sai ba zona sira iha tasi-ibun no ninia inpaktu ba ai-han, inklui populasun ikan nian no fonte ai-han ninian ba megafauna marítima. Ida-ne’e atu hadi’a jestaun ba rekursu sira iha zona tasi-ibun, ho atensaun ka foku ba seguransa ai-han ninian.

  - Amostra espasiál no temporál kona-ba ai-han (cadeia alimentar Pt.) no nutrisaun ninia sulí bá-mai.

- Dezenvolve estratejia ida ne’ebé bele adota no halo monitorizasaun ba protokolu sira hodi halo jestaun ba inpaktu ne’ebé mak bele mosu husi mudansa klima ninian ba *bacia hidrográfica* no ba rekursu sira iha tasi-ibun.
Sumário Executivo (Portugês)

**Título do Projecto:** River Catchments and Marine Productivity in Timor Leste: Caraulun and Laclo Catchments; South and North Coasts

**Líderes do Projecto:** Dan Alongi (AIMS), Robert Wasson (CDU), Narciso de Carvalho (MAF-Fisheries)


**Sumário:**

A equipa deste estudo usou as opiniões das populações locais nas duas bacias hidrográficas, as provas das ciências naturais e as técnicas analíticas das ciências sociais. Destas fontes de conhecimento e suas comparações, chegou-se às seguintes conclusões:

- A erosão geral das bacias hidrográficas (desnudação) é agora até 20 vezes mais elevada do que nos últimos milhares de anos. A causa mais provável para este aumento está relacionada com o uso da terra, principalmente com a remoção de vegetação das margens dos rios (zonas ribeirinhas), que causou erosão generalizada, e a remoção de vegetação das encostas, promovendo assim, deslizamentos de terras. A erosão de ravinhas e superficial são fontes menores de sedimento.

- O aumento da erosão das bacias hidrográficas, levou ao aumento do trânsito sedimentar dos rios, o que levou a que se tornassem mais largos e menos profundos, aumentando assim a erosão das margens. A erosão das margens também afectou gravemente a rede de transportes da zona costeira sul, resultando na queda de pontes e danificação de estradas. Estas alterações também aumentaram a frequência de cheias e provocaram alterações nos cursos dos rios que se tornaram mais erráticos com o alargamento e enraçamento dos canais.

- Tem havido maior fornecimento de sedimentos para a costa, resultando num mais rápido crescimento do delta da ribeira de Caraulun para o mar. O efeito na costa norte, na foz da ribeira de Laclo sente-se em águas profundas e é desconhecido.

- Os mangais foram parcialmente enterrados pelo aumento do trânsito sedimentary no delta da ribeira de Caraulun, mas tal impacto não se verifica na foz da ribeira de Laclo.

- Para a redução da erosão, sedimentação dos rios, cheias e deposição de sedimentos na zona costeira, é essencial proceder à replantação das fontes críticas de sedimentos.

- Os mangais são menos produtivos do que em outras regiões tropicais, como resultado do clima seco. No entanto, os mangais estão saudáveis e são uma importante fonte suplementar de madeira e alimento.

- O número de peixes grandes nas duas ribeiras e na zona costeira diminuiu, possivelmente devido a alterações de habitats causadas pela sedimentação, menos nutrientes libertados de sedimentos mais arenosos depositados na zona costeira, e pressão piscatória.

- O desenvolvimento de gestão conjunta entre instituições locais e governo é provavelmente a melhor forma de melhorar a gestão dos recursos naturais nas duas bacias hidrográficas e na costa.
Após uma sessão de trabalho em Dili, a 4-5 de Junho de 2009, foram feitas as seguinte recomendações:

- Replantar fontes críticas de sedimentos nas bacias hidrográficas, tendo em conta os benefícios para as populaces locais, posse de terra e instituições consuetudinárias.

- Compreender as orientações existentes de prioridades de gestão de bacias hidrográficas (10 críticas de um total de 27 bacias hidrográficas em Timor-Leste).

- Identificar e mapear fontes de sedimentos nas bacias hidrográficas críticas.

- Avaliação de informação socioeconómica (auditoria energética e material ao nível de aldeia) e de condições naturais em cada bacia hidrográfica crítica.

- Desenvolver orientações para a gestão integrada de bacias hidrográficas, incluindo reflorestação. Isto implicará gestão conjunta de bacias hidrográficas e zonas costeiras, com envolvimento do governo e das instituições locais para garantir a participação local.

- Aumentar a capacidade existente através de formação em inventários de bacias hidrográficas, compilação e análise de dados, e gestão de bacias hidrográficas.

- Desenvolver capacidade local em gestão de bacias hidrográficas nas comunidades através de sensibilização pública e formação.

- Desenvolver um plano conjunto de gestão de mangais

  - Importante entre Ministérios do Ambiente, Cultura, Pescas e Turismo.

  - Considerar os conhecimentos e valores locais na gestão dos mangais.

  - Fazer levantamento e mapeamento de espécies/comunidades de mangais, particularmente na costa sul (uma vez que existem dados para a costa norte).

  - Avaliar a prioridade de gestão das florestas de mangal.

  - Educação e sensibilização pública da importância dos mangais.

- Aumentar a compreensão de:

  1. A contribuição de deslizamentos de terras e erosão ribeirinha para os sedimentos das ribeiras e costeiros (e.g. deltas, praias)

  - Exercício constante, com a gestão a responder a novas informações

  - Identificar prioridades de conservação do solo (por exemplo socalcos nas encostas, gestão de fogos, gestão e reabilitação de zonas ribeirinhas, etc.)

  2. Identificar opções de gestão conjunta de bacias hidrográficas e zonas costeiras (e.g. legislação e política – nível central; e Tarabandu – nível local)

  - Compreender porque é que algumas tentativas de gestão conjunta têm sucesso e outras não.

  - Melhorar as relações e ligações existentes entre a regulamentação e o Tarabandu.
3. Compreender a relação entre os cursos dos rios e a libertação de nutrientes para a zona costeira e os impactos nas cadeias alimentares marinhas, incluindo recursos pesqueiros e fontes alimentares para a megafauna marinha. Isto para melhorar a gestão dos recursos costeiros, com um ênfase na segurança alimentar.

- Amostragem espacial e temporal das cadeias alimentares e fluxos de nutrientes.

- Desenvolver estratégias adaptativas e protocolos de monitorização para a gestão do provável impacto das alterações climáticas nas bacias hidrográficas e recursos costeiros.
# TABLE OF CONTENTS

Acknowledgements ............................................. Page 3
Executive Summary (English) ................................ Page 5
Sumáriu ( Tetum) .................................................. Page 7
Sumário Executivo (Portugese) ................................. Page 9

1.0 INTRODUCTION ............................................... Page 13

2.0 COMMUNITY CONSULTATIONS ......................... Page 15
2.1 Laclo Catchment .......................................... Page 15
2.2 Caraulun Catchment ....................................... Page 18
2.3 Key Issues raised during Community Consultations Page 21
2.4 Interpretation of Key Messages ......................... Page 21
2.5 Comparison of the Key Messages from the Laclo and Caraulun catchment Page 22

3.0 CATCHMENT PROCESSES AND CHANGE – A SCIENTIFIC VIEW Page 23
3.1 Introduction ................................................. Page 23
3.2 Vegetation Change .......................................... Page 24
3.3 Catchment Sediment Yields ............................... Page 26
3.4 Sediment Sources .......................................... Page 28
3.5 In-Channel Deposition and Delta Growth ............... Page 35

4.0 COASTAL BIOGEOCHEMISTRY, MANGROVES, NEARSHORE COASTAL ZONE, AND RESOURCES. Page 38
4.1 Carbon and Nutrient Input to the Coasts ................ Page 38
4.2 Mangroves ................................................... Page 39
4.3 Nearshore Coastal Zone ..................................... Page 54

5.0 COMPARISON OF LOCAL AND SCIENTIFIC VIEWS, AND CONCLUSIONS ................................................................. Page 55

6.0 RECOMMENDATIONS ......................................... Page 59

7.0 REFERENCES .................................................... Page 61

APPENDIX A SOCIO-ECONOMIC DRIVERS OF CHANGES DOCUMENTED DURING COMMUNITY CONSULTATIONS Page 67

APPENDIX B CHANGE IN LAND COVER, RIVERS, AND THE COAST IN THE CARAULUN CATCHMENT Page 74
1.0 INTRODUCTION

The principal question that this research aims to answer is:

‘Has land use, particularly deforestation of river catchments, impacted on coastal and nearshore resources in Timor Leste?’

Most of the observations and data presented here are from the catchments (watersheds) of the Laclo and Caraulun Rivers, flowing to the north and south coasts respectively (Fig 1). But observations have also been made at other sites to supplement those made in the two main river catchments and their adjacent coasts.

The approach of the study team from Australia and Timor Leste has been to use both natural science (presented in the formats of Figs 2 and 3) and social science data collection and analysis, and the views of local people through community consultations. The observations of local people can be thought of as either realist or mythological. Their realist views are compared with the scientific analysis and, in the majority of cases, they agree. This convergence of what might be called traditional knowledge and scientific knowledge is of great practical value because it provides a basis for catchment and coastal management that is likely to receive support from local people. If there was no convergence, management objectives would be much more difficult to achieve because of possible resistance from local people. It is important to understand that the science is not used to verify local knowledge (see Agrawal, 2002), but both knowledges are compared.

The views of local people are presented first, followed by scientific analyses and comparisons between the two knowledge systems.
2.0 COMMUNITY CONSULTATIONS

2.1 Laclo Catchment

Carvalho et al (2006) consulted with the local community at Manatuto, Laclo, Remexio, Aileu and Liquido. The key messages from these consultations are as follows:

- many trees removed during the Indonesian period, and also previously during the Portuguese period;
- major erosion occurred after tree cutting during the Indonesian period, including large gullies near Liquido, but some gullies are older;
- deforestation was followed by Chromolaena odorata which kills everything under it, thereby worsening erosion. This has also made grazing for cattle difficult;
- shifting agriculture also is a major cause of soil erosion and poor water quality, along with (settled) agriculture, in the uplands;
- burning damages the land
- chemical fertilisers are needed to improve agricultural productivity in the uplands;
- some river channels in the uplands have deepened, while downstream there is general agreement that the rivers have widened;
- at Manatuto, the bed of the Laclo River is accumulating sediment and is getting higher. It has aggraded by 1.5 to 2.0m in 20 years (average rate of 7.5 to 10cm/yr);
- in a few places the river has deepened;
- estimates of widening are: 100m in ~ 45 years in the lower Laclo, 5m/yr at Rembor and on the Sumasse River, 6m/yr near Laclo on the Laclo River, five times increase of the Laclo River width in Suco Faturileu;
- paddy fields along the margins of the large rivers are being eroded as the river widens; irrigation canals also being damaged; and
- after tree removal during the Indonesian period, springs in the uplands dried up and small rivers no longer flow during the dry season. Some people now have to walk 1 to 2 hours to get water from a large river.

The messages are now interpreted. There are four groups of key messages that are coherent linked sets of ideas. The linking was done by the local people during the community consultations, rather than by retrospective analysis by the research team. The groups of linked ideas are:

a) Deforestation during the Indonesian period led to: serious erosion, particularly by gullying and some landsliding; small channel deepening and widening in the uplands; accumulation of gravel in the larger rivers and channel widening; erosion of paddy fields and floodplains; damage to irrigation canals; greater flooding downstream; and more difficult passage across rivers during the wet season. Shifting agriculture and burning also contribute to upland erosion.

b) Deforestation has led to the cessation of both spring flow and dry season flow in the small upland rivers. Water is now much more difficult to acquire, requiring long walks to and from the large rivers during the dry season.

c) On grazing land, deforestation was followed by invasion of the Chromolaena odorata weed which suppresses all ground vegetation. Cattle suffer and erosion increases.

d) Chemical fertilisers were available during the Indonesian period but are not now. Productivity has declined and fertilisers are needed again.
### Catchments

<table>
<thead>
<tr>
<th>Natural Process</th>
<th>Human Induced Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uplift, river incision, slope erosion, landslides.</td>
<td>Deforestation, increased riparian zone erosion, gullying, landslides, erosion of roads.</td>
</tr>
</tbody>
</table>

### Rivers

- Increased delivery of sediment to rivers (not from topsoil).
- River shallowing and widening.
- Increased river bank erosion and loss of floodplains and agricultural land.
- Increased overbank flooding and infrastructure damage.

### Coasts

- Increased sediment transport offshore.
- No obvious impact on coastal habitats.

### Nearshore Coastal Zone

#### Impact on foodwebs and increased fish and megafauna production.

- Increased carbon and nutrient input, both dissolved and attached to fine sediment in the water.
- Increased mud deposition and nutrient availability by release from mud, then sand deposition and decreased nutrient availability.

#### Increased fish and megafauna production, then a decrease as sand deposition occurs.

#### This section is speculation

- Export of dissolved carbon and nutrients

### Mangroves

- Possibly a small increase of fine sediment deposition.
- No significant impact on natural resources. Continue to act as protectors against coastal erosion and nurseries for fish caught on nearshore reefs and rocky/seagrass habitats.
### Catchments

<table>
<thead>
<tr>
<th>Natural Process</th>
<th>Human Induced Process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uplift, river incision, slope erosion, landslides.</td>
<td>Deforestation, increased riparian zone erosion, gullyling, landslides, erosion of roads.</td>
</tr>
</tbody>
</table>

### Rivers

- Increased delivery of sediment to rivers (not from topsoil).
- River shallowing and widening.
- Increased river bank erosion and loss of floodplains and agricultural land.
- Increased overbank flooding and infrastructure damage.

### Coasts

- Increased coastward growth of deltas.
- Increasing dominance by sand and gravel on deltas.

### Nearshore Coastal Zone

<table>
<thead>
<tr>
<th>Increased carbon and nutrient input, both dissolved and attached to fine sediment in the water.</th>
<th>Impact on foodwebs and increased fish and megafauna production.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Increased mud deposition and nutrient availability by release from mud, then sand deposition and decreased nutrient availability.</td>
<td>Increased fish and megafauna production, then a decrease as sand deposition occurs.</td>
</tr>
</tbody>
</table>

This section is speculation

### Export of dissolved carbon and nutrients

### Mangroves

<table>
<thead>
<tr>
<th>Burial of some mangroves, on seaward margin, by coarse sediment.</th>
<th>Decreased resources including timber and molluscs/gastropods; decreased fish spawning, crocodile and crab habitat. Rapid change with low habitat stability.</th>
</tr>
</thead>
</table>
2.2 Caraulun Catchment

Consultations followed the same format and protocols used in the Laclo River catchment (Carvalho et al, 2006). After introductions and welcomes, the scene was set by stressing our interest in erosion and river sediments, river behaviour, and possible links between coastal resources and export from the river of sediments. It was made clear that we wanted to hear the views of the local people, and that these would help MAF develop management policies.

Most discussion occurred in Tetum, and some in Mambae. The discussion was translated into English for the benefit of the Australian contingent, and notes taken simultaneously with the translation. Questions were asked by the research team to clarify a point being made by a community member. Also, important matters raised at an earlier consultation were tested at later meetings.

Meetings were held as follows

<table>
<thead>
<tr>
<th>Location</th>
<th>Date and Location</th>
</tr>
</thead>
<tbody>
<tr>
<td>Samé</td>
<td>13 June 2007 – mid catchment</td>
</tr>
<tr>
<td>Betano</td>
<td>14 June 2007 – lowlands / coast</td>
</tr>
<tr>
<td>Maubisse</td>
<td>18 June 2008, 12 December 2007 – uplands</td>
</tr>
<tr>
<td>Turiscai</td>
<td>11 December 2007 – uplands</td>
</tr>
</tbody>
</table>

The meetings included farmers, fishers, small business people, village chiefs, and government officials. Female participation was low (1 woman at Samé, 2 at Betano, 2 at Turiscai) despite specific invitations.

A more detailed discussion of the meetings at Samé, Betano, and Maubisse is provided in Appendix A.

Records of the meetings follow:

**Samé (16 people)**

- Caraulun River before the Indonesian period was narrower with stronger flow and sediment movement. Attributed the widening to the unrecognised deaths of many Timorese during the Indonesian period.
- Small rivers have eroded (apparently deepened) and there are now more landslides.
- Need a traditional ceremony to settle the unrecognised dead, and require financial support of government for the ceremony. A single location in the catchment should be found for the ceremony which is very complex to organise. Need coordinators from both major branches of the catchment.
- Reforestation is essential to reduce erosion. This is needed along riverbanks and in the uplands around Maubisse and Turiscai.
- At Betano the Caraulun River is much wider and moves between different locations during floods.
- Each year a person dies in the Caraulun floods, and animals get washed away.
- A traditional ceremony should get the river to flow in one direction, if it is successful.
- From Maubisse to Samé the rivers are very steep and the riverbanks get eroded, particularly by landslides.
- Natural disasters (landslides and floods) became common in this area during Indonesian times.
- If older people do not respect nature, younger people will not respect older people.
- Land use in the uplands affects natural disasters (floods) downstream. Respecting nature is important, and not too many trees should be cut. But it is now easy to cut down trees with a chainsaw.
- Tarabandu should be organised by government not just by sucos. Also, strong unity in government is essential for this to be successful.
The people of Betano live on land that is not at the moment threatened by riverbank erosion, but they will be eventually.

Respect for areas that were traditionally not touched (lulic) no longer occurs. This is the result of human pressure on nature. Attitudes to lulic (sacred forests) need to change. Reafforestation of the catchment is need from top to bottom.

Never saw so many natural disasters during Portuguese period. Need to respect Timorese ways to respect nature.

The Indonesian and Portuguese brought many new ideas. Now Timorese do not have a clear direction for respecting nature.

Shifting agriculture in the uplands is causing natural disasters as well as farming along the rivers. Need a plan for reforestation. Timorese are now free to reforest and respect nature.

After 1975 many people were forced into settlements which resulted in loss of forest in the newly settled areas. Some people moved back but many did not because it was too far away.

In the past (grandfather’s time) Cablaci and other mountains were forested and left alone. Now technology allows large trees to be cut down.

Increased population and families in the last 20 years has increased the area of shifting agriculture and rotations are getting shorter. Maximum cropping is four years.

Failure to respect traditional ways brings punishment from nature.

Freshwater fish are taken from the local rivers. Tarabandu was applied during Portuguese time but broke down in the Indonesian period and now there are fewer species and numbers of fish.

Traditional harvesting system broke down and traditional increase ceremonies on Cablaci are no more.

Older people now fighting with younger people over what should be done.

Many trees removed and sold during Indonesian period.

**Betano (39 people)**

Caraulun River was once a small river and has widened. This is a result of land use, removing tress, and removing trees from the upland. Flooding is now more common.

Most fish are caught at the beach during floods.

River flow moves from place to place more often, deflected by trees and rocks.

May to June is the change of season with strong currents, and fishing is not possible off the beach.

During the 1990’s, the Indonesian army damaged coral reefs by using dynamite. Sand accumulation on the coral has also caused damage. Bombing has stopped and coral are recovering, but are sometimes damaged by people collecting shells and shellfish.

Sediment from the Caraulun River moves both east and west.

Mangroves (ai tassi) cannot grow as well as at Hera and Metinaro because of currents and waves.

Awaiting law enforcement of fisheries.

A flood destroyed the irrigation system in 2004, along with an extensive area of paddy fields on the delta.

Before the Portuguese time there were traditional laws to protect nature, from the mountains to the sea. These have gone. Previously, the communities knew the function of trees and the law controlled the use of nature.

Mangrove wood is collected for house building, fences, and firewood. Local people have to get a licence from Forestry to cut timber.

Freshwater prawns and fish are found in the Caraulun River, but they are small. Some fishing by electrocution.

Democracy means that anything can be done. Fishing law also cannot be applied during a crisis in the country.

Tarabandu needed to protect resources and lives. Intend to make Tarabandu permanent, with no farming along rivers, no cutting of large trees along rivers and on the beach, chainsaws are not to be used, and picking of fruit without permission of its owner will not be allowed.

Land use upstream affects the river and beach in the Betano area.
- Caraulun River at the bridge crossing has become shallower.
- The beach at Betano has doubled in width since 1971.

**Maubisse (6 people in two meetings, all village chiefs)**

- During Portuguese period, Casuarina seedlings established and planted as shade trees for coffee between 1963 and 1975. Before this, much of the land around Maubisse was grass-covered.
- During the Indonesian period and since, individuals have been encouraged to plant coffee and Casuarinas. But Acacia has been more commonly planted. Fire during the dry season has limited experiments with other species. Acacias planted to control erosion and landslides, but planting has stopped because of a lack of support from local people and also because of fire.
- Planting of trees has reduced erosion, especially landslides.
- There was more Eucalyptus on high ground 40-50 years ago. But they were replaced by Casuarinas and coffee.
- Large-scale reforestation is needed, but fire is a problem. There is tension between forest, grazing, and fire.
- Many trees removed during Indonesian period, organised especially by the army.
- When people cut down large trees, a giant snake (the owner of the trees) moves and causes landslides. To protect the land, animal sacrifice is needed under the guidance of a special old man. Nearer the coast, the giant snake is replaced by a crocodile.
- Large rains cause landslides.
- Reforestation could be carried out using Tarabandu, but this has been weak during and since Indonesian time. There has been little control of land use (particularly the use of trees) as a result.
- In Manetu, large-scale cutting of trees in 1998 and 2006 to clear land for corn. Then rainfall caused landslides. More corn was needed to feed people.
- In Aitutu, large rainfalls have caused landslides and gullies have enlarged. But some large rainfalls do not cause the land to move.
- After Independence, people do what they like and trees are being removed. After 4-5 days of heavy rain, the land moves.
- Metal baskets should be used to protect riverbanks.
- When trees are removed from hillslopes, big rains cause more spirit flow causing remaining trees to fall over assisted by high winds, then the earth moves.
- In some areas, Indonesians protected forest (eg Fatubesi).
- At Maulau lopping is now allowed but not removed of trees. Springs are larger as a result of larger rainfall, and land even moves under forest after rain. Gullies (hodo’an) have both widened and deepened throughout the area, sometimes removing crops.
- No significant widening or change of depth of rivers in the area between Maubisse and Turiscai.
- Landslides have killed animals but not people, and leave mud, sand and rocks in rivers further downstream.
- Land use in the upland causes problems downstream. Tarabandu is required to control land use.
- In Fatubesi, sacred forests were being cut but this has been stopped by the village chief.
- Need seeds and seedlings to plant on landslide areas.
- Shifting agriculture is not an erosion problem, and is very important to the local people.
- Planted trees to control erosion could be fruit trees so that the people could benefit.
- Need technical assistance to control gullies with concrete and rocks.
- Landslides (earthflows) on Fleisha Mountain have been planted with Acacias to control them. One earthflow began in 1999. Water flows at the bottom of the earthflows when they move rapidly.

**Turiscai (8 people)**

- Many landslides occurred during Portuguese time. One was so severe than an entire aldea (Kota Lalore) had to be moved. Big rain caused the landslides.
• Landslides were smaller during Indonesian period. About 7 years ago, a large rainfall caused landslides in 7 or 8 locations.
• Reforestation is needed to control landslides. Money is needed to stop people cutting trees. Grazing and burning will be a problem for reforestation.
• Landslides continue to move, even during the dry season.
• Gullies are not a problem, except when they are near farmland which they sometimes erode. Also, water pumps and animals can be destroyed.
• When big rains occur, black mud (from shale) is deposited in streams where it kills fish. This does not happen in the Caraulun River.
• A plan is needed to protect the land.
• A man born in ~1947 claimed that around Turiscai about 20% of the forest has been removed. Casuarinas for coffee were planted in 1985. Reforestation of half the area is possible.
• Many landslides on the outskirts of Turiscai (in the upper Laclo River catchment), some gullied recently.
• Very few trees removed during the Indonesian period in this area.
• No opinion about the effects on the lowland of land use in the uplands.
• Most gullies have not changed in the last 20 years, but the outer bends of small rivers have eroded.

2.3 Key Issues raised during Community Consultations

The key messages have been grouped using the approach described by Carvalho et al (2006), as follows:

• Many trees removed during both the Indonesian and Portuguese periods, but by no means uniformly across the catchment. Some replaced by Casuarinas as shade trees for coffee and by Acacias to control erosion.
• Tree removal continues with few restrictions, some to provide food for a growing population.
• Landslides and gullies have occurred after tree removal and following heavy rainfall.
• Shifting agriculture is seen by some as a cause of severe erosion and by others as a ‘non-problem’ but it is important for the local people.
• Erosion of riverbanks is a serious problem, and farming and tree removal along rivers should not occur.
• Some river channels in the uplands have deepened (and a few widened) while downstream the Caraulun has widened and shallowed causing greater floods, riverbank erosion, and lateral movement of flow paths which cause great difficulty for the local people.
• Land use in the uplands affects floods downstream.
• Gullies are not a large problem, except when they remove farmland, kill animals, and damage water pumps. Some have enlarged recently.
• Respect for nature must be increased, and Tarabandu is the preferred method of controlling land use and limiting damage to forests.
• Reforestation is needed, but in the uplands pressure from grazing and fire will limit what can be done.
• Freshwater fish in the Caraulun are no longer large.
• Beach fishing is best during floods.
• Corals have been damaged but are now recovering.

2.4 Interpretation of Key Messages

During the consultations, the local people tended to group various topics in the following ways:

a) Deforestation during the Portuguese and Indonesian periods, and since Independence, had led to: serious erosion, particularly landslides and some gullying; small channel deepening and widening in the uplands. Accumulation of sediment has also occurred in the larger rivers with channel shallowing.
and widening causing erosion of riverbanks (mostly small floodplains) and farmland (Fig 4); greater flooding and erratic behaviour by the Caraulun River causing death of people and animals. Erosion in the uplands was sometimes linked to sedimentation of rivers. Views about the impacts on erosion of shifting agriculture are diverse, some linking it to sedimentation of rivers.

b) Respect for nature must return to the Timorese way, land use planned and controlled, and Tarabandu re-instated to provide direction for the local people. This applies equally to terrestrial and marine locations. But there are differences of view between older and younger people.

c) Reforestation is necessary, to stabilize the land, provide timber and non-timber products, and respect nature. Otherwise nature will continue to punish the people for its abuse. But in some areas there is tension between the needs of grazing and reforestation, and fire is a problem for reforestation.

In addition, key messages were provided about freshwater fish, coral health, and beach fishing. Freshwater fish size has fallen, corals have been damaged by bombing and sand deposition but are now recovering, and beach fishing catches appear not to have changed, although large fish are less plentiful.

Finally, many people at almost all consultations spoke about the need for a ceremony to lay to rest the souls of those who died or were murdered and abandoned during the resistance struggle. Otherwise, natural disasters will continue.

2.5 Comparison of the Key Messages from the Laclo and Caraulun catchments

In both cases the first group of key messages are those summarised briefly in the right-hand box (Human Induced Process) in the upper left panel in Figures 2 and 3. The people consulted see a connection between deforestation (particularly during the Portuguese and Indonesian periods, and also since Independence) and upland erosion by landslides, gullying, and channel deepening and some widening. Some people also make a connection between this erosion in the uplands and increased sediment in lowland rivers and channel shallowing. Most of the local people reported lowland river channel widening along with channel shallowing and erosion of riverbanks and floodplains. Removal of tree vegetation along riverbanks (riparian zones) was blamed by some people for riverbank erosion along with increased sediment loads from upland erosion.

Some of those consulted believe that shifting agriculture causes serious erosion of hillslopes, while others do not have this view. Some people also connect erosion, caused by shifting agriculture, to increased amounts of sediment in the rivers.

In various ways there was a clear message that a lack of respect for nature is causing increased erosion and floods. This issue is clearly complex and is linked to differences of opinion and aspirations between older and younger people. It is often linked to a lack of traditional law to control land use and the taking of natural resources. The most common request was for government assistance to reinstate Tarabandu (a system of traditional prohibitions). In addition, there is a strong view, particularly among older people, that ceremonies need to be organised to lay to rest the souls of the abandoned dead. Their continued neglect is thought to create conditions of environmental uncertainty and without such ceremonies, natural disasters will continue. In cultural terms there is a widespread view that landscape and coastal waters contain and express forms of spirit agency (lulik) that may be manipulated through human ritual activity.

In the Laclo catchment, the local people spoke of the difficulties they now face in obtaining water from springs. They attribute the change to deforestation. In the wetter Caraulun catchment, spring flows do not appear to be reduced but increase after both heavy rain and earthflow movement.

In the Laclo catchment, those consulted were concerned with the spread of *Chromolaena odorata*. While this weed occurs in the Caraulun catchment, it was not mentioned during the consultations. Also, the need for chemical fertilizers was of concern in the Laclo, but was not mentioned in the Caraulun catchment.
In both catchments, a reduction in the size of freshwater fish caught in both the Laclo and Caraulun Rivers was mentioned by a few people, but this was not linked to specific causes. In the Laclo catchment near Turiscai, erosion of black shale and its deposition in channels was blamed for fish deaths.

At the coast adjacent to both river mouths, the smaller number of large fish was of concern, along with damage to coral reefs and mangroves on the coast adjacent to the Caraulun River. While of concern, these phenomena received less comment than those of river channel change in the lowlands. The relative amount of comment may reflect the amount of natural resources taken from the land and sea.

Fig 4  Erosion of the right back of the Laclo River at Manatuto

3.0  CATCHMENT PROCESSES AND CHANGE – A SCIENTIFIC VIEW

3.1 Introduction

Both Figure 2 and 3 show that erosion and sediment transport in the river catchments of Timor Leste include both natural processes and human-induced processes, and as a result rivers are cutting downward (Fig 5) into the rising land creating high erosion rates of both valley floors and on steep hillslopes adjacent to the incising rivers. Rates of uplift, particularly near the central range, of 0.6 to 2 mm/yr over ~2,000,000 years (2x10⁶ years) are estimated by Harris et al (2000).

The erosional effects of land use (particularly deforestation) are superimposed on the naturally high rates of erosion and sediment yield. The removal of forests and understorey plants reduces resistance to erosion by sheet and rill processes, gullying, shallow landsliding, and streambank erosion. Also, unsealed roads can erode fast and produce sediment that can reach rivers, although the low density of roads in Timor Leste probably means that this sediment source is small at the catchment scale.
3.2 Vegetation Change

The natural vegetation of Timor Leste has been substantially altered by both dryland and irrigated cultivation (~9% of the country, Benevides, 2003), shifting cultivation (over most of the area of woodland, ~85% of the country), fire (usually lit by local people to prepare land for shifting cultivation), commercial logging (particularly during the colonial period), firewood and building material collection (see Metzner, 1977). Closed canopy forest remnants can be seen on hilltops (Fig 5) and in deep ravines where fire has had no effect. But it is unlikely that these forests covered all of the country, particularly the dry north coast.

The appearance of pottery and domesticated animals in East Timor is dated to 3800-3600BP (Before Present), displacing a hunter-gatherer society (Spriggs et al, 2003; O’Connor, 2006) but the first use of cereal agriculture may be somewhat later (Oliveira, 2008). As agriculture developed, clearing, burning and timber use probably increased, with burning to prepare land for shifting agriculture.

There is no evidence of rice or maize in the archaeological record. Maize was probably introduced by the Portuguese soon after their arrival in the sixteenth century, and rice was already being grown at this time (Pigafetta, 1969; Oliveira, 2008). But it is not clear how widespread these crops were at this time. Sandalwood was an important commodity for trade as early as 1436AD when Chinese ships were travelling to East Timor for trade of this aromatic wood (McWilliam, 2005). The removal of sandalwood from hillslopes may have increased sheet erosion rates, depending upon how it was managed. While sandalwood was available on the north coast, it was more common on the south coast.

In 1861 the great English naturalist Alfred Russell Wallace visited Dili, and Baliba near the northern boundary of the Laclo River Catchment south of Dili (Fig 1). He described the area as ‘…bare hills whose surface was covered with small pebbles and scattered over with Eucalypti’. This description applies to much of this area today, where burning, wood collection and sheet erosion has produced an often sparse woodland with large areas of bare ground. Drawing upon the observations across what is now East Timor of a Mr Geach, Wallace (1869) observed ‘…the indigenous vegetation of Timor is poor and monotonous. The lower ranges of the hills are everywhere covered with scrubby Eucalypti, which only occasionally grow into lofty forest trees. Mingled with these in smaller quantities are acacias and the fragrant sandalwood, while the higher mountains, which rise to about six or seven thousand feet, are either covered with coarse grasses or are altogether barren. In the lower grounds are a variety of weedy bushes. In some of the valleys where the vegetation is richer, thorny shrubs and climbers are so abundant.
as to make the thickets quite impenetrable’. Again, these descriptions match in general the current state of vegetation over much of the Laclo and Caraulun catchments.

When Forbes (1889) passed through Turiscai, in the upper Laclo River catchment, in the late nineteenth century he observed ‘The mountains of Turskain (sic) were everywhere covered with a rich carpet of green grass, which gave them a pleasant and fertile appearance.’ (p448)

There is no ecologic impediment to tree growth around Turiscai as they grow there currently, around Turiscai, and so Forbes’ observation suggests that deforestation had already begun ~130 years ago at the very top of the Laclo catchment, a conclusion consistent with the observations of Mr Geach as reported by Wallace (1869) from the high mountains.

The Portuguese Governor Celestino da Silva promoted coffee cultivation in what is now Timor Leste in the late nineteenth century after he had pacified the colony by the final defeat of Dom Boaventura in Manufahi (Pelissier, 1996). Da Silva sought to convert to coffee the extensive areas that he had conquered during his campaigns of 1894-1908. How much land was converted is not clear, but coffee requires other plant species to be removed and shade trees planted. During the establishment of coffee plantations major soil erosion is likely.

The first systematic quantification of vegetation change was based on satellite remote sensing (Erikstad et al, 2001; Bouma and Kobryn, 2004). In the Districts that cover the Laclo and Caraulun catchments (Aileu, Manatuto, Manufahi), the largest change between 1989 and 1999 was a reduction of woodland (up to -50.11% in the Districts) and an increase of degraded woodland (to +209.23%). In Aileu, dense forest decreased by 40.36% and forest increased by 12.92%. In Manatuto, dense forest increased by 18.36% but covered a small area, and forest decreased by 2.09%. In Manufahi, dense forest increased by 20.48% and forest decreased by 20.09%. These broad trends are consistent with data beginning in 1972 (Erikstad et al, 2001). In summary, the largest area changes have been in the conversion of woodland to degraded woodland in the three Districts. Bouma and Kobryn (2004) attribute the changes to transmigration and relocation policies during the Indonesian period that increased pressure on timber resources and displaced some local people who developed land previously only lightly used. Also, commercial exploitation of timber during this period was significant.

Much of the increase of degraded woodland is attributed by Bouma and Kobryn (2004) to increased slash and burn agriculture as a consequence of increased population pressure, particularly by transmigration. Egashira et al (2006) argue that soil degradation, particularly erosion and fertility decline, has been a result of increased slash and burn and reduced fallow periods. Barrett et al (2007) argue that increased erosion and runoff as a result of increased clearing (including for slash and burn agriculture) leads to increased flooding and sediment loads and decreased water quality downstream. They also argue that landslide risk is increased by clearing. The hypothesis that downstream sedimentation and flood have increased as a result of clearing will be further examined below.

As we saw in the section Community Consultations, local people testify to significant deforestation during both the Portuguese and Indonesian periods. At Liquedoe, gullying and landslides are directly attributed to deforestation during the Indonesian period (Carvalho et al, 2006).

McWilliam (2001) concludes that: ‘[T]he long-term history of forests and forestry on the island of Timor is generally agreed to have been one of inexorable encroachment and conversion of natural forest reserves into swidden garden lands and secondary bushland’. While the fragmentary evidence summarised above support this conclusion. The nature of the undisturbed vegetation is poorly known. Of particular relevance is the observation that away from settlements patches of dense closed canopy and woodland riparian gallery forests still exist, at least some of which are sacred (lulik) (McWilliam, 2001). Closer to settlements, and along most of the length of riverbanks in the two catchments, riparian forests do not exist. Those observations suggest that a denser forest once covered much of East Timor which has been much reduced close to settlements which are often close to rivers.
Preliminary information of vegetation change between 1986 and 2006 and its possible causes in the Caraulun catchment are provided in Appendix B.

### 3.3 Catchment Sediment Yields

Reduced vegetation cover is likely to increase erosion rates, by sheet and rill processes, gullying, landsliding, and in riparian zones. We now turn to estimates of rates of sediment delivery to the coast; that is, sediment yield at the mouths of catchments.

There are no measured river sediment loads for Timor Leste. Therefore, to estimate the modern rate of sediment transport to the coast, we have relied upon a statistical relationship between measured sediment loads and catchment area for rivers in southeast Asia (Milliman et al, 1999). The regression relationship is:

\[
y = 3.5 x^{0.76} \quad r^2 = 0.77
\]

where \( y \) is mean annual suspended sediment load \((10^6 \text{ t/yr})\) and \( x \) is catchment area \((10^3 \text{ km}^2)\).

The results of these estimates are presented in Table 1. The mean annual suspended sediment load (ie fine sediment) is high at 3240 t/km\(^2\)/yr in the Laclo River and 3988 t/km\(^2\)/yr in the Caraulun River.

For rivers like the Laclo and Caraulun, the suspended load may be only ~50% of the total load, and so bedload (coarse particles) is ~50% given the significance of bedrock erosion by rivers, incision by rivers, and landslides, and the reworking by modern rivers of coarse alluvium in old river terraces (see Pratt-Sitaula et al, 2007). Usually, bedload is considered to be ~10% of total load.

| Table 1 Estimates of Erosion and Sediment Yield for the Laclo and Caraulun catchments. |
|----------------------------------|---------------------------------|-----------------|---------------------|--------------------|
|                                   | Modern Sediment Yield (t/km\(^2\)/yr) | Sediment Yield over 3 to 4x10\(^3\) years (t/km\(^2\)/yr) | Denudation Rate over 3 to 4x10\(^3\) years (mm/yr) | Sheet and Rill Erosion (t/km\(^2\)/yr) |
| Laclo (1386 km\(^2\))            | 3240\(^a\) 6480\(^b\) 3600\(^c\) | 450             | 0.17±0.03           | 52,000\(^d\) 5,200\(^e\) |
| Caraulun (580 km\(^2\))          | 3988\(^a\) 7976\(^b\) 4431\(^c\) | 490             | 0.2                 | -                   |

Assuming 50% bedload, the estimated specific yields are much higher: 6840 t/km\(^2\)/yr for the Laclo River and 7976 t/km\(^2\)/yr for the Caraulun River. These are very high yields by world standards (Milliman and Syvitski, 1992). Taking a more conservative approach by assuming that bedload is only 10% of the total load gives estimates that are also included in Table 1.
The data, from which the equation of Milliman et al (1999) was derived, from sites in Papua New Guinea where land use impacts have been small, and from the Philippines and Java where land use impacts are high. Therefore, it can be expected that the estimates (Table 1) for the Laclo and Caraulun rivers reflect land use impact as well as natural processes of erosion and sediment transport.

To estimate the natural rate of erosion and sediment delivery to the coast, we have employed a method that depends upon the measurement of the cosmogenic nuclide $^{10}$Be. Rivers export sediment from the entire catchment, particularly over millennia. Therefore, river sediment is a naturally mixed sample from a large area. The concentration of $^{10}$Be in the quartz fraction of river sediment is a function of the ratio of $^{10}$Be production (in soil and bedrock in the catchment) and denudation (ie erosion rate) in the catchment (Granger and Riebe, 2007). $^{10}$Be is produced in the upper few metres of rock and soil by cosmic rays that produce nucleon spallation and negative muon capture, producing $^{10}$Be from O. Quartz has abundant O and is resistant to chemical alteration, and so is an ideal material for this analysis.

In more detail, the $^{10}$Be concentration in the quartz of river sediments is inversely proportional to the erosion rate $\varepsilon$:

$$C = \frac{P_o}{(\lambda + \rho \varepsilon) / \lambda}$$

where $\lambda$ is the decay constant of $^{10}$Be, $\rho$ is the density of rock, $\lambda$ is the attenuation length (an exponential function of cosmic ray absorption with depth), and $P_o$ is the surface production rate of $^{10}$Be which depends upon the intensity of secondary cosmic rays, altitude, and topographic shielding (see Schaller et al, 2001).
Table 2 Estimates of Erosion and Sediment Yield for the Be Lulic and Caraulun-2 catchments.

<table>
<thead>
<tr>
<th></th>
<th>Modern Sediment Yield (t/km²/yr)</th>
<th>Sediment Yield over 2-3x10^3 years (t/km²/yr)</th>
<th>Denudation Rate over 2-3x10^3 years (mm/yr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Be Lulic (348.6 km²)</td>
<td>4504(^a) 6756(^b) 4954(^c)</td>
<td>880±500</td>
<td>0.3±0.2</td>
</tr>
<tr>
<td>Be Lulic (8.21 km²)</td>
<td>11082(^a) 16623(^b) 12190(^c)</td>
<td>660±530</td>
<td>0.2±0.1</td>
</tr>
<tr>
<td>Caraulun-2 (35.8 km²)</td>
<td>7783(^a) 11675(^b) 8561(^c)</td>
<td>600±200</td>
<td>0.2±0.2</td>
</tr>
</tbody>
</table>

\(a\) – based on Milliman et al (1999) – mean annual suspended load  
\(b\) – a + 50% assumed bedload  
\(c\) – a + 10% assumed bedload

Three complications arise in the use of \(^{10}\)Be. First, the calculated denudation rates apply only to quartz-rich rock. A correction is necessary for non-quartz-rich rock (e.g., limestone) although this has not been necessary in the two catchments because the relief and therefore the denudation rate is no different between quartz-rich and quartz-poor areas. Second, \(^{10}\)Be production rates vary with elevation, and will be higher in the more elevated parts of a catchment. This too has to be taken into account. Third, stored alluvium (e.g., in river terraces) will have higher \(^{10}\)Be concentrations in the upper ~1m because of radiation by cosmic rays during storage. Alluvial terraces, although prominent in both catchments, are small in area and so are unlikely to affect the calculated denudation rates.

The results of measurement of \(^{10}\)Be in quartz in river sediment at the mouths of the Laclo and Caraulun Rivers are provided in Table 1. These estimates are averages over ~4000 years (the time for 2m of denudation to occur) for the Laclo catchment and ~3000 years for the Caraulun catchment. So while there was undoubtedly some human influence on erosion rates during these periods, the estimates of sediment yield and denudation rates are the closest we have to the ‘natural’ state.

In the Laclo the modern total sediment yield (using both estimates of bedload) is between 8 and 14 times the ‘natural’ total yield. In the Caraulun, the modern yield is between 9 and 16 times the natural yield.

Additional results are available for two other south coast catchments, to Be Lulic and Caraulun-2 (Fig 1; Table 2). Using the same methods as those set out in Table 1, the modern total sediment yield (using both estimates of bedload) is between 6 and 25 times the ‘natural’ total yield.

### 3.4 Sediment Sources

The calculated denudation rates (Tables 1 and 2) do not provide information about sources of sediment within the catchments, except that the long-term rates (based on \(^{10}\)Be) apply only to quartz-rich rocks which make up the majority of the rocks in the catchments. If effective catchment management is to be designed to reduce erosion and sediment delivery to rivers and to the coast, more explicit information is required about the sources of sediment.

Four types of information are provided, namely: a qualitative account of the erosion types occurring on the main rock formations and associated soils in the two catchments; a modelled estimate of sheet and rill erosion in the Laclo catchment; a geochemical tracer-based assessment of the contribution to the fine sediment in rivers of the products of sheet and rill erosion, and, by difference from this estimate, the proportion of fine sediment in the rivers of sediment derived from processes other than sheet and rill erosion; and inferences from a map of hillslope angles in the two catchments.
Erosion Types on the Geologic Formations

From the north to the south, the main Geologic Formations in the two river catchments are listed in Table 3, along with the major rock types and erosional types. The information comes from Audley-Charles (1968) and our field observations. It is clear from this qualitative information that landslides of various kinds (mostly less than a few metres deep) are common, except on the Aileu Formation. Gullies occur on all rock units but are not common, while streambank erosion (of active floodplains along streams, river terraces, and bedrock) is very common. Evidence of sheet erosion is also common, either as shallow erosional scars or as sediment deposited on footslopes. From these observations, however, it is not possible to estimate the quantitative significance of either the various kinds of erosion or their proportional contribution to either river sediment or the coast.

Table 3 Major Rock Types and Erosional Types in the main Geologic Formations in the Laclo and Caraulun River Catchments

<table>
<thead>
<tr>
<th>Rock Formation</th>
<th>Rock Types</th>
<th>Erosional Types</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aileu Formation</td>
<td>Shale, phyllite, slate, schist, amphibolite, volcanics</td>
<td>Earthflows, and other landslides are rare; badlands and gullies and sheet erosion dominate</td>
</tr>
<tr>
<td>Maubisse Formation</td>
<td>Dense limestone, conglomerate, tuff, shale, volcanics</td>
<td>Highly unstable red clay-rich soils on limestone erode in earthflows and slumps; some gullies; sheet erosion</td>
</tr>
<tr>
<td>Wailuli Formation</td>
<td>Marl, calcilutite, shale, quartz arenite</td>
<td>Deeply incised by rivers; rare gullies; rotational slumps; sheet erosion</td>
</tr>
<tr>
<td>Aitutu Formation</td>
<td>Calcilutite, shale, calcareous shale, minor calcarenite, quartz arenite, radiolarite.</td>
<td>Earthflows and slumps on shaly rocks, with some large landslides and earthflows; gullies; sheet erosion</td>
</tr>
<tr>
<td>Lolotoi Formation</td>
<td>Schist, phyllite, metagabbro, gneiss</td>
<td>Landslides, especially on weathered schist; gullies; sheet erosion</td>
</tr>
<tr>
<td>Cablac Limestone</td>
<td>Hard, massive limestone</td>
<td>Rockfall and scree formation; minor slumping; gullies; sheet erosion</td>
</tr>
<tr>
<td>Viqueque Formation</td>
<td>Marl, claystone, chalky limestone, tuff, siltstone, sandstone</td>
<td>Slumps and debris flows; gullies, deep incision by rivers; sheet erosion</td>
</tr>
<tr>
<td>Bobonaro Complex</td>
<td>Claystone (dominantly montmorillonite and sepiolite), with exotic blocks of limestone and shale</td>
<td>Badlands and gullies; small slumps; sheet erosion</td>
</tr>
<tr>
<td>Ainaro Gravels and Alluvial Terraces</td>
<td>Interbedded sand, silt, clay, gravel with ferruginous cements (often at the surface)</td>
<td>Slumps; slab failure (by stream undercutting); gullies</td>
</tr>
</tbody>
</table>

Geochemical Tracing

To provide a quantitative estimate of the proportion of topsoil (from sheet and rill erosion) reaching the rivers of the two catchments, the topsoil tracers $^{137}$Cs and $^{210}$Pb(ex) have been used (Wallbrink et al, 1998). The topsoils are dominantly of loamy texture, with >50% silt and clay. While this fraction of river sediment is relatively small (<5% at the Caraulun irrigation headworks; SMEC 2002), it is likely to represent the material derived from sheet and rill erosion of hillslopes along with gullying and slumping of fine-grained materials. But >5% of the sediment at the Caraulun headworks is >31mm in diameter in
the active river channel which here is at least 4m deep, with a maximum gravel diameter of 20cm (SMEC, 2002). Further upstream, boulders several meters in diameter are common in the active riverbeds. It is plain that this coarse sediment cannot be derived from topsoils, given that only landslides and erosion of river terrace gravels can produce such large particles.

Samples for $^{137}$Cs and $^{210}$Pb(ex) measurements were taken from hillslopes and active riverbeds, and the <20µm fraction used to both maximise the signal and standardise the results (Table 4). Samples from hillslopes consisted of: 80% from uncultivated, but grazed sites; 20% from cultivated sites. This sampling strategy was designed to approximately reflect the ratio of uncultivated to cultivated area in the two catchments, although it slightly overestimates the cultivated area.

The weighted averaged $^{137}$Cs value for the hillslope samples is $2.11 \pm 0.26$ Bq/kg (20 samples), and for the riverbeds $0.13 \pm 0.09$ Bq/kg (20 samples). Therefore, for the <20µm sediment fraction in the rivers, ~6% (ie riverbed average as a percentage of hillslope average) comes from sheet and rill erosion of topsoils. The weighted average $^{210}$Pb(ex) value for the hillslopes is $247.5 \pm 0.07$ Bq/kg (20 samples) and for the riverbed $10.95 \pm 0.09$ Bq/kg (21 samples). Therefore, for the <20µm sediment fraction, ~4% comes from sheet and rill erosion of topsoils. These might be slight overestimates of the sheet and rill erosion component of fine river sediment, because shallow landslides and gullying will contain quantities of topsoil labelled with the two geochemical tracers. Nonetheless, it can be concluded from the available data that ~94-96% of the <20µm fraction of river sediment is derived from processes other than sheet and rill erosion; that is, from landslides, gullies and riverbank erosion. Gullies are not common, and the sediment mobilised by landslides often does not reach the rivers but is deposited on the hillslopes. By contrast, riverbank erosion contributes sediment directly to the river. While determination of the relative contribution to river sediment of each of these processes is not yet possible, it is likely that riverbank erosion is the most important, (particularly given that it is very common), followed by landslides and then gullies.

Table 4 Topsoil Tracer Results

<table>
<thead>
<tr>
<th>Field No.</th>
<th>Location</th>
<th>Site Type and elevation above sea level</th>
<th>$^{137}$Cs (Bq/kg)</th>
<th>$^{210}$Pb(ex)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ET2</td>
<td>Usu-un Creek Bed. 10m</td>
<td></td>
<td>0.61 ± 0.21</td>
<td>9.74 ± 3.45</td>
</tr>
<tr>
<td>ET3</td>
<td>Sumasse River River Bed, u/s of Laclo junction.</td>
<td></td>
<td>-0.02 ± 0.6</td>
<td>-0.99 ± 1.46</td>
</tr>
<tr>
<td>ET4</td>
<td>Laclo River River Bed near Manatuto bridge</td>
<td></td>
<td>-0.14 ± 0.16</td>
<td>-0.82 ± 3.0</td>
</tr>
<tr>
<td>ET5</td>
<td>Trib. of Sumasse River Creek bed</td>
<td></td>
<td>0.19 ± 0.16</td>
<td>-0.17 ± 2.84</td>
</tr>
<tr>
<td>ET10</td>
<td>Creek at Betfu, near Maubisse Creek Bed</td>
<td></td>
<td>0.38 ± 0.64</td>
<td>-2.0 ± 5.1</td>
</tr>
<tr>
<td>ET11</td>
<td>Cultivated field near Maubisse Slope wash from cultivated field.</td>
<td></td>
<td>0.99 ± 0.64</td>
<td>21.9 ± 5.2</td>
</tr>
<tr>
<td>ET12</td>
<td>Maubisse Pousada Uncultivated hillslope (32º), secondary vegetation. 1485m.</td>
<td></td>
<td>1.4 ± 0.6</td>
<td>19.7 ± 5.7</td>
</tr>
<tr>
<td>ET13</td>
<td>Mantane River, ~2km downstream of Aileu River Bed</td>
<td></td>
<td>0.43 ± 0.88</td>
<td>1.80 ± 5.94</td>
</tr>
<tr>
<td>ET14</td>
<td>Laclo River, at Manatuto River Bed</td>
<td></td>
<td>0.13 ± 0.60</td>
<td>-8.70 ± 3.40</td>
</tr>
<tr>
<td>ET15</td>
<td>Laclo River, at Manatuto River Bed</td>
<td></td>
<td>0.53 ± 0.95</td>
<td>-1.50 ± 4.68</td>
</tr>
<tr>
<td>Code</td>
<td>Description</td>
<td>Location</td>
<td>Data</td>
<td></td>
</tr>
<tr>
<td>-------</td>
<td>-----------------------------------------------------------------------------</td>
<td>---------------------------</td>
<td>---------------</td>
<td></td>
</tr>
<tr>
<td>ET16</td>
<td>Sumasse River, upstream Laclo junction</td>
<td>River Bed</td>
<td>0.01±0.49 -6.20±3.50</td>
<td></td>
</tr>
<tr>
<td>ET17A</td>
<td>Laclo River, upstream Sumasse junction</td>
<td>River Bed</td>
<td>0.27±0.61 -7.50±4.28</td>
<td></td>
</tr>
<tr>
<td>ET17B</td>
<td>Sananai, small creek</td>
<td>Creek Bed</td>
<td>0.29±0.47 8.50±3.88</td>
<td></td>
</tr>
<tr>
<td>ET18</td>
<td>Sananai</td>
<td>Uncultivated, burned hillslope ~20°</td>
<td>4.0±0.8 136.8±6.1</td>
<td></td>
</tr>
<tr>
<td>ET19</td>
<td>Sumasse R, Sananai</td>
<td>River Bed</td>
<td>0.47±0.55 -12.10±3.10</td>
<td></td>
</tr>
<tr>
<td>ET20</td>
<td>Malengreng 0-10cm</td>
<td>Floodplain deposit</td>
<td>0.25±0.71 -2.4±4.2</td>
<td></td>
</tr>
<tr>
<td>ET21</td>
<td>Malengreng 10-20cm</td>
<td>Floodplain deposit</td>
<td>0.42±0.71 -0.8±3.7</td>
<td></td>
</tr>
<tr>
<td>ET22</td>
<td>Malengreng 20-30cm</td>
<td>Floodplain deposit</td>
<td>0.28±0.54 -3.6±2.9</td>
<td></td>
</tr>
<tr>
<td>ET23</td>
<td>Malengreng 30-40cm</td>
<td>Floodplain deposit</td>
<td>0 2.0±3.1</td>
<td></td>
</tr>
<tr>
<td>ET24</td>
<td>Malengreng 40-50cm</td>
<td>Floodplain deposit</td>
<td>0 1.3±4.9</td>
<td></td>
</tr>
<tr>
<td>ET25</td>
<td>Malengreng 50-60cm</td>
<td>Floodplain deposit</td>
<td>0 3.1±3.8</td>
<td></td>
</tr>
<tr>
<td>ET26</td>
<td>Malengreng 60-70cm</td>
<td>Floodplain deposit</td>
<td>0 -1.0±3.8</td>
<td></td>
</tr>
<tr>
<td>ET27</td>
<td>Malengreng 70-80cm</td>
<td>Floodplain deposit</td>
<td>0 1.2±3.4</td>
<td></td>
</tr>
<tr>
<td>ET33</td>
<td>Susan River, Hera</td>
<td>River Bed</td>
<td>0.05±0.70 15.30±8.13</td>
<td></td>
</tr>
<tr>
<td>ET34</td>
<td>Hera</td>
<td>Uncultivated hillslope, ~25%</td>
<td>7.3±1.0 134.6±8.2</td>
<td></td>
</tr>
<tr>
<td>TLCA1</td>
<td>Caraulun River, upstream of bridge</td>
<td>River Bed. 90m</td>
<td>1.8±1.2 0.98±19.9</td>
<td></td>
</tr>
<tr>
<td>TLCA2</td>
<td>Suhi River</td>
<td>River Bed. 236m</td>
<td>0.6±1.4 15.83±7.9</td>
<td></td>
</tr>
<tr>
<td>TLCA3</td>
<td>Caraulun River</td>
<td>River Bed. 290m</td>
<td>0.0±2.2 34.07±8.4</td>
<td></td>
</tr>
<tr>
<td>TLCA4</td>
<td>Aisa River at road bridge on road to Suai</td>
<td>River Bed. 90m</td>
<td>0.0±2.1 3.75±8.2</td>
<td></td>
</tr>
<tr>
<td>Fleisha</td>
<td>Fleisha mountain</td>
<td>Grassed topsoil ~20°. 1853m</td>
<td>9.7±2.5 122.98±11.2</td>
<td></td>
</tr>
<tr>
<td>Suhurama</td>
<td>Suhurama hill, near chapel</td>
<td>Badly eroded hillslope ~25°. 1442m</td>
<td>0.5±1.6 32.9±10.0</td>
<td></td>
</tr>
<tr>
<td>TL2007 1</td>
<td>Eimori River</td>
<td>Colluvial footslope ~5°. 1052m</td>
<td>-2.27±1.93 421.9±25.6</td>
<td></td>
</tr>
<tr>
<td>TL2007 2</td>
<td>Eimori River</td>
<td>River Bed. 983m</td>
<td>1.28±1.46 68.4±9.1</td>
<td></td>
</tr>
<tr>
<td>TL2007 3</td>
<td>Teahul</td>
<td>Surface soil on completely cleared slope, ~24°. 231m</td>
<td>3.5±1.5 120.3±10.6</td>
<td></td>
</tr>
<tr>
<td>TL2007 4</td>
<td>Teahul</td>
<td>Creek bed in largely cleared area</td>
<td>1.22±1.38 13.9±8.3</td>
<td></td>
</tr>
<tr>
<td>TL2007 5</td>
<td>Rima (near TV tower, above Samé)</td>
<td>Hilltop, near grave (horizontal). 597m</td>
<td>-3.75±1.57 48.1±9.6</td>
<td></td>
</tr>
<tr>
<td>TL2007 7</td>
<td>Caraulun River at irrigation headworks</td>
<td>River Bed. 64m</td>
<td>1.5±1.3 9.0±8.4</td>
<td></td>
</tr>
<tr>
<td>TL2007 8</td>
<td>Caraulun upstream of crevasse splay</td>
<td>River Bed. 21m</td>
<td>-0.05±1.44 7.2±8.4</td>
<td></td>
</tr>
<tr>
<td>TL2007 9</td>
<td>Koloko River near hatchery</td>
<td>Footslope, coffee and rainforest, ~10°</td>
<td>5.8±1.5 179.2±13.9</td>
<td></td>
</tr>
<tr>
<td>TL2007 10</td>
<td>Lesuati Pass above Samé</td>
<td>Hilltop, (horizontal). 1492m</td>
<td>2.62±1.54 52.6±10.4</td>
<td></td>
</tr>
<tr>
<td>TL2007 11</td>
<td>Fleisha mountain</td>
<td>Hilltop (horizontal). 1910m</td>
<td>1.82±1.01 51.7±8.6</td>
<td></td>
</tr>
<tr>
<td>TL2007 12</td>
<td>Fleisha mountain</td>
<td>Hillslope ~9°. 1900m</td>
<td>-0.76±1.43 49.2±10.7</td>
<td></td>
</tr>
<tr>
<td>TL2007 13</td>
<td>Maubisse</td>
<td>Slopewash from cultivation, ~19°. 1430m</td>
<td>0.01±1.16 0.8±7.1</td>
<td></td>
</tr>
<tr>
<td>TL2007 14</td>
<td>Maubisse</td>
<td>Uncultivated grassy slope, ~16°. 1430m</td>
<td>0.50±1.62 0.8±7.1</td>
<td></td>
</tr>
</tbody>
</table>
Modelled Sheet and Rill Erosion

Nippon Koei Co, Ltd (2007) applied the Universal Soil Loss Equation (USLE) to estimate the rate of sheet and rill erosion in the Laclo River catchment. The authors of this report stress that the estimates are approximate, but they are all that is available. In addition, the USLE should not be applied to the very long slopes found in the Laclo catchment. In tropical Australia, only ~10%, of the sheet and rill erosion rate calculated for long slopes, reaches the base of slopes and river channels (M. Dilshad, pers. comm.). Assuming that this correction applies in Timor Leste, the delivery to the bases of the slopes of the products of sheet and rill erosion is ~5200 t/km²/yr (or 7.2x10⁶ t/yr). Of this amount, some will be trapped at the junctions between river terraces, floodplains and hillslopes. There is no measured estimate of the amount trapped in this way.

If only 4-6% (from the geochemical tracing) of the total products of sheet and rill erosion in Table 1 reaches the rivers, amounting to ~360x10⁷ t/yr (5% of 5200 t/km²/yr x 1386 km²), then ~6.8x10⁶ t/yr of fine sediment from hillslopes is stored on colluvial footslopes, at the back of river terraces and floodplains. This sediment can be a problem where it overwhelms cultivated fields, but elsewhere it contributes fresh material for cultivation.

Slope Angles

Inferences can also be drawn from hillslope angles about the likely source regions for sediment production in the two catchments. Figure 7 is a slope map which shows that only the uppermost parts of the Caraulun catchment and areas along the southern and southeastern margin of the Laclo catchment have hillslopes >30°. Such slopes are considered to be at the threshold of landsliding controlled by the rate of tectonic uplift through the rate of channel incision (Ginni et al, 2007). Such areas produce very large amounts of sediment (Montgomery and Brandon, 2002) and may therefore be the dominant source area in both catchments. It is noteworthy that almost all of the steep land in the two catchments occurs on the Lolotoi Formation (fig 4), a metamorphic complex belonging to the Banda Terrain (of Asian rather than Australian origin) of Haig et al (2008). The Lolotoi Formation consists of schist, phyllite, metababbro, and gneiss (Table 3) some of which is highly weathered producing particularly unstable sections of road. The Lolotoi thrust slices were emplaced during the Pliocene, or possibly earlier, and subsequent faulting has been by high-angle normal faults (M. Keep, pers. comm., 2009). These normal faults are likely to have resulted in the uplift that has led to stream incision and steep adjacent slopes, possibly after the rupture of the subduction slab beneath the island leading to isostatically-induced uplift and a tensional tectonic environment (Kaneko et al, 2007). The island of Timor first emerged from the sea 3.35x10⁶ years ago (Middle Pliocene) and has been shedding sediment into the surrounding sea ever since (Haig and McCartain, 2007). But uplift appears to have been particularly vigorous in the Lolotoi Formation, as judged from the slope distribution map (Fig 7).
It is important to note that the hillslopes in the area of highest angles (Fig 7) are not all at or near the threshold value of ~30°. The uppermost parts of the hillslopes are >30°, but there are concave sections below that are at angles <30°. This suggests that insufficient time has elapsed since emergence of Timor ~3.35x10⁶ years ago for threshold hillslopes to fully develop. This is clearly the case for those parts of the two catchments not on the Lolotoi Formation, where hillslopes are generally <30°. We conclude that while landslides are common (see Table 3), they do not yet dominate erosion in the way described by Montgomery and Brandon (2002). As observed above, a large proportion of the material mobilised by landslides does not reach rivers, because earthflows often do not continue from upper slopes to the rivers (e.g. on Fleisha Mountain on the Maubisse Formation) or deposition from slumps occurs on the hillslopes below the landslide scars. This is partly the result of concave hillslopes where gradients on the lower parts of slopes are either too gentle to allow earthflows to continue or the products of slumps are deposited.

Additional evidence that the Laclo catchment (at least) has not attained equilibrium between uplift and denudation is that the equilibrium denudation rate is 520-1300 t/km²/yr if the uplift rate at the coast of 0.2-0.5m/1000 years (Cox, 2009) is applied to the entire catchment. While the denudation rate (based on ¹⁰Be) of 450 t/km²/yr (Table 1) is close to the lower estimate of the equilibrium rate, the upper estimate of 1300 t/km²/yr is nearly three times greater. As East Timor continues to evolve geologically and geomorphically, the rate of denudation is likely to increase, but imperceptibility on human timescales.
Figure 7  Laclo and Caraulun catchment slopes (degrees)
3.5 In-Channel Deposition And Delta Growth

The results in Tables 1 and 2 show that the modern catchment denudation has increased by 8-16 times the ‘natural’ rate in the Laclo and Caraunl, and up to 25 times in the Be Lulic subcatchment (8.21km$^2$ in area). This increased denudation should be reflected in changes in the rivers and/or at the coast (see Figures 2 and 3). Carvalho et al (2006) showed that the Laclo River at Manatuto has shallowed and widened by floodplain erosion (Fig 4), a response that is expected in a river that has received an increased amount of sediment from its catchment (Schumm, 1977; Knighton, 1989). The local people living near the lower reaches of the Caraunl River also observed shallowing and widening (see Community Consultations), and the evidence for widening by floodplain erosion is everywhere to be seen. Comparison of satellite images from 1986 and 2006 shows an increase in total river channel area in the Caraunl catchment from 8.2 to 10.7 km$^2$, at an average rate of 0.13km$^2$/yr (13ha/yr) (see Appendix B).

The impact of the increased sediment load in the two rivers (and others on the south coast; Table 2) on the coasts where they enter the seas is not known on the north coast but can be determined on the south coast. On the north coast most rivers are choked with gravel to the coast, and there are few deltas. This is the result of a very steep offshore gradient so that sediment that reaches the offshore is deposited in deep water (Carvalho et al, 2006).

On the south coast, the offshore gradient is much gentler and deltas are common. The Caraunl delta near Betano (Fig 1) consists, at its seaward edge, of beach ridges separated by muddy swales (hollows) in which the most seaward of which mangroves occur. A transect was selected near Betano at the eastern end of the delta (Fig 8) because here the beach ridges are not buried by fluvial mud as they are further west where the ridges are marked by the alignment of trees rather than by sand deposits at the surface. On the transect (at points 2, 3, 4 on Fig 9) older beach ridges occur with much more subdued relief than the modern beach. The sediments found at each of the pits on Fig 9 are described in Table 5. The older (more inland) beach ridges consist of muddy fine sand, like the material at pit 3 on the backslope of the second youngest beach ridge. It appears that as the beach ridges age, the crests flatten by erosion and the sand in the crests becomes mixed with the muddy sand on the ridge flanks. Also, alluvial clays and silts are washed onto the older ridges as floodwaters from upstream cross the delta surface. This last process is reflected in Fig 9 where alluvium occurs landward of pit 4, as seen in pits 5 and 6, and the riverbank exposure at pit 7. At these sites, interbedded fine gravels, sands, and loams are clearly of alluvial river origin.

Optically Stimulated Luminescence (OSL) dates for the sediments at 30cm depth at pits 2, 4, 6 are shown on Figure 9, along with the position of the modern beach ridge crest were surveyed in 2007AD. The ridge at pit 4 is $2060 \pm 300$ years old, and at pit 2 is $110 \pm 20$ years old. The rate of coastal progradation (seaward growth) between pits 4 and 2 (a distance of 43.4m) is 0.02 m/yr. Between pits 2 and 1 (a distance of 79m) the rate is 0.72 m/yr, a difference of 36x. Local people note that since 1971 the modern beach has approximately doubled in width. Comparison of satellite imagery from 1986 and 2006 shows various shifts in the coastline, with the vegetation-beach boundary extending in some areas and retreating in others. Beach width at different locations along the coast has varied throughout the years. An area of beach south-west of Betano has indeed almost doubled in width, from 70 m to 120 m. Others sites adjacent to this location have however become narrower (see Appendix B).
Table 5 Descriptions and ages of sediments exposed in pits on Betano beach ridge and alluvial transect.

<table>
<thead>
<tr>
<th>Pit Number</th>
<th>Description</th>
<th>Environment of Deposition</th>
<th>Age</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>0-45cm fine to medium sand with scattered pebbles and cobbles; unstratified; grey; sand sub-rounded to rounded; grey</td>
<td>Crest of modern beach ridge; wave built</td>
<td>2007AD</td>
</tr>
<tr>
<td>2</td>
<td>0-80cm coarse sand with scattered pebbles and cobbles; sand sub-rounded to rounded; unstratified; dark gray</td>
<td>Crest of beach ridge; wave built</td>
<td>110 ± 20 years (OSL)</td>
</tr>
<tr>
<td>3</td>
<td>0-50cm muddy coarse to medium sand; unstratified; sand sub-rounded to rounded; dark grey</td>
<td>Backslope of beach ridge; built by wave washover and mud deposition from tidal action and floodwater from upstream</td>
<td>110 ± 20 years (same ridge as in pit 2)</td>
</tr>
<tr>
<td>4</td>
<td>0-77cm fine sandy loam; weakly stratified with minor changes of texture; dark brown in upper 20cm (incipient A horizon); pale brown below; red mottles at depth</td>
<td>Beach ridge built by waves and mud deposition from upstream</td>
<td>2,600 ± 300 years (OSL)</td>
</tr>
<tr>
<td>5</td>
<td>0-40cm very fine sandy loam; unstratified; pale brown; disturbed by ploughing</td>
<td>Probably alluvial, by comparison with pit 6 (below) which is only 10m away</td>
<td>~1100 years (by comparison with OSL result for pit 6, below)</td>
</tr>
<tr>
<td>6</td>
<td>0-36cm very fine sandy loam; dark brown; plough layer. Sharp, undulating boundary to 36-80cm very fine sandy loam to loamy very fine sand in thin layers; yellow brown</td>
<td>Alluvial, deposited by a stream crossing the delta</td>
<td>1,100 ± 400 years (OSL)</td>
</tr>
<tr>
<td>7</td>
<td>0-80cm very fine sandy loam; unstratified; brown in top 15cm (incipient A horizon) grading to pale brown below; pebble gravel at ~50cm</td>
<td>Alluvial, deposited by a stream crossing the delta</td>
<td></td>
</tr>
</tbody>
</table>

Landward of Pit 4, the sediment is of alluvial origin, deposited either by the channel depicted on Figure 9 (at Pit 7) or its predecessor.
Fig 8  The Caraulun Delta showing the modern beach, beach ridges, the sampled transect, and the old river channel which is being reoccupied.

Figure 9 Transect at Betano (for location see Fig 8) at the eastern end of the Caraulun Delta. Mangroves shown as tree symbols. Pits are numbered, and OSL dates are shown.
The increased progradation rate at this site since ~110 years ago is most likely the result of increased sediment delivery to the coast by the Caraulun River. While the smooth curve of the seaward margin of the delta is clear evidence of wave influence, it is also plain that beach ridges have formed either side of the present-day position of the Caraulun River. The beach ridges are however difficult to detect both on the ground and on aerial photography, because, as seen on the Betano transect, they are rapidly denuded and covered by mud of riverine origin from upstream.

The presence of sandy beach ridges either side of the river, and a small lobe of ridges at the mouth of an old channel (that is now being reoccupied by flows in the Caraulun River) to the west of the main channel (Fig 8, show that in the classification of Bhattacharya and Giosan (2003) the delta is sedimentologically symmetrical. This means that it is predominantly the product of riverine sediment from the Caraulun River rather than the product of alongshore drift under the influence of waves. Sediment is moved offshore during floods in the river, to be washed onshore by waves. Given the texture of the sediment in both the modern beach and the interior of the old beach ridges, it is clear that mostly sand-size particles are moved from offshore, deposited by hypopycnal flow.

Of the various examples of symmetrical deltas provided by Bhattacharya and Giosan (2003), the Tiber Delta in Italy is most similar to the Caraulun Delta. It too has sandy beach ridges either side of the river and its distributary (Bellotti et al, 1994). Within the last 2500 years, progradation and therefore sediment supply to the delta has been fastest during the last 500 years. Bellotti et al (1994) show that this most recent period was a time of large scale floods and increased sediment production as a result of land use.

Given that the Caraulun Delta is of the same kind as the Tiber Delta, we can assume that the increased progradation during the past ~110 years in the Caraulun Delta is the result of increased sediment supply, possibly coincident with an increased magnitude of floods in the river. Increased sediment supply is shown by the data in Table 1, but the river gauging records are insufficient to detect change in flood magnitude or frequency.

As described earlier, the beginning of the past century saw the consolidation of Portuguese colonial power with the defeat of Dom Boaventura. This led to significant changes to land use that may have increased erosion in the Caraulun catchment, sediment supply to the coast, and increased progradation of the delta. This increased progradation has buried the seaward margin of the mangroves at Betano, reducing the resources that can be extracted by the local people.

We now turn to an investigation of the mangroves near the mouth of the Laclo and Caraulun Rivers, and elsewhere in Timor Leste.

4.0 COASTAL BIOGEOCHEMISTRY, MANGROVES, AND RESOURCES

4.1 Carbon and Nutrients input to the coasts.

Along the north coast, our earlier work on the Laclo catchment (Carvalho et al. 2006) indicated a particulate organic carbon load of 132 tonnes per year, which is at the lower end of the range of other tropical rivers, especially in Southeast Asia (Milliman and Syvitski, 1992). Perhaps more importantly for ecological reasons, this POC is old and likely to be resistant to degradation, possibly due to association with clay minerals, and/or due to complex molecular structures (Komada et al., 2004). Catchments such as the Laclo tend to be dominated by physical erosion, with POC in the form of kerogen which survives substantial decomposition because oxidation is slow relative to the rate of erosion.

The concentrations of dissolved inorganic nutrients in the Laclo River in the dry season are not elevated and well within the range of concentrations found in other tropical rivers (Eyre, 1994; Mitchell et al., 1997; Robertson et al., 1998). Similarly, the tidal waters at Metinaro have concentrations of dissolved
inorganic nutrients typical of those obtained from unpolluted mangrove waters in Australia (Alongi et al., 1992). This statement is supported by the fact that the dissolved N:P ratio in these waters ranges narrowly from 17-22, which is within the range of values expected for both freshwater and seawater. Therefore, it is reasonable to conclude that the waters reaching the mouth of the Laclo river and coastal waters in the vicinity of Metinaro, are not polluted by human impacts, such as fertilizer use and other wastes.

4.2 Mangroves

Introduction

Mangrove forests are a crucial habitat along tropical coasts, including the northern and southern coasts of Timor Leste. These tidal ecosystems provide a valuable ecologic and economic resource as nursery grounds for many commercially important fish, shellfish, and crustaceans, and act as a renewable source of wood, traditional foods and medicines. They are also accumulation sites for sediment, contaminants, carbon and nutrients, and in most cases ameliorate excessive coastal erosion (Alongi, 2009).

Mangroves along the north coast are sparse, located in small, quiescent embayments. These mangroves do not appear to be directly influenced or impacted by river runoff; sedimentation rates in the Metinaro mangroves are at the low end of the range of rates measured in other mangroves, implying that most sediment is primarily of marine origin. Mangrove deposits in the high-intertidal zone are composed mostly of quartz sand, suggesting fairly slow mangrove ecosystem development when physical conditions permit. As discussed further in the next section, the greatest impact on these forests is extensive use of wood and benthic invertebrates for fuel and food, especially by refugees near Metinaro. It thus appears that river inputs to the coastal zone along the north coast are limited to rapid wet season pulses that extend as a relatively confined plume perpendicular to the mouths of the rivers. Nutrients in these plumes probably lead to limited plankton blooms and to reproductive synchrony by some fish and epibenthic organisms, such as prawns and gastropods. On the whole, most marine productivity appears to be centered on the surf zone ecosystems, where fish and other edible items are easily caught. Marine productivity further offshore is unknown.

Along the south coast, in contrast, high sediment yields (Table 1 and 2), but probably no higher than those of the north coast, a gentle offshore gradient and persistent onshore currents and wave action has resulted in the development of beach ridge plains parallel to the shore (Fig 8). Behind these beach ridges lie lagoons that are colonized by mangrove forests of variable size. It is plausible that expansion of these beach ridge plains as a result of enhanced catchment erosion and subsequent river runoff (see Section 3.5) has resulted in a number of changes to the mangroves: (1) a shift to species more tolerant to variable salinity; (2) smothering of mangroves in the low intertidal zone; and (3) an overall decline in mangrove area with stands restricted to a higher tidal elevation. Mangroves at the mouths of rivers along the south coast are sparse, small, and restricted to common species such as Ceriops tagal. Modern conditions along the south coast are too unstable to facilitate development of extensive, mature forests, especially as the dominance of sand and gravel slows growth of mangroves due to instability and the lack of a substantial soil nutrient pool to stimulate forest growth and development. What mangroves and other flora and fauna do exist on the leeward side of the beach ridge plains probably owe their existence to what appears to be significant groundwater input. However, if prograding of these beach ridge plains continues as a direct result of continued land degradation and enhanced erosion, it is likely that mangroves will be displaced either by freshwater swamps where groundwater is plentiful or by lowland terrestrial forest where a thin terrestrial soil horizon can develop, sufficient for many of the endemic species to colonise.

In the following is a summary of the results of a number of field expeditions to Timor Leste to assess (1) the size, species distribution and productivity of mangrove forests; (2) the extent of their importance in local Timorese fisheries; and (3) their connections to land-use practices, and to coastal nutrient cycles and productivity. An earlier study that assessed the impact of small-scale logging by refuges on mangroves at Metinaro was published (Alongi and de Carvalho, 2008).
Mangrove forestry and edaphic (soil) characteristics

Seven mangrove forests were sampled on the north and south coasts of Timor Leste (Fig. 10). Stations TL4 and TL5 were sampled at the end of the wet season (June 2007) and at the end of the dry season (October 2008). The other stations were sampled once in October 2008. Three plots per forest were established using the angle cruising method (Cintron and Novelli 1984; Clough, 1997). Briefly, three separate sets of angular sighting measurements were made using a relascope within each forest. The method does not encompass a consistently sized plot but covers an area in accordance with the size class of the trees which fall within the scale used. In these forests, the trees were identified,

![Map of the seven mangrove locations along the northern and southern coasts of Timor Leste.](image)

measured for diameter at breast height (dbh) and taped; the centre of each semicircular plot was staked for further sampling for sediment characteristics and microbial processes (see below). Forest data were used to calculate basal area and stem density which in turn was used to estimate above-ground biomass (AGB) using the allometric relationships in Komiyama et al. (2005) and wood density for these species in Saenger (2002).

Measurements of light absorption by the forest canopy (100-250 light readings per plot on sunny days between 1000 and 1400 h) were used to estimate canopy cover ($\eta = \frac{\log_e(I_{\text{mean}}) \cdot \log_e(I_{o\text{mean}})}{-k}$) and leaf area index (LAI) using the formula:

$$\text{LAI} = \left[ \log_e(I_{\text{mean}}) - \log_e(I_{o\text{mean}}) \right]$$

$$\quad - k$$

where $(I)_{\text{mean}}$ = mean PAR under the canopy; $(I_o)_{\text{mean}}$ = incident PAR; and $k$ = canopy light extinction coefficient (0.5). LAI was corrected for solar zenith angle.
Topographic height was estimated at each site by difference between the predicted height of the high tide for the day on which measurements were taken and ground level (Clough, 1997). These values were checked using a hand-held GPS to measure altitude. Accuracy of this method is ca. 7 cm.

During each field sampling, triplicate wells to a depth of ca. 50 cm were made in each plot using a 1.5 m length stainless steel corer. After waiting 10-15 min to allow water to seep up into the wells, triplicate water samples were taken for measurement of salinity and DIC. Samples for DIC were also taken at high tide and in obvious drainage channels adjacent to the forests at low tide. The samples were filtered (0.45 µm Minisart® filters) and either kept cool and dark until analysis. DIC concentrations were determined using the procedures of Hall and Aller (1992) and Lustwerk and Burdige (1995). Salinity was determined using a hand-held refractometer. In dry soils at Sta. TL4, soils were wetted just enough with distilled water to obtain a salinity reading. Samples for overlying and drainage water were obtained using a sterile syringe.

Sediments \((n = 5)\) were taken from the cores used to make the wells by extruding the entire core and slicing at 2 cm intervals to maximum core depth. Samples were frozen and on return to the laboratory, dried, and ground to a fine powder for determination of total organic carbon (TOC) on a Shimadzu TOC Analyzer with solid sampler and total nitrogen (TN) on a Perkin-Elmer 2400 CHNS/O Series II Analyzer. Total phosphorus (TP) was determined after strong acid digestion on a Varian Liberty spectrometer following the procedure of Loring and Rantala (1992). Statistics followed procedures outlined in Sokal and Rohlf (1995).

**Stand and soil characteristics.** Station TL4 \((9^\circ10^\prime\text{S}, 125^\circ43^\prime\text{E})\) was a mid-intertidal stand co-dominated by short (3-4 m height) *Exocoecaria agallocha* and *Lumnitzera racemosa* in compacted fine sand (Fig. 11). Station TL5 was located ca. 50 m seaward of Sta. TL4 in the low intertidal and was co-dominated by taller (10-12 m height) *Rhizophora apiculata* and *Rhizophora stylosa* in fine silt and clay. Both stations were located within a lagoon behind a sandy beach ridge.

Fig. 11. View of Station TL4 composed of short *Exocoecaria agallocha* and *Lumnitzera racemosa*

Stations BC1, SL1 and SL2 were located in lagoons further west on the south coast (Fig. 10). Station BC1 \((9^\circ15^\prime\text{S}, 125^\circ24^\prime\text{E})\) was a mid intertidal forest dominated by tall (12-15 m height) *Rhizophora mucronata* in fine silt and clay and was located near the landward edge of a sandy lagoon fronted by high beach ridges. Stations SL1 and SL2 \((9^\circ21^\prime\text{S}, 125^\circ16^\prime\text{E})\) were located within the same lagoon (Fig. 12) with Sta. SL1 located in the high intertidal and composed of short (4-6 m height) *Sonneratia urama* in fine sand and silt carpeted with algal mats.
Station SL2 (Fig. 13) was located ca. 200m seaward of Sta. SL1 in the high intertidal and was dominated by short (3-6 m height) *Rhizophora stylosa* interspersed with short *Avicenna marina* and *Exocoecaria agallocha* in fine sand and silt.

On the north coast, station TL6 (8°32"S, 125°42"E) was a low intertidal forest dominated by tall (20-25 m height) *Rhizophora mucronata* interspersed with shorter (10-15 m) *Rhizophora stylosa* and tall (45-50 m) *Sonneratia alba* in fine silt and clay (Fig. 14). Station TB1 (8°34"S, 125°28"E) was a tall (18-22 m height) *Sonneratia alba* stand located in a sheltered sandy embayment (Fig. 15).
Station TB1 had significantly highest above-ground biomass (AGB), followed by Stas. TL5 > BC1 = TL6 > SL2 > TL4 = SL1 (Table 6). Station TB1 also had the least dense forest but the largest trees (mean DBH). Above-ground biomass correlated positively with canopy cover \( (r = 0.85) \), LAI \( (r = 0.77) \) and sediment nitrogen \( (r = 0.90) \) and total organic carbon \( (r = 0.83) \). Canopy cover \( (r = 0.92) \), LAI \( (r = 0.90) \) and AGB \( (r = 0.78) \) across the seven forests correlated positively with salinity but negatively with topographic height \( (r \text{ range: } -0.77 \text{ to } -0.90) \), as salinity declined with increasing tidal height \( (r = -0.78) \), excluding Sta. TL4 at the end of the dry season (Table 7).

Fig. 14. Station TL6 was composed of few, but exceedingly tall (45-50 m) *Sonneratia alba*

Fig. 15. Station TB1 was a tall (18-22 m height) *Sonneratia alba* stand located in a sheltered sandy embayment in Bay of Tibar, west of Dili.
Table 6 Stand characteristics of the seven mangrove forests sampled in Timor Leste. Values are mean ± 1 standard error from triplicate plots within each forest

<table>
<thead>
<tr>
<th>Characteristics</th>
<th>Forest sites</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basal area (^b)</td>
<td>11±1</td>
</tr>
<tr>
<td>Mean dbh (^c)</td>
<td>6.1±1.3</td>
</tr>
<tr>
<td>AGB (^d)</td>
<td>136.1±14.6</td>
</tr>
<tr>
<td>Forest canopy cover ((\eta))</td>
<td>0.72±0.06</td>
</tr>
<tr>
<td>LAI (^e)</td>
<td>2.2±0.1</td>
</tr>
<tr>
<td>Topographic height (^f)</td>
<td>100</td>
</tr>
</tbody>
</table>

\(^a\) no. stem ha\(^{-1}\)
\(^b\) m\(^2\) ha\(^{-1}\)
\(^c\) diameter-at-breast height (cm)
\(^d\) total above-ground biomass (t DW ha\(^{-1}\))
\(^e\) leaf area index (m\(^2\) leaf area m\(^2\) ground area)
\(^f\) cm above mean sea-level
Interstitial salinity, DIC and solid-phase elements varied widely among forests and seasons (Table 7). Salinity ranged from 1 at Sta. SL1 to 55 at Sta. TL4, with higher salinities at the end of the dry season (October 2008) than at the end of the wet season (July 2007) at Stas. TL4 and TL5 (Table 7). Interstitial DIC concentrations were not significantly different from DIC concentrations in water from the drainage channels, but both were significantly greater than DIC in overlying tidal waters (Table 7). At Stas. TL4 and TL5, interstitial DIC values were greater at the end of the dry season (Table 7).

Table 7 Salinity, particulate nutrient, and DIC concentrations from sediments taken to 50 cm depth from replicate wells at the seven mangrove forests. Values are mean ± 1 SE from triplicate samples taken from each well within each forest. PW = pore water; OW = overlying tidal water.

<table>
<thead>
<tr>
<th></th>
<th>TL4</th>
<th>TL5</th>
<th>BC1</th>
<th>SL1</th>
<th>SL2</th>
<th>TL6</th>
<th>TB1</th>
</tr>
</thead>
<tbody>
<tr>
<td>OW Salinity</td>
<td>8a, 12b</td>
<td>20a, 22b</td>
<td>44</td>
<td>5</td>
<td>25</td>
<td>35</td>
<td>35</td>
</tr>
<tr>
<td>PW Salinity</td>
<td>21c, 55b</td>
<td>27a, 28b</td>
<td>31</td>
<td>1</td>
<td>20</td>
<td>38</td>
<td>36</td>
</tr>
<tr>
<td>TOCc</td>
<td>0.81±0.1a</td>
<td>3.31±0.1c</td>
<td>1.98±0.3d</td>
<td>1.46±0.2e</td>
<td>2.79±0.3f</td>
<td>3.80±0.1g</td>
<td>9.82±0.15h</td>
</tr>
<tr>
<td>TNd</td>
<td>0.05±0.0a</td>
<td>0.19±0.0b</td>
<td>0.13±0.0c</td>
<td>0.08±0.0d</td>
<td>0.14±0.0e</td>
<td>0.16±0.0f</td>
<td>0.35±0.0g</td>
</tr>
<tr>
<td>TPe</td>
<td>607±111</td>
<td>656±10</td>
<td>498±7</td>
<td>542±21</td>
<td>580±12</td>
<td>539±14</td>
<td>452±7</td>
</tr>
<tr>
<td>PW-DICf</td>
<td>13.6±0.1a</td>
<td>14.3±0.4a</td>
<td>34.7±1.3b</td>
<td>23.4±0.1c</td>
<td>11.4±0.2d</td>
<td>13.2±0.2e</td>
<td>17.5±0.3f</td>
</tr>
<tr>
<td>OW-DICf</td>
<td>4.8±0.5a</td>
<td>4.7±0.2a</td>
<td>6.7±0.1b</td>
<td>5.8±0.4c</td>
<td>3.3±1.2d</td>
<td>4.0±0.8e</td>
<td>3.6±0.4f</td>
</tr>
<tr>
<td>Drainage DICf</td>
<td>14.1±1.6a</td>
<td>14.4±0.4a</td>
<td>35.5±1.2b</td>
<td>30.0±4.6c</td>
<td>13.9±1.6d</td>
<td>14.6±2.0e</td>
<td>17.1±0.4f</td>
</tr>
</tbody>
</table>

*July 2007 (end of wet season)
October 2008 (end of dry season)
*total soil organic carbon (% sediment DW)
*total soil nitrogen (% sediment DW)
*total soil phosphorus (ppm)
*dissolved inorganic carbon, mmol L⁻¹.

Timorese mangrove forests decline in biomass, degree of canopy cover and leaf area index with increasing topographic height, mirroring a landward decline in interstitial salinity. In many tropical estuaries, mangrove forests decline in biomass and average tree height with tidal elevation in response to less tidal inundation and more variable salinities (Saenger, 2002; Alongi, 2009). At the end of the dry season in Timor Leste, interstitial salinities at high tidal elevations were less than those of normal seawater because of observable input from freshwater wetlands and bare tidal flats located immediately behind the mangroves. The exception to this generalization was site TL4 where interstitial salinity peaked at the end of the dry season after lower salinity at the end of the wet season (Table 7). Salinities in the mid- to high-intertidal mangroves along the northern coast similarly approach 50-60 during the dry months (Alongi and de Carvalho, 2008). The salinity variations at Sta. TL4 are a common phenomenon for mangrove habitats in the dry tropics as sediments from the mid- to the high intertidal zones are frequently subjected to more extreme conditions; periods of extreme dryness and hypersalinity punctuated by extended periods of submersion by low salinity water are characteristic of such marginal habitats (Alongi et al., 2000). These variable physicochemical conditions help to delimit floristic distribution patterns, explaining the dominance of moderate to high salt-tolerant species, for example, such as *Lumnitzera racemosa* and *Excoecaria agallocha* (Saenger, 2002; Alongi, 2009) at site TL4. Naturally, other factors such as recruitment and succession strategies and degree of anoxia operate synergistically or antagonistically to segregate/aggregate mangroves along intertidal gradients. This is likely to be the case for the mangroves of Timor Leste. Nevertheless, salinity as determined by the interplay between tidal inundation frequency,
precipitation, and groundwater patterns, appears to be the overriding factor in delimiting the size, structure, and species composition of Timorese mangrove forests.

Fig. 16. Comparison of net primary production of Timorese mangrove forests with others at the same latitude worldwide. Timorese forests are designated as open squares. Modified from Alongi (2009)

Compared with other mangroves worldwide, Timorese forests are of roughly equivalent biomass but are less productive (Fig. 16), probably as a result of the fact that the island of Timor is within the dry tropics. It is well-known that mangrove productivity is positively linked to precipitation (Alongi, 2009).

**Nutrient Biogeochemistry and Nutrient Cycles**

It is important to understand nutrient cycling as it is the availability of nutrients that drives primary productivity and, ultimately, fisheries production. High rates of net forest primary production are driven partly by tight links between trees, sediments, and microbes (Alongi, 2005; Lovelock, 2008). Processes occurring on and within the forest floor are crucial to understanding how mangroves function and contribute energetically to the coastal ocean. The purpose of this part of the study was to evaluate changes in and interrelationships between rates of total benthic metabolism, net microalgal production, and anoxic metabolism in mangroves residing across a spectrum of topographic heights along the northern and southern coasts of Timor Leste. Total metabolism of the forest floor was measured as sediment O$_2$ uptake and DIC release under inundated and/or air-exposed conditions. Sulfate reduction was measured concurrently as representative of below-ground anaerobic metabolism. These measurements were related to forest and edaphic characteristics in addition to changes in topographic height.

Rates of sulfate reduction were measured from 2.7-cm diameter plastic cores held within a 1.5 m length steel corer during insertion into the sediment to bedrock or consolidated sediment. Triplicate cores were taken from all plots at low and high tide, except at Stas. TL4, SL1, and SL2; samples were also taken within algal mats at Sta. TL4. The cores were capped at both ends and injected at 1-cm intervals with carrier-free $^{35}$SO$_4$. The samples were then incubated under *in situ* conditions for 6-9 h, cut into 2 cm portions, then terminated by fixation in 20% zinc acetate. Time courses were run at Stas. TL 5 and TB1 with incubations fixed hourly up to 12 h to ensure linear rates of radiolabel uptake. Samples were then frozen until a two-step distillation procedure (Fossing and Jorgensen, 1989) was
used to determine the fraction of reduced radiolabel shunted into the acid-volatile sulfide (AVS) and chromium-reducible (CRS) sulfur pools.

Fluxes of DIC were measured across the sediment-water interface within each plot in October 2008. At low tide, replicate \((n = 3)\) opaque chambers (volume = 1 l; area = 82 cm\(^2\)) were gently placed into the sediment and allowed to fill naturally with the incoming tide. Chambers were placed to avoid any obvious algal mats. Each chamber was closed with a propeller-electric motor unit (Alongi et al., 2000). Samples for DIC were taken at 1 h intervals during 3-4 h incubation via a sampling port on the side of the chamber; the port was fitted with acid-washed Teflon tubing to draw off 2 ml samples. DIC was measured as described earlier. In these same chambers, dissolved O\(_2\) was measured using a calibrated O\(_2\) probe (TPS Model WP-82 DO meters) placed into a sampling port opposite the port for solute sampling. Prior to immersion by the incoming tide, these chambers were closed and used to measure O\(_2\) concentrations over the exposed sediment surface. O\(_2\) readings were logged every 10 min for as long as the decline in O\(_2\) concentrations was linear with time (usually 3 h). Rates of benthic gross primary production were estimated with the same techniques using triplicate clear chambers placed randomly within each plot. Rates of net primary production were determined by difference in O\(_2\) flux rates between dark and light chambers and were calculated assuming 12 h daylight.

Differences in dark O\(_2\) consumption between exposed and inundated sediments and sites (Table 8) were inconsistent. At Sta. TL4, BC1, TL6 and TB1, the differences between tidal conditions were not significant; at Sta. TL5, O\(_2\) consumption rates were significantly greater from inundated sediments, whereas at Sta. SL1 and SL2, respiration rates were greater from exposed sediments. Differences between rates measured in 2007 and 2008 at Sta. TL4 were not significant. Respiration rates related positively to topographical height \((r = 0.80)\) but negatively with above-ground biomass \((r = -0.90)\), LAI \((r = -0.74)\), and salinity \((r = -0.85)\).

Rates of benthic NPP (Table 8) were also inconsistent among sites between exposed and inundated conditions. NPP rates were not significantly different between tidal conditions at Sta. TL4, but were significantly greater on exposed sediments at Stas.SL1 and SL2 and were significantly greater on inundated sediments at Stas.TL5, TL6, and TB1. Rates of NPP on exposed sediments correlated negatively with increasing mangrove canopy cover (Fig.17, top graph), but not when inundated (Fig.17, bottom graph).
NPP also correlated significantly with respiration, with a positive linear relationship under both exposed and inundated conditions (Fig. 18).

Rates of DIC release from inundated sediments (Table 8) varied among sites. DIC release rates did not correlate with rates of dark O$_2$ respiration or NPP, but did relate positively with sediment TOC ($r = 0.95$), sediment TN ($r = 0.87$) and sediment C:N ($r = 0.95$) and N:P ($r = 0.93$). The ratio of DIC:O$_2$ flux from inundated sediments ranged from 1.2 to 1.6 among sites TL4, TL5, BC1, SL1 and SL2, 2.4 at Sta. TL6 and 14.7 at Sta. TB1.
Exposed and Inundated Soil Respiration (mmol O$_2$ m$^{-2}$ d$^{-1}$)

Net microalgal production in exposed and inundated soils (mmol O$_2$ m$^{-2}$ d$^{-1}$)

\[ y = 22.303 + 2.633 \times \]

\[ R^2 \text{ (adj.)} = 0.815; P<0.001 \]

Fig. 18. Linear relationship between benthic net primary production and sediment respiration in both air-exposed and tidally inundated chambers. The data encompass oxygen measurements taken at all seven forests.
Table 8 Rates of bacterial sulfate reduction (SRR, mmol S m\(^{-2}\) d\(^{-1}\)), net microautotrophic production (NPP, mmol O\(_2\) m\(^{-2}\) d\(^{-1}\)) and O\(_2\) (DRO) and DIC (DRC) respiration (mmol m\(^{-2}\) d\(^{-1}\)) from exposed and inundated soils at the seven mangrove forests in Timor Leste. Values are mean ± 1 SE of triplicate cores per plot in each forest. Values in parentheses are maximum depths of core penetration.

<table>
<thead>
<tr>
<th>Location, date and soil condition</th>
<th>SRR</th>
<th>NPP</th>
<th>DRO</th>
<th>DRC</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>TL 4</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007 (exposed)</td>
<td>1.9 ± 0.1 (0-40)</td>
<td>NA</td>
<td>69.8 ± 12.6</td>
<td></td>
</tr>
<tr>
<td>2007 (algal mat)</td>
<td>16.3 ± 3.8 (0-10)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008 (exposed)</td>
<td>2.1 ± 0.2 (40-50)(a)</td>
<td>18.3 ± 12.0</td>
<td>59.3 ± 13.3</td>
<td></td>
</tr>
<tr>
<td>2008 (inundated)</td>
<td>49.6 ± 4.4 (0-40)</td>
<td>11.0 ± 7.4</td>
<td>47.2 ± 6.9</td>
<td>67.4 ± 7.1</td>
</tr>
<tr>
<td><strong>TL 5</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2007 (exposed)</td>
<td>24.0 ± 6.6 (0-80)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008 (exposed)</td>
<td>31.4 ± 0.6 (0-80)</td>
<td>0.05 ± 0.6</td>
<td>15.7 ± 5.6</td>
<td></td>
</tr>
<tr>
<td>2008 (inundated)</td>
<td>34.4 ± 9.1 (0-80)</td>
<td>16.8 ± 12.3</td>
<td>69.1 ± 7.1</td>
<td>81.2 ± 13.4</td>
</tr>
<tr>
<td><strong>BC 1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008 (exposed)</td>
<td>53.9 ± 13.3 (0-80)</td>
<td>NA</td>
<td>27.9 ± 6.6</td>
<td></td>
</tr>
<tr>
<td>2008 (inundated)</td>
<td>57.3 ± 9.4 (0-80)</td>
<td>NA</td>
<td>37.3 ± 6.4</td>
<td>60.5 ± 9.5</td>
</tr>
<tr>
<td><strong>SL1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008 (exposed)</td>
<td>112.2 ± 28.9 (0-40)</td>
<td>32.5 ± 8.6</td>
<td>123.9 ± 36.8</td>
<td></td>
</tr>
<tr>
<td>2008 (inundated)</td>
<td>NA</td>
<td>9.8 ± 6.7</td>
<td>67.3 ± 18.6</td>
<td>100.0 ± 11.2</td>
</tr>
<tr>
<td><strong>SL2</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008 (exposed)</td>
<td>101.8 ± 53.6 (80)</td>
<td>30.6 ± 2.6</td>
<td>98.4 ± 4.0</td>
<td></td>
</tr>
<tr>
<td>2008 (inundated)</td>
<td>NA</td>
<td>19.9 ± 6.6</td>
<td>67.5 ± 9.9</td>
<td>102.5 ± 8.8</td>
</tr>
<tr>
<td><strong>TL6</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008 (exposed)</td>
<td>58.4 ± 10.9 (80)</td>
<td>2.1 ± 5.9</td>
<td>52.7 ± 9.3</td>
<td></td>
</tr>
<tr>
<td>2008 (inundated)</td>
<td>60.3 ± 18.8 (70)</td>
<td>15.7 ± 4.4</td>
<td>48.7 ± 9.3</td>
<td>118.2 ± 5.2</td>
</tr>
<tr>
<td><strong>TB1</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2008 (exposed)</td>
<td>115.2 ± 48.0 (20)</td>
<td>0.7 ± 0.4</td>
<td>18.5 ± 9.9</td>
<td></td>
</tr>
<tr>
<td>2008 (inundated)</td>
<td>108.3 ± 22.2 (20)</td>
<td>4.3 ± 2.8</td>
<td>15.2 ± 2.8</td>
<td>223.5 ± 7.6</td>
</tr>
</tbody>
</table>

\(a\) = too dry to sample from surface to 40 cm depth
Fig. 19. Exponential relationship of sulfate reduction with (top graph) sediment total organic carbon and (bottom graph) total nitrogen, at sediment intervals where both parameters were measured within all seven forests.

Rates of sulfate reduction (SRR) varied significantly with sediment depth and location (Table 8), with increasing rates with greater depth at Stas.TL4 (2007, 2008), SL1, SL2, and TL6 and with no clear depth-related patterns at Stas.TL5 (2007, 2008), BC1, and TB1 (depth data not shown). At Sta. TB4 in 2007, SRR were significantly greater within a surface algal mat than in sediments devoid of surface mats (Table 8); in 2008, sediments were too dry to sample over the upper 40 cm, but sediments were wet enough to sample at 40-50 cm; once inundated, samples were taken and showed active SRR (Table 8). Differences between years and between exposed and inundated conditions at Sta. TL5 were not significant. The lack of change due to tidal conditions was true for the other sites. Under exposed conditions in 2008, SRR at Sta. TL5 were significantly lower than at the other sites (excluding Sta. TL4) which had equivalent rates. SRR did not relate to rates of O₂ or DIC flux. The only significant
correlations were positive exponential relationships of SRR with sediment TOC and TN concentrations across sites and sediment depths (Fig. 19).

The decline in forest size with increasing tidal height results in more canopy gaps and thus more light penetrating to the forest floor. Our data shows that less canopy cover (more light) results in greater rates of net primary production on the sediment surface which in turn stimulates oxygen consumption at the sediment-air interface. Control by available light is further illustrated by the difference in rates of net primary production in air-exposed versus inundated chambers. The simplest explanation is that when the chambers are flooded with silt-laden tidal water, available light levels drop below a threshold sufficient to stimulate rates of microalgal primary production above \( \approx 20 \text{ mmol O}_2 \text{ m}^{-2} \text{d}^{-1} \). Our data confirm earlier observations of lower NPP on sediments beneath mangrove canopies compared with rates measured on adjacent sand and mudflats (Kristensen et al., 1988; Alongi, 1994). The rates of benthic primary production measured in Timor Leste are at the low end of the range of rates measured on tidal flats (Colijn and de Jonge, 1984) but are mid-range compared with rates measured in other mangrove forests (Kristensen et al., 1988; Alongi, 1994). Rates of benthic primary production are dwarfed by rates of forest net primary production. Crude estimates of forest NPP (NPP= A x LAI x daylight hours) using the LAI values (Table 6) and an average rate of leaf photosynthesis (A) of 12 \( \mu \text{mol CO}_2 \text{ m}^{-2} \text{s}^{-1} \) (Alongi, 2009) indicate a range of forest NPP from 725-2800 mmol C m\(^{-2}\) d\(^{-1}\), well within the range of rates for dry tropical mangroves (Alongi et al., 2000) and at least an order of magnitude greater than rates of benthic NPP in these forests (Table 8). However, the comparatively low benthic NPP rates belie their trophic importance and role in influencing rates of microbial decomposition on the forest floor surface. Benthic diatoms, cyanobacteria, chlorophytes, and other microflora are key food resources for a wide array of mangrove-associated invertebrates and vertebrates (Bouillon et al., 2008b).

Rates of DIC release from inundated sediments did not correlate with either benthic primary production or oxygen consumption, but did correlate with sediment carbon and nitrogen content. O\(_2\) consumption in dark chambers represents aerobic respiration as well as oxidation of reduced metabolites diffusing across the sediment-water interface and may not be directly equivalent to rates of DIC release, especially when algal mats and carbonate are present, or under non-steady state conditions. The ratio of DIC:O\(_2\) flux in low carbonate and carbonate-free mangrove sediments averages 1.6 and 1.3 under inundated and air-exposed conditions, respectively (Alongi, 2009).

However, we measured ratios of 2.4 at site TL6, 14.7 at site TB1 and a narrow range of ratios (1.2-1.6) among the other five forests. The results from the former two sites are discordant; the high ratio at site TB1 may reflect comparatively greater contribution of DIC release from tree roots than at the other sites because we observed that the bulk of the roots of these very large trees were restricted to the very shallow (20 cm) unconsolidated sediment column.

The source of the organic matter being mineralized also plays an important role in rates and pathways of bacterial mineralization. We observed a significant positive correlation of DIC release and the ratio of DIC:O\(_2\) respiration with sediment C:N and N:P ratios. The highest stoichiometric ratios were measured at sites TB1 and TB6, where large pools of mangrove litter were observed lying on the forest floor. These detritus pools appeared and smelled sulfidic; the presence of these detritus patches suggests that oxidation of sulfides was incomplete. Rates of oxygen consumption in surface sediments therefore may not account for all anaerobic metabolism at these sites. The presence of algal mats in the other forests with more open canopies may foster more closely linked aerobic and anaerobic carbon oxidation at the sediment surface. At these sites, the DIC:O\(_2\) ratios were within those expected for the complete oxidation of model Redfield ratio organic matter (1.3) and of average marine microalga or plankton (1.45), suggesting that most organic matter decomposing at the sediment surface was of algal, and not vascular plant, origin (Middelburg et al., 2005). This notion is supported by the significant positive relationship between benthic NPP and oxygen consumption. The respiratory quotient in these sediments is therefore influenced by the quality and quantity of available organic matter.

**Function as fisheries, coastal protection, and nutrient sources**

Based on our meetings, discussions, and interviews with local villagers at Metinaro, Manatuto, Betano, Beco, Suai and Suai Loro, use of living resources within Timorese mangrove forests varies
from very limited use to near total exploitation. The best example of the latter was the extensive logging of the Metinaro mangroves beginning in early 2006 (Alongi and de Carvalho, 2008). Within these forests, there was also extensive foraging mainly by women and children for various edible invertebrates such as molluscs (Fig 20).

Exploitation of these forests has declined with the decline in numbers of refugee in the Metinaro area since mid-2008.

At the other forests sampled, there was no indication that mangrove waterways were heavily fished or used for crabbing. Most local markets exhibited reef-associated fish for sale; there were few clearly delimited estuarine fish ordinarily associated with mangrove habitats present in the local markets. This reflects the fact that the vast majority of fishing activities by villagers along the northern and southern coasts appear to be centred on shallow-water rocky/reefal/seagrass habitats rather than
within mangrove waterways. In fact, in some areas such as Suai Loro, mangrove areas are sacred to the villagers as these forests are the resting places of people killed violently during the Indonesian period.

In Suai District, data collected by MAF on the number of fishers in the various districts for 2005 (Table 9) suggest that while fishing is a universal activity along the coast, the actual number of people who identified themselves as fishermen is small compared with the total district populations. While there are a few pockets of intense fishing activity along the coasts, fishing intensity is, on average, low especially within mangrove-associated waters. Use of edible invertebrates and fallen wood within the forests appears to be the main human activities with regard to mangrove resource use in Timor Leste.

Table 9. Number of fisherman in various districts in 2005. Source: MAF

<table>
<thead>
<tr>
<th>District</th>
<th>Number of Fisherman</th>
</tr>
</thead>
<tbody>
<tr>
<td>Covalima</td>
<td>254</td>
</tr>
<tr>
<td>Manufahi</td>
<td>121</td>
</tr>
<tr>
<td>Manatuto</td>
<td>370</td>
</tr>
<tr>
<td>Dili</td>
<td>2039</td>
</tr>
<tr>
<td>Ainaro</td>
<td>25</td>
</tr>
<tr>
<td>Ambano</td>
<td>370</td>
</tr>
<tr>
<td>Liquica</td>
<td>841</td>
</tr>
<tr>
<td>Viqueque</td>
<td>217</td>
</tr>
<tr>
<td>Baucau</td>
<td>252</td>
</tr>
<tr>
<td>Bobonaro</td>
<td>315</td>
</tr>
<tr>
<td>Lautem</td>
<td>460</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>4964</strong></td>
</tr>
</tbody>
</table>

Mangrove forests are a limited, but locally important, marine resource in Timor Leste. The forests are generally of average biomass, but are less productive compared with mangroves at similar latitude in other locations; this is probably due to the low annual average precipitation throughout most of Timor Leste. Some of the mangroves along the south coast appear to have been eroded or smothered by relatively recent sand and gravel deposition, probably as a result of increased catchment erosion; nearly all mangroves have developed in estuarine lagoons behind large sand bars. The mangroves along the north coast are probably among the oldest forests, such as the very large Sonneratia trees at Metinaro and at Bay of Tibar; these trees are very likely to be more than a century old, given the low rates of net primary production.

Human use of mangrove forests in Timor Leste is highly variable, but generally limited in most coastal stretches, except for those in the vicinity of coastal towns and villages. It thus appears that mangroves function primarily as nursery grounds for some fish species caught on inshore reefs and rocky/seagrass habitats, as sites to protect portions of the coastline from excessive erosion, and as exporters of significant quantities of dissolved carbon and nutrients to support offshore food webs.

4.3 Nearshore Coastal Zone

The food chain implications for phytoplankton primary productivity off rivers and in the coastal ocean of old carbon which is resistant to degradation needs further investigation, but we believe that most particulate material leaving the rivers along the north coast, such as the Laclo, is transported quickly to the deep ocean. Our earlier estimates that $<1 \times 10^6$ t/yr of total nitrogen is delivered to the ocean from each of the major rivers of Timor-Leste indicates that the proportion of nitrogen reaching river mouths in Indonesia and Timor-Leste is between 40 and 60%, that is, between 60 and 40% (respectively) of fixed N remains on land.

The coastal zone along the north coast of Timor-Leste is dominated by sandy beaches, fringing coral reefs, rocky outcrops at headlands, and mangrove forests within small embayments to the leeward of rocky capes. Below mean sea level, the sea floor is dominated by mostly relict coral reefs and flats inhabited by diverse assemblages of seagrass and seaweed species. As noted in the Section, 5.0,
subsistence fishing is small-scale, confined mostly to the coral reef — seagrass — seaweed habitats within 100-200 m of the beach. Fishing within mangrove waterways is limited, but mangrove-associated fish (snapper, mangrove jack, grouper, crabs) form an important supplementation to the diets of these coastal villagers. Within the seagrass-coral complexes, sardines, Spanish mackerel and small pelagics are caught, with penaeid shrimps caught mostly after the rainy season. Reef fish communities are diverse, but impacted by the subsistence fishery. It is unclear where fish and shrimp spawn, but it is feasible that their life cycles are physically linked to reefs, mangroves, and seagrass beds or to seasonal plumes of riverine outwelling. We postulate that megafauna such as whales traverse these waters for two reasons: (1) as part of a migratory route and (2) to feed on abundant pelagic and epibenthic faunas offshore. It is probable that, along both the northern and southern coasts, that large charismatic organisms are attracted to, and their productivity stimulated by, tidal/boundary fronts and upwelling or downwelling events at the edge of the continental shelf; this postulate and nearshore oceanography needs to be investigated if an ecotourism industry is to be developed and sustained, and if subsistence fisheries are to be sustained.

Along the south coast, fishing is similarly conducted not in the mangrove lagoons, but in the surf zone, especially immediately off the hard rocky outcrops and terraces. We postulate that a wider, shallower shelf along the south coast facilitates retention of river-borne sediments and nutrients, and stimulates pelagic and benthic productivity. This scenario is somewhat reminiscent of coastal and marine processes occurring along the southern coast of Papua New Guinea (Alongi et al. 1992), where regions of fine sediment deposition and enhanced fisheries production alternate with zones of increased sand/gravel deposition or unstable zones where coarse sands overlie muds deposited after transport from river mouths. In the unstable zones, fauna is depauperate due to nutrient depletion and subsequent linkages to fisheries are therefore weak.

5.0 COMPARISON OF LOCAL AND SCIENTIFIC VIEWS, AND CONCLUSIONS

Without entering into the debate about the differences or similarities between local and scientific (including both natural and social science) knowledge (eg Agrawal, 1995), in this section the two sets of information are compared to determine if they largely agree or disagree. There are some realms of local knowledge in the two catchments which are of a mythological or spiritual nature that the Western scientific tradition does not encompass. Also, one of the strongest views expressed by the local people concerned the need to hold ceremonies to lay to rest the unrecognised souls of people killed over many years, particularly in conflicts. The normative (ie what ought to be) view has no strict scientific counterpart, but may be a means of accomplishing agreement on catchment management objectives and methods while simultaneously achieving the community’s ritualistic objectives of laying to rest the unrecognised souls.

Two sets of observations and suggestions are compared: Observations of Processes, Change, and Causes; and Management Issues (Table 10).

Agreement between local and scientific knowledge provides strong evidence for a conclusion about a particular case. Disagreement may weaken a conclusion, especially if a management intervention is desirable and the intervention is based on science but not supported by local people. If the scientific case is strong, but a management intervention is based on local knowledge which dramatically differs from scientific knowledge, the intervention may not be effective. If both the local view and scientific evidence are vague and weak, respectively, then clearly more investigation is required.

In the following discussions the comparisons of the two knowledges leads to conclusions, some of which are based on agreement, some on the science where local knowledge is contradictory, and some where both types of knowledge are highly uncertain.
<table>
<thead>
<tr>
<th>The views of local people</th>
<th>Scientific Evidence</th>
</tr>
</thead>
<tbody>
<tr>
<td>Observations of Processes, Change and Causes</td>
<td></td>
</tr>
<tr>
<td>1. Deforestation has led to serious (increased) erosion in the upland of both catchments, particularly landslides, gullies, and riverbank erosion.</td>
<td>The inference (based on theory) can be made that deforestation (for which there is evidence from remote sensing) has increased erosion. Also, $^{10}$Be data show that the denudation rate has increased recently by a factor of up to 20, the most likely explanation for which is deforestation.</td>
</tr>
<tr>
<td>2. Small upland channels have deepened and widened.</td>
<td>The banks and beds of many of these channels are clearly eroding, but the magnitude of the changes has not been investigated.</td>
</tr>
<tr>
<td>3. Lowland rivers are both widening and shallowing, and in the view of some people this is the result of deforestation and increased erosion in the uplands.</td>
<td>There is clear evidence for riverbank erosion (from ground observations and remote sensing) but there are no quantitative assessments of shallowing apart from that provided by the local people at Manatuto on the Laclo River. From theory and empirical evidence from other rivers, the increased denudation rates derived from $^{10}$Be data should increase river sediment loads which will result in channel widening, broadening, and braiding.</td>
</tr>
<tr>
<td>4. Lowland rivers flood more frequently and behave more erratically, and to some people this is the result of river shallowing. The reoccupation of an old channel to the west of the existing Caraultan channel on the delta is attributed to a dispute between local people.</td>
<td>There are no river gauging records to provide evidence of greater flooding, but channel shallowing and widening should lead to more floods if the flow regime has not changed; and channel braiding is likely to cause more erratic flows as water moves between channels.</td>
</tr>
<tr>
<td>5. Some people believe that shifting agriculture causes serious erosion and adds to the sediment load of rivers.</td>
<td>Qualitatively the most serious erosion is by landslides and riverbank erosion, not sheet erosion of shifting agricultural land. Topsoil tracers ($^{137}$Cs, $^{210}$Pbex) show that only 4-6% of the fine river sediment comes from topsoils of the kind cultivated by shifting agriculturalists. Furthermore, &gt;90% of lowland river sediment is coarse gravel and sand which is not derived from the loamy topsoils in the shifting agricultural plots.</td>
</tr>
<tr>
<td>6. Removal of tree vegetation along riverbanks causes serious erosion and sedimentation of the river channels.</td>
<td>Where trees have been removed along riverbanks, erosion is severe. But channels are also cutting into riverbanks that are vegetated, as a result of increased sediment loads and braiding. The margins of high river terraces, which have never been vegetated because they are vertical, are also eroding as a result of undercutting by rivers.</td>
</tr>
<tr>
<td>7. Deforestation has reduced spring water flow.</td>
<td>This topic is controversial scientifically, but it was not explicitly investigated during this project.</td>
</tr>
<tr>
<td>8. Large freshwater fish no longer exist in the lowland rivers.</td>
<td>There are no historical data to test this observation, but it is likely that habitat change resulting from sedimentation and increased pressure on fish resources could produce this result.</td>
</tr>
<tr>
<td>9. Large fish are less common in the nearshore coastal areas adjacent to both rivers.</td>
<td>There are no historical data to test this observation, and it is likely to be the result of damage to spawning grounds in coral reefs and mangroves, and to increased fishing activity without customary controls. Most productivity is in the surf zone.</td>
</tr>
</tbody>
</table>
10. Few changes have occurred to the mangroves at Metinaro until after the 2006 violence forced refugees to use timber resources. This has been documented (Alongi and de Carvalho, 2008).

11. The seaward edge of the mangroves at Betano has been buried by beach deposits, and the beach has approximately doubled in width since 1971. The mangrove zonation has clearly been truncated by beach sand deposition. Change in beach width at Betano, as seen on satellite images (1986-2006), shows a doubling. But elsewhere, to the west, the beach has narrowed.

12. There were no comments about the health of the mangroves. Mangroves on the north coast are sparse and unimpacted by river runoff, with most sediment (forming the substrate for the mangroves) being of marine origin. Impacts are from use of wood and collection of benthic invertebrates for food. On the south coast river flows affect the mangroves by sedimentation in beaches which in some cases have buried mangroves, while runoff has caused a shift to mangrove species more tolerant of variable salinity and species restricted to a higher tidal elevation. River flows, tides and waves on the south coast produce an unstable environment where mangrove forests rarely reach maturity, unlike on the north coast. Ground water plays a significant role in the health of mangroves on the south coast. Continued sedimentation however will result in replacement of mangroves by freshwater swamps and/or terrestrial forest. The long dry season on the north coast in particular means that the mangroves are less productive than other mangroves at the same latitude worldwide. These observations suggest that, although fishing in the mangroves is limited, their role as fish spawning grounds could be reduced in the future.

13. Mangroves are moderately important sources of wood and food. Resource extraction is generally limited, except in extreme cases such as at Metinaro.

14. Most fish are caught in the nearshore during river runoff events or soon thereafter. Investigation of the biogeochemistry and production of the nearshore zones near the mouths of the Laclo and Caraulun Rivers was beyond the resources of this project. However, it can be speculated that nutrients supplied by rivers promote phytoplankton growth which attracts fish. Also, disturbance by flow events of mud deposited offshore could release nutrients with the same result. More sand deposition offshore as a result of increased erosion and riverine sediment transport may reduce this source of nutrients and the fish that are depending on them.

Management Issues

1. Reforestation is necessary to stabilise the land, provide resources, and reduce natural disasters (landslides and floods). The evidence for increased erosion in the catchments, and the conclusion that most river sediment is coming from riverbank erosion, riverbed erosion (in the upland), and landslides and not from gully and sheet erosion of hillslopes, indicates that reforestation is necessary. This should be targeted at riverbanks, landslides, and gully heads (where they are threatening infrastructure such as roads and houses). But the experience of previous attempts at reforestation shows that: the new plantings must produce resources of value to local communities; there must be strong local
leadership (village heads and leaders of local clan groups; planting should reflect local tenure practices and protocols; agreements should be reached so that the tension between burning, grazing, and reforestation is resolved; and policing will be required.

| 2. Respect for nature must be increased, and customary controls (tarabundu) reinstated. | The opportunity to use local customary practice in joint management arrangements with government policy appears to be a crucial mechanism to improve natural resource management, including ritualised respect for nature. This should apply to both terrestrial and mangrove areas. |
| 3. Ceremonies are necessary to put to rest the unrecognised souls of people killed during periods of violence, and thereby reduce natural disasters. | The opportunity exists to use such ceremonies to achieve both their purpose of ‘healing’ and to provide a basis for catchment management by setting joint priorities and methods of achieving these priorities that involve all language and clan groups within the catchments. |

The strongest agreement between the two knowledge systems relates to increased erosion (particularly in the uplands) as a result of deforestation. The links between increased erosion, lowland river sedimentation, river shallowing, and river widening was not strongly held by local people; that is, some of the links were described but only a few people described the entire chain. The scientific evidence and theory is however clear.

The increased flooding and erratic behaviour of the rivers was attributed by some people to river shallowing as a result of sedimentation. Increased braiding of the river, as a result of increased sediment load, was not mentioned by the local people as an explanation of the more erratic behaviour of rivers, but seems likely from a scientific perspective.

Another area of agreement is that removal of vegetation along riverbanks causes serious erosion and sedimentation of river channels. While the scientific evidence for this is strong, it is not entirely clear that riverbank erosion is the major source of river sediment. Landslides are also very important.

An area of major disagreement concerns the role of shifting agriculture as a major source of river sediment. The particle size of most river sediment is very coarse, unlike the soils on hillslopes used for shifting agriculture. Also, geochemical topsoil tracers show that hillslope soils are a minor component of river sediment.

Strong agreement occurred about burial of mangroves at Betano by beach sands. This is likely to be the result of increased erosion in the Caraulun catchment and increased river sediment transport to the coast. The local people did not make these casual links.

Local people observed changes in the number of large freshwater and nearshore fish. In the case of freshwater fish, riverbed sedimentation is likely to be a major source of habitat change with impact on fish. While there is no supporting evidence, fishing pressure is also likely to be a factor. In the case of nearshore fishing, damage to coral reefs, possibly greater sand deposition offshore which reduced nutrient sources and therefore phytoplankton growth, and fishing pressure probably all contribute to the reduced number of large fish. But much of this is speculation.

The two sets of information agree that there have been few changes to the mangroves, except at Metinaro after 2006 and at Betano where sand deposition has increased. The local people had no comment on the health of the mangroves, but the scientific data shows that while mangrove forests are often sparse with low production, they are generally in good condition. Local people see them as an important supplementary source of wood and food.

All of the suggestions for management are supported by the scientific observations. Reforestation of critical areas within the catchments is clearly necessary, focusing on riverbanks (riparian zones), and landslides. But analysis of previous attempts at reforestation show that multiple use plantings, local
leadership, respect for local tenure, agreements about land use and management, and policing will all be necessary. The reinstatement of customary natural resource management is desirable, which should have the added benefit of ritualising a greater respect for nature. Finally, ceremonies to put to rest the souls of the unrecognised dead could also serve as the basis for catchment management.

Catchment management could be seen as a form of joint management between local people’s institutions and government. The state needs to formally recognise and empower local communities and provide the necessary legislative authority (McWilliam, 2001). Possibly by developing a set of common conserving practices for sacred (lulik) forests, a basis could be provided for a new approach to agro-ecological management in East Timor.

That there is more agreement than disagreement between the local and scientific knowledges is a good basis for catchment and coastal management. The application of scientific knowledge is unlikely to conflict with the views of local people, as long as their customs, livelihoods and tenure systems are respected.

The reforestation of critical zones in a catchment, if performed in the ways described above, and could provide a greater diversity of material and food sources (both animal and plants) based on greater biodiversity. Such diversity, including crops, is a well-known strategy for coping with disaster and climate change for Indigenous (ie local) people (see Berkes et al, 2000). Projections for East Timor include higher temperature, possibly lower but more intense rainfall, greater climatic variability, and higher sea level (Barnett et al, 2007). Higher diversity of biological resources could be a very useful basis for coping with the projected greater climatic variability.

6.0 RECOMMENDATIONS

The conclusions reached in the previous section by comparing local and scientific knowledge along with the outcomes of a workshop held 4-5 June 2009 in Dili are as follows:

1. Revegetate critical sediment sources in catchments, taking account of benefits to local people, land tenure, and customary institutions noting:
   a. Reforestation of critical sediment sources is essential if sedimentation of rivers, flooding, and damage to mangroves by sediment is to be reduced. The critical sediment sources are riparian zones and landslides, although further research is required to quantify their contributions.
   b. Reforestation should be designed to provide economic benefit to local people not just conservation and reduction of erosion. Also, local leadership must be strong, land use planning effective, local tenure respected, and policing in place. The appropriate mix of these instruments needs careful examination.
   c. Erosion from shifting agriculture lands is not a significant source of river sediment. So policies to minimise erosion on these lands should focus on agricultural sustainability and livelihoods.

2. Wider understanding of the existing guidelines for prioritising catchments for management (10 critical catchments out of 27 catchments in Timor-Leste) through:
   a. Identify and mapping sediment source areas in the critical catchments
   b. Survey information on socio-economic (energy and material audit at village level) and natural condition of each critical catchment
   c. Develop guidelines for integrated catchment management, including reforestation. This will involve joint management of catchments and coasts involving Government and the institutions of local people to ensure local ownership/engagement.
   d. Build on existing capacity through training in catchment inventory and data compilation, data analysis and catchment management.
   e. Develop local capacity in catchment management in communities, through public awareness and training.
3. Develop a national joint management plan for mangroves:
   a. To include Environment, Culture, Fisheries and Tourism.
   b. Considering of local knowledge and values in mangrove management
   c. Survey and map species/communities of mangroves, particularly on the south coast (as data is available for north coast).
   d. Prioritising mangrove forest areas for management.
   e. Education and public awareness of the importance of mangroves.

4. Gain greater understanding of:
   a. The contribution to river sediments and coastal landforms (eg deltas, beaches) of landslides and riverbank erosion. This is likely to be an ongoing with management responding to new information.
   b. Soil conservation priorities, for example hill slope terracing, fire management, riparian zone management and rehabilitation etc).
   c. Options for joint management of catchment and coasts (eg legislation & policy – central level and Tarabandu – local level).
   d. Why some joint management succeeds and why some fails
   e. Strategies for strengthening existing relationships and links between regulation and Tarabandu thus using local customary natural resource management methods to support/compliment Government policy in a framework of joint management.
   f. The value of ceremonies in the Laclo and Caraulun catchments to achieve the community’s catchment to coast objectives as well as begin to identify new objectives and priorities for catchment and coastal management.

5. Understand the relationship between river flows and nutrient release to the coastal zone and impacts on marine food chains, including fish stocks and sources of food for marine mega fauna. This is to improve management of coastal resources, with an emphasis on food security
   a. The biogeochemical support mechanisms for the offshore mega fauna needs to be understood so that an ecotourism industry based on these animals is sustainable.
   b. The biogeochemistry, food chains, and fish breeding cycles in the nearshore (particularly on the south coasts) needs to be researched.
   c. Spatial and temporal sampling of food chains and nutrient fluxes. This requires a research partnership.

6. Develop adaptive strategies and monitoring protocols for the management of the likely impact of climate change on catchment and coastal resources
7.0 REFERENCES


Egashira, K., Gusmao, M. N/A., Kurosawa, K. (2006). The present and future land management in East Timor from ‘Slush (sic) and Burn’ to ‘Slush (sic) and Mulch’, J. Faculty of Agriculture, Kyushu University, 51(2), 369-372.


APPENDIX A

SOCIO-ECONOMIC DRIVERS OF CHANGES DOCUMENTED DURING COMMUNITY CONSULTATIONS

POPULATION AND SETTLEMENT CHARACTERISTICS.

Manufahi (Samé)

Manufahi district extends from the central highlands to the southern coast of Timor. The district holds an important place in the history of Timor Leste as the site of the last great rebellion against Portuguese rule, under the leadership of Dom Boaventura, the great Liurai of Samé-Betano who violently resisted Portuguese attempts to assert their military authority but finally capitulated in 1912. The name of the district derives from the mythical origins of settlement and the division (fahé) of the lands among 7 settler brothers (maun), hence the name, Maunfahe.¹

The district capital is centrally located in the region and has attracted significant numbers of in-migrating households. The main ethno-linguistic communities of Manufahi include those of Mambai and Bunak in Samé and the northern highlands, Lakalei in Turiscai and Tetun Therik in Alas. They are distributed among four constituent sub-districts (sub-distritu) within the district of Manufahi and include Fatuberliu, Alas, Same and Turiscai.

The 2004 census identified a total population of 44,235 and the other centrally located districts, Manufahi has experienced significant population increases over the 2001 estimates (see table A.1). This includes the sub-districts of Samé, Alas and Turiscai which have experienced population rises of between 16-24% over the three years to 2004. Fatuberliu however has seen a population decline over the same period which is probably attributable to high levels of out migration by younger people and its comparative remoteness from service centres and transport links. Samé sub-district which comprises the lower reaches of the Caraulun River is the principal population centre. It contains the district capital (Same) and most of the actively utilized irrigated rice areas. During the Indonesian interregnum the subdistrict of Hatudo was split off from Samé and incorporated into Ainaro district, while the subdistrict Turiscai, previously in Ainaro, was moved to Manufahi.

Table A.1: Manufahi District population 2004.

<table>
<thead>
<tr>
<th>Sub district</th>
<th>No. of Households</th>
<th>Population</th>
<th>% change since 2001</th>
</tr>
</thead>
<tbody>
<tr>
<td>Same</td>
<td>5,088</td>
<td>25,013</td>
<td>17.6</td>
</tr>
<tr>
<td>Alas</td>
<td>1,287</td>
<td>6,463</td>
<td>23</td>
</tr>
<tr>
<td>Fatuberliu</td>
<td>1,226</td>
<td>6,324</td>
<td>-3.7</td>
</tr>
<tr>
<td>Turiscai</td>
<td>1,103</td>
<td>6,417</td>
<td>16.4</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>8,704</strong></td>
<td><strong>44,235</strong></td>
<td><strong>14.6</strong></td>
</tr>
</tbody>
</table>

Manufahi district has significant upland agricultural production with scattered rural communities pursuing near subsistence food crop cultivation throughout the highlands especially the sub districts of Turiscai and Fatuberliu. Land use mapping identified up to 40.3% of the area of Manufahi district is utilized for food crop production (table A.2). Manufahi district produces maize in all 4 sub-districts, but rice production is important in Betano and in the sub-district of Samé. The Caraulun River within the district is the site for substantial rehabilitation of irrigation infrastructure which will enable an expansion of the area planted to irrigated rice. The district is also producer of beans, vegetables, fruits and other horticulture crops such as sweet potato and cassava. In the higher reaches of the catchment including the foothills of Mount Cablaki, coffee is cultivated under canopy shade trees along with candlenut and other tree crops.

¹ Not as is sometimes thought, a term combining the Tetum words for chickens (manu) and pigs (fahi)
Table A.2: Manufahi vegetation cover and land use.

<table>
<thead>
<tr>
<th>Hectares</th>
<th>% of land area</th>
<th>Land use classification</th>
<th>Land use category</th>
</tr>
</thead>
<tbody>
<tr>
<td>7944.7</td>
<td>6.0</td>
<td>Coastal Forests</td>
<td>Forested Land</td>
</tr>
<tr>
<td>12742.5</td>
<td>9.6</td>
<td>Highland Forest - Moist Mixed</td>
<td>Forested Land</td>
</tr>
<tr>
<td>4372.8</td>
<td>3.3</td>
<td>Lowland forest single specie</td>
<td>Forested Land</td>
</tr>
<tr>
<td>9497.9</td>
<td>7.1</td>
<td>Moist Sparse lowland forest</td>
<td>Forested Land</td>
</tr>
<tr>
<td>35797.1</td>
<td>27</td>
<td>Moist Lowland Forest - Dense</td>
<td>Forested Land</td>
</tr>
<tr>
<td>339.9</td>
<td>0.25</td>
<td>Montane Forest</td>
<td>Forested Land</td>
</tr>
<tr>
<td>3308.8</td>
<td>2.5</td>
<td>Smallholder Estate Crops</td>
<td>Commercial Agriculture</td>
</tr>
<tr>
<td>150.3</td>
<td>0.11</td>
<td>Cities and Large Towns</td>
<td>Settlements / Industrial</td>
</tr>
<tr>
<td>180.5</td>
<td>0.13</td>
<td>Villages and Mixed Gardens</td>
<td>Rural Settlement</td>
</tr>
<tr>
<td>53495.7</td>
<td>40.3</td>
<td>Dryland Arable - Food Crops</td>
<td>Agricultural Land</td>
</tr>
<tr>
<td>3087.8</td>
<td>2.3</td>
<td>Wetland Arable</td>
<td>Agricultural Land</td>
</tr>
<tr>
<td>1705.2</td>
<td>1.3</td>
<td>Grassland</td>
<td>Dryland Not In Use</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>132659.8</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

(Source: ALGIS Land Use Assessment 2001)

**Historical relations**

The geography of Samé district encompasses the catchment of the Caraulun River and this awareness has formed part of the historical relationships that comprised the political community of the district. One ritual name for Samé is Be ulun Cablaki, which refers to the ‘headwaters and the mountain’ of the catchment. Cablaki forms the massive boundary between Samé and Ainaro district to the north (expressed in ritual terms as Cablaki-Taradayi).

Historically the political organisation of the region was represented in terms of a diarchic structure and expressed in terms of the ‘head’ and ‘foot’ of the land (be ulun – be ain). It was represented by two rulers or liurai who were subsequently accorded the title of Tenente Coronel by the Portuguese colonial government.² The Liurai at the headwaters and mountain (foho) was known as Liurai Malai and lived at Kota lala in the hamlet of Tomanamo (part of the village of Letefoho). The ‘lower’ Liurai at the foot of the river in the lowlands was Liurai ‘Dom’ Boaventura. Their relationship is also expressed in the familiar terms of marriage alliance, Umane:Feto sawa where the highland ruling group gave their daughters in marriage to the lowland ruler. These inter-relationships and the ritual exchange obligations that inform social relations remain significant for the different clan groups across Samé. They provide the principal means by which people negotiate access to resources and resolve local disputes. Local clan histories and their mythological origins, however, is sensitive information and restricted from general public access.

**Settlement change and land issues**

Major changes in land use patterns occurred following the Indonesian military invasion of Timor Leste in 1975. Over the ensuring years of armed resistance the scattered highland communities were gradually directed to move into concentrated settlements around the main towns and administrative settlements, ostensibly for security reasons. The principal camps were located at Turiscai, Maubisse, Alas, Fatuberliu, Same and Betano. By 1983 all settlements were clustered around these centres and forced to cultivate the surrounding areas. While this process reduced land pressures on more distant areas, it caused increased clearing and erosion in the lands surrounding the towns.

This pattern of settlement continued for a number of years, until the military situation was deemed under control and communities were gradually permitted to return to their original settlement areas. By 1992 most of the translocated population was permitted to return, opening up old food garden areas and rebuilding their hamlets.

² This system of military titles was introduced into Timor in the early eighteenth century.
During the period of Indonesian rule, attempts were made to reinstate the boundaries of the permanent forest reserve system which had been implemented during Portuguese colonial times and formalised through agreements with local village communities. However, over time as traditional protocols have eroded and population growth created pressures on available arable land resources, there have been gradual incursions into the forested zone causing deforestation and increased clearing.

Throughout the district land management and access is based on informal or customary practices. There is no significant market for land although forms of share cropping and leasing arrangements are negotiated. Throughout much of Samé district land inheritance follows maternal descent associated with the respective origin groups or clans (uma lisan) who hold traditional jurisdiction. Both Mambai and Bunak speaking communities transfer land entitlements from mothers to daughters. Men marry out of the exogamous uma lisan and cultivate the land of their wives. However, they retain responsibilities towards their mother’s and sister’s land, particularly in cases where public negotiations or dispute resolution is required.

One of the consequences of the extensive dislocations of population that occurred under Indonesian rule has been a legacy of land disputes, particularly in the sub-district towns where communities were concentrated. The local Land and Property Unit has had some success at mediating land disputes which have arisen as a result (some 167 cases since 2000 with around 50% mediated successfully). Common disputes include those where land was appropriated under Indonesian rule and the owner felt unable to protest or claim their rights. Other cases involve claims by landowners over property that was settled by people relocated to the towns, who have subsequently built assets and don’t wish to return to their former settlements. Mediation in these cases involves a consideration of evidence in support of claims and the economic means of the claimants. Where mediation fails, the Land and Property often request local arbitration by the Village head (Chefe Suco) and local traditional authorities (lian nain) who are generally well respected authorities in Timor Leste.

**COMMUNITY MEETINGS**

**Samé**

The community meeting in Samé brought together a number of senior ritual leaders as well as farmers and local residents of the town and surrounding villages. The group agreed that the Caraulun had become wider and more destructive in recent decades. They associated the increased flows (faster current) and greater levels of sedimentation in the river course to activities associated with the Indonesian war (funu). As the river fills with sediment the flow eats into the banks and takes out fringing cultivation areas. One of the participants commented that the frequency of flooding in the Caraulun had intensified and exacted a price in human life and livestock. Each year generally someone drowns in the river or cattle and buffalo are carried away.

The main causes of the increased flooding and seasonal river flow is attributed both to deforestation during the Indonesian period but people also recognized the role of swidden farmers in the upper catchment. The general view was that there was now more people and more land under cultivation in the upper catchment (Maubisse and Turiscai). As one man commented, ‘In my grandparents time, all the mountains were forested, now they are farmed’… before the trees weren’t cut, now they are cleared for planting.’ Farming activity along the river banks and riparian zones was also mentioned as a factor in both the increased erosion and the erratic flow patterns of the river.

Contributors to the discussion included Leonardo Cardoso, Alvaro da Silva and Napoleon Mallo. They attributed the increased intensity of river activity in part to deforestation in the upper catchment with associated landslides. They also raised the issue of the many people who had died in the mountains during the period of armed resistance and their bodies and spirits lost to the communities. Similar to views expressed in the Laclo River catchment community consultations (see Carvalho et al, 2006), these ideas link to notions of unrestrained spirit influences on the environment producing damaging and uncontrolled effects. For these reasons they considered that reforestation alone would not be sufficient to reduce the increased flows and flooding. They believed that there was a need to undertake appropriate restorative ritual sacrifices and invocations to resolve these unresolved
influences from the past. However, to do so would involve bringing together all the leading houses/clans (*uma lisan*) from the eight villages (Suco) that comprise the catchment. Although each ritual authority (*lian nain*) is responsible for their respective areas, the idea of organising a joint (catchment) ceremony would be seen as a sign of mutual commitment and symbolic unity of purpose.

Another participant, Florindo da Silva, also identified the decline in respect for nature and *lulik* or customary sanctions, stating that if people acted in accordance with the traditional protocols then there would be no damage. When there was no ‘respect’ accorded the natural environment (*respeito la iha*) conservation principles declined. In the past the Indonesian military had ignored all customary protocols relating to environmental conservation and many are critical of their role in forest degradation. How the community might move towards a catchment wide ceremony would depend on signs drawn from dreams and the considered views of different ritual authorities. De Silva suggested that they needed to draw on older patterns of customary management and ritual harvesting to conserve river and coastal resources. In the past all members of the clan (*uma lisan*) would follow the ceremonial cycles of cultivation which ensured that all members followed customary farming practices including periodic fallowing of garden lands (4-6 years) to allow the land to recover. In these ‘modern’ times, however, younger people see traditional practices as old fashioned and not relevant to their farming practices.

**Betano**

The Village of Betano is located near the mouth of the Caraulun River on the eastern side of the main channel. The community practices a range of mixed farming activities including irrigated rice production, seasonal rainfed maize and secondary food crop production, animal husbandry and artisinal inshore fishing along the coast.

The meeting was held in the community meeting house near the foreshore, chaired by the Village Head and Narciso Carvalho (Director of Fisheries). The general impression presented by local residents is that the Caraulun River has expanded in width over recent decades with an increased size of floods that bring large boulders and tree trunks downriver. Floods occur every year and people were not clear why this was occurring but some attribute the change to increased farming and deforestation activities in the hills. They had noticed that the increased intensity of river flooding caused damage to the river channel as it widened and shifted about.

Mr Francisco Surik observed, however, that when the river was in flood the inshore fishing catch improved. They were able to catch small pelagic species such as Kombo (*Rastrelliger sp*) and Sardines (*Sardinella sp*) in the estuaries and long the foreshore in relatively shallow waters. Fishing activities are restricted during May and July (eastern monsoon) with big seas swells (*tasi bo’ot*), waves and sea currents that surge along the coast. In the wet season the river plumes are carried both east and west by the currents. The changeable character of the Timor seas on the south coast give rise to its cultural reference as the *tasi mane* (male sea) in contrast to the ‘female sea’ (*tasi feto*) along the north coast.

The strong wave action along the coast tends to limit the development of mangroves along the foreshore. Villagers also commented that in the early 1990s the foreshore extended further out than at present, but strong tides and wave action had eroded the beachfront.

Coral reefs are found 100-200m from shore but reef fishing is still low yielding because of previous damage caused during Indonesian times when reef bombing was common. This has had an impact on the livelihoods of the community who formerly depended on the reef catch to supplement their incomes. Jose da Conceicao mentioned that local people were also implicated in these destructive activities which have now ceased and the reefs are recovering slowly. Reef gleaning at low tides is also pursued for molluscs and shellfish but the community is aware that regulations are foreshadowed to restrict these kinds of activities.

Fishing in the estuaries and main river channels is also undertaken on a limited scale. Small freshwater fish (*ika k’i’ik*) and prawns (*boik*) are sometimes gathered for consumption. But heavy levels of sedimentation in the river channels reduces habitat for these species and the catch of large
freshwater fish has declined. Further upstream people are known to use ‘electrofishing’ using batteries to stun fish in water holes and river channels.

Awareness of the importance of conserving resources and the environment remains strong in the community and plans were reported to implement a general community prohibition on a range of inappropriate activities. It was recalled that during Portuguese times (pre 1945) an older generation had local customary regulations to protect the natural resources. Everything was recognised to have a function and protected accordingly, such as restrictions on cutting trees along the foreshore to protect against high winds and destructive tides. Over time, however, adherence to these practices had weakened. As one man mentioned, these days people feel free to act as they wish and without consideration of the wider common good.

The community was planning to institute a renewed general prohibition (Re na Tara) on 27 July 2007, to cover activities on both the land and the sea (rai maran ho tasi). The ritual is designed to follow the old laws and tradition to protect ‘our lives and resources’. Under the prohibition a range of restrictions will be articulated and monitored. They include rules such as ‘no farming alongside the river banks, no cutting of large trees along the river or beachfront, no stealing of plantation crops. A system of community based fines and other censures will sanction the regulations and be based on the degree of transgression. The Re na Tara (Tara bandu in Tetum) is designed to regulate and protect human life and livelihoods, livestock and the natural environment.

River changes

During the wet season of 2004-5 a major flood on the Caraulun resulted in a dramatic change in the river course on the delta, destroying several hundred hectares of riceland and re-occupying an old river channel several hundred metres to the west (Fig 8). The ‘new’ channel is about 100m wide and cuts a swathe through the swamp forest and delta lands (an area known as Bobé) eventually draining into a small lagoon behind the modern beach.

While the dramatic change of river course may be explained in terms of natural river dynamics and the intensity of flooding that burst through low-lying natural levee banks, local explanations of the cause of the events are less prosaic. According to one version, the disastrous flood was the end result of a dispute that had festered between the villagers of Betano and their counterparts on the other side of the river in Bakala (District of Ainaro, Hatu udo sub-district). The dispute arose over a large waterhole or small lake on the delta that was a source of crabs and prawns. Bakala people resented the fact that their Betano neighbours were venturing over to deplete the resource. Betano countered by saying that the area of the lake was historically part of Betano village, and was only rezoned within Bekala during Indonesian times when the Caraulun was designated as the village and district boundary.

With no resolution to the dispute in sight, the leader of the customary land owning clan of Bobé in Betano, Uma Lisan Loro, declared that if the community of Bekala did not agree to permit them to access the prawn and crab stocks on the Bobé delta, then he would direct the river to flood them out and destroy their crops. A few months later the river broke through its banks and fulfilled the threat. 200 ha of riceland as well as the resource ponds were washed away and a broad band of sediment and gravel was deposited over much of the cultivation area. According to respondent, Francisco, a group of farmers from Bekala had recently visited Betano to apologise for the dispute and seek restoration of the damaged fields. The clan leaders (Rai nain) of Betano, however, refused to negotiate with them, stating that they would only speak with the people with whom they had the dispute.

This account highlights something of the cultural significance and interpretations that are often placed on natural occurrences on Timor Leste. The relationship between clans and the land to which they assert traditional ownership remains one that is spiritually charged. There are two aspects to this understanding. Firstly the reproduction of clan land relations over time creates an enduring bond between the living community and clan ancestors who worked the land before them and who are periodically enjoined through sacrificial invocation to ensure the production of food and sustenance of the living group. For this reason the clan maintains the status of ‘land lord’ or ‘lord of the land’ (Rai nain in Tetum). In addition to ancestral human spirits, Timorese cultural ideas also posit the existence
of an array of emplaced autochthonous spirit forms that inhabit the landscape and reside in water
sources, caves, large boulders, trees and so on. These invisible spirit entities are also referred to as
‘lords of the land’ (rai nain) and may be invoked or importuned through appropriate ritual and
sacrificial means. Over time the ritually mediated relationship between living community and the
lands to which they lay claim, establishes an enduring attachment that is not lightly contested. It is in
this sense that a culturally acceptable explanation for the disastrous flood of 2005 may be found. It
reflects a particular view of the world and its contingent events that assumes forms of agency rather
than blind processes of unintended effect.

Maubisse (18 June 2007)

The planned community meeting in Maubisse, in the upper reaches of the Caraulun catchment, did not
eventuate due to logistical and electoral campaign complications in the lead up to the national
parliamentary elections. Instead the team were able to meet with Snr Joao Bonavides, a former Chefe
do Suco of the area who held the position for 18 years from 1961 – 1979. He provided some striking
perspectives on catchment land management practice in the region from his personal experience.

One of the striking features of the Maubisse valley is the extensive stands of Casuarina trees
(Casuarina junghuniana) that form a patchwork forest cover over the lower slopes and valley floor.
The higher mountains are denuded of trees and form elevated grasslands where livestock grazing
predominates. In the early 1960s, the then Portuguese administration sought to promote expanded
coffee production in Maubisse and prepared a large number of Casuarina seedlings to utilize as shade
trees for the coffee plants. Although native to Timor Leste, Casuarina junghuniana was not endemic
to highland Maubisse where the remnant local vegetation is primarily Eucalyptus urophylla (Ai ru)
mixed with Eucalyptus alba on lower slopes. But it proved highly adaptive to the area particularly
with its capacity to withstand wind.

At the time Snr Bonavides was a young village head and became an enthusiastic promoter of the
coffee expansion area program. Four seedling preparation sites were initially developed and the shade
trees distributed and planted in grassland areas. The trees were then managed on the basis of local
customary land jurisdictions. Groups of related households (uma lisan) planted within their collective
common boundary and managed the coffee development on that basis. The coffee program was
extended annually from 1962 until 1975 and proved to be highly successful accounting for the
majority of Casuarina stands/ coffee plantations that grow in the valley today. Having seen the
benefits of the government program, local farmers also took the initiative to plant additional areas
using Casuarina seedlings as the shade tree, a practice that continues today. Over the longer
perspective, Snr Bonavides also mentioned that he had seen a reduction in erosion (rai halai) due to
the impact of the Casuarina tree expansion.

During the post 1975 period associated with the imposition of Indonesian rule in Timor Leste,
reforestation programs were also promoted and funded but, like so many of similar attempts
elsewhere, they were generally unsuccessful. In addition to Casuarina, there were also attempts to
plant acacia trees for erosion control and reforestation (reboisasi) but while the seedlings would
establish in the wet season, they were almost invariably destroyed by cultural burning in the dry
season as the hills were burnt off to encourage green vegetation for animals. Only trees located in
coffee gardens were able to avoid the fires. In other words, despite 24 years of repeated attempts by
the Indonesian forestry service to reforest the Maubisse region, there was little to show for everyone’s
efforts. The experience offers a number of important lessons on the subject of reforestation in Timor
Leste.

• Pure reforestation is very difficult to achieve in Timor Leste. Damage caused by seasonal burning,
and grazing livestock, combined with inadequate policing and the lack of a sense of ownership
will contribute to almost certain failure of the investment. (The Indonesian experience).

---

3 He is also the father of the interim Minister of Agriculture, Forestry and Fisheries.
4 Bonavides mentioned that the Portuguese forestry program extended throughout the wider region including
Ermera, Same, and other areas of Aileu.
Successful reforestation can be achieved where trees serve a more direct or immediate economic purpose. In other words, reforestation as an ancillary benefit to a more central economic concern. (The Portuguese experience – with coffee and to a lesser degree cacao).

Past success was also critically dependent on local leadership (Village head and the respective leaders of local clan groups) and strategic approaches to planting areas that reflected local tenure practices and protocols. Portuguese colonial success at coercing the development of plantations across Timor Leste (for commodities such as coconuts, coffee, rosewood and mahogany), mixed though it was, relied heavily on the authority of local rulers (Liurai) to mobilize their communities for agricultural labour and to maintain regimes of protection. These authority structures in contemporary times are much transformed but within communities, authority structures remain strong and for most people, highly legitimate institutions.
APPENDIX B

CHANGE IN LAND COVER, RIVERS, AND THE COAST IN THE CARAULUN CATCHMENT

As part of the River Catchment and Marine Productivity in Timor Leste: Caraulun Catchment to the South Coast Project, a Masters by Research project is being carried out by Ms Juno Rouwenhorst. This project aims to investigate land cover and land use changes throughout the Caraulun catchment, focusing specifically on riparian zones, and to examine the changes in the river system, coastline, and delta.

Moderate resolution (25x25 m) satellite imagery (Landsat Thematic Mapper) from 1986, 1996, and 2006 was used to map vegetation density and the river system for the mentioned years. A geographic information system (GIS) is being used to analyse changes. The changes in vegetation density are examined particularly with regard to landscape pattern (e.g. elevation, slope, proximity to villages and roads) and river network position, whereas the changes in rivers are analysed with a focus on river channel characteristics (e.g. width, area, sinuosity, position) and changes in associated riparian vegetation. This project is ongoing, but findings to date are presented below.

1.0 Vegetation changes

The Landsat TM imagery from 1986, 1996, and 2006 was orthorectified to WGS84/SUTM 51 datum/projection and then subsetted to the Caraulun catchment. This was followed by atmospheric correction of the images by dark object subtraction (DOS; Chen et al., 2005; Chavez, 1996), the masking out of the oceanic water, and spectral enhancement by breakpoint analysis. These pre-processing techniques allow for an improved visual interpretation of the imagery by making certain aspects of the imagery, such as vegetation and bare areas, stand out.

The normalised difference vegetation index (NDVI) can be used as a measure of vegetation health and density and is commonly used in vegetation cover studies. Its calculation is based on reflectance in the near infrared (NIR) and red bands as per the equation below, where $\rho$ is the reflectance of the NIR or red band ($\lambda$):

$$NDVI = \frac{\rho(\lambda_{NIR}) - \rho(\lambda_{red})}{\rho(\lambda_{NIR}) + \rho(\lambda_{red})}$$

In this study we are mostly concerned with the possible effects of land cover change on erosion and its effect on the river system. It is widely known that changes in vegetation cover increase the risk of erosion. As a consequence, changes in vegetation density and health can give a good indication of possible sources of sediment, and the use of NDVI values as an indication of vegetation density was deemed adequate for this study’s purpose.

Hence, NDVI values were calculated from the imagery using density slicing techniques and Erdas IMAGINE® software, which were then reclassified into 5 classes (Table B.1). To determine the accuracy of this classification, 70 ground truthing points collected in 2007 were used. The error matrix shows an accuracy of 88.6% (Table B.2). ArcGIS® software was used for change analysis.
<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
</table>
| Riverbed  | - Sandy areas including – beach, river/creek beds  
- Concrete areas including – construction sites, rural settlements  
- Exposed reef areas with sand or algae  
- Cleared agricultural areas                                                                                                                     |
| Bare      | - Exposed soil areas including – very sparsely vegetated agricultural areas, landslides, cleared/eroded areas  
- Grassland  
- Very open, degraded woodland with some shrub understory  
- Sparsely vegetated riverbanks  
- Canopy cover approximately up to 10%                                                                                                             |
| Sparse    | - Agricultural areas including – rice, sparsely vegetated areas, banana plantations  
- Open forests with moderate shrub understory including – eucalypt, *Casuarina*, mixed, teak, palm  
- Urban areas with variety of vegetation including – fig, pine, palms, acacia, mango, coconut palms  
- Dense grassland  
- Canopy cover approximately 10-50%                                                                                                               |
| Moderate  | - Canopy cover approximately 50-80%  
- Agricultural areas at later stages  
- Coffee plantations with either rain trees or casuarinas as shade trees  
- Mixed forest with dense shrub understory  
- Dense weed areas, e.g. *Chromulaena odorata*  
- Teak plantations  
- Rural villages with shift agricultural areas in later stages, including those that have been fallow for some time                                                                 |
| Dense     | - Canopy cover approximately 80-100%, or less, with very dense shrubbery  
- Coffee plantations with either rain trees or *Casuarina* as shade trees  
- Coastal vegetation including palm trees and mixed forest  
- Mixed forest with very dense shrub understory (80% or more)  
- Primary rainforest (high altitudes)  
- Secondary rainforest (high altitudes)  
- Swamp forest                                                                                                                                   |

Table B.1: Description of the vegetation density classes derived from Landsat TM imagery

<table>
<thead>
<tr>
<th>Ground points</th>
<th>Riverbed</th>
<th>Bare</th>
<th>Sparse</th>
<th>Moderate</th>
<th>Dense</th>
<th>Total</th>
<th>CA%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Riverbed</td>
<td>8</td>
<td>6</td>
<td>24</td>
<td>1</td>
<td>7</td>
<td>8</td>
<td>88.9</td>
</tr>
<tr>
<td>Bare</td>
<td>8</td>
<td>1</td>
<td>6</td>
<td>24</td>
<td>1</td>
<td>7</td>
<td>75.0</td>
</tr>
<tr>
<td>Sparse</td>
<td>1</td>
<td>24</td>
<td>1</td>
<td>8</td>
<td>1</td>
<td>7</td>
<td>85.7</td>
</tr>
<tr>
<td>Moderate</td>
<td>3</td>
<td>9</td>
<td>12</td>
<td>14</td>
<td>2</td>
<td>15</td>
<td>64.3</td>
</tr>
<tr>
<td>Dense</td>
<td>2</td>
<td>15</td>
<td>17</td>
<td>20</td>
<td>17</td>
<td>15</td>
<td>75.0</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>8</strong></td>
<td><strong>7</strong></td>
<td><strong>27</strong></td>
<td><strong>13</strong></td>
<td><strong>15</strong></td>
<td><strong>70</strong></td>
<td><strong>88.6</strong></td>
</tr>
</tbody>
</table>

Table B.2: The error matrix shows an accuracy of 88.6%
Figure B.1 shows the total areas for each vegetation density class for each year of imagery. All three of the total areas for the “riverbed”, “bare”, and “sparse” classes have increased overall, with the “moderate” and “dense” classes decreasing in area. It is interesting to note that the “bare” and “sparse” classes have decreased in area from 1996 to 2006, with the “moderate” class increasing in area for the same period.

**Figure B.1: Net changes in vegetation density in Caraulun catchment, Timor-Leste**

Figures B 2-4 show the land cover classifications derived from the NDVI's for each year of imagery. When comparing the classifications from 1986 and 1996 – during which period the Indonesians were still ruling Timor Leste – the ‘thinning out’ of vegetation during this time is quite apparent especially in the upper and mid catchment. Visual inspection of the 1996 and 2006 classifications – which coincide with the period before and after Independence – shows an increase in vegetation density in the mid catchment especially, with more ‘moderate’ vegetation and less ‘bare’ ground. However, a loss of vegetation can be seen in the delta area on the eastern side of the river at the site of an irrigated agricultural area as well as on the western side of the river where a new river channel has developed.
Figure B.2: The vegetation density classification for 1986

Figure B.3: The vegetation density classification for 1996
Figure B4: The vegetation density classification for 2006

Figures B.5 and B.6 show the vegetation density change images for 1986-1996 and 1996-2006. These clearly show the thinning out/removal of vegetation in the mid and upper catchment with an increase in vegetation in the lower catchment for 1986-1996; whereas for 1996-2006, an increase in vegetation density can be observed in the mid and upper catchment and some areas in the delta, with the thinning out of vegetation occurring mostly in the lower catchment area.

The areas of class-to-class change are shown in Table B.3. From 1996-2006, the area of ‘negative’ (decrease in vegetation density, i.e. a decrease in growth) changes such as those from ‘dense to riverbed’, ‘dense to bare’, and ‘moderate to bare’ was more than triple the area for the same classes in 1986-1996. However, the ‘negative’ changes ‘moderate to sparse’, ‘sparse to bare’, and ‘dense to moderate’ showed a significant decrease in area from 1996-2006 compared with 1986-1996. In total, the ‘negative’ changes are approximately 60 km$^2$ less during the 1996-2006 period than from 1986-1996 (Table B.3). Additionally, ‘positive’ (increase in vegetation density, i.e. an increase of growth) changes such as ‘bare to sparse’, ‘sparse to moderate’, and ‘sparse to dense’ have approximately doubled in area from 1986-1996 to 1996-2006. In fact, the total area of ‘positive’ changes has gone from 133.6 km$^2$ in 1986-1996 to 235.9 km$^2$ in 1996-2006. Summarising the ‘positive’ and ‘negative’ changes; for 1986-1996 the ‘negative’ changes were double the area of the ‘positive’ changes, whereas for 1996-2006 the area of ‘positive’ changes is almost 30 km$^2$ more than that of the ‘negative’ changes (Table B.3).
Figure B.5: Vegetation density change image for 1986-1996

Figure B.6: Vegetation density change image for 1996-2006
<table>
<thead>
<tr>
<th>Change in area (km²)</th>
<th>1986-1996</th>
<th>1996-2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dense to riverbed</td>
<td>0.07</td>
<td>0.24</td>
</tr>
<tr>
<td>Dense to bare</td>
<td>1.90</td>
<td>4.28</td>
</tr>
<tr>
<td>Dense to sparse</td>
<td>26.82</td>
<td>31.27</td>
</tr>
<tr>
<td>Moderate to riverbed</td>
<td>0.17</td>
<td>0.53</td>
</tr>
<tr>
<td>Dense to moderate</td>
<td>80.98</td>
<td>66.86</td>
</tr>
<tr>
<td>Moderate to bare</td>
<td>9.24</td>
<td>7.59</td>
</tr>
<tr>
<td>Sparse to riverbed</td>
<td>0.44</td>
<td>1.30</td>
</tr>
<tr>
<td>Moderate to sparse</td>
<td>93.52</td>
<td>63.63</td>
</tr>
<tr>
<td>Sparse to bare</td>
<td>51.95</td>
<td>29.20</td>
</tr>
<tr>
<td>Bare to riverbed</td>
<td>1.41</td>
<td>1.89</td>
</tr>
<tr>
<td><strong>Sum of -ve changes</strong></td>
<td><strong>266.49</strong></td>
<td><strong>206.79</strong></td>
</tr>
<tr>
<td>No change</td>
<td>568.53</td>
<td>525.96</td>
</tr>
<tr>
<td>Riverbed to bare</td>
<td>0.91</td>
<td>1.04</td>
</tr>
<tr>
<td>Bare to sparse</td>
<td>21.18</td>
<td>40.10</td>
</tr>
<tr>
<td>Sparse to moderate</td>
<td>45.26</td>
<td>82.75</td>
</tr>
<tr>
<td>Riverbed to sparse</td>
<td>0.55</td>
<td>0.48</td>
</tr>
<tr>
<td>Bare to moderate</td>
<td>4.17</td>
<td>10.01</td>
</tr>
<tr>
<td>Moderate to dense</td>
<td>49.91</td>
<td>68.62</td>
</tr>
<tr>
<td>Riverbed to moderate</td>
<td>0.09</td>
<td>0.11</td>
</tr>
<tr>
<td>Sparse to dense</td>
<td>10.71</td>
<td>29.71</td>
</tr>
<tr>
<td>Bare to dense</td>
<td>0.75</td>
<td>3.03</td>
</tr>
<tr>
<td>Riverbed to dense</td>
<td>0.04</td>
<td>0.04</td>
</tr>
<tr>
<td><strong>Sum of +ve changes</strong></td>
<td><strong>133.57</strong></td>
<td><strong>235.89</strong></td>
</tr>
</tbody>
</table>

Table B.3: Areas of change (km²)

In order to obtain an idea of whether there are certain areas where most positive or negative changes have occurred, kernel densities were calculated. These show the “change hotspots” (Fig.B.7-10). What is most striking about these results is that there appears to be a ‘boundary’ at the top of the lower catchment area which seems to divide the positive and negative changes (this can also be observed in Figs.B.5&6). For example, from 1986-1996, the positive changes appear to be concentrated in the lower catchment (Fig.B.7), whereas the negative changes occur mostly in the mid- and upper catchment (Fig.B.8). However, from 1996-2006 this pattern is reversed, with most positive changes occurring in the mid- and upper catchment (Fig.B.9), and the negative changes mostly occurring in the lower catchment, with the exception of the changes in the north-western tip of the catchment (Fig.B.10). Also interesting to note is that the majority of negative changes from 1986-1996 are occurring near the rivers in the mid/upper catchment (Fig.B.7), whereas many of the negative changes from 1996-2006 are also near the river, but in the delta area (Fig.B.10). From 1996-2006, however, many of the positive changes are also near the river in the mid catchment (Fig.B.9).

More analyses need to be carried out to properly explain the land cover changes discussed above. It is possible that the changes in the river areas are simply a reflection of the changes in river course, rather than due to land clearing, or it could be a combination of the two.

It is known that the Indonesians burned much of the upland areas in order to relocate the people from the mountains to low lying areas. As is discussed in more detail elsewhere in this report, by 1983 most people were resettled around towns like Maubisse, Samé, and Betano. By 1992 most of these people were allowed to return to their original settlements. The question is whether the changes that we observe in the upper and mid catchment for 1986-1996 are due to these people movements. The returning of people to their original settlements and growing their new food gardens after 1992 could account for some of the isolated patches throughout the mid and upper catchment. According to
Table B.3, the ‘moderate to sparse’ change is accountable for the largest area of ‘negative’ change, followed by ‘dense to moderate’ and ‘sparse to bare’. These are only ‘one-step’ changes (i.e. changes from one class to the next, as opposed to from one class to 3 or 4 classes above or below it), and although they must certainly not be ignored, they should be interpreted with caution, as the line between classes like ‘sparse’ and ‘moderate’ can be quite fine. The widespread clearing of vegetation could still suggest that a lot of burning and/or logging was occurring during the period of 1986-1996. Accordingly, the increase in vegetation density in the upper and mid catchment during the period from 1996-2006 could be due to the people not actively logging/burning any longer, and people only logging and clearing land for agriculture around settlements such as Samé and Betano. Maubisse does not show the extent of vegetation decrease for this period as near Samé and Betano, which may be due to changes in population. This needs to be explored further.

An interesting notion is that since the 1975 invasion, the Indonesians pushed the people living in the mountains to an area called Simpang Tiga, which is located approximately in between the “fork” of the river where the channels merge to form the main Caraulun River channel (Fig. B.12). It is likely that due to the increased population in that area and the scarcity of food, the people might have cleared the vegetation around the river to grow gardens. Even currently, people are farming right along the river west of Simpang Tiga (Pyone Myat Thu, pers. comm.). This could explain the ‘negative’ change ‘hotspots’ for 1986-1996 (Fig B.8). Then when they were allowed to return to their original settlements, these cleared patches were allowed to regenerate, possibly accounting for the ‘positive’ change ‘hotspots’ in Fig.B.9.

The Betano area has sustained both positive and negative changes in both 10 year periods. A number of events have been occurring in this region since 1975. Transmigrants from places like Java and Sulawesi, as well as East Timorese from as far west as Suai, worked in the rice paddies in this region (Pyone Myat Thu, pers. comm.), which is the main location for rice production in the catchment. By 1996 the Indonesians had completed the construction of a weir situated about 20 km south of Samé. This weir consisted of a fixed weir across the river with left and right intake structures and a distribution canal system on the east bank to irrigate the rice paddies near Betano (SMEC, 2002). The number of people present in the area cultivating rice based on the new irrigation works could account for the increase in vegetation in the area between the town of Betano and the Caraulun River. The removal of vegetation in the area for that time is likely to be mostly due to clearing for agriculture.

However, most of the transmigrants in this area left in 1999 (Pyone Myat Thu, pers. comm.), and the irrigation works were destroyed by a large flood in 2001 (SMEC, 2002). The irrigation works were repaired by 2006/2007, but with less people there to cultivate the rice paddies and other agricultural plots, and without irrigation it is no surprise that a decrease in vegetation can be observed for the period of 1996-2006 (Fig.B.10). After the destruction of the irrigation works, farmers were able to plant only one crop per year, as opposed to two crops per year before the event (SMEC, 2002).

Although the above gives some food for thought, more analyses needs to be carried out to determine exactly what has been happening in the catchment since 1986 and how this is affecting the region and its people.
Figure B.7: The positive change 'hotspots' for 1986-1996

Figure B.8: The negative change 'hotspots' for 1986-1996

Figure B.9: The positive change 'hotspots' for 1996-2006

Figure B.10: The negative change 'hotspots' for 1996-2006
2.0 River system changes

2.1 River channels

The “riverbed” and “bare” classes from the vegetation density classification were used as an aid to digitise the Caraulun river system in 1986, 1996, and 2006. The said classes were extracted from the classification, then merged and manually modified to create the river layers.

It is important to take note, however, that because Landsat TM imagery has a spatial resolution of 30x30m, it was only possible to digitise the larger (main) stream channels, and channels much less than 20 m in width were not digitised. Nonetheless, it was possible to digitise one of the channels up to almost 1000 m elevation above sea level (ASL).

Visual inspection of the digitised river layers shows that the channels in the upper catchment exhibit both widening and narrowing in different places along the channels for each year. This most likely means that both erosion of the riverbanks and deposition of sediment along the riverbanks are occurring. In certain locations, bars have developed inside the channel – on one occasion near the town of Samé, this was observed to have been the result of a debris flow from a landslide (Fig B.11) – whereas in other locations, these bars are being eroded away.

![Figure B.11: Photo of a river channel near Samé where the bar in the channel was caused by a debris flow from a landslide a few years earlier](image)

Further downstream, the widening of channels in certain areas becomes quite apparent. Narrowing of the channels also occurs at several locations, but overall there is more widening than narrowing.

The areas calculated for both river channels and coastlines reflect these observations. Table B.4 shows that the area of river channel has increased from 8.2 km$^2$ in 1986 to 11.3 km$^2$ in 2006, with notably the largest increase in area occurring from 1996 to 2006. These calculations include the river mouth at the delta front, which was eroded from 1986 to 1996, but accreted from 1996 to 2006 (Table B.5). This will be discussed further on. Care was taken to digitise approximately equal lengths of the river channels, so avoid false results in the area calculations.

The large increase in area from 1996 to 2006 can be attributed partially to the widening of river channels, but the formation of a new channel on the west bank of the river in the delta area between 1996 and 2006 also contributes to these results. Table B.4 shows that the area of the new river channel comprises approximately 0.6 km$^2$, which is 5.3% of the total river channel area for 2006.
<table>
<thead>
<tr>
<th>Year</th>
<th>Areas (km²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>River channels</td>
<td></td>
</tr>
<tr>
<td>1986</td>
<td>8.2</td>
</tr>
<tr>
<td>1996</td>
<td>8.8</td>
</tr>
<tr>
<td>2006</td>
<td>10.7</td>
</tr>
<tr>
<td>New channel</td>
<td>0.6</td>
</tr>
<tr>
<td>Coastline</td>
<td></td>
</tr>
<tr>
<td>1986</td>
<td>1.4</td>
</tr>
<tr>
<td>1996</td>
<td>1.2</td>
</tr>
<tr>
<td>2006</td>
<td>1.4</td>
</tr>
<tr>
<td>Total</td>
<td></td>
</tr>
<tr>
<td>1986</td>
<td>9.5</td>
</tr>
<tr>
<td>1996</td>
<td>10</td>
</tr>
<tr>
<td>2006</td>
<td>12.6</td>
</tr>
</tbody>
</table>

Table B.4: River channel and coastline areas for 1986, 1996, and 2006

These findings correspond well with what was said at the community meetings in Betano and Samé, that the river is becoming wider and shallower. There are a number of factors which could be contributing to these changes in the river channels. In order for the river to become shallower and wider means an increase in sediment load in the river is most likely. Sources of sediment are discussed elsewhere in this report, along with estimates of erosion rate change.

The removal of riparian vegetation is likely to be a contributing factor to the increase in sediment load in the river, considering that riparian vegetation maintains riverbank stability. The removal of riparian vegetation increases the risk of erosion of the river banks. As mentioned earlier, people in the Simpang Tiga area were clearing areas right up to the river for food gardens and still do so. The river channels in this area show marked widening in some areas especially from 1996-2006 (Fig. B.12).

The most drastic change in the river channels in the Caraulun delta area is the development of a new river channel on the west bank of the river from 1996-2006 (Fig. B.13). It is highly probable that this occurred during a flood event. If the river was already becoming wider and shallower, and the riverbank was already eroding or unstable, a large surge of water during a flood event could have broken through the bank to create a new channel.

The construction of the irrigation works may have contributed to changes in the river channels on the delta as well. The impact of the construction of the weir on the river system could be an increase in sedimentation behind the weir and/or channel erosion downstream of the weir. However, changes in the river system also occur well upstream and downstream of the weir, which suggests that the increase in sedimentation in the river and its widening is not due to the irrigation works. More research needs to be done with regards to this.
Figure B.12: The rivers in the Simpang Tiga area - this is where the channels merge to form the main Caraulun river channel
Figure B.13: River channel change in the Caraulun delta. The location of the irrigation works is approximately at the top of the map where the river flows from east to west.
2.2 Coastline and delta

The coastline as discussed here is taken to be that area from the waterline to the vegetation. The coastline was extracted from the imagery using the same methods as for the river system described above. The coastline discussed here actually extends slightly further either side of the Caraulun catchment.

Although the area of the coastline does not change much from 1986-2006, the shape of the coastline varies quite noticeably in some areas. The coastline can be seen to be retreating and accreting at various positions. Some areas show a retreat of the coastline from 1986-1996 with accretion from 1996-2006, whereas others show a retreat or accretion only. In some areas on the far western side of the catchment, the coast has retreated up to 65 m, whereas other areas closer to the river mouth have accreted by up to 45 m.

To the east of the river mouth, the beach has become much narrower in places, and a seaward shift in the vegetation-beach boundary can be observed. Just to the south-west of Betano, the vegetation-beach boundary has extended seaward by almost 100 m, with the beach-sea boundary extending seaward by approximately 25 meters only. Directly to the east of this location, the beach has almost doubled in width from 70m to 120m, as was mentioned at the community meeting at Betano.

The river mouth delta has also experienced some significant change, retreating by 234 m from 1986-1996, then accreting by 111 m from 1996-2006 (Table B.5; can also be seen in Fig.B.13). The erosion that occurred at and to the sides of the river mouth was sufficient to remove vegetation around the river mouth. Since 1996 the river mouth is widening and the beach and the vegetation-beach boundary to the side of it are moving seaward.

<table>
<thead>
<tr>
<th>Shift in river mouth boundary (meters)</th>
<th>Seaside</th>
<th>Landside</th>
</tr>
</thead>
<tbody>
<tr>
<td>1986-1996</td>
<td>-234</td>
<td>-155</td>
</tr>
<tr>
<td>1996-2006</td>
<td>111</td>
<td>36</td>
</tr>
<tr>
<td>1986-2006</td>
<td>-123</td>
<td>-119</td>
</tr>
</tbody>
</table>

Table B.5: The erosion and accretion of the Caraulun river mouth

Changes along the coastline are attributable to many factors, including wave action, tides, along shore currents, sea level, and wind force. Not enough research has been carried out at this stage to properly explain the changes discussed above. The erosion of the river mouth from 1986-1996 suggests a decrease in sediment supply by the river to the sea, while the accretion from 1996-2006 suggests an increase in sediment supply by the river to the sea. The vegetation removal that took place in the upper and mid catchment from 1986-1996 followed by the removal of vegetation in the lower catchment from 1996-2006 could account for the increase in sediment supply to the river mouth from 1996-2006. However, this is merely speculation and more analysis needs to be carried out.

3.0 Conclusions

From 1986-1996, ‘positive’ vegetation density changes were observed in the lower catchment with ‘negative’ vegetation density changes occurring in the mid and upper catchment. During the same period, river channels are seen to mostly become wider, although narrowing also occurs in some places, and the total area of river channel increased from 8.2 km² to 8.8 km². Additionally, shifts in coastline position and width are occurring during this time, with the river mouth delta actually retreating by 234m.

From 1996-2006, ‘negative’ vegetation density changes were seen in the lower catchment with ‘positive’ vegetation density changes occurring in the mid and upper catchment. An even greater
increase of 1.9 km² in river channel area is observed for this time with more channel widening and the river mouth delta accreting 111 m. More changes in the coastline are also taking place.

An explanation for these findings has been attempted above, although this study is still ongoing and it is clear that more research and analysis is required to come to proper conclusions.

References
