Surrey Energy Economics Centre

ENERGY AND THE ENVIRONMENT IN THE THIRD WORLD

Edited by
Peter Pearson

With papers by:
Dennis Anderson, Andy Brown, Michael Chadwick,
Richard Critchley, Terry Douglas, Andy Millington,
Phil O'Keefe, Ian Ryle, Theo Schilderman,
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Editors: David Hawdon, Peter Pearson and Paul Stevens
Department of Economics, University of Surrey,
Guildford, Surrey GU2 5XH

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ENERGY AND THE ENVIRONMENT IN THE THIRD WORLD: SOME QUESTIONS

Peter Pearson
Surrey Energy Economics Centre, University of Surrey

The papers printed in this Discussion Paper arose out of a meeting of the Third World Energy Policy Study Group organised (with financial support from the UK Economic and Social Research Council) in April 1989 at the Beijer Institute Centre for Resource Assessment and Management at the University of York by Michael Chadwick, Peter Pearson and Paul Stevens. The authors have considered a variety of problems for a variety of countries and from a variety of standpoints. This Introduction considers some of the questions that frequently underlie discussions about energy and the environment in the Third World.

Environmental issues, especially those related to energy, are once more on the policy agenda - and with more prominence than before. Many of the most serious impacts of environmental change occur in Third World countries. Moreover, the availability of and access to environmental resources, including energy resources, significantly affects the capacity of people in less-developed countries (LDCs) to meet their basic needs and improve the quality of their lives. These countries are also of major importance to international environmental issues. If they are to develop their economies, their energy use must rise and hence they are likely to play an increasing part in contributing to - and perhaps cooperating in the resolution of - global problems like the greenhouse effect and damage to the ozone layer.

When environmental issues originally attracted attention in the 1970s, it was in particular Third World representatives who argued that they embraced much more than problems of wildlife conservation and loss of green-and-pleasantness: poverty and its attributes - bad health and housing conditions, defective water supply and sanitation, damaged soils, and so on - are crucial aspects of the quality of a person's environment. Furthermore, there was a growing awareness that environmental quality affects people in LDCs not only only in their roles as consumers (through the experience of bad health or amenity losses, for example) but also in their roles as producers (through inability to work because of impaired health, or reduced farm or fishery output, for example). The poor, with their limited stocks of human and physical capital, are especially vulnerable to environmental degradation. More recently, the greenhouse effect - with its threatened impacts on agricultural and other types of production - has brought home to the developed countries that energy-related environmental impacts can also have major effects on them as producers.

Much of the concern in the 1970s focussed on the depletion of non-renewable resources and, stimulated by the 1973-74 oil price shock, particularly on the availability and price of petroleum. By the early 1980s, however, the focus had begun to shift to a different aspect of resource depletion, the degradation - through exploitation beyond sustainability - of potentially renewable resources of biomass, soil and water. The impacts of this kind of resource degradation clearly threaten many of the LDCs. Thus it has become increasingly evident that the ability of people to earn and enjoy their living in the future may depend on the nature and extent of the depreciation of the capital stock of natural resources, both renewable and non-renewable.

Concern with the impacts of environmental change for production has, therefore, altered the terms in which we think about the relationships between economic development and environmental issues. In particular, it has focussed attention on the question of whether and in what circumstances economic growth paths are compatible with the pursuit of environmental quality. In examining this question, policy-makers in both developed countries and LDCs have begun to be concerned with understanding and formulating concepts of 'sustainable development' and with finding ways of translating them into action. Moreover, the greenhouse effect and the problems with the ozone layer have demonstrated that sustainability has global as well as national dimensions.

When we analyse these broad issues of energy and environment in the context of the Third World, a number of specific questions arise. The first question is:

(1) To what extent and why are the energy-environment problems of the LDCs different from those of the developed countries?

Economic, Demographic and Social Differences

Any attempt to answer this would, of course, need to begin by considering the principal economic, demographic and social differences between LDCs and developed countries - including the dualistic nature of LDC economies, their rapidly-growing, largely rural but increasingly urbanising populations, their low per capita incomes, relatively low levels of industrialisation and mechanisation, and their limited ability to afford imported energy. These factors are closely related to differences in the energy situations.

Energy Situation Differences

Here one of the major differences lies in the fact that while developed countries rely essentially only on the commercial fuels (petroleum, coal, electricity), in LDCs the use of traditional - often also non-commercial - fuels (fuelwood, charcoal, animal dung and crop residues) is widespread, especially but not exclusively in rural areas. In this sense the energy-environment policy problems of LDCs can be said to be much more complex than those of developed countries, since LDCs have to deal with the very different problems associated with both types of fuel.

Patterns of commercial energy use tend to be different between LDCs and more affluent countries. They also depend on the availability of indigenous supplies of petroleum, coal and hydro-electricity.

For traditional fuels there is the whole range of well-known, complex and sometimes controversial problems associated with biomass fuel use. Thus, for example, in situations where wood use (usually not just or even mainly for fuel) persistently exceeds sustainable yields, local deforestion occurs. This then interacts with processes of desertification, soil erosion, sedimentation of watercourses and reservoirs and flooding. In addition, when woodfuel is scarce, people who have been forced down the 'ladder of fuel preference' towards animal dung and crop residues, may convert the conditioners of tomorrow's soil into today's inferior fuels. The consequences of these various processes include potential damage to human and degradable natural resources and lower levels of living.

Assessing the Scale of Energy Resources and Potential Problems

Any attempt to assess actual and potential energy-environment problems, whether in LDCs or developed countries, requires sound, comprehensive information on energy demand, supply and resources. Carrying out any of these tasks in LDCs tends to be much less straightforward than in developed countries, particularly but not exclusively because of the major problems associated with assessing the traditional fuel situation. However, recently there have been real improvements in the quality and quantity of data available on the demand side, particularly from surveys. On the side of supply and resources, the very promising development of techniques of remote-sensing via satellites has made it possible to develop more and better data on biomass resources and their degradation.

We have seen that both LDCs and developed countries experience energy-environment problems associated with commercial fuels, although they are exploiting the fuels in very different situations. However, key differences arise because of the role of traditional fuels in LDCs. The next two questions are interrelated:

(2) Should we expect the environmental policy targets of LDCs be the same as those of developed countries?

(3) Should we expect the same mix of policy instruments to achieve environmental policy targets?

The first point here is that, given the striking heterogeneity of LDCs, we should not expect either the targets or the mix of policy instruments to be the same between different LDCs, let alone between LDCs and developed countries.

The second point is that the differences between both the socio-economic and energy situations of the LDCs and the developed countries would lead us to expect some differences in environmental quality targets. Moreover, socio-economic, energy situation and institutional differences would imply varying mixes of policy instruments.

In terms of socio-economic differences, the question has long been posed as to whether high levels of environmental quality should be the aim only of richer countries. Put another way, is environmental quality a luxury (with an income elasticity greater than one). If so, then the demand for environmental quality rises rapidly with income and perhaps poorer countries should postpone their 'consumption' of it. However, this argument puts all the emphasis on environmental controls for consumption purposes and then mistakenly assumes that all such consumption is a luxury. Moreover, the argument ignores the impact of environmental control on productive capacities. I have argued earlier that especially if people have few assets, their ability to use and have continued access to well-maintained natural resources (land,water, air, forests, and so on) may be necessary for their survival. Thus environmental control may be essential for the basic needs of the poorer groups in the population.

Thus whether or not particular environmental quality targets should have high priority is partly an empirical question, depending both on the nature of the problems experienced and on which sections of the population are experiencing them - both now and in the future. Consequently some types of environmental control are likely to be postponable luxuries for LDCs, while others will be necessities.

On the question of the mix of policy instruments, even if the quality targets were the same, we would not expect different countries necessarily to use the same mix of policy instruments to achieve them. This is not least because of the institutional differences that exist between countries. For example there are differences in both political and legal systems and in the available or adoptable methods of implementing environmental controls. On economic grounds alone, the consequent variations in the transaction costs of information, negotiation and enforcement would suggest different mixes of policy instruments in different countries. These differences would be expected to be particularly significant between LDCs and developed countries. A further point: because of the high degree of spatial variation often observed within LDCs, the setting and implementation of energy-environmental quality targets needs to be sensitive to local conditions.

The global or transnational nature of a number of energy-environment problems, including the greenhouse effect, damage to the ozone layer and the problems of acid rain (this can also include problems such as sedimentation of watercourses and flooding), means that international cooperation is necessary if they are to be controlled. This leads to three further key questions:

(4) How serious are the energy-related environmental problems and what level(s) of control should be set?

(5) How far is it in the interests of the LDCs to cooperate with the developed countries (and possibly to observe their environmental quality targets and priorities)? To what extent is there a commonality of interests?

(6) How can appropriate and workable mechanisms of international environmental cooperation be developed?

On the fourth question, the greenhouse effect illustrates the extreme difficulties that can arise: there is much scientific debate and uncertainty, particularly about the interactions between the various physical and climatic processes involved; the impacts of climatic change are complex, hard to predict and likely to be uneven in their spatial distribution; and the economic valuation of the likely societal costs and benefits of control will be particularly problematic and speculative.

On the fifth question, as LDC delegates to conferences on the ozone layer have not been slow to point out, the issue of equity in international environmental policy-making cannot be sidestepped. And when the idea of a 'carbon tax' to limit coal use and control the greenhouse effect is discussed, the LDCs understandably question why in equity they should pay high prices now for their use of the atmosphere (or accept equivalent physical limits on coal use) because the industrialised countries in the past added so rapidly (and without charge) to the stock of carbon dioxide while their economies were maturing. For the LDCs restraints on their coal consumption could seriously constrain their economic development, for example. Thus the LDCs are likely to cooperate with the industrialised world only at a price - if they are, in various ways, subsidised or otherwise compensated, whether financially or through the transfer of technology.

This leads on to the sixth and final question about developing workable mechanisms for international environmental cooperation. The suitability for this task of the existing institutions for international financial cooperation has been widely queried. A number of alternative schemes has already been mooted, but it is clear that developing appropriate institutions will be far from easy.

The issues I have raised above are evidently complex and controversial, and can be tackled both theoretically and empirically in a variety of ways. This Introduction has aimed simply to outline some of the broad energy-environment questions to which the research reported in this collection of papers relates.

ENVIRONMENTAL MAINTENANCE AND INVESTMENT

Dennis Anderson, Shell International Petroleum Co.

How might economic output be affected by environmental concerns in the coming decades? And what are the implications for the Third World economies, whose per capita demands for commercial energy and industrial products are still less than one tenth of those of the industrial countries while their populations will soon be ten times larger? The answers to these questions will depend on societies' policies towards economic growth and the environment, in particular on the allocation of resources between:

- o Consumption,
- o Investment, and
- o The maintenance of the environment.

The purpose of this note is to summarise current issues in environmental policy. These issues arise at two levels:

- o At the national level - namely the policies required to address local emission problems, damage to soil and ground water resources, microclimatic change and the like.
- o At the international level - first to provide support to the developing countries in addressing local environmental issues, and second, increasingly, to obtain their participation in programmes to address the emerging international problems of global warming, losses of bio-diversity, acid deposition and ozone depletion.

It is fair to say that much more attention has been given to the former than to the latter. It will be argued that capital finance is much less suited to dealing with LDC environmental problems than financial transfers based on the principles of public finance and environmental policy.

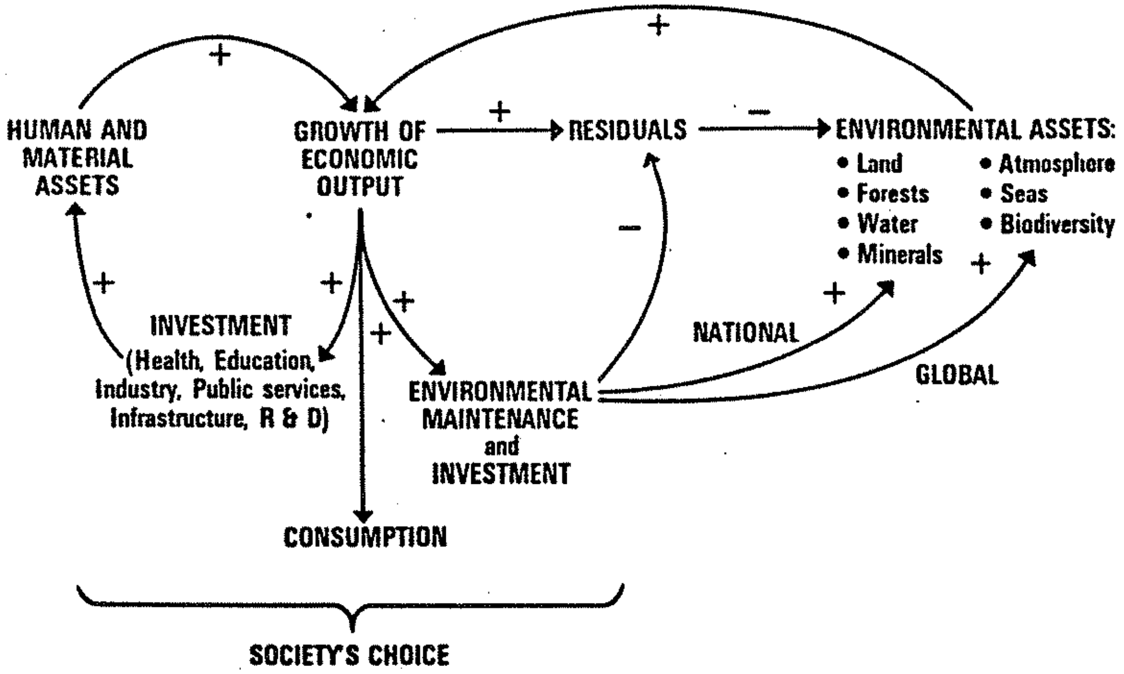
1. LINKS BETWEEN ECONOMIC GROWTH AND THE ENVIRONMENT

Perceptions on the options open to societies have changed fundamentally in recent years. In particular, the Club of Rome assumption that economic growth must unavoidably be accompanied by an ever increasing spiral of environmental damage has been shown to be false. It is now widely considered that, with a proper allocation of resources to environmental maintenance, it is possible for growth to be sustained - and in some cases increased - over the long run. Economic growth prospects self-evidently depend on the maintenance of environmental resources - safe water supplies, fertile soils, good forest reserves, an unpolluted atmosphere, and so forth. In other words, environmentally sound policies (like good health and safety policies) are economically beneficial policies as well.

The new view, with the emphasis on a proper allocation of resources between consumption, investment and the environment is illustrated in the Figure.

FIGURE

LINKAGES BETWEEN THE ENVIRONMENT AND ECONOMIC GROWTH



2. ENVIRONMENTAL POLICY

In this framework for thinking about the environment, the main issue facing today's societies relates to the nature and design of environmental policies - in particular to the sorts of policies that will lead to a proper and efficient allocation of resources going to environmental maintenance. Societies have many instruments to draw upon - or at least the open societies have. They include the instruments of law and legal liability; the 'voluntary' approach of direct negotiation between parties without recourse to government intervention, though underpinned by legally-binding agreements; the use of taxes on emissions to promote conservation; and grant aid, subsidies or tax relief on R and D and investment in environmentally more benign consumer products and methods of production. Examples are provided in the Table.

One of the instruments of policy listed in the Table is the transfer of property rights to communities or private individuals or concerns to manage the hitherto common resource. Such transfers are most effective in matters concerning the maintenance of land and forestry resources. Although there are many kinds of environmental problems that cannot be dealt with in this way, there are two aspects of the property rights 'solution' that are worth discussing further, since they are relevant for these other problems.

TABLE

ENVIRONMENTAL POLICY INSTRUMENTS

INSTRUMENT	APPLICATIONS (examples)
Economic Instruments	
Taxes (polluter pays principle)	☐ Greenhouse Gases ☐ Acid Deposition
Subsidy/Tax relief	☐ Energy conserving investments ☐ Energy research (private) ☐ Unleaded fuels; catalytic converters
Direct public investment	☐ Afforestation programmes ☐ Energy research (private)
Grant aid	☐ LDC afforestation, soil conservation, agrarian reform and land settlement programmes ☐ Regional programmes in industrial countries
Law	
Public regulation; Law; legal liability	☐ CFCs ☐ Toxic wastes ☐ Community property rights ☐ Unleaded fuels; catalytic converters
Negotiation	☐ Localised issues: Emissions; wastes; compliance with local land use and building codes
Values	
Self-regulation	☐ 'Green' consumers and producers
Positive Side-effects of Policy	
Economic policies with environmental benefits	☐ Urban congestion charges ☐ Forestry Policy (LDCs) ☐ Agrarian reform (LDCs)

2.1 The Commons Problem and External Costs

A widespread cause of external costs is what is called the 'commons problem' - that is to say, free and unrestricted access to common lands, rivers and forests, to the oceans, and to the atmosphere as a repository for the residuals of consumer and producer activities. The basic problem is that such access provides both an incentive for over-use of the common resource and, equally important, no means of generating the revenues required for its maintenance. Hence the long-observed tendency of the productivity of the resource to decline in these circumstances.

With respect to common lands, rivers and forests, there are numerous arrangements that societies, both modern and traditional, have developed in attempts to cope with the problem, ranging from the transference of the property to private ownership, though with varying laws and regulations on its use, to various forms of community and public ownership. In the case of private ownership, the revenues required for the maintenance of the property may arise from rents or from the returns to its use in production while the marketable price of the property provides the incentive against over-exploitation. In the case of community or public ownership over-exploitation may be avoided by regulations, law and customs, with levies on use or public revenues providing for maintenance.

Whatever arrangement is followed however, there are two key elements common to those cases where the environmental problem has been successfully addressed:

- First, some form of regulation with respect to access and use has been provided, whether by the market, law, custom or other;
- Second, there has been some mechanism introduced - market, levy, or other - to raise finance for maintenance.

These elements are worth noting since they are required aspects of environmental policies in those cases that cannot be addressed by the allocation of property rights to individuals or communities, as for example with atmospheric pollution or the protection of surface and ground water resources. (Until modern times, the same issue extended to the seas, though it has begun to be addressed through the Laws of the Seas and the Seabed.)

2.2 External Costs and Policy

About half of the policy proposals listed in the Table are aimed at introducing some form of tax or charge that would reflect the external costs of use of the environment. This is the 'polluter pays' principle. The basic idea is to provide incentives to producers and consumers both for conservation and for the development of alternative technologies or products that would reduce external costs and bring about a more acceptable arrangement to all parties. The idea is also (this is important) to make the development of alternative technologies or products profitable where they can be introduced at costs lower than those of existing ones (including the external costs of the latter). Environmentally more benign products or methods of production, such as gas for electricity generation, would be favoured under the approach (i.e. exempted from the taxes) while more polluting products or methods would not. Economists have long preferred the idea of dealing with environmental costs through the device of pollution charges on the grounds that it 'internalises' environmental decision making in the price system and allows producers and consumers greater flexibility. It may also reduce the costs of the bureaucratic harassment frequently associated with regulation. At the same time, it is only one of several approaches followed in practice, and not always the best.

First, when the assets affected are health and life, the main priority is to define suitable safeguards and regulations, allowable emission levels, and so forth. If the regulations are rigorously applied and upheld by the principles of law and legal liability, the effect is to bid up prices to the costs of finding products and processes that comply with them. Hence the two requirements noted earlier - regulation of demand, and a mechanism for generating revenues - can still be met profitably without tax incentives, while safeguards are defined (in these cases more appropriately) in physical terms.

Second, more often than not, pollution charges take the form of a tax. While this may serve to raise revenues for the 'use' of the environment, and sometimes lead to quite profound adjustments in producer and consumer activities, the role of the public authorities in the allocation of resources to environmental maintenance - as intermediators between the demand and the supply sides of environmental services, so to speak - has not always been a happy one. For some issues (particularly if the issue is a local one) an environmental policy is often best arrived at by negotiation between the interested parties, without interventions in the form of pollution taxes.

Third, the financial risks and long lead times associated with addressing some environmental problems may call for some forms of tax relief or public backing for (say) R and D programmes.

Fourth, there is the question of whose property is being polluted. The answer is clear when we are dealing with private and public lands in industrial countries, but less clear in many developing areas, where private and public property rights (e.g. the Brazilian forests) are still ill-defined. Transnational problems are also common here, as with British power stations and the Scandinavian forests.

The diversity of situations and issues helps to explain the wide range of policies commonly proposed to address the problem of external costs. Some options apply better in some situations than in others; analyses of the specific issue and context will generally make the preferred option clearer. Unfortunately, there have been instances when one option or another have been promoted as panaceas: the 'polluter pays' principle, property rights, and, more recently, tradeable permits have often been promoted to the exclusion of others. If there is a guiding principle to follow it is that underlying a good policy will be an analysis of its resource requirements, its benefits, its practicability and its acceptability.

2.3 Private Investment, Profitability and Environmental Policy

In modern, open societies all market systems operate within a regulatory framework established by law and government and the values of their citizens. This framework includes the setting of legal standards, regulations and safeguards, enforced by legal liability; voluntary negotiations by producers, communities and individuals on safeguards, standards and matters of compensation; the abilities of governments to tax, subsidise or provide grant aid; and the influence of the various public and private bodies on values and moral restraint in matters of production and consumption. Few economic activities and products are left untouched by these instruments of social policy - in foods, manufactures, transport and public and private services - and consumers and businesses alike are fully adapted to working with them, and indeed, in open societies, often influence them to good purpose. Provisions and safeguards with respect to environmental assets and services are an extension of the same framework.

But as in all other aspects of law and public policy as they relate to business, the market response is successfully achieved only under two conditions:

- **Compliance**

  A policy must-needs apply equally to all. Otherwise 'the bad drive out the good' or at least the profit margins of companies that do not comply with the policies rise at the expense of companies that do.

- **Consistency**

  A policy must not only be internally consistent, such that, for instance, price controls and tax incentives are not at odds with regulations on emissions, but also be reasonably consistent and stable over time, and with what is achievable technologically.

Finding a regulatory framework which meets these conditions will not be easy in practice. But if it is difficult to establish within countries, the problems increase by an order of magnitude when we turn to issues of compliance at the international level.

2.4 Global Commons and Transnational Problems

The instruments of policy for addressing the problem of external costs at the national level - negotiation, law, community and public regulation, voluntary restraint and self-regulation, subsidy and various guises of the 'polluter pays' principle - carry over in theory to the international level. However, to state the options this way is immediately to reveal their limitations. The mechanisms for establishing standards, agreements, laws, compliance with the laws, and for effecting financial transfers for environmental maintenance are appreciably weaker (and far more disputed) at the international level.

The issue is difficult enough among the industrial countries alone, as can be seen in the disputes over acid deposition in Europe and North America. But it pales by comparison with that of obtaining the participation of the LDCs in matters of global concern.

First, within many LDCs, the institutional arrangements for good environmental maintenance policies are not in place - nor were they, it should be added, in the industrialised countries at much more advanced stages of their urban-industrial development. Recently, there has been much emphasis on economic policy reform in the LDCs, including in this, environmental policy reform. However, it is clear from the range of problems to be addressed, environmental policy goes well beyond economic policy, and the weaknesses of institutions, laws and administration in many LDCs are bound to impede the implementation of environmental policy, whether the issue is local or global. The fate of the rainforests illustrates the dilemma perfectly.

Second, the low levels of per capita incomes in LDCs relative to those of the industrial countries raises unavoidable questions of fairness in environmental policy at the international level - as the LDCs have been quick to point out.

It is possible that the LDCs may be drawn into co-operating with the industrial countries on matters of global environmental concern only if they are subsidised to do so. The issue of financial support has already been raised by the LDCs (led by China) in connection with CFCs, and by the Brazilians in connection with rainforests. The point that subsidies to agriculture in Europe, Japan and the US cost these economies US$75 billion per year, more than twice the level of official development assistance, has not been lost in the discussions. It is possible that environmental issues will lead to a major restructuring of aid finance in the coming decade:

- Official aid is based on the principles of capital finance, with maturity structures, typically ten to 15 years. With respect to issues of global warming, ozone depletion and deforestation, the environmental benefits of a policy are unlikely to occur until well after the loans have matured.
- The environmental benefits accrue to the global community, not solely to the borrowing party.

For both reasons, the principles of aid may have to be reworked on the principles of public finance and environmental policy rather than those of capital finance. Whether this will occur or not is of course an open question.

Note: The responsibility for the views expressed in the paper is that of the author.

SOCIO-ECONOMIC AND ENVIRONMENTAL CONSTRAINTS ON COAL DEMAND IN DEVELOPING COUNTRIES

M J Chadwick
Beijer Institute Centre for Resource Assessment and Management,
University of York.

1. INTRODUCTION

The world has massive stocks of coal that dwarf the remnants of oil, gas and uranium deposits. Of over 10,000 x 10^9 tonnes of total deposits, 1,500 x 10^9 are economically recoverable. Developing countries have a significant proportion of these stocks as shown in Table 1.

TABLE 1 COAL RESERVES IN DEVELOPING COUNTRIES

	10^6 Tonnes
Afghanistan	10
Argentina	224
Botswana	7,000
Brazil	1,000
Chile	5,000
Colombia	2,500
India	19,500
Indonesia	3,000
Iran	200
South Korea	386
Malawi	800
Mexico	1,000
Morocco	40
Mozambique	200
Nigeria	300
Pakistan	227
Peru	105
Swaziland	186
Tanzania	335
Turkey	3,000
Venezuela	1,600
Zambia	130
Zimbabwe	2,200

Coal has much to recommend it to developing countries as a fuel: its wide geographical distribution; a well-tried technological base; its competitive price structure and the availability of promising new combustion technologies (smaller- and larger-scale) that allow increased combustion efficiency and minimize sulphur and nitrogen emissions.

A number of factors have, however, prevented developing countries from taking advantage of coal as an alternative fuel:

i) difficulties in restructuring energy consumption patterns;
ii) supply bottlenecks;
iii) transportation difficulties;
iv) experiences in cost and revenue sharing schemes in operation with multinationals;
v) lack of international marketing expertise.

To these can now be added the increasing reputation that coal means environmental degradation - acid rain, global warming, toxic metals - and hazards to health. Coal seems ready to become locked into the 'Chinese refrigerator syndrome'. But it may be that coal, and related fuels, provide the only possible means of sound economic development and energy sufficiency in many Third World countries. Sympathetic technical aid and assistance are required to demonstrate the acceptability of the new technological developments.

These areas of concern need to be addressed in relation to socio-economic and environmental constraints on coal demand in developing countries: one relates to industrialized countries, one to the developing countries themselves and the third links the two.

2. DEVELOPED, INDUSTRIALIZED COUNTRIES

Since the beginning of the rapid increase in oil prices in 1973-74 there have been many predictions (WOCOL, IIASA, Harvard Business School, World Bank) of an increase in coal use as a fuel substituting for oil. Various scenarios envisaged an increase in absolute amounts and also in proportional terms. Coal has long-term well-established reserve features; a well-developed technological base; a wide potential for use as gas, liquid fuel, heat provision and electricity generation. Certain scenarios have envisaged large increases in coal use in developed countries; others have been more circumspect and perhaps realistic. However, whatever turns out to be the exact size of the increased demand, two things seem fairly certain:

i) certain developing countries will increase their coal use considerably;
ii) much of the coal demand in Western Europe will be satisfied by coal supplied from developing countries.

3. DEVELOPING COUNTRIES

Even though the resource data for coal in developing countries is incomplete, 50 developing countries have known coal resources of which at least 19 have recoverable coal reserves.

Increased production for export and foreign currency earnings is attractive to these. So is production for home consumption, with a consequent easing of hard currency problems. Imported coal for many developing countries works out at the equivalent of less than US$20 per barrel of oil and home produced coal at the equivalent of US$6-25 per barrel. There should be therefore a high degree of substitutability of coal for oil, especially for thermo-electric generation.

Electricity can be produced from coal-fired power plants at 35 per cent less than from oil-fired - even with environmental protection devices installed, and working in terms of the first 20 years of operation. The economic benefits are compelling and yet response to oil scarcity in developing countries has been: (i) cut back on oil (and total commercial energy) use; (ii) use energy more efficiently; (iii) only thirdly use another fuel like coal to replace oil.

4. LINKAGES

There are links between the situation in western industrialized countries and Third World countries. These must take account of: the developed nations of the West are almost entirely and directly integrated into the capitalist world commercial system. Only a small part remains underdeveloped. Developing nations are only marginally incorporated into the system mainly through export enterprises sending raw materials (including coal) to developed countries to contribute to higher living standard there. Involvement in the capitalist world commercial system does not lead to, as predicted by orthodox western economic theory, a multiplier effect in the developing country and an improvement of the country's economic base; on the contrary, profit taking, interest payments, high salaries of expatriate managers and technologists, migrant labour and other features result in a flow of money to developed countries. In addition, almost all manufactured goods have to be imported, investible surpluses are shipped out by the country and little is left for investment in the manufacturing and agricultural sectors to meet the needs of the indigenous population. The economy is shaped to be externally dependent on the sale of raw materials, the importation of manufactured goods, expertise and capital supplied by foreign firms; these largely control production and trade and siphon off the surpluses produced. Anyone who doubts the truth of this analysis need only spend a few days on the cocktail circuit in a developing country. The last time I was in a developing country, at a government reception, a Canadian businessman confided in me that he was in the country to buy a mine, any mine, as this represented the best way to ship out money accumulating from another enterprise but blocked by government exchange regulations. Therefore, although economic considerations are compelling to produce a high degree of oil substitution by coal in developing countries, constraints like lack of investment, lack of, or cost of supplying infrastructure including coal handling and transport deficiencies, lack of engineering and management skills, fear of pollution and costs of abatement, mean developing countries are largely still locked into the coal export syndrome, responding to many of the constraints by relying on foreign multinational investment, foreign technical and management skills and a disregard for the environmental, human health and social problems.

5. CONCLUSIONS

All these factors need to be taken into account in addressing the problems of coal development. The lack of 'critical mass' of professionals from individual countries might be tackled by a 'network approach' for bringing together indigenous expertise from groups of countries. Problem recognition and the capability of solution of the problems could then be enhanced.

Any economic analysis needs to start with a general economic analysis of the country, particularly in relation to the stated objectives and development plans of the country. It is against this background that the energy supply and demand features of the country and the forecasts and plans must be seen.

In relation to coal specifically, developments in provision, use and export expectations have to be assessed. The provision of investment capital, through international loans, and co-operation with multinational corporations is a usual option and particular attention must be paid to the contractual agreements that are to be entered into.

Social factors can be extremely sensitive issues and environmental impacts, including occupational and public health effects, as well as conflicts of land and water use, are complicated. Analysis in advance of commitment to development is best carried out in the framework of a project development cycle. All issues arising in the fuel cycle need to be addressed.

ENERGY IN ZIMBABWE

Colin Stoneman and John Suckling
Centre for South African Studies, University of York

1. BASIC FACTS

Resources

Zimbabwe has no domestic oil or gas resources but has huge deposits of coal, substantial natural and plantation woodland, and abundant hydro-electric potential, all of which are already major contributors to energy supply. The climate makes it one of the countries in which solar energy has significant potential, and a number of companies are active in this field. Government policy is for effective national self-sufficiency, and the recent expansion of thermal power generation has taken place in preference to the cheaper option of joint development of Mozambique's Cabora Bassa hydro-electric potential or continued purchases from Zambia.

Coal has long been mined at Hwange (Wankie) as a fuel for railways, industry and domestic use, for conversion to coke (primarily for the iron and steel industry) and for municipal power stations; it has recently become the centre of major thermal electricity generation at Hwange itself. Estimated coal reserves are 2,200 mn tonnes with total resources of 30,000 mn tonnes in some twenty-three fields, but the 5 mn tonnes of annual production is entirely from the Hwange coalfield, although plans are advanced to open a new coalfield at Sengwa, south of Lake Kariba.

Hydro-electric resources have further considerable potential; in addition to over 600 mw installed capacity at Kariba, the proposed south-bank extension could add another 300 mw, and if the Batoka Gorge (50 km downstream of the Victoria Falls) scheme goes ahead, 16-1800 mw would be added.

Wood resources are to be found throughout the roughly two-thirds of the country that is indigenous forest and grazing land. Total stocks were estimated at 655 mn tons in 1987[1], with consumption at 9.5 mn tons; however supply from sustainable yields was only 6.8 mn tons (and falling), so that the remaining consumption represented irreversible depletion of resources; by 1997 a serious supply shortage is envisaged. This increasing shortage of wood for rural domestic use, and the consequent deforestation, should be seen in the context of the fact that only just over 40 per cent of the 25 mn hectares concerned is in communal areas, where about two thirds of the people live; considerably more (54 per cent) are in the commercial sector.

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[1] Beijer No.11, p.165

Usage

Electricity

The Kariba Dam and Lake were constructed during the federal period to provide hydro-electricity to Zambia and Zimbabwe, and resulted in abundant cheap electricity for many years. Total installed generating capacity was 1,539 mw in 1984, of which thermal accounted for 906 mw and hydro-electric was 633 mw; another 440 mw opened at Hwange during 1986/7. Consumption in 1987 was 8,714 gwh, of which 60 per cent was thermal in origin, 30 per cent hydro-electric, 10 per cent imported (being phased out). Hydro-electricity accounted for about 11 per cent of total energy consumed, while coal (much of it used for further electricity generation) accounted for 20 per cent in 1982.

About 20 per cent of total electricity demand is made by just two concerns: Zimalloys in its ferrochrome plant and Sable Chemical Industries in water electrolysis as a source of hydrogen for the production of ammonia (a route that only makes sense when, as in the 1960s, the cost of marginal electricity is close to zero). Railway electrification has stalled after completion of the Harare to Gweru section. Rural development plans envisage extensive electrification via growth points, with a first phase (involving 24 projects) about half completed in early 1986.

Wood

The primary energy source for most of the population, supplying 59 per cent of national energy needs in 1982, is wood: of this 47 per cent was fuel wood, 12 per cent commercial wood. Denudation of indigenous forest is a serious problem, and the World Bank has studied a Z$12.5 million tree planting scheme. However the concentration of development is on electricity supplies (unlikely to provide a realistic alternative to wood for some time to come), and it is estimated that per caput investment for non-wood sources is Z$75 per year compared with 17 cents for wood. It has been suggested that the most cost-effective approach would be to develop community-based schemes exploiting versatile bushes such as Euphorbia that can simultaneously supply fuel, fodder and fencing material.

Sugar cane is grown in the Low Veld, mainly for consumption and export, but a proportion is converted to ethanol and the standard petrol in Zimbabwe is 'blend' which is about 15 per cent ethanol, with 20 per cent projected.

Oil

Imports of oil (entirely in the form of refined products) are used mainly for transport and lubrication. Liquid fuels provided 11 per cent of energy consumption in 1982. A pipeline from Beira in Mozambique (controlled by Lonrho) leading to a refinery near Mutare was opened just before UDI, and then remained inoperative until 1982, since when it is guarded as part of the Beira Corridor (the refinery was never reopened). The pipeline is currently being extended to Harare.

2. ENERGY POLICY

Electricity

The expansion of thermal power generation represented the fruits of the immediate post-independence decision to go for energy self-sufficiency, something not even achieved by Rhodesia under sanctions. The decision appears to have been influenced by the World Bank and Western advisers; the Anglo-American Corporation of South Africa (AAC), with its equity stake and management contract in the Wankie Colliery found its position strengthened; the option to purchase surplus electricity from the Cabora Bassa Dam in Mozambique was not even investigated; and the decision was taken to phase out electricity purchases from Zambia as new units of thermal electric power became available at Hwange. In 1987 Zambia started legal action after Zimbabwe stopped purchases ahead of the agreed schedule. Previously Zimbabwe had imported about 30 per cent of its electricity from Zambia.

Coal

Aside from its central role in electricity generation, coal is repeatedly suggested in Zimbabwe as a feedstock for a chemical industry and the production of liquid or gaseous fuels. The exploitation of the Sengwa coal field which is just commencing is on the basis of its lower sulphur content; initially it will be used to produce coke, but there are proposals for gasification to provide the basis for ammonia production, and possibly methanol or other liquid fuels.

Oil

The prospects of Zimbabwe becoming an oil producer are said to be becoming brighter, with one expert talking of a 'high likelihood' of exploitable reserves being found in the Zambezi Valley; oil and 'wet gas' prospects in several areas of the Zambezi valley were identified as 'hopeful' in a 1982 West German aerial survey and the West German Government is funding a follow-up survey at a cost of US$1 mn.

It was announced early this year that Mobile Exploration may begin a three year US$15 mn search for oil in the Zambezi Valley, where it believes there is a 5 to 10 per cent chance of finding commercial deposits. The first phase will involve only aerial surveys, but environmentalists are already mobilising against the impact of a possible second phase involving seismic surveys and a technique called 'vibriosis' which involves cutting a grid pattern of roads through the forest at 15 km intervals, totalling 1,250 km, at considerable environmental risk. They maintain that the Luangwa Valley (the other side of the Zambezi in Zambia) has suffered lasting detrimental effects from a programme a few years ago.

ENERGY POLICY IN AN ENERGY RICH BUT FOREIGN EXCHANGE POOR ECONOMY: ZAMBIA IN THE 1980s

Zambia with a 1987 population of 78.56 million and per capita income that has declined from K511 in 1981 to K353 in 1987 exemplifies the paradox of a relatively energy rich but foreign exchange constrained poor country. Foreign exchange earnings are dominated by copper exports in a situation where the trend in copper prices has been downward since the early 1970s against the backdrop of a declining ore body. Some two-thirds of direct and indirect mining costs are themselves imported so for each 1 kwacha of copper exports approximately 66 ngwee is used up in imports. Thus the foreign exchange available net of the needs of the copper industry has been declining. The real value of this foreign exchange to the economy has been further reduced by a fall in the terms of trade of which the fall in copper prices is part and by the costs of servicing Zambia's foreign debt now standing at $5 billion (1987). The negative factors outlined here are compounded by bureaucratic inertia within the administrative machine which has resulted in decisions not being made, being made but not implemented, and a lack of political will that is necessary to make the admittedly hard decisions needed to gain control of the situation.

Zambia's indigenous energy resources are hydropower, coal and woodfuels. Hydropower is supplied from the jointly owned (with Zimbabwe) Kariba complex on the Zambezi river and the Kafue and Victoria Fall's hydro stations within Zambia. Coal is mined at the Maamba colliery for consumption by the copper mining industry. Charcoal and wood are used primarily for domestic consumption in the urban and rural areas respectively. Oil and coke are imported. Table 1 shows the 1981 sources of energy, Table 2 the sectoral pattern of energy consumption.

TABLE 1 ENERGY DEMAND BY SOURCE 1981

Source	'000 TOE	%
Imports		
Petroleum	748	16.5
Coke	60	1.3
Sub Total	808	17.8
Indigenous		
Hydropower	1,365	30.4
Coal	274	6.1
Bagasse	48	1.1
Woodfuel: Charcoal and Firewood	2,000	44.6
Total	4,495	100.0

TABLE 2 SECTORAL PATTERN OF ENERGY CONSUMPTION (1980/81 - PER CENT)

Sector	Petroleum	Coke	Coal	Electricity	Woodfuel	Bagasse
Mining	37	100	52	74	6	-
Industry	18	-	48	18	-	100
Transport	35	-	-	-	-	-
Agriculture	1	-	-	na	-	-
Others (including households)	9	-	-	8	94	-
Total	100	100	100	100	100	100

Zambia's energy problems are dominated by the forex situation. The lack of forex from export earnings and the significant sums needed to import oil suggest an energy policy to improve mining sector utilisation of domestic energy sources on the one hand and to reduce imports of (particularly) oil on the other. The root cause lies as much however in inadequate planning, a lack of skilled manpower and management expertise and ineffective energy policy.

The end result is a series of problems over the whole energy sector: oil refining, coal mining and its transport by rail, the whole energy pricing setup, power distribution and lastly conservation. As detailed below each of these proposals has foreign exchange implications which are not likely to be met given the present acute shortage of export proceeds. Given Zambia's level of indebtedness and her inability to service her present debt it seems unlikely that she will be able to borrow for projects even where the rate of return in actual foreign exchange savings and as measured by the payback period may be as little as 2 to 3 years.

Detailed Proposals are as Follows:

Oil: Crude oil is at present imported by pipeline from Dar es Salaam to the Ideni refinery at Ndola. The main problem here is that the refinery was designed to produce the various oil fractions in fixed proportions for a market larger than at present being serviced. As a result per barrel refining costs are high and overproduction of fuel oil has forced the government to insist on its use by the mining industry. Even though subsidised the fuel oil price is still above that of alternative energy sources available to the mining industry. Kerosene is also subsidised to protect urban household consumers. The overall result is that the price of other fuels have been increased so the refinery as a whole does not run at a loss, giving rise to serious distortions in the price structure. Solutions are to increase the spiking level in the refinery to allow greater variability of product, but this requires a higher throughput which is unlikely; close down the refinery and import refined products through the pipeline; upgrade and modify the refinery to allow variation in its output mix. The direct and indirect costs of these proposals are (a) zero, (b) $56 million, (c) $80-120 million. The last option for instance could save some $40 million of foreign exchange per year.

Electricity: the major problems here relate to the inability of ZESCO to maintain the supply system - lack of spares (forex again), shortages of experienced staff and a shortage of funds. A too low tariff structure, and uncollected bills means that ZESCO is effectively selling power at 40 per cent below its operating costs.

Coal: the single coal mine is operating at only 50 per cent of capacity. As with the other sectors the same problems pitch up again - lack of maintenance (forex), lack of management skills, etc. Investment costs are estimated at $40 million.

There are various combinations of these investment proposals but they all have very substantial returns measured in payback periods of a few years. These sums may not seem large but measured against an average deficit on current account of $400 million per annum for the 1980s and in a situation where manufacturing activity is running at 50 per cent of capacity, where the health service cannot provide the simplest of treatments because of lack of drugs, where poverty and unemployment are widespread, and where lack of forex is seen as the cause, they seem way out of reach.

THE POTENTIAL FOR COORDINATION

Zambia and Zimbabwe cooperate (as they did throughout the UDI period) in regulating the generation of electricity from the two generating stations on the Kariba Dam, which was built in the 1950s. Zambia still has surplus hydro-electric capacity, and most of Mozambique's Cabora Bassa capacity of 2,000 mw is unused; contract purchases from these (subject to contracts with South Africa in the case of the latter) should plainly be investigated before embarking on investment of the scale needed at Batoka Gorge (estimated at US$829 mn).

LOCAL PLANNING - A SOLUTION TO FUELWOOD CONSERVATION AND SUBSTITUTION

Peter Young - with Appendices
by Andy Brown and Theo Schilderman, ITDG Rugby.

Much has been said and written about energy issues in the developing countries and their dependency upon wood fuels and residues, both as a source of energy in small industries and for domestic cooking.

As a result of the plethora of debates and discussions, planners and policy makers have never been short of advice, either on matters of policy, strategy or technical development, as well as on the means to achieve dissemination.

However, in contrast, much less has been said about the problems facing practitioners who implement policy and project plans, and even far less with regards to the meagre programme successes that may not look significant at the global level nor even at national level but at the local level are monumental break-throughs. This paper argues that these successes deserve greater recognition and support in a way that enhances their development and sustainability, because only through contributions of many initiatives will efforts to save the environment be effective.

The Energy Factor in Development

It is only recently that the energy factor in development is being understood, and the idea that the environment is being changed because of increasing deforestation due to the over-cutting of wood for fuel is being challenged, and there is a greater realization that poverty is now an underlying reason for deforestation which manifests itself in increasing need for virgin agricultural land. But we must also be careful of too much generalisation, because situations and solutions are very diverse and greater industrialisation as a means to pay off indebtedness can have serious consequences too. But for the Third World it remains true that where there is lack of rural development, decreasing access to energy will bring even greater rural poverty. In relative terms the rural areas always end up going backwards in relation to towns and cities, and this contributes to the problems of urban drift.

National Planning

This does not, and cannot, take full account of the variations across socio-economic groups and geographical regions. Firstly, the interests of the planners often diverge from those of the rural poor. As an example, consider a policy restricting the cutting of wood on common ground. From the national point of view it makes sense; at local level the poorest inevitably suffer.

Secondly, the geographical variations are on a smaller scale than most people assume. Zimbabwe, for instance, generates a wood surplus every year, yet many in the communal lands face a worsening situation. A recent study in the Eastern highlands noticed that major differences in access to fuel supplies occurred over distances as small as five kilometres.

On a slightly more Machiavellian note, the national planners almost inevitably have a bias towards securing and developing the energy supplies of the urban centres. The rural areas are given relatively less consideration despite the fact that they include the bulk of the population. More importantly, the flows of energy from the rural areas into the towns, to the detriment of the countryside have often been ignored.

ITDG Policy

Over the years, ITDG has worked on a number of energy technologies including fuel efficient stoves, micro-hydro systems, furnace design, steam engines and briquetting. This work was undoubtedly prompted by the very real energy shortages faced by many people in the developing world. The rationale has been that technical measures must be introduced that help to conserve the existing supplies of fuel - principally trees. This same thinking has been reflected in the national energy plans which have set up national programmes to research, develop and disseminate improved energy technologies.

ITDG's philosophy has always been to assist the rural poor through production opportunities that give them the chance to develop and sustain a measure of economic independence. This is the theme that links our energy activities together. We, and many other development agencies have, however, realised that the technical constraints are only a small part of the story. A technical solution to a technical problem is almost always possible. The key constraints to the development process lie in the economic, social and cultural issues. Energy must be seen as a tool. Energy supplies are desirable because of what they can do - whether that be cooking the daily meals, burning bricks or running a transistor radio.

This shift in thinking challenges the simple linearity of the national energy plan. The true situation in many countries is a patchwork of different geographical and demographic regions that each have different energy 'pictures'. In Sri Lanka, for example, it has been shown how energy is traded across the country. It is in effect imported and exported from different regions. In Zimbabwe, wood rich commercial farms sit next to fuel scarce communal lands. Clearly the national planners cannot be expected to identify all the pockets of fuel surplus or deficit and there is a pressing need to understand activities at the local level to determine intervention plans. These should lead to technologies that either offer fuelwood savings or utilise alternatives, or combinations of both. If we consider the situation in Southern India where along the coast people's incomes are the lowest, they pay the highest prices for fuel, which is supplied from rubber plantations in land bordering the hilly regions. Although the utilization of rubber wood in itself does not lead to deforestation, the rate it is being replanted will decline over the next few years from about 6 per cent to 2 per cent. It is anticipated this will bring about an abrupt change in supply. If additional sources are not found, prices will rise sharply and bring further hardships creating greater poverty that is already as severe as anywhere in India.

Briquetting

The prospects for substituting fuelwood with conventional fuels look quite bleak. Although, for those households purchasing wood fuels it is nearly as cheap to use kerosene, LPG or biogas, their supply is severely restricted by Government and state policy and it is quite clear that the importation of fossil fuels is being carefully controlled. If spiralling poverty conditions are to be avoided some intervention is crucial, and a survey of the area showed in fact, that the area is quite rich in energy, but in the form of unutilised coir dust - a waste product left over after coir fibre extraction.

A low density, labour intensive briquetting technique developed in Sri Lanka shows some potential, and just from 20 km of coast line up to 300 jobs can be created, as well as providing fuel for up to 38,000 people per year - the population of an average town in the area.

This type of localised planning has benefits in not only identifying local problems but identifying local resources and skills too that are so necessary if projects are to be sustainable and expand.

Cooking Stoves

In Colombo, Sri Lanka, where the need for improved wood burning stoves was considered a priority, a project to introduce ceramic wood burning stoves was established two years ago. Production and sales based upon commercial lines have now reached levels of 100,000 stoves per annum. Local planning has been most effective here because it has enabled the project to focus not only on a targeted market but the existing business channels (ie. producer - wholesaler - retailer) have been identified. The only assistance provided has been through strategy planning, training and advertising. By working in a concentrated manner resources are not spread too thinly and it gives greater control over events such as checking quality control and monitoring consumer reaction.

In all, 11 production units have been set up in 8 factories employing 52 potters and assemblers. Plans over the next two years include establishing more factories in Colombo with the addition of a further 24 smaller units in rural areas identified with fuel wood deficits. Production will increase by another 85,000 stoves per year.

Such projects need careful planning and research if production cots and retail prices are to remain attractive to producer and consumer. Without generous profits and benefits, that are comparable to other products, projects of this nature will be very difficult to start, let alone to sustain themselves.

Although the primary motive was to save fuel wood and reduce household expenditure, frequent purchaser surveys showed that the stove was valued as much for its benefit to reduce cooking times by 20 per cent, lower smoke emissions and general increase in status than its ability to save 30 per cent fuel, paying for itself in 2-3 months.

It has been learnt that an innovation such as a stove that just saves fuel is really not enough in itself to create a demand that will enable the device to sell itself, especially where fuel saving incurs other costs, such as longer cooking times, and less fuel type flexibility.

If, on the other hand, providing for the latter concerns increases the price of the stove this, too, is unlikely to be acceptable. Particularly in India where they have tried to disseminate chimney stoves that give substantial benefits in terms of smoke-free kitchens. The overall costs have been so high that very few of the wealthier homes have purchased them at full cost which means dissemination is reliant upon government subsidies. However, substantial funding and support has been provided through the national programme but where local initiatives had been succeeding even before the national programme came into effect, much of this has been squashed. At the Gandhiniketan Ashram in South India they had been selling stoves commercially since 1955. Since the introduction of subsidies in 1985 sales have virtually stopped. This is a rather negative trend and shows that the insensitivity of a national programme can wipe out any locally established initiative.

Although the subsidy programme is achieving far higher levels of output at the present than the Ashram was ever able to achieve, by 1990 the subsidy will be withdrawn. This means that the Ashram will have to sell its stoves again through the market place, but relationships with producers and retailers have already been distorted and expectations raised beyond what most families can afford. Marketing channels will need to be re-established well before the subsidies should be withdrawn if the dissemination is to have any hope of being sustained.

If the local situation was more fully understood, Government support could have been directed toward enhancing the Ashram's production and marketing ability that could have brought about sustainability. There still remains a pressing need for subsidies whether it is for a cooking stove or some other energy saving device because most of the disadvantaged are often the most needing. Many subsidising programmes have, in themselves, aimed to achieve dissemination of large numbers of devices. While this has been achieved to some extent in some stove programmes it has not led to expansion to any great extent and there has been little immediate impact on reducing fuel consumption. This is partly due to the use of subsidies to disguise inadequate designs as well as avoiding middle men as a means to lower costs. There is no reason why subsidised programmes and those run commercially should not co-exist side by side, but it does mean that the targeting of the beneficiaries becomes critical such that subsidies go to the less well-off and those able to bear the fuel cost are encouraged to do so.

Lime Production in Malawi

Environmental and social benefits are key issues in other ITDG energy initiatives too, such as in lime production in Malawi. Here, the traditional lime producers consume enormous quantities of indigenous hardwood fuel: an average of 9000 cu.m. or 8000 to 9000 increasingly scarce hardwood trees per annum. In the Chenkumbi Hills, deforestation has been so acute over the last four years, and fuelwood reserves have been so seriously depleted, that the population must now travel up to 20 km to collect fuelwood for domestic use.

Attempts by producers to use the fast growing softwood from government plantations as fuel have been futile as softwood is unsuitable for their traditional kilns.

In the Chenkumbi Hills area, ITDG introduced a different type of limekiln, designed to reduce fuel consumption and to use the fast growing plantation softwoods to alleviate the pressure on the community. In Uliwa, Northern Malawi, ITDG has introduced a similar kiln that works on coal. For the kilns operating on soft woods 50 per cent fuel savings are achieved and for kilns that use coal, woodfuel is replaced entirely. Together with higher quality limes and less waste, these kilns more than offset the higher capital costs, and overall production costs are lower than for the traditional kiln.

Micro Hydro in Nepal

In Nepal where fuel wood collecting has denuded hillsides in much of the Terai and higher elevations local circumstances such as remoteness, lack of resources and severe poverty require more radical approaches and fuel wood substitution is vitally important. The topography in Nepal is most suited to establishing micro hydro schemes in the range of 20-100 kw. Many schemes are in remote villages or small towns and are aimed primarily at end uses such as oil expelling, rice hulling and corn milling. These work well and offer substantial business benefits to the villages who use them for processing their crops. A growing number of these schemes are now including electricity generation. Electricity is used to provide lighting for village houses, but has many other potential uses. Local deforestation has created an opportunity to promote its use in heat storage cookers for preparing rice and curries. So why not electric cookers? They can be used, but they are a very difficult load for a micro hydro set because of the 'peakyness' of the load. A 60 kw set can only run 40 typical cooker 'rings' - sufficient for perhaps 25 households even if there is no other load. But cooking is often done at peak lighting times (early morning and evening) when power for lighting is at a premium. So in reality, a 60 kw set may only meet the electric cooking needs of 15 households. This does not do so much to reduce fuelwood demand, neither does it utilize any 'spare' energy.

One answer is to use storage cookers which, like the storage heaters common in the UK, store 'off peak' energy and deliver it as heat when required. Storage cookers need only consume a few hundred watts to be effective. Devices of between 200 w and 700 w have been used in Nepal, China, Norway and Colombia. Three hundred 200 w storage cookers can be used on the same 60 kw set. As they are storage devices, they can be disconnected at peak periods.

Although heat storage cookers cannot replace the need for wood fuel entirely, in any one kitchen they can make a substantial contribution in the locations where micro hydro schemes exist. There are 650 such schemes working at present and over 100 more per year are being installed. For 50 units the estimated wood fuel savings are in the region of 6,314 tonnes per year. This is enough to meet half of the cooking requirements of about 1,000-2,000 households.

Biomass Programme

Other ITDG energy and environment initiatives that are in various stages of development focus on business opportunity, while utilising local resources.

Sugar furnaces are being adapted to burn bagasse more efficiently (reducing or eliminating needs for additional wood fuel input), and sawdust briquetting is being investigated at saw mills to provide a locally available fuel for the domestic market (alternative to firewood and charcoal).

The success of all such activities, although highly dependent upon economic feasibility, needs reliable data and understanding of the fuel supply-demand situation. Without such information, local opportunities will be overlooked. Savings and environmental improvements at the national level can only be achieved through the cumulative effect of lots of successful local projects.

With this in mind, ITDG has a biomass programme that pulls together this type of data and provides support to other programmes to identify areas of opportunity. This is achieved by establishing very localised energy assessment surveys that collaborating institutions can carry out themselves.

Only through the contributions of many initiatives will efforts to save the environment be effective. Clearly, global solutions are a misnomer and the sooner policy makers, planners and practitioners translate concepts and ideas that are workable at the local level - will real progress be made.

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APPENDIX A: LIME PRODUCTION IN MALAWI

Theo Schilderman

Traditionally, lime in Malawi is produced in rectangular box type trench kilns constructed of limestone rock and mud mortar. There are about 40 producers, divided fairly evenly between two lime producing areas: the Chenkumbi Hills near Balaka, and Lirangwe near Blantyre. Production is seasonal, and currently varies between 2,000 and 3,000 tonnes per annum. Most producers fire only one or two batches per year, only a handful operate commercially, and produce 3 to 5 batches per year. Each batch produces an average of 500 tonnes of slaked lime (lime hydrate, $Ca\ (OH)_2$).

The traditional lime producers consume enormous quantities of indigenous hardwood fuel: an average of 9,000 cu.m or 8,000 to 9,000 increasingly scarce hardwood trees per annum. In the Chenkumbi Hills, deforestation has been so acute over the last four years, and fuelwood reserves have been so seriously depleted, that the population must now travel up to 20 km to collect fuelwood for domestic use. Attempts by producers to use the fast growing softwood from government plantations as fuel have been futile as softwood is unsuitable for their traditional kilns.

The Introduction of a New Kiln

In the Chenkumbi Hills area, ITDG introduced a different type of limekiln, designed to reduce fuel consumption and to use the fast growing plantation softwoods to alleviate the pressure on the community.

The kiln is a vertical shaft kiln, built totally out of local materials at the lowest possible cost (£2,500 for the kiln) and such that the construction, maintenance and repair could be done locally by the producers themselves. The kiln was designed to cope with the coarse crystalline marble available in the area which is difficult to fire, to improve the quality of lime produced, to reduce the amount of waste and to increase productivity without affecting employment. The new kiln is operated continuously, and can produce 3.7 tonnes of slaked lime per 24 hour day, employing 37 people.

Field production trials using the new kiln have shown that a reduction in fuel consumption of 50 per cent can be achieved with relative ease. And, perhaps more important, the new technology can use the full range of solid fuels, which for Chenkumbi include the local fast growing softwoods and charcoal obtained from further north. In Uliwa, Northern Malawi, ITDG has introduced a similar kiln, that works on coal.

The results of the field trials have also shown that the quality of lime can be improved by 10 - 15 per cent and the waste reduced from 30 - 10 per cent. All these factors have contributed to a lowering of the direct costs of production, which is however partly offset by higher capital and labour costs. Still, the new kiln produces a better quality lime at a slightly lower price than the traditional kilns.

Dissemination

A project to disseminate the new technology to the small producers is underway in collaboration with local institutions. ITDG has recently organised a seminar for local producers and collaborating agencies, is regularly monitoring progress and providing technical assistance to producers in the area, whereas local agencies can provide investment finance.

APPENDIX B: STORAGE COOKERS

Andy Brown

ITDG has been involved in very small water turbine (micro hydro) technology for developing countries for ten years.

Much of the work has centred around hydro electric systems rather than purely mechanical systems capable only of, say, milling corn.

These electrical systems are in great demand for street and domestic lighting, small industries such as motorised looms, tea processing, sawmills and even photography studios.

The maximum output power of these schemes is typically between 20 and 100 kw

Many schemes are in remote villages of small towns, and are aimed primarily at productive end uses, with secondary benefits of domestic power and lighting. This works well, but there is usually excess energy at some times of the day and night, and perhaps during certain months.

In Nepal and Sri Lanka attempts are being made to match this 'spare' energy with the need to save fuelwood, the single biggest environmental issue in these localities.

Most of the fuelwood is for cooking. So why not electric cookers? They can be used, but they are a very difficult load for a micro hydro set because of the 'peakyness' of the load. A 60 kw set can only run 40 typical cooker 'rings' - sufficient for perhaps 25 households even if there is no other load. But cooking is often done at peak lighting times (early morning and evening) when power for lighting is at a premium. So, in reality, a 60 kw set may only meet the electric cooking needs of 15 households. This does not do much to reduce fuelwood demand, neither does it utilise any 'spare' energy.

One answer is to use storage cookers which, like the storage heaters common in the UK, store 'off peak' energy and deliver it as heat when required.

Storage cookers need only consume a few hundred Watts to be effective. Devices of between 200 w and 700 w have been used in Nepal, China, Norway and Colombia. Three hundred 200 w storage cookers can be used on the same 60 kw set.

As they are storage devices, they can be disconnected at peak periods.

There is a catch - in total energy terms the storage cookers are less efficient - they 'leak' heat, much like storage heaters may 'leak' heat into your home while you are at work when you don't want it. However, micro hydro systems without storage cost the same to run at full power as at half power - you can't turn down the stream.

The end result is that storage cookers can use 100 per cent of the available energy (load factor = 100 per cent), with an efficiency of around 30 - 50 per cent. Conventional electric cookers can use around 15 per cent of the available energy (load factor = 15 per cent) with an efficiency of around 80 per cent.

What benefits is this technology likely to bring to the environment? In Himalayan foothills in Nepal, there are at present around 650 micro hydro installations, and 100 or more new units each year. If 50 units are fitted with storage cookers each year, then some assumptions as to fuelwood savings can be made.

- o Average installation capacity - 40 kWe
- o Average load factor without storage cookers - 25 per cent
- o Average load factor with storage cookers - 90 per cent
- o Total energy available to electric storage cookers:

$$= 40 \text{ kwe} \times \frac{(90 - 25)}{100} \times 8760 \frac{\text{hours}}{\text{year}}$$

$$= 227{,}760 \text{ kWh/year}$$

- o On 50 micro hydro units/year this gives 11,400 MWh/year.

How much fuelwood does this save? Assuming an efficiency of 30 per cent for the storage cookers and 15 per cent for wood stoves we will be saving wood with a thermal capacity of 22,800 MWh - around 6,314 tons of 20 per cent moisture content softwood equivalent (ref: Bill Stewart, Improved Wood, Waste and Charcoal Burning Stoves, IT Publications).

In common with many other 'alternative technologies', storage cooking is not new. It was used extensively in Scandinavia for many years. ITDG's task is to co-ordinate resources to reintroduce cookers suitable for manufacture and use in those developing countries which have fuelwood problems. This should benefit the economy, the environment and the women struggling with fuelwood cookers in a deteriorating environment.

ASSESSING WOOD SUPPLIES IN AFRICA

Terry Douglas*, Richard Critchley*, Andy Millington#,
Ian Ryle* and Phil O'Keefe*

* Department of Environment, Newcastle upon Tyne Polytechnic
# Department of Geography, University of Reading

INTRODUCTION

This paper describes work in progress to map the wood resource of Africa. It is an attempt to describe where resources are located, how much there is and how much can be taken as yield. The work is financed by the ESMAP programme of the World Bank.

The paper is divided into two parts. Firstly, there is a technical section that outlines the methodology used in this analysis. Secondly, there are a series of summary results, by woody biomass class, for Africa south of the Sahara. Full results of this analysis will be available in December 1989.

USING METEOROLOGICAL SATELLITE DATA FOR VEGETATION AND LANDUSE MAPPING

Remote Sensing

Satellite remote sensing is the technique of acquiring earth surface and atmospheric data (imagery) from satellites. Sensors on-board satellites provide data at a synoptic scale from a single data-take, thereby making the analysis of remotely-sensed data a cost-effective tool for resource assessment over large areas. A further advantage of satellite data is that repeat imagery for any scene can usually be acquired. The repeat period between data-takes varies from short periods (of less than 24 hours on meteorological satellites) to between 16 and 26 days (on earth resource satellites), but can be much longer in the latter group due to a variety of technical and logistical reasons. The capability to provide time-sequential data is of great advantage in both resource assessment and monitoring, particularly biotic resources, because of their rapid response to changes in the weather and human activities.

Sensors and data products

Sensors for the acquisition of remotely sensed data are mounted on-board various satellites. These satellites can be divided into two groups - earth resources satellites (e.g. the American Landsat series of satellites and the French SPOT satellite) and meteorological satellites (e.g. the NOAA series of satellites and METEOSAT). Data are provided to the user either as a photographic (optical) products or computer compatible tapes (CCT's). The latter are more useful for resource assessment than the former as they can be digitally processed to maximise the amount of information extracted from them, this however can only be carried out effectively using digital image processing systems.

Spectral properties and vegetation

The spectral characteristics of vegetation are such that remotely-sensed data are most useful for vegetation and land-use mapping if they are acquired in the visible red and near infra-red parts of the spectrum. In the red region of the spectrum (600-700 nm) radiation is absorbed for use in photosynthesis. This is in contrast to the strong reflection of near infra-red radiation 800-1100 nm) caused by leaf cell reflection and refraction. Detailed studies relating the physiology and biochemistry of plants to their spectral characteristics has been undertaken (e.g., Sellers, 1985, 1986, and Tucker & Sellers, 1986) concluding that spectral reflectance of vegetation is related to the physiological processes that drive plant growth, namely photosynthesis and respiration.

Advanced Very High Resolution Radiomater (AVHRR) Data

The data used in this work was acquired by the Advanced Very High Resolution Radiometer (AVHRR), a sensor carried on-board the American meteorological satellites, NOAA-9 and 10. The data were supplied on CCT's from NASA/GSFC. The salient characteristics of this satellite-sensor combination are provided in **Table 1.1**.

Data is acquired for any part of the earth's surface by the AVHRR sensor on-board each NOAA satellite every 12 hours. One of the two data-takes every day is at night. The other is during the day and, at the equator, the data-take time for NOAA-9 is 14.30 hrs (local time) and for NOAA-10 is 07.30 hrs (local time). Although these data are primarily aimed at the meteorological community, because of the short time between data-takes there is a high probability that in any given period a ground resolution element (the smallest area on the ground that can be resolved on the imagery) will be cloud-free at the time of data acquisition.

Table 1.1 CHARACTERISTICS AND STATUS OF NOAA WEATHER SATELLITES AND THE AVHRR SENSOR

Satellites:

TIROS-N	Launched:	Oct. 1978	Current status[1]:	Non-Operational
NOAA 6	Launched:	Jun. 1979	Current status[1]:	Non-Operational
NOAA 7	Launched:	Jun. 1971	Current status[1]:	Non-Operational
NOAA 8	Launched:	Mar. 1983	Current status[1]:	Non-Operational
NOAA 9	Launched:	Dec. 1984	Current status[1]:	Non-Operational
NOAA 10	Launched:	Oct. 1986	Current status[1]:	Operational
NOAA 11	Launched:	Sep. 1988	Current status[1]:	Operational

AVHRR Sensor:

Coverage cycle:	9 days		
Ground coverage:	2,700 km		
Orbital height:	833 km		
Orbital period:	102 min		
Ground resolution:	1.1 km to 2.4 x 6.9 km[2]		
Spectral channels:	5 -	Ch.1	580 - 680 nm
		Ch.2	725 - 1,100 nm
		Ch.3	3,550 - 3,930 nm
		Ch.4	10,300 - 11,300 nm
		Ch.5	11,500- 12,500 nm

---

[1] as of November 1988

[2] dependent on angle of view

Normalised Difference Vegetation Index (NDVI)

The configuration of the AVHRR sensor, particularly the wavelengths of the sensors in Channels 1 (visible red) and 2 (near infra-red), means that when there is an absence of clouds, vegetation, bare ground or open water is sensed. Consequently, over land, useful ecological information can be obtained within the ground resolution elements. This information enables an index of vegetation status to be calculated for each ground resolution element. Vegetation indices are derived to reduce measurements of the vegetation canopy, ground cover and biomass to a single number (Perry & Lautenschlager, 1984). There are at least 48 different vegetation indices available to remote sensors, but the Normalised Difference Vegetation Index (NDVI) has been successfully and extensively used with AVHRR data (Justice et al., 1985; Townshend et al., 1986), principally because the normalising nature of the equation reduces atmospheric effects. It is produced on a routine basis by NASA/GSFC, and is calculated by the following equation:

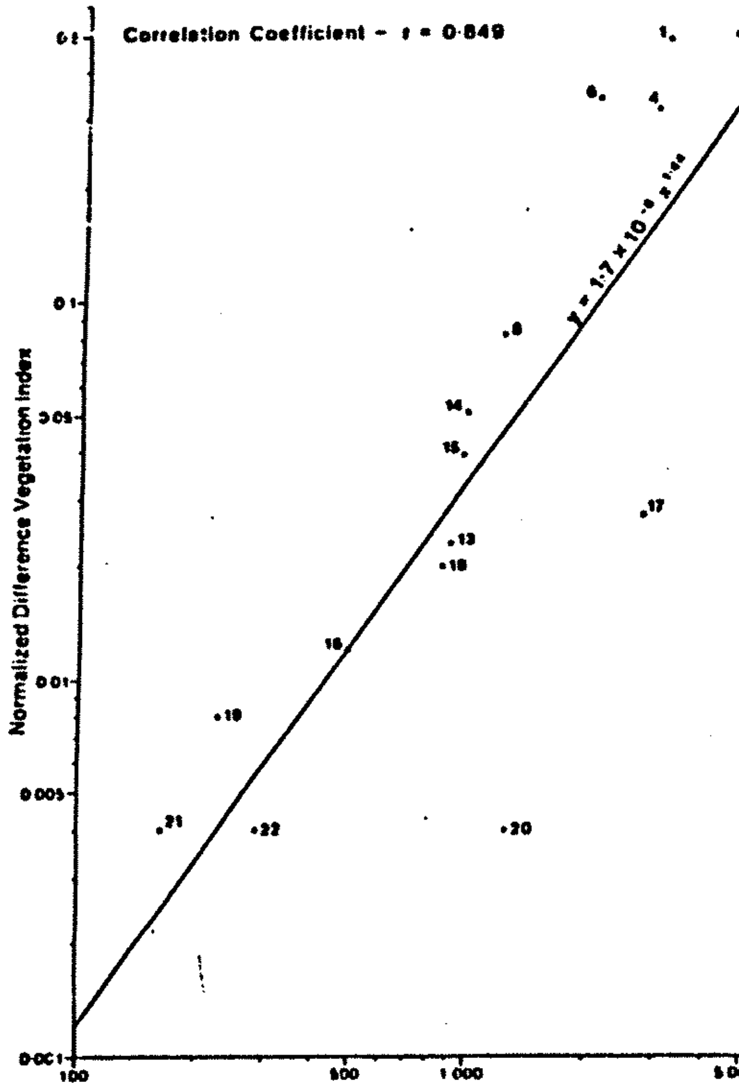
$$\text{NDVI} = \frac{\text{DN (Channel 2) - DN (Channel 1)}}{\text{DN (Channel 2) + DN (Channel 1)}}$$

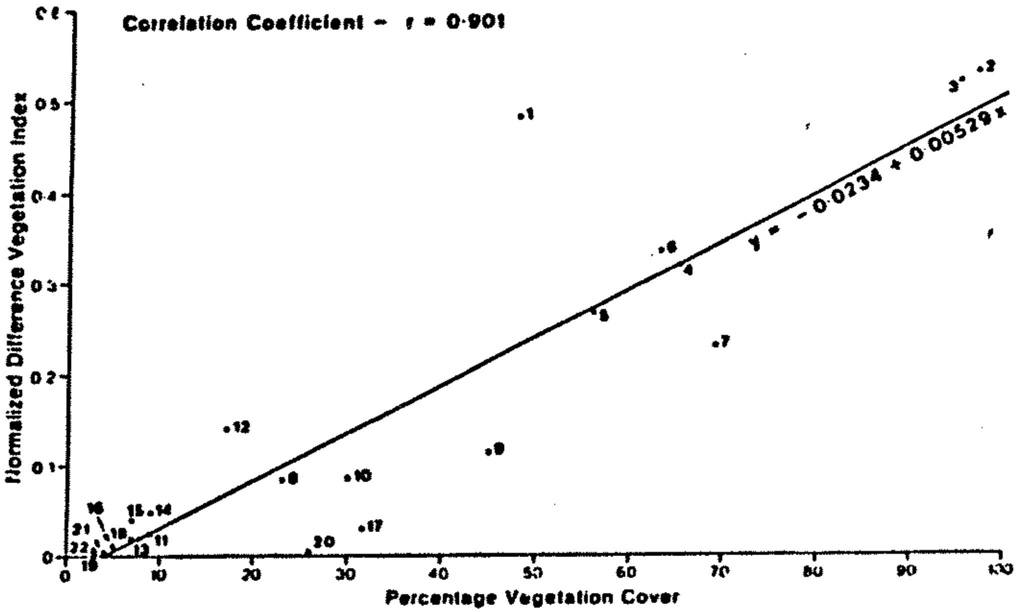
Vegetation and Land-Use Mapping from NDVI data

Advantage has been taken of such ecological data from meteorological satellites by a number of researchers since 1981 for vegetation and land-use mapping over large areas (Gatlin et al., 1983; Gray & McCrary, 1981; Norwine & Greegor, 1983; Schneider et al., 1981; Tarpley et al., 1984; Townshend & Tucker, 1984; Tucker et al., 1984a, 1984b). This work has led to a number of natural resource applications in the tropics, for instance: monitoring Lake Chad (Schneider et al, 1985; mapping biomass production for grazing in Senegal (Tucker et al, 1985); monitoring semi-arid rangelands in Botswana (Prince, 1986); monitoring cropping patterns in S.E.Asia (Malingreau, 1986); and assessing woody biomass resources for wood energy planning in southern Africa (Millington et al., 1989). A number of these studies have correlated biomass parameters, such as total above ground biomass and productivity, with NDVI (**Figs.1.1 & 1.2**). Although none of the attached graphs relate to tree and shrubs specifically they do suggest that similar correlations would be found for woody biomass; preliminary work carried out by NASA/GSFC and the Indian Forestry Department bears this out.

Fig. 1.1

Relationship between Normalized Difference Vegetation Index calculated from atmospherically corrected AVHRR data and mean dry above-ground green biomass, for selected field sampling stations: March 1986.

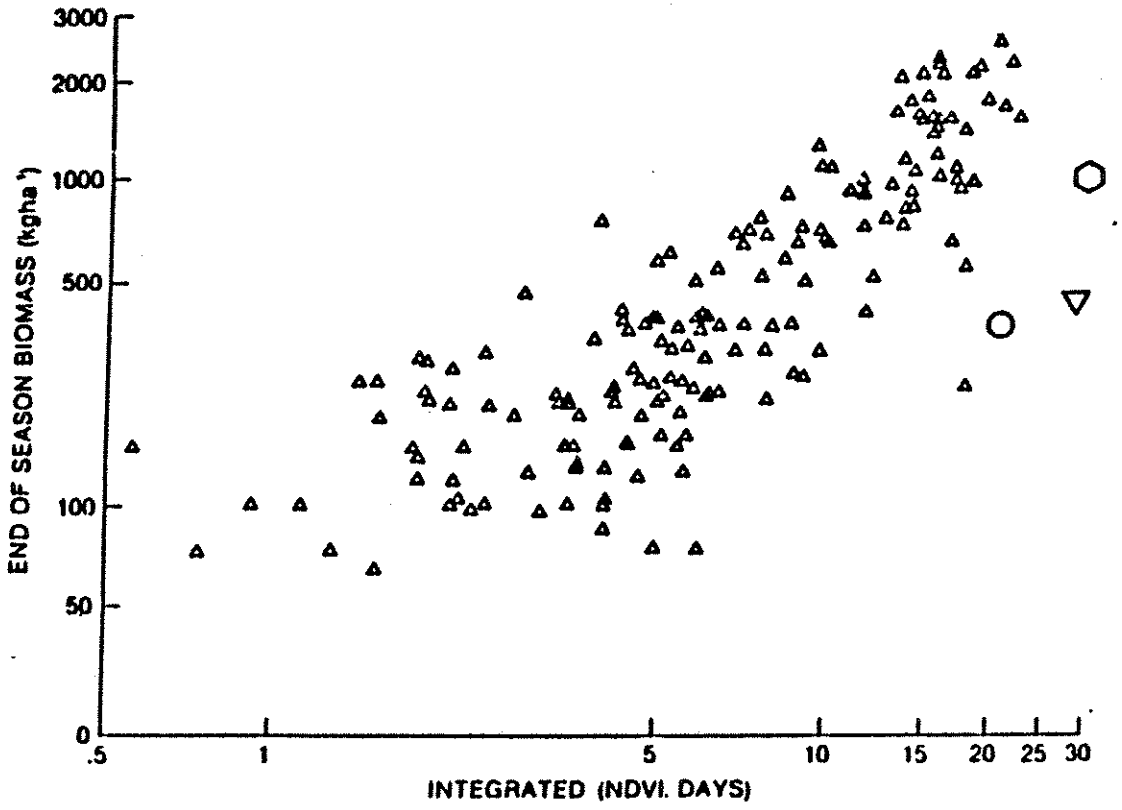




Relationship between Normalized Difference Vegetation Index calculated from atmospherically corrected AVHRR data and percentage vegetation cover for each field sampling station: March 1986.

Source: Kennedy (1989)

Fig. 1.2



The relationship between integrated NDVI and end-of-season, above-ground biomass of herbaceous plants for the Ferlo region of Senegal 1982–83 (△), and Tamasane (▽). Shakwe (○) and Masama (⬡) in Botswana in 1983–84. Data for Senegal from Tucker *et al.* (1985b). The logarithms of both variables are plotted to reduce the number of overlapping points.

Source: Prince S.D. (1986)

Production of NDVI data by NASA/GSFC

This early vegetation mapping carried out using AVHRR data so vividly illustrated the potential of these data that raw and vegetation index information calculated from the above equation is available from NOAA at different spatial resolutions:

- GVI (Global Vegetation Index) 8km + 15km resampled to PSG (Polar Stereographic Projection)
- Global Area Coverage (GAC) data, which has a spatial resolution of 4km
- Local Area Coverage (LAC) data, which has a spatial resolution of 1.1km if out of range of a receiving station. This can only be obtained on special request as it is taped on-board the spacecraft.

Vegetation index data from both Local and Global Area Coverage data is provided at ten-day intervals.

The NDVI data available from NASA/GSFC has been 'cloud screened'. In this procedure pixels with clouds in the AVHRR images are identified using thermal infra-red data and excluded from the later stages of analysis, i.e. the production of temporal composites of NDVI. This procedure works well except in areas where thin cirrus cloud is prevalent (Henderson-Sellers et al., 1987). After cloud-screening the daily data is composited over ten-day intervals. For the ten day period each pixel is examined and the day with the highest NDVI for that pixel is used to represent the ten-day period, (Holben, 1986). This procedure reduces the atmospheric, cloud and sun-angle effects of vegetation index calculation.

BIOMASS CLASS MAPPING

IMAGE PROCESSING

Introduction

The identification and mapping of biomass classes was based on the interpretation of digital AVHRR data and field verification. It was undertaken in three phases:

(a)	Phase I	-	Data inspection and preprocessing;
(b)	Phase II	-	Initial image interpretation, provisional biomass class mapping, derivation of NDVI phenologies, field verification of provisional biomass class maps;
(c)	Phase III	-	Automatic classification of biomass classes and production of biomass class maps.

PHASE I

Equipment

All image processing was undertaken on an I^2S 102 and a R-Chips image processing system at the University of Reading. These two systems are hosted by Vax 8350 and Compaq 386 computers respectively. All image processing was initially evaluated on-screen and hard-copy imagery for further interpretation, field verification and publication were taken using the following equipment: a D-Scan printer, a DEC colour ink-jet printer, and a Dunn Instruments Matrix Camera.

Data specifications and errors

NDVI data at 8km spatial resolution was provided by NASA/GSFC for 1986 in 10-day and monthly time intervals, these data were registered to each other, and were provided on the Hammer-Aitoff Conic Equal Area Projection. The 10-day data were initially inspected for errors; two types were encountered:

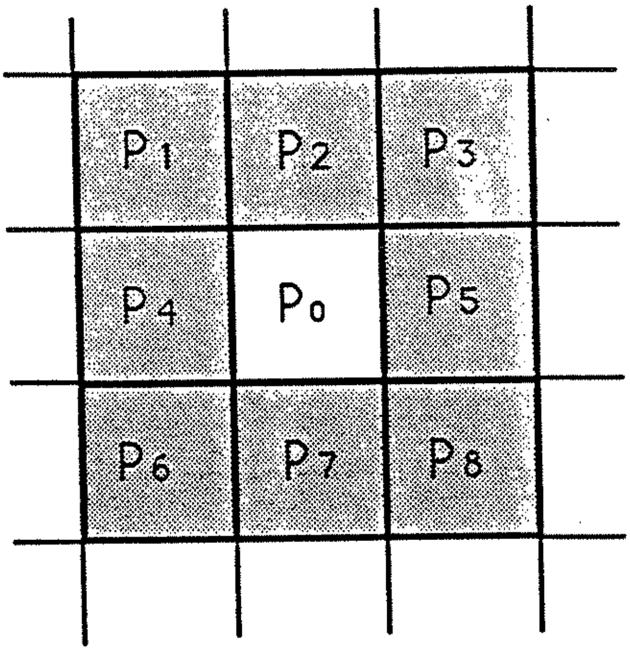
(a) pixels without NDVI values; and
(b) mis-registered data.

The digital data held on tape is configured into pixels in the image processing system; a pixel on-screen represents the ground resolution element of the sensor. An absence of data in a pixel can occur due to sensor, transmission or processing errors. In many cases this involved single pixels. We derived a digital filter to solve the empty single pixel problem. This was a modified 3 x 3 pixel average filter. The filter operated such that if a pixel fell outside the range of possible NDVI values (120-210) it was replaced by the average of the eight neighbouring pixels. A pixel was also replaced if it fell within this range, but the sum of the differences between the pixel and its neighbors exceeded a threshold.

Larger areas without data also occurred in the imagery. These occurred in areas where there was persistent cloud cover over the imaging periods and meant that during some months no cloud-free pixels could be found from which to calculate NDVI. These areas are not found in all months of the year, but because a sequence of months is used to classify biomass classes the occurrence of cloud in pixels affects the accuracy of the final map. These areas are mainly found in the coastal humid tropics, along the high mountains in East and Central Africa , around Lake Chad, and in the vicinity of Table Mountain.

The smaller areas of cloud were eliminated after classification (phase III) using an iterative median filtering approach. The original NDVI data and the filtered data were then combined using a logical 'or' operation, so that the original data were only altered where a zero (cloud) value was found in the original data (**Fig.2.1**). However some very large areas of cloud did occur in Cameroon, Ethiopia, Nigeria, South Africa and Zaire; these could not be entirely eliminated. These latter areas were not included in the final classified images because they would produce

AVHRR NOISE - REMOVAL FILTER



$$\text{IF } P_0 > 200 \ \& \ \frac{\sum_{i=0}^{8} |P_0 - P_i|}{8} > T \text{ THEN } P_0 = \frac{\sum_{i=0}^{8} P_i}{8}$$

Where T is a user specified threshold

Fig. 2.1

classes that were impossible to interpret. Therefore a cloud mask was produced and this was overlain on all of the final images. The mask was constructed by extracting cloud occurence information on a pixel-by-pixel basis for each month and then adding the months together. The mask therefore shows the pixels with cloud cover during a least one month of 1986 (**Fig.2.2**). Obviously in areas under this cloud mask there is no information on land cover and the areas are not included in the area, standing stock and increment calculations. The areas of cloud affected pixels are provided in **Table** 2.1.

Data for one of the 10-day periods in March was misregistered. This caused few problems as the 10-day period with the misregistered data was registered to the other two 10-day periods. The March NDVI image was then recalculated and the data used in the phase III analysis.

Fig. 2.2

AFRICA: Cloud Cover

Produced for ETC (UK) by
Department of Geography,
University of Reading, in
cooperation with Newcastle
Polytechnic.

TABLE 2.1

Extent of cloud cover in 1986 imagery

Country	Area (km2)	%
Burkina Faso	0	.00
Chad	0	.00
The Gambia	0	.00
Mali	0	.00
Mauritania	0	.00
Niger	0	.00
Senegal	0	.00
Benin	0	.00
Ghana	0	.00
Guinea-Bissau	0	.00
Guinea	0	.00
Ivory Coast	0	.00
Liberia	0	.00
Nigeria	11382	.01
Sierra Leone	263	.00
Togo	0	.00
Cameroon	14649	.03
Cent. African Rep.	0	.00
Congo	0	.00
Equat. Guinea	1634	.07
Gabon	0	.00
Zaire	66818	.03
Angola	1634	.00
Botswana	0	.00
Lesotho	211	.01
Malawi	896	.01
Mozambique	5744	.01
Namibia	1475	.00
South Africa	2371	.00
Swaziland	0	.00
Zambia	2002	.00
Zimbabwe	0	.00
Djibouti	0	.00
Ethiopia	15071	.01
Sudan	0	.00
Somalia	0	.00
Burundi	1686	.06
Kenya	4216	.01
Rwanda	4058	.17
Tanzania	7325	.01
Uganda	3636	.01

PHASE II

Imagery derived from AVHRR data

Various image products were derived from the monthly NDVI data for the initial interpretation phase (phase II) in which provisional biomass classes were identified and mapped. The images used in this phase of the project were:

(a) individual monthly NDVI images;
(b) mean annual NDVI images;
(c) difference images between two monthly NDVI values; and
(d) unsupervised classification images;

All of the images were produced at a variety of scales, ranging from the entire continent to individual countries, to facilitate easier interpretation and mapping.

The individual monthly GVI images were prepared for all months. As these were supplied directly from NASA/GSFC, image production required tape unloading, inspection for errors and colour coding of the image using the standard NASA scale.

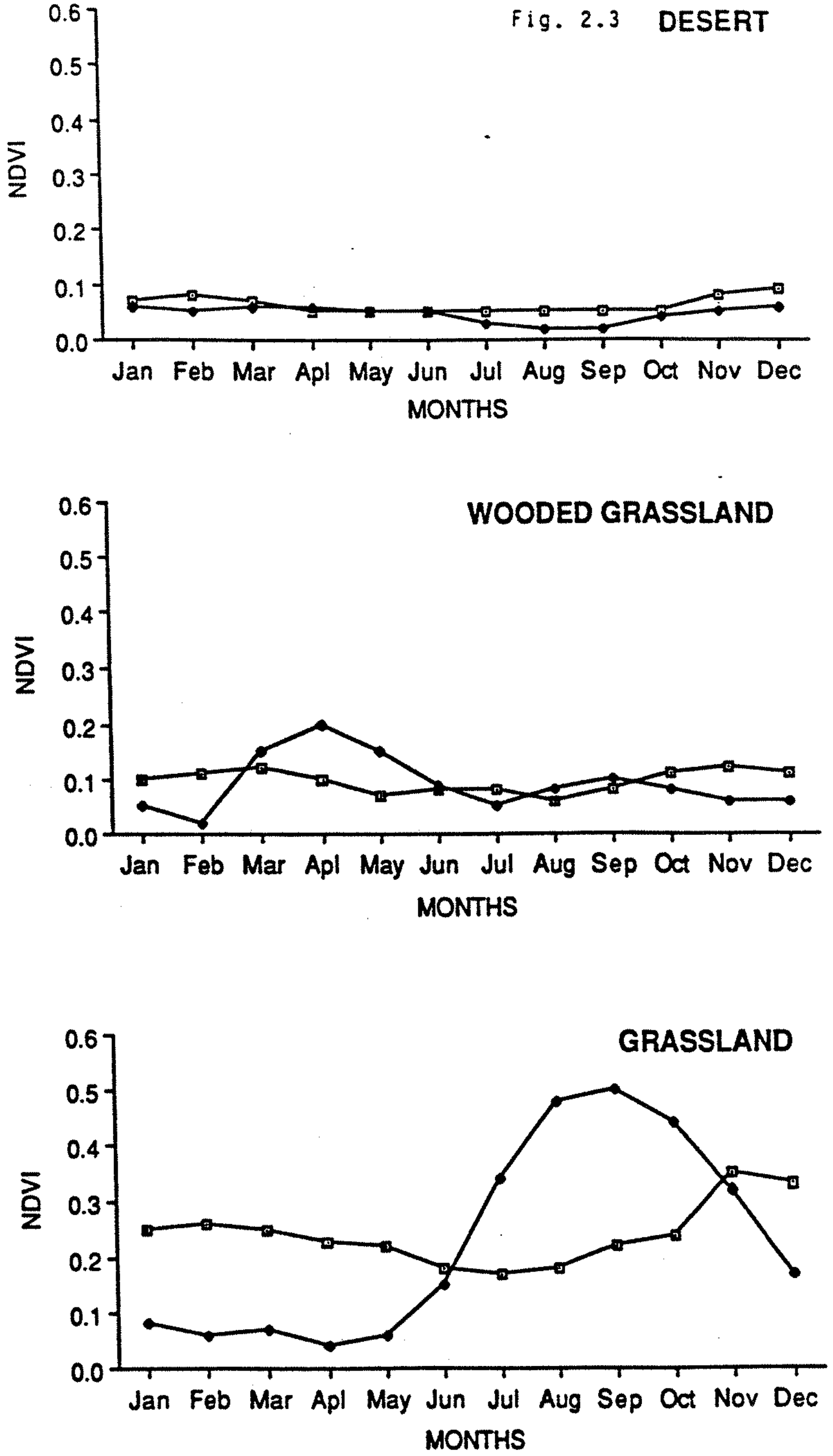
A mean annual GVI image was created by the pixel-by-pixel addition of all monthly GVI values for corresponding pixels. The total GVI values for each pixel were then divided by 12. This image provides a good indication of the amount and variation in annual vegetation productivity. It is analogous to the integrated NDVI images that have been previously produced but differs from these in that they are calculated on the basis of the area under the NDVI curve.

Difference images were created by subtracting one set of monthly NDVI data from another and adding a constant, on a pixel-by-pixel basis for corresponding pixels. The months used to create the difference images were chosen on the basis of known phenological characteristics of African vegetation and land-use. Two types of difference images are particularly useful in the interpretation of biomass classes. First, those in which imagery from the low NDVI period (the period of vegetation senescence) is subtracted from the high NDVI period (the period of maximum greenness). Such images provide a good indication of vegetation die-back in response to declining seasonal rainfall, varying levels of residual soil moisture, or the onset of winter conditions, such as cooler temperatures or increased frequency of frosts. Secondly, images where the high GVI period image is subtracted from the low NDVI period image. These images provide information on greening-up of vegetation.

In this phase of the analysis classification of images was restricted to unsupervised classification. Four months were chosen to represent the periods of high and low NDVI and the intermediate periods, when NDVI values decrease or increase at varying rates depending on the vegetation and land-use types. These data were then clustered such that pixels with a statistically similar range of values over the four months were grouped together into the same class.

In addition to these images temporal profiles of NDVI values were plotted. These profiles indicate the seasonal fluctuations of NDVI which can be used to analyze the seasonal variations in photosynthesis, leaf area index, and biomass production. Each point represents the average NDVI over the same 3x3 pixel square area on each of the monthly images. Temporal profiles are attached (**Figs 2.3, 2.4, 2.5**). Although they relate to some of the biomass classes mapped in phase II they are also typical of the profiles derived in phase II and were used in provisional biomass class identification and field verification.

Fig. 2.3



DESERT

WOODED GRASSLAND

GRASSLAND

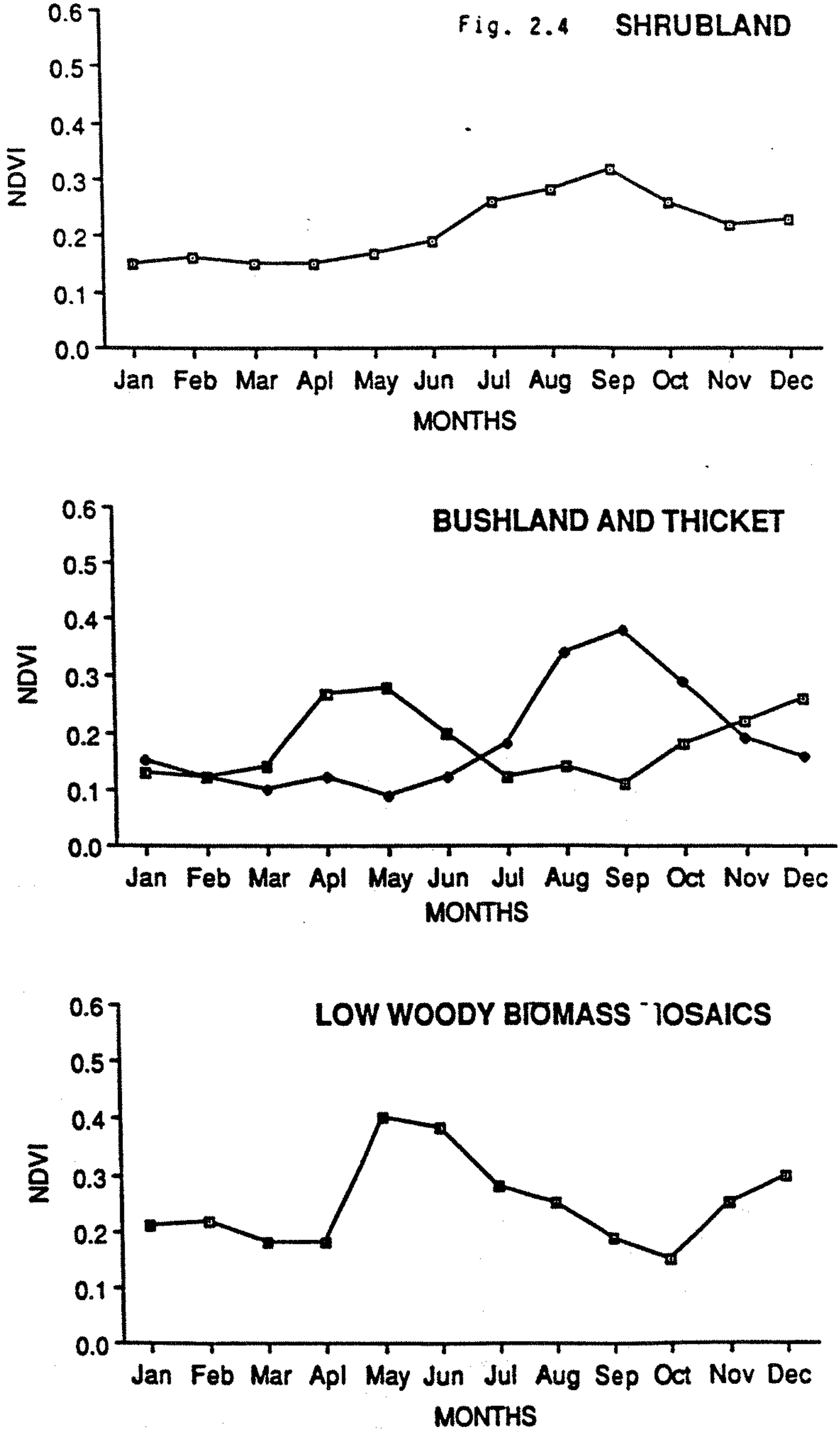
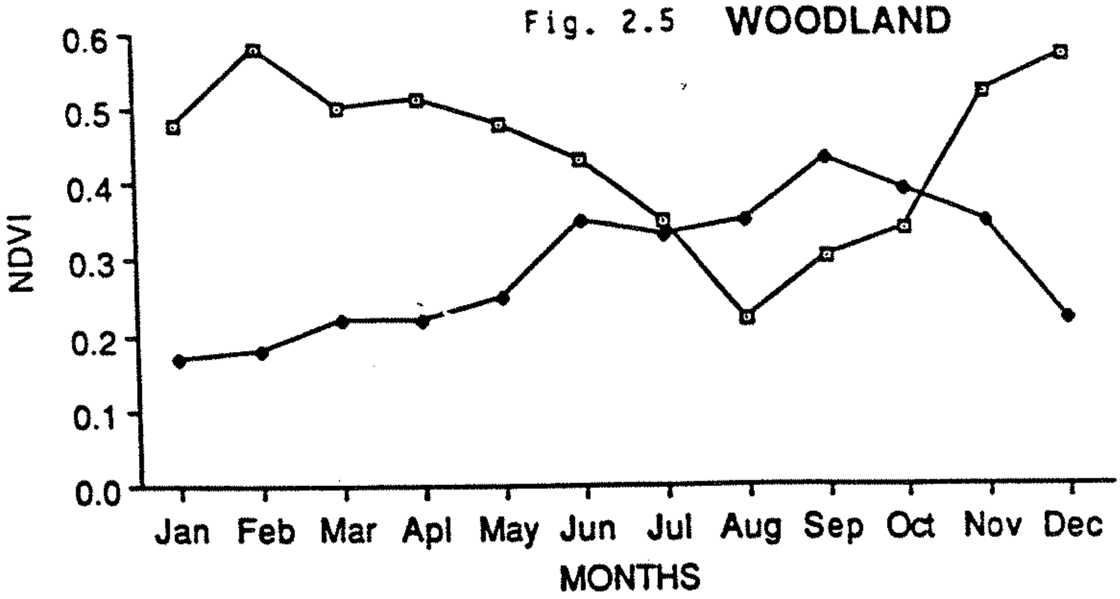
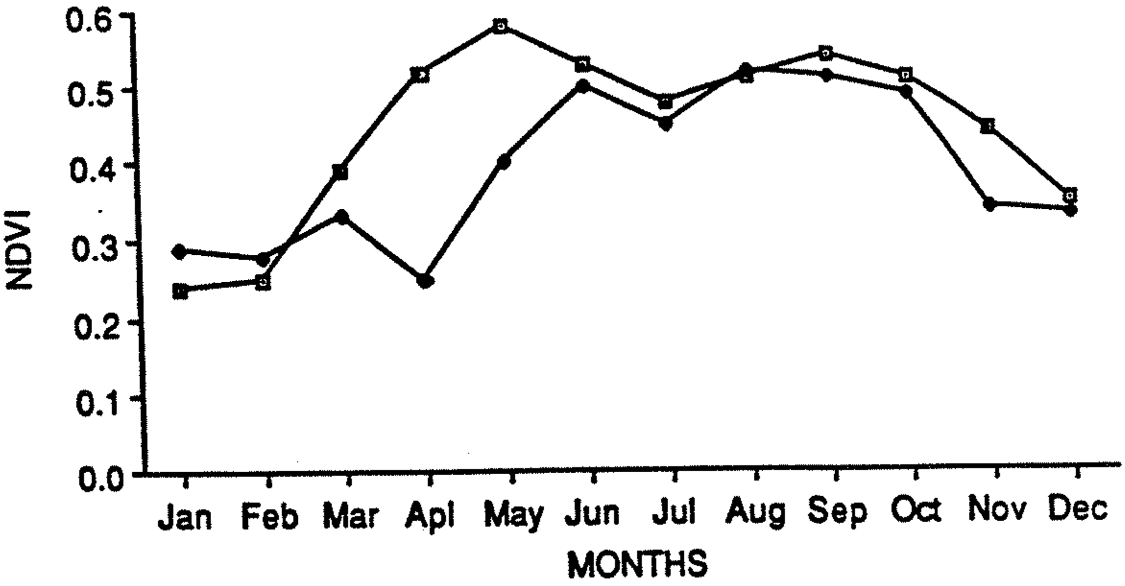


Fig. 2.4
SHRUBLAND
NDVI
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Jan
Feb
Mar
Apl
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
MONTHS
BUSHLAND AND THICKET
NDVI
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Jan
Feb
Mar
Apl
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
MONTHS
LOW WOODY BIOMASS MOSAICS
NDVI
0.0
0.1
0.2
0.3
0.4
0.5
0.6
Jan
Feb
Mar
Apl
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
MONTHS

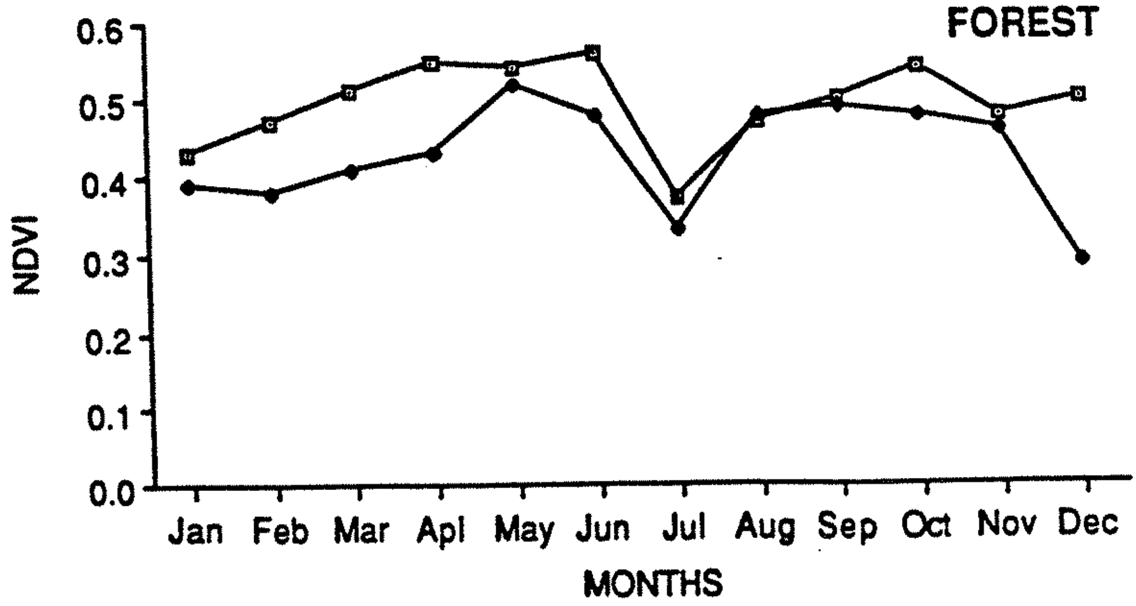
Fig. 2.5 WOODLAND



HIGH WOODY BIOMASS MOSAICS



FOREST



Identification and Mapping of Provisional Biomass Classes

All of these images were evaluated on-screen and then hard-copy was obtained. The hard-copy images were used to identify and map the vegetation types on 1:5,000,000 scale base maps for the five areas where field checking was undertaken:

(a) South Africa, Swaziland, Lesotho and Namibia;
(b) Southern Zaire, Congo and Gabon;
(c) two regions in West Africa, including Mauritania, Senegal, The Gambia, Mali, Burkina Fasso, Guinea Bissau, Guinea, Sierra Leone, Liberia, Ivory Coast, Ghana, Togo and Benin; and,
(d) Ethiopia, Somalia and Djibouti.

Identification of vegetation types in these areas was based on the following criteria:

(a) vegetation phenology (obtained from temporal profiles of NDVI values and the seasonality (difference) images);
(b) monthly and annual vegetation productivity (based on monthly and mean annual NDVI images)
(c) secondary data sources (particularly vegetation, land- use and forestry maps) but also other environmental information, particularly geological, soils and topographic maps and climatic statistics.

It was decided to undertake the initial mapping of provisional biomass classes at this scale for two reasons (i) this scale was successfully used previously for biomass class mapping in the SADCC region (Millington et al., 1989), and (ii) the UNESCO Vegetation Map of Africa (White, 1983) was produced at this scale. The UNESCO map is the most recent vegetation map covering all of Africa and provided the most consistent reference source for checking image interpretations, although substantial modifications have been made to it. These modifications are discussed in phase III but are due to the fact that the biomass classes are related to different types of vegetation communities (e.g., forest, woodland, shrubland, bushland, grassland and desert) or land-use types. Consequently their distribution does not exactly correspond to any one previous botanical or ecological study of the region, although they are broadly comparable to most regional vegetation maps.

PHASE III

Supervised Classification

The final biomass class maps were produced using supervised classification methods on the I2S image processor. Supervised classification is a particularly powerful image processing procedure in this respect as the values of each pixel in each spectral channel are compared to various sets of pixel values (training statistics) from preselected, known areas (training sites). The individual pixels are assigned to the most suitable class based on the training site statistics. Different algorithms can be used in supervised classification, but in this project a maximum likelihood classifier was used. Training sites were identified on the basis of phase II interpretations. These were located in areas where the provisional classes had their maximum areal extent, or were known to be distinctive. Training statistics for all the vegetation types were generated and the data were classified on the basis of these. This produced an automated classification of 60 biomass classes for sub-Saharan Africa.

The classification was based on six months of data and training sites selected on the basis of the field team reports and previous research. The decision to base the classification on six months of data was based on the following criteria. First, in the woody biomass assessment carried out for the SADCC region (Millington et al, 1989) both the NDVI values and first three principal components were classified separately and examined. Interpretation and evaluation of the two images showed that the classification of biomass classes based on the monthly GVI values was most meaningful. Secondly, there is a significant amount of temporal autocorrelation in the NDVI data for adjacent months, which would tend to lead to data redundancy if all 12 months were used in the classification. Two sequences of alternate months were classified (January to November) and (February to December). The differences between the classified images were insignificant. The final classification was based on the following six months: January, April, June, July, October and December. These months were chosen by a process of elimination: August had high cloud cover north of the equator, and one of each of the following pairs of adjacent months with correlation coefficients >0.9 were eliminated January and February; April and May; May and June; September and October; October and November. A by-product of this decision was that CPU time for the classification using six months data fell dramatically compared to using 12 months of data.

Previous work on land cover mapping has shown that the more months used in the analysis the greater the accuracy of classification (Townshend et al., 1987). Whilst this work does not question this finding the decision to use 6 months of data was based on operational, rather than scientific, criteria. It should not necessarily be assumed that accuracy will increase as the number of months from 1986 used in the classification increases; but it would increase significantly if data from other years were included. This is because NDVI is very sensitive to rainfall and soil moisture variations which vary considerably from year-to-year over much of Africa. Currently, the most accurate map of land cover that could be produced would therefore be one which used a data set dating back to 1981 (when NDVI data first became available) and it is strongly recommended that future work on natural resource applications using NDVI data is based on long-term data sets.

Biomass Class Mapping

The biomass classes were reinterpreted using the same criteria used to identify them in phase II. At this stage biomass classes with strong similarities were merged, leaving a total of 43 biomass classes. These biomass classes were then reviewed by experts in the workshops held in Abidjan and Nairobi and recommendations made to merge other classes.

Most of these mergers are of classes with statistically similar NDVI curves which, on the basis of floristic and ecological criteria, were 'incorrectly' split in the phase III analysis. However the special case of cultivation mosaics in West Africa and Ethiopia provided more difficult problems. In the West African coastal zone the areas originally classified as different types of humid tropical forest and forest regrowth were merged to into two classes:

a) West African Mixed Agriculture and Forest Fallow Mosaic (High productivity phase), and
b) West African Mixed Agriculture and Forest Fallow Mosaic (Medium productivity phase).

This merger was based on the realization than in this region there is very little humid tropical forest remaining. That which is in small blocks and reserves is interspersed with rubber, cacao, and coffee plantations, farms, and a seral succession forest regrowth. This pattern of land use occurs at scales that cannot be mapped from 8km AVHRR data.

In the highlands of Ethiopia a similar problem of small land parcels with different biomass levels and NDVI profiles exists, but here the additional problem of altitude is a factor. In this case it was decided to introduce altitude into the mapping procedure. The 2000 and 3500 m contours were digitised and overlain on the classified image. With the exception of the montane forest class all of the classes occurring between 2000 and 3499 m in the area were merged to form a Highland Cultivation Mosaic and those above 3500m were merged to form an Ethiopian Montane Steppe.

The problem of variations in land use over small areas is accentuated in areas of steep slopes and high altitude such as the Ethiopian Highlands and it causes difficulties in mapping all of the land cover types in such areas from 8km AVHRR data. Obviously it is a problem in East and Central Africa, as well as Ethiopia, but the problems in these areas were less acute than in Ethiopia.

Biomass classes are defined as areas with a vegetation or land-use type, or types, which are comparable in terms of overall biomass, productivity and seasonality. They may, however, combine more than one type of ecological structure (e.g. forests and woodlands) and many floristic units. In this respect they differ significantly in places from the UNESCO Vegetation Map of Africa, but for the purposes of wood energy planning a classification based on parameters which have been correlated with growing stock and productivity elsewhere, are of more use than a floristic-ecological map.

The map of biomass classes provides one of the final products of the project - a biomass class map of sub-Saharan Africa. The biomass class maps are produced in four forms:

(a) a map of individual biomass classes (in colour) at a scale of 1: 38,000,000
(b) a series of 6 regional maps of biomass classes, based on the image maps, at a scale of 1:5,000,000;
(c) a summary map of biomass classes (in colour) at a scale of 1: 38,000,000; and
(d) a series of 6 regional summary maps of biomass classes at a scale of 1:5,000,000.

The summary maps have been constructed by categorizing the biomass classes into 8 groups on the basis of the dominant ecological structures. These groups are defined by White (1983).

Validity of the interpretation of the AVHRR NDVI products in terms of wood biomass and mean annual increment

The biomass classes were identified with the aid of various types of imagery derived from AVHRR data, together with ecological, environmental and forestry data. The principal characteristics used to distinguish the classes were differences in vegetation cover, as indicated by their monthly NDVI values; differences in annual primary production, as indicated by their annual sums on monthly NDVI values; and differences in phenology, as indicated by their temporal profiles of AVHRR NDVI (see attached temporal profiles). The general arguments for the interpretation of the AVHRR NDVI data in terms of primary production are reviewed by Tucker et al., (1985) and Townshend et al., (1987) in which it is also shown that the classifications resulting from analysis of the satellite data correspond closely to vegetation maps and field observations of the location of the principal vegetation types of Africa. This material has already been dealt with in the presentation on AVHRR imagery.

In summary the reasons for this are:
(1) the strong relationship between the NDVI and Leaf Area Index (LAI); and
(2) the regular acquisition of cloud-free imagery using the AVHRR which enables the phenology of the vegetation to be observed throughout the entire continent.

The most important factor which determines the type and production of the vegetation over most of Sub-Saharan Africa is rainfall; although in the far south and on high ground temperature fluctuations are important. Strong correlations between rainfall and vegetation have often been observed in Africa (in southern Africa by Lamotte & Bourliere (1983) and Rutherford (1978); in Zaire by Malaisse (1978); and in west Africa by Menaut & Cesar (1979, 1982)) both with community type and composition, and with production. There is also a very strong seasonality in the vegetation owing to the clearly distinguished dry and rainy seasons (Sarmiento & Monasterio, 1983; Rutherford, 1978). The seasonality of rainfall affects the vegetation directly by its effect on primary production (Woodward, 1987) and indirectly by the prevalence of fires in the dry season which has selected species having various forms of dormancy (Sarmiento & Monasterio, 1983). The phenology of African vegetation is easily detected by AVHRR measurements of NDVI and this contributes significantly to the information content of the multi-temporal classifications used in this project (Tucker et al., 1985).

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SECTION TWO - SUMMARY RESULTS

THE VEGETATION OF SUB-SAHARAN AFRICA

On a continental scale, the vegetation of sub-Saharan Africa forms a series of fairly distinct bands stretching west to east, although this zonation disintegrates on meeting the extensive highlands associated with the Rift Valley of east Africa, especially in Ethiopia. A map of standing stock shows a similar pattern, with the greatest density of woody biomass centered on the Guineo-Congolian rain forest belt which extends through much of coastal west Africa and across northern Congo as far as Uganda. To the south, biomass stocks decrease steadily from the extensive miombo woodlands between about 5^0 and 15^0S to the open woodlands, shrublands and eventually the veld grasslands and deserts of southern Africa. North of the rain forest belt, a similar decrease in standing stock occurs through rather narrower zones of Guinean and Sudanian woodland, dry Acacia-Commiphora bushland and thicket, and the semi-desert wooded grassland which eventually merges into the Sahara at about 20^0N. East of the Rift highlands, much of Kenya and the Horn are covered by dry bushland and semi-desert vegetation, giving way to desert in coastal Ethiopia, Djibouti and parts of northern Somalia, and to a lesser extent in northern Kenya. In total, sub-Saharan Africa contains an estimated $51{,}122{,}113 * 10^3$ tonnes of woody growing stock, producing a Mean Annual Increment estimated at $3{,}037{,}566 * 10^3$ tonnes.

The Sahara Desert dominates the north of the studied area, extending into large areas of Sudan, Chad, Niger and Mali, and covering most of Mauritania. Desert also covers coastal regions of the Horn, as far south as northern Somalia. Apart from a few woody species at the southern fringe of the Sahara, most biomass is in the root system of drought resistant plants. In southern Africa, the Namib Desert stretches along the west coast from southern Angola, through Namibia and into South Africa. The other major desert areas are parts of the Kalahari in Botswana. In total, the desert (Class 0) covers nearly 4.1 million km^2 in sub-Saharan Africa. However, despite the dwarf shrubland on the fringes of the Namib Desert, and a few widely scattered trees in the Kalahari of south west Botswana, the overall contribution of Africa's desert areas to woody biomass stocks is negligible.

Veld grassland (Class 11) covers only small areas over much of Africa, but is of considerable extent in the southern Africa region, of which it covers nearly 6%. The largest block covers most of Lesotho, and much of the Orange Free State and southern Cape Province. Outliers are found throughout north west Botswana, and around the north east border of Angola. Woody biomass is largely restricted to riparian woodlands, and to rather small, widely spaced trees in the Kalahari thornveld of north west Botswana. Once again, the total contribution to standing stock in Africa is negligible.

Semi-desert wooded grassland (Class 21) is most extensive along the southern edge of the Sahara Desert, stretching eastward from southern Mauritania through the central areas of Mali, Niger, Chad and Sudan. The southernmost areas are in northern Kenya, and the class is also important in Somalia and the eastern half of Ethiopia. The vegetation is of grassland with bushes and small bushy trees (White, 1983). The grassland is dominated by annual species, and the cover tends to be rather ephemeral in the dry season, unless shaded by larger trees. The woody component is largely of Acacia spp., with a crown cover of less than 10%. woody biomass stocks are low - for example, semi-desert wooded grassland covers over 18% of the west African Sahel region but provides less than 6% of the regions total growing stock. Population density is low, although it increases towards the south of the belt. In Somalia, however, the semi-desert area supports over 40% of the population, which has meant severe stress on the trees (Kamweti, 1984). Semi-desert wooded grassland has a total growing stock of nearly 364 million tonnes, with a MAI of less than 14 million tonnes. The severe social consequences of depleting this resource base make sustainable management vital.

Transitional wooded grassland (Class 24) covers 11% of the southern Africa region, including 40% of Botswana, 20% of Namibia, and areas of northern and central South Africa which add up to 14% of the country. Over much of this area the vegetation is similar to that of the veld grasslands. In parts of Botswana and the Orange Free State, this class consists of Aristida dominated grassland, with a number of Karroid shrub communities of up to 5m in height. In the Transvaal and southern Mozambique, this class includes Acacia dominated Zambezian woodland in a mosaic with veld grassland. Despite its' large area, this class holds only 1.28% of the standing stock for southern Africa. Nonetheless, these areas are heavily used for cultivation and grazing. Since the majority of biomass is non-woody, and access is restricted due to land tenure, the transitional wooded grasslands are poor suppliers of fuelwood. In total, Class 24 has an estimated growing stock of nearly 146 million tonnes, producing a MAI of about 5.6 million tonnes.

Class 33, bushy shrubland, occurs mainly in the regions of east Africa and southern Africa, covering 1.8% and 1.96% respectively. In Kenya, this class consists mainly of small bushes and stunted trees, dominated by Acacia reficiens subsp. misera, although it also accounts for areas of montane vegetation in eastern Aberdare Mountains. In southern Africa, the largest areas are found along the west coast of Cape Province, and on the northern fringe of the Namib Desert along the coast of Angola. In Cape Province, the vegetation is of sclerophyllous shrubland, with a few taller bushes but very few trees. In coastal Angola, this class contains a rather open vegetation of small shrubs, with occasional taller Acacia-Commiphora shrub communities. Once again grass forms a large proportion of the biomass, and wood production is low; from a total growing stock estimated at 96.66 million tonnes, bushy shrubland produces a mean annual increment of less than 1.6 million tonnes. Thus, the potential for large scale, sustainable exploitation of fuelwood is extremely limited.

Kalahari shrubland (Class 34) covers 4% of southern Africa, including 10% of South Africa, 9% of Botswana and 8% of Namibia. In Botswana, Namibia and northern Cape Province, this class consists largely of rather sparse sand-dune vegetation, with scattered trees on the dune crests, and shrubs restricted to the troughs. In the hills bordering the Namib Desert, tall succulents and bushy trees up to 5m tall are scattered in an open shrub layer of about 2m in height. Similar to Kalahari shrubland is Class 35, wooded shrubland. Although it's distribution is close to that of Kalahari shrubland, it tends to occur in slightly moister areas, often at higher altitudes. Each of these classes has a standing stock of a little under 150 million tonnes, although the MAI of over 30 million tonnes for Kalahari shrubland compares with only 2.5 million tonnes for wooded shrubland. Even in such barren surroundings these classes represent a relatively poor source of fuelwood, and the present rate of fuelwood extraction easily outstrips yearly production.

Dry Acacia-Commiphora bushland and thicket (Class 41) is found in the countries of east Africa and the Horn. It extends over much of south eastern Ethiopia, and inland areas of southern Somalia and eastern Kenya. Major outliers are found in central and north west Kenya, northern Tanzania, north eastern Uganda and the extreme south east of Sudan. The bushland is dense, often forming impenetrable thickets, and reaches up to 5m in height, with scattered emergent trees up to 10m tall. With a total growing stock of nearly 944 million tonnes, this class produces a MAI of only 10 million tonnes. Overpopulation and overgrazing have severely degraded large areas of the bushland, often leading to desertification around boreholes, and the considerable demand for fuelwood is exacerbating the problem.

Patches of moist Acacia-Commiphora bushland and thicket (Class 43) are spread across southern and eastern Africa in a roughly arc-shaped distribution. The most northerly large area extends down the coastal strip of east Africa from about 4^0N in Somalia to the south coast of Kenya. A large triangular area of moist bushland covers much of central Tanzania as far as lake Nyasa, and the "arc" continues through Malawi and parts of Mozambique and Zambia, eventually reaching the coast of southern Angola. Large outlying areas are found in the south of Mozambique, and especially in Swaziland and the Transvaal. In east Africa, this class is principally dense bushland, up to 7m tall, with a grass cover reaching up to 1.5m. In southern Africa, however, it covers a wide range of floristic regions. The major similarity between theses areas lies in their rather seasonal phenology. Productivity peaks in the summer, sometime between December and May depending on the area of Africa concerned. A decline sets in from May, with the lowest productivity occurring towards September, the end of the dry season. After this, production climbs steadily. The moist bushland is rather more productive than the dryer bushland of Class 41, having a MAI of nearly 77 million tonnes on 1,685 million tonnes of standing stock. Nonetheless, the pronounced dry season ensures that productivity is till relatively low, limiting the potential for fuelwood exploitation.

Sahel-Sudanian Acacia wooded bushland (Class 44) forms a belt across north Africa centered on about 12^0N, from Senegal in the west to central Sudan and northern Ethiopia in the east. This belt lies between Sahelian semi-desert (Class 21) to the north and dry Sudanian woodland (Class 62) to the south. Class 44 is generally found in areas receiving between 250 and 500mm of rainfall per year. There is a herbaceous layer of mainly annual grasses, although perennial species are more common towards the south of the zone, and the ground layer is more persistent than that of semi-desert, surviving for most of the dry season. The major woody species are Acacia, increasing in height from 4m in the north to 8m in the south of the belt. The total growing stock of nearly 4,203 million tonnes is the third largest of any class, and produces a MAI of over 178 million tonnes. Processes such as agricultural and pastoral intensification (Graham, 1969) and overgrazing around tube wells have destroyed a great deal of woody biomass, and careful management is needed if this class is to supply a sustainable yield of fuelwood.

Acacia woodland mosaic (Class 51) is found for the most part in southern Africa, where it covers large areas of eastern Botswana and the Namibian interior, as well as northern Transvaal and the fringes of South Africa's veld grasslands. Extensive area are also found in the southern regions of Mozambique and Zimbabwe. Generally this class consists of rather open woodland with trees up to 10m tall, most commonly Acacia, Commiphora, Combretum and Terminalia species. These woodlands have frequently undergone scrub invasion. In southern Africa this class is dominated by agriculture, mainly pastoral, which restricts access to woody biomass. Productivity is fairly low, with 35 million tonnes of MAI from nearly 1,100 million tonnes of growing stock, so exploitation once again requires management.

Class 52, east Africa low woody biomass mosaic, is found mostly in a belt running from north east Uganda to the highland region of south west Kenya, although there are small outliers in the countries of the Horn. Much of this vegetation is of Combretum small tree savanna, becoming evergreen and semi-green bushland around the Kenyan highlands. With a growing stock estimated at 399 million tonnes, and producing nearly 32 million tonnes of MAI, this class is of considerable local importance.

Open woodland (Class 61) is found scattered amongst the miombo woodlands of Tanzania, where its composition is similar to that of the surrounding vegetation, and in Burundi, where the class is represented by moist Acacia-Commiphora bushland and Acacia wooded savanna. However, the vast majority of this class lies in the southern African region. Here it covers much of south eastern Angola and north eastern Namibia, northern Botswana, south western Zambia, much of Zimbabwe and parts of southern Mozambique, forming an irregular west-to-east belt between the miombo woodlands to the north and shrublands to the south. Open woodland encompasses a variety of vegetation types, including woodlands dominated by Brachystegia spp., Baikiaea spp. and Burkea africana. The total growing stock of Class 61 is estimated at 743 million tonnes, producing a MAI of nearly 63 million tonnes. Despite being an important source of fuelwood in South Africa and Lesotho, the rather low productivity of this class makes high rates of sustainable exploitation impossible in moist areas.

Dry Sudanian woodland (Class 62) lies in a west to east belt immediately south of the Sahel-Sudanian Acacia wooded bushland previously described. from west to east, it appears in; southern Senegal and the Gambia; southern areas of Mali and Burkina Faso; northern Ghana, Togo and Benin; northern Nigeria, CAR and Cameroon; southern parts of Chad and Sudan; and finally in northern Ethiopia. The vegetation is mainly a rather open tree savanna, 15 - 25m in height, or shrub savanna. Both Acacia and Combretum species are common, and there is a ground layer of annual and perennial grasses which burn easily during the dry season. The total standing stock for this class is a little under 1,050 million tonnes, with a MAI of over 213 million tonnes. Large areas of woodland have been degraded by agriculture and grazing. Fuelwood collection for cities such as Khartoum (Lewis and Berry, 1988) has left considerable areas almost treeless. The current fuelwood shortages, and associated environmental degradation, will almost certainly become worse at present rates of extraction.

Sudanian woodland (Class 64) forms another west to east belt across Africa lying immediately to the south of the dry Sudanian woodlands (Class 62), the belt is rather scattered, but broadest in the region of the west African coast. From the west, this class covers areas of Guinea-Bissau, Guinea, Mali, the Ivory Coast, Burkina Faso, Ghana, Togo, Benin, Nigeria, Cameroon, southern Chad, northern CAR, southern Sudan, and small areas in the highlands of Ethiopia. This class corresponds with areas which White (1983) classed as "Sudanian woodland with abundant Isoberlinia", and a mosaic of lowland rain forest and secondary grassland. Much of the area may be described as derived savanna, ranging from closed canopy savanna woodlands to thicket savannas. Sudanian woodland contains a growing stock of nearly 1,184 million tonnes, producing a MAI of over 391 million tonnes, the second highest of all the classes. Disturbance has been low, and the prospects for sustainable fuelwood extraction at present rates are good.

Moist Sudanian woodland (Class 65) is found scattered along the south of the Sudanian woodland belt in coastal west Africa, spreading eastward from central Guinea into central Africa. The largest area of this class lies across the border between Sudan and CAR, and the zone finally ends in northern Uganda. The vegetation is generally an open woodland savanna with trees reaching up to 15m in height. The most usual dominant tree species is Isoberlinia doka, and there may be an understorey of shrubs. Total standing stock is 1,887 million tonnes, with a MAI of over 282 million tonnes.

Seasonal miombo woodland (Class 66) covers huge areas of central and eastern Africa between about 15^0S and the equator. It is most extensive in northern Angola, southern Zaire, Zambia, Zimbabwe, Tanzania, Malawi and Mozambique, and also extends along the Indian Ocean coast from Beira in southern Mozambique to Port Elizabeth on the southern Cape. This class covers a wide range of woodland types, but the most common include Brachystegia, Julbernardia and Isoberlinia woodland, often up to 20m tall, and frequently with a woody understorey. Seasonal miombo contains the largest growing stock of any class, at over 6,836 million tonnes, and MAI is nearly 138 million tonnes. This represents a considerable potential for fuelwood exploitation, although access is often restricted due to cultivation, and reserves in South Africa.

Wet miombo (Class 67) is most extensive in northern Zaire, northern and central Angola, northern Zambia, south east Tanzania and Mozambique, especially near the coast. Generally found in wetter, less seasonal areas than Class 66, wet miombo has a similar species composition, but with rather dense thickets often forming the understorey. In total, wet miombo has a growing stock of nearly 2,540 million tonnes producing a MAI of over 43 million tonnes. With few exceptions, this class represents an important fuelwood resource in the countries where it is found.

Guinean woodland (Class 74) has a similar distribution to the moist Sudanian woodland (Class 65) already described. It is most extensive in 3 major areas; firstly in the region of coastal west Africa, where it is found in every country except Liberia; secondly in the Central African Republic and adjoining areas of Cameroon, northern Zaire and southern Chad; and thirdly, in the border region of southern Sudan, north west Uganda and north east Zaire. Rainfall is fairly high, so trees and shrubs tend to form fairly dense stands separated by grasslands or herbaceous wooded savanna (Laclavere, 1980). Guinean woodland has a growing stock estimated at nearly 3,123 million tonnes, greater than all but 4 of the other classes, producing a MAI of 256 million tonnes.

The most extensive biomass class in the region of coastal west Africa is Class 76, the medium productivity west African cultivation and forest mosaic. It is found in every country of the region, and forms a broad band from Guinea-Bissau to south eastern Nigeria. This class contains remnants of semi-deciduous humid tropical forest in a mosaic with areas cleared for agriculture and timber. The mosaic typically contains both rain forest and savanna species at its northern limits, where it may represent an ecological transition from humid tropical forest and Guinea woodland. Generally, forest and woodland dominate in areas of low population density, and clearance is more extensive in heavily populated regions, especially around towns and cities. The mosaic has the fourth largest growing stock of any class, over 3,641 million tonnes, coupled with the largest MAI, nearly 561 million tonnes. Ongoing forest clearance makes this class an important supplier of fuelwood both locally and to deficit areas.

Highland cultivation mosaic (Class 77) confined to Ethiopia, of which it covers about 17%. Found on plateaux areas between 2,000 and 3,000 masl, it is the result of thousands of years of deforestation due to fuel collecting, grazing and cultivation. Large areas are now treeless, although there are a wide range of land uses from dense cultivation to tree plantations, as well as remnants of forest and woodland. Total growing stock is a little under 1,350 million tonnes, but with a MAI of less than 15 million tonnes. The region has long suffered from critical fuelwood shortages, and these look set to continue and worsen.

Mangroves (Class 81) grow extensively on the coasts of eastern, central and west Africa, especially around river estuaries. Local pressure on mangrove swamps can be intense, especially along the west African coast. Mangrove wood makes excellent fuel, and is also used for smoking fish, so mangroves may be heavily exploited in densley populated areas, despite frequent protection by law. The failure of the satellite images to resolve very narrow fringes of mangrove swamp, notably on the east African coast, means that the figures for growing stock (193 million tonnes) and MAI (68 million tonnes) are almost certainly underestimates.

Evergreen forest (Class 82) mainly represents montane forest vegetation, and is found in a number of highland areas including the mountains of southern Tanzania and eastern Cape Province in south Africa, and the rift escarpment in eastern Zaire. These areas typically experience high rainfall and humidity, and encompass a wide range of both montane and lowland rain forest species. The total growing stock for the class is 1,310 million tonnes, with a MAI of over 90 million tonnes. Clearance has occurred in some areas, with only the steepest slopes remaining forested.

Mesophilous humid tropical forest (Class 85) is most extensive on the northern fringe of the equatorial ombrophilous forest (Class 87), where it covers large areas of Cameroon, Rio Muni, Gabon, Congo, CAR and especially Zaire. South of the equatorial forest, Class 85 is found in a broad swathe along the west coast from Cabinda to southern Gabon. The mesophilous forests are rather more seasonal than the equatorial forests, showing a more pronounced dry season, and correspond partly to Whites' (1983) drier Guineo-Congolian rain forest. The range of species is wide, as is the degree of species dominance. In all, this class represents about 2,850 million tonnes of growing stock, producing a MAI of over 72 million tonnes.

Humid tropical swamp forest (Class 86) forms a narrow strip near the equator, with areas around the western shores of Lake Victoria in Tanzania and Uganda, and in Zaire, Congo, southern Cameroon and Gabon. In total, swamp forest covers up to 6% of central Africa, and constitutes a growing stock of about 1,540 million tonnes. Annual increment is a little over 39 million tonnes.

Finally, there is the ombrophilous humid tropical forest (Class 87) which extends along the equator, covering huge areas in Zaire, Congo, Gabon, Cameroon, CAR and Rio Muni. There is little seasonality, with the mean annual rainfall of 1,500 - 2,100mm distributed fairly evenly through the year, and productivity is consistently high. The forest has a tall, closed canopy which may reach 45m in height. Most species are evergreen, although there are a few deciduous species which shed their leaves during the brief dry season. The ombrophilous forests have a total growing stock of nearly 5,932 million tonnes, second only to the much more extensive seasonal miombo to the south, and a MAI of over 150 million tonnes. Much of the remaining forest areas throughout Africa are protected within reserves. Much of the present equatorial forest area has been cultivated in the past, and the vegetation is secondary. Within some reserves, older secondary forest may be impossible to distinguish from primary forest. This enormous biomass resource has been largely removed from potential fuelwood reserves in the interests of science and tourism.

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KEY TO NUMBERING OF BIOMASS CLASSES

0	**DESERT**
0	Desert

1	**GRASSLAND**
12	Veld grassland
13	Hydromorphic grassland
18	Ethiopian montane steppe
19	Montane grassland and heathland

2	**WOODED GRASSLAND**
21	Semi-desert wooded grassland
22	*Acacia* wooded grassland *
23	Plateau wooded grassland
24	Transitional wooded grassland
25	Edaphic wooded grassland

* Irrigated areas in Sudan

3	**SHRUBLAND**
31	Veld shrubland and cultivation
32	Hill shrubland
33	Bushy shrubland
34	Kalahari shrubland
35	Wooded shrubland

4	**BUSHLAND & THICKET**
41	Dry *Acacia-Commiphora* bushland and thicket
42	Moist *Acacia-Commiphora* bushland and thicket
43	Sahel-Sudanian *Acacia* wooded bushland
46	Fynbos thicket
47	Escarpment wooded thicket

5 LOW WOODY BIOMASS MOSAICS

52	*Acacia* woodland mosaic
53	East African low woody biomass mosaic

6 WOODLAND

60	Sudanian woodland
61	Open woodland
62	Dry Sudanian woodland
63	Sudan/Ethiopian woodland and thicket
64	Moist Sudanian woodland
65/68	Wet miombo
66/67	Seasonal miombo

7 HIGH WOODY BIOMASS MOSAICS

72	Cultivation and forest/woodland mosaic
73	Guinean woodland
74/76	Cultivation and forest regrowth mosaic
75	High productivity West African cultivation and forest mosaic
77	Medium productivity West African cultivation and forest mosaic
78	Highland cultivation mosiac
79	Evergreen woodland mosaic

8 FOREST

81	Montane forest
82	Coastal and gallery forest
83	Evergreen forest
84	Mesophilous humid tropical forest
85/86	Humid tropical swamp forest
87	Ompbrophilous humid tropical forest
89	Mangrove