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Medicinal and Aromatic Plants' Productivity and Sustainability Monitoring Framework

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Author's contribution

This work was carried out solely by the author who designed the study, performed the data collection, performed statistical analysis, wrote the protocol and screening, managed the literature searches and wrote the first draft of the manuscript.

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ABSTRACT

Aims: To establish a programmatic framework facilitating all stakeholders harmonize their approaches and methodologies in ensuring sustainable management of Medicinal and Aromatic Plants.
Study Design: Combination of semi-structured interviews, questionnaire, and direct observation research methods.
Place and Duration of Study: Selected towns and villages in South Western States of Nigeria between January 2010 and June 2012.
Methodology: 'Participatory approach' adopted to explore individual perceptions, values and attitudes through in-depth interviewing and administration of semi-structured questionnaires with open-ended pertinent questions for all stakeholders' joint inputs. 413 stakeholders (General Practitioners with Complementary and Alternative Medicine (CAM) knowledge, CAM practitioners with biomedicine knowledge, pharmacists, MAPs consumers, and community members), 127 Parks and Gardens government officials, 58 conservation scholars/researchers, and 14 legal practitioners on MAPs conservation were interviewed to perform stakeholder analysis. Model-driven engineering

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tools were used to create the static behaviour aspects of MAPs management. A logistic productivity and sustainability potential of a village medicinal plants harvesting was simulated with a written software.

Results: CAM practitioners demanded appropriate information on the sustainable use of MAPs. Regulatory/government body ensured stakeholders' compliance with the laws governing harvesting of MAPs, while reducing or avoiding policies/political changes that could result in MAPs' loss. Doctors/nurses showed interest seeking integration of conventional medical practice with MAPs-based therapies. Pharmacists expressed interest exploring MAPs for new therapeutics. Scholars/researchers demanded research grants/funding from governments and their research findings' implementation.

Conclusion: Coordination among different stakeholders, significant involvement of the parks management, improvement in national education standards, and a legal framework that provides a basis for co-management agreements that constitute critical success factors needed to implement viable and sustainable conservation agreements within the program. MAPs' productivity and sustainability demand individual and collective responsibilities from all stakeholders for better management of ecosystem and public health in a viable option using a 'participation model'.

Keywords: Biodiversity; conservation; framework; healthcare; logistic growth model; medicinal and aromatic plant; productivity; sustainability.

ABBREVIATIONS

BDCP : Bioresources Development and Conservation Programme
CBD : Convention on Biological Diversity
EDD : Empowered Deliberative Democracy
FCAMN : Federal College of Complementary and Alternative Medicine of Nigeria
MAPs : Medicinal and Aromatic Plants
NIPRD : Nigeria Institute for Pharmaceutical Research and Development
NNMDA : Nigerian Natural Medicine Development Agency
TMK : Traditional Medicine Knowledge
IPR : Intellectual property Rights
PVP : Patents and Plant Variety Protection

1. INTRODUCTION

Health is both a resource for, as well as an outcome of, sustainable development. Medicinal and Aromatic Plants (MAPs) are increasingly recognized worldwide as an alternative source of efficacious and inexpensive medications to synthetic chemo-therapeutic compounds.

Local indigenous communities make direct links between environmental assets and human well-being, because many of them have depended on nearby ecosystems for their livelihood for many generations and have developed specific knowledge about keeping those ecosystems in good health [1]. Environmental degradation, mismanagement of natural resources, and unhealthy consumption patterns and lifestyles impact health. Ensuring access to good quality health care—whether physical or economical—has been a major challenge to planners and policymakers. Ensuring environmental sustainability would demand (1) encouragement of community level good practices on sustainable use as well as management of medicinal, nutritional and cultural resources; and (2) identification and strengthening of traditional knowledge-based practices for safe drinking water [2].

Biodiversity monitoring needs to be grounded in clear goals and objectives, effective in generating reliable assessments of changes and realistic in light of real-world financial, logistical and social constraints [3]. Industry, governments, certifiers, resource managers and collectors are concerned about declining MAPs populations and supplies, and are searching for methods to verify the sustainability of wild collections [4]. Although sustainability covers a broad range of domains, such as shown in Fig. 1, most sustainability issues share challenges of architecture, scale, heterogeneity, interconnection, optimization, and human interaction with systems, each of which is also a problem central to Computer Science (CS) research. A chief goal of CS in sustainability can be viewed as that of informing, supporting, facilitating, and sometimes automating decision making—decision making which leads to actions that will have significant impacts on achieving sustainability objectives [5].

Fig. 1. Broad Range of Sustainability Domains [5]

Declining wild stocks of medicinal plants are accompanied by adulteration and species substitutions, which in turn reduce efficacy, quality and safety. MAPs' sustainability remains in jeopardy creating a gap between promises from computing technologies and expectations in the healing process under Complementary and Alternative Medicine (CAM) [6,7]. According to ([8], degradation of the natural environment and the need for conservation measures have constituted urgent concerns with ever more evidence of how human activities are despoiling the planet, exacerbated by current climate change predictions. According to [9], the medicinal plants sector involves various stakeholders, ranging from collectors to end users; local traders to exporters; traditional healers to professional practitioners; small formulators to industrial manufacturers; community-based organizations (CBOs) to national nongovernmental organizations (NGOs) and government agencies. All stakeholders can cause – or can be affected by – fluctuations in the medicinal plants sector, at varying degrees of scale, power and interest. Hence, it is challenging to integrate the interests of all stakeholders in a sustainable, integrated management strategy. Holistic approaches that would improve communication among conservationists and scientists in medicine, environmental health, ecology, anthropology and forestry – all dealing separately with similar issues – are rare, resulting in failure to exchange views or share findings [10]. There is a demonstrated need to focus on academic and individual researchers working on different and innovative ways of conducting research into conservation of MAPs globally. Information Technology has dramatically changed the way scientific research is conducted, giving rise to multidisciplinary fields such as biodiversity informatics [11].

Different societies of the world use the MAPs according to their own beliefs and knowledge and previous experiences. Their knowledge about the use of the MAPs is usually not known to the other world societies or scientists. These hidden areas need to be explored [12]. For example, Fig. 2 shows a CAM practitioner home for MAPs prescription and sales.

Non-governmental conservation organizations are an important stakeholder in biodiversity conservation and their conservation behaviour and strategies will impact on the conservation of biodiversity and ecosystem services [13]. Indigenous communities have accumulated a wealth of traditional knowledge through centuries of close dependence on nature – including knowledge about MAPs, wild foods and agricultural practices, and knowledge embodied in the native seed varieties and livestock breeds that they have improved and conserved. Researches by eminent scholars as exemplified in Fig. 3 represent a significant effort knowledge exposure on MAPs.

Fig. 2. CAM Practitioner Home, Ota, Nigeria

Fig. 3. Medicinal_plants_in_Nigeria.com [14]

In recent years, indigenous organizations have become increasingly concerned about the privatization of their knowledge and bio-resources, alienation of their rights and unfair exploitation of these resources, without permission or respect of customary laws. Intellectual Property Rights (IPRs) regimes – such as patents and plant variety protection (PVP) – are becoming increasingly strong and ubiquitous as a result of trade agreements of the World Trade Organization (WTO) and the proliferation of bilateral Free Trade Agreements. This is accelerating the commercial use and privatization of indigenous knowledge and resources [15]. Indigenous peoples' and local communities' conserved territories and areas (ICCAs) contribute to the resilience and diversity of many ecosystems around the world. Their cultures, identities, languages, customary laws, traditional knowledge and practices, and worldviews are equally diverse and inextricably linked to those specific territories and areas. Due to these inextricable links between indigenous peoples and local communities and the territories and resources upon which they depend, the loss of biological diversity is fuelling the loss of cultural and linguistic diversity and inter-generational transmission of knowledge and practices [16]. The absence of an internationally agreed methodology for sharing economic benefits from the commercial exploitation of biodiversity with the primary conservers and holders of traditional knowledge and information is leading to a growing number of accusations of

biopiracy committed by business and industry in developing countries [6]. A number of international and national policy initiatives are seeking to respond to the challenge of ensuring that the rights of indigenous and local communities over their traditional knowledge are respected and protected. Many people agree that existing IPRs – such as patents and PVP – are not suitable for protecting traditional knowledge and that alternative 'sui generis' systems are needed. IPRs are designed to protect commercial inventions and mostly grant individual and exclusive rights; whereas traditional knowledge of communities is first and foremost for subsistence and is largely held collectively, as ancestral heritage [17]. There is an implementation gap in global environmental policies as a result of the limited involvement of local stakeholders who would be affected the most by and, theoretically, benefit most from those policies [18]. By enhancing stakeholder involvement, participatory management strengthens policy relevance, diminishes uncertainties, improves monitoring and raises enforcement rates [19].

1.1 Challenges of Regulating Medicinal Plants in Nigeria

Nigeria is rich in biodiversity and is endowed with a variety of plant and animal species as there are about 7, 895 plant species identified in 338 families and 2, 215 genera [20]. The low accessibility or inaccessibility and non-affordability of modern drugs among the rural populations of tropical Africa have made a large proportion of rural people depend on traditional herbal drugs in order to be healthy and economically productive [21,22,23,24,7,25].

The Government of Nigeria has realized that there is a need to conserve the plant resources within the overall framework of its policy on the environment, which advocates biodiversity conservation and sustainable utilization of resources through effective management plans and resources inventories, as well as community participation. One of the greatest challenges facing the management of MAPs diversity and traditional medicines in Nigeria is the dearth of comprehensive, adequate and reliable information to inform precise and rational decision-making with respect to policy and implementation in the country. There is a need to harmonize national activities around environmental protection, sustainable use and conservation of natural resources, especially of MAPs, so as to develop new economic opportunities [26]. CAM practitioners need appropriate information on the sustainable use of MAPs and alternative ways of earning their living.

In partly responding to the above challenges, Nigeria's present network of protected areas includes a biosphere reserve, 8 national parks, 445 forest reserves, 12 strict nature reserves and 28 game reserves. The eight national parks cover a total surface area of 24,000 sq. km or 3% of the country's land area (923,000 sq. km). The national parks are on the exclusive legislative lists in the country's constitution and are therefore managed and controlled by the Federal Government of Nigeria [27]. The key players of Documentation of Traditional Medicine Knowledge (TMK) in Nigeria are Nigerian Natural Medicine Development Agency (NNMDA), Nigeria Institute for Pharmaceutical Research and Development (NIPRD), and Bioresources Development and Conservation Programme (BDCP), and Federal College of Complementary and Alternative Medicine of Nigeria.

Co-management of protected areas is widely considered to be a promising approach to overcoming conflicts between nature conservation and economic development. In particular, negotiated agreements between communities and the management of protected areas, often facilitated by NGOs, are a major approach to co-management such as depicted in Fig. 4 [28].

Protected areas in developing countries are one of the fields where negotiation approaches are particularly promising, because conflicts of interests are frequently observed and conventional strategies of state management have often failed. Table 1 gives an overview of the strategies applied by the three NGOs (Advocacy NGO, Rural Development NGO, and Conservation NGO).

Table 2 summarizes the challenges pertaining to sustainable management, use and commercialization of MAPs in Rasuwa District of Central Nepal as discovered by [9].

1.2 Decision-Making on MAPs' Sustainability Development

Most sustainability challenges will not be addressed by a decision made at a single point in time. Instead, decisions must be made

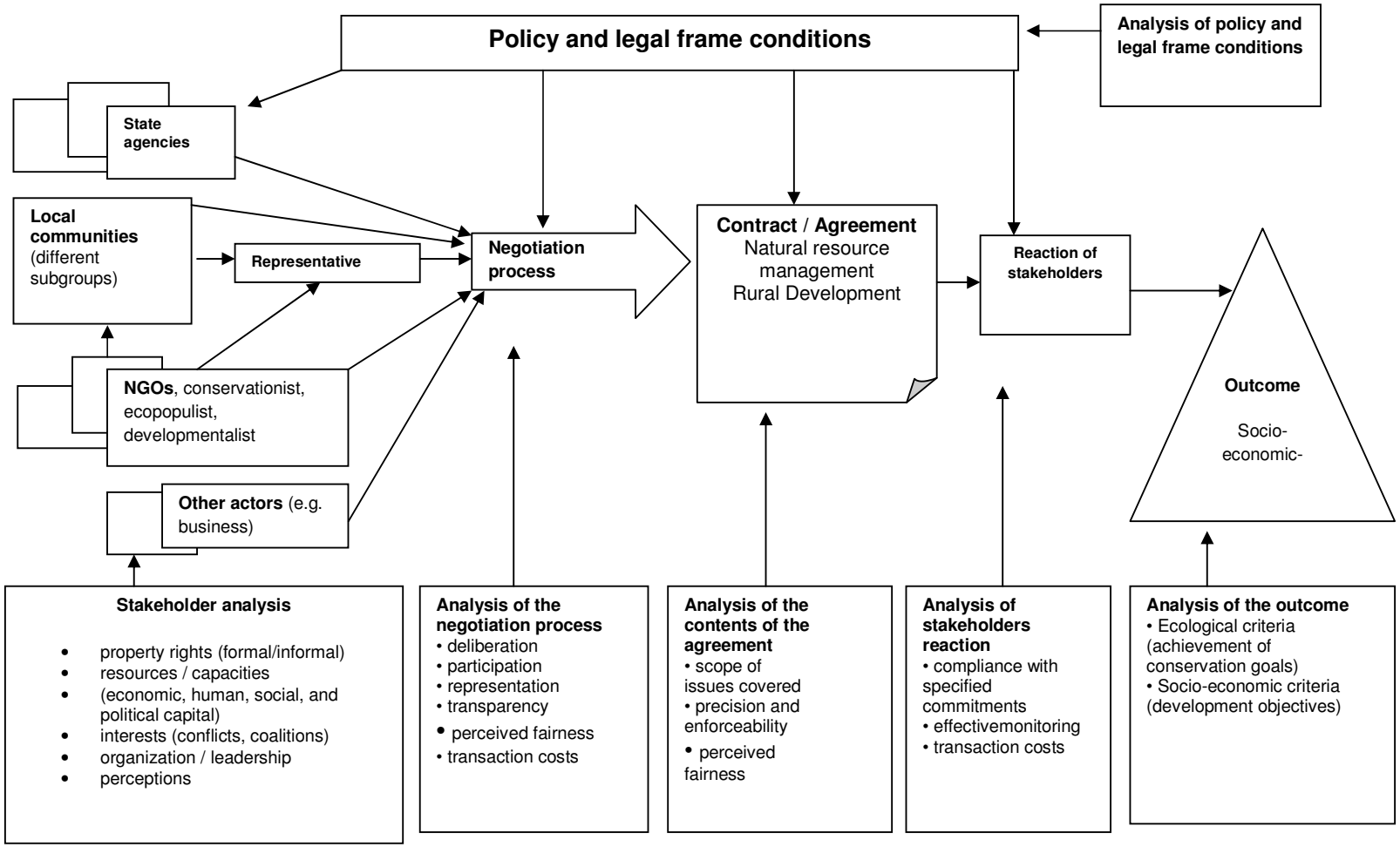


Fig. 4. Analytical framework of negotiated agreement on nature conservation [28]

Table 1. Overview of the agreement strategies of different NGOs [28]

Type of organization	Local advocacy NGO with international funding	International development NGO, with international and local staff	International conservation NGO (with a local sister organization focusing on community activities)
Focus of activities in general	Advocacy for indigenous rights, 'watchdog' of government and international activities	Rural/community development (agricultural extension, infrastructure provision, etc.), sustainable management of natural resources	Community development activities as complementary measure for nature conservation activities (such as improved park management)
'Logic' behind community agreement	Commitment to keep rules on conservation, enforced and sanctioned by traditional village institutions, as part of a strategy to regain traditional resource use rights in the park	Rules on conservation as part of a general set of the village; prerequisite required for providing development services, including infrastructure development	Commitment to keep clearly specified rules of conduct within rules on conservation in exchange for provision of development services and infrastructure by government organizations and projects
Selection of villages	Villages that request assistance for agreement; at present: only indigenous villages	All villages where the NGO conducted activities in Phase 1 of its programme in the Lore Lindu region	Villages where conflicts concerning the protection of the National Park appear severe
Role of the NGO concerning the Agreement	Facilitator of agreement, provider of support for social mobilization and capacity building in the village, promoter of policy dialogue with various organizations	Facilitator of agreement and provider of development services and infrastructure	Facilitator of agreement, broker between conservation organization and organizations/projects providing development services and infrastructure
Representation of the villagers concerning the agreement	Traditional village institutions (LembagaAdat)	Formal village government (KepalaDesa)	Representatives of the village chosen especially for the purpose of the village agreement
Mapping of resource use	Community-based mapping of traditional resource use rights (using global positioning system (GPS), but not GIS)	So far not applied	Community-based mapping of actual resource use (with GPS and GIS

Table 2. Summary of MAPs sustainable management challenges [9]

Rank*	Local collectors	Local traders	District and national organizations
1	Lack of market information.	Lack of infrastructure in the district for value addition and grading.	Limited species-specific information such as availability, distribution, productivity, regeneration potential, etc.
2	Inadequate supply of inputs and technical support for cultivation.	Ambiguous policies.	Declining resources availability due to overexploitation, over-grazing and habitat loss.
3	Oligopoly maintained by a few local traders.	Illegal trade link with 'big mafia'.	Lack of resources for management and monitoring.
4	Depletion of the medicinal plants.	Lack of market information on prices, quality standards, required herbs and proper identification.	Ambiguous policies.

**1 = most important, 2 = important, 3 = fairly important, 4 = least important*

iteratively over a long time horizon since a system is not sustainable unless it can be operated indefinitely into the future. For example, in problems involving natural resource management, every year provides a decision-making opportunity [5]. Decision-making on MAPs' sustainable development would therefore depend on answers to the following questions, among others: What indicators and prices should be used for biodiversity? What viability thresholds should be considered for MAPs' population sustainability? What harvesting quota levels for, say, *Anacardiumoccidentale* (Cashew nut), *Azadirachtaindica* (Neem), *Allium sativum L.* (Garlic), *Zingiberofficinale Roscoe* (Common Ginger), and *Carica papaya* (Pawpaw)? What size reserves will assure the conservation of MAPs species in Africa and where should they be located? What land-use and degree of intensification are appropriate for agro-environmental policies in Africa? How high compensation payments should there be for the biodiversity impact and damage caused by development projects? How may compromises be found? How can one build decision rules and indicators based on multiple observations and/or criteria? What should the coordination mechanism to implement heterogeneous agents exploiting natural resources be? [29].

1.3 Aim

Understanding our stakeholders' concerns and interests as an important step in building a targeted and relevant communications strategy has been widely acclaimed. The aim of this paper is to establish a framework that offers an opportunity for all stakeholders harmonize their approaches and methodologies in working together to ensure sustainable utilization of the available MAPs biodiversity.

1.4 Objectives

a. To halt the decline of plant resources, associated indigenous and local knowledge, innovations and practices that support sustainable livelihoods, local food security and health care.
b. To ascertain existing and potential collaborative relationships between stakeholders, and the barriers to and drivers of these relationships with respect to monitoring the productivity and sustainability of MAPs.
c. To unravel the mechanisms through which the ecosystem services provided, displaced, diverted and degraded by agricultural landscapes are linked to human well-being and how they can contribute to poverty alleviation.

2. MATERIALS AND METHODS

Stakeholder analysis is a process that: i) defines aspects of a social and natural phenomenon affected by a decision or action; ii) identifies individuals, groups and organisations who are affected by or can affect those parts of the phenomenon (this may include nonhuman and non-living entities and future generations); and iii) prioritises these individuals and groups for involvement in the decision-making process. Within policy, development, and natural resource management, stakeholder analysis is increasingly seen as an approach that could empower marginal stakeholders to influence decision-making processes [30]. In stakeholder analysis, the following, among, others, are addressed:Who are the resource users, who has an interest in managing the resource? Who should be involved in gathering and interpreting the data on which the decisions will be made? Who should be involved in using this information to weigh options and make final decisions? How can these groups be represented in the management activities? [31]. Stakeholder analysis is used to identify people, groups, and institutions that will influence your project (either positively or negatively), anticipate the kind of influence, positive or negative, these groups will have on your project, and develop strategies to get the most effective support possible for your project and reduce any obstacle to successful implementation (WHO, 12). To achieve sustainable management of medicinal plants, it is crucial to identify the respective roles, responsibilities and viewpoints of the various stakeholders involved [9].

2.1 Study Area

Nigeria operates a Federal System of Government with three levels; the Federal, the State and the Local Government Areas/Councils (LGAs). There are 774 LGAs within the 36 states and Federal Capital Territory (FCT) Abuja (Fig. 5).

The 774 LGAs are further sub-divided into 9,565 wards. The states and FCT are grouped into six geo-political zones, namely: the South-South, the South-East, the South-West, the North-East, the North-West and the North Central zones [32] as shown in Table 3.

Fig. 5. Political Map of Nigeria [32]

Table 3. Geo-Political Zones of Nigeria [32]

SN	Zones	No. of States	Names of States
1.	North Central	7	Benue, Kaduna, Kogi, Kwara, Nassarawa, Niger, and Plateau.
2.	North Eastern	6	Adamawa, Bauchi, Borno, Gombe, Taraba, and Yobe
3.	North West	6	Jigawa, Kano, Katsina, Kebbi, Sokoto, and Zamfara
4.	South East	5	Abia, Anambra, Ebonyi, Enugu, and Imo
5.	South South	6	Akwalbom, Balyesa, Cross River, Delta, Edo, and Rivers
6.	South West	6	Ekiti, Lagos, Ogun, Ondo, Osun, and Oyo
7.	FCT	1	FCT (Federal Capital Territory)

The study, which covered January 2010 through June 2012, was carried out in some Nigerian research institutes (International Institute of Tropical Agriculture (IITA), Ibadan; Forestry Research Institute of Nigeria (FRIN), Ibadan; National Institute of Horticultural Research (NIHR), Ibadan; and University Botanical Garden, Ibadan); General Practitioners (GPs) with Complementary and Alternative Medicine (CAM) knowledge, CAM practitioners with biomedicine knowledge, Pharmacists; Traders, herbs hawkers, and numerous CAM practitioners in the following towns and villages in South Western States of Nigeria: Akungba-Akoko, Idanre, Oba-Akoko, Oka-Akoko, Ondo, Owo, and Supare-Akoko (Ondo State); Abeokuta, Ota, and Ijebu-Ode (Ogun State); and Agege, Lagos, Mushin, and Oyingbo (Lagos State). The South Western States of Nigeria are endowed with abundance of MAPs and the communities there heavily rely on MAPs as food sources and healing.

Focus groups, interviews, and workshops approaches were adopted for this study. After identifying the key stakeholders and their interests (positive or negative) in the project, we differentiated between and categorised them to assess the influence of, importance of, and level of impact upon each stakeholder. We then investigated the relationships among the various stakeholders to determine how best to engage them for collaboration. A non-probability sampling procedure (purposive sampling) was employed. This facilitated the use of professional assessment, instead of randomness, in choosing

the respondents thereby restricting the survey only to key informants who were considered to be endowed with indigenous knowledge. A "Participatory Approach" was adopted to explore individual perceptions, knowledge, values, attitudes, and barriers to collaboration efforts through interviewing and semi-structured questionnaires for the joint inputs of all stakeholders. 700 semi-structured questionnaires were administered.The following aspects, adopted from [9] were covered by the questionnaires and checklists: perspectives on the use of medicinal plants; collection, trade systems, market availability and contribution of medicinal plants to income generation and livelihood improvement for the local people; conservation and management issues and perspectives; perceived institutional and legal challenges and opportunities. For each community covered, two workshops were organized to get together all stakeholders: one before the start of the project, and another at the end. The first workshop helped identify the major stakeholders, and the second allowed to corroborate the main results of the study. The collected data were coded and input as nominal and ordinal data into the Statistical Package for Social Sciences (SPSS for Windows version 15). Nonparametric tests of statistical significance were performed. Focus groups for in-depth interviews consisted of 413 stakeholders made of General Practitioners (GPs) with Complementary and Alternative Medicine (CAM) knowledge, CAM practitioners with biomedicine knowledge, pharmacists, MAPs consumers, community members; 127 government officials (40 Parks and Gardens, 87 Forestry Research Institutes), 58 conservation scholars/researchers, and 14 legal practitioners on MAPs conservation.

In the questionnaire, the most predictable answers had been pre-stated for data capturing convenience, but were not read out to respondents to minimize the researcher's influence on the respondent's view. Recording of the responses was conducted during the interview process. In addition, notes were made on the relevant additional information provided by the respondents. A 'participation model' was explored and adopted for this study. This model was built on an Extended Peer Community concept where various stakeholders with various perspectives were brought into the dialogue to assess the input from science to decision-making. Borrowing from [33]'s approach, this methodology was developed through the joint inputs of all stakeholders including community members, agricultural specialists, extension services, researchers, local institutions, and decision makers. The pillar of the methodology was an effective communication where all stakeholders negotiate a community development plan (CDP) on an equal basis and where all sources of knowledge were explored, encompassing both indigenous and research-based knowledge. Respondents were interviewed on their awareness of the potential extinction of MAPs, the causes of the potential extinction of MAPS and their belief in what those causes are, the importance of the various MAPs extinction impacts, how prepared they are to cope with the impacts, their willingness to incur costs in order to protect themselves (from the impacts), and their level of trust in institutions.

Fig. 6. Interview with Prof. C.K. Ayo, a researcher / scholar

In adopting proven techniques previously reported in the literature, interviewers were recruited from local universities and made to undergo several days of training. The survey instruments included detailed questions on demographic characteristics and the value of various commodities and services provided by the parks. The survey instruments were refined through a process that included review by local experts, focus groups and pre-tests. The author was part of the questionnaire and study design, as well as the training and monitoring team.

Figs. 6 to 11 represent some of the interview sessions with reseachers/scholars, CAM practitioner, and discussion of a MAP at different fora.

The Model-Driven Engineering development approach (including Unified Modeling Language (UML) tool) was used to create the static behaviour aspects of MAPs management and abstract models to describe systems. The models were systematically transformed to concrete implementations. A simulation program was written in C++ programming language to validate the logistic productivity and sustainability potential of a village medicinal plants harvesting aspect of the framework.

Fig. 7. Views exchanges with Prof. V.W. Mbarika, a researcher/scholar, at an international conference

Fig. 8. Author's interview with Prof. L.O. Egwari, a pioneer in a Carica papaya (pawpaw) demonstration farm

Fig. 9. A woman CAM practitioner being interviewed on MAPs sustainability

Fig. 10. Interviewing a scholar at an international Exhibition Stand

Fig. 11. Author discussing essentials of *Zingiber officinale* Roscoe (Common Ginger) medicinal plant to Prof. (Mrs) Aize Obayan and other members of the audience at an international Exhibition Stand

3. RESULTS AND DISCUSSION

The various stakeholders identified with their respective role and impact on the MAPs' productivity and sustainability monitoring project are presented in Table 4. Women consume MAPs mostly. The MAPs consumers and indigenous community members, who are

Table 4. Stakeholders versus Role Matrix

Stakeholders	Number	Stake / Mandate	Potential Role in Project	Marginalized?	Key?	Per cent
General Practitioners (GPs) with Complementary and Alternative Medicine (CAM) knowledge	62	Control CAM consumption with orthodox recommendations	Integration of conventional and CAM practice to increase access to essential healthcare services, especially for rural and underserved populations.	No		8.86
CAM Practitioners with biomedicine knowledge	102	Harvest MAPs for healing.	Increase access to essential healthcare services, especially for rural and underserved populations.	No		14.57
Pharmacists	21	Explore MAPs for new drugs against synthetic drug-resistant ailments	New therapeutics	No		3.00
MAPs consumers	115	Harvest MAPs as sources of food and medicine.	Mostly women. Depend on MAPs for healthy living.	Yes.	Yes	16.43
Indigenous community members	113	Indigenous knowledge custody with Intellectual Property Rights honoured.	Depend on MAPs as a means of livelihood.	Yes	Yes	16.14
Parks and Gardens government officials	40	Protection of MAPs from intruders.	Protection of MAPs from over-harvesting	No	Yes	5.71
Forestry Research Institutes officials	87	Protection of MAPs from intruders	Conservation of MAPs from over-harvesting. Provide specimen for researchers.	No		12.43
Conservation scholars/researchers	58	Researches on MAPs: ethnobotany, phytotherapy	Undertake research.	No		8.29
Legal practitioners	14	Provide guidelines on lawful exploitation and use of MAPs	Legislation & enforcement provisions	No		2.00

indispensable to the success of MAPs' productivity and sustainability monitoring project, are marginalized. These marginalized stakeholders lack the recognition or capacity to participate in collaboration efforts on an equal basis, and particular effort must be made to ensure and enable their participation.

Out of 700 questionnaires administered, 612 (87.43%) questionnaires representing 62 General Practitioners (GPs) with CAM knowledge (8.86%), 21 Pharmacists (3.00%), 102 CAM practitioners with biomedicine knowledge (14.57%), 115MAPs consumers (16.43%), 113 Community members (16.14%), 40 Parks and Gardens government officials (5.71%), 87 Forestry Research Institutes officials (12.43%), 58 conservation scholars/researchers (8.29), and 14 legal practitioners on MAPs conservation (2.00%) responded while 88 (12.57%) declined as shown in Fig. 12.

The dependence of local communities on MAP resources as a major source of health and livelihood security is indisputable. 330 respondents (47.04%) being the sum of MAPs consumers, CAM Practitioners with biomedicine knowledge, and Indigenous community members confirmed this assertion. Conservationists perceive a population decline in overharvested MAPs. Local communities and conservationists traded accusations as being responsible for the decline. Communication protocol frictions have been responsible for the exchange of accusations and conflicts between local communities and conservationists.

Conflicts between western and local legal systems regarding the use and management of genetic resources, and social and equity issues, especially the rights of indigenous communities and protection of their traditional knowledge surfaced. Local communities initially resisted disclosure of knowledge because of former interviewers' failure to acknowledge their significance in a similar project. They expressed fear of getting their IPRs honoured vis-à-vis cost-benefit analysis to ensure financial viability of the local communities. Understanding the system dynamics was not doubted by all the stakeholders. Stakeholders agreed on the need for co-management of MAPs resources. As monitoring is practicable, management and monitoring costs must be low enough to be profitable. The government authorities must be prepared to devolve power and responsibility to local communities. With a robust institutional structure responsive to changes in circumstances in place, external threats would be containable. All stakeholders expressed commitment to success.

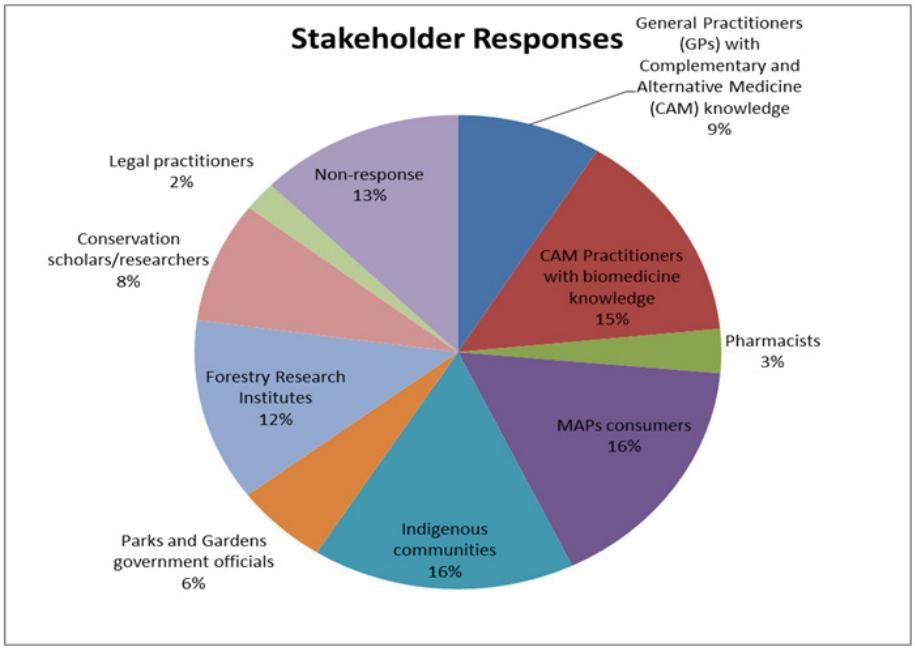


Fig. 12. Stakeholders' Questionnaire Responses

Fig. 13 presents all the various stakeholders and their respective responsibilities in the framework for a sustainable management of MAPs. The aggregated framework shows the communications infrastructure and the principal stakeholders including: (1) CAM practitioners / harvesters featuring the harvesting dynamics for regulation, otherwise, there would be over-exploitation of MAPs that could result in the latter's extinction. (2) Regulatory/government body is to ensure stakeholders' compliance with the laws governing harvesting of MAPs. Government should also reduce or avoid policies/political changes that could result in loss of MAPs. Funding research on MAPs is required. (3) Doctors / nurses are seeking integration of conventional medical practice with MAPs-based therapies in view of emerging new infectious, chronic and drug-resistant but life-threatening diseases. (4) researchers/pharmacists have been prompted to focus on MAPs to be explored as MAPs have been recognized worldwide as agents for treatment and prevention of ailments/diseases. New therapeutics are required, following patients' increasing demands for less aggressive forms of therapy, and the fact that patients are leery of the toxicity of pharmaceutical drugs since adverse drug reactions have become the sixth leading cause of death in hospitalized patients. Researchers/pharmacists also expressed interest in diseases research/epidemiology, research grants/funding from governments, and implementation of their research findings about MAPs. Variations / changes including environmental, climatic, business and socio-economic changes constitute important entities in the sustainability of MAPs.

A bi-directional link was established between *Research Component* and *National Park*to desirably facilitate the expected research activities and feedback by each party as shown in Fig. 14. The illustrations in Fig. 14 depict samples of expected players in the conservation exercise from Fig. 13.

3.1 Validation by Simulation

Most models validate or evaluate collaboration from the perspective of the professionals and stakeholders involved. But, due to the complexity of intersectoral collaboration as depicted in Figs 13 and 14, there is not likely to be a single comprehensive model of evaluation that can be applied everywhere in assessing structural integration, functional integration, and integration effects on outcomes. Instead, research and development has concentrated on specific models evaluating different aspects of collaboration from different perspectives. This stage considers the bioeconomic model of harvesting dynamics of the framework in Fig. 12 in the evaluation exercise of MAPs.

3.2 Simulation of Village Harvesting

A logistic productivity and sustainability potential of a village medicinal plants harvesting was obtained using *(1)* in a simulation program by varying the indicated variables (parameters):

$$PrF = r * Pop[t]*(1-Pop[t]/K);\ 0<= t <= (y-1) \text{ for a model of } y \text{ Years} \quad (1)$$

Where K = the carrying capacity; $N1$ = starting population size; r = intrinsic rate of increase;

Table 5. Sample simulation input parameters for Model Evaluation

Program Runs	Starting Population (N1)	Carrying Capacity (K)	Intrinsic rate or increase (r)	No of Harvesters (H)	Harvester price (P)	1st Cost calc constant (a)	2nd Cost calc constant (b)	Cost SD (s)	No of Years (Years)
1	1750	2000	0.2	250	105	200	0.2	10	50
2	500	1000	0.1	100	100	100	0.1	5	50
3	2000	4000	0.5	200	150	150	0.4	10	50
4	1000	3000	0.4	200	120	100	0.3	10	20
5	5000	10000	0.5	250	200	150	0.4	15	50
6	25000	25000	0.2	240	130	100	0.6	20	50
7	300	1000	0.8	50	200	100	0.5	30	10
8	50000	25000	0.7	150	250	250	0.6	50	50
9	30000	50000	0.9	50	300	150	0.4	20	50
10	50	1000	0.9	5	100	100	0.3	20	10

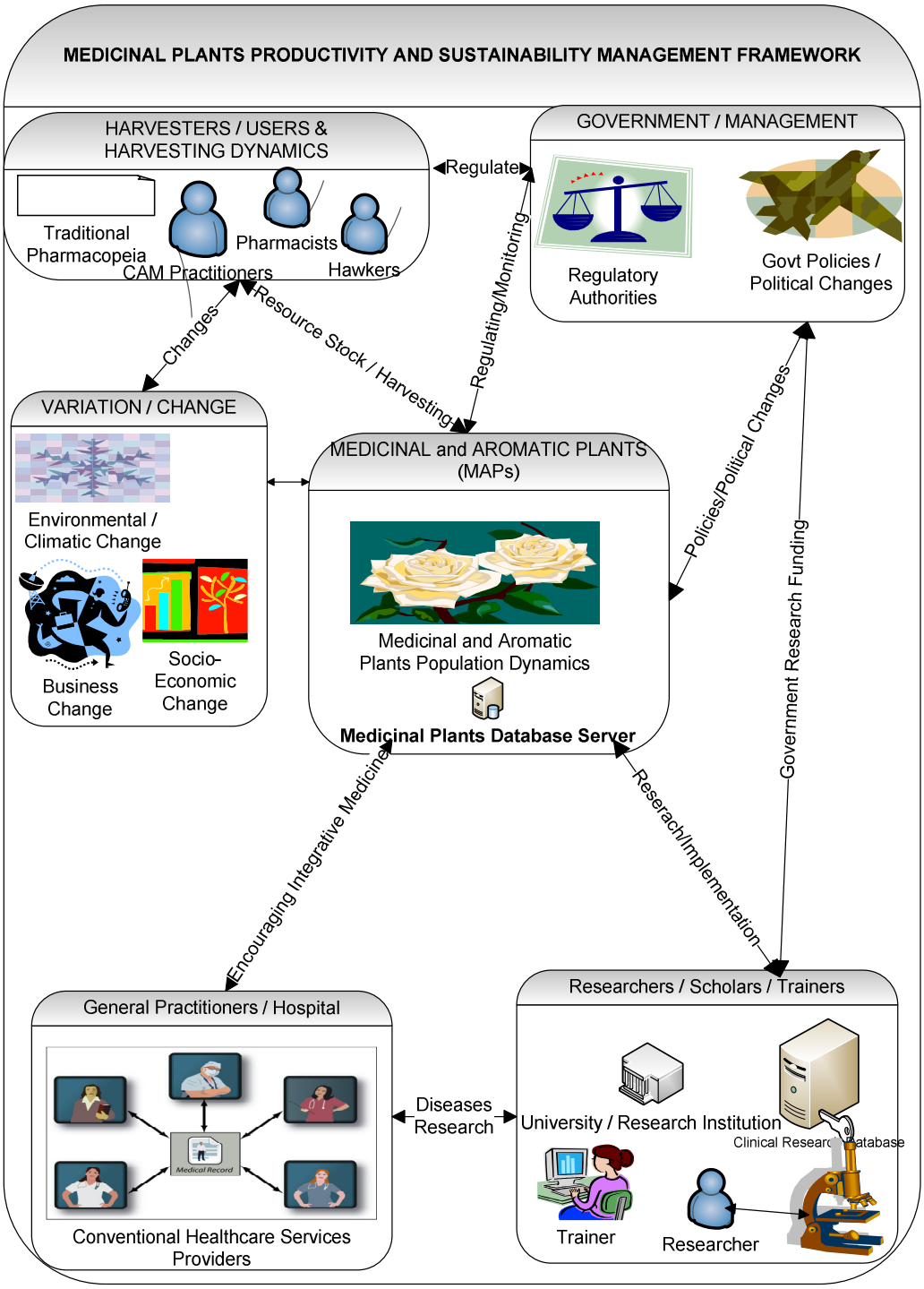


Fig. 13. Medicinal and Aromatic Plants Productivity and Sustainability Monitoring Framework

a = first constant for cost calculation; *b* = second constant for cost calculation; *s* = cost SD; *y* = number of years the model was run (Years) kept constant; *P* = Harvesters' price. *P* could be varied also to determine if motivating enough to embark on harvesting. Principally, sustainability of any plant species depends primarily on the carrying capacity, *K*, and the intrinsic rate of

increase, *r*, from logistic productivity, *PrF*, computation. Other parameter is *Harvesters* representing number of harvesters.

The larger the value of the carrying capacity, *K*, the lower the logistic productivity depending on the value of intrinsic rate of increase, *r*. If both *K* and *r* are large, say 50000 and 0.9 respectively, the logistic productivity value might remain constant after a few years. Harvest can only take place if the harvest for that year is more than the sum of the population for that year and the production (newly planted) i.e. cannot harvest more than is available. The simulation program written in C++ programming language was used to implement the algorithm. Table 5 was developed and used to validate this concept. By varying the values for the parameters as indicated, different results depicting the sustainability of the species were generated. Users were guided in supplying values for each of the parameters listed through an interface.

Fig. 15 shows the generated result for the first row from Table 5. From Fig. 15, in the first year (Year_0), the starting population of 1,750 had 250 harvested while 44 were newly introduced (planted = productivity) leaving 1,544 (i.e. 1750 + 44 – 250) for next year's population. Next year's population was computed by summing current year's population and productivity, and then subtracting harvested quantity. Next year's population becomes the brought forward population figure for the computation of the productivity and harvested quantity for that year. This iteration continues until Year_49 (making 50 years since we started with Year_0). At the end of the 50 years, population carried forward to 51st year was 455. This figure is significant implying the species considered has sustainability potential. If the number_of_years parameter were more than 50, say 75, the species might approach extinction, while retaining other parameters' values.

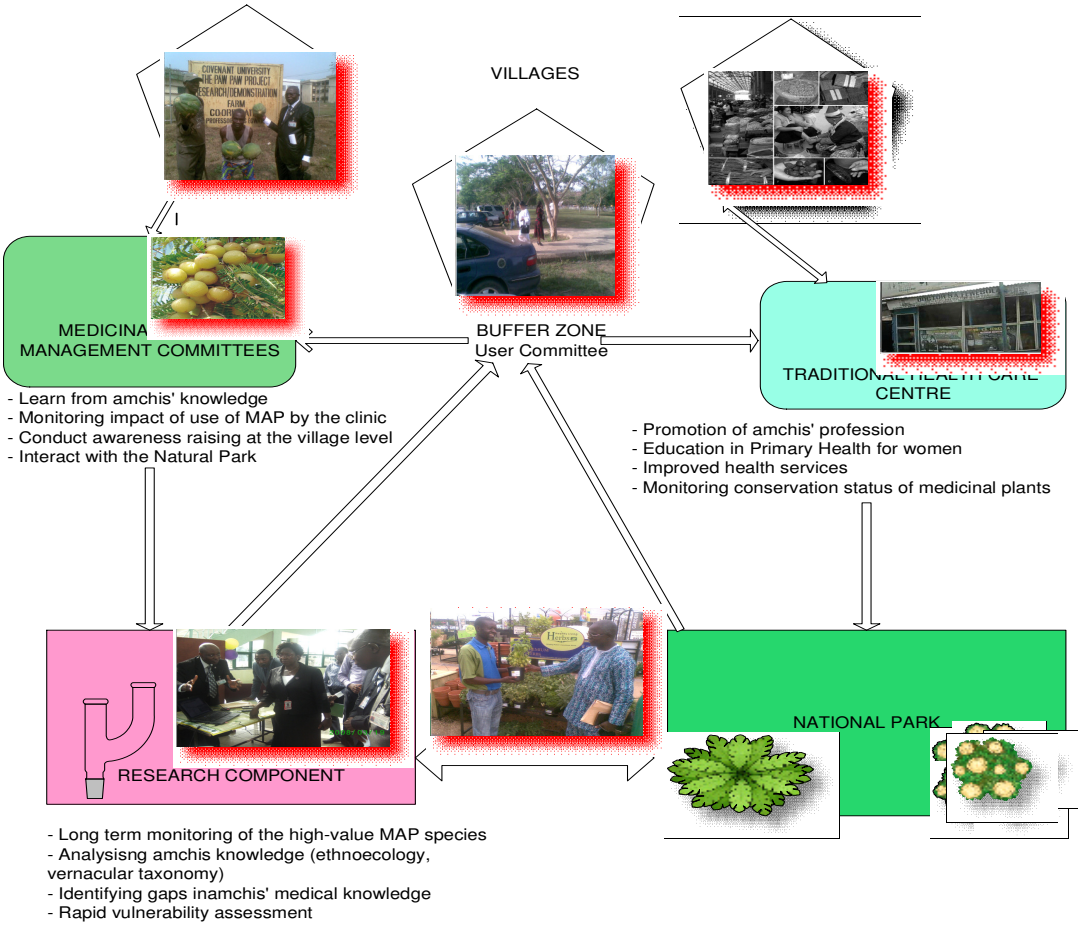
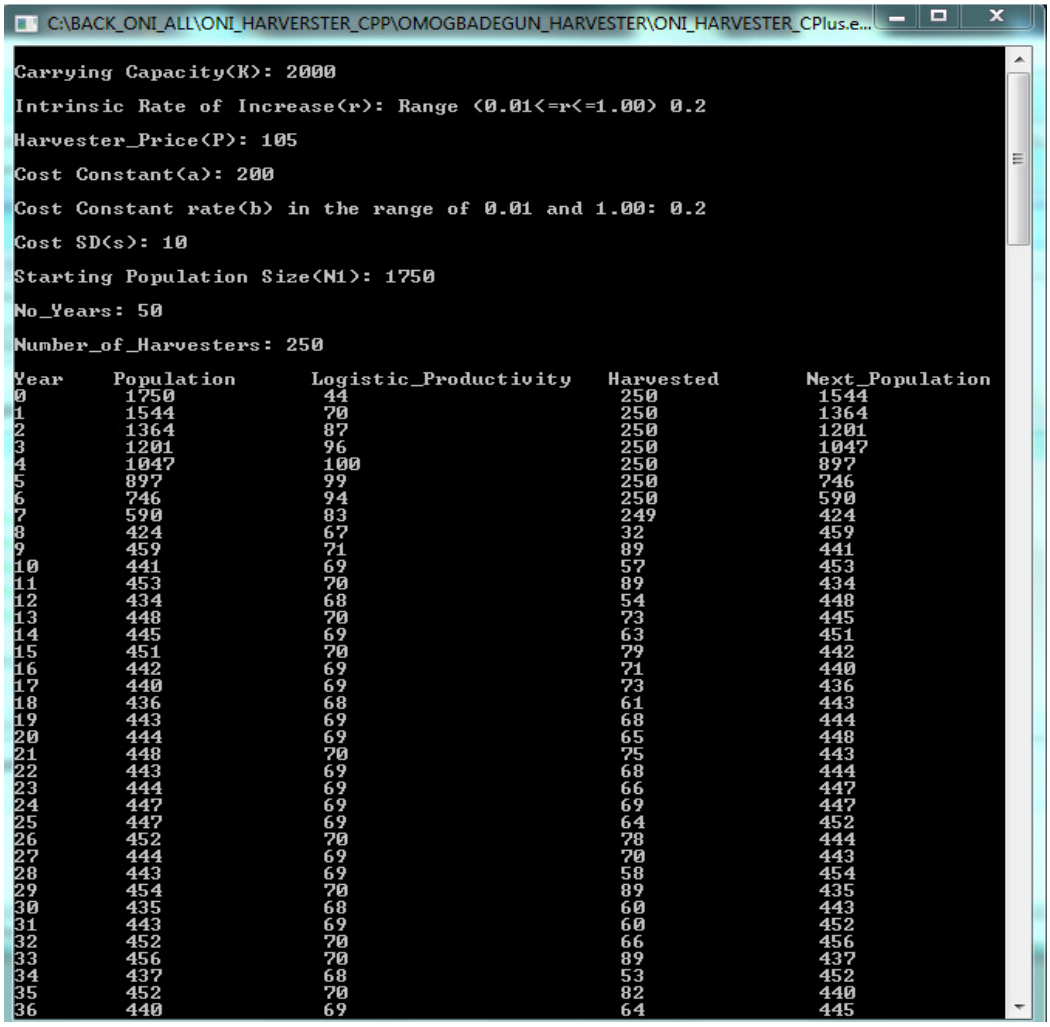


Fig. 14. Medicinal Plants Conservation Model (adapted and modified from [34])



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Carrying Capacity(K): 2000
Intrinsic Rate of Increase(r): Range (0.01<=r<=1.00) 0.2
Harvester_Price(P): 105
Cost Constant(a): 200
Cost Constant rate(b) in the range of 0.01 and 1.00: 0.2
Cost SD(s): 10
Starting Population Size(N1): 1750
No_Years: 50
Number_of_Harvesters: 250
```

Year	Population	Logistic_Productivity	Harvested	Next_Population
0	1750	44	250	1544
1	1544	70	250	1364
2	1364	87	250	1201
3	1201	96	250	1047
4	1047	100	250	897
5	897	99	250	746
6	746	94	250	590
7	590	83	249	424
8	424	67	32	459
9	459	71	89	441
10	441	69	57	453
11	453	70	89	434
12	434	68	54	448
13	448	70	73	445
14	445	69	63	451
15	451	70	79	442
16	442	69	71	440
17	440	69	73	436
18	436	68	61	443
19	443	69	68	444
20	444	69	65	448
21	448	70	75	443
22	443	69	68	444
23	444	69	66	447
24	447	69	69	447
25	447	69	64	452
26	452	70	78	444
27	444	69	70	443
28	443	69	58	454
29	454	70	89	435
30	435	68	60	443
31	443	69	60	452
32	452	70	66	456
33	456	70	89	437
34	437	68	53	452
35	452	70	82	440
36	440	69	64	445

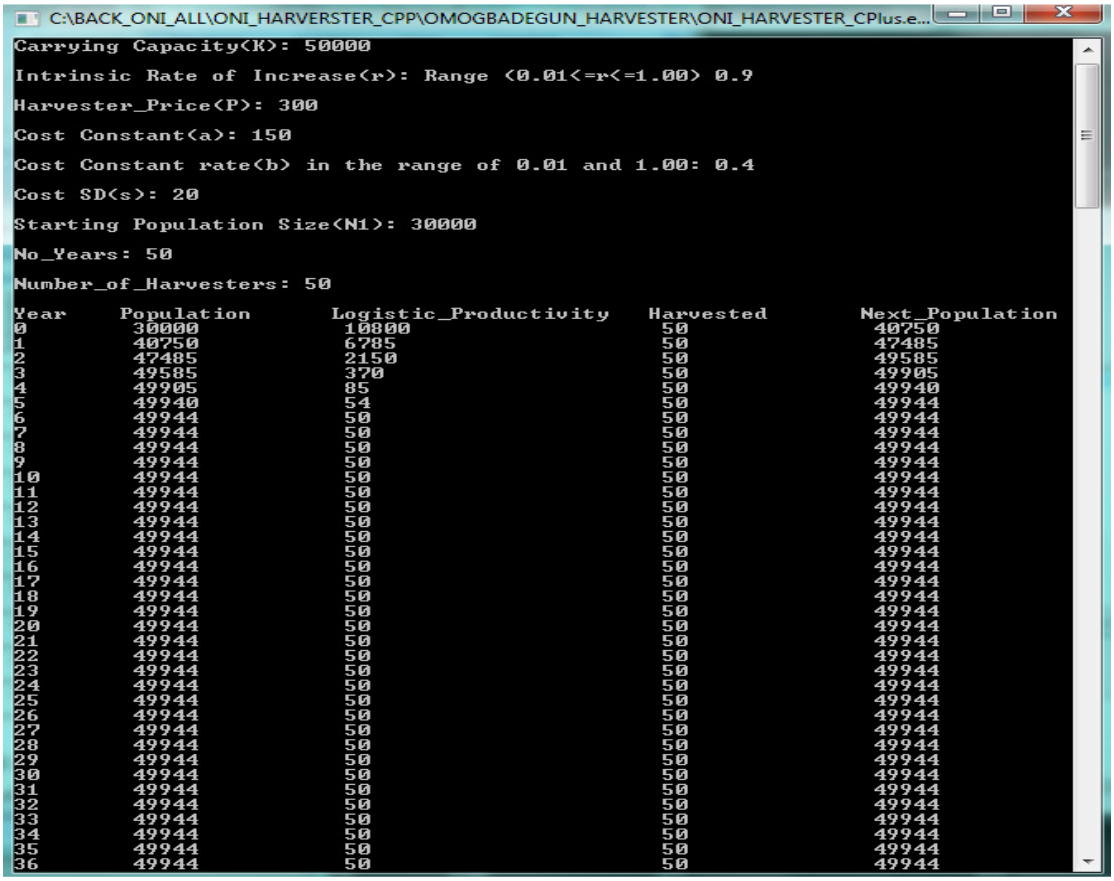
Fig. 15. Species Sustainability_Simulation_Test_Case_1

In the case of Fig. 16, using row 9 values from Table 5, it could be observed that after the 6th year (i.e. Year_5), the value generated for each of the displayed output remained same till the end of the period of 50 years. Stability of population was reached. This arose due to the large value of the intrinsic rate of increase (0.9). Very minimal effect (if any at all) could only be contributed by the other driver parameter (carrying capacity, *K*) for the logistic productivity computation. By implication, specie with this scenario is highly productive and would be sustained for long. The result would be different if, say, number_of_harvesters were increased.

The validity of the assessment model can be reviewed in many different ways, but for the purpose of this Research, the main focus was on construct validity. The test data were based on random number generation theory which gave good construct validity. This validity was strengthened by successive refinements based on same theory principally relying on intrinsic rate of increase, *r*, and carrying capacity, *K*.

The results obtained from the simulation exercise here have re-confirmed several predictions about attributes of species that correlate with vulnerability to extinction following from hypotheses commonly found in the literature that:

i. Small populations are more likely to die out than large ones: demographic stochasticity, local catastrophes, slow rates of adaptation, and inbreeding are all more serious for populations with few individuals;



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Carrying Capacity(K): 50000
Intrinsic Rate of Increase(r): Range (0.01<=r<=1.00) 0.9
Harvester_Price(P): 300
Cost Constant(a): 150
Cost Constant rate(b) in the range of 0.01 and 1.00: 0.4
Cost SD(s): 20
Starting Population Size(N1): 30000
No_Years: 50
Number_of_Harvesters: 50
```

Year	Population	Logistic_Productivity	Harvested	Next_Population
0	30000	10800	50	40750
1	40750	6785	50	47485
2	47485	2150	50	49585
3	49585	370	50	49905
4	49905	85	50	49940
5	49940	54	50	49944
6	49944	50	50	49944
7	49944	50	50	49944
8	49944	50	50	49944
9	49944	50	50	49944
10	49944	50	50	49944
11	49944	50	50	49944
12	49944	50	50	49944
13	49944	50	50	49944
14	49944	50	50	49944
15	49944	50	50	49944
16	49944	50	50	49944
17	49944	50	50	49944
18	49944	50	50	49944
19	49944	50	50	49944
20	49944	50	50	49944
21	49944	50	50	49944
22	49944	50	50	49944
23	49944	50	50	49944
24	49944	50	50	49944
25	49944	50	50	49944
26	49944	50	50	49944
27	49944	50	50	49944
28	49944	50	50	49944
29	49944	50	50	49944
30	49944	50	50	49944
31	49944	50	50	49944
32	49944	50	50	49944
33	49944	50	50	49944
34	49944	50	50	49944
35	49944	50	50	49944
36	49944	50	50	49944

Fig. 16. Species Sustainability _Simulation_Test_Case_9

ii. Small geographical ranges and low population densities are therefore likely to confer an enhanced extinction risk; and
iii. Species where individuals have large home ranges are particularly vulnerable to habitat loss and degradation.

The outcomes of this study included (i) organization of local institutions to facilitate both collective and individual responsibility and response to MAPs conservation, (ii) an innovative approach to MAPs sustainable improvement and management including institutional solutions for access to communal/collective MAPs, (iii) better use of local natural resources with an emphasis on MAPs harvesting and appropriate use of adapted indigenous plant species to enhance nutrition and health monitoring.

4. CONCLUSION

Biodiversity losses occur due to habitat destruction, over-harvesting, pollution, inappropriate and often accidental introduction of exotic plants and animals, etc. Habitat destruction is often related to development projects like land conversion, construction of dams, etc. Biodiversity is also lost due to sudden natural calamities like floods, cyclones, hurricanes, earthquakes, etc. Biodiversity conservation is a paramount concern worldwide to preserve the natural habitats of vulnerable MAPs species and achieve sustainable exploitation in less vulnerable areas. Action should be taken now to conserve the MAPs base of traditional medicine, as well as safeguarding its potential for modem medicines in other parts of the world.

The ultimate goal of the conservation process is certain to preserve the natural habitats of vulnerable medicinal plant species and to achieve sustainable exploitation in less vulnerable areas. The conservation of MAPs is by necessity a long-term project requiring the development of trained staff supported by organisations and a general public that is aware

of the issues at stake. Indubitable improvement in national education standards is a key factor in the conservation issue, which will come about only as a result of economic development.

Close monitoring of any change in medicinal plant resources and the recovery of habitats is desirable. This key activity requires strict regulation enforcement consistently in line with enumerated changes. The productivity and sustainability of MAPs demand individual and collective responsibilities from all stakeholders in a viable 'participation model'. Negligence or non-performance of the assigned obligations on the part of any stakeholder has adverse effects on the continued existence of the MAPs under consideration.

More importantly, the sustainability of this framework should constantly be guided by the following lessons already reported in literature in a similar scenario: (i) participatory characterisation of communities is essential for cooperation and trust among stakeholders; (ii) recognition of local know-how is an important step for successful diagnosis; (iii) the preparation of annual and long-term development plan approved by communities is an efficient tool to mobilize resources and ease project implementation; (iv) not to underestimate the ability of communities to identify appropriate technical solutions, to solve internal conflicts particularly relating to property rights and land use, and the importance of additional-income generating activities; (v) the success and the sustainability of the process depends on the promotion of elected community-based organizations that play a key interface role between communities and other actors (government agencies and decision makers, non-government agencies, donors, and other communities).At the core of communities demands stands that dialogue between local stakeholders and authorities must be increased since, as they say, without dialogue and real participation in decision-making, MAPs' productivity and sustainability policy can never become sustainable and reach acceptance.

Cooperation, communication, and coordination between different NGOs, NGOs and park management, significant involvement of the parks management, and a legal framework that provides a basis for co-management agreements constitute critical success factors for viable and sustainable conservation agreements within the framework. In other words, coordinated participation of stakeholders, namely federal and local authorities, academics, educators, and local people has been adjudged as the panacea for successful and sustainable natural resources management.

Because of the stakeholder conflicts, potential and actual, a more inclusive decision-making procedure is required. Stakeholder analysis has always provided a basis for engaging a representative cross-section of stakeholders on issues that are often highly contentious. Due to existing conflicts between certain stakeholder groups, fair representation is imperative. By using the stakeholder analysis research methodology, the depth and breadth of representation are highly valued by stakeholders as marginalization is minimized. Regulatory provisions for MAPs collection have been put in place for users' knowledge and easy enforcement to protect IPRs of community/state/national owners. These provisions would give knowledge holders confidence to disclose information about the medicinal plants in their domain without fear of being robbed of their rights.

5. FUTURE RESEARCH

As Computer Science and Biotechnology communities join forces (bioinformatics and medical informatics disciplines in Health Informatics) to create new technologies for the advancement of medical science and improvement of medical service delivery, this might prove to be promising for enabling people to lead normal, healthy lives. The increasing interest of people in medicinal plants commands a special attention to organize the actors and preserve the plant genetic resources. This research represents one of the required processes to be set up to bridge gaps between physicians, CAM practitioners, government agencies, researchers, communities and policy makers. This disseminates research results towards integrative medicine using traditional medicine reliant on medicinal plants in Africa. The framework from this study will be replicated and implemented in other States of Nigeria towards achieving a national framework for effective MAPs Productivity and Sustainability Monitoring. By extension, the achieved national framework would be extended to other nations in Africa and the world. Quantitative analysis of extinction risk is one of the five criteria set by the International Union for Conservation of Nature and Natural Resources (IUCN). Population

Viability Analysis (PVA) has been given as an example of this criterion. Mathematical models based on this PVA capable of quantitatively providing scientific proofs for the management of natural resources and sustainability concerns, should be fully explored and developed in immediate future research to complement this work.

CONSENT

As per international standard or university standard, patient's written consent has been collected and preserved by the author.

ETHICAL APPROVAL

It is not applicable.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

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