Annual Report 2024

LABEF

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Acknowledgements

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Abbreviations & acronyms

ACE-MSA	:	African Excellence Center for Mathematics Sciences and Application
AGNES	:	African German Network of Excellence in Science
AGriDI	:	Accelerating inclusive green growth through Agri-based Digital Innovations in West Africa
AI	:	Artificial Intelligence
BMBF	:	Federal Ministry of Education and Research
DAAD	:	Deutscher Akademischer Austauschdienst
EU	:	European Union
FAO	:	Food and Agriculture Organization
FCDO	:	Foreign, Commonwealth & Development Office
HRH-SEMCA	:	Socio-Ecological Modeling of COVID-19 dynamics in Africa
IF	:	Impact factored journals,
INRAB	:	National Institute of Agricultural Research of Benin
LABEF	:	Laboratoire de Biomathématiques et d'Estimations Forestières
MBIOST	:	Master in Biostatistics
ML	:	Machine Learning
MsC	:	Master of Sciences
NGO	:	Non-Governmental Organizations
OWSD	:	Organization for Women in Science for the Developing world
PhD	:	Doctor of Philosophy
PNLP	:	National Malaria Control Programme
RUFORUM	:	Regional Universities Forum for Capacity Building in Agriculture
TWAS-IsBD	:	The World Academy of Science - Islamic Development Bank
UAIML	:	Unit of Artificial Intelligence and Machine Learning
UBM	:	Unit of Biomathematics
UFE	:	Unit of Forest Estimations
UNDP	:	United Nations Development Programme
USD	:	United States Dollar
WAfriCLP	:	West African Climate Leadership Program for Women
WIF	:	Without impact factor journals

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Statement of the head of the Lab

Dear colleagues and friends,

I am delighted, as usual, to introduce the 2024 annual report of the "Laboratoire de Biomathématiques et d'Estimations Forestières" (LABEF).

There has been significant progress of team members, and we have attracted several Bachelor and Master's students, PhD-students, post-docs, and visiting researchers in our research units.

Thanks to the commitment of our members, we have sustained our standards in terms of scientific research. Although we still have room for improvement, I would like to take this opportunity to congratulate all the members for their efforts and contributions to increasing the visibility of the laboratory through the quality of our research and its relevance to society.

LABEF will continue to make biostatistics, climate change and biodiversity conservation a priority of its research themes to inform and guide stakeholders. Mathematical modelling in Forestry has remained a priority of our research agenda, and this has been recently extended to the field of Epidemiology. Furthermore, Precision Agriculture is now part of LABEF's research portfolio and we are making progress in developing ML & AI tools for diseases detection, yield prediction, and biomass estimation.

Enjoy reading this report, and I look forward to sharing with you the future progress of LABEF.

Prof. Romain GLELE KAKAÏ

Head of LABEF

CHAPTER 1.

LABEF: Overview and Team

1.1. Mission, vision, and objectives of LABEF

Created on 27th May 2014 by Romain GLELE KAKAÏ, Professor in biometry and forest estimations, the "Laboratoire de Biomathématiques et d'Estimations Forestières", is part of the "Ecole d'Aménagement et Gestion de l'Environnement", Faculty of Agronomic Sciences, University of Abomey-Calavi.

The Laboratory aims to:

- raise awareness of the importance of Mathematics, particularly Statistics in Biological Sciences;
- analyze the applicability of mathematical tools in life sciences with a particular focus on understanding the interactions between ecological processes, anthropogenic factors, and terrestrial ecosystems' structure to deliver clear management actions and policies.

The mission of LABEF is to enhance understanding of biological systems through the effective use of biomathematics.

Its vision is to be, by 2030, a leading institution in developing mathematical tools for biologists and supporting decision-makers in forestry for a better society.

1.2. Organization of LABEF

LABEF is organized into four departments, including the (i) fundraising department, (ii) social life department, (iii) administrative department, and (iv) research department. The research department now includes three units, namely: Unit of Biomathematics (UBM), Unit of Artificial Intelligence and Machine Learning (UAIML), and Unit of Forest Estimations (UFE).

- **The Unit of Biomathematics (UBM)** deals with biology and mathematics and is interested in applications of mathematics in biology. This unit is interested in the use of mathematical theories in biology and especially in publishing scientific notes describing the application of different mathematical tools in life sciences.
- **The Unit of Forest Estimations (UFE)** falls into the overall perspective of assessing wood resources, biomass, and carbon stock available in forest ecosystems. The Unit is interested in developing accurate and robust methods and models for estimating forest resources. It is equally interested in understanding ecological processes and patterns and developing clear and applicable management policies for forest managers and decision-makers. The unit also investigates forest governance approaches, effectiveness, replicability,

socio-economic and ecological outcomes, decision-making process, and benefit-sharing.

- **The Unit of Artificial Intelligence and Machine Learning (UAIML)** aims to operationalize and develop machine learning (ML) and artificial intelligence (AI) methods to assist innovation in the field of biology, particularly Forestry and Agriculture.

1.3. Research topic covered at LABEF

The ecosystem of research topics covered at LABEF is diverse and illustrated in figure 1.

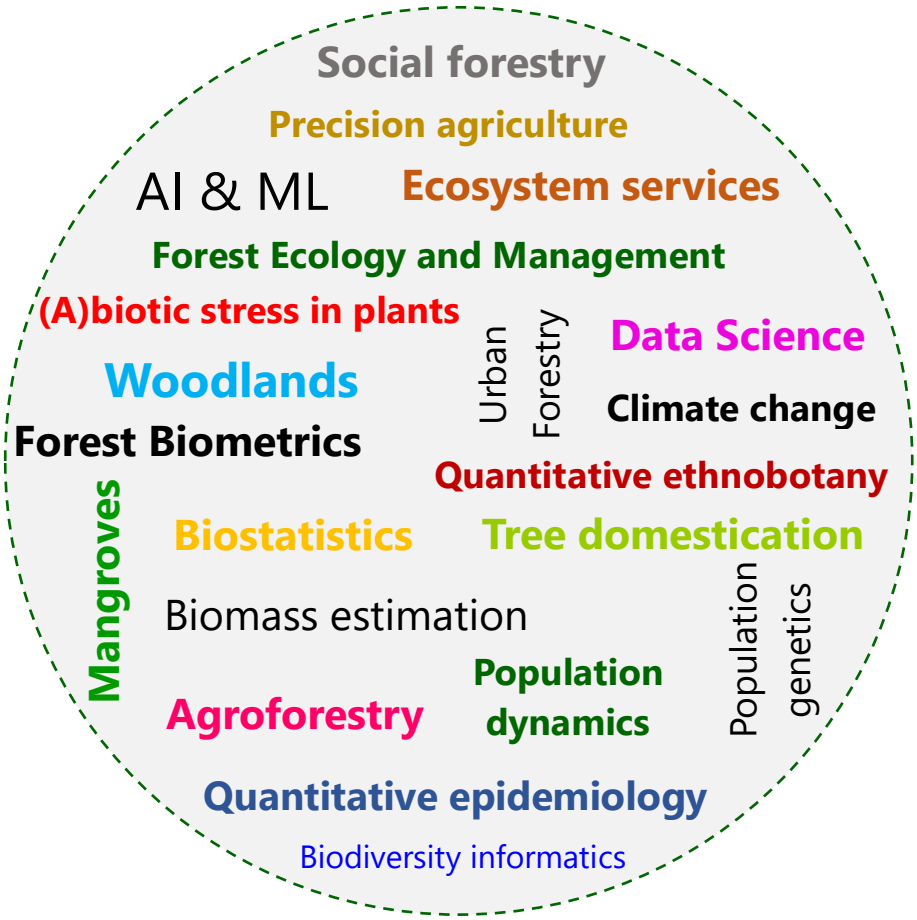


Figure 1. View of research topics covered at LABEF

Our works contribute to six Sustainable Development Goals (SDGs).

1.4. The core management team of LABEF in 2024

Prof Romain GLELE KAKAÏ is the head of LABEF. He is a Full Professor in Biometry and Forestry, researcher, and lecturer at the Faculty of Agronomic Sciences. He is a fellow of the African Academy of Science (AAS). He has served as the chairman of the scientific council of agronomic sciences, the Scientific Council of the National Institute of Agricultural Research of Benin (INRAB), and the African German Network of Excellence in Science (AGNES). He is coordinating the Doctoral program in Biometry at the University of Abomey-Calavi. His current research areas include Mathematical and Statistical modelling of Epidemics, ML and AI applications in Agriculture, Forest estimations and management.

Dr Jonas Doumate is the deputy head of LABEF and head of the Biomathematics research unit. He is Assistant Professor of Mathematics. His research areas include Applied mathematics – Analysis - Mathematical Statistics - Series Analysis – and Financial Mathematics.

Dr Emile Agbangba is the head of the Artificial Intelligence and Machine Learning research unit. His research areas include Machine Learning – Statistical Probability - Climate Science -Precision Agriculture - Linear and nonlinear mixed models.

Dr Kolawolé Valère Salako is the scientific coordinator and head of the research unit in Forest estimations. He is a lecturer and researcher in Forestry and Biometry. His research areas include population and community ecology – Forest Biometrics – agroforestry systems analysis – Quanitative ethnobotany - Plant Ecophysiology - Infectious Diseases Modelling.

Dr Marcel Donou is the head of the social life department. He is also the Teaching manager of the Master Program: Major Biostatistics. His research areas include population Ethnobiology - Conservation Biology – Forest Biometrics.

Mr. Carl AKOTO is leading the administrative department. He is in charge of the administration and all related tasks. He assists the coordinator of the master program in statistics major Biostatistics for students' day-to-day management. He ensures that students have their timetable, receive their lectures, submit their homework, and sit their exams on time.

CHAPTER 2.

RESEARCH: *Milestones & Highlights*

2.1. Scientific publications in 2024

2.1.1. Publications Milestones

In 2024, LABEF produced a total of 48 scientific articles in peer-review journals.

2.1.2. Diversity of Journals and scientific disciplines covered by publications of LABEF in 2024

In 2024, the scientific articles were published in 36 journals as summarized in table 1. Several research domains were covered. Among the sixteen research domains covered, biometry (12 published papers), forestry (10 published papers), machine learning (7 published papers), agroforestry (4 published papers), Ecology (4 published papers), and Epidemiology (3 published papers) were the most investigated (figure 2).

Table 1. *Diversity of journals for published, in press, and under review papers*

Journals	Type of journals	Impact factor (IF)	Number of papers
Future Foods	IF	7.2	1
Smart Agricultural Technology	IF	6.3	1
Biological Conservation	IF	4.9	1
Forest Policy and Economics	IF	4	1
Scientific Reports	IF	3.8	2
Forest Ecology and Management	IF	3.7	1
Frontiers in Sustainable Food Systems	IF	3.7	1
Global Ecology and Conservation	IF	3.5	1
Marine Policy	IF	3.5	1
Heliyon	IF	3.4	1
Infectious Disease Modelling	IF	3	2
Plos one	IF	2.9	1
Modeling Earth Systems and Environment	IF	2.7	5
Trees, Forests and People	IF	2.7	2
Annals of Forest Science	IF	2.5	1
Ecology and Evolution	IF	2.3	1
Genetic Resources and Crop Evolution	IF	2.08	4
Agroforest Systems	IF	2	1
Mathematical Biosciences	IF	1.9	1
Plant Ecology & Evolution	IF	1.15	1
African Journal of Ecology	IF	1.1	1
Agronomy Research	IF	1.02	1
All Life	IF	1	1
Stats	IF	0.9	2
Contemporary Mathematics	IF	0.6	1
African Journal of Food, Agriculture	IF	0.56	1
African Crop Science Journal	IF	0.263	1
Advances and Applications in Statistics	IF	0.1	1
JP Journal of Biostatistics	IF	0.1	1
Applications of modelling and simulation	WIF	0	1
Communications in Mathematical Biology and Neuroscience	WIF	-	2
Discover Environment	WIF	-	1
Forestry Studies	WIF	-	1
IAES International Journal of Artificial Intelligence (IJ-AI)	WIF	-	1
International Conference on Deep Learning Theory and Applications	WIF	-	1
Position Papers of the 19thConference on Computer Science and Intelligence Systems	WIF	-	1

IF = Impact factored journals, WIF = Without impact factor journals

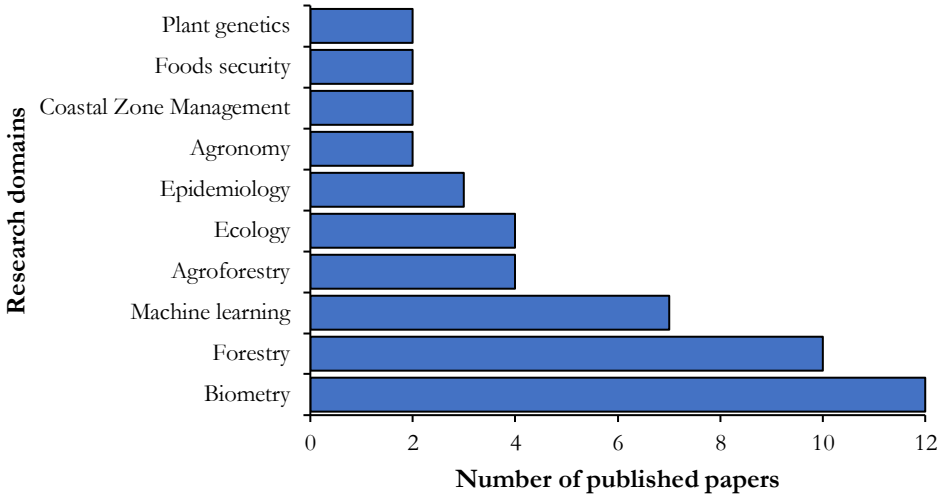


Figure 2. *Diversity of research domains for published papers by LABEF in 2024*

2.1.3. Performance and highlights in publication

LABEF produced slightly less scientific articles in 2024 than in 2023 (figure 3a). Among the 48 scientific publications in peer-review journals of 2024, 40 publications (83.33%) were published in journals with an impact factor (figure 3b).

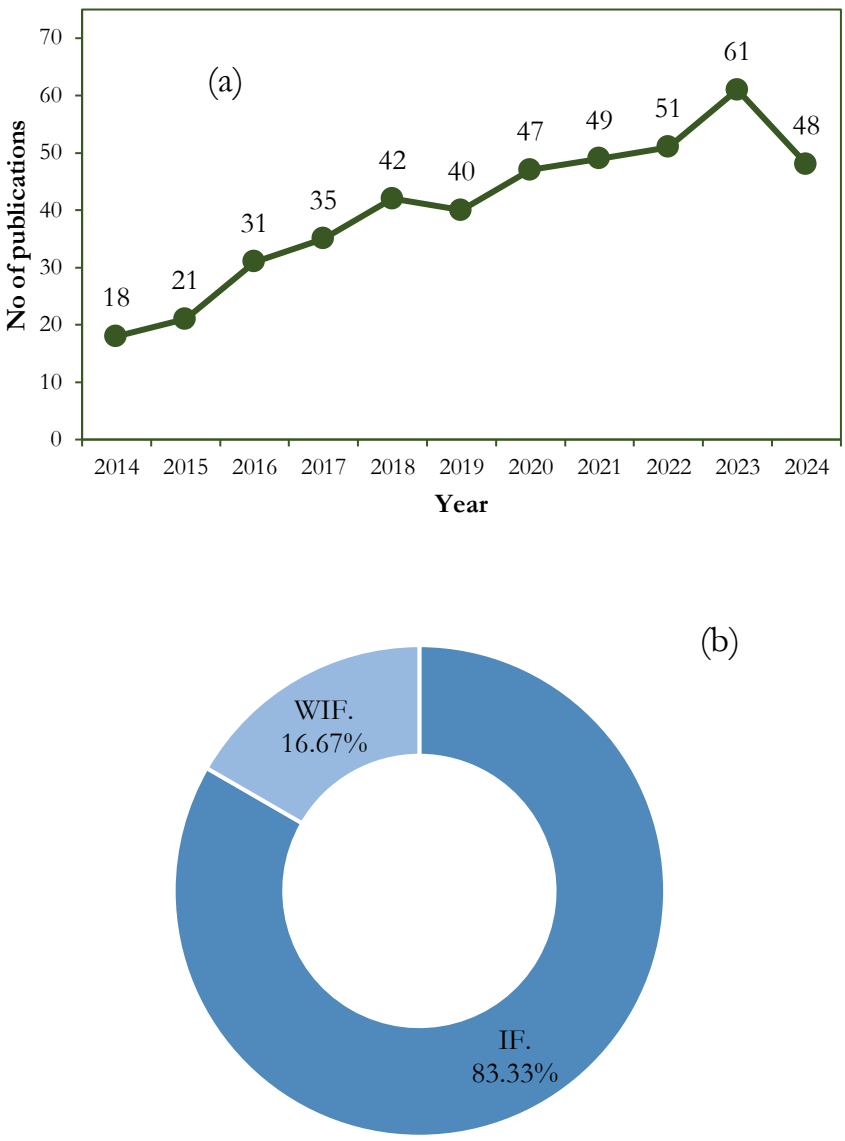


Figure 3. *Trends in annual publications from 2014 (a), and quality of publications (b)*

Among the papers published in peer-review journals with an impact factor in 2024, 6.90%, 51.72% and 20.69% were in journals with an impact factor above 5, between 2 and 5, and between 1 and 2 respectively (figure 4).

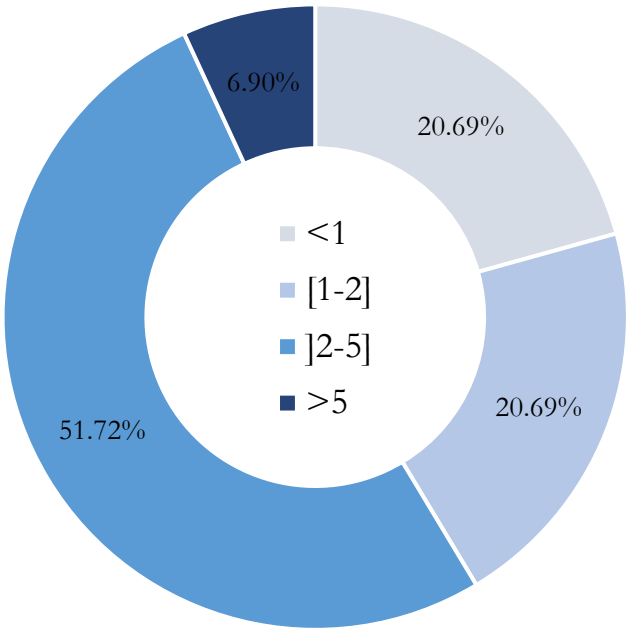


Figure 4. *Range of impact factor of published papers*

2.1.4. Authorship and leadership position in publications in 2023 and 2024

For the 48 scientific papers published in 2024, members of LABEF have occupied variable positions. Members of the lab were exclusively the first author in nine published papers (18.75%). In 11 of the published papers, members of LABEF were among the first three authors. The leadership (last) position was occupied by members of the lab in 8.33% of the published papers, while in 29.17% of the papers, the last as well as the first positions were ruled by LABEF's members (figure 5).

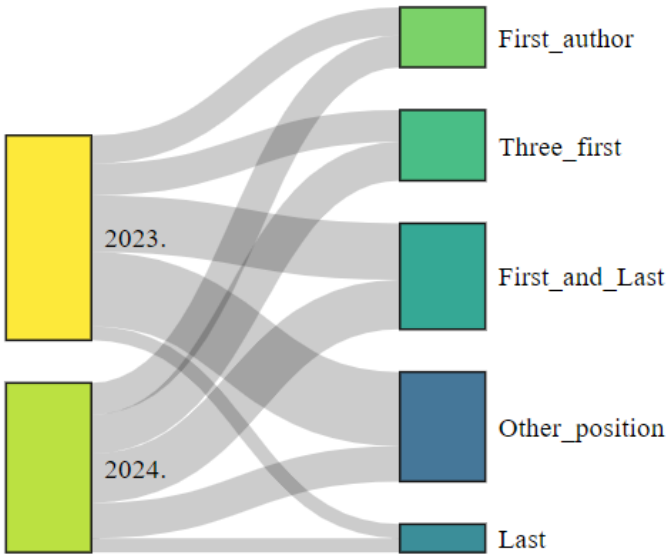


Figure 5. *(Co-) Authorship position of LABEF members in publications in 2024*

2.2. Research projects in 2024

The research projects implemented by LABEF in 2024 included, as usual, small (less than USD 25000), medium (USD 25 000-200 000), and large (more than USD 200 000) grants. Six individual small grants were implemented by members of LABEF in 2024 (see table 2). Furthermore, it is notable that three doctoral fellowships and four postdoctoral fellowships have been awarded to our members (Table 2).

Table 2. *Individual fellowships and small research grants in LABEF in 2024*

N°	Funder	Recipient	Topic/subject	Status
1	TWAS-IsBD	Mahoutin Gildas Serge	Landscape historic trough spatial changes of mangroves in Benin Coastal area (West-Africa) using random forest algorithm applied to Landsat images	Ended
2	AGNES	Mahoutin Gildas Serge	Spatio-temporal dynamics and future evolution of Ramsar site 1018 (Benin, West-Africa)	Ended
3	International Foundation for Science (IFS)	Hounsou-Dindin Guillaume	Towards the domestication of *Ricinodendron heudelotii* (Bail.) Pierre: insights from ecophenotypic assessment in Benin	Ended
4	European Union (EU) student exchange programme. Erasmus+	Mirabelle Gandji	Conservation biology of *Ricinodendron heudelotii* (Bail.) Pierre ex. Heckel: state of knowns and research avenues	Ended
5	Federal Ministry of Education and Research (BMBF)	Sedoami Flora Dogbo	Vegetation attributes in peri-urban agroforestry systems and their socio-economic determinants in Benin (West Africa)	Ongoing
6	British Ecological Society	Enagnon Bruno Lokonon	Best practices for rural women smallholder farmers inclusion in teaching local ecological coping solutions to climate change in Benin	Ongoing
7	Alexander von Humboldt Foundation	Dr. Corine B. Laurenda Sinsin	Research Fellowships	Ongoing
8	Alexander von Humboldt Foundation	Dr. Guillaume Hounsou-Dindin	Research Fellowships	Ongoing
9	Make Our Planet Great Again	Dr. Mahoutin Gildas Serge Zanvo	Research Fellowships	Ongoing
10	Sub-Saharan African Consortium for Advanced Biostatistics (SSACAB)	Dr. Souand Peace Gloria Tahi	Research Fellowships	Ongoing

11	West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL)	David AKODEKOU	Research Fellowships	Ended
12	Organization for Women in Science for the Developing world (OWSD) and Centre d'excellence Africain en Sciences Mathématiques et Applications (CEA-SMIA)	Rachidatou Orounla	Research Fellowships	Ongoing
13	ANSO-CAS-TWAS/UNESCO	Moustapha Arèmou Kolawole	Research Fellowships	Ongoing

Dr. Corine B. Laurenda Sinsin
Post-Doctoral Alexander von Humboldt Foundation Research Fellowships, Germany

Dr. Guillaume Hounsou-Dindin
Post-Doctoral Alexander von Humboldt Foundation Research Fellowships, Germany

Dr. Zanvo Mahoutin Gildas Serge
Post-Doctoral Make Our Planet Great Again (MOPGA) Research Fellowships, France

Dr. Souand Peace Gloria Tahi
Post-Doctoral Sub-Saharan African Consortium for Advanced Biostatistics (SSACAB) Research Fellowships, Benin

David AKODEKOU
PhD Research Fellowships West African Science Service Centre on Climate Change and Adapted Land Use (WASCAL), Mali

Rachidatou Orounla
PhD Research Fellowships
Organization for Women in Science for the Developing world (OWSD) and Centre d'excellence Africain en Sciences Mathématiques et Applications (CEA-SMIA), Ghana

Moustapha Arèmou Kolawole
PhD Research Fellowships ANSO-CAS-TWAS/UNESCO, China

Constant S. Gnansounou
PhD Reseach Fellowships
University of Namur, Belgium

Two small, one medium and five large research projects have been implemented in LABEF in 2024 (Table 3). In the frame of these projects, LABEF partnered with several institutions from diverse countries in Africa (Ghana, DRC, Malawi, Tanzania, South Africa), and Europe (Germany, United Kingdom). For more details on these projects, please visit our website (LABEF)

Table 3. *Ended, ongoing small, medium and large research projects in LABEF in 2024*

N°	Project title	Project type	Funding institution	Status
1	Agroforestry systems: women's power and decision-making in climate change mitigation in Benin.	Small	West African Climate Leadership Program for Women (WAfriCLP)	Ended
2	Mathematical modelling of malaria dynamics in sub-Saharan Africa: Accounting for population opinion and behaviors regarding prophylactic preventive methods	Small	DAAD	Ongoing
3	Blue carbon and economy in West Africa: mobilizing datasets to better understand mangrove health in relationship to climate change	Medium	LACUNA	Ongoing
4	Socio-Ecological Modeling of COVID-19 dynamics in Africa (HRH-SEMCA)	Large	Alexander von Humboldt	Ongoing
5	Valorization of Pineapple Residues for Soil Fertility Management and Energy Autonomy in Benin	Large	VLIR-UOS-COLEAD	Ongoing
6	Digital-assisted smart integrated agroecological maize pest *Spodoptera frugiperda* management in Benin	Large	Ekhagastiftelsen	Ongoing
7	DELTAS Africa II. Sub-Saharan Africa Consortium for Advanced Biostatistics training.	Large	Wellcome and the United Kingdom's Foreign, Commonwealth & Development Office (FCDO)	Ongoing
8	Accelerating inclusive green growth through Agri-based Digital Innovations in West Africa (AGriDI)	Large	Agropolis fondation	Ongoing

2.3. Master, and Ph.D. degree dissertations in 2024

Eight (8) MSc students (3 females and 5 males) completed their MSc degree in biostatistics at LABEF (figure 6).

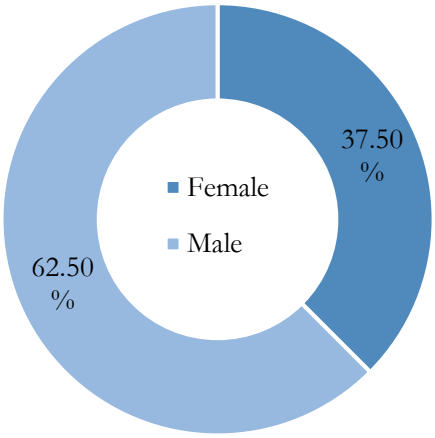


Figure 6. *Gender balance for Master theses*

Regarding the Ph.D. students in 2024, five students (2 females and 3 males) defended their theses in biometry. Thirty-one Ph.D. initiatives are ongoing (8 females and 26 males). These Ph.D. initiatives covered several research domains, with, biostatistics and biometry being the most investigated discipline (27 initiatives, see figure 7a). Moreover, 58% of the Ph.D. students are at least in their third year in 2024 (figure 7b).

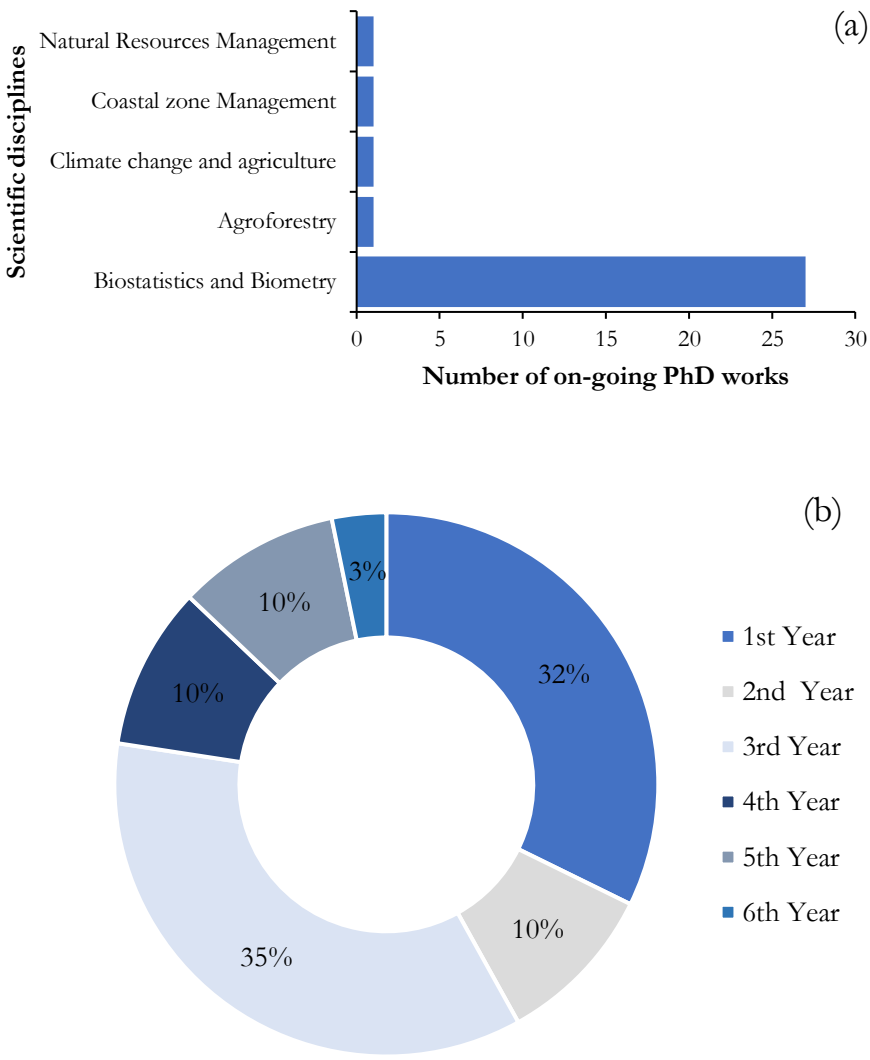


Figure 7. *Fields of research (a) and stages of ongoing Ph.D. theses in 2024*

CHAPTER 3.

RESEARCH: *Connection, share, and networking*

3.1. Collaboration for publication in 2024

In 2024, LABEF collaborated with researchers from 26 countries, national collaborations being the most dominant (46.46%, figure 8a). The most represented continent for these collaborations was Africa more than 77.78%, followed by Europe more than 17.17% (figure 8b).

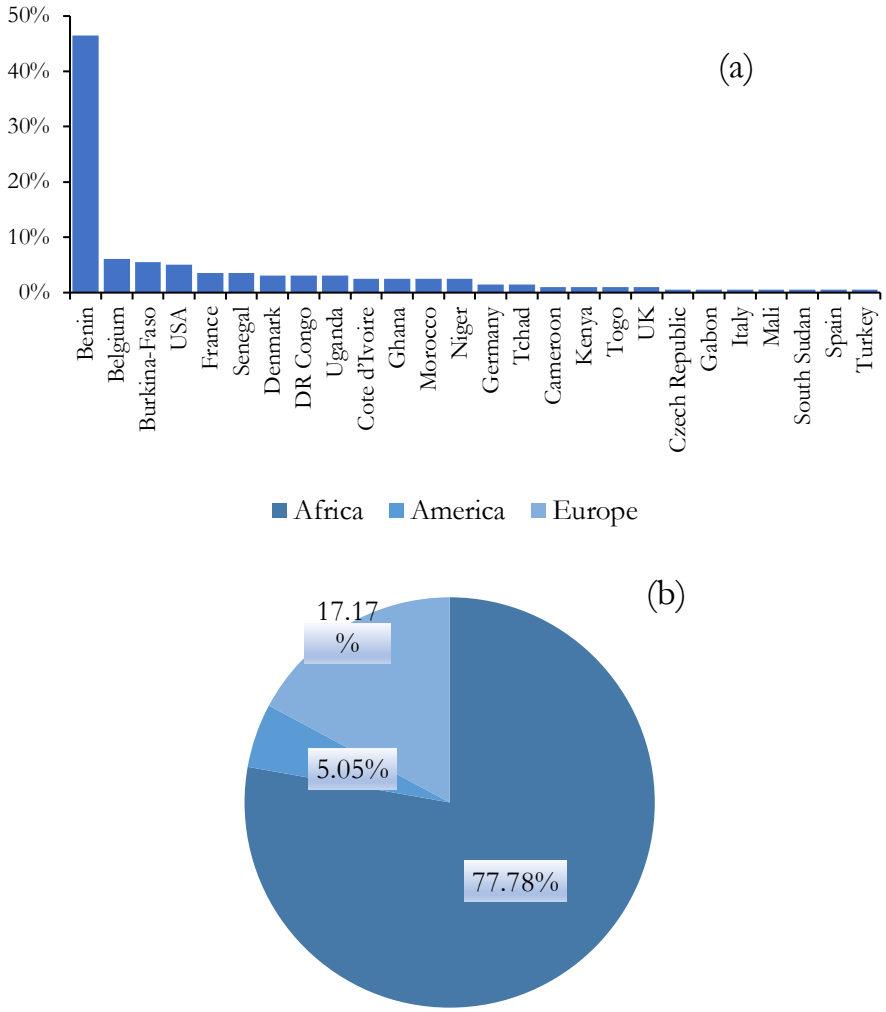
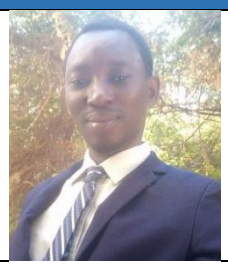


Figure 8. *Countries (a) and world regions (b) of co-authors of publications of LABEF in 2024*

3.2. Visiting researchers and post-docs at LABEF in 2024

In 2024, LABEF received two international post-doctoral researchers and one visiting researcher from two countries (Burkina-Faso, and Côte d'Ivoire) for visiting research.

N°	Photo	Name	Sex	Position	Country	Research topic/Object	Level	Funder	Supervisor(s)
1		Dr. Zerbo Issouf	M	Lecturer and Researcher & Head of the department of Plant Production and Agronomy at University Center of Tenkodogo / University Thomas Sankara	Burkina-Faso	Impact of climate change and land use on the conservation of *Pterocarpus* species in Burkina Faso (West Africa)	Post-Doc	TWAS-IsDB	Prof. Romain Glèlè Kakaï & Dr. Valère Salako
2		Dr. Kabre Blaise	M	Assistant Professor at University Center of Tenkodogo / University Thomas Sankara	Burkina-Faso	The distribution of the ecological niche of *Ziziphus mauritiana* are underway	Post-Doc	TWAS-IsDB	Prof. Romain Glèlè Kakaï & Dr. Valère Salako
3		Dr. Pagny Franck Placide Junior	M	Assistant Professor, Jean Lorougnon Guédé University	Côte d'Ivoire	Attended training on data analysis and statistical methods relevant to ecological research	Visiting researcher	Jean Lorougnon Guédé University	Prof. Romain Glèlè Kakaï & Dr (MC) Charlemagne GBEMAVO

CHAPTER 4.

CONTRIBUTION: *Capacity building*

4.1. Graduate program in Biostatistics and Doctoral program in Biometry

4.1.1. Graduate program in Biostatistics (MBIOST)

4.1.1.1. Presentation of the MBIOST

Since its creation in May 2014, LABEF has been running an international graduate program in Biostatistics. This master's program offers extensive and unique training in recent statistical methods and tools for their applications in Life sciences. At the end of the training, graduated students can easily go into professional life as Biostatisticians or engage in research in Biostatistics by integrating into a doctoral school. This training is open to holders of a Bachelor Degree in Life Sciences (agronomy, health, biology, environment, etc.), or in Mathematics/Statistics or Master, Degree holders wishing to acquire knowledge and know-how in the field of data collection, management, and analysis. The Master programme in Biostatistics has already trained and released ten batches of skilled biostatisticians and data analysts. The 12th batch of students started in September 2024 and enrolled 33 students from 07 countries (Benin, Burundi, Congo, Ethiopia, Kenya, Rwanda and Tanzania). To date, 211 students have been trained. The program has been supported by several programs in the past (e.g., Intra-ACP Academic Mobility Programs). Currently, it is supported by, the German Federal Ministry of Education and Research through DAAD In-Country/In-Region Program, the African Excellence Center for Mathematics Sciences and Application (ACE-MSA, through World Bank Group fund), and the DELTAS Africa II Sub-Saharan Africa Consortium for Advanced Biostatistics training.

4.1.1.2. Aims of the MBIOST

The MBIOST program aims to provide Food Enterprises, Projects, Health Sector (Units of Clinical research), Department of Medical Information, etc.), Public and Private Research Institutions, Non-Governmental Organizations (NGO), International Organizations (FAO, UNDP, World Bank, etc.), Education and International Research Institutions, talented Biostatisticians and data analysts. The abilities this training gives in data collection, data management, statistical analysis, and valorisation allow graduates to practice the job of Biostatisticians in charge of Statistical Studies in various sectors. Our alumni work as data scientists and Statisticians in multiple institutions (e.g., AfricaRice, MTN, Global Fund TB, Benin National Institute of Agricultural Research, University of Malawi, University of Abomey-Calavi) and PhD-students or post-docs in Africa, Europe, Asia, and America.

4.1.1.3. How to apply?

Visit the website (LABEF) and fill in the online application form (Application-form). Candidates from Benin could submit their applications to the secretary of the program, located at the Laboratoire de Biomathématiques et d'Estimations Forestières. Please visit the webpage of the Master for detailed information (LABEF-Master).

4.1.2. Doctoral program in Biometry

In addition, since 2017-2018, the Doctoral School of Agronomic and water Sciences has been offering a PhD program in Biometry under the coordination of Prof Romain GLELE KAKAÏ (the head of LABEF and coordinator of the master's program in Biostatistics). Thus, to date, 38 students are enrolled in the PhD program, 6 will defend their thesis in 2025 while 10 have already graduated.

CHAPTER 5.

Statements from lab members

5. Statements from our members

This annual report is based on information from 32 members, comprising 25% female and 75% male. Of the respondents, 72% were PhD students, the remaining being researchers and lecturers.

Regarding the resources and support available in the laboratory, only 3.1% of respondents expressed dissatisfaction. 15.6%, 43.8%, and 37.5%, respectively, indicated neutrality, satisfaction, and high satisfaction with the resources available. Furthermore, a few recommendations were made to improve the laboratory's resources. These recommendations include the following:

- enhance technical assistance and additional information resources,
- provision of high-performance computers within the computer room,
- increase tables and chairs in the doctoral students' room,
- establish additional classrooms for students,
- addition of offices, and the subscription to paid Overleaf plans to facilitate collaboration on projects involving multiple collaborators.

Furthermore, 78% of respondents acquired new skills during the year 2024, reflecting the continuous interest of laboratory members in acquiring new knowledge. Among the 72% who learned new skills, 52%, 68%, 36%, and 16% respectively learned how to use new statistical tools (e.g., R, Python, SAS, Matlab, etc.), scientific writing, new algorithms for modelling, and the use of GenAI in scientific activities. In addition, researchers stated that in 2024, they had acquired knowledge of the use of "Terrestrial Laser Scanning" and "Quantitative Structure Models." While these new skills are primarily intended for use in their respective research fields, lecturers, researchers, and PhD students also made suggestions for the laboratory. These comprised :

- training for laboratory members (52%),
- increase partnerships with other institutions or laboratories (44%), and
- proposals for projects under the laboratory's leadership (66%).

They also recommended that the laboratory establishes a unit dedicated to project management and training, with the objective of enhancing the laboratory's capacity for continuous learning and development. The unit would be responsible for organizing seminars and training for laboratory members, as well as reviewing the projects proposed by members for funding.

PhD students highlighted some challenges encountered during 2024. The most significant challenges include difficulties related to doctoral training, a lack of

competence in certain essential analysis methods for their PhD, and limited access to high-performance computing resources, which occasionally hinders model training and experimentation. Other PhD students have mentioned difficulties related to the datasets to be used in their research. In response to these challenges, recommendations were made including:

- the organization of training on various analysis methods and sessions on developing mobile applications to integrate AI models into user-friendly tools for farmers.
- PhD students also propose that the laboratory establish collaborations with other institutions or laboratories, such as the PNLP (National Malaria Control Program), as well as institutes that could help provide access to high-performance computing systems and quality data.

APPENDIX 1.

Scientific activities in 2024

A1.1. Defended theses in 2024

Name	Sex	Research topic	Research field
MUSHAGALUSA Ciza Arsène	M	Practical Applications of Random Forests in Count Data Analysis and Species Abundance Modelling	Biometry
MUGUMAARHAH AMA Yannick	M	Spatial point process model for analysis of presence-only data: accounting for species characteristics and uncertainties in data	Biometry
AHLONSOU Galilée	M	Empirical performance of Distance functions for farm efficiency analysis with application on organic cotton farming systems in Benin	Biometry
TAHI Souand Peace Gloria	F	Optimization of machine learning techniques parameters for maize yield prediction under controlled weather and fertilization patterns	Biometry
HOUETOHOSSOU S. C. Ariane	F	Empirical Evaluation of Machine Learning Techniques for Disease Detection and Yield Prediction in Tomatoes under Simulated Climate and Infection Conditions	Biometry

Dr. TAHI Souand Peace Gloria

Optimization of machine learning techniques parameters for maize yield prediction under controlled weather and fertilization patterns

Machine learning, a branch of artificial intelligence, allows machines to learn and make decisions based on data without needing to be explicitly programmed. This approach provides an effective alternative for dealing with non-linear phenomena and large datasets. It stands out from other statistical methods due to its accuracy and adaptability, as it can respond to data variability and emphasizes the importance of an advanced strategy. Machine learning is widely used to predict or detect phenomena or identify patterns among different elements. In agriculture, it is frequently used to address challenges such as disease detection and crop yield prediction through supervised or unsupervised learning methods. Given the increasing global population, intensifying production efforts to reduce malnutrition rates is crucial. Agricultural production is under threat from various factors. Machine learning offers a valuable alternative for optimizing productivity and streamlining decision-making in the face of these challenges. In agriculture, it is frequently used to address challenges such as disease detection and crop yield prediction through supervised or unsupervised learning methods. Given the increasing global population, intensifying production efforts to reduce malnutrition rates is crucial. Agricultural production is under threat from various factors. Machine learning offers a valuable alternative for optimizing productivity and streamlining decision-making in the face of these challenges. However, many machine learning methods are intricate and challenging to grasp and identify the critical variables. Thoroughly evaluating these model's effectiveness in predicting crop yields and facilitating decision-making is imperative. In Benin, significant improvement is required in developing such models, particularly regarding climate change and the lack of data. This study aimed to determine the optimal and least complex machine learning model for maize yield prediction in Benin. Then, we offered in Chapter 1 a comprehensive review of the machine learning techniques used for cereal yield prediction, covering the species studied, input variables of the models studied and the optimal ones, relationships between the models and their accuracy, and relationships between the data scale and its accuracy. A total of 115 articles were selected according to the PRISMA (Preferred Reporting Items for Systematic Reviews and Meta-Analysis) guidelines from six databases spanning 2007 to 2023. The results revealed that most papers used data from secondary sources, with only 28.68% utilizing experimental or primary data. China (31 papers) and the United States (18 papers) were the principal producers. Wheat (48%), maize (33%), and rice (17%) were the most studied cereals. The most studied predictive variables were climate, remote sensing data, and soil parameters. The frequently used machine learning techniques for cereal prediction were Support Vector Machine (SVM) (51%), Multilayer Perceptron (MLP) (41%), Linear Regression (34%), Random Forest (RF) (24%), and Extreme Gradient Boosting (XGBoost) (20%). However, the RF, MLP, XGBoost and SVM models were the best-performing techniques for grain yield prediction based on the coefficient of determination (R^2) and mean absolute error (MAE). The study also highlighted that data availability and quality are the primary factors influencing grain yield prediction. We researched the best weather conditions to maximize maize yield using association rule techniques. The data spanned 26 years (1995 to 2020) and included climate and maize yield data from five districts' agroclimatic zones (Sudanian and Sudano-Guinean) featuring synoptic weather stations. The results indicated that the Sudano-Guinean zone yields high maize for average minimum and maximum temperatures, rainfall, evapotranspiration, and humidity. In the Sudanian zone, high maize yields were also associated with average values for minimum and maximum temperatures and maximum humidity. We also analyzed how the best weather conditions identified affect maize yield in response to different fertilizer types. The data came from a greenhouse experiment, including maize emergence, growth, and yield parameters. This experiment involved two sets of climatic scenarios, labeled as Weather 1 and Weather 2 (combinations of minimum and maximum temperature and maximum humidity), combined with five fertilizer types: organic, chemical, intermediate 1 (1/4 organic, 3/4 chemical), intermediate 2 (1/2 organic, 1/2 chemical), and intermediate 3 (3/4 organic, 1/4 chemical). Various models were analyzed based on the studied parameters. The results indicated that the DNNsurv model outperformed the Cox model in germination parameters, recording better performance. Additionally, a higher probability of emergency was observed between 2 to 5 days, with over 80% of the seeds germinating on the fifth day. Moreover, maize yields were higher for organic, chemical, and intermediate fertilizers under climate scenario 2. Subsequently, we compared machine learning models and developed the final optimal model for maize yield prediction in Benin. Different models were initially compared using diverse secondary data and then applied to the experimental data. The model hyperparameters were optimized using a grid search technique. Among these models, the Extremely Randomized Trees (ERT) model proved to be the best performer, demonstrating more precise accuracy and better generalization to new data. Consequently, the ERT model was retained for the final predictions of maize yield in Benin.

Keywords: Zea maize, Models hyperparameters, Association rules, Ensemble learning, Yield prediction.

Dr. HOUETOHOSSOU S. C. Ariane

Empirical Evaluation of Machine Learning Techniques for Disease Detection and Yield Prediction in Tomatoes under Simulated Climate and Infection Conditions

Global population growth places immense pressure on food systems, demanding sustainable food production to protect natural resources for future generations. This issue is particularly pressing in developing countries, where agricultural infrastructure, technology, and financial resources are often inadequate to meet increased food demands. Enhancing traditional farming practices and incorporating modern technologies can boost production efficiency and reduce post-harvest losses. Tomato (*Solanum lycopersicum*), a globally important vegetable, faces numerous challenges, including climate change, pests, diseases, and resource constraints. Effective disease management is one of the major hurdles, as plant diseases can lead to substantial losses. Artificial intelligence (AI) provides innovative solutions to this problem, particularly through early detection systems based on machine learning algorithms that analyze images and data in real-time to identify initial signs of plant disease or stress, enabling timely intervention. Additionally, accurate yield prediction is vital for optimizing tomato production, distribution, and marketing, with AI-based predictive models offering reliable yield estimates, contributing to sustainable and stable production. This thesis evaluates the performance of machine learning methods in tomato disease detection and yield prediction, demonstrating the superior accuracy of Deep Learning methods for disease identification, especially in scenarios with unbalanced data. The thesis also identifies the models that most effectively predict tomato yield and the critical features for improved predictions.

The dissertation is organized into six chapters. Chapter 1 reviews deep learning techniques in agriculture for detecting biotic and abiotic stress in fruits and vegetables, outlining their benefits and user challenges. A literature review of 132 scientific papers reveals a strong focus on biotic stresses, with the most common issue being fungal diseases. Data scarcity and class imbalance were noted as significant challenges, highlighting the need for further research on climatic variability impacts and additional abiotic stress studies.

Chapter 2 addresses the search for optimal climate conditions for high tomato yield, applying the Frequent Pattern Growth (FPG) algorithm to identify associations among climate variables across three agro-ecological zones in Benin. Results show high yield is linked with moderate evapotranspiration, with optimal climate patterns varying by zone, offering guidance for adaptive agricultural practices under changing climate conditions.

Chapter 3 examines how climate parameters and fertilizer compositions affect tomato growth and yield in controlled greenhouse environments. Findings indicate that while fertilizer impact is limited, climate conditions significantly affect growth and yield, with specific climate-fertilizer interactions suggesting that climate conditions influence fertilizer efficacy. The insights gained offer valuable guidance for developing climate-adapted fertilization strategies.

Chapter 4 applies various supervised machine-learning models to predict tomato yield, with the XGBoost model achieving the highest accuracy, explaining over 90% of yield variability. Key variables include minimum temperature, specific fertilizer treatments, and plant attributes, with ensemble models effectively capturing complex environmental interactions, underscoring their potential in yield optimization.

Chapter 5 evaluates the performance of deep learning architectures (GoogleNet, VGG16, ResNet50) for classifying diseases in tomatoes, peppers, and peaches under class imbalance conditions. Results show that data balancing techniques, such as Random Over Sampling and Random Under Sampling, significantly enhance model performance, with GoogleNet exhibiting the highest stability under class imbalance. This chapter emphasizes the necessity of balanced datasets for robust disease classification.

Chapter 6 summarizes the key findings and suggests future research directions, advocating for larger and balanced datasets to improve AI model performance in tomato disease detection and yield prediction. This thesis underlines AI's potential to transform agriculture by enabling adaptive, precise interventions for sustainable food production.

Keywords: Deep Learning, Climate, fertilizer, XGBoost, optimization, GoogleNet, Resampling

Dr. AHLONSOU Galilée

Empirical performance of Distance functions for farm efficiency analysis with application on organic cotton farming systems in Benin

Distance function (DF) methods are arisen from the necessity to model multiple output production technologies increasingly applied in many fields including agriculture. However, organic farming system being one of the production systems promoted in agriculture, the use of these methods in organic farming systems performance analysis is poorly documented. In addition, although DFs have attracted particular interest from researchers, the literature on their performance is scarce and does not allow definitive conclusions to be drawn, as it is limited to specific factors. This research was carried out to assess the use and empirically the performance of the most DF methods used in organic farming efficiency analysis in order to permit an accurate use of these methods. Chapter 1 presented research and the objectives. Chapter 2 critically reviewed the use of DF approaches for efficiency analysis of organic production units from 2010 to 2020. A total of 27 papers were finally retained after careful reading of the abstracts. Four DF methods were identified, and the most used in organic farming efficiency analysis were output distance function (ODF, 40%) and directional output distance function (DODF, 25%). The performance of these methods has been assessed through Monte Carlo experiments using median absolute deviation, average bias and/or Spearman rank correlation coefficient. Chapter 3 assessed the performance of ODF under varying conditions (sample size, distribution of the noise term v, heteroscedasticity and variance of the inefficiency term u). The results showed that the accuracy of ODF is improved for sample sizes from 50 to 200, when the variance of the inefficiency term is small, under homoscedasticity in u and heteroscedasticity in v. However, the opposite trend is observed about the bias. Furthermore, the results showed that ODF with more outputs was the most accurate estimation model across all scenarios. In Chapter 4, the performance of DODF was evaluated according to variations of sample sizes, distribution of the noise term and variance of the inefficiency term. The results showed that for larger sample sizes (from n = 300) and for a large value of the variance of the inefficiency term, DODF performed better. Chapter 5 applied stochastic ODF approach to measure the performance of organic cotton farming units in Benin (West Africa) using data collected in the framework of the project SYPROBIO during the agricultural campaign 2012-2013. The results showed that producers have an average performance score of 75%. The analysis of determinants of efficiency revealed that crop rotation with leguminous plants (Goussi/Sesame) is the main determinant factor of technical efficiency of organic cotton production. Chapter 6 presents the study's primary conclusions and proposes potential directions for further investigations.

Keywords : Multiple-output production technology; Monte Carlo study ; performance analysis; organic farming; cotton; accuracy.

Dr. MUGUMAARHAHAMA Yannick

Spatial point process model for analysis of presence-only data: accounting for species characteristics and uncertainties in data

Species Distribution Modeling (SDM) is a critical tool in ecology, particularly under the mounting pressures of climate change and anthropogenic disturbances on natural ecosystems such as forests. Among the most significant methodological advances in SDM are the Inhomogeneous Poisson Point Process (IPP) models and their extensions, which provide a probabilistic framework for analyzing species occurrence data. However, a persistent challenge—especially in under-resourced regions such as Africa—is the scarcity of structured, high-quality data. Most available datasets are presence-only (PO), often collected opportunistically, resulting in sampling biases and uncertainties that compromise the accuracy and applicability of SDM in conservation planning and sustainable natural resource management. This thesis investigates the impact of these biases and uncertainties on the reliability of IPP models and their extensions. It explores how species-specific characteristics, spatial autocorrelation (SAC), and data-related uncertainties influence model performance. The work is structured into seven chapters: Chapter 1 provides a conceptual overview of species distribution modeling, emphasizing the theoretical foundations of spatial point process models. A solid understanding of these concepts is essential for designing robust ecological models and supporting biodiversity conservation.

Chapter 2 addresses detection-related biases in PO data, particularly sampling bias and imperfect detection. It demonstrates that failure to account for these errors can lead to distorted parameter estimates, thereby misinforming conservation strategies. Integrated models that incorporate auxiliary point count (PC) data are shown to offer more accurate estimates by explicitly addressing detection errors. Chapter 3 examines the influence of positional uncertainty and spatial niche truncation on model outcomes under different detection error scenarios. The findings suggest that, in isolation, these factors exert minimal influence on model accuracy.

Chapter 4 explores how species-specific ecological characteristics affect model sensitivity to detection errors. It reveals that predictive accuracy decreases with increasing ecological specialization of species, and that the magnitude of detection error effects varies across species types. Chapter 5 focuses on the issue of spatial autocorrelation (SAC), which is often overlooked in SDM applications. The results indicate that neglecting SAC can lead to significant biases in parameter estimates and reduced predictive performance. While the Log-Gaussian Cox Process (LGCP) model effectively accounts for short-range SAC, its performance declines when SAC occurs at broader spatial scales. Furthermore, model performance deteriorates substantially when both SAC and detection errors are present in the data. Chapter 6 proposes a practical decision framework for selecting appropriate statistical models based on data quality and species characteristics. This framework is applied to a case study involving the red-bellied guenon (*Cercopithecus erythrogaster*), a critically endangered primate in Benin. The analysis reveals the presence of both sampling bias and SAC in occurrence data, suggesting that an integrated LGCP model would be best suited—though such a model is not yet available in practice.

Chapter 7 synthesizes the findings and discusses their implications for ecological modeling and conservation practice. It underscores the importance of jointly addressing detection errors and spatial autocorrelation to improve the robustness of species distribution predictions.

In conclusion, this thesis emphasizes the need for more sophisticated modeling approaches that can accommodate the dual challenges of detection bias and spatial autocorrelation. Addressing these issues is crucial for enhancing the reliability of SDM, particularly in data-poor regions, and for informing effective biodiversity conservation under global environmental change.

Dr. MUSHAGALUSA Ciza Arsène

Practical Applications of Random Forests in Count Data Analysis and Species Abundance Modelling

This dissertation aims to evaluate the effectiveness and efficiency of Random Forests (RF) in modelling count data, focusing on species abundance distributions. Traditional count data models have limitations in capturing complex non-linear interactions and are not suitable for small-n-large-p problems. Machine learning (ML) methods such as RF have gained popularity, but are often used as black boxes with unclear efficacy and assumptions. Most RF studies focus on classification rather than regression tasks, so their performance on count data is less understood. The thesis consists of two main parts: a comprehensive overview of supervised machine learning, presenting the properties and characteristics of Breiman RF, and empirical studies on the validation of RF models. The first empirical study examines the effect of data characteristics and over-dispersion on RF parameters in regression tasks and finds that RF parameters are not affected by sample size, number or type of predictors, but the stability of optimal parameters is affected by the ratio of observations to predictors. The second study shows that the choice of validation approach significantly affects the performance of the learning algorithm, with effectiveness varying depending on the complexity of the dataset. Conditional inference forests are more reliable than standard RF in identifying important variables when outcomes are over-dispersed. The third study shows that standard RF performs poorly in the presence of high spatial autocorrelation and low species detection probability. Blocked spatial CV with a checkerboard pattern is the most effective CV method for clustered samples. The fourth study reveals that the effectiveness of spatial RF variants is influenced by the class of species abundance and the complexity of the relationship between abundance and environmental variables. Spatial RF variants outperform conventional models in terms of prediction accuracy and power, especially when spatial autocorrelation and species detection probabilities are high. However, no single model is superior for all prediction objectives. This dissertation emphasises the importance of performance metrics, careful model specification and consideration of data features in ML models validation to avoid unrealistic predictions and misinterpretation of species abundance patterns. It also advises against treating RF algorithms as black boxes.

Keywords: Machine learning, Species distribution modelling, Resampling, Random forest, Over-dispersion, discrete data, spatial-autocorrelation.

A1.2. On-going thesis in 2024

N°	Name	Sex	Level	Topic	Field of research
1	YALINKPON Florent	M	1st year	Developing a predictive model for cotton yield in Benin using Artificial Intelligence: A strategic approach for adaptive and sustainable agriculture in the context of climate change	Biostatistics and Biometry
2	LALY Judicaël	M	1st year	Predictive performance evaluation of machine learning models with multiple outputs for decision-making in agriculture	Biostatistics and Biometry
3	CRINOT Fabrice Désiré Géraud J. C. E.	M	1st year	Optimization of Causal Machine Learning Methods for Heterogeneous Treatment Effect Estimation for Agricultural Decision Making	Biostatistics and Biometry
4	DOSSA Hubert	M	1st year	Dynamics of Helicoverpa armigera and Bacterial Blight Disease: Economic Impacts on Cotton Production in Benin	Biostatistics and Biometry
5	ACHIKPA Yabi Akinro Olivier	M	1st year	Mathematical modeling of tuberculosis transmission in the presence-absence of vaccination, and treatment.	Biostatistics and Biometry
6	DUKUNDANE Didier	M	1st year	Mathematical and Numerical Modeling of COVID-19-Induced Respiratory Dynamics Using Coupled Stokes–Biot Equations: Development of Personalized Models from Computed Tomography Scans	Biostatistics and Biometry
7	KENENISA ABDISA KUSE Kenenisa	F	1st year	A comparative study of high-accuracy surface modeling and Machine learning with Euclidean distance field techniques: Exploring the influence of sample size, spatial dependence, Skewness, and outliers on predictive performance with Application in soil science	Biostatistics and Biometry
8	BIYAGUI Issifou	M	1st year	Fractional-Order Approaches to Pandemic Modeling: Insights from COVID-19 Dynamics	Biostatistics and Biometry
9	HAKIZIMANA Emmanuel	M	1st year	Optimal Control Modeling of African Maize Stalk Borer (Busseola fusca) Dynamics	Biostatistics and Biometry
10	GANDJI Mirabelle	F	1st year	Ecology, biology of conservation and domestication of *Ricinodendron heudelotii* (Bail.) Pierre ex. Heckel in Benin	Natural Resources Management
11	Sonon Bienvenu	M	2nd year	Application of artificial intelligence in combination with exponantial autoregressive to modèle rainfall onset-cessation for the improvement of agriculture planning in Benin	Biostatistics and Biometry

N°	Name	Sex	Level	Topic	Field of research
12	Tinhoun fréjus Stéphane Sèdjro Cossi	M	2nd year	Understanding the impacts of interventions on COVID-19 dynamics in West Africa: a hybrid bayesian machine learning framework	Biostatistics and Biometry
13	SODE Akoeugnigan Idelphonse	M	2nd year	Spatial Fusion Framework for the Joint Analysis of Geospatial Data from Multiple Sources: Ecological and Epidemiological Applications	Biostatistics and Biometry
14	ZINZINHEDO Mahoukpégo Luc	M	3rd year	Combined approach of Machine Learning and spatiotemporal models for cassava (*Manihot esculenta* C.) yield prediction in Benin under pathogen infestation conditions.	Biostatistics and Biometry
15	GUEDEZOUME Behanzin Marthe Paulette	F	3rd year	Using machine learning techniques to predict soil fertility in Benin	Biostatistics and Biometry
16	TRAORE Kassifou	M	3rd year	A mathematical model for the analysis of malaria incidence and mortality in sub-Saharan Africa: Accounting for population opinion of modern and traditional treatments and prevention methods.	Biostatistics and Biometry
17	ODOUNFA Mireille Gloria F.	F	3rd year	Using deep learning techniques for early detection of chili (Capsicum spp, Tailor and Francis) diseases under constraints of limited sample image, climate variations, and pests.	Biostatistics and Biometry
18	Dereje Gebeyehu Ababu	M	3rd year	Cointegration of Markets and Their Impact on Income and Productivity of Cereal Crops Producing Households: The Case of Ethiopia	Biostatistics and Biometry
19	BEH MBA Romuald	M	3rd year	Empirical performance of Generalized linear mixed model for point-referenced spatial data with Application to epidemiological data: Disease Mapping	Biostatistics and Biometry
20	DETE Houénafa Clarisse	F	3rd year	Relative performance of model selection criteria based on Kullback's symmetric Divergence in survival analysis with application in animal production	Biostatistics and Biometry
21	ANTENEH Leul Mekonnen	M	3rd year	Modeling of Cholera Epidemics in Ethiopia	Biostatistics and Biometry
22	MONTCHO Yvette	F	3rd year	Socio-Ecological and spatio-temporal Modeling of COVID-19 dynamics in Africa	Biostatistics and Biometry
23	ADEOTI Olaiya Mathilde	M	3rd year	Bayesian nonlinear modelling for correlated epidemic data using flexible distribution: A Casablanca study with COVID-19 data	Biostatistics and Biometry
24	AKIN Y. Yanik	M	3rd year	Phylogenetic diversity, perturbation and transient dynamic of tropical fuelwood tree	Biostatistics and Biometry

N°	Name	Sex	Level	Topic	Field of research
25	Constant Setondé Gnansounou	M	4th year	Social-Ecological Resilience of Mangroves in Benin	Coastal zone Management
26	AGBANGBA Codjo Emile	M	4th year	Experimental designs and data analysis with linear model in the presence of spatial autocorrelation with applications in soil sciences	Biostatistics and Biometry
27	OROUNLA Bissilimou Rachidatou	F	4th year	Interplay between personal characteristics, Socio-economic determinants, environmental changes and diseases through Causal Modeling and Structural Equation Modeling	Biostatistics and Biometry
28	TABOE Hemaho Beaugard	M	5th year	Mathematical meta-population models of emerging and re-emerging communicable diseases' dynamic patterns in developing countries: Application to COVID-19 pandemic and Lassa Fever virus outbreak in West Africa.	Biostatistics and Biometry
29	BOUROBOU Judie Armel	M	5th year	Inhomogeneous Poisson Process and its extensions for species distribution analysis: Accounting for sampling bias, imperfect detection, non-linear effect and spatial dependence.	Biostatistics and Biometry
30	DAH-DOVONON Virgile-Marx	M	5th year	Evaluation des stratégies innovantes d'adaptation et apport de l'information climatique dans la Gestion des risques climatiques dans les exploitations agricoles au Bénin	Climate change and agriculture
31	KAKPO Dolou Angeline Reine	F	6th year	Uses, fertilizing power, populations dynamic and conservation of some agroforestry species high soil fertilizing potential in Benin.	Agroforestry

A1.3. Completed Master in 2024

N°	Name	Sex	Topic	Supervisor(s)	Field of research
1	ODAH Kodjo Abel	M	Machine learning techniques for tomato yield prediction: Systematic literature review	Prof. Romain GLELE KAKAÏ Dr. Ratheil V. HOUNDJI	Biostatistics
2	BANKOLE Adédogni Arikè Rihanatou	F	Analysis of the effects of outliers and the skewness of explanatory variables on the empirical performance of random forest classification: Application to infant meningitis data	Prof. Romain GLELE KAKAÏ Dr. Valère SALAKO	Biostatistics
3	CODJO Melvine Ridvane Houefa	F	Modeling of the climate, ecological, socio-economic, and demographics factors on the dynamics of malnutrition in West Africa.	Prof. Orou G. GAOUE Dr. Emile AGBANGBA	Biostatistics
4	AMOUSSOUVI Toussaint	M	Assessing the potential seasonality of COVID-19 dynamic in Africa: A mathematical modeling Study	Prof. Romain GLELE KAKAÏ	Biostatistics

5	ONONOGBU, Chimmuanya Emmanuel	M	Meta-analysis of the asymptotic and transient response of plant populations to harvest across ecological systems and life-forms.	Prof. Orou G. GAOUE Dr. (MC) Charlemagne D. S. J. GBEMAVO	Biostatistics
6	BATEKA MPUTU Plandi	M	Grain maize yield prediction: A systematic review of machine learning methods	Prof. Romain GLELE KAKAÏ Dr. Ratheil V. HOUNDJI	Biostatistics
7	ALAYE Eustache	M	Direct And Indirect Effects Of Environmental And Socio-Economic Factors On The Dynamics Of Covid-19 In Africa	Prof. Romain GLELE KAKAÏ	Biostatistics
8	FURAHA MPURANYI Julie	F	Assessment of the effects of sample size on Spatial Point process models under different scenarios of spatial dependence and species characteristics	Prof. Romain GLELE KAKAÏ Dr. Jonas DOUMATE	Biostatistics

A1.4. Scientific papers published in peer-review journals IF in 2024

N°	Discipline	Authors' Names	Title of the article	Journals	IF
1	Forestry	Hounsou-Dindin G., Salako K.V., Gandji K., Adomou A.C., Assogbadjo A.E., Glèlè Kakaï R.	Tree size partially mediates the influence of climate on fruit and seed production in Ricinodendron heudelotii (Baill.) Heckel	African Journal of Ecology	1.1
2	Forestry	Luambua N.K., Kadorho A.S., Nshimba H.S., Beeckman H., Ewango, C., Salako K.V., Musepena D., Rousseau M., Laurent F., Bourland N., Hardy O.J., De Mil T., Hubau W.	Light-demanding canopy tree species do not indicate past human disturbance in the Yangambi rainforest (Democratic Republic of the Congo)	Annals of Forest Science	2.5
3	Ecology	Dassou G.H., Agoundé G., Akouété P., Favi G.A., Kpétikou G.C., Salako K.V., Ouachinou J.M.A.S, Makponsè J, Kouyaté A.M, Sari I., Glèlè Kakaï R.L., Yédomonhan H., Adomou A.C.	Past, present, and future potential distributions of the African multipurpose tree Detarium senegalense (Fabaceae)	Plant Ecology & Evolution	1.15
4	Agroforestry	Djidohokpin D., Dassou G.H., Hounkpèvi A., Ouachinou J.M.A.S., Favi G.A., Houessou G.L., Yédomonhan H., Adomou, A. C.	Factors affecting population structure and fruit production of Strychnos innocua Delile and Strychnos spinosa Lam. In Benin, West Africa	All Life	1.0
5	Biometry	Orounla B.R., Alaye A.E., Salako K.V., Agbangba C.E., Aheto J.M.K., Glèlè Kakaï R.	Direct and Indirect Effects of Environmental and Socio-Economic Factors on COVID-19 in Africa Using Structural Equation Modeling	Stats	0.9
6	Plant genetics	Adéoti K., Salako K.V., Daa-Kpodé U.A., Ouédraogo A., Santoni S., Aberlenc F., Kpatènon M.J., Latreille M., Tollon Cordet C., Etsè K.D., Mahmoud O.H.A., Faye A., Jaligot E., Beulé T.	Efficiency of simple sequence repeat (SSR) markers in genetic diversity study and differentiation of Borassus aethiopum Mart. and Borassus akeassii Bayton, Ouédr. & Guinko	Genetic Resources and Crop Evolution	2.08
7	Epidemiology	Adéoti O. M., Agbla S., Diop A., Glèlè Kakaï R.	Nonlinear mixed models and related approaches in infectious disease modeling: a systematic and critical review	Infectious Disease Modelling	3.0
8	Agroforestry	Akakpo A.D., Salako V.K., Houndonougbo J.S., Akin Y., Pedanou C.L., Agbangla C., Assogbadjo A.E.	Farmer-perceived phenotypic variation and preferences reveal potential for multi-traits selection in the desert date Balanites aegyptiaca (L.) Delile in Benin	Genetic Resources and Crop Evolution	2.08
9	Foods security	Anagonou G.H., Gandji K., Salako K.V., Houetohossou A., Zannou E.T., Mensah G.A., Assogbadjo A.E., Chadare F.J.	Socio-economic and cultural drivers of local perceptions and willingness to consume edible insects in Benin	Future Foods	7.2

N°	Discipline	Authors' Names	Title of the article	Journals	IF
10	Biometry	Azokpota P., Nalwanga R., Montcho Y., Traoré K., Doumatè J.T., Glèlè Kakaï R.	Mathematical Analysis of the Dynamics of COVID-19 in the Face of Vaccination in African Countries	Contemporary Mathematics	0.6
11	Foods security	Chirinda N., Abdulkader B., Hjortsø C.N., Aitelkadi K., Salako K.V., Taarji N., Mhada M., Lamdaghri Z., Romanova G., Assogbadjo A.E., Chadare F.J., Saidi M., Sassi M., Mugonola B., Gogo E.O., Ssekandi J., Okalany E., Egeru A., Mshenga P.M., Chfadi T.	Perspectives on the integration of agri-entrepreneurship in tertiary agricultural education in Africa: insights from the AgriENGAGE project	Frontiers in Sustainable Food Systems	3.7
12	Plant genetics	Kégbé A.M., Salako K.V., Lokonon B.E, Mensah S., Noba K., Assogbadjo A.E.	A comparative study of morpho-physiological responses of wild and cultivated Solanum species to water stress: the case of S. sisymbriifolium and S. macrocarpon	Genetic Resources and Crop Evolution	2.08
13	Forestry	Akin Y.Y., Glèlè Kakaï R., Gaoue O.G.	Chronic anthropogenic disturbance and climate synergistically shape demographic trade-offs in a tropical fuelwood tree	Forest Ecology and Management	3.7
14	Forestry	Akakpo A.D.M., Kolawole M.A., Dimobe K., Salako K.V., Sacla Aide E., Chadare F.J., Agnangla C., Assogbadjo A.E.	Impacts of land use and abiotic factors on fruit, seed, and leaf morphology of the desert date Balanites aegyptiaca in Benin: Implications for management	Trees, Forests and People	2.7
15	Forestry	Deguenonvo T.A.G., Adjacou D.M., Idohou R., Sodedja R., Sobakin F.E.D., Houehanou T.D., Gouwakinnou G.N., Natta A.K.	Synergizing climate dynamics, species distribution, and structural parameters for sustainable management of Pseudrocedrela kotschyi in Benin (West Africa)	Global Ecology and Conservation	3.5
16	Machine learning	Odounfa M.G.F., Gbemavo C.D.S.J., Tahi S.P.G., Glèlè Kakaï R.	Deep learning methods for enhanced stress and pest management in market garden crops: A comprehensive analysis	Smart Agricultural Technology	6.3
17	Forestry	Lykke A.M., Rømer N., Gonzalez P., Glèlè Kakaï R., Rabiou H., Amegnaglo K.B., Ganaba S., Sambou B., Niang F., Herault B., Guuroh R.T., Ouoba P., Yaméogo J.T., Traoré L., Sinsin B, Amahowe O.I., Bay S.S., Houehanou T.D., Houessou L.G., Gouwakinnou G.N., Yetein M.H., Tankoano B., Ouédraogo A., Ouédraogo I., Taita P., Amani B.H.K., Coulibaly B., Kouyate A.M., van Damme P., Vanhove W., Mahamane A., Bonache C., Sambou	Tree populations show low regeneration of valued species in West Africa	Biological Conservation	4.9

N°	Discipline	Authors' Names	Title of the article	Journals	IF
		S., Soumana I., Amani A., Maârouhi I.M., Barfod A.S.			
18	Forestry	Dogbo S.F., Salako K.V., Agoundé G., Dimobe K., Adiko A.E.G., Gebauer J., Adou Yao C.Y., Glèlè Kakaï R.	Potential impacts of future climate on twelve key multipurpose tree species in Benin: Insights from species distribution modeling for biodiversity conservation	Trees, Forests and People	2.7
19	Forestry	Dogbo S.F., Salako K.V., Mensah S., Akakpo D.M.A., Assogbadjo A.E., Gebauer J., Glèlè Kakaï R., Adou Yao C.Y.	Vegetation attributes in peri-urban agroforestry systems and their socio-economic determinants in Benin (West Africa)	Agroforest Systems	2.0
20	Biometry	Gongnet E.E., Agbangba C.E., Affossogbé T.A.S., Vihotogbé R., Glèlè Kakaï R.	Assessing the impact of hard data patterns on Bayesian Maximum Entropy: a simulation study	Scientific Reports	3.8
21	Ecology	Salako K.V., Sode A.I., Dicko A., Alaye E.A., Wolkewitz M., Glèlè Kakaï R.	Cross-Country Assessment of Socio-Ecological Drivers of COVID-19 Dynamics in Africa: A Spatial Modelling Approach	Stats	0.9
22	Biometry	Alier G·, Idohou R·, Hounsou-Dindin G., Glèlè Kakaï R.	Assessing the potential impact of climate change on Kobus megaceros in South Sudan: a combination of geostatistical and species distribution modelling	Modeling Earth Systems and Environment	2.7
23	Epidemiology	Anteneh L.M., Lokonon B.E., Glèlè Kakaï R.	Modelling techniques in cholera epidemiology: A systematic and critical review	Mathematical Biosciences	1.9
24	Biometry	Bourobou B.J.A., Zinzinhedo M.L., Fandohan A.B., Glèlè Kakaï R.	Evaluating spatial resolution and imperfect detection efects on the predictive performance of inhomogeneous spatial point process models trained with simulated presence-only data	Modeling Earth Systems and Environment	2.7
25	Epidemiology	Nkwayep C. H.., Glele Kakaï R., Bowong S.	Prediction and control of cholera outbreak: Study case of Cameroon	Infectious Disease Modelling	3.0
26	Machine learning	Agbangba C.E., Toha, R.O.Y., Bello A.W., Adetola J.	Enhancing interpretability and fidelity in convolutional neural networks through domain-informed knowledge integration	Advances and Applications in Statistics	0.1
27	Biometry	Agbangba C.E., Sacla Aide E., Honfo H., Glèlè Kakaï R.	On the use of post-hoc tests in environmental and biological sciences: A critical review.	Heliyon	3.4
28	Biometry	Agbangba C.E., Aubin A., Sossa E.L.	Optimal sample size for DRIS model parameterisation to diagnosis nutrients status in fruit crops.	African Crop Science Journal	0.263

N°	Discipline	Authors' Names	Title of the article	Journals	IF
29	Biometry	Agbangba E.C., Yalinkpon F., Sossa E.L., Gongnet E.E., Glèlè Kakaï, R.	A simulation study on the comparison of Diagnosis and Recommendation Integrated System (DRIS), Modified-DRIS (M-DRIS), and Compositional Nutrient Diagnosis (CND) for pineapple nutrient diagnosis.	Agronomy Research	1.02
30	Ecology	Agbangba C.E., Vianou A., Sossa, E.L., Vodounnon M.E.J., Glèlè Kakaï R.	Ecological Niche Modeling to Identify Cultivation Areas for Pineapple in the Republic of Benin	African Journal of Food, Agriculture	0.56
31	Biometry	Gongnet E.E., Vihotogbé R., Agbangba C.E., Affossogbé T.A.S., Djondang K., Glèlè Kakaï R.	Impact of box-cox transformation technique on the Bayesian Maximum Entropy (BME) prediction accuracy.	JP Journal of Biostatistics	0.1
32	Agronomy	Sossa E.L., Agbangba C.E., Koura T.W., Ayifimi O.J., Houssoukpèvi I.A., Bouko N.D.B., Yalinkpon F., Amadji G.L.	Dynamics of co-composting of pineapple harvest and processing residues with poultry litter and compost quality.	Scientific Reports	3.8
33	Machine learning	Houetohossou S.C.A., Ratheil Houndji V., Sikirou R., Glèlè Kakaï R.	Finding optimum climatic parameters for high tomato yield in Benin (West Africa) using frequent pattern growth algorithm.	Plos one	2.9
34	Agroforestry	Kakpo A.R., Vodounnon M.J., Agbangba E.C., Hounsou-Dindin G., Dagbénonbakin D.G., Amadji G.L., Buri M.M., Glèlè Kakaï R.	Vulnerability of Parkia biglobosa, Vitellaria paradoxa and Vitex doniana to climate change: wild indigenous agroforestry species in Benin.	Modeling Earth Systems and Environment	2.7
35	Biometry	Matazi A.K., Gognet E.E., Glèlè Kakaï R.	Digital soil mapping: a predictive performance assessment of spatial linear regression, Bayesian and ML-based models.	Modeling Earth Systems and Environment	2.7
36	Ecology	Tietiambou S.R.F., Idohou R., Agounde G., Lankoande B., Avocevou C., Ouédraogo A., Glèlè Kakaï R.	Modelling the potential impact of climate change on Carapa procera DC. in Benin and Burkina Faso (West Africa).	Modeling Earth Systems and Environment	2.7
37	Agroforestry	Daï E.H., Salako K.V., Hotes S., Assogbadjo A.E.	Morphological variability of 'bush banana'(Uvaria chamae) and its environmental determinants in Benin, West Africa.	Genetic Resources and Crop Evolution	2.08
38	Coastal Zone Management	Gbedomon R.C., Salako K.V., Gnansounou S.C., Gandji K., Failler P., Assogbadjo A.E., Glele Kakai R.	Small-scale marine fishing in Benin, West Africa: A comprehensive assessment of the processed fish value chain.	Marine Policy	3.5
39	Coastal Zone Management	Gnansounou S.C., Salako K.V., Visée C., Dahdouh-Guebas F., Glele Kakai R., Kestemont P., Henry S.	The role of local deities and traditional beliefs in promoting the sustainable use of mangrove ecosystems.	Forest Policy and Economics	4.0

N°	Discipline	Authors' Names	Title of the article	Journals	IF
40	Forestry	Price C.A., Branoff B., Cummins K., Glèlè Kakaï R., Ogurcak D., Papeș M., Ross M., Whelan K.R.T., Schroeder T.A.	Global Data Compilation Across Climate Gradients Supports the Use of Common Allometric Equations for Three Transatlantic Mangrove Species	Ecology and Evolution	2.3

A1.5. Scientific papers published in peer-review indexed journals WIF in 2024

N°	Disciplines	Authors' Names	Title of the article	Journals
1	Forestry	Tokannou I.E.T., Sanogo S., Houndonougbo J.S.H., Salako K.V., Fandohan A.B.	Three decades of research efforts on the uses, conservation, and management of Cola nitida (Vent.): State of knowledge and prospects in Africa	Forestry Studies
2	Machine learning	Tahi S.P.G., Houndji V.R., Hounmenou C.G., Glèlè Kakaï R.	Using pattern mining to determine fine climatic parameters for maize yield in Benin	IAES International Journal of Artificial Intelligence (IJ-AI)
3	Agronomy	Eclou I.B·, Glèlè Kakaï R.	Contamination and pesticide multiresidue analysis in cotton production systems in Benin	Discover Environment
4	Machine learning	Tahi S.P.G., Houndji V.R., Salako K.V., Hounmenou C.G., Glele Kakaï R.	Machine Learning Techniques for Cereal Crops Yield Prediction: A Comprehensive Review	Applications of modelling and simulation

A1.6. Scientific papers published in non-indexed peer-review journals in 2024

N°	Disciplines	Authors' Names	Title of the article	Journals
1	Machine learning	Houetohossou S.C.A., Hounmenou C.G., Houndji V.R., Glèlè Kakaï R.	Empirical Performance of Deep Learning Models with Class Imbalance for Crop Disease Classification	International Conference on Deep Learning Theory and Applications
2	Machine learning	Hounmenou C.G., Agbangba E.C., Amagbégnon G., Marone R.M.N.	Relative performance of Neural Networks and Binary Logistic Regression in a Variable Selection framework	Position Papers of the 19th Conference on Computer Science and Intelligence Systems
3	Biometry	Anteneh L.M., Glèlè Kakaï R.	Mathematical modelling and analysis of cholera dynamics via vector transmission	Communications in Mathematical Biology and Neuroscience
4	Biometry	Agbi D.M., Doumate T.J., Opoku N.K.O., Glèlè Kakaï R.	Eco-epidemiology of lassa fever: a mathematical modeling approach	Communications in Mathematical Biology and Neuroscience

A1.8. Participation to conferences/seminars/workshops in 2024

N°	Title, Place and period of the conference/seminar	Type of Presentation (oral, poster, ..)	Attendee
1	Chronic anthropogenic disturbance and climate synergytically shape demographic trade-offs of Tropical fuelwood tree, Rwanda, July	Oral	AKIN Yaï Yanik
2	Bayesian flexible multilevel nonlinear models in infectious diseases modelling, Togo, October	Oral	ADEOTI Olaiya Mathilde
3	Bayesian flexible multilevel nonlinear models in infectious diseases modelling, Benin, July	Oral	ADEOTI Olaiya Mathilde
4	Potential impacts of future climate on 12 key multipurpose tree species in Benin: Insights from species distribution modeling for biodiversity conservation, England, December	Oral	DOGBO Sèdoami Flora
5	Climate Change Adaptation, Germany, September	Training	ZINZINHEDO Mahoukpégo Luc
6	An experimental analysis of traditional machine learning algorithms for maize yield prediction, Benin, January	Oral	TAHI Souand Peace Gloria
7	Maize yield prediction: A machine learning study based on experimental data from Benin, Rwanda, November	Oral	TAHI Souand Peace Gloria
8	Mathematical modelling and analysis of cholera dynamics via vector transmission, Nigeria, August	Oral	Anteneh Leul Mekonnen
9	Modelling techniques in cholera epidemiology: A systematic and critical review, Kuwait, November	Oral	Anteneh Leul Mekonnen
10	Artificial Intelligence in Health, Agriculture and Environment in Africa: Achievements, Challenges and Perspectives, Bénin, January	Training	TRAORE Kassifou
11	Infectious Disease Modelling with a focus on Malaria Vaccination, Gambia, July	Training	TRAORE Kassifou
12	Infectious Disease Modelling, Ghana, December	Training	TRAORE Kassifou
13	Relative performance of model selection criteria for Parametric Accelerated Failure Time model based on Kullback's Symmetric Divergence, Rwanda, November	Oral	DETE Houénafa Clarisse
14	Relative performance of model selection criteria for Parametric Accelerated Failure Time model based on Kullback's Symmetric Divergence, Togo, October	Oral	DETE Houénafa Clarisse
15	Importance of quality scientific publishing|scientific writing| Avoid plagiarism & auto-plagirism in scientific writing|Predatory journal detection, Benin, January	Training	DETE Houénafa Clarisse

16	Direct and Indirect Effects of Environmental and Socio-Economic Factors on COVID-19 in Africa Using Structural Equation Modeling, Cameroon, November	Oral	Orounla Rachidatou
17	Direct and Indirect Effects of Environmental and Socio-Economic Factors on COVID-19 in Africa Using Structural Equation Modeling, Togo, October	Oral	Orounla Rachidatou
18	Prediction of Tomato Yield in the Guinean Zone of Benin Using Machine Learning Models, Rwanda, November	Oral	HOUETOHOSSOU Seton Calmette Ariane
19	Empirical performance of Deep Learning models under class imbalance influence for crop disease classification, Senegal, September	Poster	HOUETOHOSSOU Seton Calmette Ariane
20	Empirical performance of Deep Learning models under class imbalance influence for crop disease classification, France (Online), July	Oral	HOUETOHOSSOU Seton Calmette Ariane
21	Finding optimum climatic parameters for high tomato yield in Benin (West Africa) using frequent pattern growth algorithm, Bénin, January	Oral	HOUETOHOSSOU Seton Calmette Ariane
22	Barriers to developing interventions through mathematical modeling for pandemic preparedness in the context of One Health in Africa: The experience of the Afrique One consortium, South Africa, September	Oral	Lokonon Enagnon Bruno
23	Historical line of spatial mangrove changes in Benin Coastal area (West-Africa) using random forest algorithm applied to Landsat images., France, October	Oral	ZANVO Mahoutin Gildas Serge
24	Drone piloting, Côte d'Ivoire, july	Training	ZANVO Mahoutin Gildas Serge
25	DNA barcoding and metabarcoding, Benin, June	Training	Kolawole Moustapha Arèmou
26	Artificial Intelligence Algorithms Used to Evaluate Soil Fertility: Diversity, Performance, and Limits • Critical review of machine learning algo-, TOGO, October	Poster	GUEDEZOUME BEHANZIN Marthe Paulette
27	Environmental and Remote Sensing Data Analysis via Geospatial Technologies in Research and Teaching", GERMANY, September	Oral	GUEDEZOUME BEHANZIN Marthe Paulette
28	Création de Richesse en Afrique avec la Télématique, la Robotique et les Cubesats, Cotonou, Golden Tulipe, Bénin, June	Oral	AGBANGBA Codjo Emile
29	Performance of linear mixed-effects models in spatial structured data analysis of common experimental designs, Benin, September	Oral	AGBANGBA Codjo Emile
30	Improving kriging methods performance using box-cox transformation on highly skewed data, Benin, October	Oral	AGBANGBA Codjo Emile

31	Kriging and Bayesian Maximum Entropy robustness to kurtosis and skewness : simulation based analysis, Bénin, November	Oral	AGBANGBA Codjo Emile
32	Bayesian spatial modeling for joint analysis of presence-only and abundance data: Case study of baobab in Benin, Rwanda, April	Oral	SODE Idelphonse
33	Introduced Species and Land Covers on Fogo Island, Germany, September	Oral	SODE Idelphonse
34	DIGIFACE: SCIENCE COMMUNICATION AND NETWORKING, Germany, September	Training	TINHOUN Fréjus Stéphane Sèdjro Cossi
35	Sensibilisation sur les bonnes pratiques de publication, Benin,	Training	TINHOUN Fréjus Stéphane Sèdjro Cossi
36	I3AFD school on Artificial Intelligence: Machine Learning and Data mining, Cameroun, March	Training	TINHOUN Fréjus Stéphane Sèdjro Cossi
37	Importance of quality scientific publishing|scientific writing| Avoid plagiarism & auto-plagirism in scientific writing|Predatory journal detection, Benin, January	Training	Gandji Mirabelle
38	A new indicator-based approach to assess the social-ecological resilience of mangroves, Cameroon, December	Oral	GNANSOUNOU Constant

APPENDIX 2.

Abstracts of published scientific papers in peer-review journals in 2024

Tree size partially mediates the influence of climate on fruit and seed production in *Ricinodendron heudelotii* (Baill.) Heckel

Hounsou-Dindin G., Salako K.V., Gandji K., Adomou A.C., Assogbadjo A., Glèlè Kakaï R.

African Journal of Ecology, 62(3), e13302
DOI: https://doi.org/10.1111/aje.13302

Understanding environmental drivers of fruit and seed production in wild edible fruit species is essential for their valorisation. *Ricinodendron heudelotii* is an oilseed plant whose kernels are particularly treasured in cosmetic and medical industries. This study assessed fruits and seeds production patterns of *R. heudelotii*. Data were collected for three consecutive years on 30 trees in the phytodistricts of Plateau, Pobè and South Borgou where it naturally occurs. Tree dbh, total height, crown diameter, number of fruits and seed mass were measured. Climatic data were obtained from NASA Power Database. Data were analysed using linear (seed mass) and generalised linear (number of fruits) mixed models and structural equation modelling. Fruit and seed production were significantly higher in the South-Borgou phytodistrict (1433 ± 1144 fruits, 4.26 ± 3.39 kg of Dry matter per tree) and Plateau phytodistrict (1.66 ± 0.35 g DM/seed). Tree dbh further significantly mediated the effect of minimum temperature, and relative humidity on seed mass. Tree dbh, irradiance and dry season rainfall were identified as the best-predictors of seed mass production (kg DM). These results improved current knowledge of the fruit and seed production of *R. heudelotii* and are of significant importance for the exploitation of the species.

Keywords: Dendrometric trait, environmental variable, predictive model, seed mass production, SEM

Light-demanding canopy tree species do not indicate past human disturbance in the Yangambi rainforest (Democratic Republic of the Congo)

Luambua N.K., Kadorho A.S., Nshimba H.S., Beeckman H., Ewango, C., Salako K.V., Musepena D., Rousseau M., Laurent F., Bourland N., Hardy O.J., De Mil T., Hubau W.

Annals of Forest Science, 81(1), 45
DOI : https://doi.org/10.1186/s13595-024-01263-6

In a former paper, we investigated whether the presence of light-demanding tree species in the forest canopy of the Yangambi Biosphere Reserve (central Congo basin) might be a result of past human disturbances (Luambua et al., Ecol Evol 11:18691–18707, 2021). We focussed on the spatial distribution of the most abundant light demanders, but this approach did not yield conclusive results. In the present study, we focus on all species in the forest and conclude that light demanders are not a transient feature of successional tropical forests but an intrinsic component of old-growth forests in Yangambi. Central African rainforests are characterised by an abundance of light-demanding tree species, which are aggregated in the canopy but underrepresented in the understorey. A popular explanation is that these forests are recovering from slash-and-burn farming activities preceding the relocation of settlements during the colonial era. In a former paper, we showed that the abundance of light-demanding tree species in the Yangambi Biosphere Reserve (central Congo basin) cannot be unambiguously attributed to past human disturbances, using an approach that focused on the spatial distribution of the most abundant light demanders (Luambua et al., Ecol Evol 11:18691–18707, 2021). As the former study was inconclusive, the present study aims to further test the assumptions behind the 'recovery from human disturbance hypothesis', by considering all species in the forest of Yangambi. We addressed four specific research questions: (i) do light demanders occur in large 'pockets' occupying large areas of forest? (ii) Are light demanders abundant? (iii) Do they exhibit a regeneration deficit? (iv) Is species composition in pockets of light demanders different from the surrounding forests? We identified the location and size of pockets of light demanders in several transects cumulating to 50 km. We installed permanent inventory plots within and outside these pockets and calculated the diameter and age distributions of light demanders within each pocket. We assessed whether pockets of light demanders are different from surrounding forests, using plot clustering analysis. Our results showed that light demanders were aggregated, but the pockets were small, scarce, and rep resent a minor fraction of the total forest area. Furthermore, light demanders were not abundant, even in pockets where they were aggregated. Their age distributions did not show a regeneration deficit. Finally, species composition in pockets of light demanders did not differ substantially from surrounding forests where they were scarce or absent. We conclude that light-demanding canopy species do not indicate past human disturbance in Yangambi and that they are an intrinsic component of old-growth forests rather

than a transient feature of successional forests. Our insights show that the large carbon sink observed in mature forests in this region is not driven by successional forest dynamics.
Keywords: Central African rainforest, Forest composition, Forest history, Light-demanding canopy species, Recovery from human disturbance hypothesis, Yangambi Biosphere Reserve

Past, present, and future potential distributions of the African multipurpose tree *Detarium senegalense* (Fabaceae)

Dassou G.H., Agoundé G., Akouété P., Favi G.A., Kpétikou G.C., Salako, K.V., Ouachinou J.M.A.S, Makponsè J, Kouyaté A.M, Sari I., Glèlè Kakaï R.L., Yédomonhan H., Adomou A.C.

Plant Ecology & Evolution, 157(3)
DOI : https://doi.org/10.5091/plecevo.122470

Climate change induces increasing temperatures and drought, with possible profound shifts in species' presence and distribution. Ecological niche models are widely used to assess plant species responses to climate change. However, such data are scarce for West Africa, particularly for vulnerable multipurpose species. This study focuses on modelling the ecological niche and the conservation status of the multipurpose tree *Detarium senegalense* to improve insights into its habitat suitability in West Africa under past, present, and future climatic conditions. This will provide an essential basis for setting up global management plans through efficient conservation and ecological restoration policies. The potential distribution of *D. senegalense* under past, current, and future climate scenarios were assessed using four algorithms including generalized additive models (GAM), generalized linear models (GLM), random forest (RF), and Maximum Entropy (MaxEnt). We also assessed the shift direction of suitable habitats and the conservation status of the species based on IUCN criteria. Overall, 220 occurrences were combined with a set of five bioclimatic variables to run the models. Models performed well with good values of AUC (0.92) and TSS (0.73). Isothermality (41.10%) and Precipitation of Wettest Month (21.50%) contributed most to the distribution of the species. The distribution of *D. senegalense* was relatively constant from the past to the present but could decrease in the next decades. In the future, only 17.70% and 13.98% of the areas were predicted to be suitable under respectively ssp245 and ssp585. In protected areas, the suitable areas under ssp245 were estimated at 21.01% with a decrease of 2.50% and 14.60% with a decrease of 8.61% under ssp585 by 2050. The direction of the distribution shifted to the south-east under future climate scenarios. The conservation status assessment of the species is Least Concern (LC). This study improves our understanding of the past, present-day, and future distribution of the species and provides support to better manage the conservation of *D. senegalense* in West Africa.
Keywords: Centroid, climate, conservation, Detarium senegalense, ecological niche modelling.

Factors affecting population structure and fruit production of *Strychnos innocua* Delile and *Strychnos spinosa* Lam. In Benin, West Africa

Djidohokpin D., Dassou G.H., Hounkpèvi A., Ouachinou J.M.A.S., Favi G.A., Houessou G.L., Yédomonhan H., Adomou, A. C.

All Life, 17(1), 2401896
DOI: https://doi.org/10.1080/26895293.2024.2401896

Local practices in West Africa, including in Benin, critically affect fruit production of some key wild plant species. This study aims to assess how land use types, dbh, tree height, and fire, affect the fruit production of *Strychnos innocua* and *Strychnos spinosa* (Loganiaceae) and the extent of the phenological variability across various bioclimatic zones in Benin. 320 trees were randomly selected for each species across four land use types and two bioclimatic zones in Benin to assess fruit production. The mean number of fruits produced per tree varied between 43.3 and 81.2 in the Sudanian zone and 12.7 and 20.8 in the Sudano-Guinean zone for *S. innocua* and *S. spinosa*, respectively. The bioclimatic zone significantly affected ($p < 0.001$) the number of fruits produced by individuals of both species. A strong relationship was also found between fruit production and dendrometric characteristics, land use types, and human disturbance ($p < 0.001$). The study concluded that sites of both species in the Sudanian zone are more suitable for conservation.

Keywords: Benin, chorological regions, wild fruit production, land management, Strychnos

Direct and Indirect Effects of Environmental and Socio-Economic Factors on COVID-19 in Africa Using Structural Equation Modeling

Orounla B.R., Alaye A.E., Salako K.V., Agbangba C.E., Aheto J.M.K., Glèlè Kakaï R.

Stats, 7(3), 1051-1065
DOI : https://doi.org/10.3390/stats7030062

Understanding direct and indirect relationships of environmental, socio-economic and climate variables and the dynamics of epidemics is key to guiding targeted public health policy and interventions. This study investigates the direct and indirect effects of environmental and socio-economic factors on the COVID-19 dynamics in Africa (54 African countries from 2019 to 2021) using SEM approach. Specifically, the study aimed to: (i) assess the performance of two SEM estimation methods (Lisrel and PLS-SEM) in relationship to sample size (100, 200, 500, and 1000) and level of model complexity (No, two, and four indirect effects) and (ii) use the most performing SEM estimation method to examine direct and indirect effects of factors influencing the number of cases and deaths of COVID-19 in Africa. The results highlight a positive spatial correlation between factors such as temperature, humidity, age, the proportion of people aged over 65, and the COVID-19 incidence. Under the control of confounding factors, Lisrel turns out to be the most performing method, identifying climate, demographic and economic factors as the main determinants of COVID-19 dynamics. These factors have a direct and significant impact on the incidence of COVID-19. An indirect relationship was also observed between economic factors and the incidence of COVID-19 through air pollutants. The results highlight the importance of considering these factors in understanding the spread of the virus to avoid further disasters.

Keywords: COVID-19 dynamics, PLS, Lisrel, fit measures, estimation methods, climate.

Efficiency of simple sequence repeat (SSR) markers in genetic diversity study and differentiation of *Borassus aethiopum* Mart. and *Borassus akeassii* Bayton, Ouédr. & Guinko

Adéoti K., Salako K.V., Daa-Kpodé U.A., Ouédraogo A., Santoni S., Aberlenc F., Kpatènon M.J., Latreille M., Tollon-Cordet C., Etsè K.D., Mahmoud O.H.A., Faye A., Jaligot E., Beulé T.

Genetic Resources and Crop Evolution, 1-17
DOI: https://doi.org/10.1007/s10722-024-02067-3

The African fan palm, *Borassus aethiopum,* is widely distributed in West and Central Africa. To contribute to the understanding of its evolutionary history and geographical distribution, we have performed the analysis of its genetic diversity and population structure through a wide samples collection in different countries. Simple sequences repeat (SSR) markers were used to assess the population structure and genetic diversity of such samples. Genetic diversity was estimated for a total of 201 samples of *B. aethiopum* using 13 SSR markers. The result of our analysed populations indicated a mean value of expected heterozygosity (He) of 0.395, suggesting a moderate genetic diversity, with 62% and 37% of molecular variance within individuals and among populations, respectively. Clustering analysis by using Bayesian method and principal component analysis clustered populations into two main groups corresponding to the two sampling regions (West and Central Africa), and each group consists of two genetic clusters. In addition to this, we tested the ability of the same SSR markers to discriminate between both fan palm species occurring in sub-Saharan Africa, namely *B. aethiopum* and *B. akeassii*. Hence, our markers can be used as molecular tools for differentiating both species and furthermore for genetic diversity of *B. akeassii* populations.

Keywords: *Borassus akeassii*, Genetic markers, Population structure, Rhon palms, Sub-Saharan Africa

Nonlinear mixed models and related approaches in infectious disease modeling: a systematic and critical review

Adéoti O. M., Agbla S., Diop A., Glèlè Kakaï R.

Infectious Disease Modelling, 10(1), 110-128
DOI: https://doi.org/10.1016/j.idm.2024.09.001

The level of surveillance and preparedness against epidemics varies across countries, resulting in different responses to outbreaks. When conducting an in-depth analysis of microinfection dynamics, one must account for the substantial heterogeneity across countries. However, many commonly used statistical model specifications lack the flexibility needed for sound and accurate analysis and prediction in such contexts. Nonlinear mixed effects models (NLMMs) constitute a specific statistical tool that can overcome these significant challenges. While compartmental models are well-established in infectious disease modeling and have seen significant advancements, Nonlinear Mixed Models (NLMMs) offer a flexible approach for handling heterogeneous and unbalanced repeated measures data, often with less computational effort than some individual-level compartmental modeling techniques. This study provides an overview of their current use and offers a solid foundation for developing guidelines that may help improve their implementation in real-world situations. Relevant scientific databases in the *Research4life* Access initiative programs were used to search for papers dealing with key aspects of NLMMs in infectious disease modeling (IDM). From an initial list of 3641 papers, 124 were finally included and used for this systematic and critical review spanning the last two decades, following the PRISMA guidelines. NLMMs have evolved rapidly in the last decade, especially in IDM, with most publications dating from 2017 to 2021 (83.33%). The routine use of normality assumption appeared inappropriate for IDM, leading to a wealth of literature on NLMMs with non-normal errors and random effects under various estimation methods. We noticed that NLMMs have attracted much attention for the latest known epidemics worldwide (COVID-19, Ebola, Dengue and Lassa) with the robustness and reliability of relaxed propositions of the normality assumption. A case study of the application of COVID-19 data helped to highlight NLMMs' performance in modeling infectious diseases. Out of this study, estimation methods, assumptions, and random terms specification in NLMMs are key aspects requiring particular attention for their application in IDM.

Keywords: Epidemic, Heterogeneous data, Multilevel nonlinear models, PRISMA, Comparison

Farmer-perceived phenotypic variation and preferences reveal potential for multi-traits selection in the desert date *Balanites aegyptiaca* (L.) Delile in Benin

Akakpo A.D., Salako V.K., Houndonougbo J.S., Akin Y., Pedanou C.L., Agbangla C., Assogbadjo A.E.

Genetic Resources and Crop Evolution, 1-18
DOI : https://doi.org/10.1007/s10722-024-02103-2

Due to their historical interactions with plants, farmers have gained knowledge of natural variations in plant traits that can be useful for the domestication and sustainable management of genetic resources. This study focused on *Balanites aegyptiaca* (L.) Delile, a neglected and underutilized wild fruit tree species in Benin. The objectives of the study were to assess farmers' (1) perceived phenotypic variations in fruit, seed, leaflet, thorn, and stem bark, (2) desirable and undesirable traits, and (3) on-farm management of the species. Using semi-structured interviews (461) in 14 communities spanning the species distribution area, data were collected on perceived phenotypic variation, criteria of classification, desirable and undesirable traits, and on-farm management practices of the species. Descriptive statistics and principal component analysis were used for the data analysis in R software. Results revealed 10 criteria to differentiate morphological types of the species, the most cited criteria being thorns length (100%), stem bark color (91.1%), leaf shape (70%), fruit size (54.2%), and fruit pulp taste (45.8%). Preferred characteristics were large fruits (50.4%), sweet fruits (42.8%), elongated leaf (70%), yellowish stem bark (88.9%), long thorn (64.5%) and fruiting trees (100%) and depended on age, geographical location, and gender. Interestingly, reasons supporting these preferences reveal potential for multi-traits selection. The most encountered farmer management practices were tree sparing on-farm (18.5%), and protection against grazing (10.2%) and fire (10.4%). However, the extent of these practices does not guarantee sustainable management of the species. Our findings provide interesting insights for further domestication initiatives. However, further research is needed to understand the interrelated relationship between genotypes and environmental factors in shaping the observed morphological variations.

Keywords: Domestication, Genetic resources, Genotypes, Neglected and underutilized, Morphological variations, On-farm management

Socio-economic and cultural drivers of local perceptions and willingness to consume edible insects in Benin

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Insects serve as alternative protein sources for humans. While entomophagy, the practice of eating insects, has deep historical roots in some regions, it remains less common in Benin. Understanding perceptions and determinants of entomophagy can guide actions for promoting the consumption of edible insects. The present study aimed to assess local perceptions of consuming edible insects and the drivers of their adoption. An ethnozoological study using interviews was conducted with 450 individuals from rural and peri-urban areas in Benin's humid and semi-arid zones. Data were analyzed using descriptive statistics, univariate inference, and classification models. Findings showed greater acceptance of insects' consumption in the semi-arid zone (33.56 %) than in the humid zone (23.11 %) and in rural areas (33.11 %) than in peri-urban areas (23.56 %). Edible insects' consumption was also higher in rural areas (34.22 %) than in peri-urban areas (27.11 %), with no significant difference between biogeographical zones. Gender, age, and biogeographical zones were key determinants of local perceptions regarding the consumption of edible insects. Furthermore, factors influencing the decision to adopt the consumption of edible insects included perceptions of their nutritional value, gender, duration of residence, and geographical location. These factors can inform awareness raising about the usefulness of edible insects in promoting their consumption.

Keywords: Rurality, Nutritional value, Edible insect, Adoption, Food security, Benin

Mathematical modelling and analysis of cholera dynamics via vector transmission

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In this study, a deterministic model for the transmission of cholera via fly vectors is derived and examined. We consider in detail the human population, vector/houseflies population, and the environmental reservoir. The study splits the class of infected individuals into symptomatic and asymptomatic infected individuals and incorporates the exposed compartment in the vector population to build a system of ordinary differential equations. Theoretically, the developed model is analysed by studying the stability of equilibrium points. The results of the analysis shows that there exist a locally stable disease free equilibrium point, E 0 when R 0< 1 and endemic equilibrium, E∗ when R 0> 1. In an attempt to examine the effect of some parameters of the dynamic of the disease sensitivity analysis is employed. Finally, numerical simulations are also performed to verify the analytic results. The simulation study has revealed that reducing the rate of exposure to contaminated water and each infected vector's contribution to the aquatic environment is necessary to achieve a significant and effective control.

Keywords: infectious disease; mathematical model; basic reproduction number; stability analysis; numerical simulation.

Mathematical Analysis of the Dynamics of COVID-19 in the Face of Vaccination in African Countries

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DOI: https://doi.org/10.37256/cm.5320243404

The ongoing COVID-19 pandemic has posed significant global challenges; its impact in Africa, in particular, has been a subject of increasing concern. Vaccination against COVID-19 started in many African countries in 2020. Despite the remarkable progress made by a selected number of countries initiating vaccination campaigns in 2020, the global vaccination coverage against the targeted disease remains inadequate. This study aimed to assess the dynamics of COVID-19 in the face of vaccination in Africa. We used an extended deterministic Susceptible-Exposed-Infectious-Recovered (SEIR)-type model stratified by vaccination status to mathematically analyze the effect of vaccination on the dynamics of COVID-19 in ten African countries, namely: Benin, Namibia, South Africa, Rwanda, Lybia, DRC, Nigeria, Algeria, Gabon and Kenya. We studied some basic properties of the model and derived the control and basic reproduction numbers R c and R 0, respectively. We further utilized the Castillo-Chavez method to investigate the global stability of the model at the disease-free equilibrium point under the condition R c< 1. In addition, we developed the expressions of the sensitivity and elasticity of the control reproduction number (R c) with respect to vaccination coverage, level of adherence to control measures (ψ u and ψ v), infection probabilities, and relative infectiousness of different compartments of Infected. The model was fitted using cumulative daily COVID-19 case data corresponding to each country's third wave of the pandemic. The unknown parameters are estimated using the non-linear least square method. We used the resulting parameter values to compute the sensitivity and elasticity indices. The study demonstrates the importance of sustaining high vaccination coverage and control measures to mitigate COVID-19 transmission in Africa. Results identify vaccination rates and population compliance to control measures as most influential based on sensitivity analysis. By generating evidence tailored to the African context, this research provides crucial insights to inform resource allocation and interventions to combat COVID-19, where needs are greatest.

Keywords: mechanistic model, pandemic, vaccination coverage, theoretical analysis, application, Africa

Perspectives on the integration of agri-entrepreneurship in tertiary agricultural education in Africa: insights from the AgriENGAGE project

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Frontiers in Sustainable Food Systems, 8, 1348167
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The underperformance of agricultural education systems in Africa is evident through various indicators such as increased unemployment among recent agricultural graduates, inefficiencies in agricultural product value chains, and a decline in enrollment in agricultural schools. The AgriENGAGE project, which included eight African universities, was supported through the Erasmus+ Capacity Building in Higher Education program funded by the European Commission to address these challenges. The project aimed to contribute toward revitalizing agricultural education systems to stimulate agricultural transformation and enhance the sector's competitiveness while meeting the labor market's demands. This article draws on lessons learned at eight universities to provide a perspective on agri-entrepreneurship education integration in African universities. We provide descriptions, experiences, and insights on agri-entrepreneurship education integration in partner universities in Kenya, Benin, Morocco, and Uganda. Based on these experiences, we provide perspectives on reducing youth unemployment and improving the effectiveness of agricultural education in contributing to the development of sustainable food systems.

Keywords: agricultural education, enterpreneureship, sustainability, agricultural productivity and innovation, Africa higher education.

Empirical Performance of Deep Learning Models with Class Imbalance for Crop Disease Classification

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Class imbalance refers to a situation where the number of observations in the different classes of a dataset is not equally distributed. This situation is most often encountered in agriculture for the classification of crop diseases. This can lead to challenges in training deep learning models, as they may become biased toward the majority class and perform poorly in predicting the minority class. One common approach to address class imbalance is resampling techniques, such as oversampling the minority class or undersampling the majority class. This study examined the performances of deep learning architectures (GoogleNet, VGG16, and ResNet50) for disease classification of tomatoes, peppers, and peaches in contexts of class imbalance. Data has been collected online from different websites (PlantVillage and PlantDisease). Each model was run in transfer learning and evaluated in three situations: without balancing, with Random Over Sampling (ROS) and with Random Under Sampling (RUS). The batch size and the number of epochs were set at 32 and 10, respectively. Recall, F1 score, Area Under the Receiver Operating Characteristic Curve, and the computing time were recorded. Results indicated that RUS significantly improves the precision, recall, and F1 score for GoogleNet despite a longer processing time than ROS. For VGG16, ROS proves superior in terms of learning time and performance. ROS and RUS enable Resnet50 to maintain high performance in the face of increasing class imbalance. Moreover, GoogleNet demonstrated more excellent results stability than VGG16 and ResNet50, especially under various levels of imbalance. This study highlights the importance of data balancing while acknowledging certain limitations, such as the size of the datasets and the model parameters used, paving the way for future research to optimize these methods.

Keywords: Machine learning, Classification, Comparison, GoogleNet, Resampling techniques

A comparative study of morpho-physiological responses of wild and cultivated Solanum species to water stress: the case of *S. sisymbriifolium and S. macrocarpon*

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Crop wild relatives are closely related taxa of cultivated crops and are well adapted to a wide range of environmental conditions. With the current global warming and challenges in agriculture and food production, increasing attention must be given to these crop wild species as they can provide genetic resources that may be helpful to address some of the current challenges in agriculture (e.g., adaptation to drought). In this study, we compared the morpho-physiological performances of *Solanum macrocarpon* and its wild relative *Solanum sisymbriifolium* under different watering conditions in Benin. Seedlings were grown in plastic pots under shade-house and subjected to low, moderate, and high-water supply (i.e., 25%, 50% and 75%, respectively of the pot holding capacity). Parameters related to seedlings growth, biomass allocation and stomatal density were investigated. Descriptive statistics and linear mixed effect models were used for data analysis. Results revealed highly significant differences of morpho-physiological parameters between wild and cultivated *Solanum* species along the watering gradient. First, seedlings from the wild relative demonstrated higher morphological growth parameters than seedlings of the cultivated species irrespective of the watering level. Second, the wild relative also showed better performances in terms of biomass allocation and number of stomata, regardless of leaves faces and watering level than the cultivated species. Water stress reduced values of morpho-physiological parameters for both wild and cultivated species. Contrary to our expectations, the wild relative instead of being resistant, was found to also be sensitive to water stress. However, it was found to be more tolerant to drought than the cultivated species, and therefore could be considered when selecting rootstocks for crop improvement.

Keywords: Morpho-physiology, Biomass allocation, Water stress, Stomatal density, Wild relative of Solanum

Chronic anthropogenic disturbance and climate synergistically shape demographic trade-offs in a tropical fuelwood tree

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Forest Ecology and Management, 573, 122339
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Understanding intraspecific demographic trade-offs is fundamental for capturing plant responses to global changes such as disturbance and climate variability. The coordinated resource allocation hypothesis suggests that plants invest in demographic processes (such as survival, growth, or fecundity) relative to resource availability and environmental challenges. Most studies have primarily focused on the effects of disturbance or climate regions on species demographic processes separately, with limited attention given to the associated trade-offs. However, it is crucial to understand the synergistic effects of climate variation and disturbance on these processes to accurately forecast forest species dynamics. Three series of data were collected from 12 populations of African mesquite trees, *Prosopis africana*, distributed across three contrasting ecological regions in Benin, West Africa. Within a permanent plot, individuals of *P. africana* were tagged with numbered aluminum tags, and data were collected on the demography parameters of each individual. We found demographic trade-offs between survival and growth, growth and fecundity but not between survival and fecundity. The patterns of trade-offs mainly varied across synergistic effects of climate zone and disturbance. These findings highlight the strategies plants may employed under disturbance and climate variations in tropical forests and emphasize their significance in ecology and forest management.

Keywords: Size dependent survival, Disturbance, Tropical plants, Demographic trade-offs

Impacts of land use and abiotic factors on fruit, seed, and leaf morphology of the desert date *Balanites aegyptiaca* in Benin: Implications for management

Akakpo A.D.M., Kolawole M.A., Dimobe K., Salako K.V.,Sacla Aide E., Chadare F.J., Agnangla C., Assogbadjo A.E.

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DOI: https://doi.org/10.1016/j.tfp.2024.100710

Preserving intraspecific phenotypic variation within socio-economically important but declining species is fundamental in the current context of rapid change in land use and environmental conditions. *Balanites aegyptiaca* (L.) Delile is a valuable seed oil tree species native to the arid and semi-arid regions of Africa. Notable morphological variations within the species are recognized by local communities, who often select trees with preferred traits for preservation in croplands. This study compared phenotypic variation in *B. aegyptiaca* based on sixteen phenotypic traits of fruits, seeds, and leaflets between trees in a strictly protected area and those in croplands. Furthermore, the relative role of land use, soil characteristics, bioclimatic variables, elevation, and slope in the observed variation was analysed. Student *t*-test, principal component analysis, redundancy analysis, and variance partitioning were used for data analysis in R software. Results showed that, after accounting for tree variation, significant differences were observed in only two traits: seed ratio, and leaflet dry weight, with mean values in cropland being 1.470 (higher), and 0.943 (lower) times that of wild trees, respectively. Furthermore, principal component analysis showed great overlap between ellipses of cropland and wild trees. The variance partitioning analysis showed that bioclimatic variables explained 18 % of the total variation followed by soil characteristics (11 %), and land use (9 %). These findings collectively suggest weak impacts of croplands and a lack of domestication syndrome in *B. aegyptiaca* in Benin, potentially due to persisting gene flow between wild and cropland trees, inadvertent species management, or low intensity of selection pressures. Future studies should explore organoleptic properties, physico-chemical characteristics of the pulp and seed oil and discern the extent to which observed differences are attributable to genetic factors and biotic factors (pest attacks, plant-plant interactions, etc.).

Keywords: Croplands, Intraspecific variation, Biotic and abiotic factors, Domestication, Wild edible fruits, Semi-arid climate

Synergizing climate dynamics, species distribution, and structural parameters for sustainable management of *Pseudrocedrela kotschyi* in Benin (West Africa)

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Climate change poses significant threats to biodiversity, profoundly impacting plant species. *Pseudocedrela kotschyi*, a vital component of tropical ecosystems is experiencing severe population decline due to habitat degradation and regeneration issues. Understanding how climate change exacerbates these problems combined with assessment of its structural parameters is essential for developing conservation strategies and ensuring the survival of this species. Occurrence records and bioclimatic data were utilized for niche modeling. Additionally, forest inventories were conducted across various habitats of the species in Benin, to characterize the structural parameters of its populations. An ecological niche modeling approaches was used to depict niche differentiation among subpopulations of *Pseudocedrela kotschyi* and assess the climate change impacts on the sepecies in Benin. The Maximum Entropy Algorithm (MaxEnt) was used to simulate the species' current and future distributions under different shared socio-economic pathway (SSP) climate scenarios. Three distinct populations of the species were identified. The populations exhibited no niche overlap among subpopulations indicating local adaptation. In non-protected areas, *P. kotschyi* individuals tend to be smaller in size. This trend is particularly pronounced in the Sudano-Guinean zone, where protected habitats benefit from a higher monthly thermal amplitude. In contrast, in the Guineo Congolian zone, both protected and unprotected habitats are influenced by the minimum temperature of the coldest month and the mean annual temperature, leading to higher densities of regeneration and adults of *P. kotschyi*. In the Sudanian zone, regardless of the protection status, higher annual rainfall supports larger mean diameters for *P. kotschyi* and its population. This study underscores the importance of preserving the species' habitats, regulating potentially harmful human activities, and incorporating future climate forecasts into management plans to ensure the sustainable conservation of *P. kotschyi*.

Keywords: Adaptation, climate change, niche conservatism, *Pseudocedrela kotschyi*, structural parameters

Eco-epidemiology of lassa fever: a mathematical modeling approach

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Lassa fever, a fatal zoonotic hemorrhagic disease caused by the Lassa virus, persists as a significant health concern in West Africa. Despite ongoing efforts to mitigate its impact, both the incidence and mortality rates remain alarmingly high, posing a potential risk of a global spread. Recent studies have focused on understanding the dynamic behaviour of Lassa fever. However, the ecological relationship between the reservoir host (rodents) and humans, involving factors such as rodent predation and migration, remains inadequately understood. In this study, we developed and analysed a non-linear mathematical compartmental model for Lassa fever, incorporating both human and rodent populations together with an infested environment. Rodent predation was modelled using the Holling type II functional response. We rigorously established key properties of the model, including the existence of solutions, boundedness, and positivity. The reproduction number (R) was determined using the next-generation method. Additionally, a sensitivity analysis of model parameters was conducted, utilising the Normalized Forward Sensitivity Index to identify the most influential processes affecting the disease threshold and critical factors for effective infection control. Numerical analysis of the total infected human population performed using the odeint function in Python programming revealed several insights. Notably, human-to-human transmission became predominant when the contact rate exceeded 50%. The infected human population experienced drastic decline when the rate of rodent migration exceeded 50%. In addition, we observed that rodent predation led to an initial surge in human infections. The findings of this study underscore the importance of implementing strategies that prioritise minimising environmental transmission, human-to-human contact, mitigating rodent predation, and increasing rodent migration to effectively control and prevent the transmission of Lassa fever.

Keywords: Holling type II functional response; rodent predation; migration; sensitivity analysis.

Deep learning methods for enhanced stress and pest management in market garden crops: A comprehensive analysis

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Smart Agricultural Technology, 9, 100521
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Various deep learning methods are employed to detect stress and diseases in market garden crops, as well as to assess their severity. This study aims to comprehensively analyze these techniques and identify potential research avenues. The diversity of deep learning techniques was explored through a literature review based on the PRISMA guidelines. Research equations were defined, resulting in a sample of 1, 422 publications, of which 72 were deemed usable and considered in the final analysis. For classification tasks, hybrid CNN models were the most widely used (19.2%). Commonly utilized models included VGG16 (10%), InceptionV3 (6.1%), DCNN (5%), and YoloV5 (5%). In object detection tasks, Fast R-CNN was used six times, followed by YoloV5 (three occurrences) and YoloV3 (two occurrences). In segmentation tasks, Mask R-CNN accounted for 28.67% of the models, while DeepLabV3+ accounted for 24.98%. Assessing disease severity in market garden crops is complex due to the unique criteria for each plant disease and the presence of multiple diseases across different crop types. To address this complexity, establishing a standardized method is crucial. Further research is essential to enhance the application of deep learning techniques in the study of market garden crops. This includes gathering extensive datasets that encompass various scenarios of crop diseases and considering the impact of climate variations on stress manifestation.

Keywords: Artificial intelligence, Vegetable crops disease detections, Pests, Severity estimation, Review

Tree populations show low regeneration of valued species in West Africa

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Biological Conservation, 301, 110891
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Tree populations have declined substantially in West Africa in recent decades, raising concerns since trees provide numerous ecosystem goods and services. Regional information on the population status of tree species could guide more effective conservation and regeneration of natural vegetation. Here, we report results of the first regional analysis of tree population structure across the Sahel and Sudan zones, a meta-study of vegetation inventories, including 23,586 individual trees sampled across nine countries. We evaluated current status and forecast future trends of 16 species and one genus of trees of ecological and socio-economic importance. Size class distribution (SCD) reflects the population structure of an individual species and can provide early warning of composition change and population decline. SCD is analysed widely at a local scale, but analysis at a regional scale is needed to detect widespread population changes. Many native species lacked trees in the smaller size classes, implying unsustainable populations and future decline. Some species show sound regeneration at the regional scale, but high variation among sites. Eight species, including *Adansonia digitata* and *Afzelia africana*, show regional declines in regeneration and risks of future extirpations. Four of these severely lack regeneration. Protected areas show higher tree regeneration, but protected status did not assure good regeneration. Our results identify priority tree species across West Africa, indicate a more urgent need for conservation and regeneration of native tree species, and highlight the benefit of effective conservation. More widespread protection could increase tree populations, conserving biodiversity, and ecosystem services essential for people's livelihoods.

Keywords: Conservation, Degradation, Regional analysis, Size class distributionSahel and Sudan zones, Tree population structure

Three decades of research efforts on the uses, conservation, and management of *Cola nitida* (Vent.): State of knowledge and prospects in Africa

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Forestry Studies | *Metsanduslikud Uurimused*, 80, 57–76
DOI: https://doi.org/10.2478/fsmu-2024-0004

Cola nitida is a key multipurpose fruit tree species widely distributed across African countries. Several studies have investigated different aspects of the species, but there is a lack of synthesis on the current state of available literature and prospects for sustainable conservation and management of the species. Using the PRISMA approach for systematic review over the last three decades (1990–2022) in Africa, this study gathered key existing research findings on *C. nitida*. A total of 280 scientific publications were finally retained for this review. Several studies were focused on the socio-economic importance of the species (n = 139 ~ 50%), nutritional and chemical properties of its organs (n = 48 ~ 17%), improvement of its propagation methods (n = 30 ~ 11%), pest and pesticide control (n = 39 ~ 14%), morphological and genetic diversity (n = 21 ~ 7.5%), its botanical description and ecology (n = 2 ~ 0.7%), and climate change threats on the species (n = 1 ~ 0.3%). The review revealed a gap in knowledge on the methods for improving the species' resilience to climate variability. Future research on the species should focus on its ecophysiological traits, the identification of elite accessions, and the type of agroforestry system that could optimize its productivity. The review provides a baseline for developing innovative management programs for *C. nitida* in Africa. Moreover, it highlights the need for more research efforts in the Central and East African native range of the species.

Keywords: *Cola nitida*, overexploitation, agroforestry system, sustainable conservation, systematic review

Global Data Compilation Across Climate Gradients Supports the Use of Common Allometric Equations for Three Transatlantic Mangrove Species

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Ecology and Evolution, 14(11), e70577
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Predicting the distribution, structure, and biomass of mangrove forests is an area of high research interest. Across the Atlantic East Pacific biogeographic region, three species are common and abundant members of local mangrove communities: *Rhizophora mangle*, *Avicennia germinans*, and *Laguncularia racemosa*. Biomass prediction for these species has relied on two approaches: site-specific allometries based on the idea that environmental or climatic differences between sites drive growth differences, or the use of common allometric equations assuming minimal site-driven differences. This study compares allometric equations derived from 590 individuals across nine sites and explores the influence of climatic variables on growth allometries. Results show significant climatic effects, particularly from minimum temperature and precipitation seasonality, but also suggest the utility of common equations for biomass prediction. Future improvements, such as larger sample sizes across diverse growth conditions, are recommended to further refine biomass estimation techniques.

Keywords: Allometry, *Avicennia germinans*, biomass, DBH, height, *Laguncularia racemosa*, mangrove, *Rhizophora mangle*, root mass

Using pattern mining to determine fine climatic parameters for maize yield in Benin

Tahi S.P.G., Houndji V.R., Hounmenou C.G., Glèlè Kakaï R.

IAES International Journal of Artificial Intelligence, 13(4), 3930–3941
DOI: https://doi.org/10.11591/ijai.v13.i4.pp3930-3941

This study investigates the relationships between Benin's climate and maize production to develop an association rule algorithm for accurate yield prediction. The datasets utilized extend 26 years (1995 to 2020) and include climate and maize yield data from five districts with synoptic weather stations in two agroclimatic zones (Sudanian and Sudano-Guinean). Climate variables were combined with yield using "year" and "districts" to find the association rules. Several techniques were used to determine the correlation between weather parameters and maize yields: support vector machines, K nearest neighbor, artificial neural networks, decision trees, and recurrent neural networks. The most performed method was the decision tree (R2=0.998, mean squared error (MSE)=0.021, and mean absolute error (MAE)=0.0008). The frequent pattern growth technique was then applied to facilitate the discovery of the rules. The Sudano-Guinean zone exhibits high maize yields for medium minimum and maximum temperature values, rainfall, evapotranspiration, and humidity. In the Sudanian zone, medium minimum and maximum temperatures and maximum humidity levels are associated with high maize yields. These association rules demonstrate reliable and effective ways to optimize maize output.

Keywords: Association rules, climatic pattern, machine learning, yield prediction, Zea mays

Potential impacts of future climate on twelve key multipurpose tree species in Benin: Insights from species distribution modeling for biodiversity conservation

Dogbo S.F., Salako K.V., Agoundé G., Dimobe K., Adiko A.E.G., Gebauer J., Adou Yao C.Y., Glèlè Kakaï R.

Trees, Forests and People, 19, 100744
DOI: https://doi.org/10.1016/j.tfp.2024.100744

The global decline of biodiversity threatens ecosystem stability and human well-being. This study modeled the future suitable habitats of twelve key multipurpose tree species (MPTS) in Benin under two climate scenarios, Shared Socioeconomic Pathways 245 (SSP245) and 585 (SSP585), based on the 2070 horizon time. The research focused on peri-urban areas (Cotonou, Abomey, Savalou, Parakou, Natitingou, and Kandi) and the protected areas network in Benin. We evaluated environmental variables influencing MPTS distribution, projected habitat changes, identified hotspots, and compared impacts on native versus non-native species. Four modeling algorithms—Generalized Additive Models, Generalized Linear Models, Maximum Entropy, and Random Forest—were used. Climate factors, particularly isothermality (Bio3) and annual precipitation (Bio12), predominantly influenced the distribution of the studied species. The models performed well, with a mean Area Under the Curve (AUC) of 0.88 and a mean True Skill Statistic (TSS) of 0.64. Projections indicated a decline in suitable habitats for 67% of species, minor changes for 8%, and increases for 25%. The effectiveness of protected areas was mixed, with species showing varied responses. Savalou and Abomey peri-urban areas emerged as key conservation hotspots, underscoring the need to shift conservation focus to these areas. Native species showed greater resilience to future climate conditions, emphasizing the importance of native species and species-specific conservation strategies under changing climates.

Keywords: Agroforestry, multipurpose tree species, habitat suitability modeling, peri-urban areas, biodiversity conservation

Vegetation attributes in peri-urban agroforestry systems and their socio-economic determinants in Benin (West Africa)

Dogbo S.F., Salako K.V., Mensah S., Akakpo D.M.A., Assogbadjo A.E., Gebauer J., Glèlè Kakaï R., Adou Yao C.Y.

Agroforest Systems, 98, 3269–3286
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As the world experiences unprecedented urbanization, particularly in Africa, urban areas face complex challenges of climate change, food security, and environmental sustainability. Peri-urban agroforestry systems (PUAFS) have emerged as promising solutions to address these issues. This study investigated the socio-economic factors shaping tree diversity and density in PUAFS in Benin. Woody vegetation inventory and socio-economic data (e.g., gender, resident status, farm size, land tenure, and farming experience) were collected from 323 PUAFS in three climatic zones in Benin. Generalized Linear Models (GLM) and piecewise structural equation modeling (pSEM) were used to analyze tree diversity and density predictors. Results indicate notable variations in tree diversity and density among climatic zones, with wetter climatic areas exhibiting the highest diversity. Significant predictors included resident status, farm size, and farmers' willingness to plant trees, positively influencing tree density. These findings highlight the importance of considering socio-economic factors in agroforestry planning and management, emphasizing the need for context-specific strategies to promote sustainable agroforestry practices in peri-urban areas.

Keywords: Peri-urban agroforestry, woody vegetation attributes, socio-economic factors, Benin

Assessing the impact of hard data patterns on Bayesian Maximum Entropy: a simulation study

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This study empirically tested the robustness of Bayesian Maximum Entropy (BME) in predicting spatiotemporal data, focusing on skewness, sample size, and spatial dependency levels. Simulated data, both Gaussian and non-Gaussian, were generated using the unconditional sequential simulation method, with sample sizes ranging from 100 to 500 at intervals of 50, and varying skewness (0, 1, 3, 6, and 9) and spatial dependency levels (weak, moderate, and strong). Findings revealed that sample size variations and spatial dependence levels did not significantly influence BME prediction's Mean Square Error (MSE) and bias. While skewness significantly impacted MSE (p-value < 0.001), bias remained unaffected. Moreover, skewness and spatial dependence interactions affected both MSE and bias. Despite this, BME proved robust to sample size and skewness, demonstrating a negligible MSE on the graphical plot (heatmap). The results emphasize BME's reliability for handling diverse data distributions in complex spatiotemporal modeling scenarios.

Keywords: Bayesian Maximum Entropy, spatial prediction, data skewness, spatiotemporal modeling, simulation study

Cross-Country Assessment of Socio-Ecological Drivers of COVID-19 Dynamics in Africa: A Spatial Modelling Approach

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Understanding how countries' socio-economic, environmental, health status, and climate factors have influenced the dynamics of COVID-19 is essential for public health, particularly in Africa. This study explored the relationships between African countries' COVID-19 cases and deaths and their socio-economic, environmental, health, clinical, and climate variables. It compared the performance of Ordinary Least Square (OLS) regression, the spatial lag model (SLM), the spatial error model (SEM), and the conditional autoregressive model (CAR) using statistics such as the Akaike Information Criterion (AIC), Bayesian Information Criterion (BIC), Root Mean Square Error (RMSE), and coefficient of determination (R2). Results showed that the SEM with the 10-nearest neighbours matrix weights performed better for the number of cases, while the SEM with the maximum distance matrix weights performed better for the number of deaths. For the cases, the number of tests followed by the adjusted savings, Gross Domestic Product (GDP) per capita, dependence ratio, and annual temperature were the strongest covariates. For deaths, the number of tests followed by malaria prevalence, prevalence of communicable diseases, adjusted savings, GDP, dependence ratio, Human Immunodeficiency Virus (HIV) prevalence, and moisture index of the moistest quarter played a critical role in explaining disparities across countries. This study illustrates the importance of accounting for spatial autocorrelation in modelling the dynamics of the disease while highlighting the role of countries' specific factors in driving its dynamics.

Keywords: Coronavirus, cases, deaths, climate, spatial regression

Assessing the potential impact of climate change on *Kobus megaceros* in South Sudan: a combination of geostatistical and species distribution modelling

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Kobus megaceros is a wetland antelope listed as endangered by United Nations Educational, Scientifc and Cultural Organization (UNESCO) in its natural habitat in South Sudan. The population of the species in South Sudan's wetlands remains unknown. Climate change is expected to have a signifcant impact on the species population in a variety of ways. This paper aims to estimate the current population density and investigate the impact of climate change on K. megaceros by the end of the century. Bayesian Maximum Entropy (BME) and species distribution modelling (SDM) were used to estimate spatial density and predict habitat suitability for Kobus megacero in RCP4.5 and RCP8.5 pathways. The observed occurrences and abundances of Kobus megacero were downloaded from the global biodiversity information facility (GBIF) website. The Africlim online database was used to gather environmental predictors for current and future scenarios. We implemented SDM in R biomod2 package with Maxent algorithm to determine the geographical extent of habitat suitability for RCP4.5 and RCP8.5. The area under the ROC curve (AUC) and true skill statistics (TSS) were used to evaluate the model. The fndings revealed that the current population density of Nile lechwe is too small; hence, this could accelerate the extinction of Nile lechwe. Although 4.97% of the country is currently highly suitable, future scenarios show that about 79–83% of the current suitable habitat will be lost due to climate change in the mid-2055s and mid-2085s. This implies that a proactive conservation strategy should be implemented to reduce the species' chances of extinction.

Keywords: SDM, Geostatistics, BME, Kobus megaceros, Climate change, Habitat suitability

Modelling techniques in cholera epidemiology: A systematic and critical review

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Diverse modelling techniques in cholera epidemiology have been developed and used to (1) study its transmission dynamics, (2) predict and manage cholera outbreaks, and (3) assess the impact of various control and mitigation measures. In this study, we carry out a critical and systematic review of various approaches used for modelling the dynamics of cholera. Also, we discuss the strengths and weaknesses of each modelling approach. A systematic search of articles was conducted in Google Scholar, PubMed, Science Direct, and Taylor & Francis. Eligible studies were those concerned with the dynamics of cholera excluding studies focused on models for cholera transmission in animals, socio-economic factors, and genetic & molecular related studies. A total of 476 peer-reviewed articles met the inclusion criteria, with about 40% (32%) of the studies carried out in Asia (Africa). About 52%, 21%, and 9%, of the studies, were based on compartmental (e.g., SIRB), statistical (time series and regression), and spatial (spatiotemporal clustering) models, respectively, while the rest of the analysed studies used other modelling approaches such as network, machine learning and artificial intelligence, Bayesian, and agent-based approaches. Cholera modelling studies that incorporate vector/housefly transmission of the pathogen are scarce and a small portion of researchers (3.99%) considers the estimation of key epidemiological parameters. Vaccination only platform was utilized as a control measure in more than half (58%) of the studies. Research productivity in cholera epidemiological modelling studies have increased in recent years, but authors used diverse range of models. Future models should consider incorporating vector/housefly transmission of the pathogen and on the estimation of key epidemiological parameters for the transmission of cholera dynamics.

Keywords Infectious diseases, Modelling, PRISMA, Gaps

Evaluating spatial resolution and imperfect detection effects on the predictive performance of inhomogeneous spatial point process models trained with simulated presence-only data

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Modeling Earth Systems and Environment, 10, 4675–4693
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Species distribution models (SDMs) are crucial in ecology, conservation, and ecosystem management. Numerous SDMs have been developed over time, and studies have shown that these tools can be affected by a range of factors, such as data type, spatial resolution, number of explanatory variables, sample characteristics, and collinearity between environmental variables. New SDMs have often been developed to address some of these issues. Understanding the performance of new statistical tools is crucial for researchers in various fields. Thus, we assessed the predictive ability of the Poisson point process and log Gaussian Cox process models, considered as new SDMs, by simulating two factors, spatial resolution and imperfect detection, which are likely to have significant effects on SDMs, and considering Gabon as the study area. The observed model performance metrics, such as the Area Under the Receiver Operating Characteristic Curve (AUC), Mean Absolute Error (MAE), and Pearson correlation (CORR) between the true and predicted intensities, were used to evaluate the predictive performance of these models. The results showed that, although most of these models failed to estimate the intercept α_0 and covariate coefcients ($\beta_x x(z)$) correctly, they at least had the merit of demonstrated good performance (AUC more than 70%, CORR more than 67%, and MAE less than 0.61%). However, the spatial resolution of the environmental variables and imperfect detection of simulated species occurrences significantly affected the predictive performance of the two models ($P < .0001$). This study offers important insights for ecologist modellers, environmentalists, and conservators

Keywords: Spatial resolution, Presence-only data, Inhomogeneous spatial point process models, Simulation, Species distribution modeling

Contamination and pesticide multiresidue analysis in cotton production systems in Benin

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Discover Environment, 2, 54
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High quantity of chemical pesticides spraying in conventional cotton production systems may affect negatively natural ecosystems components. This study examined the contamination levels of soil in Benin's cotton production system in West Africa by residues of pesticides used in cotton farming. One hundred and fourteen soil samples from six conventional and organic cotton production systems were collected and analysed. Multi-class pesticide residues were extracted from the soil samples, and analysed using respectively modifed QuEChERS extraction and LC–MS/MS chromatography methods. Results showed an overall soil contamination to emamectin benzoate (18.5 µg/kg), imidacloprid (116.3 µg/kg), profenofos (12.7 µg/kg), acetamiprid (10.8 µg/kg), triasophos (12.6 µg/kg), abamectin (14.3 µg/kg), and deltamethrin (10.4 µg/kg). Especially, emamectin benzoate was detected with a high contamination in Banikoara district (18.5 µg/kg). Nevertheless, these contaminations were not deemed threatening from a toxicological perspective. Soils in conventional cotton cultivation displayed lower organic matter levels but higher concentrations of pesticides, whereas soils in organic cotton cultivation were less degraded and contaminated. Consequently, it is imperative to conduct environmental risk assessments and monitor key pesticide metabolites to establish sustainable cotton production systems in Benin.

Keywords Environmental impact · Pesticides · Soils contamination · Conventional cotton production systems

Prediction and control of cholera outbreak: Study case of Cameroon

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Infectious Disease Modelling, 9, 892-925
DOI: https://doi.org/10.1016/j.idm.2024.04.009

This paper deals with the problem of the prediction and control of cholera outbreak using real data of Cameroon. We first develop and analyze a deterministic model with seasonality for the cholera, the novelty of which lies in the incorporation of undetected cases. We present the basic properties of the model and compute two explicit threshold parameters R_0 and R_0 that bound the effective reproduction number R_0, from below and above, that is $R_0 \leq R_0 \leq R_0$. We prove that cholera tends to disappear when $R_0 \leq 1$, while when $R_0 > 1$, cholera persists uniformly within the population. After, assuming that the cholera transmission rates and the proportions of newly symptomatic are unknown, we develop the EnKf approach to estimate unmeasurable state variables and these unknown parameters using real data of cholera from 2014 to 2022 in Cameroon. We use this result to estimate the upper and lower bound of the effective reproduction number and reconstructed active asymptomatic and symptomatic cholera cases in Cameroon, and give a short-term forecasts of cholera in Cameroon until 2024. Numerical simulations show that (i) the transmission rate from free Vibrio cholerae in the environment is more important than the human transmission and begin to be high few week after May and in October, (ii) 90% of newly cholera infected cases that present the symptoms of cholera are not diagnosed and (iii) 60.36% of asymptomatic are detected at 14% and 86% of them recover naturally. The future trends reveals that an outbreak appeared from July to November 2023 with the number of cases reported monthly peaked in October 2023. An impulsive control strategy is incorporated in the model with the aim to avoid or prevent the cholera outbreak. In the first year of monitoring, we observed a reduction of more than 75% of incidences and the disappearance of the peaks when no control are available in Cameroon. A second monitoring of control led to a further reduction of around 60% of incidences the following year, showing how impulse control could be an effective means of eradicating cholera.

Keywords Vibrio cholerae, Mathematical models, Ensemble Kalman filter Basic reproduction number, Impulsive control

Machine Learning Techniques for Cereal Crops Yield Prediction: A Comprehensive Review

Tahi S.P.G., Houndji V.R., Salako K.V., Hounmenou C.G., Glèlè Kakaï R.

Applications of modelling and simulation, 8, 174–190
DOI: https://arqiipubl.com/ojs/index.php/AMS_Journal/article/view/622

Cereals are sensitive to small changes in complex combinations of biotic and abiotic factors. Such a complexity can be deciphered using techniques such as Machine learning (ML). Using the PRISMA approach, this paper explores the features and ML techniques in cereal yield prediction based on 115 articles from 2007 to 2023 in six databases. Results showed that most data in the articles were from secondary sources and only 28.68% used experiments or primary data. China (31) and the United States (18) contributed most. Wheat (48%), maize (33%), and rice (17%) represented the most studied cereals. Climate, remote sensing data, and soil parameters were the most used predictors. The most frequently used ML techniques for cereal prediction were support vector machine (SVM) (51%), multi-layer perceptron (MLP) (41%), linear regression (34%), random forest (RF) (24%), and XGBoost (20%). However, RF, MLP, and SVM models were the best-performing techniques to predict grain yield based on reported R-square and mean absolute error (MAE). The models in the studied articles generally performed well from test data, with an R-square between 0.7 and 1. The study further reveals that the data's availability and quality are the main obstacles to using ML models for crop prediction.

Keywords: Cereal, Deep learning, Machine learning, PRISMA, Yield prediction.

Enhancing interpretability and fidelity in convolutional neural networks through domain-informed knowledge integration

Agbangba C.E., Toha R.O.Y., Bello A.W., Adetola J.

Advances and Applications in Statistics, 91(9), 1165-1194
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This study addresses the need for robust disease detection methods in vegetable crops by introducing a novel initialization method for convolutional neural networks (CNNs). Rather than creating a new CNN architecture, our approach focuses on infusing expert knowledge from phytopathology directly into the model's foundation. This innovative initialization ensures that the CNN possesses a contextual understanding of intricate disease patterns specific to tomatoes. Additionally, our study redefines the role of heatmaps as a dynamic metric for assessing model fidelity in real-time. Unlike traditional post hoc applications, heatmaps are integrated into the model evaluation process, providing insights into decision-making processes and alignment with expert-derived expectations. This dual innovation aims to enhance transparency and fidelity in CNNs, offering a nuanced and effective solution for disease detection in agriculture. The study contributes to advancing artificial intelligence applications in agriculture by providing accurate predictions and a deeper understanding of the underlying decision mechanisms crucial for crop health management.

Keywords: ion implantation, multilayer structure, changing of distribution of concentration of dopant, model of process, analytical approach for analysis

On the use of post-hoc tests in environmental and biological sciences: A critical review

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Post-hoc comparison procedures are commonly used to determine which group means differ after a significant analysis of variance (ANOVA). Several post-hoc tests have been proposed, but their use requires certain assumptions to be met, such as normality, equality of variance, and balanced group size. This review examined the statistical literature on post-hoc tests and their use in the environmental and biological sciences. Through this review, we found that post-hoc tests are effective but often inadequately used in these sciences. We conducted a search of reputed search engines to identify articles in which post-hoc tests were used and found ten post-hoc tests used in the environmental and biological literature. Tukey HSD (30.04%), Duncan's (25.41%) and Fisher's LSD (18.15%) were the most commonly used post-hoc tests over the past 20 years, whereas the Games-Howell (1.13%), Holm-Bonferroni (1.25%), and Scheffe's tests (2.25%) were the least used. The choice of post-hoc test depended on the statistical method used prior. In addition, the assumptions of applying post-hoc tests were not always verified. In fact, the normality condition was mostly only checked in the cases of Tukey HSD, Duncan's, and Fischer's LSD tests, and equality of variance was often met for the Tukey HSD, Duncan's, Fischer's LSD, and Bonferroni tests. This review opens a new avenue for comparing post-hoc test performance in ANOVA using linear or generalised mixed effect models.

Keywords: Multiple comparison tests, Review, Assumptions, Effective use

Optimal sample size for DRIS model parameterisation to diagnosis nutrients status in fruit crops

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African Crop Science Journal, 32(2), 185-192
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Diagnosis and Recommendation Integrated System (DRIS) is an approach to nutrient diagnosis of crops, holistically through the relationship between nutrient balance of plants and soil. The objective of this study was to investigate the influence of sample size in DRIS model parameterisation, to diagnose nutrients status in fruit crops. Published data were resampled to obtain different sample sizes, ranging from 40 to 1000, with steps of 30. For each sample size, 1000 replications were generated to determine the mean value of the desired parameter (nutrient indices and Nutrient Balance Index). All nutrient indices decreased rapidly as sample size increased from 40 to 200. For each nutrient considered, indices varied slightly from 200 to 1000. This study has revealed that the size of sample used to establish DRIS norms, determines the accuracy of nutrient diagnoses in pineapple (*Ananas comosus* (L.) Merr.). The optimal data bank for nutrient diagnosis in the crop (pineapple) used in this study is 200.

Keywords: *Ananas comosus*, Nutrient Balance Index, nutrient indices

A simulation study on the comparison of Diagnosis and Recommendation Integrated System (DRIS), Modified-DRIS (M-DRIS), and Compositional Nutrient Diagnosis (CND) for pineapple nutrient diagnosis

Agbangba E.C., Yalinkpon F., Sossa E.L., Gongnet E.E., Glèlè Kakaï R.

Agronomy Research, 22(3), 1380-1404
DOI: https://doi.org/10.15159/AR.24.101

Foliar diagnostic helps assess plant nutritional status and drives appropriate fertilizer recommendations to enhance quality and productivity of plants. Several foliar diagnostic methods are used but the literature is not sufficiently documented regarding the comparison of these methods using a varied range of comparison criteria. This study compared DRIS (Diagnosis and Recommendation Integrated System), M-DRIS (Modified-DRIS), and CND (Compositional Nutrient Diagnosis) in diagnosing pineapple leaf nutrient levels with varying sample sizes. Empirical data from a subtractive experiment was used to simulate and constitute a new database considering that nutrient contents were normally distributed. For each sample size, data were generated per treatment and replicated 3,000 times. DRIS, M-DRIS, and CND indices were computed from the simulated data for each nutrient. The methods were subsequently evaluated based on four criteria: (i) the Diagnosis Concordance Frequency, which assesses the consistency of diagnoses across different methods for determining nutritional indices; (ii) the sensitivity, or True Positive Rate, which gauges a model's ability to accurately identify a specific nutritional status when it is present; (iii) the precision, or Positive Predictive Value, which indicates the proportion of correctly identified diagnoses for a particular nutritional status relative to the total number of diagnoses made for that status; and (iv) the accuracy, which measures the closeness of the model's results to the true value. As results, we found that N, P, and K nutrient indices differed significantly between DRIS, M-DRIS, and CND models and with sample size. The nutritional diagnosis methods were also discordant, except DRIS versus M-DRIS (mean agreement = 66%). Compared to DRIS, and M-DRIS models, CND appeared to be the most sensitive and accurate model (average accuracy of 27.86%) for nutrient deficiency and excess diagnosis. The models' accuracy varies with the sample size, but it becomes almost unchangeable from a sample size of 330. For all sample sizes, the CND model was more accurate and efficient for N, P, and K nutrient status diagnosis, compared to DRIS and M-DRIS models.

Keywords: accuracy, foliar analysis, true positive rate, precision, *Ananas comosus*.

Ecological Niche Modeling to Identify Cultivation Areas for Pineapple in the Republic of Benin

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Pineapple is one of the most important tropical fruit species, widely cultivated and economically important in Benin. This study aimed to identify potentially favorable areas for the cultivation of pineapple under current and future environmental conditions in Benin. The two cultivars of pineapple grown in Benin were separately considered: Sugarloaf and Smooth Cayenne. Five (05) modeling algorithms such as Maxent, Random Forest (RF), Support-Vector Machines (SVM), Boosted Regression Trees (BRT) and Generalized Linear Model (GLM) were compared using the criteria: area under the curve (AUC), sensitivity, specificity, Cohen's Kappa, deviance and True Skill Statistic (TSS). The future climate models available for Africa at horizon 2055 were used under the "Representative Concentration Pathways" scenario 4.5 and 8.5. Results suggested that pineapple suitable areas were governed by a combination of effects of climate (temperature and precipitation) and soils characteristics. Indeed, soil pH, temperature seasonality and precipitation of driest quarter were the main variables driving pineapple production in Benin. Results also indicated that RF was the most suitable technique to model the distribution of pineapples regardless of the variety. The current potential range of favorable areas for the two varieties was mainly found in the central and southern parts of the country. In the future, following the RCP4. 5 scenario, there will be an increase in the area favorable for the cultivation of Smooth Cayenne variety by 5.28% compared to the current situation whereas, the area favorable for the cultivation of the Sugarloaf variety will be increased by 7.7%. However, suitable areas for cultivation of Smooth Cayenne and Sugarloaf following the RCP8. 5 scenario will be increased, respectively by 21.82% and 31.64%. The low and medium suitability areas for the cultivation of smooth cayenne will decrease by 15.57% and 2.93%, respectively at the horizon 2055 with future conditions under RCP4. 5, and 15.48% and 4.97%, respectively at the horizon 2055 with future conditions under RCP8. 5. For sugarloaf, the low and medium suitable cultivation areas will decrease by 1.59% and 14.24, respectively at the horizon 2055 with future conditions under RCP4. 5. According to RCP8. 5, the low suitable areas will decrease by 5.08%. This study constitutes an initial step towards a sustainable scheme for planning exploration of the possibility of extending pineapple cultivation in Benin.

Keywords: Climate change, modeling, algorithms, pineapple, potential area distribution

Relative performance of Neural Networks and Binary Logistic Regression in a Variable Selection framework

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This study evaluates the predictive capabilities of a binary response variable using Multilayer Perceptron neural networks (BLMLP) and binary logistic regression (BLR) in a variable selection context. The data used was related to the identification of prenatal factors linked to premature birth in women already in labor. The stepwise selection method on BLR and the Olden selection method based on the neural network approach were used to select the most relevant variables to predict the probability of premature birth by women. Then, the two selection methods were combined with BLR and BLMLP models. Using performance criteria such as sensitivity, precision, classification accuracy, F-score, and Area Under the Curve, the selection methods were compared to identify the best model. It appears from the analysis that the best procedure for selecting variables in a binary variable prediction is the use of the Stepwise procedure followed by multilayer perceptron neural networks.

Keywords: Binary logistic regression, neural network, multilayer perceptron, selection of variables, prediction

Impact of box-cox transformation technique on the Bayesian Maximum Entropy (BME) prediction accuracy

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This study investigated whether increasing the normality of an attribute using Box-Cox transformation improves Bayesian Maximum Entropy (BME) prediction accuracy. Furthermore, we examined if BME accuracy is affected by sample size or spatial dependence. For hard data, the unconditional sequential approach was used to simulate symmetric data (skewness= 0) and data positively skewed (skewness: 1, 3, 6, and 9) with sample size ranging from 100 to 500 at the interval length of 50. Soft data was randomly distributed throughout a square of unit size and a width of 1.5. Data was then transformed using Box-Cox transformation. The prediction accuracy was assessed using the Mean Square Error (MSE) and bias, and transformation methods were compared using the Multivariate Analysis of Variance (MANOVA). The results showed BME accuracy is affected by transformation methods but not the sample size and the spatial dependency. However, in comparing the transformed data with the untransformed data, the MSE and bias of the untransformed data (lambda= 1) were closer to zero than the transformed data lambda≠ 1. As a result, we concluded that BME is robust to skewness, sample size, and spatial dependency.

Keywords: Box-Cox transformation, skewness, spatial dependence, Bayesian maximum entropy

Dynamics of co-composting of pineapple harvest and processing residues with poultry litter and compost quality

Sossa E.L., Agbangba C.E., Koura T.W., Ayifimi O.J., Houssoukpèvi I.A., Bouko N.D.B., Yalinkpon F., Amadji G.L.

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The production of pineapple generates significant quantities of harvest and processing residues, which are very little used. This study evaluates compost quality using pineapple residues and poultry litter. Five composting treatments were tested, varying following proportions of crown, pineapple processing wastes (PPW), pineapple harvest residue (PHR), and poultry litter (PL). Various parameters were analyzed, including pH, electrical conductivity, CO_2 evolution rate, water content, organic carbon, nitrogen compounds, phosphorus, potassium, calcium, magnesium, copper, and zinc. Additionally, the perceptions of producers and processors regarding compost quality were gathered. Results indicated that microbial decomposition increased temperature, pH, CO_2 release, and nitrogen content while reducing electrical conductivity and organic carbon. Composts demonstrated favorable characteristics for crop fertilization, with C4 (75% PHR + 25% PL) compost showing the best chemical properties. Producers and processors preferred the color, odor, and structure of C4 (75% PHR + 25% PL) and C5 (56.25% crown + 18.75% PPW + 25% PL) composts. Overall, composting pineapple residues with poultry litter yields composts suitable for plant fertilization, particularly C4 and C5 formulations, offering potential for sustainable waste valorization in agriculture.

Keywords: Valorization, Mineralization, Fertilization, Organic fertilizer, Environment

Finding optimum climatic parameters for high tomato yield in Benin (West Africa) using frequent pattern growth algorithm

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Tomato is one of the most appreciated vegetables in the world. Predicting its yield and optimizing its culture is important for global food security. This paper addresses the challenge of finding optimum climatic values for a high tomato yield. The Frequent Pattern Growth (FPG) algorithm was considered to establish the associations between six climate variables: minimum and maximum temperatures, maximum humidity, sunshine (Sun), rainfall, and evapotranspiration (ET), collected over 26 years in the three agro-ecological Zones of Benin. Monthly climate data were aggregated with yield data over the same period. After aggregation, the data were transformed into 'low', 'medium', and 'high' attributes using the threshold values defined. Then, the rules were generated using the minimum support set to 0.2 and the confidence to 0.8. Only the rules with the consequence 'high yield' were screened. The best yield patterns were observed in the Guinean Zone, followed by the Sudanian. The results indicated that high tomato yield was associated with low ET in all areas considered. Minimum and maximum temperatures, maximum humidity, and Sun were medium in every Zone. Moreover, rainfall was high in the Sudanian Zone, unlike the other regions where it remained medium. These results are useful in assessing climate variability's impact on tomato production. Thus, they can help farmers make informed decisions on cultivation practices to optimize production in a changing environment. In addition, the findings of this study can be considered in other regions and adapted to other crops.

Vulnerability of *Parkia biglobosa*, *Vitellaria paradoxa* and *Vitex doniana* to climate change: wild indigenous agroforestry species in Benin

Kakpo A.R., Vodounnon M.J., Agbangba E.C., Hounsou-Dindin G., Dagbénonbakin D.G., Amadji G.L., Buri M.M., Glèlè Kakaï R.

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Climate change is a major threat to biodiversity, with global greenhouse gas emissions exceeding the Paris Agreement, which has a significant impact on the distribution of species at risk of facing extinction. Thus, predicting climate change's influence on species distribution is crucial. In Sub-Saharan Africa, particularly in Benin, some useful plants such as *Parkia biglobosa, Vitex doniana,* and *Vitellaria paradoxa* contribute greatly to improving socio-economic standards. However, they are subjected to overexploitation and climate change, which potentially could lead to their extinction. To predict the habitat suitability of these native agroforestry species for their conservation and cultivation, we assessed the best-performing algorithm among Maximum Entropy, Random Forest, Support Vector Machine, Generalized Linear Models and Boosted Regression Tree. Data were collected from field occurrences and Global Biodiversity Information Facility, and coupled with environment variables selected based on collinearity tests, contribution of variables, and Jackknife tests. We analyzed the main variables affecting their distribution under Representative Concentration Pathways (RCP) 4.5 and RCP 8.5 scenarios by the year 2055. Results showed that Random Forest (RF) was the most appropriate model for predicting the distribution of the three species, with an area under the curve (AUC) > 0.90. Cation exchange capacity, isothermality, and potential evapotranspiration are the environmental factors that all three species depend on. Under current environmental conditions, *P. biglobosa, V. paradoxa,* and *V. doniana* covered 52.10%, 76.91%, and 70.22% of the suitable habitats throughout the study area (11,540 km2). A probable expansion of the suitable habitats was noted, with up to 76.19% for *P. biglobosa* and 82.82% for *V. paradoxa*. Exceptionally, *V. doniana* will lose 7.36% of its suitable habitats under the pessimistic (RCP 8.5) scenarios by the year 2055. These findings represent a step forward in the process of conserving *P. biglobosa, V. paradoxa,* and *V. doniana* in appropriate habitats in the context of climate change.

Keywords: Ecological niche, Climate change, Algorithms, IPCC, Soil fertility, Random Forest

Digital soil mapping: a predictive performance assessment of spatial linear regression, Bayesian and ML-based models

Matazi A.K., Gognet E.E., Glèlè Kakaï R.

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Nowadays, information on the spatial distribution of soil properties is considered a key element for environmental research and for agricultural planning and decision-making to monitor soil conditions, agricultural policies, etc. Developing models for spatial data is easy, but reliable predictions from such models are sometimes challenging due to the data features. Using simulation and data from the WoSI-ISRIC SoilGrid 250 m, we compared the predictive performance of five models: Spatial Linear Regression (SLR-REML), Machine learning (ML)-based models (Random Forest: RF and Random Forest Residual Kriging: RFRK), and Bayesian models (Integrated Laplace Approximation-Stochastic Partial Differential Equations: INLA-SPDE and spBAYES). Considering data characteristics such as spatial autocorrelation, range parameter, strength and type of relationship between the response variable and covariates, we cross-validated the models' results using the following criteria: precision, unbiasedness, and uncertainty (RMSE, coefficient of determination (R^2), Lin's concordance coefficient (pc), and predicted interval coverage probability (PICP)). The results revealed the high precision of SLR-REML with a small bias in the case of low spatial autocorrelation. ML models (RF and RFRK) stood by their ability to account for nonlinearities, particularly the flexibility of RFRK to handle high spatial autocorrelation. The INLA-SPDE model was robust to all data characteristics. Despite its drawbacks related to the computation time observed, the SLR-REML model relaxed the minimum limit about the number of observations required in the classical regression by linear mixed modeling (REML-LMM) to make better predictions in Digital Soil Mapping (DSM). In addition to commonly used machine learning (ML) techniques, INLA-SPDE and SLR could be suitable for the understanding, characterization and mapping through spatiotemporal modeling of soil properties and environmental variables.

Keywords: Spatial linear regression, Flexibility, Uncertainty, INLA-SPDE, RFRK, RF, DSM

Modelling the potential impact of climate change on *Carapa procera* DC. in Benin and Burkina Faso (West Africa)

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Carapa procera plays an important socio-cultural and economic role for local people. The species is threatened by several factors including climate changes. This study explored the current and future distribution of the species in Benin and Burkina Faso. The maximum entropy (Maxent) software was used which combined the occurrence data of the species with a set of environmental layers. The future distribution of the species was assessed using the shared socioeconomic pathways (SSP) 245 and 585 for 2061–2080 and 2081–2100 periods. Globally, the models performed well, with mean AUC and TSS values of 0.90 and 0.67, respectively, suggesting good performance of the models. A set of five (05) variables drives the distribution of the species with rainfall and isothermality as the most important. For the current distribution, the findings showed that the highly suitable areas were mainly located in Guinea Congolian, and Sudanian zones respectively in Benin and Burkina Faso. The model indicated similar future patterns regardless of the general circulation models (GCMs) and shared socioeconomic pathways (SSPs). The MIROC6 model predicted that the species could lose around 10% of its currently suitable areas, whereas the CNRM model predicted that it would lose 8%. The WAPOK complex was identified to harbor the species in the natural habitats. Our study provides good insight into the current and future distribution of *C. procera* which can be decisive for the species management.

Keywords: *Carapa procera*, Ecological niche models, Species distribution models, West Africa

Morphological variability of 'bush banana' (*Uvaria chamae*) and its environmental determinants in Benin, West Africa

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Uvaria chamae is an edible wild fruit of great importance as a resource in West Africa. However, it is threatened in its natural habitats in Benin, and no specific measures are currently implemented to ensure its sustainable management. To provide information needed for developing such measures, this study (i) described the morphological variability of *U. chamae*; (ii) assessed the influence of environmental variables on these morphological traits; and (iii) characterized its morphological types along the environmental gradients in Benin. Data on morphological traits were collected on shrubs, leaves, fruits, and seeds of 210 individuals from seven phytodistricts of the Guineo-Congolian and Sudano-Guinean biogeographical zones of Benin where this species occurs. Descriptive statistics, linear mixed effect model, redundancy analysis, principal components analysis, and hierarchical clustering were used to describe the morphological variability of *U. chamae* and its environmental determinants. Results showed that morphological traits varied significantly at the 25% threshold across biogeographical zones phytodistricts. Localities within phytodistricts (29–98%) followed by biogeographical zone (0.8–65%) were the greatest source of variability for most of the morphological traits. Environmental variables namely isothermality, mean temperature of warmest quarter, precipitation of wettest month, rainfall of driest quarter, and land cover together explained 52.20% of the variation in *U. chamae* morphological traits. Hierarchical clustering suggested three morphological types. Morphotype 1, found in the Guineo-Congolian zone, mainly in Plateau and Oueme Valley, had the highest values of most traits (interesting for domestication). Morphotype 2, also from the Guineo-Congolian zone, especially in Coastal and Pobe phytodistricts (urban areas), had low values for most traits. Morphotype 3, which presents intermediate characteristics of the morphological traits, was found in the Sudano-Guinean zone (Bassila, Zou, and South Borgou phytodistricts). Therefore, morphotype 1, which had the highest values recorded in morphological traits, could be considered in breeding programs for the domestication of the bush banana but other morphotypes need to be conserved.

Keywords: Domestication, Morphological variation, *Uvaria chamae*, West Africa, Wild edible fruit.

Small-scale marine fishing in Benin, West Africa: A comprehensive assessment of the processed fish value chain

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The processed marine fish sector represents an important component of small-scale marine fisheries in Benin. It plays a crucial role in terms of seafood provision and job creation in the country. However, its socioeconomic performance has been limitedly explored since few investigations have been dedicated to the sector over the past decades. This study investigated the value chain of processed marine fish (VC-PF), focusing on its functional, economic, social, and environmental dimensions. Data was collected using a mixed method approach via in-depth interviews (n = 35), quantitative surveys (n = 121), and direct observations. Results evidenced four nodes (fishing, processing, trading, and consumption) along the VC-PF. Adult and local men dominantly operated the fishing node, while the processing node was entirely handled by adult and local women. The trading node had a higher representation of women and a significant proportion of migrants. On average, 2321.4 kg of fish belonging to 21 species is processed annually in the sector, which generates an annual added value of 8217,756 €, corresponding to 3.67% of the GDP of the total fishery sector in Benin. Although the VC-PF's contribution to Benin's economic growth is still marginal, it was observed to be profitable and resilient. Unfortunately, the VC-PF has a negation protection (NPC<1), indicating limited or no protection for the domestic VC-PF against regional and international competition. Policy actions such as actors' engagement, the promotion of environmentally friendly fishing and subsidised fishing and processing equipment provision are vital to sustain the sector.

Keywords: Marine Fisheries, Benin, Value Chain, Stakeholder Engagement, Sustainability

The role of local deities and traditional beliefs in promoting the sustainable use of mangrove ecosystems

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Customary laws and traditional beliefs are progressively used in conservation and management of natural resources. However, their effectiveness has received limited attention. This case study from the Benin Republic (West Africa) examines how local deities and traditional beliefs can reduce manmade threats to mangroves. Data were collected from three categories of mangroves (sanctuary, sacralised, and non-deity mangroves) via direct observations, informal interviews (*n* = 5), in-depth interviews (*n* = 10), focus group discussions (*n* = 3) and household surveys (*n* = 200). We used twelve indicators including the quantity of resources collected, the use value and the perceived diversity of fish and plant species to characterize each category of mangroves. Eight of these twelve indicators showed significant variation among the categories of mangroves. Highly destructive uses were generally associated with non-deity mangroves, whereas moderately and less destructive uses were mostly associated with sacralised and sanctuary mangroves, respectively. Local deities can thus assist to limit unsustainable use of mangrove forests. Among the mangrove users, salt producers and residents with many children collect and commercialise more mangrove resources than others and should be continually involved in sensitization and community engagement to foster the sustainable use of mangroves.

Keywords: Sacralised mangroves, Customary laws, Local governance, Traditional beliefs, Sanctuary mangroves

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