World Conference on Natural Resource Modeling

WCNRM 2026

Abstract Book

1–3 July 2026

Resource Modeling Association (RMA)

Conference Day 1: 1 July 2026

Keynote: Lorien Pichegru

Institute for Coastal and Marine Research, Nelson Mandela University

A decade of science-based conservation for African Penguins – lessons learnt

Abstract
African penguins are endemic to Southern Africa and their populations have dwindled to a mere 1% of their historical numbers, due to various threats over the past century. Recently, the collapse of the fish stocks they depend on accelerated their decline and called for the downgrade of their IUCN status to Critically Endangered, the only penguin species globally to face this level of threat. Experimental fishing exclusion zones around key penguin colonies were tested since 2008 to assess their benefits for the birds (the Island Closure Experiment - ICE), and in 2013 the African Penguin Biodiversity Management Plan (BMP) was gazetted to "halt the decline of the African penguin population (...)" within the five years of its implementation. Several working groups were created to discuss the ICE and to facilitate the implementation of the actions emanating from the BMP. Conservation actions included the provision of artificial nests, the rehabilitation of adults and chicks, or predator management, among others. Long-term monitoring were set in place to measure the impact of these actions, which were proven to have slowed the decline of the species. Inadequate management of competition with fisheries however prevented population recovery and called for more permanent fishing exclusions, which were declared in Court in 2025.

Keynote: Frankie Cho

Queensland University of Technology, Australia

Natural resource management strategies must be robust to uncertainties

Abstract
Many natural resource managers try to find the best strategies to balance human needs and natural resource extraction by solving complex mathematical problems. These strategies, however, often ignore the vast uncertainties behind our understanding of natural systems. In this talk, I show that even simple perturbations to our uncertain modelled ecosystems can have drastic effects on the effectiveness of natural resource management strategies. These uncertainties affect everything from what our best actions for managing natural resources are, to how we quantify the value of new information that resolves these uncertainties. My talk also demonstrates new tools for how natural resource managers can begin to explicitly account for uncertainty in their decisions, paving the way forward for robust natural resource management strategies that work across a wide range of possible futures.

Keynote: Wisdom Akpalu

GIMPA, Achimota-Accra, Ghana

Modeling illegal behavior in small-scale capture fisheries in developing coastal countries

Abstract
Wild fish stocks provide substantial economic and social benefits to developing coastal countries, yet they are often managed under regulated open-access regimes, leading to overcapitalization and biological overfishing. In addition, some fishers adopt destructive fishing practices to increase their harvests, driving stocks further towards collapse. While certain violations—such as fishing in closed areas or exceeding catch limits—can be explained by fishers behaving as rational agents who maximize a short-term (one-period) expected utility function, other infractions involve longer-term strategic behavior. In particular, some fishers invest in destructive fishing gear to increase catch efficiency over time, continuing to do so until they are detected and punished. This latter form of illegal activity can be modeled as an investment decision under uncertainty, where returns persist until the offender is apprehended.

This study develops both static and dynamic models of such behavior, incorporating time discounting, and presents empirical evidence based on small-scale fisheries in Ghana.

Session 1

Melissa Chapman

ETH Zurich

Designing robust conservation and restoration strategies under sociopolitical uncertainty

Abstract
Designing robust conservation and restoration strategies under sociopolitical uncertainty Strategic planning for cross-jurisdictional conservation and restoration targets increasingly accounts for bioclimatic uncertainty and change. Yet sociopolitical risk (such as policy reversals, regime change, or democratic backsliding) remains largely absent from quantitative planning studies and frameworks in this problem domain. However, political dynamics strongly influence where conservation and restoration actions are implemented, how burdens and benefits are distributed across jurisdictions, and whether the interventions and objectives endure over time. We first examine how sociopolitical factors shape the spatial distribution and durability of conservation and restoration strategies. We focus on two contrasting case examples (the United States and the European Union) to analyze how sociopolitical risks manifest across federal and multi-national governance systems. We then use these insights to design planning strategies that diversify across space and interventions with differing ecological benefits and political fragilities, identifying robust strategies that maximize expected biodiversity outcomes while limiting exposure to governance failure and therefore failed targets. The approach provides and approach for designing conservation strategies that remain effective in an era of geopolitical uncertainty.

Luc Doyen

CNRS & CEEM

Bioeconomic Sustainability and Resilience of Biodiversity under Invasive Species Pressures

Abstract
As a major cause of species extinction, invasive species pose a significant threat to biodiversity and ecosystems. In a context of limited resources and mistrust toward environmental measures, the management of invasive species requires compromises between conservation objectives, economic constraints, and the acceptability of the measures taken. In this article, we develop a stylized bioeconomic model of native-invasive species dynamics to analyze management strategies that enable the long-term preservation of native species. Considering a viable control framework, we characterize the conditions under which coexistence of the two species or eradication of the invasive species are sustainable, taking into account budgetary and conservation constraints. We identify a "viable corridor" — a set of states in

which native species can be sustainably preserved — and deduce the corresponding viability control efforts. By contrasting the solutions obtained via viability and optimal control frameworks, we highlight how viability principles can lead to more sustainable and resilient outcomes. A numerical application to the case of grey versus red squirrels in the United Kingdom illustrates the policy relevance of our findings.

Adrian Lopes

American University of Sharjah, United Arab Emirates

Co-authors: Shadi Atallah, Koustuv Saha, Sahan Dissanayake

Coexistence, Conflict, And Wildlife Spiritual Values Among Indigenous Herders.

Abstract
The spiritual values of wildlife are often excluded from conservation policy, particularly in indigenous communities where cultural beliefs strongly shape human–wildlife coexistence. We empirically estimate these values among Rabari pastoralists in Rajasthan, India, who view leopards as divine manifestations and livestock predation as a religious offering rather than solely as economic loss.

We surveyed goat herders living near the Jawai-Bandh Leopard Conservation Area using a discrete choice experiment to elicit preferences for a conservation program that implements an expanded buffer zone. Program attributes included changes in leopard populations, associated increases in goat predation, compensation levels, and the administrative ease of obtaining compensation. Measures of religiosity, wildlife spirituality, and risk tolerance were also collected. Importantly, compensation for predation is already institutionalized, allowing valuation without introducing culturally inappropriate hypothetical payment vehicles. Preferences were estimated using mixed logit regression and latent class models.

Results reveal pronounced heterogeneity. While increases in leopard populations were not valued on average, risk-tolerant herders exhibited a positive preference for population growth. Predation increases were generally disliked; however, herders with wildlife spirituality beliefs—particularly Rabaris who interpret kills as offerings—demonstrated greater tolerance for predation up to a threshold. This nonlinear response provides a quantitative estimate of marginal wildlife spiritual values. In contrast, broader religiosity measures did not significantly influence preferences. All herders preferred lower-transaction-cost compensation procedures but were unwilling to accept reduced compensation levels.

This study provides rare quantitative evidence on wildlife spiritual values and underscores the importance of incorporating cultural heterogeneity into conservation policy.

Session 2

Ben Wittenberg

Statistics for Ecology and Environmental Conservation, University of Cape Town, South Africa

Whodunnit: attributing the causes of population trends of an endangered amphibian in relation to wildfire and climate patterns

Abstract
Combatting biodiversity loss is greatly aided by accurately attributing the causes of decline. In amphibians, the most threatened vertebrate class, many extinctions and declines go without any obvious causes. Structural causal modelling and counterfactual analyses of observational data can help us attribute observed changes to their causal drivers. We used long-term monitoring data (2007 - present) on South Africa's most threatened amphibian, Roses' mountain toadlet (Capensibufo rosei) to determine how climatic variables and wildfire drive population fluctuations. Capture-mark-recapture data and hierarchical population models (Cormack-Jolly-Seber, Pradel, and Closed population models) were used to estimate

adult survival, recruitment and population size over the entire study period, while a full record of climate data was compiled and interpolated from various sources. Demographic and climate data were then combined with records of fires on the Cape Peninsula in a structural causal model framework. Results show that temperature, rainfall patterns and fire all impact C. rosei, with recruitment increased by fires (β = 12.76 $\pm$ 1.22) and rainfall (β = 0.13 $\pm$ 0.04) but decreasing with evaporative water loss (β = - 2.0 $\pm$ 1.4). Survival, meanwhile, decreased immediately following fires (β = -7.53 $\pm$ 3.00) with smaller reductions driven by evaporation and temperature extremes. Structural causal interventions support an inverse relationship between survival and recruitment with lack of fire driving low recruitment and high survival while burns produce a spike in recruitment and corresponding drop in survival. These results have real-world implications for the future of this species and other amphibians in the region as well as showcase the potential for population modelling integrated into a structural causal framework.

Sandra MacFadyen

Stellenbosch University, South Africa

Co-authors: Cang Hui, Astrid J.A. Van Teeffelen, Peter H. Verburg

Dynamic Interactions of Rainfall, Fire, and Mega-Herbivores Shape Landscape Functioning in Kruger National Park, South Africa

Abstract

In the face of global biodiversity decline, protected areas are crucial for conservation. Large protected areas are important as they maintain diverse species, shield habitats from disturbances, and foster ecological processes for ecosystem health. To manage protected areas, managers need to develop an understanding of the interactions among ecological variables to maintain ecosystem integrity. This study uses Piecewise Structural Equation Modelling to assess the impact of landform, river proximity, rainfall, herbivore densities, and fire frequency on landscape heterogeneity in the Kruger National Park over 28 years (1985-2012). We analyse data from managers and remote sensing products to understand how seasonal variation in landscape heterogeneity is influenced by interactions among rainfall, fire, and large herbivores. Our findings reveal patterns of influential factors that fluctuate spatially and temporally. Increased herbivory generally correlates with greater temporal and spatial heterogeneity, except higher elephant densities which are linked to temporal homogenization in both wet and dry seasons. Fire initially increases dry season heterogeneity but decreases it in the wet season. Diverse physical landforms are associated with increased heterogeneity in both seasons. Spatial heterogeneity in the dry season decreases towards the southeast and increases towards the northwest in the wet season. Ecological systems are complex and adaptable, with physical and stochastic factors shaping landscape patterns and influencing ecosystem processes at various scales. The mosaic of landscape heterogeneity reflects this complexity and is a key indicator of global biodiversity. Our analysis shows how ecologists and protected area managers can isolate the effects of physical and stochastic factors on landscapes and their impacts on ecosystem processes. This approach can aid in developing effective conservation methodologies for large, complex adaptive systems like Kruger.

Joe Millard

University of Cambridge

Compounded uncertainty of ecosystem service risk under environmental change

Abstract

Predicting the consequences of biodiversity change for nature's contribution to people is difficult. In large part the problem is uncertainty. Although we understand that the global climate and biodiversity are both changing, and that biodiversity is related to services provided to people, the magnitude of change and the shape of these relationships across scales are typically unknown. However, we do

often know regions of parameter space within which the future lies. For risks to crop pollination, for example, we know that the interaction of land-use and climate change is associated with a significant reduction in insect pollinator abundance on cropland; that the relationship between pollinator abundance and crop production is likely some form of concave function (i.e. crop production declines slowly until a large proportion of pollinators have been lost); and that the climate will warm according to quantifiable socioeconomic decisions of future humanity.

In this talk, I will show how a space-for-time model of pollinator biodiversity change, together with estimates of global pollination dependent crop production, future projections of climate change, and a range assumptions on the relationship between pollinator abundance and crop production, can be used to derive compounded intervals of ecosystem service risk that account for many uncertainties together. I will conclude by discussing the utility of projections which are transparent on multiple forms of uncertainty, and how compounded intervals could be updated as new evidence becomes available.

Session 3 – Fisheries, Marine and Aquatic Systems

Sipesihle Booi

Nelson Mandela University, South Africa

Economic Valuation Modeling of Estuarine Ecosystem Services: Evidence from the Swartkops and Sundays Estuaries Using the Travel Cost Method

Abstract
Estuaries are highly productive coastal systems that provide critical ecosystem services to local communities and regional economies. This study applies economic valuation modelling to quantify the contribution of the Swartkops and Sundays estuaries in Algoa Bay, Gqeberha, to estuary users and the broader Nelson Mandela Bay Municipality. Primary data were collected between December 2021 and April 2022 using the Travel Cost Method and a Choice Experiment framework to estimate recreational and provisioning ecosystem service values.

Results show that the Swartkops Estuary supports subsistence and small-scale income generation, with anglers and bait collectors earning an average of R77.41 per catch and many households relying on provisioning services as a primary livelihood source. In contrast, the Sundays Estuary is predominantly used for recreational purposes. Recreational users of both estuaries contribute substantially to the local economy, with annual expenditures exceeding R4.7 million and R2.2 million, respectively, generating significant multiplier effects within the municipality.

By integrating non-market valuation modelling with expenditure-based economic impact analysis, the study demonstrates how estuarine ecosystem services contribute to local livelihoods and regional economic activity. The valuation outputs generated in this study can be incorporated into coastal management decision-support tools to inform resource allocation, conservation prioritisation, and sustainable extraction policies. The findings provide quantitative evidence to support resource monitoring and integrated coastal management strategies. The results further underscore the importance of incorporating ecosystem service valuation into coastal decision-making frameworks to balance economic use with long-term ecological sustainability.

Pietro Landi

Stellenbosch University

Co-authors: Cang Hui, Ulf Dieckmann

Eco-evolutionary modelling of fisheries: disruptive selection and collapse

Abstract
Harvesting induces adaptive responses in fish populations, in particular by shifting the age and size at maturation through directional selection. In addition to such evolution, the corresponding fishery itself may adapt, in terms of fishing policy, technological progress, fleet dynamics, and adaptive harvest. The aim of this talk is to explore how the interplay between natural and artificial selection, under fishery and stock co-adaptation, can lead to disruptive selection on the stock or to fishery collapse. We use an eco-evolutionary model for a size-structured population, in which both the stock's maturation schedule and the fishery are adaptive, while fishing may be subject to a selective policy based on fish size and/or maturity stage. Fisheries-induced disruptive selection can readily happen under commonly used fishing policies or without regulation. The interplay of fleet dynamics and stock evolution can lead to fisheries collapse in different ways. We discuss the broader implications of our results and highlight how these can be taken into account for designing evolutionarily informed fisheries-management regimes.

Nokuthaba Sibanda

University of KwaZulu-Natal

Co-authors: Charles TT Edwards, Marie-Julie Roux

Data integration and zero-inflation for low information species in fisheries

Abstract
Biomass data for low information fish species can be extremely zero-inflated, where the percentage of zeros can be over 90

Despite their significance, research on zero-inflated models has predominantly focused on count models such as zero-inflated Poisson or negative binomial regressions. Such models are not suitable for biomass data which are semi-continuous. In such cases, hurdle models are commonly used. The zero-inflated (ZI) Tweedie model is emerging as a suitable model for zero-inflated semi-continuous data. The ZI Tweedie model is a mixture model that integrates a Tweedie model with a binary model to distinguish between excess zeros — those resulting from an independent process, and true zeros — those resulting from the Tweedie model itself. We use a Bayesian approach to estimate the model parameters.

Session 4

Leif Kristoffer

Norwegian School of Economics (NHH)

Optimal policy contraction by applying Dynamic and Potential rent in Natural Resource Economics

Abstract
Dynamic optimization encompasses a wide range of research questions in both theoretical and applied economics. This paper presents a simple, fast-converging iterative scheme capable of generating high-quality analytic (closed-form) approximations—including explicit error bounds—for a class of nonlinear problems. The algorithm is also well-suited for producing numerical solutions.

We define and operationalize the concepts of dynamic rents and potential rents, and show how our approach leverages a balancing relation between these rents to derive optimal policies. A powerful result emerges in the case of zero discounting, where the exact Catching-up optimal policy is obtained in a single iteration.

By applying a specific initial seed within our general framework, it recovers known results from the bioeconomics literature, thereby illustrating the constructive nature of our theorem and the versatility

of the procedure. It provides error bounds for these formulas—bounds that were previously unavailable—enhancing both their theoretical robustness and practical applicability.

Michael Kelly

Transylvania University

Co-author: Suzanne Lenhart

Optimal Control of Coastal Fisheries in Heterogeneous Habitats

Abstract
Coastal fisheries are vital to global food security and local livelihoods, yet face increasing pressure from overfishing, habitat degradation, pollution, and climate change. These challenges are amplified by spatial heterogeneities inherent in coastal environments, complicating effective management. We develop a spatially explicit partial differential equation model with mixed boundary conditions to represent a coastal fishery and its underlying habitat. Within this framework, we formulate an optimal control problem to determine the dynamic distribution of harvest effort that maximizes the discounted net present value of the fish stock while accounting for harvesting costs. Numerical simulations explore how habitat heterogeneity, spatial boundaries, and domain size influence optimal harvesting strategies, highlighting key ecological and economic tradeoffs relevant to sustainable coastal fishery management.

José M. Maroto

Complutense University of Madrid, Spain

Equilibrium and transient dynamics in age-structured fish population dynamics models under low productivity and age-specific survival rates

Abstract
Scientific advice provided by scientific advisory bodies, based on spawning stock biomass (SSB) status relative to key precautionary approach reference points, such as Blim, is crucial for sustainable fisheries management, aiming to maintain or rebuild fish stocks to levels at least capable of producing maximum sustainable yield (MSY), while avoiding stock collapse (below Blim). However, many fish stocks have failed to recover despite reduced fishing mortality, indicating low productivity. For these stocks, we develop here an equilibrium-based method that, in contrast to standard methods, characterizes transient dynamics toward the stable SSB equilibriums. Transient dynamics analysis allows to determine the range of low productivity levels (including low age-specific survival rates) and low SSB growth rates which are consistent with the observed low SSB growth. Consequently, we show that transient dynamics analysis provides a useful tool for understanding the observed slow recovery of many fish stocks, even for low fishing pressure.

Carryn de Moor

University of Cape Town, South Africa

Managing the fishery for South African sardine during periods of changes in the understanding of stock structure

Abstract
Best practice for sustainable fisheries management requires quantitative stock assessment models fitted to both fishery independent and fishery dependent data. These models are designed taking cognisance of the resource's stock structure, and associated uncertainties. However, as data collection and methods of analysing stock structure advance, understanding of a population's structure can change. Consequential updating of assessment models is essential to ensure that catches are sustainable and fishing effort does not have an untoward impact on any individual stock(s) within the targeted population.

South African sardine provide a prime example of this. Understanding stock structure has morphed over the past two decades from assuming a single homogeneous population to accepting two distinct stocks, with some mixing in their distributions. Sardine are harvested with the mixed-fishery for small pelagic fish - the second most valuable in South Africa, and provides the largest landed volume. The fishing industry has also changed in terms of participants (right holders) and the distribution of 'home ports' along the coast, impacting the overall industry's preferences for where to fish.

This presentation will highlight some of the important changes in the modelling of South African sardine, given changes in understanding of stock structure. These will also be discussed in a management context, particularly given the uncertainty in stock structure as research developed, and continues to advance. Management has had to adjust to avoid fishing effort being too high on one stock, while taking cognisance of the industry's preference to fish closer to 'home'. Management Strategy Evaluation has been used to simulate the impact of both single-area and two-area management alternatives for the fishery under alternative models of population structure. The preferred option, meeting the majority of management objectives, was a mix of both explicit and implicit spatial management.

Conference Day 2: 2 July 2026

Keynote: Jill Slinger

Delft University of Technology, The Netherlands

Modelling to support ecosystem-based water and coastal management

Abstract
Ecosystem-based water and coastal management is favoured as an approach to integrating development and conservation goals. As such, nature-based solutions (NbS) are receiving increasing attention in water and coastal management. NbS include actions like ecological flow releases in rivers and estuaries, beach nourishment strategies along coasts, dunes as flood defences along sandy coasts, mangrove-levee flood defence systems along tropical muddy coasts or vegetated dike foreshores along temperate muddy coasts, as well as the restoration and/or construction of wetlands or seagrass meadows for water quality improvement. Such solutions signal a shift away from traditional hydraulic engineering infrastructure towards ecosystem-based water and coastal management. However, the design, operation and maintenance of dynamic natural infrastructures rests on appropriate modelling tools, participatory development processes, and stakeholder-inclusive decision processes. Within this context, the paper undertakes an exploration of: (i) diverse commonly applied modelling tools, (ii) the associated modelling processes (for instance, (non)participatory or co-creational) and (iii) the requirements and opportunities inherent to model-based decision making with stakeholders. Each of these aspects is addressed through illustrative examples in rivers, estuaries and deltas. The paper concludes with practice-based insights on the role that modelling can play in supporting adaptation and transformative change in water and coastal management.

The paper serves as a thought-provoking introduction to the session Modelling to Support Water and Coastal Management.

Keynote: Charlotte Gerling

BTU Cottbus-Senftenberg, Germany

Climate-ecological-economic modelling for a better future for biodiversity

Abstract
Climate change and land use are two of the greatest threats to biodiversity. Because climate change affects both ecosystems and land-use decisions, conserving biodiversity in the future is a complex challenge. Integrated climate-ecological-economic (CEE) modelling offers a powerful framework to explore the complex interactions between ecosystems, climate, land use, and policy. In this talk, Dr. Charlotte Gerling will present a general CEE modelling approach and illustrate its application through examples that reveal how ecological and economic systems interact under climate change. A key focus will be on designing cost-effective policies for biodiversity conservation, highlighting why current approaches may be insufficient and how CEE models can inform adaptive, future-ready strategies. This includes

the evaluation of existing policies such as agri-environment schemes, land purchase, and offsets, as well as novel incentive structures to conserve biodiversity in a changing climate. Despite the great promise that CEE modelling holds for improving conservation under climate change, it is still in its infancy. Because of this, Charlotte Gerling will also highlight pressing challenges and specific, promising avenues of research as a call for the resource modelling community to engage with CEE modelling to generate actionable insights that improve the future for biodiversity in a changing world.

Session 5

Jai Clifford-Holmes

Association for Water and Rural Development (AWARD), South Africa

From Catchments to Coasts to Net-Zero: 15 Years of System Dynamics in South Africa

Abstract
This presentation reflects on 15 years of using system dynamics modeling (SDM) in natural resource management in complex multi-stakeholder contexts. Four cases are analysed, the first being the use of SDM to explore the 'modes of failure' of local government in providing drinking water to residents of a small rural town in the Eastern Cape. The second case study used participatory SDM to help stakeholders think through different scenarios of change in a catchment characterised by diverse activities and interest groups, in the Olifants River Catchment, in the north-eastern part of South Africa. The third case study featured the use of SDM to support marine spatial planning in the coastal city around Algoa Bay, where rich biodiversity, eco-tourism, fisheries, and two active harbours compete for resources and space. Finally, the fourth application features SDM supporting a national department to develop grounded scenarios for how South Africa could reach Net-zero by 2050, while trying to meet developmental prerogatives around poverty reduction, inequality, and unemployment. In all four case studies, a qualitative process was undertaken as part of the process of developing a quantitative model – with varying levels of stakeholder input – resulting in four simulation models: the 'Modes of Failures' model, the ResiMod model in the Olifants catchment, the Algoa Marine Systems Analysis Tool (AlgoaMSAT) in Algoa Bay, and the South African iSD model for national climate planning. In each circumstance, the model was framed as a tool to support rigorous thinking, rather than an oracle for accurate predictions. The presentation describes the insights gained from these different case studies, including the ways in which different stakeholders' perspectives and sectoral interests were integrated into common planning frameworks, enabling 'what if?' questions to be asked and explored. Finally, these insights are reflected upon in relation to modeling best practices and guidelines.

Willem Kruip

Delft University of Technology

Co-authors: Jill Slinger, Carles Ibáñez, Ferran Bertomeu, Floortje d'Hont, Lieke Hüsken

Modelling the systemic effects of Nature-based Solutions in the Ebro Delta.

Abstract
The Ebro Delta in Catalonia, Spain, is a social ecologically rich Mediterranean landscape where human use and a diverse range of ecosystems coexist, supporting both high levels of biodiversity and a local economy centered on rice cultivation, fisheries, and tourism. Today, this system faces severe threats from sediment starvation, erosion, subsidence, and climate driven sea level rise, placing much of the deltaic plain — and its social, economic and ecological functions — at risk within this century. To address these threats, local stakeholders are exploring sustainable adaptation options, and have identified various Nature-based Solutions (NbS) which offer means for climate adaptation while supporting societal development and maintaining biosphere integrity. Yet, an integrated assessment of the systemic effects

of such NbS, spanning the social, economic, and ecological domains across the delta, is still lacking. In response, this research adopts a systems modelling approach using (participatory) System Dynamics to enable an integrated assessment of the systemic effects of NbS in the Ebro Delta. We use ecosystem services as the central lens to examine how the dynamics of this complex deltaic system shape the varying impacts of NbS interventions. Different system components in the Ebro Delta (e.g. sediment, coastal adaptation, (rice) farming, (eco-)tourism, natural capital, etc.), are identified and connected, resulting in a purpose-built systems model. In doing so, the research serves to explore the role of collaborative systems modelling for integrated management of Anthropogenic deltas, and investigates the applicability and added value of such an approach for NbS science and practice.

Jane Tanner

Rhodes University; SLR Consulting, South Africa

Co-authors: Sinetemba Xoxo, David Gwapedza, Denis Hughes

Participatory water allocation modelling in a semi-arid, intensively farmed catchment with water conflicts.

Abstract
The KoueBokkeveld is an intensively farmed and water scarce, semi-arid region in South Africa. The study area (404 km2) is in a winter rainfall (450 mm yr-1) area with highly seasonal streamflow. Irrigation constitutes 98% of water use, largely based on storage of winter runoff in 18 farm dams (volumes of 0.17-6.30 $\times$ 106m3). Water management challenges include dry season water conflicts and a serious neglect of environmental water requirements. The study objectives were to collaborate with the farmers, to explore improved strategies for managing the scarce water resources and resolving conflicts. The study was based on the application of a water allocation model, integrating uncertainty ensembles of natural streamflow simulated by a hydrological model, environmental flow requirements from a Environmental Reserve Model and water use data and risk profiles provided by the local stakeholders. Continuous stakeholder participation exposed the users and decision-makers to alternative approaches to demand management. The allocation model allows for the evaluation of water shortage risk tolerance among different users. Risk tolerance in the model is represented by the frequency of months with different levels of impact and users can evaluate their impacts under four water sharing strategies to collectively decide on an equitable management approach. Communicating the results of different strategies allowed all stakeholders to understand the likely impacts of decisions and collectively agree on a preferred option. Ultimately, the water users opted to remain with their current water sharing strategy, partly, as the alternative options were very new to them, and partly because they were wary of a strictly formalised agreement. Water supplies are often shared with downstream users through agreements on dam releases and the farmers preferred to retain a trust-based system, despite the fact that some are at a distinct disadvantage under the current management approach.

Session 6

Sinetemba Xoxo

GCS (Pty) Ltd, South Africa; Rhodes University, South Africa

Co-authors: Jane Tanner, David Gwapedza, Karen Bradshaw, Bruce Paxton, Olivier Barreteau

Modelling and gaming to support equitable water sharing under uncertainty

Abstract
Water supply shortages are a common feature of water allocation in semi-arid contexts due to uncertain water availability. Therefore, water restrictions, especially those based on the equality principle are commonly used in allocation management. This re-allocation option ignores the fact that water users

across catchments are affected differently by different levels of droughts, depending on their coping capacity, and that the level of vulnerability may be worsened by the re-allocation decisions. Here, the socio-economic and ecological performance of the commonly applied re-allocation rule, along with three novel alternatives, is evaluated using a participatory modelling approach and validated with water users through a co-designed Role-Playing Game. The setting is a semi-arid and commercial agricultural use in the Koue-Bokkeveld region of Western Cape, South Africa. The model simulates the relationship between water deficits and likely socio-economic impacts of water deficits across users. The game tests the acceptability of the proposed alternatives by water users and facilitates discussion among users who are not familiar with joint decision-making. The analysis showed that innovative strategies, multi-stakeholder partnerships, and trust building, can play a substantial role in reshaping inclusive decision-making towards the progressive realisation of fairness/justice in water allocation in South Africa. This is especially relevant in local scales where nuances in differentiated vulnerability are more common, and specialist support is lacking.

Deepanjali Prasad

Delft University of Technology, The Netherlands

Co-authors: Alethea Barbaro, Salah Alrabeei, Sam Subbey

Combining bioenergetics and individual-based models: A review of forage fish modelling

Abstract
Forage fish are typically small, schooling fish that play a central role in marine food webs by transferring energy from lower to higher trophic levels. Species we consider include anchovy, sardine, saury, and capelin. Their management depends on an understanding of how their spatial distributions and seasonal movements respond to environmental variability, which represents an increasing challenge under climate change and other anthropogenic stressors. An approach commonly applied in the literature to study these processes is individual-based or agent-based models (IBMs or ABMs), which define movement rules at the level of individuals while potentially incorporating behavioral rules, environmental forcing, and physiological constraints. Many forage fish species undertake seasonal movements associated with key life-history stages such as foraging, spawning, and overwintering, moving between pelagic zones and coastal waters. These movements reflect trade-offs between energy acquisition, expenditure, and other ecological constraints. Bioenergetic processes influence movement alongside factors such as predation risk, habitat structure, and environmental forcing. By linking movement decisions to underlying metabolic activity, models can represent condition-dependent and environmentally mediated behavioral responses, provided individual variability is explicitly represented. In this review, we synthesize the literature on forage fish movement models, focusing on IBMs that incorporate energetics. We describe the diverse range of ways of coupling models of movement and physiology, and the most frequently represented abiotic and biotic interactions. By synthesizing stakeholder concerns, we make suggestions for the inclusion of under-represented abiotic and biotic stimuli like oxygen depletion, light intensity, and interactions with zooplankton.

Alethea Barbaro

TU Delft, The Netherlands

Co-author: Bjorn Birnir

Modeling the capelin, an indicator species for climate change

Abstract
The capelin, a small pelagic fish that lives in the Northern oceans, is a key part of the marine ecosystem of the Arctic and subarctic regions. The Icelandic capelin, one of the four main stocks, acts as a biological pump between the plankton bloom in the Arctic sea and commercially-fished species such as cod,

herring, and haddock in the Greenland Sea. In this talk, we present an interacting particle model for the spawning migration of the Icelandic capelin. We then discuss the ecological and mathematical questions it raises, and how the capelin could give us insight into the timing of climate change.

Steven Weerts

Council for Scientific and Industrial Research

Co-authors: Susan Taljaard, Jill Slinger, Heleen Vreugdenhil, Cebile Nzuza

Abstract
Natural resource systems operate at the interface of global sustainability agendas and contextual local realities. Ports exemplify this challenge as critical economic infrastructures embedded in sensitive coastal social–ecological systems, facing pressures related to climate change, biodiversity loss, resource efficiency, and social accountability. While numerous sustainability indicators and indices exist, many remain difficult to operationalise because they privilege either globally standardised, top-down metrics or locally specific, bottom-up knowledge, but rarely both in an integrated and empirically verifiable way.

This presentation introduces a novel, co-designed spreadsheet modelling approach to assess sustainability in ports -a Port Sustainability Performance Index. Grounded in design science and sustainability systems thinking, the approach combines globally comparable indicator frameworks aligned with the Sustainable Development Goals with place-based measures, targets, and ratings co-designed with practitioners. The index spans governance, environmental, social, and economic dimensions, reflecting the coupled nature of natural and human systems.

A key innovation lies in translating complex, multidimensional performance data into an accessible empirical scoring model and intuitive visualisation method supporting interpretation and comparison. This enables ports to track sustainability, identify trade-offs, and prioritise interventions, while remaining transparent and adaptable to local contexts.

Using empirical insights from coastal and port management pilot studies in the Global South, the presentation demonstrates how mathematical structuring, weighted parameter aggregation, and visual analytics can bridge the science–practice divide. The work contributes to coastal management by offering a transferable framework for integrating quantitative assessment, stakeholder knowledge, and decision support in ports as complex social–ecological systems.

Sergei Schreider

Rutgers Business School, Rutgers University

Co-authors: Mayya Podsosonnaya, Maria Schreider

Logistic regerssin modelling of blue-green algae bloom in estuary lagioons

Abstract
This presentation develops a mathematically structured framework for the detection and probabilistic classification of macroalgal blooms using multi-spectral satellite imagery, with a primary focus on logistic regression as the core analytical model. Spectral indices derived from satellite data are first evaluated as quantitative predictors of bloom occurrence, and the Floating Algae Index (FAI) was used as an indicator of blooming. The problem is formulated as a binary classification task (“bloom” versus “non-bloom”) at the pixel level, allowing direct mathematical representation through a multi-variable logistic regression model, where several environmental variables were used as the predictors and bloom presence is treated as a Bernoulli response variable. The optimal set of variables were selected using stepwise regression. Model parameters were estimated via maximum likelihood estimation, producing a continuous probabilistic output that represents the likelihood of bloom presence for each spatial location and time step. Classification is implemented through a probability-threshold decision rule, where

optimal thresholds are not assumed a priori but are derived mathematically through cross-validation and bootstrapping procedures. This enables simultaneous estimation of regression coefficients and classification thresholds that minimize total misclassification error. Model performance is formally evaluated using confusion matrices, sensitivity and specificity measures, and overall classification error, providing a statistically rigorous assessment of reliability and robustness.

Session 7

Bernard Cazelles

CNRS - ENS

Reducing Practical Non-Identifiability in Epidemic Models Using Seroprevalence Data

Abstract
Mathematical models play a central role in understanding and predicting the dynamics of infectious diseases. However, a significant challenge in epidemiological modeling lies in the non-identifiability of developed models. This non-identifiability stems mainly from two causes: structural non-identifiability, which is inherent to the model's mathematical structure, and practical non-identifiability, which is linked to the limited data available for parameter estimation.

In this work, I will begin by illustrating the consequences of non-identifiability through examples from simple epidemic models. These examples will demonstrate how insufficient or uninformative data can severely affect model predictions.

I will then turn to the integration of seroprevalence data into epidemiological model's inference to reduce practical non-identifiability and constrain model trajectories. I will present case studies focusing on the early stages of the Covid-19 pandemic in France and Ireland, where data from seroprevalence surveys prior to the rollout of vaccination programs were critical in refining model predictions. These cases will highlight the importance of the information contained in the available data and demonstrate how seroprevalence data can reduce uncertainties surrounding the predicted model's trajectories. Additionally, I will explore the dengue epidemic in the Fiji Islands.

Ultimately, this work underscores the importance of integrating diverse data sources, such as seroprevalence data, into epidemic models to mitigate practical non-identifiability and enhance the reliability of predictions.

Luz Pascal

University of Queensland

Co-authros: Matthew Holden, Katriona Shea, Shouli Li

Do I really need more models? Value of information for decision-making under uncertainty

Abstract
From biodiversity conservation to climate change and epidemiology, mathematical modelling are essential tools for anticipating future trajectories and simulating the effects of interventions. A multi-model approach, where independent research teams design separate models, is a common method to improve the reliability of predictions, better capture uncertainty and support informed decisions. The intuition is that "the more models we have, the more reliable our predictions and thus our decisions". However, developing models is costly, time-consuming and may lead to diminishing returns. Decision-makers therefore face a difficult trade-off: should they invest their limited resources in developing more models (and risk delaying action), or should they embrace uncertainty and act with available information from existing models. In this talk, I will discuss how the value of information guide modelling decisions and improve decision-making outcomes, through an example in epidemic management.

Stacey Smith?

The University of Ottawa, Canada

Early-warning signals for infectious diseases with a social-media compartment

Abstract
Early-warning signals (EWSs) are crucial tools for anticipating disease emergence and guiding public-health responses, but uncertainties in transmission and incomplete data can limit their reliability. Additionally, the performance of EWSs is rarely evaluated when disease emergence is delayed, and their use in the context of interactions between disease transmission and communication through social-media platforms has largely not been considered. We evaluate the relative performance of EWSs in predicting disease emergence under varying noise conditions and explore the use of EWSs with social-media dynamics to predict disease emergence. We develop a mechanistic model coupling infectious disease and social-media dynamics, introduce stochasticity and generate simulated time series. We detect change-points, quantify delays relative to the bifurcation point and assess the performance of EWSs across different segments of the time series. The “reporting" infected compartment proves most reliable, and variance outperforms autocorrelation in high-noise scenarios. However, in the social-media compartment, variance and autocorrelation have weak predictive power. Our work provides a framework to advance understanding of how EWSs can be applied to forecasting disease emergence, contributing to improved disease preparedness and response.

Ilse Kotzee

Council for Scientific and Industrial Research (CSIR), South Africa

Modelling Hydrological Connectivity for Ecosystem-Based Flood Risk Management Across Urbanising Catchments

Abstract
Urban areas in South Africa face increasing flood risk driven by rapid urbanisation, ecological infrastructure degradation, and intensifying rainfall extremes. Although flood management is typically dominated by hydraulic modelling and grey infrastructure planning, ecosystem-based adaptation (EbA) is increasingly recognised for its role in enhancing flood regulation services. This study applies the SCIMAP-Flood hydrological connectivity model across three contrasting municipal contexts — the Garden Route District, eThekwini Municipality, and the City of Johannesburg — to assess spatial patterns of relative flood predisposition and their implications for EbA prioritisation.

Using rainfall thresholds associated with historical flood events, the model integrates land cover, topographic routing, and hydrological connectivity to generate mean flood risk indices. Results reveal spatially structured runoff concentration aligned with drainage networks and downstream accumulation zones in all case studies. However, dominant drivers vary: steep topographic convergence in the Garden Route, high-intensity rainfall and rapid hillslope–channel connectivity in eThekwini, and urban imperviousness coupled with engineered routing in Johannesburg.

Across municipalities, high-connectivity corridors extend beyond statutory floodlines, indicating potential blind spots in conventional riverine flood planning and highlighting areas susceptible to pluvial and flash flooding. Interpreted through an ecosystem service lens, these zones reflect reduced flood regulation capacity and degraded ecological infrastructure.

The findings demonstrate that hydrological connectivity modelling provides a scalable screening tool to identify priority areas for restoration, green infrastructure investment, and catchment-scale planning, supporting the integration of ecosystem-based adaptation into municipal flood risk management strategies.

Session 8

Christopher Stapenhurst

Brandenburg University of Technology, Germany

Co-author: Charlotte Gerling

Relative performance payments: improving result-based compensation for biodiversity conservation in uncertain times

Abstract

Results-based compensation for biodiversity conservation attracts owners of sites with high ecological value and incentivises conservation innovation. But it exposes landowners to risk, because stochastic events such as extreme weather or random dispersal patterns can prevent species occurrence, despite significant conservation investments. Conservation agencies must compensate landowners for this risk to ensure their participation, which may be expensive, especially as climate change brings greater conservation costs and riskier outcomes. We propose Relative Performance Schemes (RPS) as a novel policy instruments for reducing landowners' risks in results-based schemes. RPS combine two payments: a standard results-based payment tied to own-site biodiversity, plus a 'hedge' payment that moves inversely with regional biodiversity. The negative weight on regional performance provides insurance: common negative shocks reduce the regional average, triggering higher hedge payments that partially offset lost results-based income. Thus, RPS hedge common risks while preserving strong marginal incentives for conservation effort. We use a contract theory model of conservation with heterogeneous landowners and general biodiversity correlation structures to study optimal RPS, and compare their effectiveness against benchmark results-based payments. We find that RPS deliver the greatest advantages when landowners are risk-averse, face greater marginal conservation costs, experience higher variance of biodiversity outcomes, or own land with higher correlation with other sites in the region. If outcomes are perfectly correlated, then hedging completely mitigates risks and drastically increases the level of biodiversity achieved by a given budget. Only if outcomes are independent or landowners are risk-neutral does hedging provide no additional value over results-based schemes. We calibrate our model with empirical cost and species observation data and conduct sensitivity analysis.

Thorsten Upmann

Fraunhofer IKTS, Germany

Co-authors: Stefan Wrzaczek, Michael Kuhn

Designing Environmental Policy under Deep Uncertainty: The Value of Information with Regime-Shift Risk

Abstract

Governments increasingly rely on industrial and environmental policies to steer the transition toward a low-carbon economy in the presence of substantial uncertainty and irreversible risks. In many policy domains — ranging from climate mitigation and biodiversity protection to critical resource management — decision makers face the possibility of abrupt regime shifts or system collapse, while key parameters governing these risks are only imperfectly known. This raises a fundamental policy question: when, and to what extent, is it optimal to invest in information acquisition as part of environmental policy design?

This paper develops a dynamic framework that integrates the Value of Information into an optimal control model with collapse risk and regime-shift uncertainty. We consider a decision maker who faces stochastic system collapse with an unknown hazard rate and can invest in information to improve policy choices before committing to a long-run control path. Hence, information acquisition affects the entire intertemporal policy trajectory.

We show that optimal policies exhibit a most-rapid-approach path followed by a singular policy regime, regardless of the information structure. Improved information alters both the timing and the level of policy intervention, thereby increasing expected welfare. We derive the value of perfect information analytically and compute the value of partial information numerically, highlighting how VoI depends on collapse risk, discounting, and the initial system state.

From a policy perspective, our results demonstrate that information itself constitutes a policy instrument that can complement or substitute traditional regulatory tools such as pricing or quantity controls under deep uncertainty. The framework provides guidance for evaluating public investments in monitoring, data collection, and learning in the context of climate and environmental policy, where irreversible damages and structural change play a central role.

Dieter Koemle

Federal Institute of Agricultural Economics, Rural and Mountain Research

Co-authors: Yvonne Stickler, Christoph Tribl, Sebastian Lakner

Effects of Natura 2000 Designation on Farm Efficiency: Using Machine Learning to Address Environmental Selection

Abstract
The Natura 2000 network (N2K) encompasses agricultural land across Europe, yet its impact on farm performance remains poorly understood. Designation based on habitat and species criteria, often coinciding with marginal farmland, which creates environmental selection bias when comparing farms inside versus outside designated areas.

We address this identification challenge through a two-stage approach. First, we estimate N2K propensity scores for Austria—the predicted probability of designation based on environmental characteristics—using regularized Random Forest on 1×1km gridded data (weather, topography, land cover). This allows us to compare farms facing similar environmental production constraints regardless of designation status. Second, stochastic frontier analysis of Austrian Farm Accountancy Data Network (FADN) data (2015-2024) uses the propensity score to control for environmental constraints in the frontier, while N2K coverage categories capture management efficiency effects.

Results suggest a non-monotonic relationship between farm N2K coverage and revenue inefficiency. Compared to a baseline (0-1

Agnieszka Wiszniewska-Matyszkiel

University of Warsaw

Co-authors: Silvia Faggian, Dominika Machowska

Partial cooperation in resource extraction on networks: sharing wealth versus sharing extraction rights

Abstract
We study a differential game of resource extraction in which players' resource deposits are interrelated and the spatial relations between resources of players can be modelled by a network. This holds if e.g., a marine fishery is divided into Exclusive Economic Zones of countries. The interactions can be asymmetric and players' areas can have different reproduction rates. For this game, we study the potential of cooperative behaviour. We compare the Nash equilibrium payoff to payoffs if at least a fraction of players cooperate and check stability of various types of coalitions. We also study the problem of sustainability. Besides the typical approach with coalitions maximizing sum of payoffs of its members when each players extract in their own node only and side-payments only are possible, we consider

maximization of collaborative extraction when besides side payments, extraction rights can be shared. This increases the chance of forming a stable coalition and to reduce the “tragedy of the commons”.

Andrew Robinson

The University of Melbourne, Australia

Making more of models: off-label uses

Abstract

Models span a considerable range of detail and complexity, ranging from statements about things and how they are related to one another to minutely programmed simulation models that can be used to provide complete probability statements about conditional outcomes. Drawing from examples in biosecurity, I will cover two off-label uses for models that arguably expand their domain of utility. First, I will argue that at their heart, models can be thought of as ontologies, which has important implications for their construction and broadens their sphere of application. Second, I will show how a sequence of carefully chosen counterfactual challenges to a model can answer a richer set of questions than is typically put to them. I then trace the implications of these two extensions to propose strategic research programmes for the modelled system, and discuss their benefits and challenges.

Conference Day 3: 3 July 2026

Keynote: Joel S. Brown

Moffitt Cancer Center, Tampa, Florida, USA

Using Evolutionary Game Theory to Manage Evolving Resources, Pests and even Cancer

Abstract
Nature is not an art gallery, and species are not masterpiece paintings. They are ecologically and evolutionarily dynamic. Furthermore, nature plays games, evolutionary games that is. Organisms evolve strategies to better survive in their environment and to more successfully interact with conspecifics, competitors, and predators. For example, one can ask the almost Zen-like question: "Why is there wood?" The answer lies as the solution to an evolutionary arms race for height as woody plants strive for light.

Human actions also exert selection forces. Humans can wittingly or unwittingly become part of nature's games. When humans alter the ecologies of other species the wrong question to ask is "Will they evolve?" rather we should ask "How fast and into what will they evolve?" As humans alter the eco-evolutionary dynamics of other species – valuable and pesky ones alike – the game can and should become a Stackelberg evolutionary game where the manager or decision makers take the lead by anticipating and steering both the ecological and evolutionary dynamics of the managed species.

I will introduce the G-function approach to evolutionary game theory (akin to adaptive dynamics) to examine modelling opportunities and applications in managing valuable resources (e.g., fisheries), agricultural pest species, antibiotic resistance, and even cancer. The evolution of therapy resistance by cancer cells explains most patient deaths. Novel evolutionary therapies have proven effective in several clinical trials of prostate cancer. In these clinical trials and others, mathematical models are leading the way towards "algorithms as drugs" (sensu Christopher Gregg) with the goal of rendering some currently incurable cancers as containable, and others as curable. For cancer and for evolving resources, pests and diseases evolutionary game theory can contribute to a resistance management plan.

Session 9

Karol Bronisz

Warsaw University of Life Sciences, Institute of Forest Sciences, Department of Forest Management Planning, Dendrometry and Forest Economics

Taper Models for Climate-Smart Forest Management

Abstract
Climate-smart forest management increasingly depends on quantitative tools that help managers make informed decisions in the face of climate change, site degradation, and evolving management goals. Taper models offer a practical and flexible way to describe stem form and to estimate merchantable

volume, biomass, and wood assortments, making them well suited for planning across different spatial scales and time horizons.

This presentation brings together recent developments in taper modeling, with a particular focus on black locust (Robinia pseudoacacia L.) - a fast-growing and drought-tolerant species used in forest as well as in the restoration of degraded and post-mining sites. Empirical studies from Central and Southern Europe show that variable-form taper models consistently outperform simpler formulations when predicting both over-bark and under-bark diameters and volumes. Fixed-effects models provide robust estimates at the population level and are well suited for forest inventories, while mixed-effects approaches significantly improve predictions for individual trees by accounting for hierarchical data structures and tree-level variability. This added flexibility is especially important in heterogeneous stands and under changing site conditions.

Integrated taper functions allow direct estimation of total and merchantable volume and often perform better than traditional volume equations when detailed information on assortments or biomass is required. In addition, compatible taper models enable the joint estimation of stem diameter and bark thickness, leading to more accurate under-bark volume estimates and carbon-related metrics that are essential for climate-smart assessments.

The goal of this presentation is to show how taper models can be effectively incorporated into climate-smart forest management frameworks to support adaptive planning, improve volume and biomass estimates, and increase resource-use efficiency under changing environmental conditions.

Luiza Tymińska-Czabańska

University of Agriculture in Krakow

Co-authors: Krzysztof Leszczyński, Piotr Janiec, Jarosław Socha

Spatial scaling of drought impacts on forest mortality: when climate signals emerge from local noise

Abstract
Drought-induced forest mortality is accelerating across temperate regions, yet prediction remains challenging because climate–mortality relationships are scale dependent. Local heterogeneity can obscure climatic signals, whereas aggregation can reveal coherent patterns. Here we analyse Scots pine (Pinus sylvestris L.) mortality across Poland using the nested administrative levels of the State Forests (forest divisions, forest districts, and regional directorates) to quantify how drought signals emerge with spatial scaling.

We used annual sanitation-felling records (2012–2023) to express mortality as dead volume relative to standing volume in pine-dominated stands (>70

Across all spatial levels, drought legacy effects were consistent: lower SCWB in the preceding one and two years was associated with higher mortality, with stronger effects for the one-year lag. The drought–mortality signal strengthened with spatial aggregation as local extremes were smoothed and climatic coherence increased. Dispersion modelling indicated that drought increases not only mean mortality but also variability among stands, implying uneven vulnerability rather than random noise. Spatial predictions highlighted elevated mortality risk in central and south-central Poland, aligning with areas strongly affected by the 2015–2019 drought sequence.

Overall, scale-aware modelling that captures both mean response and variance structure improves inference and prediction of drought-driven mortality and supports integration of operational forest records into early-warning and adaptive management under intensifying drought.

Jarosław Socha

University of Agriculture in Krakow

Co-authors: Vahid Nasiri, Luiza Tymińska-Czabańska, Piotr Janiec, Jakub Miszczyszyn, Paweł Hawryło

Greening Without Growth: Canopy Recovery Masks Stem Growth Loss After Drought—Evidence from Tree Rings and Remote Sensing

Abstract
Recent severe droughts across Central Europe have highlighted the need for multi-source assessments of forest resistance and post-drought recovery. In this study, we quantified the drought response of Scots pine across 291 dendrochronological plots distributed throughout Central Europe. Tree-ring width (TRW) was measured from increment cores collected from dominant trees within each stand and processed using standard dendrochronological methods to obtain annually resolved growth chronologies. To characterise canopy physiological status, we derived four vegetation indices—NDVI, CIGR, NDWI, and PPI—from Sentinel-2 MSI surface reflectance data.

As a dedicated research module, we assessed forest responses to major drought events (2018, 2019, 2020) by integrating TRW and Sentinel-derived VIs with established drought-response metrics. For each drought year, we calculated resistance (Dr/PreDr), recovery (PostDr/Dr), and resilience (PostDr/PreDr) following Lloret et al. (2011), enabling direct comparison between canopy-based and growth-based indicators.

Our results reveal pronounced discrepancies between TRW-derived and VI-derived drought metrics. TRW resistance was consistently lower than resistance inferred from Sentinel indices, indicating that canopy greenness and chlorophyll-sensitive signals substantially underestimate true growth suppression. In contrast, VI-derived recovery and resilience were markedly higher, suggesting rapid post-drought re-greening that does not correspond to the much slower rebound of cambial activity.

By combining high-resolution Sentinel-2 observations with dendrochronological data, this study demonstrates how drought legacies amplify the decoupling between canopy status and wood formation. Our findings underscore the critical importance of integrating explicit drought-response metrics into remote-sensing-based forest monitoring frameworks, particularly as climate variability intensifies across temperate forest ecosystems.

Session 10

Krishna Paudel

Texas Tech. University, USA

Co-authors: Madhusudan Bhattarai, Archana Timsina, Stephen Devadoss, Nathan Holtman

Deforestation and Agriculture

Abstract
This paper examines factors affecting land-use decisions and derives conditions for the optimal allocation of agricultural and forest land in an economy. The steady state resulting from this study suggests that the optimal land-use decision is affected by the discount rate, land productivity, rates of return on capital and labor, and society's preferences for consumption. From a comparative statics and comparative dynamics perspective, the study provides the conditions under which the Environmental Kuznets Curve (EKC) for deforestation will emerge and persist as a cumulative effect over a long time. The results from the comparative statics and comparative dynamics analyses clearly suggest that there will be an EKC for deforestation when land productivity and the preference for environmental services from

forest land reach critical levels. Unlike population pressure and other structural factors found in previous studies, the results of this study show that agricultural and resource productivity growth are key factors in the emergence of the EKC–deforestation relationship. The theoretical analysis is supported by simulation models indicating that a change in the preference-weighting value is the most sensitive factor determining the level of deforestation in an economy. Overall, under short-run naïve parameter ranges, a significant portion of land is allocated to agricultural production.

Stephan van der Westhuizen

Stellenbosch University

Co-author: Khaled Masoumifard

Modelling compositional environmental variables with a Dirichlet-based random forest

Abstract
Compositional environmental variables such as soil texture fractions and geochemical proportions are multivariate measurements constrained to a constant sum and therefore reside in the simplex space. In terms of conventional machine learning, this constraint violates assumptions underlying many statistical methods, making their direct application problematic in environmental modelling and spatial mapping. With compositional data analysis, composites are typically transformed into real space using log-ratio transformations after which conventional statistical methods can be applied. In practice, transformation-based workflows dominate the literature, while direct probabilistic approaches are less frequently adopted, partly due to perceived limitations and inflexibility of the Dirichlet distribution, the primary distribution defined on the simplex.

Recent advances in machine learning provide new opportunities for flexible, structure-preserving modelling of compositional data. In this study, we investigate a Dirichlet-based random forest framework that directly models compositional responses while retaining the advantages of ensemble tree methods. We compare this approach with established log-ratio transformation methods in an environmental prediction setting of mapping soil texture data in Germany. Results show that the Dirichlet-based random forest achieves competitive and, in some cases, superior predictive performance, while maintaining coherence with compositional constraints. These findings highlight the potential of direct simplex-based machine learning methods for environmental and geospatial applications involving compositional variables.

Jack Jansma

Stellenbosch University

Co-authors: Pietro Landi, Cang Hui

Interaction networks and community dynamics shape the microbial responses to different resource regimes

Abstract
Microbial communities are ubiquitous in all natural ecosystems. They regulate carbon and nutrient cycling in the soil, support food webs in the ocean, and maintain host health in the animal gut. Therefore, it is critical to elucidate the interactions within these microbial communities for the restoration of disturbed microbial communities and subsequently the conservation or restoration of natural ecosystems. Despite enormous experimental and theoretical progress, translation into consistently successful therapies targeting microbial ecosystems has remained limited due to poor precision and reproducibility. Highlighting a discrepancy between theory, experiment and application. Bridging this gap requires theoretical models to accurately describe the microbial community, their interactions, and their dynamics under naturally occurring conditions. However, due to the large compositional and functional diversity, fast ecological and evolutionary turnover rates, and complexity of interactions, this is a daunting

task. In the present work, we represent a microbial community as a set of coupled ordinary differential equations (ODEs), which makes it becomes possible to explicitly encode species interactions and resource dynamics, and to systematically interrogate how community structure, and resource variability shape community stability and performance. Specifically, we investigate how the topology of the microbial interaction network determines community dynamics and stability under varying resource influx regimes. By refining our understanding of microbial dynamics, this framework is capable of assessing microbiota-targeted interventions and their potential to improve the health of the macro-ecosystem.

Izni Zahidi

Monash University Malaysia, Malaysia

Co-authors: Ewilly Liew, Erniel Barrios, Aznie Rahim

Building Climate-Resilient Communities through Integrated Water-Energy-Food-Environment (WEFE) Nexus Modelling

Abstract
Selangor River basin is a critical region in Malaysia, supplying water, energy, food, and ecosystems (WEFE) for six million people. However, it faces intensifying pressures from climate variability, urbanisation, and fragmented sectoral planning, resulting in competing demands on natural resources. Current decision-making overlooks the interdependencies among the WEFE sectors, limiting the effectiveness of climate adaptation efforts. Supported by the UK government's climate program, CARA (Climate Action for a Resilient Asia), this study introduces an integrated methodological framework for developing a WEFE nexus model that enhances climate-resilient planning and informs nature-based solutions (NbS). The co-creation approach in this study provides insights into a basin-specific WEFE schematic diagram that visualises resource flows, cross-sector linkages, and climate-sensitive areas across the basin. Geospatial analysis is incorporated to characterise land-use dynamics, climate hotspots and ecosystem services. To assess efficiencies and trade-offs, the study employs an econometric Stochastic Frontier Analysis (SFA) to estimate a joint production frontier for WEFE-related outputs. The SFA identifies inefficiencies in water allocation, energy intensity, agricultural productivity and ecosystem performance under varying policy and climate conditions. When integrated with geospatial layers, these results generate WEFE efficiency maps that highlight vulnerable zones, resource stress or suboptimal system performance. By combining participatory modelling, econometric analysis and spatial diagnostics, the study advances a climate-resilient and socially inclusive WEFE governance model which is scalable and adaptable for other river basins and regions facing similar nexus and climate resilience challenges.

Sturla Kvamsdal

Centre for Applied Research, Norway

Co-authors: Yuanming Ni and Leif Sandal

Downward drag effects on natural capital asset prices under uncertainty

Abstract
Dynamic models of natural capital typically specify stochastic resource dynamics using Itô stochastic differential equations. We show that multiplicative noise systematically reduces effective growth rates and equilibrium stock levels through a mechanism we term downward drag — embodied by the Itô–Stratonovich correction applied to renewable resource dynamics. We derive the deterministic equivalent, a tractable ordinary differential equation capturing the central tendency of the stochastic system, and apply it to characterize natural capital asset prices under uncertainty. We show that the impact of uncertainty on shadow prices decomposes into two distinct channels: a biological channel, whereby downward drag reduces effective carrying capacity and growth rate, and an economic channel, whereby the option value of conservation raises shadow prices. These channels operate in opposite directions

with regard to the stochastic steady state, and with the biological channel dominating at higher volatility with regard to the asset price. At moderate noise levels, ignoring downward drag understates the shadow price by over 50

Jai Clifford-Holmes

Association for Water and Rural Development (AWARD), South Africa

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An AI-driven Digital Twin for Water Management in the Limpopo River Basin, Southern Africa

Abstract

The Limpopo Digital Twin is a cloud-based water management platform that creates a digital replica of the Limpopo River Basin. Led by the International Water Management Institute (IWMI) – under the CGIAR Initiative on Digital Innovation – the Limpopo Digital Twin has been developed in collaboration with the Limpopo Watercourse Commission (LIMCOM) in order to manage the Limpopo River Basin (which crosses South Africa, Botswana, Zimbabwe and Mozambique). A digital twin is a continuously-updated virtual representation of a system that integrates real-time, historical and forecast data with modelling and Artificial Intelligence (AI), allowing users to explore scenarios and to support decision-making. In a transboundary basin, this enables a single, accessible picture of hydrology, climate and ecosystem indicators to support coordinated action. Since 2024, the Association for Water and Rural Development (AWARD) has been supporting IWMI and LIMCOM on operational aspects of the digital twin, drawing heavily from the AWARD-developed INWARDs system (INWARDS being the Integrated Water Resources Decision System). Innovations have included (1) developing a machine learning model for reservoir storage estimation from satellite imagery to address monitoring gaps by complementing sparse or intermittent gauge station records, and (2) working with Microsoft and other partners to develop an AI agent that enables plain-language questions to return concise answers to stakeholders from different disciplinary backgrounds. The Limpopo Digital Twin is currently being applied in two other contexts: for the transboundary watercourse commission of a neighbouring catchment (the Incomati and Maputo Watercourse Commission (INMACOM)), and to validate a global model being developed through the UAE AI Hub, which combines the power of AI with a proven physics-based hydrological model in a tool that will be officially launched at the UN Water Conference, in the UAE, in December 2026.

Djiby Thiam

Water and Production Economics, School of Economics, University of Cape Town

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Groundwater management and land subsidence impacts on Groundwater-Dependent Ecosystems

Abstract

Rising surface water scarcity has intensified groundwater extraction, which drives land subsidence (LS) and, in turn, damages groundwater-dependent ecosystems (GDEs). However, the LS-GDEs relationship remains largely underexplored in the economic literature. In this paper, we develop a dynamic economic optimization model that explicitly incorporates LS within a GDEs (LS-GDEs) framework and evaluate alternative policy instruments aimed at curbing overexploitation to mitigate the negative effects of groundwater depletion. These instruments include quota systems, taxes on land sinking and on aquifer storage loss, as well as packaging and sequencing of taxes and quotas. Using data from a major aquifer in South Africa, we calibrate the model and assess the private and social welfare implications. Our results show that taxes on land sinking and aquifer storage loss significantly influence extraction behaviour and raise water table levels, thereby enhancing social welfare. Among the policies, quotas yield the lowest private net benefits to farmers (0.1395 million USD), while the baseline scenario generates

the highest. The LS–GDEs and no policy intervention scenario deliver the second-highest private net benefits. Packaging and sequencing of policy interventions provide private net benefits equal to those under the tax policy. Overall, these findings highlight the importance of designing policies that account for LS-driven impacts to safeguard GDEs' health.