Institution: King's College London		
Unit of Assessment: 14 Geography		
Title of case study: King's spatial policy support systems enhance conservation decision-making by organisations across 183 countries		
Period when the underpinning research was undertaken: 2013 – 2020		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s):	**Role(s) (e.g. job title):**	**Period(s) employed by submitting HEI:**
Mark Mulligan	Professor of Physical & Environmental Geography	From 01/09/1994
Period when the claimed impact occurred: 2014 – July 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Global expenditure on nature conservation is approximately GBP16.5 billion per year. Ensuring these investments are prioritised effectively and with due consideration of the complex trade-offs between different land-use options is crucial. King's researchers have developed two open-access and user-friendly spatial policy support systems, WaterWorld and Co$tingNature, to analyse the various trade-offs between productive and protected land-use options. These are spatial tools that integrate new concepts, models and comprehensive global datasets across biodiversity, hydrology, ecosystem services and land/water management to produce dynamic digital maps supporting decision-making. Used by at least 3500 organisations worldwide, these tools have helped international conservation and development organisations – including Conservation International, UNEP's World Conservation Monitoring Centre and the Inter-American Development Bank – support a range of governments, NGOs and businesses in their land-use decision-making and conservation investments. Decisions are now better linked with the latest evidence and better tailored to local spatial, physical and socio-economic circumstances. Outputs from the tools have been instrumental in guiding, for example, conservation investments in Ecuador and Brazil, the establishment of a 1.5 million ha protected area in Bolivia, and support for a range of governments and NGOs in planning land-use changes to reduce greenhouse gas emissions in line with their international climate commitments.

2. Underpinning research

Incorporating environmental and ecological spatial data into land-use policy is critical to all high-profile sustainable development decisions such as the location of mines, dams and protected areas. While good quality global data are now available on everything from population density to precipitation and deforestation, these are large-scale and often complex datasets that need to be integrated and synthesised to be accessible to policymakers and the highly-specific decisions they make. King's research has addressed this gap by developing two state-of-the-art spatial policy support systems, WaterWorld and Co$tingNature, that are user-friendly and freely-available as web-based tools. These combine spatial data with new models to produce local- to national-scale digital maps and analyses for any country or region.

Both tools were developed through a series of competitively-funded EC and UKRI research projects. These enabled King's researchers to increase the sophistication and accuracy of the tools by developing new synthesising algorithms, metrics and global datasets from remote sensing and crowd-sourced inputs, and new sophisticated spatial models describing environmental and social processes. The projects also demonstrated and improved the usefulness of the tools for a range of different decision-making settings, including through development of training materials.

(i) WaterWorld provides policy support for managing land to improve water resources [1]. King's research into the impact of land-use changes on downstream water quality and diarrheal disease in children in 35 developing countries led to the integration of the land-use/water-quality model into the tool so that it can now be applied across the world [2]. Modelling the hydrological

impacts of protected area policies in Madagascar quantified the impacts of data uncertainty (e.g. in rainfall estimates) [3]; the inclusion of several alternatives for each input dataset in WaterWorld and Co$tingNature now allows users to explore the impact of these uncertainties on policy-relevant outcomes.

(ii) Co$tingNature provides support for prioritising investments in nature conservation, by mapping and economically valuing 18 ecosystem services (the benefits people obtain from nature) including carbon sequestration, firewood provision and nature-based tourism [4]. King's research on agriculturalisation scenarios for South America [5] led to integration of commodity flow data into the tool. This enables a better understanding of the dependence and impacts of these commodities on ecosystem services across the world. Research in Madagascar and Ghana's Volta Basin led to the development of metrics to assess the impact of land-use planning on nature's contribution to the UN Sustainable Development Goal 6 (clean water) [6].

This body of research indicates how new knowledge has been developed from the use of WaterWorld and Co$tingNature in different national contexts, often from meeting with stakeholders to define general policy support needs and identify locally relevant policy scenarios which are then built into the tools for all to use [6]. The datasets underpinning WaterWorld and Co$tingNature now form the most comprehensive global geographic database of any public environmental policy support system, comprising 837 environmental, social, and economic variables at multiple spatial resolutions. By bringing together and curating such a wide diversity of datasets with state-of-the-art modelling, King's research has promoted the concept of complex 'bundles' of multiple ecosystem services, rather than narrowly-defined priorities, such as water or carbon alone, and also facilitated the distinction between realised (or currently used) and potential ecosystem services [3,5].

3. References to the research

All supporting outputs are published in internationally recognised, peer-reviewed journals.

[1] Mulligan, M. (2013) WaterWorld: a self-parameterising, physically based model for application in data-poor but problem-rich environments globally. *Hydrology Research* 44(5), 748–769. DOI: 10.2166/nh.2012.217

[2] Herrera, D., Ellis, A., Fisher, B., Golden, C.D., Johnson, K., Mulligan, M., Pfaff, A., Treuer, T. and Ricketts, T.H. (2017) Upstream watershed condition predicts rural children's health across 35 developing countries. *Nature Communications* 8(1), 811. DOI: 10.1038/s41467-017-00775-2

[3] Van Soesbergen, A. and Mulligan, M. (2018) Uncertainty in data for hydrological ecosystem services modelling: Potential implications for estimating services and beneficiaries for the CAZ Madagascar. *Ecosystem Services* 33(B), 175–186. DOI: 10.1016/j.ecoser.2018.08.005

[4] Naidoo, R., Gerkey, D., Hole, D., Pfaff, A., Ellis, A.M., Golden, C.D., Herrera, D., Johnson, K., Mulligan, M., Ricketts, T.H. and Fisher, B. (2019) Evaluating the impacts of protected areas on human well-being across the developing world. *Science Advances* 5(4), eaav3006. DOI: 10.1126/sciadv.aav3006

[5] Mulligan, M. (2015) Tropical agriculturalisation: Scenarios, their environmental impacts and the role of climate change in determining water-for-food, locally and along supply chains. *Food Security* 7(6), 1133–1152. DOI: 10.1007/s12571-015-0506-1

[6] Mulligan, M., van Soesbergen, A., Hole, D.G., Brooks, T.M., Burke, S. and Hutton, J. (2020) Mapping nature's contribution to SDG 6 and implications for other SDGs at policy relevant scales. *Remote Sensing of Environment*, 239. DOI: 10.1016/j.rse.2020.111671

4. Details of the impact

Since 2010, human population has increased by almost a billion, while terrestrial protected areas have increased globally from to 17.5 million km^2 to 29 million km^2 under the UN Convention on Biological Diversity. These trends are leading to increasing pressures on land for agricultural, urban and extractive uses (such as mining and forestry) and nature conservation. Defining protected areas therefore involves complex trade-offs between: the intrinsic value of nature; its

economic and livelihood value to local, downstream and nearby populations (ecosystem services); land rights; and lost opportunities for other uses of the land, such as energy and food production, and the support of globally important carbon sequestration and biodiversity. Policy support systems that bring together the best available data and knowledge for a locality or country – in a form that is easily used by stakeholders to make their own evidence-based decisions – are in high demand but short supply.

Outputs of King's research, WaterWorld [building on 1,2,3] and Co$tingNature [building on 4,5,6], have helped to fill this gap by making complex new spatial planning concepts and data sets easily accessible through a user-friendly and free online platform (www.policysupport.org) to support more effective land-use planning. Together WaterWorld and Co$tingNature provide a one-stop shop for planners, advocates and investors wanting to understand how their proposals will affect a wide range of ecosystem services and their beneficiaries. As outlined below, the tools have wide reach, significantly affecting the capacity of a range of organisations to take evidence-based land-use decisions.

A. Reaching land-use decision-makers around the world

Co$tingNature and WaterWorld have been disseminated through user engagement and through the marketing and delivery of training in person or online. The tools have been used by more than 3500 organisations from a wide range of areas, including government, commercial and international organisations, as well as the non-governmental sector, across over 183 countries. They have either replaced other tools or provided actionable information where none were available previously.

The tools are now included in key sector and industry toolkits such as those from: World Business Council on Sustainable Development (200 companies, revenue USD8.5 trillion, 19 million employees) [A1], Ecosystems Knowledge Network [A2], CGIAR Solutions [A3], The Natural Capital Protocol [A4], Business for Social Responsibility (270 companies) [A5], Climate, Community and Biodiversity Alliance standards [A6], Association of Wetland Managers [A7], SDG knowledge hub [A8], DEFRA [A9], World Resources Institute [A10], UN Food and Agriculture Organization [A11], US National Ecosystem Services partnership [A12], IUCN [A13].

The tools are self-financing (with some organisations paying for commercial use) and research projects fund their further development. All users provide feedback on how they use the tools, with more than 100 case studies of model application written by users since 2014 [B1–4] and over 770 responses to the user feedback form. Based on this feedback, the tools have supported decisions at both national scale (Fig 1a) and local scale (Fig 1b) around the world, and on a diverse range of land-use related topics.

Fig 1a. Countries and basins in which King's tools supported analyses at regional scale

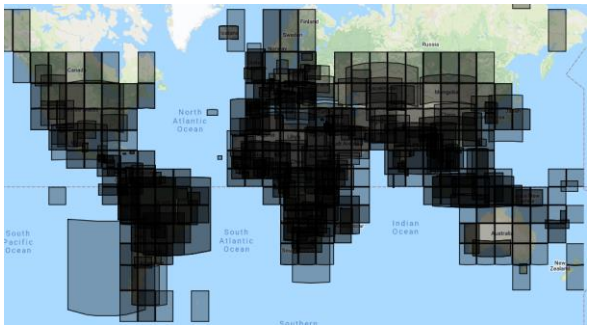

Fig 1b. Sites at which King's tools supported analyses at local scale

B. Supporting land-use decisions of local and regional significance

The Co$tingNature and WaterWorld policy support systems provide new metrics, models and curated global datasets that support a wide range of land-use decisions. Here we give examples of their significance in decision-making by three important international users:

(i) Better prioritisation of conservation areas

The international NGO Conservation International has used Co$tingNature to highlight the hitherto unrecognised (and hence unvalued) ecosystem services provided by existing protected areas. Conservation International's Vice-President for Global Solutions explains that the "*tools help us to better prioritise geographies for conservation investments, test the impact of conservation interventions and support local stakeholders in scenario analysis … Co$ting Nature has influenced our investment decisions and helped us to raise more funding for particular areas*" [C]. For example, "*one of the most important drivers in securing the funding [for a new 1.5 million ha protected area in Bolivia] was our Amazon Strategy and in particular the freshwater priority of this area identified by WaterWorld and Co$ting Nature*" [C]. In Colombia, "*the use of WaterWorld has been fundamental to add robust technical information to evaluate the implementation feasibility of these [mining and infrastructure] projects*" [B1]. At a regional level, Conservation International used both WaterWorld and Co$tingNature to produce maps and spatial datasets that identified the most important areas for biodiversity and ecosystem services in support of multiple partners building a regionally integrated vision for Amazonia's sustainable development [B2,C]. Conservation International have also used Co$tingNature outputs with companies (e.g. Kering, Walmart, Mastercard) to identify priority areas for conservation, restoration and improved management within the spatial footprint of their supply chains [C]. Without these tools the sophisticated concepts of ecosystem services could not be factored into this decision-making.

(ii) Supporting governments to make better decisions on Reducing Emissions from Deforestation and forest Degradation (REDD+)

For the United Nations Environment World Conservation Monitoring Centre (WCMC), an important recent focus has been the use of the tools to support governments in planning multi-billion dollar REDD+ (forest protection) programmes [D]. WaterWorld is promoted by UN-REDD, the main global programme supporting nationally-led REDD+ processes, as a tool for governments to determine how land-use change promoted or prevented by REDD+ investments will affect downstream water quantity and quality [E]. WCMC has been instrumental in training government staff in countries including Colombia, Honduras, Madagascar, Mongolia, Kenya, Nepal and Vietnam to use WaterWorld to evaluate the importance of forests for water provision and soil erosion mitigation, informing decisions about the location of REDD+ investments in those countries [B3,B4,D]. Without these tools, decision-makers would often be blind to the potential negative impacts of REDD+ investments on water and other ecosystem services.

(iii) Evaluating impacts of past land-use decisions to inform future investments

A senior economic adviser at the Inter-American Development Bank (speaking in his personal capacity) found "*WaterWorld to be a very useful tool for testing the impacts of and prioritising investments in green infrastructure*" [F]. For example, the Bank used WaterWorld to evaluate three forest conservation investments in Ecuador and Brazil, which were funded through the Latin American Water Funds Partnership, a consortium of more than 40 local initiatives aimed at improving the quality and quantity of water flows to metropolitan areas by investing in nature conservation [F]. WaterWorld was used to model (and value) the effect on water quality of the deforestation avoided by the projects and, in particular, to model the effect of this conservation versus the counterfactual (business-as-usual) land-use change on water quality at water-treatment plant intake points. Understanding the water quality impact of past investments "*led us to make recommendations about how Water Funds projects can maximise net benefits by improving spatial targeting of their investments in natural infrastructure*" [F].

(iv) Enabling sophisticated spatial analyses for land-use investments has improved policy and practice

All three organisations emphasise the significant impact these world-leading tools have had on their policy and practice. As outlined by the Vice-President of Conservation International, "*without these tools we would be reliant on collecting datasets and producing new and separate analyses for each and every local and regional conservation project. The tools provide us with a rapid and consistent methodology that can be applied across all geographies, but still recognises local geographical detail*" [C]. The ease of use of the tools is appreciated because it means that they can be used by staff with "*less GIS experience, ensuring those who best understand policy questions and conservation context can also run the required spatial analyses, a key advantage over other more technical approaches*" [F]. Furthermore, the tools are simple enough that partner

organisations can be trained to undertake future work independently [D]. WCMC's Director states that Co$tingNature's capacity to map and value 18 different ecosystem services "*has supported a broadening of our prioritisation work beyond biodiversity and carbon. The embedded land use model within WaterWorld and Co$tingNature, coupled with the extensive multi-scenario capability of WaterWorld in particular, has helped us to deliver more varied and comprehensive scenario analyses, based on stakeholder input, quickly and cheaply… Use of Co$tingNature ….has also brought new concepts to our work such as realised vs potential ecosystem services, bundled ecosystem service metrics, as well as novel metrics in water quality, quantity and regulation and, more recently, nature's contribution to the SDGs. These tools are at the forefront of all these conceptual developments and support our own world-leading expertise in these areas*" [D].

5. Sources to corroborate the impact

[A] Compilation of reports and webpages recommending use of Co$ting Nature and WaterWorld [A1] World Business Council for Sustainable Development (2013) "Eco4Biz: Ecosystem services and biodiversity tools to support business decision-making". [A2] Ecosystems Knowledge Network (2016) "Tool Assessor: The UK's online resource on analytical tools that link the environment and society". [A3] CGIAR research program on water land and ecosystems (2015) "Co$ting Nature to Improve Ecosystem Management". [A4] Natural Capital Protocol Toolkit (regularly updated website). [A5] Business for Social Responsibility (March 2014) "Making the Invisible Visible: Analytical Tools for Assessing Business Impacts & Dependencies Upon Ecosystem Services". [A6] The Climate, Community & Biodiversity Alliance (2013) "Third Edition; Climate, Community & Biodiversity Standards". [A7] Association of State Wetland Managers (2016) "A comparative analysis of ecosystem service valuation decision support tools for wetland restoration". [A8] SDG Knowledge Hub (2018) "IUCN Report Guides Practitioners in Selecting Tools for Ecosystem Services Assessment". [A9] UK Department for Environment, Food and Rural Affairs (2020) "Guidance - Enabling a Natural Capital Approach: tool summaries". [A10] World Resources Institute (2018) "A guide to selecting ecosystem service models for decision-making: Lessons from Sub-Saharan Africa". [A11] Food and Agricultural Organization of the UN (no date) "Assessment and valuation tools for Biophysical, social and cultural valuation". [A12] US National Ecosystem Services Partnership (2016) "Federal Management and Ecosystem Services Guidebook: Resources". [A13] International Union for Conservation of Nature (2018) "Best Practice Protected Area Guidelines Series No. 28: Tools for measuring modelling and valuing ecosystem services".

[B] Four sample blog posts by WaterWorld and Co$tingNature users [B1] C.A. Ruiz-Agudelo, Conservation International (November 2017) "Using WaterWorld as a fundamental tool in the Prioritization of Actions and Areas to Environmental Compensation in Mining and Infrastructure Projects of Colombia". [B2] N. Acero, Conservation International (September 2016) "Conservation International deliver WaterWorld training to guide decision making for Mapping Natural Capital in Amazonia". [B3] Y. Shennan-Farpón and X. de Lamo, UNEP-WCMC (August 2017) "Using WaterWorld to assess potential non-carbon benefits of REDD+ in Honduras". [B4] C. Hicks and X. De Lamo, UNEP-WCMC Monitoring Centre (March 2016) "Using WaterWorld to assess REDD+ multiple benefits of boreal forests in Mongolia".

[C] Testimonial from: Dr David Hole, Vice President for Global Solutions at Conservation International, 6th January 2021.

[D] Testimonial from: Dr Neville Ash, Director of UN Environment World Conservation Monitoring Centre (UNEP-WCMC), 15th January 2021.

[E] UN-REDD+ use of WaterWorld: [E1] UN-REDD Programme Collaborative Workspace webpage, "Mapping to support REDD+ planning and secure multiple benefits". [E2] UN-REDD programme tutorial (2017) "Evaluating the importance of forests for Water provision and limiting soil erosion: A modelling approach using WaterWorld".

[F] Testimonial from: Allen Blackman, Principal Economic Advisor in the Climate and Sustainable Development sector at the Inter-American Development Bank (IDB), 21st January 2021, given in a personal capacity and not representing positions or policies of the IDB.