Institution: Imperial College London		
Unit of Assessment: 5 – Biological Sciences		
Title of case study: A5-1 Calculation of ecological thresholds determines policies for restoration in the Atlantic Forest of Brazil		
Period when the underpinning research was undertaken: 2014 – 2018		
Details of staff conducting the underpinning research from the submitting unit:		
Name(s): Dr Cristina Banks-Leite & Dr. Morena Mills	**Role(s) (e.g. job title):** Senior Lecturer & Senior Lecturer	**Period(s) employed by submitting HEI:** October 2013 to present & September 2016 to present
Period when the claimed impact occurred: 2014 – 31 December 2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact (indicative maximum 100 words)

Banks-Leite calculated that the Brazilian Atlantic Forest requires 30% of native habitat to preserve biodiversity (*Science* 2014). These results underpinned three environmental laws on: (1) offsetting practices in São Paulo State, prioritising areas for restoration in (2) Rio de Janeiro State and (3) across the entire Atlantic Forest. The latter prioritisation was performed by Mills (*Nature Ecology and Evolut*ion 2018) aiming to increase forest cover back to 30% in selected areas. Examples of behaviour change as a result of the legislation include: tree planting by Brazil's 2nd busiest airport, a management plan for water resources and a collaboration between two government agencies to allocate funding for restoration.

2. Underpinning research (indicative maximum 500 words)

In 2014, Banks-Leite led the publication of a paper in *Science* showing there is an ecological threshold at 30% of forest cover, below which biodiversity and ecological functions become dramatically different to that of protected areas of the Brazilian Atlantic Forest **[1]**. This research was ground-breaking because until then the majority of studies searching for a "minimum area required for sustaining biodiversity" had failed to obtain consistent responses among taxa and to generate a precise target for conservation and/or restoration. Banks-Leite was able to circumvent these issues by using an innovative approach, which consisted of measuring: (1) forest cover at the landscape scale as a proxy for habitat changes and (2) community integrity and phylogenetic integrity as a proxy for biodiversity changes and ecological functions, respectively. Forest cover is a more parsimonious approach than the commonly employed measures of fragment size and patch-scale connectivity, and it is often more strongly correlated to changes in species and communities. Integrity metrics measure similarity in forest fragments relative to continuous forests. This approach summarises community-wide dynamics, hence it is more robust and pragmatic than measuring losses in single species or functions. Banks-Leite then used a piecewise regression to estimate the breakpoint, and confidence intervals, associated with the existence of a threshold.

These findings were also used to estimate the costs of restoring priority areas. Banks-Leite et al. calculated that an annual investment in Payment for Ecosystem Services (PES), and active reforestation practices (i.e., watering seedlings), worth U.S. $198 million per year would allow 37,000 priority landscapes to restore biodiversity to levels that matched protected areas **[1, 2]**. This cost corresponds to just 0.0092% of the Brazilian GDP, or 6.5% of what Brazil spends on agricultural subsidies. This is a "Highly Cited Paper" in Web of Science (188 citations as of 18/12/20), and it was featured in over 50 interviews, blogs, magazines, newspapers and government reports.

Banks-Leite's 30% threshold was later used by Mills in a collaborative study to develop a restoration prioritisation for the Atlantic Forest. This prioritisation was commissioned by the Brazilian Ministry of Environment to guide the implementation of the Native Vegetation Protection Law and the National Policy for Native Vegetation Recovery, and it was later published on *Nature Ecology and Evolution* **[3]**. Mills and her colleagues developed a novel approach that incorporates ecological and economic efficiencies of scale and that takes into account multiple criteria, including whether forest cover is below 30% **[1]**. The final result of this restoration prioritisation is a priority map that prevents 26% of the biome's current extinction debt of 2864 plant and animal species (an increase of 257% compared to the baseline), and sequesters 1 billion tonnes of CO_2 equivalents (a 105% increase) while reducing costs by US$ 28 billion (a 57% decrease) compared to business as usual approach.

3. References to the research (indicative maximum of six references)

[1] Banks-Leite, C., R. Pardini, L. R. Tambosi, W. D. Pearse, A. a Bueno, R. T. Bruscagin, T. H. Condez, M. Dixo, A. T. Igari, A. C. Martensen, and J. P. Metzger. 2014. Using ecological thresholds to evaluate the costs and benefits of set-asides in a biodiversity hotspot. *Science* 345:1041–1045. https://doi.org/10.1126/science.1255768

[2] Banks-Leite, C., R. Pardini, L. R. Tambosi, W. D. Pearse, A. a Bueno, R. T. Bruscagin, T. H. Condez, M. Dixo, A. T. Igari, A. C. Martensen, and J. P. Metzger. 2015. Response to comment on "Using ecological thresholds to evaluate the costs and benefits of set-asides in a biodiversity hotspot". *Science* 347:731. https://doi.org/10.1126/science.aaa1602

[3] Strassburg B. B. N., H. Beyer, R. Crouzeilles, A. Iribarrem, F. Barros, M. F. de Siqueira, A. Sánchez- Tapia, A. Balmford, J. B. B. Sansevero, P. H. S. Brancalion, E. N. Broadbent, R. Chazdon, A. O. Filho, T. Gardner, A. Gordon, A. Latawiec, R. Loyola, J. P. Metzger, M. Mills, H. P. Possingham, R. R. Rodrigues, C. A. de M. Scaramuzza, F. R. Scarano, L. Tambosi, and M. Uriarte. 2018.Strategic approaches to restoring ecosystems can triple conservation gains and halve costs. *Nature Ecology and Evolution* 3: 67-70. https://doi.org/10.1038/s41559-018-0743-8

External funding
The paper published in Science presented the results of two of the main goals of Banks-Leite NERC Postdoctoral fellowship entitled "Community disassembly rules and the erosion of ecosystem functions in fragmented landscapes" (NE/H016228/1).

Banks-Leite was the runner-up for NERC Impact Awards (NERC promotional video) and received a cash prize of £5,000

4. Details of the impact (indicative maximum 750 words)

Brazilian legislation requires landholders to set aside 20% of their farm for natural habitats in the Atlantic Forest biome, however the Science 2014 study **[1]** shows that this is not enough to protect biodiversity. This paper was the first to provide policymakers with a clear-cut figure regarding "how much habitat is enough", and drove the development of three policies:

State level resolutions and impacts

1) The Director of the Centre for Ecological Restoration within the Secretariat for the Environment of the State of São Paulo states that "*After a water constraint in 2014, the State Government decided to remodel some rules of the existing offsetting policies, to make it more effective for both water provisioning and biodiversity conservation. The Banks-Leite et al paper influenced the decision of: (a) prioritising restoration projects […] and (b) setting higher offsetting standards (for legally-cut trees) in municipalities that do not meet the minimum thresholds of remaining habitat.*" **[A]**. These new rules are part of Resolution SMA 7/2017 (enacted in 2017) **[A]**.

Implementation:

a) São Paulo/Congonhas Airport expansion (2017) – The extension of Brazil's second busiest airport required cutting trees. The environmental impact assessment produced for this development states that to comply with the Resolution SMA 7/2017, 1456 new trees will need to be planted to offset the environmental damage (**[B]** page 11).

b) Centro de Disposição de Resíduos Pedreira (2019) – This landfill receives an average of 6,000 t/day of waste materials from São Paulo city and its expansion requires clearing a forested area of roughly 56,000 m^2 (page 18). Resolution SMA 7/2017 was used to determine that the company must restore a larger area elsewhere with an estimated cost of nearly R$60m to offset the environmental damage (**[C]** page 18**,** page 40).

c) Condomínio Habitacional Américo Barbosa (2019) – Housing development plans to build four 17-storey buildings and will need to cut 63 trees. Thus 780 trees will need to be planted in a protected area nearby to comply with Resolution SMA 7/2017 (**[D]** page 8).

2) In response to the same water shortage in 2014, the Rio de Janeiro State Institute of Environment published an Atlas of Water Resources to increase protection for headwaters and bodies of water within the state **[E]**. Their multi-scale/multi-criteria approach to identify priority areas for forest restoration used the same landscape scale as the Science 2014 paper **[1]** (i.e., 200 ha, see Table [Quadro] 31), and their decision on the high priority areas for reforestation (Table [Quadro] 36, Map [Mapa] 14) was directly based on the Science 2014 **[1]** (**[E]** Page 136). Banks-Leite is cited in this report as one of the specialists who contributed to the report **[E]**. This prioritisation is now part of Resolution CERHI-RJ Nº 218/2019 (enacted in 2019).

Implementation:

a) Management Plan for Water Resources in the Baia de Guanabara – This technical report revised the current management plan given new laws (including CERHI-RJ Nº 218/2019) and needs (**[F]** page 17).

Federal level legalisation and impacts

3) The results from the Science 2014 paper **[1]** were critical for defining an optimal restoration scenario to underpin the prioritisation undertaken by Mills and colleagues as published in Strassburg et al. (2018) **[2]**. This prioritisation is the official map used by the Brazilian Ministry of Environment to help support the Native Vegetation Protection Law (Nº 12.651/2012) and the National Policy for Native Vegetation Recovery (nº 8.972/2017 enacted by Federal Decree in 2017) **[G]**. The prioritisation uses Banks-Leite's 30% threshold alongside socio-economic layers to select where reforestation should be prioritised and bring these areas back to 30% forest cover **[G, H]**. The deputy director of the Department for Conservation of Ecosystems within the Brazilian Ministry of Environment confirms that "*the results from Banks-Leite and colleagues (2014) were critical to define a restoration scenario where landscapes with at least 30% of forest cover can be reached through restoration."* **[H]**

Implementation:

a) Brazilian Ministry of Environment (2017) – This term of reference establishes the rules for hiring a consultant to elaborate strategies for increasing funding to promote restoration in four regions of the Atlantic Forest (**[I]** page 1). These regions were defined as priority areas by the restoration prioritisation undertaken by Mills. This Term of Reference cites the Decree nº 8.972/2017 as the main drive for the need to obtain more funding (**[I]** page 3).

b) Partnership between Brasilia Ambiental and Banco do Brasil Foundation (2020) – These are two government agencies that have entered into a partnership to allocate funding to projects aiming to restore native habitats to comply with the Decree 8.972/2017 (**[J]** page 1). Banco do

Brasil will provide the funding and Brasilia Ambiental will manage the grants (e.g. R$20m to projects in the Distrito Federal State).

5. Sources to corroborate the impact (indicative maximum of 10 references)

Whenever possible we provide two links, one with the website where the document was downloaded from and a Dropbox link in case the internet page becomes unavailable:

[A] Banks-Leite has received a letter of support from the Director of the Centre for Ecological Restoration within the Secretariat for the Environment of the State of São Paulo to demonstrate the impact that the Science 2014 paper had on Resolution SMA 7/2017. The letter explains the reasons why the current policy needed to change and the importance of providing clear thresholds, or a clear-cut figure, to support decision makers.

[B] Environmental Impact Assessment for expanding Congonhas Airport can be found here or here. (Archived here)

[C] Environmental Impact Assessment for landfill expansion can be found here or here. (Archived here)

[D] Environmental Impact Assessment for housing development can be found here or here. (Archived here)

[E] The Rio de Janeiro State Institute for the Environment published an Atlas of Water Resources that presents the framework created to identify priority areas for restoration to protect headwaters and other bodies of water. This atlas explicitly mentions that the team adapted the results from the Science 2014 paper both to choose a landscape size (200 ha) and to identify the range of forest cover that would bring optimal results for biodiversity. Banks-Leite is cited as one of the specialists involved in designing the framework. The Atlas can be found here and here. (Archived here) The priority areas identified in the Atlas are now part of Resolution CERHI 218/2019.

[F] Management Plan for Water Resources in the Baia de Guanabara can be found here and here. (Archived here)

Banks-Leite received two letters of support to demonstrate the influence the Science 2014 paper had on the implementation of the Native Vegetation Protection Law (Nº 12.651/2012) and the National Policy for Native Vegetation Recovery (Federal Decree nº 8.972/2017).

[G] One letter from the research Coordinator of International Institute for Sustainability, a think-tank based in Rio de Janeiro, explains how the results from the Science 2014 paper were used for defining an optimal restoration scenario (published in Strassburg *et al*. 2018 Nature Ecology and Evolution).

[H] The second letter is a declaration from the deputy director of the Department for Conservation of Ecosystems within the Brazilian Ministry of Environment, stating that the optimal restoration scenario identified by the International Institute for Sustainability will be used to implement the law mentioned above.

[I] Term of Reference published by the Department for Conservation of Ecosystems within the Brazilian Ministry of Environment can be found here or here. (Archived here)

[J] Cooperation agreement between Brasilia Ambiental and Banco do Brasil Foundation can be found on here or here. (Archived here)