Institution: University of Nottingham		
Unit of Assessment: 14 Geography and Environmental Studies		
Title of case study: Using Earth Observation to tackle modern slavery		
Period when the underpinning research was undertaken: 2014-2020		
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:**
Professor Doreen Boyd	Chair of Earth Observation	2007 to present
Professor Giles Foody	Chair of Geographical Information Science	2007 to present
Period when the claimed impact occurred: 2018-2020		
Is this case study continued from a case study submitted in 2014? N		

1. Summary of the impact

Boyd and Foody delivered the world's first comprehensive geospatial analyses of modern slavery sites. Boyd then worked with governments, intergovernmental organisations and NGOs to help them use this research to take action against slavery, with new national action plans, lawsuits, inspections, and interventions. For example, in Greece, the research supported the government and NGOs to protect the rights of thousands of exploited migrants. In India, the research accelerated the work of the United Nations Development Programme (UNDP) and civil society to liberate enslaved workers and improve working conditions for thousands of people.

2. Underpinning research

Since joining the University of Nottingham, Boyd and Foody have used remotely-sensed imagery and developed and deployed methods that include machine-learning and citizen science. Since 2016, they have applied their methodological innovations in Earth Observation (EO) to the mapping of sites where there is a high risk of modern slavery.

In their first 'Slavery from Space' article (Research 1 (R1)), they provided wall-to-wall data on kilns in the 'Brick Belt' of South Asia. The article used a data sampling approach and citizen science to generate testing data, and delivered the first robust estimate: 55,387 kilns (95% confidence interval). They argued that one of the biggest barriers to ending slavery is a lack of spatially explicit and scalable data. The article was the first demonstration of how remote sensing for EO can tackle slavery. In a second article about the Brick Belt (R2), they built on R1 to develop an advanced machine-learning method for rapid, accurate and repeatable automated mapping of kilns. They trained a contemporary deep-learning classifier founded on region-based convolution neural networks to classify brick kilns, applied a second classifier to produce a map with an overall accuracy of 94.94%, and argued that this accurate map could help to direct antislavery activity on the ground.

After noting the connections between slavery and environmental issues in brick kiln contexts (R1), Boyd examined the wider state of research on the bi-directional relationships between modern slavery, environmental degradation and climate change. She and co-authors published the first literature review of this topic, also proposing a future research agenda for exploring the slavery-environment nexus (R3). Identifying four key sectors (fisheries, fields, forests and factories), she argued that research needed to show how slavery and environmental change intersect. Boyd and Foody then began to deliver the research agenda proposed in R3, with an article that used remote sensing methods to assess the location and impacts of fish-processing activities in Bangladesh's mangrove forests (R4). The article identified ten fish-processing camps, including in locations where prohibited human activity results in the destruction of protected areas. Its spatial and temporal analysis revealed the camps' operational and seasonal trends and linked these findings to the bidirectional causal relationship between slavery and environmental degradation.

Focusing again on the relationship between environmental degradation and slavery, Boyd turned from fisheries to forests, publishing an article on tree loss and modern slavery in Brazil, Ghana, Indonesia, and Mozambique (R5). It used EO data and derived data to estimate the risk for slavery-related tree loss, revealing the full co-occurrence of slavery and tree loss due to mining, illegal logging, and agriculture. It argued that the conservation and antislavery communities could benefit by working together. Boyd and Foody then focused on one sector from R5—mining—and used remote-sensing to identify cobalt mines in the Democratic Republic of the Congo (DRC) (R6). They tested the feasibility of a key method, teamed with high temporal frequency imagery, for monitoring mining activity in the DRC's "Copperbelt." They showed that the method can: (i)

separate mining and non-mining areas based on surface motion values; and (ii) distinguish different mine types.

Across all six 'Slavery from Space' articles (R1-R6), Boyd drew out key findings in policy and method briefings, maps, and research reports for NGO and policy partners, explaining for example that remote sensing can: (i) produce proxy data for slavery and exploitation risk; (ii) bring a new methodological rigour to prevalence and risk estimation; (iii) produce mapping data for areas that are physically inaccessible to ground surveying techniques; and (iv) deliver geospatial coordinates for high-risk sites that can aid stakeholders' strategy and intervention development.

3. References to the research

1. **Boyd, D.S.**, Jackson, B., Wardlaw, J., **Foody, G.M.**, *et al*. (2018) "Slavery from Space: Demonstrating the Role for Satellite Remote Sensing to Inform Evidence-Based Action Related to UN SDG Number 8", *ISPRS Journal of Photogrammetry and Remote Sensing*, 142: 380-388. Refereed Journal paper. DOI: 10.1016/j.isprsjprs.2018.02.012.
2. **Foody, G.M.**, Ling F., **Boyd, D.S.**, *et al*. (2019) **"**Earth Observation and Machine Learning to Meet Sustainable Development Goal 8.7: Mapping Sites Associated with Slavery from Space", *Remote Sensing*, 11(3), 266. Refereed Journal paper. DOI: 10.3390/rs11030266.
3. Brown, D., **Boyd, D.S.**, *et al*. (2019) "Modern Slavery, Environmental Degradation and Climate Change: Fisheries, Field, Forests and Factories", *Environment and Planning E: Nature and Space.* Refereed Journal paper. DOI: 10.1177/2514848619887156.
4. Jackson, B., **Boyd, D.S.**, Ives, C.D., Sparks, J.L.D., **Foody, G.M.**, *et al*. (2020) "Remote Sensing of Fish-Processing in the Sundarbans Reserve Forest, Bangladesh: An Insight Into the Modern Slavery-Environment Nexus in the Coastal Fringe", *Maritime Studies* 19: 429-444. Refereed Journal paper. DOI: 10.1007/s40152-020-00199-7.
5. Jackson, B., Sparks, J.L.D., Brown, C. & **Boyd, D.S.** (2020) "Understanding the Co-Occurrence of Tree Loss and Modern Slavery to Improve Efficacy of Conservation Actions and Policies", *Conservation Science & Practice*, 2(5), e183. Refereed Journal paper. DOI: 10.1111/csp2.183.
6. Brown, C., Daniels, A., **Boyd, D.S.**, Sowter, A., **Foody, G.M.**, *et al*. (2020) "Investigating the Potential of Radar Interferometry for Monitoring Rural Artisanal Cobalt Mines in the Democratic Republic of the Congo", *Sustainability*, 12: 9834. Refereed Journal paper. DOI: 10.3390/su12239834.

Grants (G)

1. PI Foody, "Satellite Remote Sensing of Sites Associated with Slavery," EPSRC, 2017-18, GBP14,883.74.
2. PI Foody, "Remote Sensing to Inform Sustainable Development," BA, 2018-19, GBP24,600.
3. Co-I Boyd, "The Role of Data Science/AI for Combating Modern Slavery and Other Exploitative Organised Crimes," EPSRC, 2018-22, GBP49,070.
4. PI Boyd, "An Evidence-Based Framework to Support Improvements to Antislavery Policy and Practice in the Agricultural Sector in Greece," ESRC, 2019-20, GBP45,671.
5. PI Boyd, "Citizen Science for Earth Observation," BBSRC, 2019-20, GBP16,508.00.

4. Details of the impact

Modern slavery is spread across the world's 37,000,000,000 acres of habitable land. The most accurate estimate to date, by the International Labour Organization (ILO), is that 40,300,000 people are enslaved today. The UN and all countries have set the target (SDG 8.7) of ending slavery by 2030. But no country has a system for actively monitoring slavery and this data deficit leads to poor interventions and policies, with very few victims identified each year. Hidden in plain sight as an illegal activity, slavery is difficult to locate and therefore hard to combat.

In 2016, Boyd launched a 'Slavery from Space' programme at the University of Nottingham to address this problem of slavery's unobservability. The programme uses Earth Observation (EO) to identify and track the scars left on the Earth by the industries with high levels of slavery. Working closely with NGO, intergovernmental or government partners to deliver recommendations for action in response to her data, Boyd and her team, which includes Foody, mapped slavery in fish-processing in Bangladesh (2016), brick-making in India, Pakistan, Bangladesh and Nepal (2017-19), deforestation in Mozambique (2019), cobalt-mining in the DRC (2019-20), agriculture in Greece (2019-20), and multiple sectors in Uganda (2020), among other countries and industries.

Impacting intergovernmental, governmental and NGO responses

Boyd's 'Slavery from Space' programme has been utilized and praised across the global antislavery sector, by intergovernmental organisations, governments, and NGOs. For example, in the area of intergovernmental response, the UN featured 'Slavery from Space' at the launch of an AI-for-Antislavery working group (Code 8.7) at the UN headquarters in early 2019, and this UN-led group has frequently highlighted Boyd and her team's work (R1, R2, R5) to intergovernmental stakeholders (Impact a (Ia)). The ILO pointed to 'Slavery from Space' (R1) as an example of "*technological advances in traceability*" that are advancing labour rights in supply chains (Ib), in a major report on *Ending Forced Labour by 2030*. And the UN Special Rapporteur featured 'Slavery from Space' (citing R1) in an annual report as an effective way to identify high-risk sites (Ib). In the area of governmental response, the Government of Uganda believes Boyd's methods are a valuable addition to its antislavery efforts and "*augment*" government work towards SDG 8.7 (Ic). In the area of NGO response, the NGO, Verité, used Boyd's deforestation-slavery insights from EO (R5) in a large investigation, launched with the US State Department Office to Monitor and Combat Trafficking in Persons that laid out steps for companies and governments towards reducing slavery and environmental degradation (Id). The leading NGO, Free the Slaves, said the team's brick-kiln research (R1, R2) showed remote-sensing was a "*necessary addition*" to prevalence measurement efforts because it "*allows NGOs to tackle specific and localized cases*." Free the Slaves explained: "*Most companies that operate illegally remain under the radar but are exposed by Slavery from Space*" (Ie). Another leading NGO, Hope for Justice, said the team's unique forms of data, including its Africa-focused research (R5, R6) allow the NGO to better identify and predict "*vulnerabilities within communities*" and "*hotspot areas*" (Ie), enabling targeted prevention where it works in Africa. Hope for Justice explained that because the research shows vulnerability and enslavement patterns, it helps the NGO "*formulate a more streamlined approach to victim-facing strategies, increase survivor welfare, and reduce risks of re-exploitation*" (Ie).

In recognition of this sustained impact across several years, the Group on Earth Observations (GEO) 'Earth Observations for the SDGs' (EO4SD) Initiative gave Boyd the 2020 GEO SDG Award (Academia), citing her "*remarkable efforts to integrate Earth observations to develop new knowledge and practices*" for achieving SDG 8.7 (If). This award from a partnership of more than 100 national governments is for "*those making an impact on the 17 global goals*" (If). The 2020 awards panel was chaired by the director of NASA's Earth Applied Sciences Program.

Two of Boyd's most sustained collaborations have been with partners in India and Greece.

Using EO to combat slavery and labour exploitation in Indian brick kilns

NGOs and the ILO estimate that there are 23,000,000 brick kiln workers in India and 4,000,000 in Pakistan, a third of whom are children, and that 70-90% of kiln workers are in forced labour. The areal extent of the 'Brick Belt' that runs across South Asia is 1,551,997 km^2 and crosses country and regional borders. Using her remote-sensing method which crosses these boundaries, Boyd produced spatially-explicit maps of all kilns in the Brick Belt (R1, R2). She delivered the maps and underlying data in different formats to NGOs and intergovernmental organisations in India, to aid their understanding of the scale and location of the industry and therefore their action in the form of community prevention, liberations, inspection and regulation.

Since July 2019, the India-based NGO Volunteers for Social Justice (VSJ) has used Boyd's data and maps to liberate bonded labourers from kilns in northern India. VSJ has worked since 1985 to identify and liberate bonded labourers, and has liberated 30,000 people to date (Ig). As VSJ confirmed, the "*map data for Brick Kilns and the training we have received on how to use the data…has been immensely useful to us in our operational activities. Previously no such mapping existed and this constrained our work. The Brick Kiln mapping has revolutionised how we work… [it] enabled us to target attention on specific kilns as well as provide formal evidence we need to gain permission to undertake a raid and then to plan the logistics of a raid*" (Ig).

VSJ uses Boyd's detailed maps across its multi-stage liberation process, from kiln identification and raid authorisation to detailed raid planning and execution (Ig). Using Boyd's research, the process by VSJ is (Ig): 1. *Case identification.* VSJ staff talk to workers or receive distress reports from workers and their families; 2. *Kiln analysis*. VSJ asks workers to indicate the location of the kiln where they have observed or experienced exploitation. Workers can often only give rough locations or landmarks, and so VSJ determines a precise location from a combination of these

verbal reports and Boyd's maps (Ig); 3. *Case filing.* After confirming bonded labour conditions, VSJ secures permission to conduct a raid and release exploited workers. It files a case with the District Magistrate or the National Human Rights Commission. It again uses Boyd's maps to present kiln locations when filing the case (Ig); 4. *Raid planning.* VSJ has to determine transportation options for quick access to a kiln in order to minimize tip-offs to kiln owners. It previously had no maps for this planning and now uses Boyd's maps to plan its transport routes (Ig); 5. *Conducting the raid.* Previously VSJ led raids joined by law enforcement individuals who would sometimes intentionally guide them to an incorrect location, and it now uses Boyd's maps to ensure correct kiln locations are targeted during raids (Ig). VSJ has now successfully conducted three raids on brick kilns, involving 138 bonded labourers, using this new approach (Ig).

VSJ also has used Boyd's data for other areas of its work on brick kiln labour, including on improving working conditions and securing unpaid wages and access to welfare. VSJ explained: "*having accurate locations of kilns from University of Nottingham data has enabled us to make many achievements…we were able to resolve brick kiln wage disputes for workers at 17 brick kilns with a total of Rs.1,21,46000 paid to the workers*" and "*respond to…grievances of 1,307 workers*" about unpaid wages (Ig). They were able to register 1,278 workers with a nationwide welfare scheme and another 500 families for health insurance, train 148 leaders from one union and 58 from another on worker rights, run an awareness campaign for 7,000 workers about bonded labour, and organise protests with another 3,130 workers about kiln conditions, with results that include the improvement of working conditions at nearly 20 kilns, and the provision of transport, soap and emergency food to thousands of migrant workers during Covid-19 (Ig). As VSJ explained, "*Previously there was no accurate mapping of brick kilns to enable us to prioritize areas for our vital work to release bonded labourers from kilns, improve worker rights, secure compensation, register workers with welfare schemes and health insurance, and organize them to secure better working conditions. The mapping from the University of Nottingham has therefore revolutionised our work, changing how we prioritise activity and target our resources*" (Ig).

As VSJ was revolutionising its approach to liberation in India, Boyd also worked with the UNDP India Accelerator Lab to deploy her maps and data (R1, R2). The UNDP Accelerator Lab network works in 90 locations to support 114 countries in the testing and dissemination of solutions to development challenges. Working with Boyd, UNDP developed a GeoAI platform to help regulators take action on brick kilns that do not comply with environmental and labour regulations. The platform displays 47,131 brick kilns, mapped by Boyd, and she worked with UNDP to first focus on non-compliance in three states. As UNDP explains, before Boyd's data on kiln numbers, location and compliance, "*inspectors had no data-driven way to select kilns for inspection*" (Ih).

UNDP integrated Boyd's data into a mobile app, with modules on both environmental and labour issues that inspectors use to select specific kilns for ground-level inspection (Ih). Informed by Boyd's research on the slavery-environment nexus (R3, R4, R5), the labour module builds on the environmental module, as non-compliant kilns in terms of environmental standards are more likely to also violate labour standards. Boyd made detailed suggestions for the question set in the app's labour module (Ih), including the addition of questions about: numbers of children, migrants, and families working at the kiln; transfers of bonded workers from one kiln owner to another; meals per day, promised pay and worker debt; worker access to healthcare and whether identity papers are held by kiln owners, among 64 final questions (Ih).

The app assists regulators to take action on non-compliant brick kilns and as UNDP notes "*this is particularly useful in taking action on sites that are large in number and spread out across large geographies*" (Ih). UNDP explained that Boyd's data and the resulting app has "*changed the way that inspections are conducted… enabling inspectors to more efficiently target non-compliant kilns for inspection*" (Ih). UNDP partners with state and central governments in India to respond to inspection results from the app, including authorised kiln raids in the case of violations, and believes this is "*improving working conditions for labourers*" (Ih). For example, inspections were first piloted on all 162 kilns in one district, and the app's next roll-out in another state covered 9,000 kilns (Ih). The first three states already using the GeoAI app "*cover 30% of all the brick kilns across northern India*" (Ih). UNDP sees the data and app as "*a vital tool*" (Ih), and noted: "*The impact of your data and maps on the governance of the operations of the brick kilns cannot be overstated. It has led to a level of scrutiny…never before possible, and on-the-ground action in response*" (Ih).

Using EO to combat slavery and labour exploitation in Greek agriculture

Greece is the world's 8th largest exporter of strawberries. Over 90% of Greek strawberries are produced in the area around Nea Manolada in southern Greece and nearly all seasonal agricultural labour is done by 10,000-12,000 undocumented Bangladeshi migrants. In 2013, field guards shot and injured 30 of these Bangladeshi migrant workers. In 2017, the European Court of Human Rights (ECHR) ruled in *Chowdury and Others v. Greece* that they and other migrant workers had been subjected to forced labour in strawberry picking and that Greece had violated Article 4 of the European Convention on Human Rights by not preventing human trafficking. The ruling mandated the Greek state to proactively identify victims of trafficking and labour exploitation through multi-agency inspections of high-risk industries and sites. But reports from NGOs and field visits by members of Boyd's team in 2019, showed that living and working conditions for migrant agricultural workers around Nea Manolada had not improved.

Boyd therefore adapted the spatial and temporal analysis methods and EO data types from a paper (R4) in order to map workers' makeshift housing amid the surrounding vegetation. She initially identified 52 informal settlements and then through field visits confirmed 48 settlements housing an estimated 6,000 migrant workers. She monitored changes in the number of settlements over time, provided tailored monthly location reports on new informal settlements to Greek NGO, G2RED, and supplied a tool for estimating the risk of forced labour conditions at the sites. This enabled G2RED to prioritise settlements for its interventions against exploitative migrant labour. G2RED explained: "*Knowing where the camps are, and what the conditions are in each, is the first step of our work. Some of this we can do based on physical inspection, but this is very resource-intensive and we can't always keep track of new camps or when they become defunct. The new data you were able to provide…was very useful to us and has already helped us with our on-going work to help vulnerable migrants and with our future strategic planning*" (Ii).

Boyd's data and risk assessment tool were also embedded at the national level in Greece's overall set of actions for complying with the ECHR ruling in *Chowdury and Others v. Greece*, which mandated Greece to implement and report on actions to address forced labour. In its required *Updated Action Report* (March 2020) to the Council of Europe, the Greek government noted that its collaboration with Boyd to combat slavery was now part of the country's National Action Plan (2019-23) and was one of five "*most outstanding developments*" in the delivery of the plan (Ij).

The report stated that the country's actions, including collaboration with Boyd in the area of forced labour in agriculture, were compliant with the ECHR judgement and requirements (Ij). In September 2020, the Council of Europe's Committee of Ministers resolved that the Greek government's action plan, including its use of Boyd's data and tool, showed that the country had taken measures to prevent similar violations and had complied with the ECHR judgment (Ij).

The Greek National Rapporteur on Trafficking in Human Beings thanked Boyd for her data and tool that help Greece assess risk at sites of exploitation. He called her "*innovative use of technology*" a "*significant factor... in our efforts*" to tackle forced labour (Ij). Confirming that her work is included in his country's National Action Plan, he called it a "*valuable contribution*" (Ij). The Council of Europe's Directorate General Human Rights and Rule of Law further attested to Boyd's role in helping Greece to deliver on its legal obligations under the ECHR judgment: her data enables inspectors to identify and prioritise high-risk sites, with the impact of "*improving working conditions and ensuring that European human rights standards are safeguarded*" (Ij).

5. Sources to corroborate the impact

a. United Nations Code 8.7 materials.
b. Responses by the ILO and UN Special Rapporteur.
c. Testimonial from Gov of Uganda and UK Gov announcement of Uganda project led by Boyd.
d. Verité report launch and report.
e. Responses from Free the Slaves and Hope for Justice (NGOs).
f. GEO Award materials.
g. Testimonial from VSJ (NGO).
h. UNDP testimonial, report, and app screenshots.
i. Testimonial from G2RED (NGO).
j. Council of Europe materials.