P Grogan – Supporting Information

WebPanel 1. Examples of ways for authors to explicitly acknowledge awareness of the environmental impacts of research activities in their science publications, and of specific measures that could be taken to reduce, avoid, or mitigate those impacts

1. Published example of an acknowledgement and associated table containing an impact reduction measure

The Acknowledgements section of Andruko *et al*. (2020) concluded with the following sentence: "*Several specific measures were deliberately taken by the authors to reduce the environmental impacts of the activities associated with completing the science reported in this study (Appendix K)*". The associated supplementary appendix table is copied below:

Appendix K. Specific measures deliberately taken by the authors to reduce the environmental impacts of the activities associated with completing the science reported in this study.

Category of research-associated activity	Details of the research-associated activity necessary to complete the study	Environmental impacts of the activity that may be avoidable	Measure taken to reduce those environmental impacts
Travel	Travel from Queen's University in Kingston to Toronto airport (~250 km) for commercial flight to Yellowknife en route to arctic tundra	Greenhouse-gas emissions associated with Kingston–Toronto flights	Travelled from Kingston–Toronto airport by train or bus instead of flying
Travel	Chartered air travel from Yellowknife to the remote tundra research field-site at Daring Lake each summer for various science research groups, including multiple universities and government scientists	Greenhouse-gas emissions associated with each charter flight	Maximized the number of passengers per flight, and minimized the total number of flights by careful, ongoing scheduling coordination of travel plans among the different research groups

2. Table containing multiple examples of specific measures that could be taken to reduce, avoid, or mitigate the environmental impacts of various science research activities

This expansive table identifies a wide range of research activities across the sciences whose environmental impacts could be reduced, avoided, or mitigated using the specific measures described. The research activities are categorized into three groups: Travel, energy management, and supplies use. The table is aimed at helping other researchers to become more aware of their particular environmental impacts and of potential measures that could be adopted to address those impacts. It was developed from ideas and support generously provided by a wide range of students and colleagues, including K Moniz, V Walker, D Sauve, L Nepali-Colston, D Gerrish, M Vankoughnett, A Priemé, Y Tse, L Osborne, T Martinek, M Fellows, M Thaker, M Bredow, K Buckeridge, S Gordon, M Hamp, B Pham, and the Queen's University SustainabilityAction committee.

Category of research-associated activity	Details of the research-associated activity necessary to complete the study	Environmental impacts of the activity that may be avoidable	Measure taken to reduce those environmental impacts
Travel	Travel to research collaboration meetings	Greenhouse-gas (GHG) emissions associated with travel	Held majority of meetings via phone conference calls instead of always meeting in person
Travel	Travel to major annual science meetings for data presentation and research networking	GHG emissions associated with national and international travel	Reduced travel frequency by attending such meetings only every second year
Energy management – data storage and analysis	Use of data centers or computer clusters to analyze and store data	GHG associated with the large energy consumption of computer clusters	Researched available online data storage methods and chose the one that was most efficient and least energy intensive. Careful and concise selection of data to minimize total amount uploaded to the cluster
Energy management – data collection	Images from the drone needed to "map" out shallow water along shore for fish sampling	GHG emissions as well as transport of a boat to remote sites	Used a drone in remote locations rather than the hiring of a boat with a depth finder
Energy management – refrigeration	Storage of DNA/RNA, and associated enzymes, as well as special reagents	GHG emissions associated with the energy required by regular and ultralow deep freezers	Reduced the operating temperature from –80°C to –70°C in ultra-low freezer Initiated a formal stockholding system to maximize space use within the freezers; removed expired chemicals/enzymes; emptied and turned off freezers that were then no longer required Ensured freezer filters and coils were cleaned, and that storage space was defrosted as necessary

			Optimized efficiency of refrigeration facilities by sharing among multiple lab research groups
Energy management – ventilation fume hoods	Fume hood is required for working with noxious chemicals	GHG emissions associated with the energy required by ventilation systems, as well as the associated loss of the building's internally regulated air. This latter loss consequently often necessitates additional heating (or cooling) within lab buildings during winter (or summer).	Labeled fume hoods to remind users of the optimum opening position to minimize energy use (appropriate for buildings with regular ventilation systems which have an optimum fume hood opening (about ¼ up) that minimizes air flow, but for which closing the hood completely often causes imbalance problems elsewhere in the building's ventilation system) Installed an alarm to remind users to fully close the hood to reduce energy use (appropriate for variable-air-volume ventilation systems, which automatically decrease airflow when the fume hood is completely closed) Organized for sharing of fume hood facilities among multiple lab research groups, and re-designated some rooms that were originally designed as specially ventilated space for lab chemistry work (ie use of hazardous or noxious-smelling chemicals) to other research purposes such as for sample preparation machinery and sample storage. Consequently, the fume hoods in those rooms could be removed and the overall building ventilation infrastructure modified to reduce total air flow, thereby reducing overall air heating losses and reducing circulation energy
Energy management – lab and office equipment	Lab analytical equipment and office computers and printers	GHG emissions associated with the energy required by such equipment – even when in standby mode	Designated person was made responsible for completely switching off such equipment over extended holiday and other

			shut-down periods when the lab was not being used
Supplies use – chemicals	Acquisition of chemicals needed to make reagents	GHG emissions associated with packaging and shipping	Bought several different chemicals in bulk at one time, made up aliquots, and attached a safety chemical identification label to each
Supplies use – pipette tips and plastic containers and tubes for use in molecular biology research	Contamination is a large concern in molecular and microbiology research, and so lots of single-use new plastic products such as pipette tips, vials, centrifuge tubes and PCR tubes are used. Certain types of pipette tips are supplied pre-packaged in plastic sealed boxes, which creates further waste.	Resource use, as well as waste associated with packaging and shipping of pipette tip and other plastic products. Energy use associated with autoclaving and incineration during processing this plastic lab waste	Ordered pipette tips in bulk bags, that can then be stacked into old plastic boxes and autoclaved Purchased these supplies from companies that use more sustainable practices such as taking back used plastic pipette boxes Switched from plastic pipettes to washed glass pipettes for re-use, avoiding disposable plastic use Dedicated pipettes needed for measuring out commonly used chemicals were designated as such and labeled appropriately, and kept for that particular chemical to eliminate need for disposal after a single-use Coordinated with university administration and waste haulers to reduce the flow of potentially recyclable non-hazardous lab plastic waste materials that are unnecessarily going to landfill or hazardous waste by diverting them to the recycling stream (See Eizagirre [2019] and multiple website references below) Decontamination washing and autoclave-sterilization of plastic (eg Falcon) tubes for re-use; substitution of single-use microbiology items with reusable ones; careful experiment planning that specifically includes the goal of

			reducing single-use items (Alves *et al*. 2020)
Supplies use – sterile lab gloves	Single-use latex and nitrile gloves are necessary in molecular and microbiology research where avoiding contamination is a critical concern	Disposal of gloves either to the hazardous waste stream or to landfill sites as appropriate depending on the nature of the contamination	Nitrile gloves were purchased from suppliers that take back the used ones for recycling (See Eizagirre [2019] and multiple website references below)
Supplies use – examination gloves	Examination gloves (latex and nitrile) are used to maintain hygiene during procedures with potential exposure to non-toxic contaminants only	Disposal of gloves to landfill sites	Used biodegradable examination gloves that have not been in contact with hazardous substances were placed in the compost waste stream afterwards, rather than going to landfill
Supplies use – nucleic acid extraction kits in molecular biology research	Some DNA extraction "kits" include excess components and may contain several hazardous chemicals (eg phenol/chloroform)	Resource use and waste associated with manufacture of extraction kits, and hazardous waste production	Used a salt-based DNA extraction protocol (Aljanabi and Martinez 1997) which required less tubes for extraction and does not create hazardous waste. Furthermore, the ingredients needed can be purchased in bulk, creating less waste than pre-packaged "kits"
Supplies use – screening kits for use in molecular biology research	Rapid screening method for selecting and pooling DNA transformants	Commercial DNA kits are filled with plastic from non-renewable resources and are shipped at freezing temperatures across the country, resulting in fossil fuel energy consumption and landfill waste	Used new rapid screening method developed from basic in-lab components that avoided the purchase of multiple DNA kits as well as enzymes
Supplies use – purified water	Deionized-distilled water required for stock solutions	Fossil fuel energy required shipping and manufacture of the plastic involved in packaging deionized-distilled water, as well as in shipping pre-made solutions that would be required in place of lab-made stock solutions	Used an in-lab still for "making" one's own pure water. Such stills can also be shared between labs, reducing overall costs as well as environmental impacts of acquiring commercially prepared pure water
Supplies use – associated packaging	Purchasing reagents and supplies from vendors that use recycled or biodegradable packaging material	GHG emissions as well as huge amounts of packaging going into landfill sites	Reduced energy use and landfill waste by recycling packaging. Energy cost for return and recycling avoided by choosing items supplied with biodegradable packaging
Supplies use – weigh boats	Plastic weigh boats needed for weighing out common materials	Oil and energy resources required for manufacture,	Dedicated weigh boats were labeled with agarose or sucrose, etc, and kept for

		and subsequent disposal increases landfill waste	that particular compound to eliminate need for disposal after a single use
Supplies use – sterile containers, petri dishes, and test tubes	Use of sterile containers, petri dishes and test tubes	Disposable plastics are currently made from non-renewable oil resources, are sterilized by irradiation (resulting in additional burdens for disposal of spent Cobalt sources), and are wrapped in sterile paper resulting in extra packaging and shipping	Re-used glass beakers, petri dishes and test tubes instead of disposable plastic; these items were sterilized by autoclaving and then sealing with aluminum foil instead of the larger environmental impact of using a gamma-radiation sterilization source
Supplies use – sample bags	Collecting soil samples for subsequent chemical analyses	Clean plastic sealable heavy-duty freezer sample bags are an oil-product and their production entails GHG emissions	Rinsed and washed the emptied sample bags for re-use where absolute chemical cleanliness was not a stringent criterion
Supplies use – paper towels	General lab cleaning	Single-use paper towels	Purchased and used towels made from recycled paper
Supplies use – timber	Strengthening timber frames of experimental rainout shelters that have been in place for 9 years in an old field meadow and were deteriorating/rotting	GHG emissions associated with the commercial production and transport of new lumber Loss of the lumber source trees that represent a carbon sink	Disassembled those initial replicate timber frames that were no longer necessary (as their plots had been harvested), and removed the remnant strong lumber to make strengthening struts for those rainout shelters that are still in use in the experiment

3. Example of an M.Sc. thesis statement acknowledging awareness of the science's environmental impacts

The following paragraph was included in a M.Sc. thesis, Acknowledgements section (Colston-Nepali, 2019):
"I would like to further acknowledge the environmental impact of my project. Extraction of DNA requires numerous single use plastic tubes and pipette tips. The project also required long-distance travel by many researchers to collect samples, and the use of high-performance computing clusters to analyze genomic data. Our lab has been working towards reducing our environmental impact by attempting to recycle the plastic waste that we can, and by moving from the use of hazardous chemicals such as phenol and chloroform for extraction to more environmentally friendly methods such as salt extraction. I believe we still have a long way to go to reduce the impact that science has on the environment, and I will continue to work towards this throughout my career."

4. References (including those for additional reading) and useful resources

Aljanabi SM and Martinez I. 1997. Universal and rapid salt-extraction of high quality genomic DNA for PCR-based techniques. *Nucleic Acids Res* **25**: 4692–93.

Alves J, Sargison FA, Stawarz H, *et al*. 2020. A case report: insights into reducing plastic waste in a microbiology laboratory. *Access Microbiol* 1-8.

Andruko R, Danby R, and Grogan P. 2020. Recent growth and expansion of birch shrubs across a low Arctic landscape in continental Canada: are these responses more a consequence of the severely declining caribou herd than of climate warming? *Ecosystems* **23**: 1362–79.

Bearzi G. 2009. When swordfish conservation biologists eat swordfish. *Conserv Biol* **23**: 1–2.

Colston-Nepali L. 2019. Can genomic tools aid conservation of an Arctic seabird, the northern fulmar (*Fulmarus glacialis)*? M.Sc. thesis. Kingston, Canada: Department of Biology, Queen's University.

Dolšak N and Prakash A. 2018. The climate change hypocrisy of jet-setting academics. *Huffington Post* (31 Mar). https://www.huffpost.com/entry/opinion-dolsak-prakash-carbon-tax_n_5abe746ae4b055e50acd5c80?ncid=engmodushpmg00000006.

Eizagirre S. 2019. Science has a garbage problem. Why aren't recycling schemes more popular? https://massivesci.com/articles/research-labs-generate-plastic-waste-recycling-sustainability-gloves.

Le Quéré C, Capstick S, Corner A, *et al*. 2015. Towards a culture of low-carbon research for the 21st Century. Tyndall Centre for Climate Change Research, Working Paper 161. https://tyndall.ac.uk/publications/tyndall-working-paper/2015/towards-culture-low-carbon-research-21st-century.

Madhusoodanan J. 2020. DIY approaches to sustainable science. *Nature* **581**: 228–29.

Paasche Ø and Österblom H. 2019. Unsustainable science. *One Earth* **1**: 39–42.

Rosen J. 2017. A greener culture – creative minds are shrinking research's big carbon footprint. *Nature* **546**: 565–67.

Urbina M, Watts AJR, and Reardon EE. 2015. Labs should cut plastic waste too. *Nature* **528**: 479.

For more information on reducing the environmental footprint of doing lab-based science and specifically on lab waste issues, the following resources are strongly recommended:

https://sustain.ok.ubc.ca/initiatives/labplastics/

https://www.i2sl.org/working/labwaste.html

https://sustainability.ucsb.edu/labrats-best-practices/

https://www.ed.ac.uk/roslin/news-events/latest-news/sustainable-lab-scheme-cuts-plastic-waste-costs

https://www.colorado.edu/ecenter/greenlabs

https://www.mygreenlab.org

https://www.freezerchallenge.org

https://www.labconscious.com/

https://zerowasteboxes.terracycle.ca/collections/ppe/products/safety-equipment-and-protective-gear-zero-waste-boxes

https://betrgrants.weebly.com

LEAF (The Laboratory Efficiency Assessment Framework)
https://www.ucl.ac.uk/sustainable/staff/labs/%20leaf-laboratory-efficiency-assessment-framework