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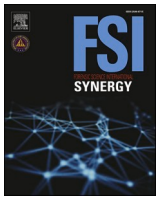

The impact of climate change and sustainability initiatives on forensic practice

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ABSTRACT

The climate change crisis affects all aspects of our lives, and this includes national and global scientific endeavours. The forensic sciences are no different but are yet to engage meaningfully with this agenda or to consider what it means for future practice. This paper explores and discusses a range of impacts on forensic and crime scene practice derived from climate change and proposes the potential implications. The paper concludes by laying out a way forward and a programme of activity to support the forensic sciences to manage the implications of climate change and related sustainability initiatives on the criminal and medico-legal investigative community.

Our climate is changing. Organisations such as the United Nations, NASA, The Royal Society, the African Centre for Meteorological Applications for Development, the Institute of Global Environmental Strategies, and the World Bank have all underlined the role that human activity is playing in changing the world's climate by more than can be explained by natural processes. Indeed, the Intergovernmental Panel on Climate Change [1] has laid out the evidence very clearly, along with the impact, particularly with regard to extreme weather events. This situation, compounded by the lack of serious mitigating action, is rapidly developing into a global crisis which will affect us all.

Much of the current focus of climate change discussion concentrates on the immediate impact of these changes on settlements and the environment. This focus is understandable given that these impacts are clearly visible and affect the day-to-day lives of millions. The hazards experienced often derive from the intensity of new weather conditions, which overwhelm the infrastructure in places not used to extreme events. Climate change is a world-wide problem, although it does not affect all populations or locations equally. In the context of disaster management, Fothergill and Peek [2] argued that despite disasters being perceived as 'status levellers' as entire populations may be exposed to the same weather event, they do not in fact distribute risk and vulnerability equally – socioeconomic status is a key predictor of impact. As with many mass disasters, the immediate impact of climate change often affects the poorer more intensely. It is therefore of no surprise that the biggest challenges will be faced in the global south. Indeed, the threat of climate change is so significant that it can be linked to at least six of the seventeen United Nations Sustainability Development Goals, including Climate Action (Goal 13), as well as Affordable and Clean Energy (7), Sustainable Cities and Communities (11), Responsible Consumption and Production (12), Life Below Water (14) and Life on Land (15).

No area of human activity is immune to the impact of climate change, and this is true of the forensic sciences. It is therefore incumbent on forensic practitioners to consider how climate change will impact on the contexts and methods of practice, and how we will proactively engage with the associated sustainability agenda. This paper will explore points of consideration by taking specific forensic disciplines and laying out the potential impacts on medico-legal investigations.

1. Forensic anthropology

Forensic anthropologists focus their efforts on the human body with a view to identifying the deceased and commenting on the context of death. This is the lens through which the impact of climate change will therefore be viewed in this section. Taphonomic change is a key aspect of forensic anthropology, and understanding the various factors that can affect the body post-mortem allows for a more accurate discussion of the context of death. A fundamental tool in this area is the calculation of the post-mortem interval (PMI) – a method which is significantly affected by climate. Previous work has already shown that PMI is impacted by a diverse range of variables (see Ref. [3] for a discussion). Recent work, particularly from the global south, has shown that environmental conditions are highly influential in PMI and time-since-death Accumulated Degree Day calculations, and that standards created in more temperate conditions will be inaccurate when applied elsewhere [3,4]. Likewise,

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earlier work in the United States demonstrated the ineffectiveness of a standardised prediction equation by comparing cold and tropical regions [5]. Thus, changing global temperatures are likely to have a similar effect when it comes to the standards being used today and, unless we adjust, our estimations of PMI and related contextual interpretations will become increasingly inaccurate.

Increasingly, a key context in which forensic anthropologists contribute is with respect to the identification of irregular migrants. For the most part, people are moving to escape violence in their country of origin, economic deprivation, or other forms of persecution. As parts of the world become less habitable or difficult to sustain populations, socio-economic and political pressures are likely to intensify, resulting in greater numbers of people seeking to move. The hazards associated with such journeys may also intensify as countries close off their borders (e.g.: USA, UK, Hungary, Australia). This will intensify the demand/pressures on forensic anthropologists when the death toll, already regarded as a humanitarian crisis in many parts of the world, is liable to increase.

While DNA profiling may be affected by the period of decomposition, the environment, and a lack of sampling and centralised data handling, forensic anthropological methods are able to provide some demographic and contextual information about the dead without requiring knowledge of who that person may be as well as being quick and comparatively easy to deploy [6–9]. Crucially, work has also shown that anthropological methods can identify signs of stress and structural violence on the skeleton associated with migration, particularly when a biocultural approach is taken [10].

The current global response to migration following significant armed conflicts has been disappointing, yet the scale of migration due to environmental and climate change is likely to be greater. Increased migration from a wider range of locations because of climate change will also further expose a key weakness of forensic anthropology: that of a lack of population specific reference data for many populations. Recent work by Dwyer et al [11] exploring this issue argues that this is not only a scientific weakness but further continues the structural violence faced by these groups. Thus, the impact of climate change will be felt by some groups more in life and in death.

In a context of increased global travel and migration [12] stable isotopic analysis can be used to determine non-local origin and diet of the deceased from a range of forensic contexts, including undocumented border crossers [13,14]. For example, oxygen ratios are related to precipitation and temperature and so can be related to region of origin [13,15] with samples recovered from bone and teeth as well as hair and nails [12]. This can also be very useful if the challenge is to determine whether a deceased victim is likely local to a particular area, or a recent migrant to it [12]. This approach is also used in historical cases stemming from large-scale armed conflict. For example, Lockyer and Davis [16] discuss the work of the Canadian Armed Force's Casualty Identification Program and the use of stable isotope analysis of oxygen ratios to separate Canadian deceased from British in First World War graves. The impact of temperature changes could impact vegetation growth and the underlying fractionation process which in turn will impact the ratios associated with diet and geography.

2. Forensic archaeology

One of the more interesting implications of changing climate is the impact on methods and techniques applied within forensic archaeology. In the UK, changing seasonal weather is resulting in a number of previously unknown archaeological features being revealed from the air.

Temperature is a key aspect in many methods of remote imaging and therefore changing temperatures will impact archaeological practice. For example, when using thermal imaging to detect human remains, the focus is on the differences between surrounding temperature and that generated by an active maggot mass [17] and therefore a concern would be that an increase in environmental temperature will have an impact on the efficacy of this method. Thankfully, longitudinal work by Lee et al [18] demonstrated that even with climatic variations, a temperature differential between the environment and the remains can still be detected – although they noted that the hours proceeding dawn showed the greatest difference between the two temperatures, and that extreme climate temperatures can result in the sudden death of the maggots. In another example, research has suggested that the effectiveness of water penetrating radar is dependent on the temperature of the body of water being surveyed [19].

In other contexts, human remains can be revealed through more drastic environmental change. Gaudio et al [20] discuss how retreating glaciers in the Alps have revealed soldiers killed during the First World War. Other forensic situations where bodies are revealed as ice melts include mass disasters that have occurred in these regions [21]. The incidence of this is likely to increase as global temperatures rise and solid ice is reduced [20]. A shift from permanently frozen conditions to one of freeze-thaw cycles will further damage the exposed bodies [22,23].

3. Forensic entomology and botany

There are many branches of entomology which range from agricultural to veterinary to forensic [24], and climate change will impact all of them. In fact, there has already been some discussion of the impact of climate change on forensic entomology, for example Atencio-Valdespìno and Collantes-González in the context of the developing practice in Panama whereby changes to entomological distributions have been discussed (2023). This is perhaps not so surprising given the well-known association between insect distribution and environmental conditions.

One of the challenges facing entomologists is the impact of species extinction as a result of changing environments [25]. Forensically this is less of an issue, since it is not the insect *per se* that is important, but the associated environmental and living conditions needed to support that species which is what is used to associate remains with location. Further, changing environments can cause the reduction of some species but provide new habitats for others [21]. For example, Hågvar and Gobbi [26] describe how retreating glacier ice reveals new ground which can be colonised by successions of biological communities, including arthropods. Thus, within forensic entomology, we must be cognisant of the fact that changing environments cause changes in species distribution patterns which may differ from currently accepted patterns in the published literature.

The considerations raised above for forensic entomology are also applicable to forensic botany. Forensic botany can be a useful approach for determining the location of a burial or crime site, as well as post-mortem interval, time since deposition and determining the origin of food/drugs/bioweapons etc [27–29]. In addition to plants, this work can include mosses and fungi. Within this group of applications, perhaps its greatest strength concerns the use of botanical assemblages for geolocation. Nonetheless, the strong link with a specific habitat and environmental conditions [28,29] means that climatic change will also influence distribution patterns and thus impact the ability of the forensic practitioner to confidently match evidence to place based on existing standards and distribution maps. Note as well that climate conditions also affect tree ring growth [28] and so changes in the climate may be detected through dendrochronological analysis.

4. Forensic medicine

Climate change will have a direct impact on mortality patterns. As Marrone et al. note (2023), this is because of its impact on communicable diseases, propensity for psychiatric conditions and the physiological response to the heat itself. Further, there is the consequence of resultant environmental change, such as with increased famine and malnutrition (through desertification, drought and extreme storms), water-borne diseases following severe flooding and availability of clean

water, increased concentrations of air pollutants (warmer temperatures impact ozone and particulate matter) and aeroallergens, and the geographical spread of ticks, mosquitoes, typhoid and so on [30,31]. The spread of infectious diseases is especially worrying since temperature influences both the proliferation of the infectious agent and their vectors.

Extreme heat is already a significant cause of death. Data from Arizona in the USA has demonstrated that cases of heat-related illness have been increasing to nearly 3000 per year, with deaths reaching a record high of 552 in 2021 [32]. In Europe, the heat wave of 2003 resulted in 22,000 deaths [30]. Clearly more vulnerable people are at greater risk, and therefore it is of no surprise that the evidence underlines the particular risk to the elderly and children, as well as those with pre-existing conditions [30]. Anatomically, the cardiopulmonary and gastrointestinal systems are particularly susceptible [30,33,34]. Note that much of the focus is on the medical impact of increasing temperatures, but some regions will experience colder weather as a result of climate change, and there is data to show that this can also have an effect on occurrence of cardiac arrest [34]. Work along the US-Mexico border has suggested that an increase in mortality rates among undocumented border crossers could be the result of climate change – although this has also been questioned since there are significant number of other variables at play [32].

Perhaps a key impact we should expect from continuing climate change is the impact on mortality patterns due to changes in faunal distributions. Research exploring the clinical implication of jellyfish stings highlighted how increasing temperatures are resulting in increasing blooms, distribution and human injuries [35]. It has also been suggested that changes like the melting of glaciers may release frozen pathogens that humans have not encountered in recent years [36]. Note that increasing temperatures may improve habitats for some species but may hinder others and that changes in temperature will affect the whole food chain through increasing or decreasing faunal or flora numbers at each trophic level.

Wildfires, another consequence of climate change, are increasing in number and are becoming an increasingly complex and worldwide issue [37] whilst also presenting particular forensic human recovery and identification challenges [38–41]. The scale of destruction and the speed at wildfires spread can be overwhelming, with the Butte County, California fire of November 2018 damaging over 150,000 acres of land moving at 80 acres per minute [39,40]. They are particularly impactful when they make contact with informal settlements, such as ghettos and shantytowns [42], in which housing is poorly constructed and tightly packed. This presents another example of a greater impact on poorer and more vulnerable communities harder.

5. Crime scene investigation

As societies attempt to address the challenges resulting from climate change and move cities and towns towards a net zero existence, we are seeing the development and deployment of new technologies and infrastructure which support this aim. We can expect these to proliferate and potentially result in a new type of crime scene. Shevade and Montalto [43] discuss the placement of 'green infrastructure' which address water-related challenges resulting from climate change. Effectively channels and drains, these structures may increasingly become a place for forensic evidence to collect. Environmental crime scenes may also become more prominent with crime scene and forensic investigators increasingly working to examine such things as industrial pollutants on beaches or in water courses.

Some of these new technological developments create more dangerous working contexts for CSIs. For example, Electrical Vehicle (EV) fires in enclosed spaces (like carparks or tunnels) or in complex situations like on ferries [44] as well as at charging points [45]. This is compounded by the toxic gases produced by burning batteries, the difficulties in suppressing fires in EVs with the higher quantities of water needed to do this, and the possibility of batteries reigniting [44].

There is a recognition that many of the techniques used within crime scene science investigations can be harmful to the person and the environment, for example due to the composition of the fluids and powders used, and the impact of applying them within the environment. As such, there is interest in finding alternative ingredients to such things as fingerprint developers. Work has suggested that seaweed, certain spices and chalcones could be used instead since they are cheaper, have lower toxicity and are less impactful on the environment [46].

One of the growing areas of forensic and crime scene investigation is that of digital forensics. Within this area, both the rapid increase in volume of data seized [47] and the increasing complexity of the digital environment [48] are proving challenging. The response has been to develop specialised tools and techniques [48] to process this data. The consequence of this is a significant increase in the computer processing required and the additional demands on power. Despite some benefits to environment of an increasingly digital world (some examples below), there are also consequences to consider.

Within the sciences, single-use plastics have been highlighted as posing a major threat to the environment and public health [49,50] with seventy-nine percent of all plastic ever produced ending up in landfills of the environment [49]. This is a key concern at the crime scene and in the laboratory since our supplies are likely not biodegradable albeit they ensure that cross-contamination does not occur. This issue is also true of body bags and of course, the ubiquitous disposable glove [51]. Indeed, biodegradable body bags are now available for purchase through medical supply companies, whilst researchers have been experimenting with alternatives ([52,53] - less expensive albeit still with significant environmental impact). Research within the biosciences has demonstrated that washing and sterilising of items is sufficient to permit reuse without impact on experimental results [49] while other work has shown that re-use leads to a sizeable carbon footprint reduction, largely through the reduction of the production and distribution supply chains [54]. Much more work is needed to explore the issue of cross-contamination in terms of crime scene samples, but also with regard infection and wider health and safety issues for the practitioner [55].

6. Forensic science training

The impact of climate change will affect all aspects of forensic science, including education and training. In this respect, we should consider more sustainable approaches to pedagogy. This may involve a greater use of remote delivery to reduce the impact of travel. The forensic sciences have readily embraced this agenda, albeit mostly in response to the COVID-19 pandemic [56]. Most would agree that the forensic sciences require 'hands-on' experience, yet nonetheless, even practical elements of the forensic science curriculum have been successfully delivered remotely and digitally [57,58] and in some institutions a model where the practical component could be undertaken at home has been deployed [59]. This approach requires a new pedagogical framework to succeed [60] but student feedback has been very positive to this digital shift [61]. Further, in addition to reducing travel a shift to digital approaches reduces the volume of consumables required for teaching purposes – although it does place new burdens on staff and students to access the technical equipment required to create, view and interact with the digital resources [61].

Further discussion should also be encouraged concerning the requirement to attend international conferences in person. As an example, for the author to fly and attend the AAFS conference in 2025 would release 1.45 tonnes of CO_2 into the atmosphere whereas to attend the ANZFSS conference would release 6.09 CO_2 tonnes (www.carbonfootprint.com). While some conferences have adopted a hybrid format, this is not universal and often the online provision remains of a lower quality than the in-person variant.

Finally, where travel is necessary, thought should be given to the creation and development of carbon neutral laboratories and buildings.

This approach will need to be expanded further to include net zero supply chains, or at the very least, the reduction in overseas shipping. Of course, this is only possible where such resources exist regionally, a factor which may again negatively affect poorer and more remote regions of the world.

7. Conclusions

Regardless of the current debate surrounding the existence of climate change, forensic scientists are evidence-based practitioners. As such, we need to respond to the overwhelming scientific evidence for climate change. Once we have accepted this, we are then compelled to consider the implications for forensic practice. Part of the challenge that we will face in the forensic sciences relates to a point Wilson [62] made about the impact of Brexit on the forensic sciences, simply that the forensic sciences are not a policy priority. This will be true within the climate change agenda as well. It is within our gift to develop our own policies on this subject, yet even discussions within the field on the nature of forensic practice now and in the near future (such as [63,64]) do not highlight this issue, and indeed the impact of climate change does not feature in recent lists of challenges that forensic practice faces (e.g.: [65]).

But as Wilson [62] also notes, times of uncertainty such as this also provide opportunities. For example, as we have seen in other sectors, new method development can be stimulated (for example, the challenges presented by the 2018 California wildfire allowed for the novel application of Rapid DNA methods), while one of the long-lasting changes following the COVID-19 lockdowns has been new approaches to communications (including research and teaching).

As can be seen above, the impact of climate change on forensic practice is nuanced and underexplored. As such, it is important to set out an agenda for action and further research. There are four key areas for initial work: 1) coordinated research projects between universities and industry to explore the development and deployment of new forensic products to support the net zero and sustainability agenda; 2) inter-agency collaboration to address the impact of climate change on the global practice of the forensic sciences; 3) development and evaluation of new ways of practice, including remote working, non-contact methods and more at-scene testing; 4) engagement with policy makers to highlight concerns and potential solutions.

Whether we formally recognise it or not, forensic practitioners are political activists in a range of contexts (see Ref. [66–68] for some recent examples of this within the field). The very act of 'following the evidence to the objective truth' is itself politically motivated in some countries, such as when it is applied in contexts of transitional justice. As such, we should not feel that advocating for change is outside of our remit. We need to respond as a discipline and as practitioners to the evolving climate change context and worry less about how others perceive this response.

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T.J.U. Thompson: Writing – review & editing, Writing – original draft, Resources, Investigation, Conceptualization.

Declaration of competing interest

I confirm that I have no conflicts of interest concerning this original piece of work.

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