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When undone science stifles innovation: the case of the Tasmanian devil cancer

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Gaps or deficits in knowledge present opportunities for new and innovative research, but when studies are undone much is lost. The concept of 'undone science' can be understood within related concepts, including ignorance, nescience, non-knowledge and the chilling effect. The Tasmanian devil cancer, devil facial tumour disease (DFTD), is a new and novel cancer, potentially providing many opportunities for innovative research. The contagious cancer hypothesis for DFTD is also novel. In the research it has sponsored, the Tasmanian government elected to follow this pathway, neglecting an alternative plausible hypothesis that toxins in the devils' environment may have played a role in the initiation or progression of the cancer. The studies were not viewed as opportunities to fill gaps in devil cancer knowledge, and remain undone.

Introduction

The Tasmanian devil, the largest surviving carnivorous marsupial, inhabits Tasmania, an island south-east of mainland Australia and one of the country's six states. Tasmanian devils are facing extinction from a deadly facial cancer, termed devil facial tumour disease (DFTD). The disease was first identified in 1996 in the north-east of the state. The Tasmanian government's Department of Primary Industries, Parks, Water and Environment (DPIPWE) has managed all the scientific research into this cancer. Scientists agree the cancer is a neuro-endocrine tumour of unknown origin (Loh, 2006). A viral cause was discounted because a test for virus particles had proved negative, and a trial to test for a range of chemical toxins was proposed (Tasmanian Government, 2005). In 2006, Anne Maree Pearse and Kate Swift published a short article in *Nature* proposing that the cancer was an allograft, a contagious cancer spread from devil to devil.

The DPIPWE sponsored research to pursue the contagious cancer pathway. A plausible alternative hypothesis – that pesticides used in plantation forestry (Jenkin and Tomkin, 2006), which contaminate much of Tasmania, including the devils' environment, may have played a role in either the initiation or the progression of the cancer – was at first ignored. However, in 2007, following a journalist's request for the toxicology results (discussed later), a small pilot study was undertaken. Despite calls for further investigations, there have been no subsequent toxicology studies.

The Tasmanian devil cancer is unique, unknown in other species or in humans, and thus provided an opportunity for innovative research. However, innovation in

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research cannot thrive if political obstacles prevent scientific investigation into new and novel diseases. The devil cancer is one of four documented wildlife cancers afflicting sub-populations of animals worldwide. The other species are the beluga whale in the St Lawrence estuary in Canada (Martineau *et al*., 2002), the California sea lion in San Francisco Bay (Ylitalo *et al*., 2005) and the green sea turtle in Moreton Bay, Queensland, Australia and elsewhere (Greenblatt *et al.*, 2005). All provide opportunities for scientific studies, but few scientists have investigated the role of environmental toxins in the initiation or development of the cancers. The focus here is on the devil cancer and the lack of toxicology studies. In the absence of scientific studies, knowledge production is hindered. Greater knowledge can reveal areas of ignorance worth investigating, but such opportunities are squandered if the ability to undertake studies is stymied.

In the following sections, an overview of the dimensions of the concept of ignorance is presented, situating undone science within the larger body of ignorance as non-knowledge. David Hess has been the key figure in developing and promoting the concept of undone science to describe the distortion of research fields (Woodhouse *et al*., 2002; Hess, 2004, 2007; Frickel *et al*., 2010). According to Hess (2007, p.9), undone science describes the studies that are not pursued for various reasons. To borrow his analogy, some lines of inquiry flourish, while others wither on the vine. A classification of reasons for undone science is then presented before the case of the Tasmanian devil cancer is used to show the relevance of the concept.

Ignorance

Ignorance exists at the border of current scientific knowledge and what is known to be unknown. Ignorance is particularly relevant when scientific research is conducted into new and emerging diseases, such as AIDS or SARS, because then research takes place within narrow boundaries of knowledge. In science, ignorance is the umbrella term for the general field that includes nescience and non-knowledge. There are only two main branches of ignorance: the deep ignorance of nescience, in which we are not even aware of what we do not know, and the knowable forms of ignorance, represented by the term 'non-knowledge'. Production of knowledge brings about a paradox – the more we know, the more we realise how much we do not know. 'Every state of knowledge opens up even more notions of what is not known' (Krohn, 2001, p.8141). Noting the dilemma, Socrates insisted that his wisdom lay in knowing what he did not know.

For Matthias Gross (2007, p.751) ignorance is 'knowledge about the limits of knowledge in a certain area'. Ignorance, therefore, necessarily constitutes a known gap in existing knowledge. There are also surprise events in research to which scientists aspire because they open windows to new and unexpected knowledge (Gross, 2010). Even though people may welcome the unexpected, 'they also seek to control, steer, or even reverse the surprising events' (Gross, 2010, p.5). Thus, surprises, like knowledge, present a paradoxical relationship: in the laboratory, surprises are welcome, but in the real world they are often not welcomed (Gross, 2010). In the devil cancer case, toxicology studies may have been abandoned to avoid surprise results which might have proved negative and therefore unwelcomed (Proctor, 1995; see also Martin, 1999b).

From a different perspective, Robert Merton (1968) sees that the unanticipated consequences of ignorance can sometimes have desirable effects, which he terms 'serendipity', an anomalous finding that gives rise to a new theory. Merton makes

ignorance a central theme in his deliberations and defines two types: unrecognised and specified ignorance. In a comparison between knowledge and ignorance, he states 'yesterday's uncommon knowledge becomes today's common knowledge and yesterday's unrecognized ignorance becomes today's specified ignorance' (Merton, 1987, p.10). Merton also recognises that new knowledge brings an awareness of more specified as well as unspecified ignorance. An example of current scientific ignorance is in the area of environmental pathways and modes of action of endocrine disrupters, synthetic chemicals that mimic natural hormones in living organisms (Myers *et al.*, 2001).

Unlike the examples of undone science described in Frickel *et al.* (2010), there have been no public calls from scientists or environmental groups seeking studies of environmental causes of the devil cancer. However, the need for toxicology studies to determine the possible role of a carcinogen in the aetiology of the cancer has been identified on a number of occasions. In 2005, the DPIPWE identified key areas for research, including the cause of the disease and a trial to test for a range of chemical toxins. In 2006, Pearse and Swift concluded that further studies were needed to reveal the disease's toxicology, progression and epidemiology. Many calls for more studies followed (e.g. McGlashan *et al.*, 2006; Harington *et al.*, 2006; Vetter *et al.*, 2008; Moore, 2008; Ross, 2008). Obendorf and McGlashan (2008) specifically requested 'a truthful investigation of the local environmental conditions that preceded the index outbreak' in the devil population. Finding polybrominated biphenyls (PBB) residue, shown to cause cancer in rats (US Environmental Protection Agency, 2010), in devil tissue in the pilot studies shocked Mariann Lloyd-Smith (co-chair of the International Persistent Organic Pollutants Elimination Network): 'although the sample of the recent study was too small for firm conclusions … the toxins weakened the immune system and might theoretically be a factor in the disease that threatens to wipe out the Tasmanian devil' (*Cosmos Magazine Online*, 2008).

Apart from isolated calls for further studies into the toxicology of the devil cancer, there were no public or environmental groups pressing for investigations. There were no counterpublics, 'a type of mobilized public opinion that is based on subordinate social positions that have emerged to contest "official publics"' (Hess, 2011). In the case of the Tasmanian devil cancer, official public views were informed by the dominant political, economic and civil society elites, which were largely uncontested. There was also an effective communication strategy adopted by the DPIPWE (Tasmanian Government, 2010). The strategy identified target audiences and communication tools. It also covered media management and coordination for all media releases and publications. Meanwhile, individual scientists who expressed doubts about the allograft hypothesis or the role of environmental factors (such as habitat destruction or the use of chemicals in plantations) in contributing to the cancer were silenced (Warren and Martin, 2014).

What might be called 'undone science' can be viewed as the negative space surrounding a body of research selected for study. Scott Frickel (2014), in an attempt to describe how we might study what is not there, compares undone science with an absence. As a category of non-knowledge, or an awareness of ignorance, undone science is divided into either positive or negative, depending on the results of the findings of the research when undertaken from different perspectives. As those who seek further knowledge are considered to have a positive attitude to research, it is only appropriate here to tease out why there would be a negative attitude to doing research. It is only from this perspective that practical or political reasons for undone

science are worth pursuing. Hence, in order to distinguish the political aspects of knowledge production, undone science can be categorised according to whether practical or political reasons exist for not undertaking research (see Figure 1).

Nescience

Gross (2007, p.751) categorises nescience as the 'lack of any knowledge: prerequisite for a total surprise beyond any type of anticipation …'. It is the complete lack of knowable ignorance of the existence of potential knowledge. It is what Ann Kerwin (1993) terms 'unknown unknowns'. It is similar to Brian Wynne's (1992) definition of indeterminacy when applied to environmental policy. Wynne (1992, p.119) views indeterminacy as 'the open-endedness in the processes of environmental damage due to human interventions'. Nescience is a complete unawareness of non-knowledge which can be made visible only in sociological analysis, when, like knowledge, its utterances, constructions or negotiations can be registered. Gross (2007, p.746) would disagree with the inclusion of nescience in Figure 1, believing that nescience 'belongs to a fundamentally different epistemic class from non-knowledge or ignorance' since it can be detected only in retrospect:

> No one can refer to their own current nescience because it is not part of their consciousness. … At most, people can refer to someone else's or their own earlier nescience. (Gross, 2007, p.746)

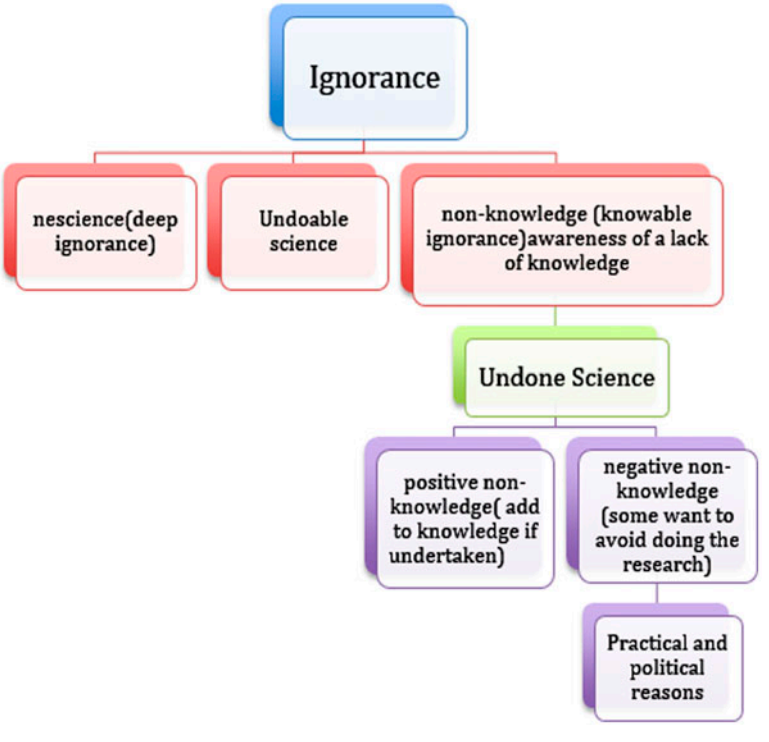

Figure 1. Categories of ignorance

The unanticipated and surprisingly detrimental outcome of the use of DDT is an example of nescience. Only in retrospect did scientists identify a lack of knowledge of the harmful effects of the widespread use of the chemical.

Non-knowledge (knowable ignorance)

Non-knowledge, according to Gross (2007), who groups ignorance and non-knowledge as connected, is defined as knowledge about what is not known. Gross (2007, p.749) further categorises it as 'knowledge about what is not known but taking it into account for future planning'. In a general crisis of knowledge, there has been an increased acceptance that ignorance and uncertainty in science exist. Consequently, it is necessary to know what is unknown. As an example of non-knowledge, Gross (2007) describes the state of knowledge in relation to the flooding of an abandoned brown coal strip mine in Germany. Engineers decided to flood the mine, aware of their lack of knowledge of the rate of ground water and runoff, with totally unexpected results (Gross, 2007).

Undoable science

Science can be undoable because of the constraints of existing methods or technology. However, science that appears to be undoable may actually be thwarted by insufficient resources and technical ability (Frickel *et al.*, 2010). An example is when scientists are faced with chemicals that act as endocrine disrupters (WHO/UNEP, 2013). These chemicals are dispersed from non-point sources throughout the environment. They are broken down into metabolites that add to the parent chemicals and mix with other chemicals in the environment. These chemicals may then work in synergy to enter organisms in ways often unknown, finally to interact with hormonal and other systems at the molecular level. Endocrine-disrupting chemicals challenge the boundaries of scientific knowledge and it is often only the harm they cause that is truly evident.

Undone science as negative or positive non-knowledge

In all scientific endeavours, there are scientific questions and problems which are not pursued because they are simply not seen (Kuhn, 1970). It is beyond the scope of most research projects to follow all avenues of enquiry. Consequently, a quantity of potential scientific research is left undone. This undone science is classified as non-knowledge, known ignorance. It can also be further categorised as either negative or positive non-knowledge when viewed from different perspectives. Negative non-knowledge is that which is stifled or avoided when viewed from the perspective of those who would think or feel intuitively that the findings of studies might produce results damaging to their interests. On the other hand, those interested in addressing environmental problems would perceive such undone science as positive non-knowledge because the findings could add empirical data to support their contention that industry or human activities are responsible for a perceived harm.

Reasons for undone science

By using a sociological approach that understands scientific knowledge as a social construction, undone science falls within the framework of a political sociology of science (Blume, 1974) in which knowledge development is shaped by political factors. For example, Proctor (1995, p.9) looks at 'why scientific tools are sharp for certain kinds of problems but are dull for others'. Frickel and Moore (2006) continue Blume's work through the development of what they call a 'new political sociology of science', exploring how institutions and networks shape knowledge production systems.

Hess (2009) asserts that a special sort of undone science frequently occurs when research pathways are selected and funded by elites in society, not for scientific reasons, but for political expediency. Thus, research agendas can be politicised, which requires a new framework of political sociology of science to analyse how knowledge is shaped, not only by the scientific communities, but also through industry and government influence. In order to distinguish the political aspects of knowledge production, types of undone science are organised according to whether there are practical or political reasons for not undertaking research (Table 1).

Practical reasons for undone science

Practical reasons for gaps in research, which form undone science according to Gross (2007) in his categorisation of knowledge, include non-knowledge, ignorance and nescience. Non-knowledge, ignorance and nescience describe gaps in the research, 'a deficit of research knowledge on health and environmental risks' (Frickel *et al*., 2010, p.5). These gaps in scientific knowledge or lack of research are attributable primarily to constraints in either technical knowledge or equipment. A deficit in theoretical framework would also inhibit progress in scientific research, resulting in knowledge gaps. Hence, the science is not necessarily avoided for political reasons or because it is deemed not worth researching, but because there are practical constraints on the research. Nescience as an unknown unknown falls easily into a practical reason for undone science. Non-knowledge as a practical reason for undone science relies on an awareness that the knowledge is not known, but there is no immediate pressure or desire to carry out the research. Negative non-knowledge, as opposed to positive non-knowledge, is more likely to occur for political reasons. Undoable science, when there are constraints arising from existing methods or technology, fits into the category of practical restraints on scientific research. There are practical reasons for undoable science, but the reasons are political if science is labelled undoable as an excuse; for example, if used by regulators or toxicologists to extend the registration of endocrine-disrupting chemicals.

Practical reasons for undone science, such as lack of funds or technical expertise, may also be adopted as a conscious political strategy to avoid undertaking particular research. For example, in the case of Tasmanian devil cancer research, there are few appropriate studies on the detection of atrazine. Toxicology studies were undertaken for the detection of atrazine in devil tissue and fat samples, which resulted in no detection. Atrazine is usually detected by analysis of urine samples (Zhou *et al.*, 2007). No reasons have been given why urine samples were not tested in Tasmanian devils, but a possible practical reason could be the difficulty posed in obtaining urine samples from devils in the wild. However, the researchers have trapped wild devils

Table 1. Reasons for undone science

Practical reasons	Political reasons
Non-knowledge – knowable forms of ignorance	Knowledge considered not worth exploring
Nescience – deep ignorance or unawareness of limits of knowledge	Uncertainty in science and in interpretation of existing research
Undoable science – limited resources or practical constraints	Forbidden knowledge – not funded on ethical grounds – stem cells, cloning
	Scientist-targeted research abandoned because of ethical concerns – weapons, nuclear
	Negative non-knowledge or harmful knowledge to mainstream – problematic, irrelevant or dangerous, incomplete, non-selected
	Self-imposed censorship: the chilling effect
	Suppressed knowledge – suppression of intellectual dissent
	Formal and informal manifestations of power – control or capture of research

across Tasmania to undertake other studies. Urine samples could also have been taken. It is likely that a practical reason for undone science is, in fact, a political strategy to avoid undertaking these tests.

Negative non-knowledge or forbidden knowledge

Undone science as a form of ignorance or non-knowledge can be perceived as dangerous knowledge by those who fund research, as with science left undone by elites (Hess, 2009). Undone science from the perspective of vested interests or those who do not want the research done is negative non-knowledge and consequently abandoned. In other words, the research is left undone for political reasons. In the case of the devil disease, toxicology results that may have identified dangerous levels of chemical residues in devil tissues constitute negative non-knowledge.

However, there are circumstances in which scientific research can be classified as negative non-knowledge for ethical reasons. It becomes forbidden knowledge and is not funded on ethical grounds. Science left undone or abandoned because it is considered unethical has included the testing of new designs for nuclear weapons and the cloning of human embryos. Because the science is considered too dangerous to pursue, pressure is put on governments and industry to leave it undone: 'more pragmatically, forbidden knowledge is produced when inquiry threatens powerful interests' (Kempner *et al.*, 2011, p.479). In Tasmania, scientific research into the devil disease has not been abandoned or left undone because of ethical concerns.

Uncertainty in science

When science is undoable because of either limitations in technology or non-knowledge, as is the case with the mode of action of endocrine-disrupting chemicals, it can lead to uncertainty in science. Knowledge limits can also be reached as a consequence of uncertainty in the interpretation of research results (Gunter and Kroll-Smith, 2007).

This uncertainty can stem from genuine disagreements among researchers 'because both the production and interpretation of "facts" rest on models and background assumptions that are open to dispute' (Gunter and Kroll-Smith, 2007, p.113). Uncertainty in science is often found in environmental problems where the complexities are extreme. This uncertainty can also provide reasons for delays in decision making by policy makers and regulators, resulting in benefits to vested interests. When science is conducted in a limited and secretive manner, uncertainty can be manufactured and used to the advantage of vested interests (Michaels, 2006). Meanwhile, openness and transparency in research and publication through peer review allow scientific uncertainty over research results and different interpretations of research to be openly debated, negotiated, mediated and resolved.

Censorship and the 'chilling effect'

Scientific research that is compromised by a lack of openness and transparency can produce a further two types of undone science: first, suppressed knowledge (when the science is done but not made public), and second, censorship (either by powerful elites or self-censorship). Suppression is restraint or inhibition without physical force, such as occurs when publication is blocked (Martin, 1999a). Martin finds that scientists avoid doing research if they expect to be attacked, and sees this as self-intimidation. Joanna Kempner (2008) agrees with Martin that intellectual suppression has been the focus of most censorship (along with distortion or manipulation of knowledge) in the intimidation and silencing of researchers. She also agrees that scientists frequently practise self-censorship, which she calls the 'chilling effect'. She finds that scientists themselves employ a variety of methods in order to self-censor, including:

- disguising the most controversial aspects of their research;
- removing 'red flag' words from titles and abstracts;
- deleting sensitive keywords;
- not publishing;
- making minor modifications;
- making omissions;
- reframing studies to make them less politically sensitive;
- dropping studies considered politically non-viable; and
- changing careers.

Suppression can occur through employment, where dismissal is threatened, or such actions as funding cuts, media campaigns and litigation are implemented to discredit and exhaust challengers (Hess, 2009). The worst suppression is reserved for high-status challengers, which has a chilling effect on not only targeted scientists, but also on sympathisers and challengers. Although Kempner (2008) finds no causal relationship between political controversy and self-censorship, she does find that the political environment might serve as a powerful force in shaping scientific research practices. Political controversy might also encourage scientists to avoid some areas of scientific inquiry, but no studies have formally investigated this possibility. Both Hess and Kempner call for an investigation into why certain science is left undone and what role political influence and controversy play.

Summary of practical versus political reasons for undone science

A typology of undone science enables gaps in scientific knowledge to be attributed to either practical or political causes. There are often practical explanations for the development of knowledge being inhibited, such as ignorance, nescience and non-knowledge about a subject area. Science is sometimes rendered undoable by the absence of technical capabilities and/or a lack of funding. The research genuinely cannot be carried out.

In comparison, political reasons for undone science – the absence of knowledge (Hess, 2009) – involve the shaping of research through the selection of particular pathways by those who fund the research. Political reasons for undone science include uncertainty in science, negative non-knowledge, research abandoned for ethical reasons, censorship and suppression of knowledge that has been produced. Uncertainty in science is often the catalyst for an increase in interest, but used by decision makers to delay action, it is political. Negative non-knowledge can result when the production of scientific knowledge is considered dangerous to vested interests. Political pressure brought to bear on government and industry for ethical reasons is less common; pressure through censorship and suppression of knowledge are more widespread.

Devil facial tumour disease (DFTD) case study

The Tasmanian devil is facing extinction from a fatal cancer, devil facial tumour disease (DFTD), first observed in 1996 in the north-east of Tasmania. It is a new and novel cancer, previously unseen in either humans or animals. Following a noticeable decline in devil numbers, the Tasmanian government, through the then Department of Primary Industries, Water and Environment (DPIWE), now with the addition of parks to its responsibilities (DPIPWE), convened an urgent meeting of wildlife specialists in October 2003 to develop a strategy to address the problem (Darby, 2003). The meeting excluded journalists, who were told they could not attend, talk to scientists or report on the meeting. No more than a brief communiqué was provided, and only to Hobart's daily paper.

In February 2005, DPIWE released *Tasmanian Devil Facial Tumour Disease (DFTD) Disease Management Strategy* (Tasmanian Government, 2005), reporting scientific consensus amongst researchers that the cancer was a neuro-endocrine tumour of unknown origin (Loh, 2006). In the same year, DPIPWE published a *Progress Report* identifying key areas for investigation – haematology, blood biochemistry, immunology, endocrinology and the aetiology of the disease. A viral aetiology was discounted because a test for virus particles had proved negative, but a trial of a statistically-valid number of tissue samples to be tested for a range of toxins was proposed (Tasmanian Government, 2005). Also recommended for future investigation were transmission trials for the passage of tumour cells to determine whether the cancer was transmissible.

The following year, it was proposed by Anne Mareee Pearse that the devil cancer is a transmissible tumour – an allograft – spread from devil to devil *via* biting when they mate or feed. The hypothesis was based on cytogenic research conducted at the Tasmanian government's laboratory in Launceston before any toxicology studies had been carried out. Pearse had observed a chromosomal anomaly in all the cells of one

devil that was not observable in any of its tumour cells as would have been expected had the cancer been initiated within its body. Pearse and her technical assistant, Kate Swift, published this finding, the basis for the allograft theory, in the prestigious scientific journal *Nature* (Pearse and Swift, 2006). Although proposing that it was a transmissible tumour, they acknowledged in their conclusion that a carcinogen may have been the initial cause of the disease.

Following the publication of this novel finding, the scientific research papers into the devil disease were listed on the DPIPWE *Save the Tasmanian Devil Program* website. As of July 2011, there were 52 publications.[1] All research had been overseen by DPIPWE and funded by the Australian and Tasmanian governments and by money raised publicly. As of 2009, Elizabeth Murchison, a former Tasmanian, had conducted the only studies outside Tasmania, at Cold Springs Harbor in the United States (Murchison, 2009). Initially, she had been refused devil samples for her analysis, gaining access only after her public protest. Many scientific studies into the devil cancer remain inconclusive, including transmission studies to confirm that the malignant cancer cells are capable of establishing in a new host. The precedent proposed for DFTD, the dog transmissible benign tumour, was uncovered in a study of 1876 (Murgia *et al.*, 2006). The focus here is on the abandoned and undone scientific research into the possibility that one or more pesticides or poisons used in Tasmania may be the primary cause of the devil cancer, or possibly a contributing factor in its continuation.

Methodology

The theoretical framework for this analysis is the concept of undone science, which Hess (2007) developed when analysing research in the areas of food production and medicine. In both areas, Hess found the majority of research undertaken focused on conventional methods while competing methods, such as organic food production and alternative medicine, were largely neglected.

To gain information about research on the devil cancer, local, national and international media were consulted for reports of conferences and meetings on the devil disease. Unstructured interviews were conducted with scientists engaged in the research. Many participants were guarded in their comments. Some interviews took place without the knowledge of the interviewees' supervisors. Requests for interviews with senior scientists were either ignored or rejected. Attempts to gain a better insight from the research scientists into why lines of enquiry were abandoned met with resistance or refusal. Some scientists were actively hostile in personal emails sent in response to an article in *Conversation* (Warren and Martin, 2014). Requests to accompany scientists on a publicised field trip (for which volunteers had been publicly sought) were denied.

The methodology eventually adopted was informed non-specialist assessment of the issues, examining why a competing hypothesis that environmental toxins used in forestry plantations, such as pesticides, was side-lined and then abandoned after an initial pilot study. The focus of the analysis was on the published scientific research into whether an environmental and/or manufactured toxin, acting as a carcinogen, played a causal role in devil cancer DFTD. Particular interest was in whether the case offered an example of practical or political reasons for undone science.

Toxicology studies into DFTD

The DPIPWE *Progress Report* of 2005 identified as necessary a pilot study of a statistically-valid number of tissue samples to test for a range of toxins to determine the aetiology of the disease. Following this pilot study, normal devil cell cultures would be exposed to 10 of the most commonly isolated toxins in amounts similar to those found in affected devils. Positive effects of the toxins on the cell cultures would indicate the need for a much larger project. In a new and novel cancer, these studies would have provided opportunities for innovative research, especially in the field of toxicology, but they remain to be carried out.

In 2004, a national dioxins programme looked at the concentrations of PCDD/PCDFs and PCBs in Australian fauna, but did not include Tasmanian devils amongst the marsupials studied (Correll *et al*., 2004). However, in the same year, the Australian government analytical laboratories published figures on levels of brominated flame retardants, in particular polybrominated diphenyl ethers (PBDEs), in Australian fauna (Symons *et al*., 2004). Detectable levels of PBDEs were found in all eight Tasmanian devils studied.[2] It was a surprising result as these chemicals had not been manufactured in Australia, but the authors noted an estimated 340 tonnes of PBDE are imported yearly. Pilot studies on Tasmanian devils were not carried out until 2007 and even then the research was extremely limited and expedient in execution.

In 2007, Simon Bevilacqua, a journalist with the *Sunday Tasmanian,* requested information about the toxicology studies for an article he wished to publish.[3] The studies had not been undertaken at that time, but in the following month, devil tissue was sent for toxicological analysis. The samples from eight diseased devils and eight non-diseased devils were sent from the DPIPWE Mount Pleasant laboratory to three separate government laboratories. All the laboratories were accredited through the National Association of Technical Authorities (NATA), a private body which is Australia's government-endorsed national authority. The laboratories were the National Measurement Institute (NMI) in Sydney, the Alan Fletcher Research Station in Brisbane and Analytical Services Tasmania (AST) in Hobart (see Table 2). The full results of these studies have never been published. However, Matthew Denholm of the *Australian* newspaper obtained the results through a freedom of information request. A limited version is now available on a SourceWatch website.[4] The NMI results were published in the journal *Rapid Communications in Mass Spectrometry* in 2008. Results from the other laboratories were not published. There were however two official opinions of the results published on the Save the Tasmanian Devil website.

The National Measurement Institute (NMI) and dioxin testing

The NMI is responsible for Australia's national infrastructure in analytical, biological, chemical and physical measurements. The NMI is able to carry out what it terms 'environmental analysis' into dioxins, organic pollutants, pesticide contaminants, as well as metal pollutants, microbiological contaminants and water (Australian Government, nd). Devil samples sent to the NMI were to be tested for only a limited range of chemicals. The tests DPIPWE asked the NMI to carry out were for dioxins (PCDD/PCDF in I-TEQ, USEPA method 1668A – Isotype dilution), polycyclic aromatic hydrocarbons (PAHs) (indicator benzio-a-pyrene PBDEs) and polybrominated biphenyls (PBBs).[5]

Table 2. Results of toxicology studies

Laboratory	Chemicals tested	Date of study	Conclusions
National Measurement Institute (NMI), Bob Symons	Dioxins – PCDD/PCDF, PAHs, PBDEs, organic pollutants, PBBs in fat samples	May 2007	Need for more studies into PBB residues found in devils
Alan Fletcher Research Station (Bob Parker)	Sodium fluoroacetate (1080) poison	May 2007	1080 residue not detected
Analytical Services Tasmania (AST)	Inorganic (arsenic, lead and mercury);	May 2007	Inorganic analysis (arsenic, lead, mercury) – less than 1ppm detected;
	organo-chlorines and metabolites;		organo-chlorines and metabolites – one devil above detection range (limit <0.20 ppb)
	organo-phosphates and triazine herbicides (including atrazine) – liver samples		organo-phosphates and triazine herbicides (including atrazine) – not detected

Vetter *et al.* (2008) published the test results from the NMI in the journal *Rapid Communications in Mass Spectrometry* in September 2008. They found concentrations of PBB153 in the range 0.3–11ng/g lipids in all but two devil samples. Levels were significantly lower than those causing toxic effects, but 'PBB concentrations were one level or even higher than PBDEs' found in the previous 2004 study by Symons and colleagues (Vetter *et al.,* 2008, p.4165). The Vetter *et al.* (2008) paper highlights the need for more detailed environmental PBB residue studies in devils. PBBs have been shown to cause cancer in rats and the international agency for research on cancer (IARC) has determined that PBBs are possibly carcinogenic for humans (US Environmental Protection Agency, 2010). Vetter *et al.* (2008) is the only peer-reviewed paper published on the toxicology studies. The authors claim 'the contamination status of Tasmanian devils with anthropogenic pollutants was investigated' (Vetter *et al*., 2008, p.4166). In support of this statement, they cite a newspaper article and the DPIPWE website. The newspaper article does not make reference to environmental contaminants, while the DPIPWE web link is broken.

Vetter *et al.* (2008) did not cite a paper that did document evidence of the need for an investigation into the possibility of a toxin-related aetiology from human land use activities in Tasmania. McGlashan *et al.* (2006) was published earlier in the year in the *European Journal of Oncology.* Coincidentally, Pyecroft, co-author of the Vetter article and head of the DPIWE laboratory in Launceston, also failed to cite McGlashan *et al.* (2006) in the journal *EcoHealth* (Pyecroft *et al.,* 2007). The reason for the omission is not known, but may be compatible with a chilling effect.

The failure to undertake further studies into the role that flame retardants found in the devil tissue might have had in the devil cancer not only suggests an avoidance of potentially dangerous knowledge, but also points to a lost opportunity for new knowledge. The hazards of flame retardants have only recently been recognised, although these chemicals are now ubiquitous in our environment. Innovative

toxicological studies in the fields of endocrine disruption and epigenetics have been denied to researchers.

Alan Fletcher Research Station – 1080 testing

Tasmanian devil liver samples were sent from the DPIPWE laboratory in Launceston to Bob Parker at the Alan Fletcher Research Station (AFRS) in Sherwood, Queensland for 1080 (sodium monofluoroacetate – used as a poison in baits) analysis. Australia has no maximum residue limit for 1080 (Australian Government, 2008). The results from the laboratory showed that 1080 was not detected in any of the tissue samples. This is not unexpected as the tendency of this chemical is not to accumulate in tissue post exposure (Twigg *et al*., 2003). Parker had requested fresh samples of stomach contents, liver and kidney, noting that tissue samples would be acceptable but not ideal.[6] There is no published report on the analysis undertaken at this laboratory. The Alan Fletcher Research Station has since closed. However, it appears there would have been scope to investigate the role of 1080 in the devil cancer had better protocols been established for measuring the chemical. Again, opportunities for innovation in research were missed when further tests on a chemical used in Tasmania, and plausibly involved in the devil cancer, were not undertaken.

Analytical Services Tasmania (AST) – testing of pesticides used in plantations

The critical analysis of the devil tissues for pesticides used in plantation forests was carried out in the AST laboratory for the DPIPWE. At the time, DPIPWE was also in charge of: monitoring chemicals used in forestry; funding devil research through the University of Tasmania; and analyses of chemical residue in the devil tissues. A conflict of interest is apparent when the body charged with promoting the forestry industry is also charged with monitoring chemicals in the environment and assessing chemical residues in devil tissues.

It is likely that samples similar to those sent to the other laboratories were also sent to AST. The AST is an accredited NATA laboratory for the testing of chemicals, but only in water and sediment – not in biological samples, such as devil tissue.[7] The analyses at AST were for endocrine disrupters, such as atrazine, which are usually detected in urine (Zhou *et al.,* 2007). It is also known that there are critical times in the development of an organism when these chemicals cause most damage. Effects may not be evident until later in life and in some instances only in the next generation (Myers and Hessler, 2007). Consequently, non-detection of an endocrine disrupter is not necessarily an indicator of lack of earlier harm.

The AST tests did not detect triazines (atrazine/simazine) or other pesticides. The study generated no negative knowledge (scientific research results which may prove harmful to vested interests or those funding the research). Finding any of the triazine chemicals in the devil tissue, although these chemicals are usually detected in blood and urine samples, would have implicated chemicals used in plantation forestry practices. Further toxicological studies of the effects of these chemicals on devils have not been undertaken. It can be argued that further studies into the role of these chemicals and the endocrinology studies identified in the DPIPWE report of 2005, should not be avoided simply because these limited tests resulted in non-detection. When tests for known endocrine disrupters, such as the triazines, result in lack of detection,

it must be decided whether further studies are required. This raises a further question: if the limit to detection has been reached, is this undoable science?

Scientific opinions on the toxicology results

The details of the chemical testing carried out on devil tissues at the various laboratories were not made public in Australia, but two opinion pieces appeared on the Save the Tasmanian Devil website, a joint initiative of the Tasmanian government and the University of Tasmania on 27 February 2008.[8] Hamish McCallum of the Department of Zoology at the University of Tasmania and head of the DFTD research project asked Michael Moore from the University of Queensland to provide an opinion on the results of the toxicology studies. In his response, Moore (2008) raised concern about the levels of concentrations of PCDDs and polybrominated diphenyl ethers (PBDEs). Although he states that the numbers tested were too low to be significant, Moore acknowledges that they warrant further study. He states that these chemicals are known for the suppression of the immune function and the perpetuation of cancerous cell lines.

A further opinion was sought from Tony Ross (2008), a veterinary pathologist. He was also asked to assist in the interpretation of the chemical results based on the statistical analysis carried out by McCallum at the University of Tasmania. Like Moore, Ross also suggested further studies into PBDEs were warranted as the effects of dioxins on marsupials (including devils) was not known. Ross notes that not all animals or tissues were analysed for all chemicals because of sample size and cost restrictions. However, PBDEs are ubiquitous in the environment as they leach out of finished products, such as furniture, computers, televisions and carpets, and can be found in landfill sites, whence they find their way into water, soil, sediment and the food chain, accumulating in higher predators and fish. Some PBBs that resemble PBDEs have been linked to higher risks of developing lymphoma and breast cancer (Siddiqi *et al.*, 2003). In conclusion, it was the expert opinion of both scientists that further toxicological studies on devils be carried out.

Practical limitations or political influence?

The toxicological analysis of devil tissue for chemicals used in plantation forestry was carried out in Tasmania by a laboratory that is closely connected to the DFTD research, not an independent laboratory. The University of Tasmania and DPIPWE work in close collaboration on the Tasmanian devil DFTD project. As a research and educational institution, the university receives substantial funding from the forestry industry and the Tasmanian government. Meanwhile, DPIPWE controls the use of chemicals, the monitoring of water, and manages the threatened species unit. The same Tasmanian government minister presides over DPIPWE and the Department of Industry, Energy and Resources (now the Department of State Growth), which regulates Forestry Tasmania, the Tasmanian Regional Forest Agreement and the Forestry Practices Code. In Tasmania, the DPIPWE, the University of Tasmania and the forestry industry form what Hess describes as the ‘elites’. DPIPWE and the University of Tasmania control both the funding and the scientific research into the Tasmanian devil disease DFTD. Vested interests are served when a scientific theory is dismissed unfairly or bias is displayed or double standards are used in evaluating theories (Martin, 2010). Political influence and the avoidance of negative knowledge rather

than practical limitations or undoable science were the reasons for restricting the tests at the Tasmanian facility.

Why test for chemicals?

Tasmania's economy is dominated by the forestry industry, particularly the production of woodchips, presently sourced from the controversial logging of native and old growth forests. Public pressure to conserve these forests prompted the intervention of the Australian Government (1997), and the expansion of plantation forests. Gunns Limited (2015), then the largest forest products company in Australia, alone developed over 200,000 hectares of plantations in Tasmania over 25 years (Beresford, 2015). Gunns also negotiated finance for a proposed $A2 billion pulp mill in the north of the state, which would rely predominantly on plantation timber. Plantation forests are now located in 44 of the 48 river water catchments in the state. The plantations are monocultures, relying heavily on pesticides to kill competing flora and fauna, mostly native species. Some of these pesticides, although designed to kill target species, are also known to cause harm, such as endocrine disruption and cancer, to non-target species.

Chemicals used in Tasmanian plantation forests are registered by the Australian pesticides and veterinary medicines authority (APVMA) (Australian Government, 2009). However, even this extensive list omits terbuthylazine, fluazifop and sodium monofluoroacetate (1080), all known to be used in Tasmanian plantation forests. The chemical compound 1080 is distributed throughout plantations to protect the eucalypt seedlings from browsing native animals. Although the lethal dose of 1080 for Tasmanian devils is high compared with the lethal dose for other native species, marsupial carnivores are the first to show signs of 1080 poisoning (Statham, 1996). The long-term effects have not been studied. Other chemicals of concern include the triazine herbicides – atrazine, simazine and terbuthylazine – and the chemical paraquat, all used to kill weeds. Atrazine is a known endocrine disrupter in frogs (Hayes *et al.*, 2003) and a suspected carcinogen in humans (MacLennan *et al.*, 2002). Simazine and terbuthylazine, with almost identical chemical structures to those of atrazine, are suspected of having the same harmful effects, although these suspicions are supported by fewer studies (US Environmental Protection Agency, 2006). Atrazine has been the focus of a controversy between the manufacturer Syngenta and its critics (Aviv, 2014). Paraquat, on the other hand, is acknowledged as the cause of serious ill health and even death in humans (Madeley, 2002).

This widespread use of chemicals has led to reports of surface and drinking water contamination throughout Tasmania (Davies *et al.*, 1994). Between 1989 and 1992, 20 of the sampled 29 streams draining plantation forests contained detectable residues of atrazine and simazine. Streams draining forestry land generally contain more pesticides than agricultural streams (Radcliffe, 2002). Chemicals used in Tasmanian plantation forests are registered for use by APVMA, which also determines what appears on the use label. However, it is the responsibility of state governments to monitor and regulate chemical use. In Tasmania, this is delegated to DPIPWE, the very department responsible for scientific research into the devil cancer.

Conclusion

In the case of the Tasmanian devil cancer, the toxicology studies that would prove most detrimental to the Tasmanian government's interests were first delayed and finally abandoned. Consequently, the potential for innovative research to discover the possible effects of environmental toxins on Australian native species, in particular the Tasmanian devil, has never been realised.

Toxicology findings indicating that chemicals used in plantation forests were responsible for the devil cancer would have been damaging for the forestry industry and the Tasmanian government (which depends on forestry jobs and votes) and the chemical industry (which depends on profits from the sale of chemicals used in plantations). For all three powerful elites, adverse toxicology results would have been negative knowledge. It was in their interests that further toxicological studies into the possibility that a carcinogen is involved in DFTD were not carried out. It is also possible that the prospect of political and economic fallout from adverse toxicological studies had a chilling effect on those making critical research decisions.

The limited scientific research into the Tasmanian devil DFTD has followed the research pathway determined by the allograft theory, that the cancer is contagious. The possibility that singular or multiple carcinogens in the environment might contribute to devil cancer DFTD has not been investigated as vigorously as it might have been. Initial toxicology studies, which remain statistically insignificant because of small sample size, revealed only PBBs in devil fat tissues. No further studies have sought to expand or replicate these tests. There are no practical reasons preventing further studies being carried out. The necessary studies are routine toxicological analyses that are regularly and easily done to identify environmental carcinogens. No knowledge currently exists on the effects of pesticides used in plantation forestry on native Australian marsupials.

A systematic analysis of the DFTD published research revealed only one paper reporting the findings of laboratory testing. No practical reasons have been found for delaying or abandoning the toxicology studies into the Tasmanian devil cancer. Applying the typologies of practical or political reasons for undone science suggests that political influence plays a role in directing the research agenda towards the contagious cancer hypothesis. A plausible reason why the toxicology pathway has been neglected is the likelihood that negative knowledge will be produced. The toxicological analyses of the devil tissues were revealed only after a successful freedom of information application. In major publications on the allograft theory, key papers linking the use of chemicals with the devil cancer are not cited. The possibility that political factors have played a role in these omissions cannot be excluded. The political controversy surrounding the continued contamination of surface and ground water, massive plantation expansion and the use of chemicals may also be contributing to self-censorship. The Tasmanian devil may well become extinct before the aetiology of this cancer is established.

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Notes

1. At the time my research was conducted, the list contained only publications up to July 2011. It was updated on 13 August 2015. List available from http://www.tassiedevil.com.au/tasdevil.nsf/Research/439C797EFD63B24BCA257761002EB4D0 [accessed February 2016].
2. PBDEs persist in the environment and accumulate in living organisms. Toxicological testing indicates that these chemicals may cause liver toxicity, thyroid toxicity and neurodevelopmental toxicity.
3. Email dated 23 April 2007.
4. A limited version of the toxicology results is available from http://www.sourcewatch.org/images/d/d3/Tasmanian_devil_POPs_residues_in_fat%28new%29.pdf [accessed February 2016].
5. Email from DPIWE to NMI dated 11 April 2007.
6. Email from Alan Fletcher Research Station to DPIWE, 25 May 2007.
7. Personal communication with National Association of Testing Authorities, Brisbane, Queensland, 19 May 2009.
8. Save the Tasmanian devil website. Although it states the two reports are available (see links below), Moore's report does not appear. Available from http://www.tassiedevil.com.au/tasdevil.nsf/TheDisease/01E084030D8DE533CA2576D200176CC3 [accessed February 2016].

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