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Perspective

Devil women

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Abstract. The Tasmanian devil, an iconic carnivorous marsupial, is at risk of extinction due to a contagious cancer called devil facial tumour disease. Saving any species from extinction requires strong partnerships between government agencies, zoo bodies and academia. The Devil Tools & Tech project brought these groups together under a single banner to achieve a common goal. The project has strong leadership from women. Here we tell our personal stories as to how we came to be involved in saving the devil and emphasise the importance of strong networks for women to reach their full potential.

Additional keywords: conservation, genetics, management, Tasmanian devils

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Introduction

The Tasmanian devil (*Sarcophillis harrisii*) is the largest remaining carnivorous marsupial, found only on the island state of Tasmania. Roughly the size of a Staffordshire bull terrier dog, devils normally live to 5–6 years of age in the wild and are predominantly nocturnal. While capable of taking sick and injured prey, the devil is typically a scavenger, making use of the plethora of roadkill on the Tasmanian roads (Owen and Pemberton 2011). In a normal healthy population of devils, females usually begin breeding at the age of 2 years (Guiler 1970), giving birth to a maximum of 4 four altricial young after a gestation period of ~21 days (Guiler 1970). These young, barely the size of a grain of rice, crawl up to the mother's pouch, where they will stay for the next 3 months, until they are too big for the mother to carry in her pouch and she deposits them in a maternal den. Here they will stay for the next 4 months, growing, playing and fighting with their siblings, and gradually making forays away from the den.

In 1996, a photograph was taken of a devil with large growths on its face in the north-east of Tasmania. This was the first evidence of the emergence of devil facial tumour disease (DFTD), a contagious clonal cancer (Loh *et al.* 2006; Pearse *et al.* 2012), which has now spread across 90% of the State. Over the past 15 years a large team of biologists, immunologists and geneticists have focussed on understanding what DFTD is, where it is and what effect it has on devil populations (e.g. (Woods *et al.* 2007, 2015; Deakin 2012; Ujvari *et al.* 2012; Siddle *et al.* 2013; Grueber *et al.* 2018; Lazenby *et al.* 2018). To date we know that DFTD is a clonal cell line (Pearse and Swift 2006) that is passed from one devil to another by cells sloughing off a diseased animal and passing to a healthy animal during fighting or mating (Hamede *et al.* 2013). Data suggest that DFTD originated as a random mutation in Schwann cells, found in the sheath around nerves (Murchison *et al.* 2010). The original devil with DFTD appears to have been female (Murchison *et al.* 2010). The biggest question surrounding DFTD has always been, why does the devil's immune system not mount a response against these cancerous cells when they are passed to the healthy individual (Siddle *et al.* 2007; Kreiss *et al.* 2011)? The story is complex but fascinating and something Professor Katherine Belov (Kathy) and her team have been focussing on for over 10 years (Siddle *et al.* 2007, 2013; Cheng *et al.* 2012; Morris and Belov 2013; Cheng and Belov 2014; Morris *et al.* 2015). Over the past 20 years DFTD has spread from the north-east corner of Tasmania, to cover almost the entire State. Currently, the north-west corner and the south-west World Heritage Area are the only known disease-free areas (Save the Tasmanian Devil Program, unpubl. data). Classically, once DFTD has been present in a population for a period of several years, the demographics of the population change as the older cohorts succumb to the disease (Jones *et al.* 2008). Populations are now reduced to ~5% of their original abundance, and animals over the age of 2 years are rare (Lazenby *et al.* 2018). Females begin breeding earlier, at the age of 1 year, and the average number of pouch young produced has increased (Lazenby *et al.* 2018).

In 2003, following a State-wide survey of devil populations, the Save the Tasmanian Devil Program (STDP) was created as the State and Federal Governments response to the spread of DFTD and the decline of the Tasmanian devil. The devil is now listed as Endangered under Australian Commonwealth legislation (*Environment Protection and Biodiversity Conservation Act 1999*), Tasmanian State legislation (*Threatened Species Protection Act 1995*) and the IUCN Red List of Threatened Species (Hawkins *et al.* 2006). The initial response from the STDP was to try to understand what effect DFTD was having on devil populations over time, and where the moving 'front' of the disease was. State-wide monitoring using trapping, spotlighting, remote camera surveys and reports from the public showed the extent of the disease and the decline of devils (Hawkins *et al.* 2006). An effort to remove DFTD from a population by culling all individuals exhibiting signs of DFTD only served to remove those individuals who would die anyway, quicker (Lachish *et al.* 2010), and changed the evolutionary trajectory of the disease (Ujvari *et al.* 2014). Without a preclinical test to determine which animals were carrying the disease before they showed clinical signs, any hope of removing the disease from a population is currently futile (Lachish *et al.* 2010; Beeton and McCallum 2011).

In 2006, a captive insurance population of devils was established (Hogg *et al.* 2017*b*), as modelling showed that devils would be extinct within 25–30 years (McCallum *et al.* 2009). The idea was to house devils in captivity, away from the disease, and to repopulate the wild once the devils and DFTD had died out. What started as a population of 40 devils in four zoos in 2006 is now a metapopulation with over 700 devils living in 37 zoos (intensive and group housing), free-range enclosures and an island (Hogg *et al.* 2017*b*). To enhance the large insurance metapopulation the STDP created a healthy population of devils on Maria Island (a small island off the east coast of Tasmania) from a small group of founders from the zoo-based insurance population (Thalmann *et al.* 2016; McLennan *et al.* 2018). This isolated population, which is part of the metapopulation, is now being used to supplement diminished wild devil populations on mainland Tasmania as a part of the agency's Wild Devil Recovery project, to ensure devils remain a viable and functional predator in the wild.

The STDP work closely with the team at the University of Sydney (USyd) and the Zoo and Aquarium Association (ZAA) (who manage the zoo-based insurance population on behalf of the STDP) to ensure the maintenance of genetic diversity and the persistence of devils in both the insurance metapopulation and the wild. The Devil Tools & Tech project, started in 2012, is a collaboration between the STDP, USyd, the ZAA and San Diego Zoo Global (SDZG). The premise of the project is to provide research findings in real-time, 'from the lab bench to the forest floor', without the need to wait for lengthy peer-review (Hogg *et al.* 2017*a*). In essence, our teams share the latest data regularly so that each can build on the other's body of work without delay. This requires a significant level of trust, and excellent communication and collegiality. We are not located in the same city, state or even country so we maintain this regular communication over the phone, email, Skype and, as often as possible, in person. The Tools & Tech team consists of many people, who have and still make significant contributions, but here we discuss our personal stories on how we became 'Devil Women' and integral players in the Devil Tools & Tech project.

Professor Kathy Belov – Pro-Vice Chancellor and Professor of Comparative Genomics (University of Sydney)

I did a biology degree at Macquarie University, largely because I liked biology and I wasn't sure what else I would like to do. After I completed my Honours degree I was still a little directionless. I had majored in genetics and molecular biology, but still wasn't hooked on a particular area. After University I got a job with Professor Des Cooper at Macquarie University managing his laboratory. At the time his laboratory primarily focussed on both human and animal genetics. I spent some time doing routine genetic analyses, gainfully employed, but still uninspired. Then a colleague of Des' (who will remain nameless) commented in my presence that marsupials have 'a primitive immune system'. This didn't make sense to me. Marsupials have been around for millions of years, why should their immune system be inferior to ours? This single question had me hooked. I started looking into immunity in marsupials and continue this work 20 years later.

When I started in 1997 I began characterising immune genes, one by one, the old fashioned way, by making and screening cDNA libraries to identify transcripts. Soon I characterised IgM, IgA, IgG and IgE (Belov *et al.* 1998, 1999*a*, 1999*b*, 1999*c*). As I predicted, these genes were present in marsupials, it was just that their sequences were quite divergent from those in eutherians, so off-the-shelf antibody reagents did not cross-react. The *Monodephis domestica* genome was published in 2007 (Mikkelsen *et al.* 2007) and that fast-tracked my research. No longer was cloning required. We quickly annotated the major histocompatibility complex (MHC) (Belov *et al.* 2007) and other immune gene clusters within the genome (Wong *et al.* 2006), and discovered highly divergent immune genes, including cytokines (Wong *et al.* 2011). We also discovered novel antimicrobial peptides that had expanded within the genome via gene duplication (Wang *et al.* 2011; Peel *et al.* 2017). We have since shown that these independent gene expansions have occurred in different marsupial and monotreme lineages and that these peptides are expressed in the mammary gland, in the pouch (in marsupials that have a pouch) and skin of the young themselves (Peel *et al.* 2017). These peptides are powerful antimicrobials and hold great potential as novel antibiotics for humans and other animals.

The opossum was the first of the marsupial and monotreme genomes published – but my team has been quick to jump onto new genomes to characterise immune genes. We used the opossum (Mikkelsen *et al.* 2007), platypus (Warren *et al.* 2008), tammar wallaby (Renfree *et al.* 2011), Tasmanian devil (Murchison *et al.* 2012) and, most recently, koala (Johnson *et al.* 2018) genomes to gain insights into the evolution of immunity and its applications to conservation.

In the case of the devil, we started characterising immune genes the old-fashioned way back in 2006, as the genome wasn't published till 2012. For me, it started when I read Anne-Marie Pearse and Kate Swift's *Nature* paper ('Allograft theory: transmission of devil facial-tumour disease') in 2006 (Pearse and Swift 2006). They had shown that the tumour cells are transmitted between individuals as allografts. The first thing that came to

mind was we should look at MHC genes! The MHC is the key region of the genome involved in immune response against disease, but it is also the region of the genome that is involved in graft rejection. Since devils have been through repeated genetic bottlenecks (Jones *et al.* 2004) it would make sense that diversity in a key region of the genome that was involved in graft rejection could be low. The reason that this idea popped into my head so readily is that as an undergrad I learned about the famous skin graft experiments Steve O'Brien and his team did on cheetahs (in 1985) to demonstrate that cheetahs, too, have low MHC diversity (O'Brien *et al.* 1985). Together with my first PhD student, Hannah Siddle, we discovered the first devil MHC genes and then showed that MHC diversity in devils is low. We published this work in 2007 (Siddle *et al.* 2007) and I have been hooked on devils ever since.

The MHC story gets a little more complex. Together with Greg Woods and his team we showed that low MHC diversity alone does not prevent skin rejection (Kreiss *et al.* 2011). Hannah went overseas to the University of Cambridge to show that the tumour cells also downregulate cell surface MHC, and that is how they slip under the radar of the immune system (Siddle *et al.* 2013). Another formidable Australian woman, Elizabeth Murchison, from the University of Cambridge, led the sequencing of the devil genome (Murchison *et al.* 2012). This opened a plethora of genetic and immunogenetic studies that could be undertaken.

Over the years I have had the pleasure of mentoring a team of amazing women in my laboratory – Hannah Siddle, Claire Sanderson, Emily Wong, Camilla Whittington, Beata Ujvari, Amanda Lane, Yuanyuan Cheng, Katrina Morris, Catherine Grueber, Vanessa Barrs, Mette Lillie, Belinda Wright, Emma Peel, Rebecca Gooley, Jian Cui, Jolanta Marzec and many others. Together we have uncovered all sorts of remarkable things about the genetics and immunology of Australian animals. Their achievements are truly impressive. They have won scholarships, fellowships, awards and made significant contributions to science. Several have now started their own laboratories.

When I started my research, it was largely academic. I was interested in understanding how the immune system evolved. But, in 2010, Carolyn Hogg entered my life. Carolyn had just started working at the ZAA and had taken on managing the devil studbook. She had been told I worked on devil genetics and wanted to understand the genetic relatedness of the founders that had been brought into the STDP insurance population. We have been collaborating ever since. Carolyn has opened my eyes to the importance and advantages of working side to side with industry partners. Carolyn now manages my laboratory and the research we do is much more applied (and useful!).

Over the years we have strengthened our links with industry partners, including the STDP, and started to design projects together. This makes for a much happier partnership as everyone is invested in seeing the project succeed.

I have been very fortunate during my career to be supported by Australian Research Council (ARC) funding, industry funding from STDP, SDZG and the ZAA, as well as fellowships from both the ARC and USyd. This support meant that as well as building a strong team in the laboratory, I was able to progress through university ranks quite quickly – and now hold a leadership position at the University – Pro-Vice-Chancellor (Global Engagement). The devil program (and the Devil Women in particular) helped me to develop the skills I needed to work in such a role. The program brings together a range of people – field biologists, vets, immunologists, geneticists, ecologists, cancer biologists, stakeholders from zoos and government. Collaboration is key. With many passionate people in the room, discussions can be robust. But the rewards are immense. Knowing that we are releasing vaccinated devils back into the wild is very satisfying.

Dr Carolyn Hogg – Research Manager (University of Sydney), previously the Tasmanian Devil Species Coordinator (Zoo and Aquarium Association)

I grew up in South Africa where watching wildlife was a national pastime. Australians go to the beach for holidays; South Africans go to the bush. I was fascinated by all animals and how they interacted, how they lived, bred, fed, moved through their landscape and how they interacted with the biological system around them. I had a particular fascination for big mammals. After immigrating to Perth with my family in the 1980s, my passion for big things grew to the marine mammals as, let's face it, most Australian mammals are small, brown and furry. This led me to major in marine biology and zoology at the University of Western Australia. Sadly, my passion for all things whale was not shared by academics within the School of Zoology, and so upon gaining employment to undertake whale research in Hawaii and Queensland at graduation, I switched to Murdoch University for a part-time Honours degree. I never really aspired to be an academic but rather a field biologist who could work outside in the environment to answer questions. My time in Hawaii and Queensland led me to working in small research jobs in Alaska and Canada before landing a research position in Nova Scotia. I spent four summers in the Bay of Fundy working with the North Atlantic right whale in the late 1990s – the most endangered whale species on the planet. My role encompassed field surveys, aerial surveys and working as a responder for disentanglements. In 2000, the International Whaling Commission released a report stating the three causes of declining northern right whale populations was due to ship strikes, entanglements in fish gear and inherent reproductive failure (Reeves *et al.* 2001). The last one piqued my interest. How could we possibly measure reproductive failure in a free-swimming whale? Other whale researchers at this time were just commencing research into non-invasively collected faecal samples (Rolland *et al.* 2005). However, this method could not be used for assessing whales in the Southern Hemisphere as the baleen whales in the Southern Hemisphere are feeding (and defaecating) off Antarctica, but breeding off Australia, South Africa and South America. Surely, you would want to measure reproductive hormones where they breed! After being 'snotted' on by many a whale over the years, I knew that there was something in the blow (exhalation when the whale surfaces). Whales have large lungs, and use ~80% of them. This massive volume of air is expelled rapidly through two (in the case of baleen whales) relatively small blowholes. When you get blow on your sunglasses, you can feel the mucosa in the blow along with the water. What if we could use blow to assess hormones and

microbiota of free-swimming whales? So began my PhD journey. I returned home to Australia after being gone for 7 years to undertake a PhD with the Australian Marine Mammal Research Centre, a joint research initiative between the Faculty of Veterinary Science, University of Sydney, and Taronga Zoo. Like many PhD students, I was ambitious and clueless in the ways of the scientific world. I thought if you wanted to do a project, found your own money and had an original idea that you would be welcomed with open arms. However, this was not the case, as there was a small contingent of Australian marine mammal researchers who believed that all I would test was water quality and that I would not achieve a PhD. Three and half years later I was glad to prove them all wrong – not only did I find hormones in whale blow (Hogg *et al.* 2005, 2009), I theorised that we could use it to collect DNA and study microbiota using it (Hogg 2005), and won two awards from the International Society of Marine Mammalogy for my work.

What to do now? I had a PhD but did not want to move back overseas after having been away for so long. My problem was solved when I started working as a research associate with my PhD supervisor, Tracey Rogers, on leopard and elephant seals (Rogers *et al.* 2005; Constable *et al.* 2006; Tripovich *et al.* 2011). During this time the laboratory group moved from Taronga Zoo to the University of New South Wales, I had my first child, and life was good. Whilst pregnant with my second child I had a career crisis. I was based at a university watching other women in my cohort struggling to juggle parenthood with early career academia. Is this what I wanted for my life? I was not afraid of hard work or long hours, anyone who has done field work understands this, but did I want to work that hard and that many long hours and not see my small kids. It was at this time I made the heart-wrenching decision to turn my back on my research aspirations and find something else that would fulfil my need to work with wildlife, use my scientific training and be there for my kids. I took on a 6-month role with the ZAA rewriting their Australasian Species Management Program documentation (Hogg *et al.* 2013) and other policy work in relation to government and the recovery space (Hogg 2013). ZAA asked if I would stay in a more permanent role, but one in species management. 'Sure, I can do that!' was my reply. My 'training' in species management was to undertake the Tasmanian devil breeding recommendations in 2010. Talk about baptism by fire! Here was the largest recovery program that the zoo industry was involved in, with 24 zoos and 350 devils in captivity. During this time, I thought I would be helpful to the then Tasmanian devil species coordinator, Chris Hibbard, and analyse the Tasmanian devil studbook as there were several zoomours (zoo rumours) in regard to breeding and productivity of devils that did not make biological sense to me. Little did I know what path I was about to start on.

One of the underlying assumptions of species management is that all founders in a population are unrelated. This concerned me, as a preliminary map we had made showed that the founders of the devil insurance population were predominantly from the north-west of Tasmania (Hogg *et al.* 2015). I was informed 'Kathy Belov at Sydney University does devil genetics – go speak to her'. So I contacted Kathy in 2010, having no real idea of who she was or what she actually did, and asked if she would be able to assist me in answering the question 'How related are the Tasmanian devil founders for the insurance population?' How that one little question changed things for both Kathy and me. For me it opened my eyes to the power and complexity of molecular genetics. So many of the questions that I have had over the years could start to be answered by new molecular methods. For Kathy, it opened her eyes to the importance of having academia and conservation managers working more closely together to provide information in real time. The seeds for 'Tools & Tech' had started to germinate. Later that year I was able to secure funding from San Diego Zoo Global to fund a postdoctoral position (Catherine Grueber) at USyd with Kathy's group on Tasmanian devil research. Minor problem was we needed better engagement with the STDP to make my dream of academia and conservation managers working hand in hand a reality (Hogg *et al.* 2017*a*). Kathy and I flew to Hobart in late 2011 to meet with the STDP, including Sam Fox. We decided to work on one small project together, the management of Tasmanian devils on Maria Island and so 'Devil Tools & Tech' was born! Much of our work in the early years was focussed on the insurance population (Farquharson *et al.* 2017; Gooley *et al.* 2017, 2018; Hogg *et al.* 2017*b*), and making it better. Now that we know Tasmanian devils are persisting in the landscape we are working more and more closely with the STDP on all aspects of the metapopulation. Devil Tools & Tech is now a large collaboration that started small with few funds. It took time to build trust between the teams at the STDP, ZAA, SDZG and USyd. Working in Sydney, I needed to have a better understanding of the needs of the STDP and so I started to visit Hobart one day a quarter in 2011. By 2016, when I left ZAA and moved over to the USyd, I was in Hobart every 2 months for 3–4 days, as well as participating in field trips. We have never looked back.

My journey to being a Devil Woman is long and more convoluted than others. However each experience, whether living on a lobster fishing island in the Bay of Fundy, Canada, to the frustrations of proving whale blow can be used for a multitude of biological measurements or juggling a family and a career in science – all of these have led me to be the scientist I am today. These experiences have taught me to be persistent, be open-minded, ignore the naysayers, and work with those you trust who have the same visions as you. Above all, communication is the key to our success!

Dr Samantha Fox - Team Leader, Wild Devil Management and Monitoring (Save the Tasmanian Devil Program)

I started my University education late, choosing to spend a few years travelling before starting my BSc at Auckland University. The main reason for the delay was that I didn't know what I wanted to do with my life. I knew I wanted to work with animals but I didn't want to spend 5–6 years at University becoming a vet. Ironically, I ended up spending 8 years studying! It wasn't until I met a couple studying elephants for their PhDs in Namibia that I thought, yeah, I could do that!

Auckland University is a large campus in the middle of Auckland city, and after spending 2 years living in Namibia, it was a bit overwhelming. So after my first year, I chose to move to Australia, and a smaller town and campus – James Cook University in Townsville. I spent 12 years there, finishing my

undergraduate degree, doing an Honours year (on mate choice in Gouldian finches: Fox *et al.* 2002), spending 3 years working as a research assistant in the Wet Tropics on everything from frogs, to birds to mammals (Williams *et al.* 2003, 2010), and then finally completing a PhD on a vulnerable species of flying fox, the spectacled flying fox (Fox *et al.* 2007, 2008*a*, 2008*b*, 2012; Richards *et al.* 2008; Luly *et al.* 2010).

I had moved to remote New South Wales, was still teaching field studies for James Cook University on the odd occasion and was looking for more permanent work, when a friend sent me an advert for a Wildlife Biologist position working with Tasmanian devils, saying 'you should apply for this, you could do it with your eyes closed!'. I nearly didn't. I thought every man and his dog would apply for it. As it turned out, nearly every man and his dog *did* apply for it, but I still got an interview … unfortunately on a day when I was travelling to Townsville to go in the field to do some teaching. So I did my interview on the phone, sitting on the ground outside Brisbane airport under the airtrain, with people walking past me every few minutes. Afterwards I didn't give the interview or the job much thought, as I didn't think I had done well. I went in the field and returned a week later to find five messages on my phone from Tasmania, asking me to please return their call as soon as I could because they needed to know if I was still interested in the Wildlife Biologist job.

That was 10 years ago. Within a year of taking on the Wildlife Biologist position I became Team Leader for the Wild Devil Management and Monitoring team, and I now manage a team of eight biologists and field officers, and help run the STDP, the Tasmanian State Government–run conservation program to save the devil. My position within the program is incredibly varied and very busy. I still spend time in the field, as a regular wildlife biologist, but my time in the office has a stronger management theme to it than other biologists. I write funding proposals to secure State and Federal funding, I oversee the budget for the program, I manage our field schedule and most of our on-ground field projects, I am regularly involved with the communications and media side of our program, and I am heavily invested in working with stakeholders and collaborators. Regular administration and staff management also takes up ~30% of my time. And, importantly, for many of our collaborations, I oversee all of our sample collection in the field and ensure samples are collected correctly and are sent to the right recipient.

As the management agency tasked with actually solving a conservation issue and doing something about it, we realise that we are not going to have all the information we need at our fingertips when we need it, and for some management agencies this is enough not to act. We also know that we will not always have the resources, including the skills, required to bring that information to bear. So collaborations are critical to agencies like ours. One particularly strong collaboration, the Devil Tools & Tech project, has enabled us to take advantage of current knowledge as it is discovered, without having to wait for the manuscript to be published! From this collaboration, not only have we been provided with up-to-the-minute information that is important for our adaptive management decisions moving forward, but many researchers, including PhD students, have been able to take advantage of having samples collected on their behalf from a cryptic endangered species, from populations around the State of Tasmania, throughout the year, without leaving their laboratory in Sydney. There has to be give and take from each collaborator, and as the management agency, our time in the field with wild devils has enabled us to provide valuable and vital devil and tumour samples to Kathy's laboratory in Sydney for them to answer questions they are interested in, as well as questions that we are interested in. We also have years of intimate knowledge of devil ecology and behaviour to be able to help interpret data in a wholly organic way. This trust and understanding between all parties has resulted in a win–win situation for all.

For me, one of the greatest surprises I have had in my job as a wildlife biologist, is that I get great enjoyment working with people. The strong friendships forged through some of my collaborations are one of the most important aspects of my job to me. Working in the field with devils is, of course, one of those rare and wonderful things that a lucky few of us have experienced, and will never forget. But don't underestimate the significance of working with like-minded people, with different skills to enhance what you are trying to achieve. Historically, the field of biology was dominated by men, but that is changing. For women, creating those strong networks through collaboration is not only common sense to enrich your own work and working environment, but it also broadens your personal and social environment. Special working relationships such as these do not just become pleasant memories, but often forge strong friendships that last lifetimes.

Dr Catherine Grueber – Research Fellow (University of Sydney)

There was a time, in the early 1990s, when primary schools would raise layer chicks in the classroom, and families would take the adult hens home as pets. In suburban Christchurch, New Zealand, my young self collected every egg laid by our two backyard chooks, weighed it, and wondered whether the eggs would get bigger as the birds aged. Should I include the double yolkers? (I didn't know the word 'outlier' then). My affinity for biology, and my curiosity for understanding how nature works, have been fundamental aspects of my personality for my whole life. I guess you could say I've always been a nerd!

With biology as my best subject in high school, the adults in my life supported my early interest in medical school. So at 18 I left home for Dunedin and the University of Otago, to claim my place as a 'scarfie' in First Year Health Science. But my attention was quickly diverted by evolutionary and wildlife biology, and I changed my major to Zoology & Genetics. Although I found those topics fascinating, I was still not sure what I wanted to do with my life. One day I sat outside the office of my favourite lecturer, Professor Ian Jamieson, and waited for him to come back from a meeting so I could organise a Master's project. I still remember his face when he saw me and asked if I'd made an appointment. I hadn't (oops!). But I was prepared, and had read all of his papers. Perhaps it was at that moment that Ian realised I might have the right combination of traits for a career in science, so he took me on. It was a mentoring relationship that was to last 14 years, until Ian passed away in 2015.

Through my PhD with Ian, I discovered that there were a lot of unanswered questions in conservation biology that we could start to address with genetics. From the very applied, such as

'how big does a population need to be?', to the more fundamental, such as 'when can we expect natural selection to occur in small populations?'. With Ian, I also developed an appreciation for the challenges faced by practical conservation management, through his many connections with the New Zealand Department of Conservation and, in particular, the Takahe Recovery Group. Ian's passion for science that makes a difference was contagious.

My work in New Zealand covered many fascinating threatened bird species: takahē, South Island robin, kākāriki, Chatham Island black robin, and many others. These projects began by answering questions about inbreeding, because many of the populations we studied were very small. We showed that even inbred populations still need management to prevent further inbreeding (Grueber *et al.* 2010; Kennedy *et al.* 2014), leading to practical changes in the way species are managed (Grueber *et al.* 2012). I discovered the power of using computational (Weiser *et al.* 2013) and statistical modelling (Grueber *et al.* 2011) to address tricky biological questions: with the right idea and analysis, even a sample as small as three birds might be informative (Grueber and Jamieson 2011). All of the species I studied face unique conservation challenges, but I started to notice similarities too. Conservation geneticists had largely used neutral markers (e.g. microsatellites) to answer their questions, because functional regions were difficult to study. With Ian's encouragement, I developed sequencing protocols for innate immunity toll-like receptor genes, transforming the way we study functional diversity in birds (e.g. Grueber *et al.* 2015, 2017; Knafler *et al.* 2016). New technologies are now making it easier to study and understand more and more of the genome (e.g. Wright *et al.* 2015), and I became increasingly interested in the role of evolutionary processes in conservation (e.g. Grueber *et al.* 2013; Farquharson *et al.* 2018).

Like many people, I have faced challenges along the way – my PhD journey was abruptly interrupted for a year by cancer – but the support of my mentors (not to mention a persistent feeling that I wouldn't want to be doing anything else!) has encouraged me to continually renew my resolve and push the limits of my potential. For my PhD research, I was awarded the D. G. Catcheside prize by the Genetics Society of Australasia, which afforded me the opportunity to present my work at the Society's annual meeting in Australia. It was there that I first met Kathy Belov, and learnt about the incredible problems faced by the Tasmanian devil. Later, when Kathy visited Otago, we discussed submitting a grant application that would enable me to join her team. The grant was not funded, but in the meantime another opportunity had come up, so that before long I relocated to Sydney to join the Devil Tools & Tech project, in collaboration with San Diego Zoo Global and the rest of the team.

Joining the devil project has been fantastic – it is a large program, full of clever people that each bring a unique set of skills. From my perspective it is this diversity that makes the project so powerful. The devil is a fascinating and important animal, and the enthusiasm amongst the team is tangible. Of course, we do not all have the same goals all the time, but communication allows us to work together effectively. In my current role, under the mentorship and guidance of the wonderfully successful people around me, I have been fortunate to see my own research team grow too. Helping PhD students follow their passion, overcome difficulties, and learn how to be scientists, is one of my favourite parts of the job. Every student has something different to learn and comes with a unique perspective; often I'm sure that I learn just as much from them as they do from me.

Throughout my career so far I have learnt to be open to chance encounters. We never know where opportunities are going to come from, so I try to keep a curious mind when I meet other biologists, go to talks, and hear about the work of others. The most intriguing new ideas happen at the intersection of old ideas. I count myself lucky to spend my days grappling with fascinating questions and working with great people, in a career of learning and discovery.

Conclusion

We believe that the Devil Tools & Tech project has been successful because of the strength of our team. You have read our personal stories. There are many other men and women also involved in saving devils and we salute them. We hope that the way we have built the team with a strong sense of trust (and friendship) will serve as a blueprint for others working in endangered species conservation (Hogg *et al.* 2017*a*). Along the way we have all met our 'dementors' (the opposite of mentors) and, chances are, so will you. Having a strong network of like-minded collaborators will help you to survive and then thrive.

Below we have some words of advice for young women aspiring to careers in conservation – we hope they help.

1. Follow your passion. For Kathy it was understanding the genetics of immunity (but cuddling devil pups is a close second), for Carolyn and Sam it was about being wildlife biologists, and for Catherine it was tackling evolutionary genetics problems in conservation.
2. Seek out great mentors to help you find your way (just remember to make an appointment and be prepared!). We were lucky to have people like Des Cooper, Jenny Graves, Marilyn Renfree and Ian Jamieson to support our early careers in science.
3. Join a great team and work with people who inspire you.
4. Keep an open mind. We can learn a lot from one another: our collaborators, peers, mentors and students alike all have something to teach us.
5. Be visible. We must admit this was initially a terrifying concept! But to win grants, people need to know you and your research. So get out to conferences; talk to the media. Make sure you are seen.
6. Be brave. There will be setbacks and criticisms, so try to take these as constructive, not negative. Every one of us has missed out on grants, had many papers rejected, and had projects that didn't go to plan. Science is a difficult field, as you pour so much of yourself into your work that the reviews and criticisms can feel personal. Keep perspective, aim to do your best work always, and ignore the naysayers.
7. Volunteer. There is a shortage of jobs/careers in conservation so you must stand out from the crowd. The best way to do this is to volunteer on many and different projects. This not only provides you with new skills, it also shows that you are keen and proactive, all important characteristics to a prospective employer.

8. Laugh! Find collaborators of like mind, those who you not only enjoy working with but who you can have a drink and a laugh with. Life really is too short for anything else!

Conflicts of interest

The authors declare no conflicts of interest.

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