Tasmanian Devil PHVA
Final Report

3-6 July 2008
Tasmania, Australia

SAVE THE TASMANIAN DEVIL
www.tassiedevil.com.au

Tasmania
Explore the possibilities

TARONGA
CONSERVATION SOCIETY AUSTRALIA™

CONSERVATION
BREEDING
SPECIALIST GROUP

Cover photo: © Roger Smith

A contribution of the IUCN/SSC Conservation Breeding Specialist Group

CBSG. 2008. *Tasmanian Devil PHVA Final Report.* IUCN/SSC Conservation Breeding Specialist Group: Apple Valley, MN.

To order additional copies of *Tasmanian Devil PHVA Final Report*, contact the CBSG office: office@cbsg.org, 001-952-997-9800, www.cbsg.org.

Dedication: Dr. Eric Guiler

This workshop is dedicated to Dr. Eric Guiler, who died on the first morning of the workshop at the age of 85. Dr. Guiler was born in Ireland and moved to Tasmania in 1947 to work at the University of Tasmania, which now offers three wildlife scholarships in his honour. He was soon recognised as the pre-eminent expert in marsupial ecology, with a passion for Tasmania's wildlife. His species of special interest was the Thylacine, but Dr. Guiler's seminal research into the Tasmanian devil also remains relevant today. Dr Guiler mentored some of the participants of the workshop and authored two books: *The Tragedy of the Tasmanian Tiger*; and *Tasmanian Tiger, A Lesson to Be Learnt*. The participants of the workshop unanimously agreed that the workshop and its outcomes be dedicated to Dr. Eric Guiler to honour his life's work.

Tasmanian Devil PHVA
Final Report

Tasmanian Devil PHVA
Final Report

Section 1
Executive Summary and Actions Table

Executive Summary

The Save the Tasmanian Devil Program

The Tasmanian devil (*Sarcophilus harrisii*) has suffered significant population decline in recent years due to Devil Facial Tumour Disease (DFTD), an infectious cancer which is transmitted between individuals through biting. The low genetic diversity in Tasmanian devils has increased their susceptibility to this disease and animals usually die within months of clinical expression. Average sightings have declined by 53% over the past 10 years and the current prognosis is extinction of the species within 25-30 years.

Significant Federal, State and non-government resources are being directed towards a number of conservation and research efforts under the *Save the Tasmanian Devil* (STTD) program. A *Steering Committee,* consisting of National and State representatives, the University of Tasmania, non-government stakeholders and conservation experts, has been established to oversee implementation of recovery actions designed to guide the overall direction of the STTD program.

Workshop participants determined that the actions listed in priority order below require immediate implementation and support:

Establish a Tasmanian devil recovery team, employ a Project Officer, and put in place a project management team.

Support the free range extensive enclosures.

Draft options for reintroduction of Tasmanian devils into the wild.

Conduct a costing workshop for ARAZPA capacity expansion and DPIW capacity expansion (extensive managed pens and mini enclosures).*

Ensure that all breeding animals are in the right place within captive institutions for the 2009 season.*

Address research needs identified in this report.

** Actions already completed*

Workshop Goals

One of the first priorities of the STTD program was the establishment of an insurance population in 2006 to guard against complete extinction of the species and to provide a source of animals for reintroduction should this be needed. The insurance population has been established under the *Insurance Population Strategy*, which provides a framework for managing Tasmanian devils in a number of interacting components — from intensive management in captivity to extensive populations within DFTD exclusion areas.

The stated goal of the Save the Tasmanian Devil Insurance Population Strategy is:

> *The maintenance of a healthy, viable population of devils that:*
>
> a) *is disease free (DFTD-free);*
> b) *is genetically representative of the species;*
> c) *is able to sustain a harvest of animals for release to the wild; and*
> d) *provides for the maintenance of the suite of associated flora and fauna (commensal, symbiotic and parasitic) and wild behaviours wherever possible, to facilitate reintroduction to the wild.*
>
> *Further, to ensure maximum retention of genetic diversity for the duration of the insurance population program, the insurance population strategy sets a target of achieving an effective population size of 500 individuals. Populations that are closely managed can achieve higher effective to actual size ratios than unmanaged populations. As an example, an effective population size of 500 in captivity might require 1,500 actual individuals, whereas in the wild, 5,000 individuals might be required to achieve the same genetic target.*

The goals of this workshop were to review the strategy in light of current knowledge, assess the feasibility of its component parts and, from the result, build a plan of action – what needs to be considered before action is taken, what needs to be done, when, by whom and with what resources. To this end, The Hon. David Llewellyn MHA, Minister for Primary Industries and Water, Tasmania, invited the Conservation Breeding Specialist Group (CBSG) — a specialist group of the IUCN's Species Survival Commission – to facilitate the workshop. Using CBSG tools and processes designed specifically for this type of conservation problem, the workshop brought together key stakeholders, conservation practitioners, and subject experts to resolve issues inhibiting implementation of the insurance population strategy. At the request of the Minister, workshop discussions were limited to exploring Australian solutions to housing and resourcing the insurance population. Though flagged in various working groups, overseas options were considered out of scope.

The Workshop Process

Participants were invited from a variety of organisations with expertise in Tasmanian and Federal Threatened species and habitat conservation legislation; Tasmanian devil, ecology, behaviour, reproduction, health and captive management; and, aboriginal land management and captive management with particular emphasis on the Tasmanian devil and DFTD. State and Federal government representatives and liaisons were also invited. A full list of attendees can be found in Appendix I of this report.

The *Tasmanian Devil Population and Habitat Viability Assessment Workshop Report* presents the results of the efforts and energy the participants contributed to the workshop. Editing of the draft report was done with the assistance of workshop participants. Outside review by non-participants was not part of the process. No content changes were made by the editors and participants checked to ensure that accurate representations were made of their workshop products.

This intensive, 4 day workshop was conducted July 03 - 06, 2008 in Hobart, Tasmania. There were 40 participants, most present for the entire duration of the workshop, and all taking an active part in the discussions. This provided for sustained interactions and the benefit of full attention to the goals and process of the workshop. The workshop was opened with a moving Welcome to Country by Aunt Pat Green acknowledging and paying respect to the Aboriginal Tasmanian community as the indigenous owners and continued custodians of this land. Participants were then asked to introduce themselves and write out and then read aloud answers to two introductory questions: What do you hope will be accomplished during this workshop; and what do you hope to contribute? This process allows for expression of individual perspectives without being immediately influenced by previous responses, indicates potential areas of common ground and can provide a first insight into the diversity of perceived issues present in the group. It also provides a check on whether workshop deliberations respond to the concerns and issues raised. Answers to these questions can be found in Appendix I.

A series of overview presentations were then given to ensure that everyone in the room was familiar with the current status of the wild populations, the disease status of the devil, and all elements of the insurance population strategy. Next, participants were asked to identify issues to be discussed in the individual working groups which covered four main areas of the insurance population strategy: captive management, free range enclosures, islands and secure peninsulas, and disease risk management. A fifth group was formed later in the workshop to develop the draft plan for integrating each of these strategies. Participants in the workshop self-selected into one of the four working groups. With the exception of periodic plenary sessions for presentation of progress reports and cross pollination of the work of the groups, the remainder of the workshop was spent in separate working groups. Each group identified individuals to serve as working group facilitator (to keep the discussions focused and ensure that each person wanting to speak was heard), recorder (to keep track of group discussion on computer), and presenter (to deliver the working group report in plenary). The groups were tasked with defining, sorting and prioritising their key issues and questions, and to work with the population modeling experts to develop insurance strategy-specific models to evaluate the scientific hypotheses and management alternatives that each group developed. Based on the answers to each group's questions, a set of detailed management recommendations was developed to address the root cause of the problem addressed by the question. To increase the potential for implementation, the recommendations were written to meet the "SMART" criteria: Specific, Measurable, Achievable, Results-oriented and Time-fixed. Each group produced a report on their discussions and conclusions. Those reports can be found in Sections 2 through 6. Section 7 contains the model results. An additional working group was formed when the isue of resitance to DFTD arose and the report of that discussion is in Sections 8.

Priority Workshop Outcomes

Each of the working groups presented their recommendations in the workshop's final plenary session. The recommendations were then prioritised by all workshop participants on the basis of both the urgency with which the recommendation is needed and the potential impact of the recommendation if implemented. The high priority workshop recommendations are summarised below (not necessarily in order of priority). All of the recommendations are presented in the working group reports.

Islands and Virtual Islands

Workshop participants agreed that protecting populations of disease-free devils in the wild, within fenced peninsulas and other suitable areas in Tasmania, is of considerable value to the overall recovery effort – particularly with respect to achieving point d) of the stated goal of the Save the Tasmanian Devil Insurance Population Strategy.

Priorities identified for action included:

- ***Develop fenced enclosures at key DFTD free sites on the west coast of Tasmania.***
- ***Establish and fill a project officer position to realise fencing proposals for priority wild areas in Tasmania. The role would include assessing feasibility of fencing proposals and negotiating with key stakeholders. This must be done urgently to allow completion of any fencing work before disease has reached these areas.***

Free Range Enclosures

Workshop participants recognised that free range enclosures are a largely untested option, particularly with respect to the impact on devil dynamics of increased density. However, with cost potentially placing an upper limit on intensively managed captive facilities, and a range of social, political and logistical difficulties preventing islands/virtual islands from short-term implementation, it was also acknowledged that free range enclosures offer the most promising means by which insurance population capacity can be achieved within the time-frame required. Examination of preliminary models of free range enclosures, planning and construction are an immediate priority.

Priorities identified for action included:

- ***Endorsement by the Steering Committee of free ranging enclosures, as described at the workshop, as an integral component of the insurance population, and to recommend appropriate funding.***
- ***Set up an implementation committee to ensure a strong relationship between facility managers and researchers for optimisation of this novel strategy.***

Captive Populations

Workshop participants agreed that, as the only immediate option for housing the insurance population, the captive space in Tasmanian Wildlife Parks (approximately 100 animal spaces) and in ARAZPA zoos (approximately 150 spaces) should be fully mobilised immediately. It was also agreed that consideration should be given to mobilising the additional space available in overseas zoos in New Zealand, Europe and the USA (approximately 200-300 animal spaces).

Priorities identified for action included:

- ***Ensure that disease-free animals recently captured from the wild for the insurance population are placed in breeding situations in time for the 2009 breeding season.***
- ***Convene a costing workshop to discuss ARAZPA and DPIW capacity expansion of captive facilities and the establishment of free-ranging enclosures.***

Meta-population Integration

Workshop participants agreed that an insurance population effective size (Ne) of 500 is still required.

Though islands/virtual island populations have considerable intrinsic value, at best in the next 2-3 years they might provide a maximum of 35 effective spaces (approximately 350 actual spaces), intensively managed captive populations a maximum of 150 (approximately 450 actual spaces), leaving a shortfall of Ne=315 which, under current circumstances, can only be filled by free range enclosures.

Preliminary models suggest that under certain conditions these enclosures have the potential to perform better genetically than wild populations – that is, at an effective to actual size ratio of approximately 0.2. This suggests that an effective size of 315 spaces may require a free ranging enclosure capacity of approximately 1,575 animal spaces; however, there is substantial uncertainty in this estimate due to the diversity and uncertainty regarding management conditions and population response encompassed under this option.

Priorities identified for action included:

- ***Undertake a feasibility study to assess the ecological, financial and community impact of (i) fencing Woolnorth in time to prevent disease exposure of resident devils and (ii) releasing devils on an offshore island.***
- ***Expedite the establishment and expansion of free range enclosures in Tasmania and mainland Australia.***
- ***Develop management options for senescent animals to optimise space in intensively managed facilities.***

Project Management

Workshop participants agreed the importance of organisational structure in effective project management.

Priorities identified for action included:

- ***Establishing a recovery team as a matter of urgency.***

Reintroduction

Workshop participants acknowledged that reintroduction protocols and guidelines need to be developed as a matter of urgency, so that this option can be mobilised as soon as conditions allow. There are disease, behavioural, and logistical dimensions to this.

Priorities identified for action included:

- ***Draft options for reintroduction to the wild.***

Disease Management

The workshop included a comprehensive review and assessment of disease risks associated with the movement of devils to establish – and then maintain – the DFTD-free insurance population. In addition to DFTD, six diseases of concern were identified: Ectoparasites, Salmonellosis, Lymphoproliferative disease, Pseudotrichinosis, young age neoplasia other than DFTD, and other neoplasias (cancers).

Priorities identified for action included:

- ***Review current disease management protocols and risk categorisation in light of the PHVA disease risk assessment.***
- ***Develop biosecurity guidelines for responding to: 1) the detection of DFTD in an insurance population; 2) known incursion of a wild devil into a captive population; and 3) diagnosis of another significant (non-DFTD) disease in a devil population.***

Next Steps

The recommendations made by the participants at this workshop include timelines and parties responsible for championing their implementation. All workshop participants, members of the Executive Committee, and the *Save the Tasmanian Devil Steering Committee* will receive a copy of the final workshop report and be asked to endorse it and to assist in implementing the workshop recommendations.

		WORKSHOP RECOMMENDATIONS			
Impact score	Urgency score	CAPTIVE	Impact ranking	Urgency ranking	Overall ranking
0	2	Move out senescent animals Find additional capacity for senescent animals and expansion* Review of ARAZPA/WAZA documentation*			
1	8	All breeding animals in the right place for 2009 season**		3	5
3	6	Costing workshop for ARAZPA capacity expansion and DPIW capacity expansion (extensive managed pens and mini enclosures)**		5	4
3	0	Incorporating Tassie wildlife park pop into program			
2	0	Genetic analysis: wild vs. captive populations to ensure founder base is a representative sample of wild diversity			
3	0	Submission to DEWHA on use of overseas capacity			
4	0	Establish and put in place a protocol/policy for surplus animals	5		
		Vet protocol needed for movement*			
		Establish recovery team, and put into place a project management team ***			
5	0	Establish pilot reintroduction program and husbandry research program	4		
		Appoint research co-ordinator/manager*			
		DISEASE RISK			
2	1	Selection for resistance			
8	7	Draft options for reintroduction into the wild	3	4	3
1	2	Salvage/use of genetic material from DFTD infected animals			
1	1	Revised biosecurity protocols			
0	0	Complete PHVA disease risk assessment report			
0	0	Risk analysis			
4	5	Address research needs	5	6	6
2	5	Response to breaches			
1	1	Information management			
		ISLANDS			
12	21	Establish recovery team and employ Project Officer to realise fencing proposals including feasibility/stakeholder negotiations	2	1	2
1	5	Identify current DPIW employee to initiate stakeholder negotiations, and contract and tenders, for first fenced enclosure at Woolnorth			
4	3	2nd project officer employed to conduct comprehensive environmental and social risk and benefit assessment of all Tasmanian Islands will focus on dual conservation and wildlife refuge from foxes.	5		
		FREE RANGE EXTENSIVE ENCLOSURES			
17	15	Steering Committee support of free range extensive enclosures	1	2	1
3	3	ARAZPA and DPIW to set up fundraising and reporting structures			
3	2	Constant feedback loop is to be maintained between facility managers and researchers			
		Husbandry Advisory group to be established			
		Project manager to prioritise research needs and opportunities, and fund accordingly			
		Record keeping must be standardised and integrated amongst facilities and coordinated by the species coordinator and husbandry group			
		Design for maximum biosecurity and pest-predator proofing of facilities			
		Site selection			
		Proactive media and community communication and consultation			

*Action not listed until after prioritisation exercise completed.
** Action completed
***Action combined with similar action under Enclosures

Tasmanian Devil PHVA
Final Report

Section 2
Islands Working Group Report

Islands Working Group Report

Working Group Participants: *Clare Hawkins, Mark Holdsworth, Hank Horton, Menna Jones, Dan Lunney, Hamish McCallum,*

Objectives

The overriding purpose of the Devil Program is to maintain the devil as an ecologically functional species in the wild. Wild-living insurance populations achieve more than just an insurance population – they also satisfy:

- Ecological functionality including conservation of parasitic communities
- Maintenance of wild behaviour and adaptations
- Will reduce the risk of the species being listed as 'Extinct in the Wild'
- Maintenance of the Tasmanian devil's intrinsic, social, economic and political value

Description

The Islands Working Group considered both true (offshore) islands and virtual islands (i.e., landscape scale fenced areas). The working group limited consideration to Tasmania only because of the political reality of maintaining Tasmanian devils within the State and the legislative and impact assessment problems associated with introducing Tasmanian devils into other jurisdictions.

Carrying Capacity of Offshore Islands

An assessment of the carrying capacity of islands and fenced areas was made based on the expert opinion of Menna Jones and Clare Hawkins. Tasmania has over 300 offshore islands; however, most are too small to hold significant numbers of Tasmanian devils. The working group limited detailed consideration to the larger of these offshore islands to inform discussion. The working group noted that selection of any island for translocation of Tasmanian devils must be subject to more detailed environmental, social and economic assessment. Examples of potential carrying capacity for some of the larger islands include Maria, off the east coast of Tasmania (80-120); Bruny, south of Hobart (300); and King, in western Bass Strait (1,500). These islands were considered to have the potential to hold devils with minimal ongoing supplementation of the food base. Several smaller islands in the Furneaux, Fleurieu island groups have the potential to hold 50-75 devils but may require regular food supplementation.

Carrying Capacity of Fenced Populations

The STTD program has received many offers from landowners within the State to provide land to fence and house Tasmanian devils. While these offers are gratifying, the working group considered most of these too small to carry sustainable populations and all are within areas currently with unmanaged DFTD infection, making quarantining problematic. The carrying capacity of potential fenced areas is as follows:

DFTD Free

- Woolnorth (250),
- Cape Sorell (100 or 400-600 depending on fence location)
- Robbins Island – considered a peninsula at low tide (<50)
- West coast mine leases (total maximum 150)
- Areas between Hydro canals (100)
- Mt Solitary in Lake Pedder (20)

Within DFTD Range

- Freycinet, east coast (100-130)
- Forrestier Peninsula (300)
- Areas between Hydro canals (400)

Modeling Parameters

The working group considered the population demographics from DFTD-free areas as baseline for modeling islands and fenced areas. However, some allowance was given to the effect of emigration and immigration on wild populations. For example, mark-recapture data probably biases survivorship low because permanent emigration is assumed to be mortality**.** Polygyny is probably not very strong, but up to 4 mates per male per year is considered to be reasonable. The working group acknowledged that females may have multiple mates, too, although this is probably rare and cannot be represented in the *Vortex* model. The maximum reproductive age for females is considered to be most commonly 4 years and 5 years for males. The minimum reproductive age of both males and females is considered to be very important and is likely to be density dependent. For example, where there are unlimited resources, first year females are more likely to breed. To account for this, it was recommended to the modelers to look at the sensitivity of the model to the proportion of first year breeders – ranging from 0% to 10% at carrying capacity, but 30% to 50% when not at carrying capacity (i.e., in the situation where a few animals have just been introduced to an island). While some data suggests 100% of either sex breeds each year, the working group believes this to be unrealistic and recommended that the sensitivity of this be tested (i.e. whether 95% breeding makes a difference for both sexes, at both high and low density).

The working group discussed the effect of environmental variation on proportion of adult females breeding and mortality, especially for 0-1 and 1-2 year olds. Age structures seem to be quite variable from year to year and it is more likely that mortality between leaving den and maturity is the parameter that varies most. The working group considers a coefficient of variation of 10-20% as appropriate.

Mortality through the first year is likely to vary greatly (i.e., it is very different at 3 different stages – 6 months in pouch, 3 months in den, and last 3 months independent from mother) but is variable depending on prevailing conditions. The working group recommended incorporating results of inter-annual variation at Mt. William recorded by David Pemberton to address this issue. The following general scale could be used to account for this variation.

- Good year: 0-1yr = first 6 months, zero mortality; next 3 months (in den), 'very low'; next 3 months (first months of independence), 'high'
- Bad year: 0-1yr = first 6 months, zero mortality; next 3 months (in den), 'higher'; next 3 months (first months of independence), 'very high'

Mortality of 1-2 years is estimated to be 55% from mark-recapture studies; however, this may be biased due to some level of permanent emigration.

The intrinsic rate of increase – currently 10% – was considered to be too low by the working group. Information from the removal of an illegally translocated population on Badger Island (Furneaux Group) indicates approximately 130 animals were produced over 10 years from 3-8 individuals. This represents $r = 0.37$ and $r = 0.28$, respectively, and therefore the working group recommends refining the model to reflect a rate of increase of $r = 0.2$-0.3.

The application of mean litter size, sex ratio, and inbreeding depression was considered reasonable; however, the effects of catastrophes, particularly on offshore islands, warranted further consideration. Catastrophic fires and/or severe drought is likely to be positively affected by climate change (i.e., becoming more frequent and prolonged) and therefore some account for this needs to be factored into the long-term model. Based on current events, prolonged (3-5 year) droughts occur every 20 years, with a single year severe drought every 8-10 years; however, it was considered that these should be treated as environmental variation rather than catastrophes. Prolonged or severe drought and climate change is likely to create a serious management issue for populations on islands with no permanent water. Provision for supplementation or artificial sources may need to be considered to ensure the devil population and prey species have sufficient water to survive. Climate change is also likely to increase the likelihood of lightning strikes causing catastrophic bushfires. Up to 75% of islands could be destroyed in a single fire, and these bushfires were estimated to occur once every 20 years.

However, the effect on the devil population would be variable and dependant on the timing of fires. It was considered that appropriate fire management of islands would minimise the potential for catastrophic events and significantly reduce the level of impact on the devil.

Apart from DFTD, there is no evidence of mass mortality caused by disease; however, the health of devils placed on islands or within fenced areas will be managed through biosecurity measures, regular surveillance and, where necessary, treatment to minimise the risk.

Population explosion (i.e., overcompensation) on islands and within fenced areas is most likely to be influenced by prey dynamics and other factors influencing carrying capacity. It was considered that this could be addressed by using very high values for carrying capacity to demonstrate that this is an issue and by exploring how many animals might need to be removed to bring the population under control. There is currently no evidence of reproductive suppression (except in small enclosures) in Tasmanian devils and further work will be required if islands or fenced areas are established to determine if and when reproductive suppression is manifested.

Issues

The working group agreed that an unacceptable risk or uncontrollable impact on a threatened species under State or Commonwealth value could prevent the use of some offshore islands as translocation sites. This problem is less likely to be a major issue within fenced areas because this would be considered *in situ* management. While some offshore islands have the potential to sustainably hold devil populations, it was also recognised that many islands have intrinsic natural values and some may have other values for translocation of other species. For example, some islands may be better suited as refuges for small marsupials (i.e. Eastern Barred Bandicoot, Tasmanian Bettong) as a response to an uncontrollable fox population in Tasmania (*viz* incompatible with Tasmanian devils). Care is required to adequately assess all values of offshore islands as refuges and translocation sites before devils are established. Likewise local, regional, national and, in some cases, international community concerns need to be addressed when selecting islands for translocation. Comprehensive environmental, social and economic assessments are required to address these issues.

Offshore Islands

The working group selected several offshore islands to consider as potential translocation sites. These islands were selected as a point of discussion to assess the various carrying capacities and highlight the range of values and problems that may be encountered. The working group did not set out to identify any particular island as a priority, and ultimate selection will be subject to appropriate assessments procedures outside the responsibility of this workshop. The working group also notes that, apart from the smallest islands, translocation of Tasmanian devils is unlikely to be reversible and any assessment and approval must take this into account.

The working group was informed that the Tasmanian aboriginal community is currently not supportive of translocation of Tasmanian devils to any offshore island. The aboriginal delegates at the workshop clearly expressed their concerns, which were based on the bad experience and mistrust surrounding the illegal introduction of devils onto Badger Island. The delegates also did not want their islands to be used for experimental purposes and feared their heritage could be destroyed. In particular, the impact of devils on short-tailed shearwater colonies on many islands is seen as a major issue. There was, however, a degree of goodwill in finding ways to support the insurance population program, provided that the aboriginal community is central to the decision-making process and there are demonstrable social and economic benefits for the community. Before islands are considered, there may be good opportunities for the aboriginal community to become actively involved in the construction and management of fenced populations.

Generally, many of the Furneaux Islands were considered not ideal for Tasmanian devils due to the continued drying of areas, the presence of significant short-tailed shearwater populations and breeding Cape Barren geese. However, in some cases, these issues could be managed through fencing.

Clarke Island was discounted because of very important aboriginal social programs and cultural activities. While Flinders Island is very large and able to hold significant numbers of devils, it would be very difficult to get the support of many of the landowners there, in particular from the sheep farmers, for the translocation of devils to the island. From an aboriginal perspective, Flinders Island was considered less important and there is a relatively good chance for support from the elders, but again, negotiations would center on the protection of natural and cultural values. Other islands within the Furneaux Group discussed were Prime Seal, Mt. Chappell Island, Inner Sister, Little and Big Dog Islands and Badger Islands. All of these are relatively small, have significant cultural issues and may require intensive management of food and water resources; nevertheless, they're all worthy of further consideration. In addition, the possibility exists for fencing part of Cape Barren Island – a significant aboriginal land. While Cape Barren Island is large the habitat is generally poor and may not support sufficient numbers. The other problem raised is recent plans by the aboriginal community to harvest remnant forest and to convert to plantation. This may result in significant management conflicts in relation to promotion versus control of browsing animals. In the northwest of the State, Trefoil, Three Hummock and Hunter Islands were considered by the working group. Trefoil was considered problematic because of the significant commercial muttonbird industry. Three Hummock Island, while capable of holding over 100 devils, has currently undergone a significant drought and the prey base has been decimated. Hunter Island in contrast has a significant population of wallaby and is less susceptible to drought. However; the island contains significant natural and cultural values that may be difficult to manage.

Bruny Island in the south of the State is capable of holding 300 devils, has a significant prey base and reasonably reliant water sources. The biggest hurdle will be convincing sheep farmers and the significant numbers of private landowners who have holiday houses throughout the island. Another significant problem will be the protection of The Neck short-tailed shearwater and little penguin colony. Maria Island, with a carrying capacity of 80-120 individuals, has only one owner (Parks and Wildlife Service); however, it does have significant cultural importance to the aboriginal people. A large proportion of the island has shell middens and was used as a burial site. Introduction of devils to Maria Island also has the potential to create devil-human conflict through tourists feeding or being injured by devils and therefore requires careful consideration within the assessment process. Nevertheless, Maria Island contains a large prey population of wallaby, kangaroo and wombat, all of which have been introduced to the island and therefore is likely to be self-maintaining.

King Island, with a carrying capacity of c. 1,500 individuals, is considered the best place to establish a large insurance population of devils. King Island has a significant prey base (wallaby and possum), is isolated from accidental or deliberate introduction of DFTD-infected devils, is not a contemporary aboriginal site and does not have a sheep farming industry (beef and dairy cattle are the predominant farming industries). The risk of devil road kill is seen as a concern but is not considered a major problem provided that sufficient founder animals are released to begin with. King Island has the advantage of not requiring any management of the prey base or water resources; however, significant fencing would be required to protect short-tailed shearwater and little penguin colonies throughout the island. In addition, devils may have an impact on pheasant populations, which are an important for recreational hunting.

The working group concluded that, in terms of minimal management and maximising population size, the larger islands – King, Maria and Bruny – are more likely to be successful translocation sites from a devil perspective. In considering the smaller islands, the working group acknowledged that, in some instances, these would require intensive management of food and water. Nevertheless, smaller islands should not be discounted. While these would require more intensive management, they have the advantage of ease of monitoring and, if required, reversibility. With each option, care must be taken to develop research and management regimes to ensure the successful implementation of translocations. It is also important to recognise that the cost of introduction to any island would incur significant increases in order to undertake the necessary pre- and post- introduction research, impact monitoring and, if required, population control. It is also important to start public consultation as soon as possible because plans for devil translocation will rapidly spread through the community and may result in misinformation and confusion.

Fenced Peninsular - DFTD Free

Robbins Island in the far northwest of the State is considered a peninsula for the purposes of managing DFTD, because small numbers of devils are able to cross mud flats during spring low tides. While Robbins is relatively large, the vegetation is dominated by wet sedgland and melaleuca scrub and therefore could only sustain a population of fewer than 50 individuals. Fencing or management of the mudflats would also be problematic. In contrast, the nearby Woolnorth region contains a mosaic of vegetation types, has a significant prey base and has a large population (c.250 individuals) of devils. The region includes several large cattle properties and is bordered on the eastern flank by an existing cattle fence for almost its entire length. This provides the potential to install a devil proof fence/s along the same easement thus minimising earthwork costs. Obviously, such a fence would require the approval of the respective landowners and possibly involve the local aboriginal community in construction and management. The most significant constraint on this project would be the exclusion of devils at the major public road access at the Woolnorth property boundary. This will require an engineering solution similar to that being developed to prevent devils from moving across the Dunalley canal to the Forrestier Peninsular (see below). Providing the technical problems and management agreements can be reached, Woonorth is seen as the highest priority site for fencing.

Cape Sorell is situated south of Strahan on the west coast and has an estimated carrying capacity of 400-600 devils. Cape Sorell is an attractive option because habitat east of the region is poor, effectively isolating the area from rapid incursion of DFTD-infected devils. This may act as a good buffer zone and reduce the risk of DFTD-infected devils breaching the fence. While the entire area is within the South West Conservation area, construction of a devil-proof fence for the entire length from Birchs Inlet to Low Rocky Point would be difficult and expensive. An alternative option is to fence smaller areas across the peninsular from Birchs Inlet west to the coast. This could contain 1-200 individuals depending on sighting of the fence.

The cost of fencing areas should include consideration of ongoing maintenance of the infrastructure and, most importantly, include provision for monitoring and managing impacts of fencing on other species and the cost of trapping outside the fenced to decrease the risk of incursion. The working group acknowledged that these works may provide employment opportunities for landowners and the local aboriginal people.

While the working group did consider fence design in detail, the following points were noted to be incorporated into consideration of fencing proposals:

- Some fences may not need to be a 100% perfect barrier, particularly if population densities are low and sufficient trapping effort is in place to reduce incursion risk.
- The fence lines could be used as a trapping line similar to that applied to the dingo fence on the mainland.
- Wombats and fallen trees are the most likely natural cause of breaches.
- Double fences could be used as a secondary barrier to the failure of the primary fence.
- Further work is required to confirm the limited capacity of devils to swim along the coast to get around a fence.
- Consideration should be given to the location and design of fencing in case refuges from foxes are required in future.
- A ‘dog-line’ inhabiting the area between the double fences may have some application in some areas (i.e., near farm house at Woolnorth).

Fenced Peninsulas – within DFTD Zone

Freycinet Peninsula is situated on the east coast of the State and has an estimated population of c.100-130 individuals. Approximately 4 kilometers of fencing would be required to isolate the peninsula; however, this is reliant on DFTD extirpating the population or, more problematically, may require active eradication of devils inside the fence line. Currently, this problem exists for all options within DFTD areas and would add significant cost to the program. The Tasman-Forestier Peninsular in the southeast of the State has a wild population of c. 350 individuals and is currently the subject of active management to determine if the incidence of DFTD can be reduced through removal of diseased animals. While there has been a slight reduction from 15% to 8%, the presence of a major, uncontrolled bridge across the Dunalley canal has compromised this project. Work is underway to put in place devil barriers to further test this management technique.

Landscape Scale Fenced Areas

The working group agreed that most of the areas within Tasmania available for fencing are no longer within the disease-free area and therefore successful implementation would involve significant resources for surveillance, management and eradication of DFTD infected animals within proposed enclosures.

Some areas within the DFTD-free zone in the west of the State may present some opportunities to create “virtual islands” through fencing. At least seven mining leases within this region have the potential to be developed as landscape scale enclosures and may have the advantage of involving mining companies for in-kind and financial support. It is estimated that each of these sites could hold 30-40 devils. Similarly, many parts of the central highlands have significant canal infrastructure connecting hydro-electric impoundments and associated infrastructure. These canals are often concrete, vertical walled structures 2-3 metres wide and could be linked (with fences) to create “virtual islands”. Discussion with the mining companies and Hydro Tasmania is required to determine if these options are feasible.

Size of Populations

The working group determined that, in general, smaller populations on islands or within fenced areas would require more management and that populations of fewer than 50 devils will ultimately have major breeding problems. The latter can be resolved by frequent seeding of small numbers of new genetic stock from other islands, fenced areas or captivity.

Source (Wild or Captive)

In all cases, the disease front needs to be monitored to guide sourcing plans. Ideally, animals should be sourced from the wild to maximise natural behaviours. However, appropriately bred and maintained captive animals can be used for introduction to these sites. The working group discussed the minimum requirements for seed populations and agreed that, depending on the size of the site, 20-40 animals would be required as a founder population. Consideration should be given to using east coast animals on Bruny and Maria Islands (if they proceed) to maintain some integrity in this genetically distinct group. However, there is a view that a mixed east and west, both captive and wild, full range of genotypes and phenotypes (no special selection for resistant devils) should be used as source animals. Further work is required to elucidate these issues.

Timeline and Actions

The lack of a technically focused Recovery Team has been inhibiting implementation of many components of the Insurance Population Strategy. The working group identified the following key actions and timelines to bring this program to fruition:

- PHVA Report to the Steering Committee by next meeting
- Appoint a dedicated project officer for establishing wild insurance populations starts December 2008
- Feasibility study finished for Woolnorth by end 2008, including environmental and social risk and benefit assessment
- Funds committed to Woolnorth fence by February 2009
- Woolnorth fence completed by end 2009 – urgent, disease spread issue.
- Environmental and social risk and benefit assessment for all priority islands by 2009

- Investigate/negotiate budgeting and plan for mine and Hydro Tasmania fencing proposals in October 2008
- First intake onto the island(s)/fenced areas by 2009.
- Also needed: a fencing feasibility study covering engineering and ecology for, in order of priority: 1. Woolnorth; 2. Cape Sorell; 3. Freycinet; 4. Robbins.

Site	Disease status	Carrying capacity	Priority (urgency & achievability)	Timeline to release/ fencing	Establishment cost	Resource management (water, food, habitat)	Population management (demographic & genetic) (high for first island implemented)	Stakeholder issues (tenure 1, few, many; cultural, economic, environmental, political issues)	Biosecurity risk (ongoing risk)	Risk of ecological impact of devil on natural values (important species; utility of island as refuge for other species) (establishment risk)
Islands										
Maria	No	80-120	BA	2009	low	low	medium	1; medium	medium	low; high
Bruny	No	300	BC	2010	medium	low	low	many; high	high	low; medium
King	No	1500	BB	2010	medium	low	low	many; high	low	low; low
Furneaux Group	No	50-150	BC	2011	low	medium	medium	few; high	medium	medium; low
Fleurieu Group	No	75-175	BB	2011	low	medium	medium	few; high	medium	medium ; low
Mt Solitary (Lake Pedder)	no	20	BB	2009	low	low	medium	1; low	medium	low; low
Fenced populations										
Woolnorth	no	250	AA	2009	high	low	low	few; low	high	nil
Cape Sorell option 1	no	100	BA	2010	high	low	low	1; low	high	nil
Cape Sorell option 2	no	400-600	BC	2012	very high	low	low	1; low	high	nil
Robbins Is.	no	50	AB	2010	high	low	low	1; low	high	nil
Mines	no	7 x 20	BB	2011	medium	medium	medium	few; low	high	nil
Hydro canals	no	100	BB	2010	medium	low	medium	few; medium	high	nil
Hydro canals	yes	400	CB	2010	high	low	medium	few; medium	high	nil
Freycinet	yes	100-130	CB	2011	high	low	low	few; low	high	nil
Forestier	yes	300	AB	underway	high	low	low	few; low	high	nil
Private offers	yes	30	CB	2009	medium	medium	high	few; low	high	nil

Note: The above table provides a starting point of current 'best guesses' for a feasibility study, which may in the end give a quite different set of values.

Tasmanian Devil PHVA
Final Report

Section 3
Free Range Enclosures Working Group Report

Free Range Enclosures Working Group Report

***Working Group Participants**: David Pemberton, David Sinn, John Weigel, Bruce Englefield, Paul Andrew, Cheryl Hill, Rebecca Spindler, Mark Flanigan*

Objectives

To maintain 1,500-5,000 genetically and phenotypically diverse devils in a controlled, ecologically relevant environment with economic efficiency. The aims should be to:

- Maintain phenotypic and genetic diversity.
- Maintain maximum ecological functionality (this is obtained through maintenance of phenotypic and genetic diversity).
- Have minimal disturbance of random events.
- Provide for the re-release of animals to the wild should DFTD circumstances improve.

Description

Free Range Enclosures (FREs) are large pens with somewhat managed populations at densities greater than that found in the wild but lesser than that found in intensive management. This may include very small islands and large numbers of smaller pens in a large area with modular flexibility. This can be seen as a midway point between intensive management and wild population parameters with benefits and limitations inherent in each.

- A degree of wild behaviours is enabled by the relatively large size of the enclosure, but differing levels of management and reproductive control are possible to manipulate population growth, etc.
- Two management trials can be used to provide preliminary data:
  - Type 1: Devil Island - 12 animals per 11 hectares, with subdivisions for detailed manipulation, (e.g. reproductive control possible via m/f ratio). End goal would see up to 20 islands of up to 40 animals each. Density reaching up to 3 devils/ha.
  - Type 2: Enclosure Complex - Multiple 3 ha pens each holding 4.4 animals in large complex with modular ability to change pen size, complexity, etc. In this way genetic control is exercised, and various scenarios are possible, as well as movement between pens. Density is 8 animals per 3 ha (2.67 devils/ha).
- Goal is overall 1,500 animals across a number of facilities that can be compared and managed as a metapopulation with a strategy for moving animals between facilities and interchanging between other insurance strategies.

Carrying Capacity and Expected Timeline

a) Devil Island:

- Currently 12 + 2 in existing pen: 11 hectares
- Projecting up to 20 facilities (including 320 animals at a 3 animals per hectare ratio). Within two years: 6-8 facilities with 80-100 animals per enclosure complex at density of 1 animal per 0.33ha (total 600 animals in 2 years).
- Model parameters: No genetic supplementation from zoos, but possibly additional supplementation from wild and TFPs. Potential for orphan placement and additions from Tasmanian Fauna Parks, dependent on recommendations (species coordinator) and transfer regulations (veterinary advisory group).
- Estimated breeding success (% of females breeding): 2yr, 70%; 3yr, 60%; 4yr, 40%
- Senescent animals removed (6+ years old)
- Mean litter size: 3
- Breeding strategy: Panmictic
- Expected to reach 80% in 7 years, 100% in 10 years from preliminary modelling data

b) Enclosure Complex:

- None in operation yet; within 2 years projected to have 120 x 3ha pens containing 4.4 animals (total 900 in 2 years; 1 animal per 0.375ha)
- Model parameters: Year 1- enlistment of 20 animals from zoos, 40 from wild; Year 2 - 30 from zoos; Year 3 - 30 from zoos
- Estimated breeding success (% of females breeding): 1 yr, 15%; 2yr, 70%; 3yr, 60%; 4yr, 40%
- Senescent animals removed (6+ years old)
- Mean litter size: 3
- Breeding strategy: Panmictic
- Expected to reach 80% in 7 years, 100% in 10 years from preliminary modelling data

Benefits of the Free Range Enclosure Model

- Maintenance of natural behaviours
- Allows control for maximum reproductive success and maternal competency
- Allows a wide variety of unique research opportunities
- The potential to manage and to replicate/understand the role of natural demographics
- Provides immediate feedback on research on management success of insurance population with minimum cost
- Good public perception
- Public education opportunities for natural behaviours and potential habitat
- Potential to manipulate selection of candidates for reintroduction; genotypic and phenotypic management to maintain genetic and phenotypic diversity
- Can manipulate Ne/N
- Costs are known/knowable
- Relatively cost effective production of devils
- Fundraising opportunities: personal experience up close with devils in a naturalistic environment will have personal benefits for benefactors and will encourage support
- Modular flexibility enables a rapid change of direction depending on the observable results of management actions
- Easily assessable
- Replicable for experimental evaluation, phenotypic and genetic diversity, and biosecurity
- Can expand facilities immediately ahead of population expansion

Table 1. Risks and Contingency Plan I.

Risk	**Likelihood**	**Consequences**	**Importance of mitigation**	**Recommendations**
Density projections unrealistically high	Medium	Low/medium	High	• Compare with densities known from other captive or wild situations (see Table 2) • Use figures from *Vortex* models for lowest productivity for planning (change projections for how populations will perform) • Alter enclosure density/complexity (adaptive management on the ground to alter pen density, hides/dens and sex/age structures) in an endless feedback loop
Poor record keeping/lack of coherence of methods amongst enclosure participants	Low	High	High	• Set and monitor standards • Husbandry group needs to set up standardised record keeping
Natural disasters	Low	High	High	Spreading enclosures in a geographically spatial manner across mainland Australia and Tasmania
Disease	Low	High	High	• Biosecurity and effective disease prevention methods • Based on disease group, we could come up with a number of quarantine recommendations
Pests and predators (cane toads, wedges, foxes)	Low	Low	Medium	Use site-specific design and location to mitigate predator effects

Loss of funding	Low	Catastrophic	High	• Get the right person in the project manager position so that they ensure fundraising • Setting up fundraising and reporting structures • Joint responsibilities between Tasmanian state government (who own animals) and people running enclosures
Biodiversity impacts	Low	Medium	Low	Working with threatened species groups to choose appropriate enclosure sites
Loss of facility	Low	High	High	Correct use of governance structure (who gets enclosures)
Loss of skilled/key players	Medium	High	High	• Succession planning/training protocols • Correct use of governance structure (employment/monitoring of key staff outcomes and providing support so people want to stay around)
Overpopulation	Medium	High	High	Breeding management; keeping enclosure building ahead of devil numbers, especially in early years of program
Political, public relations, and community unknowns	Low	High	High	Proactive media community consultation and decision

Contingency Plan 2: Management Strategies

In recognition of the fact that this is a largely untried method of captive management, some parameters likely to improve success were discussed. All group members agreed that basic minimum standards for each facility to meet needed to be established. While the project manager or staff is likely ultimately responsible for these standards in detail, the discussion below may provide a basis from which to work, is based on the experience of this group with both wild and captive populations of devils, and answers some of the issues brought up in the plenary session.

Management Strategy 1: Establishment of a Management Advisory Group

It was recognised that there was a need to establish a husbandry advisory group to assist with the development of further guidelines and communication between species coordinator, project manager and facilities. The group should be comprised of members from various backgrounds including free-ranging enclosure managers, captive managers, field researchers, etc. The group must also be sufficiently flexible to incorporate data coming back from various sources, and rapidly modify management practices where appropriate.

Management Strategy 2: Close Relationship with Research

In order to determine the success of the FRE program as a whole, as well as to identify individual factors that may be altered to increase/decrease reproductive success, the facilities must be designed not only for maximum security (including bio-security), animal welfare and productivity, they must also be designed to execute experiments and efficiently yield data on specific parameters. The most important parameters to monitor include:

- Reproduction (including manipulation of mate access), sex ratio of offspring, effect of age at first breeding, gamete recovery and preservation
- Behaviour: diversity of behaviour to maximise reintroduction success, effect of captivity
- Required territory size and complexity
- Food and water supplementation
- Enclosure elements: dens, hiding spaces
- Mate choice, MHC, suite of correlated traits
- Required age and gender structure for maximum reproduction
- Genotypic diversity and drift in captivity
- General allelic diversity versus MIC diversity
- Use of excess animals for research

Examples of resources available to research community:

- Full access to senescent animals (e.g. access to ‘retirement’ community)
- Full access to all animals for non-invasive studies that fit within recovery team guidelines and standard husbandry techniques
- Replicate pens for robust experimental design (within recovery team priorities and husbandry practice)
- Logistic support (housing, skilled staff, animal maintenance)

Research caveats:

- Project manager to prioritise research needs and opportunities, and recommend funding accordingly.
- Access to all researchers and requests for samples must be coordinated through a single point person on the recovery team.
- Research priorities of facility not funded through recovery team recommendations will be taken up by facility manager and managed with research partners on husbandry advisory group.

Management Strategy 3: Choice of Location

There are currently 20 Tasmanian locations and 6-10 mainland locations being considered. The factors this group considered important as selection criteria are below (not necessarily in order of importance):

- Habitat type
- *In situ* impact (environmental impact)
- Cost
- Accessibility
- Legislation
- Availability
- Disease risk
- Pest and predator risk
- Climate
- Photoperiod
- Integration ability

- Barriers to international sites
- Overall facility security

Management Strategy 4: Required Density

In an effort to maximise cost efficiency and recognising the economy of scale, target density is 1 animal/0.25 ha. This number was reached separately by two independent facility managers on the verge of building. This density was placed in the context of data from captive and wild populations and all agreed this should be a reasonable starting point, given active monitoring and ability to reduce density if needed.

Table 2. Anecdotal and published reports of densities of animals that successfully breed.

Location	Density	Source	Peer-reviewed published?	Notes
Badger Island	10,000/square meters	N. Mooney	No	
Mt William	250,000-400,000/square meters	D. Pemberton	Yes	
Granville Harbour		C. Hawkins		
Taroona density		M. Holdsworth		
Trowanna	7/500 square meters	Androo Kelly	No	
Bicheno	15,000-20,000/square meters	Bruce Englefield	No	
Woolnorth		C. Hawkins		
Tasmania Zoo	3 animals (2 females and 1 male)/275 square meters	Dick Warren	No	
NatureWorld	4 animals (2 males/2 females)/100 square meters	B. Englefield	No	After females were mated, then males and females housed separately
Zoos on mainland	4/50 square meters	J. Weigel	No	Animals are socialised with one another in these pens sporadically; not held long-term
East Coast Bird life and Animal park	5 animals/100 square meters	B. Englefield	No	

Management Strategy 5: Reproductive Management

Given the minimalist nature of the management style, there are some basic reproductive management strategies that must remain constant throughout facilities:

- Facilities should agree to follow the MAI (Mean Avoidance of Inbreeding) method of plotting animal movements between enclosures – to be designed by species coordinator.
- Density within each enclosure should remain constant – i.e., excess animals removed after weaning of offspring.

- Groups to be made up of related and unrelated groups in replicated relatedness and demographic structure.
- Maternity should be known and must be recorded; paternity options are limited and must be recorded.
- Senescent animals need to be removed through one or several of the following options to be decided by the project manager and recovery team (policy governing this needs to be transparent): 1. send to facilities for display and education (international/local); establishment of retirement pens (higher density; gender separated; 2. build cost in to programme; investigate innovative methods); 3. medical retirement (euthanasia under medical criteria); 4. reintroduction - test survival rates of captives; NB reintroduction entails bio-security and welfare issues; but there is an opportunity to identify and have devils perform an important ecological role in appropriate areas.

Management Strategy 6: Nutritional Management

Should replicate wild situation within financial constraints (allowing for innovative techniques), and recognise that fresh meat is an important part of the devil diet, although scavenging is used as a back-up. Wild diet includes: possums, birds, rabbits, wallabies, wombat, echidna, insects, and amphibians.

- Replication in captivity: Variety is important, and whole carcasses are desirable. Need best mix of ideal/desirable/possible, e.g., bird, rabbit, kangaroo plus occasional supplementation or moth lamps to attract insects. Road kill where feasible. There appear to be political implications for Australia Zoo and affiliates who are not to use culled kangaroo, but other avenues should be feasible.
- Feeding regime: See husbandry manual for framework. To be developed by husbandry advisory group. Wild observations show devils gorge 40% of bodyweight 3 times per week. In captive situation, sufficient feeding needs to be conducted to avoid threats to young.

Management Strategy 7: Social Management

- Den Availability: Dens designed using wild data and consultation with field researchers will be made available. A minimum of 3-4 dens per female are to be made available. Structure will be varied to consider different structure for mating and breeding. Suitable substrate will also be made available so females may dig their own burrows should they prefer. John Weigel responsible for den design prototype.
- Latrine Management: Scat collection and overactive hygiene regime may disrupt social communications. Latrines must be allowed to be established and may actually assist with the animal transfer, socialisation and the creation of virtual pens by moving material between pens.
- Water stations: Placement of water stations must also take into consideration the social needs of the group.

Management Strategy 8: Monitoring

The following factors must be monitored and recorded on an ongoing basis, and ameliorative action taken where necessary. Records must be standardised and integrated with other facilities and species coordinators.

- Environmental: Microclimate - temperature, humidity
- Health: Ongoing monitoring - scat monitoring; visual monitoring and opportunities to weigh at feeding/water stations; veterinary preventative medicine; veterinary intervention (criteria for intervention from medical group); behavioural observation whenever possible
- Genetics: High level of investigation needed initially; paternity analysis, % founder representation, feed in to species coordinator
- Absolute reproductive rates: Total number of pouch young, maternity, paternity
- Biosecurity: Facilities must have double fences and interspace gap monitored regularly

Funding Issues

There is need to develop inclusive cost estimates for all strategies and cost reduction approaches. Cost estimates for Free Ranging Enclosures include:

- Moderately high initial capital costs
- Ongoing operating costs that reduce per devil as the number in a complex increases due to staffing and resource sharing (economy of scale)
- Costs of reversing actions must be considered

Capital Costs

a) Devil Island (enclosure): 1 devil per hectare, 11 hectares $135,500* (proposed 3 p hectare) = $4,000 p devil
b) ARP (modular enclosure): 8 devils/3ha X 120 pens, $3m for 900 animals and 600 h = $24,000 per pen, $3,000 per devil
c) Current zoos: $5,000- $15-000 per devil

**This does not include land cost*

TOTAL AVERAGE COSTS (with inflationary increases considered over 5 years):
$5,500 per devil
PROJECTED COST OF REVERSIBILITY: $1,000 per devil

Operational Costs

Elements:

a) Feed
b) Staff
c) Monitoring: health; genetics; demographics; behaviour
d) Other
e) Seed funding for research
f) Costs related to land (rent?? maintenance??)
g) Reference costs
    i) ARP $2,000/devil per year in first year, then down to $600/devil per year after that
    ii) Devil Island: $2,000/devil per year in first year, then down to $600/devil per year after that
    iii) Current zoos: $4,000 - $8,000/devil per year

TOTAL AVERAGE COSTS (with inflationary increases considered over 5 years):
2,000 per devil

Funding Sources

We encourage Federal and State Government support for the insurance population as well as research and management actions

Funding Recommendations: Investigate other funding sources specifically for the insurance population (i.e. public, foundations). This must be coordinated through the STTD and possibly lead by ARAZPA or ARAZPA institutions. There should be no individual requests to funders or to zoos for funds.

Mechanisms:

- ARAZPA or a coalition of facilities provide matching funds for insurance population and possible seed money for relevant research applications – this ensures government goals are met and put into action.
- Individual fundraising efforts are not to be excluded.
- Fair distribution is essential, probably by committee comprising stakeholders STTD, ARAZPA, operational?

Other Resources Necessary to Run Program

- State and Federal government commitment is essential: this includes a functional administrative structure, including a long term project manager, recovery team, and species coordinator (studbooks, movements).
- Communications strategy for NGOs, animal welfare groups, community, education, benefactors, government, and internal communications such as annual husbandry workshop and trainings.
- Legislative support/advice on novel management ideas

Triggers to Gear Up and Down

Gear Up Triggers:

- Initiation of stable populations
- Recovery after loss of any population
- Drop below 80% target population
- Increased need for animals to supplement wild or other captive management strategies

Strategies include:

- Breed 1year olds. Note: care must be taken when considering breeding younger animals, as this will be a selective pressure that in the long-term may aversely affect wild reproductive fitness
- Decrease generation time
- Increase breeding opportunities

Gear Down Triggers:

- Population has reached 80-100% capacity (est. within 7 years)
- Targets are reduced
- Facilities not available

Strategies include (upon advice from species coordinator or project manager where appropriate):

- Making animals available to other insurance facilities
- Increase generation time
- Decrease breeding opportunities
- Offer to non-insurance facilities
- Offer to repatriation projects
- Contraception
- Pouch management

Criteria for Success/Failure

Success: Retention or reestablishment of an enduring and ecologically functional population of Tasmanian wild devils in Tasmania. This involves the following factors:

- Retention of 90% of genetic diversity over 50 years
- Management strategy that retains sufficient phenotypic diversity to ensure later ecological functionality
- Maintain at least an effective population size of 300 in a variety of enclosures
- Humane, innovative & useful method of dealing with senescent animals
- Excellent welfare standards maintained throughout
- Supply of a resource (not necessarily financial) for external research activities
- Supply of animals for harvest for other management work as needed
- Development of plans, procedures and strategies for large-scale management of native species across methodologies

Failure: The lack of any of the above, resulting in the extinction of the species, or the presence only of a captive population with no feasible options for release to the wild.

Exit strategy: Once the project is deemed a complete success or failure, the FREs will either be:

- Modified for other species (including moving facilities and modifying them for large-scale research)
- Dismantled and recycled

Timeline and Actions

1) Establish Husbandry Advisory Group
When: 3 months of STTD S.C. approving report
Who: John Weigel

2) Research I: A constant loop is to be maintained between facility managers and researchers for 5 years to ensure enclosure design is set up to test specific factors and optimise design for maximum animal welfare, reproduction and management.
When: Within 3 months of establishment - ongoing
Who: Husbandry group

3) Research II: Project manager to prioritise research needs and opportunities and fund accordingly.
When: 3 months before each breeding season
Who: Project manager

4) Record keeping must be standardised and integrated amongst facilities and coordinated by the species coordinator and husbandry group.
When: 3 months of establishment
Who: Husbandry group

5) Design for maximum biosecurity and pest-predator proofing of facilities
When: 3 months of establishment
Who: Husbandry group

6) Set up fundraising and reporting structures
When: 3 months of STTD Steering Committee approving report
Who: ARAZPA and DPIW

7) Site selection
When: 3 months of STTD Steering Committee approving report
Who: Facility managers to propose, project manager to assess in consultation with threatened species groups and recovery team

8) Proactive media community consultation and decision
When: ongoing
Who: Project manager

9) Steering Committee to endorse free-ranging enclosures project and recommend funding as appropriate
When: Within a month of receiving report
Who: STTD Steering Committee

Tasmanian Devil PHVA
Final Report

Section 4
Captive Management Working Group Report

Captive Management Working Group Report

Working Group Participants: *Stewart Huxtable, Lisa Keen, Androo Kelly, Caroline Lees, Martin Phillips, Carla Srb, Dick Frankham.*

Objectives

To provide the total insurance population for up to 3 years (until Islands/Enclosures ready), then to provide a component of the metapopulation.

Description: PHVA

A Population and Habitat Viability Assessment (PHVA) for Tasmanian devils was undertaken in Hobart from 3 – 6 July 2008.

In the Captive Management team, the following broad areas for planning were identified:

1. Population management
2. Sourcing and seeding individuals into the program
3. Husbandry and related requirements
4. Costs and resourcing
5. People and capabilities (not included here but in the Overview Group section)

Resulting from these scoping and planning activities, an implementation plan has been developed. The following overall approaches were confirmed.

Goal

A healthy, viable captive population of Tasmanian devils in Australia that is:

- Disease free
- Genetically representative of the species
- Capable of providing animals for release to the wild[1]

Measures of Success

- To be able to provide surplus healthy animals to the metapopulation for placement in islands, enclosures or for wild reintroduction.
- Establishment of 400 captive places for Tasmanian devils by 2012.
- Achievement of an effective size to actual size ratio of at least 0.3.
- Retention of at least 95% wild source genetic diversity in the captive population over 50 years.
- Captive population is DFTD free.
- Animals bred can be successfully translocated to the wild, either indirectly or directly.
- Funding is available to meet targets.

Population Management

Intensive captive management of Tasmanian devils has been one option amongst various management programs selected as part of the response to the decline of the wild devil population due to Devil Facial Tumour Disease (DFTD).

Captive management is currently the only proven option. It has the benefit of allowing intensive management to preserve heterozygosity and offers the most controlled disease protection.

Protocols for Population Management

It is intended to manage a separate Tasmanian captive sub-population, with its own studbook, which will interact with the mainland insurance population and any island and enclosure populations as part of a meta-population.

---

[1] DPIW-ARAZPA Captive Management Plan

Management of these aspects will be undertaken by a Tasmanian studbook manager in association with the Tasmanian Captive Management Group (CMG established in June 2008).

Additionally, an ARAZPA[2] Captive Management Plan was produced in 2005 in consultation with Department of Primary Industry and Water (DPIW) and has underpinned the establishment of the initial captive population of Tasmanian devils in mainland zoos.

The Captive Management Plan establishes protocols for effective management of the mainland captive insurance population, including provision for management of demographics, genetics, training of personnel, program administration and governance. A Memorandum of Understanding is in place between DPIW, ARAZPA and participating ARAZPA zoos, which identifies the responsibilities of each party towards the program.

The DPIW-ARAZPA captive Tasmanian devil population is also managed as part of the overall Save the Tasmanian Devil Program's Insurance Population Strategy.

Status of Current Captive Population and Short-Term Management Needs

There are currently 108 adult Tasmanian devils held in mainland ARAZPA institutions with an overall carrying capacity of 150. Of those held, approximately 20% are post-reproductive and therefore not able to contribute to the essential genetic diversity of the breeding program.

There are a further 63 devils in quarantine facilities in Tasmania that can be transferred into the captive breeding program in preparation for the next breeding season.

The team considered actions required to optimise captive breeding places and ensure all places were filled with viable devils in preparation for the 2009 breeding season.

A summary of possible options (both best and worst case scenarios) to deal with senescent individuals was developed (Attachment A). To achieve a realistic interim resolution, it was recommended that:

- Immediate placement of the current mainland senescent devils be investigated for transfer to ARAZPA (and possibly non-ARAZPA but still Australian) institutions that are not participating in the breeding program but with facilities to care for the 30 individuals.
- It was considered that, in future, there may be a need for senescent devils to be used in agreed behavioural and other research programs.
- Alternatively, they may be utilised to study the ecological impacts of devil release into defined environments, such as enclosures or islands, before releasing a breeding population.

> **Note:** If real options within Australia are not able to be developed for placement of these individuals, then consideration must be given to placing senescent animals in agreed zoos overseas as part of an internationally managed program under the auspices of the World Association of Zoos and Aquariums (WAZA).[3]This strategy has the benefit of overseas zoos gaining husbandry and veterinary expertise in caring for Tasmanian devils, which would be useful should the breeding program need to be expanded to other regions, potentially offering further safeguard to the species against disease or otherwise catastrophic events on mainland Australia.

There are attendant potential international philanthropic benefits that need to be investigated through permanent placement of some senescent individuals into specific overseas zoos.

---

[2] Australasian Regional Association of Zoological Parks and Aquaria

[3] Early advice regarding the possible overseas zoo scenario received from the disease group is that individuals eventually returning to Australia could only be placed in an A1 grade quarantine zoo and would never leave that facility. The earliest progeny eligible for reintroduction into the program wound be F2 and these would be subject to a defined quarantine and health protocol, TBA.

Note: An ARAZPA/DPIW workshop has been convened for late July 2008 to scope all components and produce a fully costed budget for presentation to the next Steering Committee.

Sourcing and Seeding Individuals into the Program

The actual or general location of the source of all Tasmanian devils currently in the captive population is known and has been plotted. Baseline data of sources of devils is summarised in Attachment B. Further, genetic profiles for some individuals have been mapped.

In order to optimise the preservation of genetic diversity represented within the captive breeding program, it is recommended that:

- Priority be given to undertake genetic profiles of the current captive population.
- Priority also be given to study remaining wild genotypes with the aim of identifying and preserving existing variation.
- A seed model be developed to optimise diversity of the captive program devils.
- A deliberate strategy be adopted to achieve a 1:1 ratio of East and West provenance devils in the captive population.
- Monitor the possible emergence of resistance to DFTD and adjust genetic population management in response, e.g. maintenance of non resistant genotypes in captivity as insurance against future non DFTD disease threats.

Note: Gamete recovery and storage was discussed and has been included in the research recommendations. It should be noted that there are existing ARAZPA protocols and facilities that plan for and enact these activities.

Husbandry and Related Requirements

ARAZPA Husbandry Guidelines have been developed in consultation with the management of member organisation Trowunna Wildlife Park and drawing from the excellent husbandry and captive breeding results it has achieved. This has included the development of a training course for zoo keepers to establish effective procedures and protocols optimising breeding and husbandry outcomes. Studbook and other record keeping are currently performed at a standard common to all ARAZPA institutions.

DPIW/ARAZPA has recommended a husbandry research component to be included as part of a pilot reintroduction project, the results of which can be used to inform or be included in the Husbandry Manual and subsequent training programs and husbandry protocols. This is necessary to achieve the primary goals of the captive program, i.e. a DFTD-free, genetically representative population capable of release to the wild.

Cross Communications

A List Serve has been developed which enables all participating institutions and Life Sciences staff to share data, observations, experiences and updates. It has been recommended to expand this resource to allow access to the List Serve by all facilities in the program.

Record Keeping

There are disparities between the record keeping systems in institutions holding devils. Given the need for accurate records for all individual animals, a standard record keeping form has been developed and a training program by the ARAZPA Records Officer Group is available. These will be integrated for use at Tasmanian facilities by DPIW. ARAZPA records and DPIW records will then be fully integrated by the studbook keeper.

Further joint approaches on managing the captive population should consider data generation and communication as a component of husbandry research in the following areas:

- Diet
- Health

- Breeding successes
- Impact of densities
- Behaviour
- Utilisation of facilities
- Training updates
- Observational studies
- OHSE requirements/constraints[4]

Triggers for Gearing Up and Gearing Down

The following factors would trigger expansion or reduction of the captive management program.

Up	Down
• Other options not available, e.g., islands and enclosures not ready • Current circumstance, i.e., response to DFTD • Outbreak of novel secondary disease/threat • Research indicates higher N or Ne requirement • Responding to program recommendations to actively manage genetic types, e.g., C5 • If global plan is initiated	• Success of the program • Responding to reduced Program needs, e.g. decline in disease • Islands, enclosures and other options are more effective in meeting needs of the program, e.g.,. breeding targets, etc. • Capacity of other option exceeds forecasts • Achieve a better N or Ne ratio than forecasted • Other options are more effective for Ne • Insufficient funding

Summary of Suggested Areas for Further Research

The following research areas were noted/suggested by the working team:

- Improving Ne to N ratio
- Pilot re-introduction and husbandry research program
- Impact on behaviour of captivity, including constraints due to enclosure size/population densities
- Explore extent to which male desirability/breeding competence can be manipulated
- The incidence and circumstances of pseudo pregnancies
- Diet appropriate
- Clarification of genetic structuring of captive population and compare against wild variation
- Demographics
- Gamete recovery and artificial insemination
- Monitoring MHC

Timeline and Actions

(See table below)

- Fill 150 mainland places with breeding individuals (Ne) by October 2008.
- Develop capacity in the program for a total of 400 animals (N) by 2012.

---

[4] For example, some institutions are constrained by their OHSE guidelines from constructing optimum maternal dens (deep dug, relatively inaccessible). There is a need to assess impacts and open dialogue with member agencies in these matters.

Action	**Measure**	**Who**	**When**	**Cost**	**Risk**
Move out senescent animals	Spaces available for breeding animals	ARAZPA members waiting to receive devils. Existing ARAZPA participants through facility expansion.	September 2008		Need all new ARAZPA members trained, facilities approved and part of MOUs by September 2008
Veterinary protocol based on Tasmanian best-practice knowledge developed and provided to facilities receiving senescent animals	Protocol provided to receiving facilities	Tasmania CVO	By September 2008		
All breeding animals in the right place for the 2009 season	All potential breeding animals in place to breed, including provision for appropriate E/W mix	Species manager recommends location and animals, including E/W mix	By end October 2008		Spaces not available Approval not given by receiving State CVO for devils to complete 12 month quarantine in A1 Q certified zoos
Costing workshop for expanding ARAZPA/DPIW capacity, in particular, consideration of intensive management and mini enclosures	Costed plan produced for Steering Committee	ARAZPA office and members, DPIW	29-30 July at Australian Reptile Park		Steering Committee meeting scheduled for 21 July needs to be delayed to September 1.
Incorporate Tasmanian wildlife park population into the program	Animals in program in right mix	DPIW	By October 2009		Unresolved issues of capacity, ownership
Continue liaison, trust-building & partnerships with stakeholders and engage through Tasmanian Captive Management Group (established June 2008).	Engagement of stakeholders	DPIW	Ongoing		
Review permitting, identification, ownership & management in light of status change to “endangered”.	Permitting reviewed and issued	DPIW	End September 2008		
Establishment of Tasmanian studbook with	Studbook and records in	DPIW	End September 2008		

appropriate record keeping and management through ISIS (ARKS & SPARKS).	place				
Expand List Serve access to all facilities involved in the program	List Serve availability to participating facilities	ARAZPA and species coordinators	September 2008		
Identification of founders, other genetically important animals, and animals important for education & marketing purposes – developing appropriate management options for all.	Database of animals	Tas studbook keeper/Tas CMG	September 2009		
Identify mechanisms for exchange between facilities & studbooks for Tasmania, mainland Australia, captive enclosures, enclosures, islands, the wild, or any other location.	Develop and test exchange protocols		Currently 'disease' working group in conjunction with studbook owners	August 2009	
Genetic analysis of wild and captive populations	Determining gaps in the genetic variability between the wild and captive population	DPIW oversight	2010		
Submission to DEWHA re use of OS capacity	Report submitted and capacity/processes established	ARAZPA (Caroline and Paul)	End 2008 for report Process by mid 2009		
Protocol/policy for surplus animals (Recommendation from workshop)	Capacity maximised for breeding animals	DPIW, recovery Team, with stakeholders	Pre start of 2010 season		
Establish Recovery Team, project management team in place	People in place; Costed resource plan to Steering Committee	DPIW, include ARAZPA, Unis and others	1. Oct 2008 2. Oct 2008 +		Project failure without right people and enough people
Pilot reintroduction program and husbandry research program	Animals can be introduced to enclosures, islands and the wild.	Recovery team	Reintroduction by: 2010/11 Husbandry by: 2009/10		Be able to move animals
Research into pseudo oestrus, pregnancy,	Data that assists in	ARAZPA with DPIW	Supported/funded by 2009		

birthing	increasing birth rate	assistance			
Investigate limitations of male reproductive success	Optimise number of competent males for breeding	ARAZPA with DPIW support	2009 onwards		
Monitor breeding outcomes of crossing East x North-West origin animals through to F2	F2 viable and fertile	ARAZPA, holding facilities, studbook keepers, records managers	From 2008 to late 2010 and beyond		
Gamete recovery, storage and research project	Define scope of current activities and consider areas for expansion. ID funding source.	DPIW/ARAZPA			
Review of ARAZPA/WAZA documentation.	Update CMP, MOU, CCP.	ARAZPA Office Species Coordinator.	October 2008		

Attachment A: Options considered for immediate and long-term dispersal of senescent animals

1) Increased capacity created within the zoo industry – contingent on resource availability including space at facilities, personnel costs

2) Removal to non-insurance population institutions including overseas zoos
   Potential benefits:
   - Capacity building
   - Training in husbandry
   - Fundraising
   - Education

   Potential issues:
   - Ethical
   - Political and ownership issues
   - Governance issues, e.g., Ambassador Agreements

3) Translocate to free range extensive enclosures and islands - for capacity building and as a test population to establish local impacts.

4) Reintroduce to the wild
   Issues include:
   - Welfare concerns
   - Public perception
   - Need for a pilot reintroduction program

5) Euthanise
   - Ethical issues
   - Consider in terms of behavioural fitness for transfer to any other circumstances
   - Last resort – not considered acceptable

6) Send to research projects (subject to this being agreed scope)
   - Need to ID numbers and demographics
   - Gamete recovery

7) Manage to capacity, thereby avoiding surplus production, through pouch management
   - Pouch management used for population management to control age and sex requirements
   - Will be the best way to control the issue of surplus animals once at capacity
   - May be too early to use this method in the project
   - Ethically more palatable than euthanising adults/juveniles
   - Can be used to improve genetic profile and maintain sex/cohort balance

Recommendation for the future:

- Use senescent animals for pilot introduction programs
- Increase fundraising paradigm
- Fundraise to build ‘retirement’ facilities

Attachment B: Data on Captive populations

Provenance

- ARAZPA-held animals: mainly NW animals, some East
- Non ARAZPA: East and mixed providence
- Private Tasmanian holders: mainly East and mixed
- Tasmanian Government: mainly West and mixed
- OS: Eastern
- Carers: mixed

Current mainland insurance devils: 89
Current Trowunna + Cradle Mountain devils: 63
Current devils in DPIW quarantine: 55

Total in ARAZPA and DPIW facilities: 207

Overall recommendation is to manage towards a 50/50 W/E mix

Tasmanian Devil PHVA
Final Report

Section 5
Integration Working Group Report

Integration Working Group Report

Working Group Participants: *Paul Andrew, Dick Frankham, Menna Jones, Androo Kelly, Caroline Lees, Hamish McCallum, David Pemberton*

Objectives and Description:

The group was tasked with synthesising three components of the insurance population in a way that would:

- Minimise risk of devil extinction.
- Achieve demographic stability.
- Maintain genetic diversity (goal Ne=500).
- Minimise inbreeding rate.
- Minimise impacts of catastrophes.

Summary of insurance meta-population component parameters – next 5-10 years:

Component	**Sub-population**	**Total N**	**Ne/N**	**Ne**	**Required Movements (over 50yrs)**
CAPTIVE	ARAZPA/DPIW Mainland	150	0.3	50	4+ per generation
	DPIW Tasmania	100?	0.3	33	?
	Other Global Spaces	200?	0.3	66	?
ISLANDS	Island 1.	100	0.1	10	
	Woolnorth	250	0.1	25	?
ENCLOSURES	Mainland	900	0.2	180	MAI*
	Tasmania	600	0.2	120	MAI*

**Maximal Avoidance of Inbreeding – movements here will be between sub-units within each of the populations – possibly according to an MAI scheme (regular single sex rotation of animals to avoid within-family matings) or similar. That is, no net input of animals over the 50- year period, once numbers are established.*

Mechanisms and Requirements

- To construct the meta-population it is necessary to know capacities, timelines and required supplementation rates; these parameters are too uncertain now. Detailed modelling will need to be done later.
- The program will definitely need capacity above what can be provided in captivity (zoos).
- Initially, excess captives could go to the “Gosford” enclosure project. Tasmanian enclosures could take the excess from Tasmania.
- More data are needed to improve/build models – need to make sure that these data requirements are captured and built into monitoring programs for captive, enclosure and island populations.
- Source of animals for enclosures:
    - Wild population (young animals)
    - Animals excess to the captive population
- Source of animals for “islands”:
    - Woolnorth – animals existing there already would be fenced in
    - Cape Sorell – as above
    - King, Maria, Bruny - wild, captive or free range extensive enclosure populations

Summary:
From Insurance Strategy Goals: we need an insurance population Ne of 500. At best, in the next 2-3 years, islands could provide a maximum of 35 effective spaces, intensively managed captive populations a maximum of 150, leaving a shortfall of **Ne=315** that could only be filled by enclosures **– an estimated 1,575 animals**

Tasmanian Devil PHVA
Final Report

Section 6
Disease Risk Analysis Working Group Report

Disease Risk Analysis Working Group Report

Working Group Participants: *Rod Andrewartha, Kathy Belov, Colette Harmsen, Richard Jakob-Hoff, David Obendorf, Anne-Maree Pearse, Kim Skogvold, Greg Woods, Rupert Woods*

Objectives

The following objectives were agreed to by the DRA group:

1. To review and analyse the disease risks associated with management of the insurance population of devils;
2. To develop a disease risk management plan that is integrated with the insurance population management plan; and
3. To document the disease risk management plan in a way that is transparent and that defines the *appropriate level of protection (ALOP)* and takes into consideration the communication needs of all stakeholders, e.g. some people will not need the amount of technical detail that veterinarians might need, such as the media, politicians, etc. (i.e., there will be different levels of communication needs).

Description

The group aimed to achieve the following outputs:

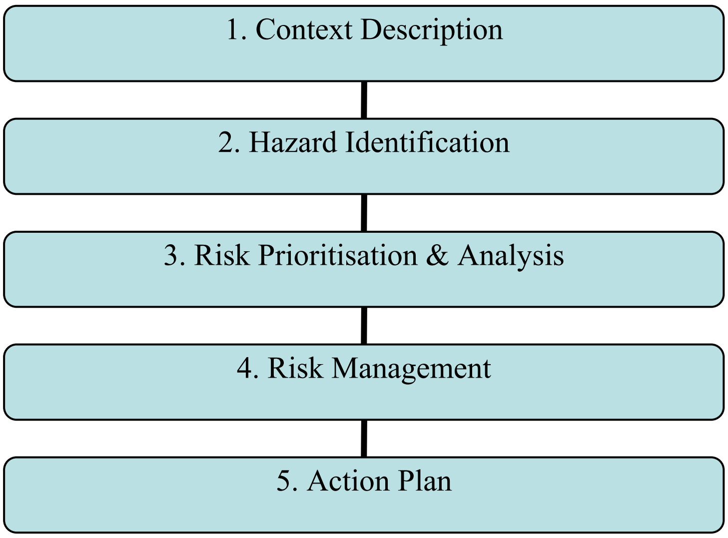
1. Diseases of concern have been identified for each animal movement type involved in the establishment and on-going management of the insurance meta-populations of the Tasmanian devil.
2. Critical control points for each movement type have been identified and a risk management plan proposed for each disease of concern in relation to movements of devils.
3. Existing risk management protocols have been reviewed and revised and/or endorsed based on the most up-to-date information available.
4. Additional disease risk management protocols for movement and management of Tasmanian devils have been developed as identified at this PHVA workshop.
5. Disease risk management standards have been revised and endorsed as required for captive and wild-managed populations.
6. The draft DFTD Research Strategy has been reviewed, revised and prioritised as appropriate.
7. The Term "DFTD-free status" has been defined.
8. A protocol for security breaches of "DFTD-free" sites has been developed.

The group also agreed, from the outset that:

1. Our focus should be on selection of a genetically diverse insurance population (as opposed to selection for resistance to DFTD).
2. We should also bear in mind the option of managing wild devils with DFTD.
3. We will need to consider which potentially pathogenic organisms need to be actively managed or maintained (treatment options).
4. We should consider the risk of DFTD going into other species. If this is highly unlikely it would remove some of the barriers for moving devils intra/interstate.
5. The situation will need to be continually reviewed.
6. In terms of reintroduction of devils back into Tasmania from the mainland – need to formulate a comprehensive list of possible diseases that might be brought back to Tasmania and species that might be affected.
7. There will need to be set in place a similar process to Objective 3 (ALOP) to get devils back into Tasmania – re-importation of devils from mainland will need a higher level of assessment, i.e., our process will need to capture disease risk for devils on the mainland and problems associated with bringing them back to Tasmania.
8. Also need to consider the risk of spontaneous tumours occurring in devils and other animals
9. It will be impossible to maintain parasites with an indirect life cycle (i.e., those requiring an intermediate host or local vector) in populations elsewhere (especially outside Tasmania) – we have to accept there will be some loss of the endemic gut, skin, etc. flora and fauna.

Process

The flow diagram below describes the disease risk analysis process followed by the group:



1. Context Description

The context for this disease risk analysis is provided by the following extract from the **Strategic Plan endorsed by the Save the Tasmanian Devil Steering Committee on 24 July 2007**:

“The survival in the wild of the world's largest carnivorous marsupial, the Tasmanian devil (*Sarcophilus harrisii*), is threatened due to the impact of Devil Facial Tumour Disease (DFTD), first observed in NE Tasmania in 1996. The scientific consensus is that DFTD is a transmissible cancer. Death appears to occur in every case, usually within a year.”

Objectives

1. Maintain genetic diversity of Tasmanian devil populations.

i) Understand DFTD transmission and develop and implement husbandry and management practices to minimise transmission risk
ii) Understand the genetic diversity of the Tasmanian devil population.
iii) Understand the nature of DFTD and its relationship with the genome and the biology of the Tasmanian devil throughout the natural range of the species.
iv) Develop and implement a comprehensive insurance population strategy.

2. Maintain Tasmanian devils in the wild.

i) Understand the progression and impact of DFTD on the wild Tasmanian devil population.
ii) Develop and implement measures to suppress DFTD in the wild Tasmanian devil population.
iii) Identify potentially resistant genomes and manage the Tasmanian devil population to favour the persistence of those genomes.
iv) Develop and apply vaccine treatments for DFTD.
v) Build an insurance population to levels which will allow reintroduction of Tasmanian devils into their natural range.

3. Manage the ecological impacts of reduced Tasmanian devil populations in their natural range.

i) Understand the ecological consequences of a reduced Tasmanian devil population over the natural range.
ii) Develop and implement management strategies to minimise negative impacts including those associated with feral predator populations such as cats and foxes.

iii) Minimise the loss of diversity of the organisms associated with Tasmanian devils – including commensal, symbiotic and symbiotic flora and fauna – by understanding their nature, diversity and variability and by maintaining wild populations of devils with a full natural suite of associated organisms.

Principles

1. Understanding of DFTD should be in order to inform disease management actions rather than an end in itself.
2. Understanding should be based on sound science and peer review.
3. Effective collaboration should be encouraged and facilitated so that tasks are undertaken by those best suited to them.
4. Attention and resources should be focused on those tasks with the best prospects of contributing to saving the devil.
5. The Tasmanian and world community should be kept informed of progress and those who can assist should be engaged.
6. Actions should be consistent with and guided by a statutory Tasmanian Devil Recovery Plan."

Movement Diagram and Critical Control Points (CCP)

In order to identify the critical control points for disease risk management, a movement diagram was developed – initially for each of three meta-populations: "Captive", "Free Range Extensive Enclosures" and "Islands". Subsequently these were consolidated into a single diagram as shown in Figure 1. The group's expertise was used to allocate critical control points for the identified movement pathways. Five levels of disease risk management were identified based on a combined assessment against the following criteria:

- Level of exposure to disease
- Level of monitoring
- Potential for novel diseases

Thus, in descending order of risk, the five levels of risk management are:

1. Wild to wild

- Differences in disease demographics between subpopulations

2. Wild

- Exposed to full range of diseases
- Little monitoring

3. Movement to different land mass

- Potential for prior exposure to different pathogens
- Consequences of introducing disease

4. Free Range Extensive Enclosures

- Wildlife access
- Limited monitoring
- Broad range of disease

5. Captive

- Close observation
- Possible amplification of disease
- Limited range of diseases
- Site specific risks (other animals in zoo, etc.)

Using the criteria above a simple, additive formula was used to derive a 'disease risk exposure' factor for each of the meta-populations as shown in Table 1.

Table 1: Numeric scale for allocating Critical Control Points; 1 = Low risk, 2 = Medium risk, 3 = High risk.

	Fudge factor* (density dependence; stress etc)	Potential Exposure to a range of diseases	Lack of monitoring	Total
Wild	1	3	3	7
Enclosure	1	2	2	5
Captive	2	1	1	4

"Fudge factor" = exposure to extraneous influences that may increase disease susceptibility

To test the internal logic of the CCP rankings, the following matrices were used to obtain a semi-quantitative estimate of the level of risk associated with the various movement combinations. The higher the number, the higher the risk:

Table 2: Movements within Tasmania.

Within Tasmania	Wild	Enclosure	Captive
Wild	14	12	11
Enclosure	12	10	9
Captive	11	9	8

Table 3: Movements within the Mainland.

Within Mainland	Wild	Enclosure	Captive
Wild	N/A	N/A	N/A
Enclosure	12	10	9
Captive	11	9	8

Table 4: Movements between Tasmania and the Mainland.

Within Tasmania	Wild	Enclosure	Captive
Wild	14	12	11
Enclosure	12	10	9
Captive	11	9	8

Figure 1: Tasmanian Devil Movement Diagram.

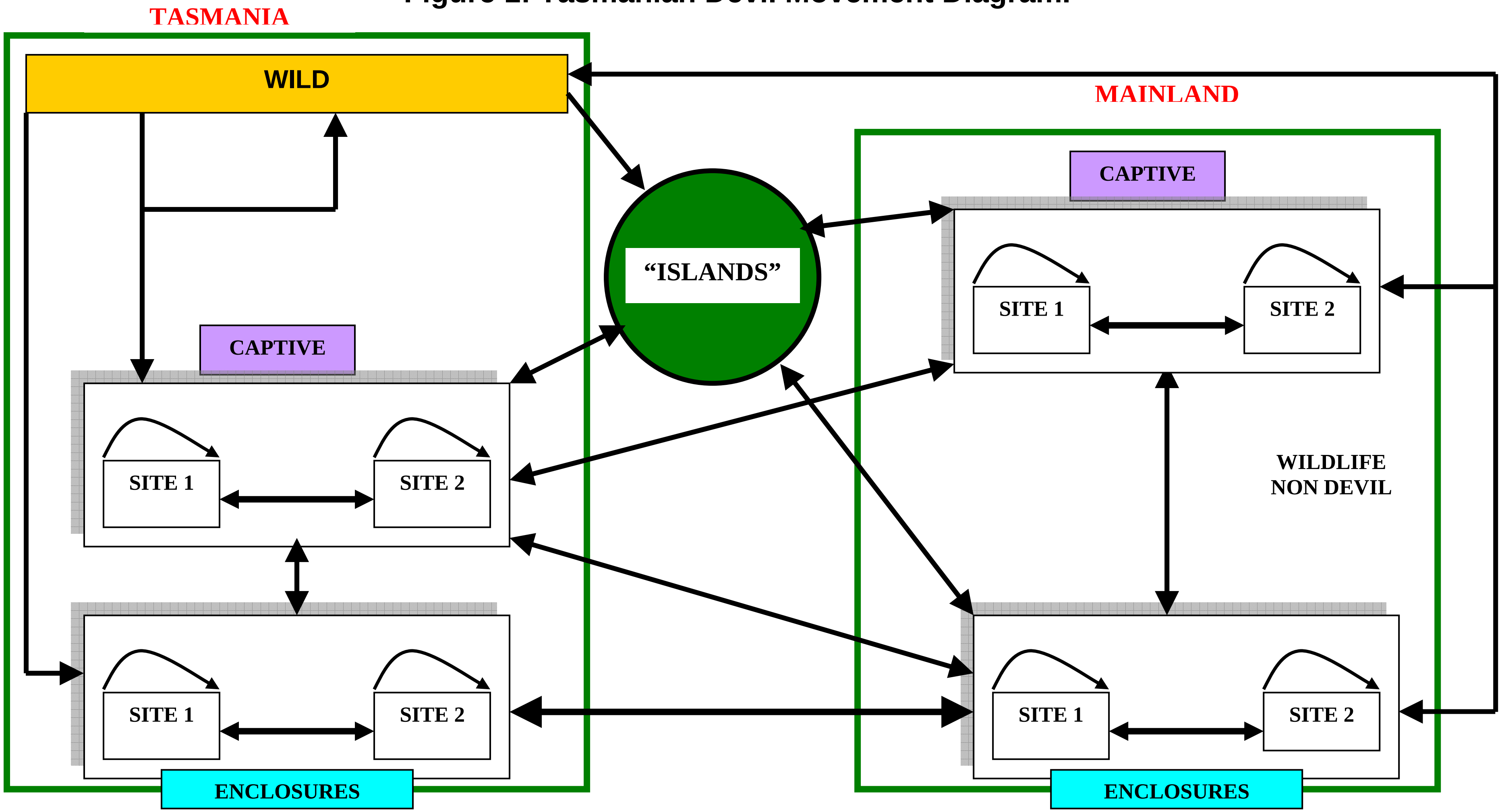


Table 5: Critical Control Points for animal movements (refer to Figure 1 above).

MOVEMENT	**Critical Control Points** 1 = highest risk 5 = lowest risk
Within TASMANIA	
WILD to CAPTIVE	2
CAPTIVE to WILD	2
WILD to ENCLOSURE	2
ENCLOSURE to WILD	2
CAPTIVE to ENCLOSURE	4
ENCLOSURE to CAPTIVE	3
CAPTIVE to CAPTIVE	4
PEN to PEN (CAPTIVE)	5
ENCLOSURE to ENCLOSURE	3
ENCLOSURE to ISLAND	1
ISLAND to ENCLOSURE	1
WILD to ISLAND	1
ISLAND to WILD	1
CAPTIVE to ISLAND	2
ISLAND to CAPTIVE	2
WILD to WILD (area dependent based on genetic subpopulations)	1
TASMANIA to INTERSTATE	
WILD (TAS) to CAPTIVE	2
CAPTIVE (mainland) to WILD (TAS)	2
WILD (TAS) to ENCLOSURE	1
ENCLOSURE (mainland) to WILD (TAS)	1
CAPTIVE (TAS) to ENCLOSURE	2
ENCLOSURE (mainland) to CAPTIVE (TAS)	3
CAPTIVE (mainland) to CAPTIVE (TAS)	3
CAPTIVE (TAS) to CAPTIVE (mainland)	3
ENCLOSURE (mainland) to ENCLOSURE (TAS)	2
ENCLOSURE (TAS) to ENCLOSURE (mainland)	2
ENCLOSURE (mainland) to ISLAND	1
ISLAND to ENCLOSURE (mainland)	1
CAPTIVE (mainland) to ISLAND	2
ISLAND to CAPTIVE (mainland)	2
Movements within the NORTH ISLAND	
CAPTIVE to ENCLOSURE	4
ENCLOSURE to CAPTIVE	3
CAPTIVE to CAPTIVE	4
PEN to PEN (CAPTIVE)	5
ENCLOSURE to ENCLOSURE	3

CCP1

Lack of monitoring – 4
Potential for exposure to disease – 4
Consequence to recipient population - 4
Fudge Factor (relates to density dependence/stress) – 1
TOTAL=13

CCP2

Lack of monitoring – 3

Potential for exposure to disease – 3
Consequence to recipient population – 4??
Fudge Factor (relates to density dependence/stress) – 1
TOTAL=11

CCP3
Lack of monitoring – 1
Potential for exposure to disease – 1
Consequence to recipient population - 2
Fudge Factor (relates to density dependence/stress) – 2
TOTAL= 6

CCP4
Lack of monitoring – 1
Potential for exposure to disease – 1
Consequence to recipient population - 1
Fudge Factor (relates to density dependence/stress) – 2
TOTAL= 5

CCP5
Lack of monitoring – 1
Potential for exposure to disease – 1
Consequence to recipient population - 0
Fudge Factor (relates to density dependence/stress) – 1
TOTAL= 3

2. Hazard Identification

A. Infectious Disease Hazards

The following disease susceptibilities were identified from a search of the literature (including references kindly provided by Dr. Phillip Ladd) and cases recorded in the Australian Wildlife Pathology Registry (kindly supplied by Dr. Karrie Rose, Taronga Zoo, Sydney) (Appendix 1) combined with the expert knowledge within the DRA working group:

- DFTD
- Young age onset neoplasia other than DFTD
- Other neoplasia (other than the above)
- Lymphoproliferative diseases
- Allergic dermatitis
- Salmonellosis
- Pseudotrichinosis (trichinella)
- Sarcocystosis (muscle condition)
- Toxoplasmosis?
- Fungal infections
- Ectoparasites (mites, uropsylla, ticks)
- Intestinal helminths (cestodes, nematodes)
- Protozoa (giardia, entamoeba, sarcocystis sporocysts)
- Coccidia
- Metabolic diseases (e.g. osteodystrophy)
- Bacterial infections (abscess, septicaemia, etc.)
- Viral (herpesvirus, endogenous retroviruses)
- Degenerative diseases (e.g. spondylosis and osteoarthritis in aged animals)
- Nutritional disease (e.g. obesity)
- Mycobacterial diseases* look into this…

B. Non-Infectious Hazards (Courtesy Dr. Menna Jones)

For completeness significant non-infectious hazards to Tasmanian Devils are:

1. Road accidents*
2. Persecution (poisoning – mostly organophosphates)
3. Predation by dogs (especially two dogs together)
4. Shooting

*Road kill mortality can be very high in local areas (e.g., 50% devils and 100% quolls in one area where a road was upgraded and average vehicle speed increased from 40 – 80km/hr). Also 20% mortality recorded on Freycinet in a drought year.

3. Risk Prioritisation and Analysis

The highlighted diseases were considered to be of highest risk and, to aid prioritisation, were subjected to further analysis using the Rough Assessment Worksheet in Table 6.

Table 6: Rough Assessment Worksheet for diseases of the Tasmanian devil, *Sarcophilus harrisii*.

(scale: 1 = low; 2 = moderate; 3 = high)

Disease **CCP1**	**Likelihood of susceptibility**	**Likelihood of exposure**	**Likelihood of becoming infected**	**Transmissibility to others**	**Probability of developing clinical disease**	**Severity for the individual if clinical**	**Severity for the population**	**Estimated significance to the program (Total score)**
Devil Facial Tumour Disease (DFTD)	3	3	3	3	3	3	3	21
Young age onset neoplasia other than DFTD	1	0	0	0	3	3	1	8
Other neoplasia	2	0	0	0	3	3	1	9
Lymphoproliferative diseases	1	1	1	1	3	3	2	12
Salmonellosis	3	3	2	3	1	2	1	15
Pseudotrichinosis	3	2	3	2	1	0	0	11
Ectoparasites	3	3	3	3	1	3	1	17

NB - columns two and three are the variable characteristics with respect to critical control points; all the other columns will stay relatively the same. Our assessment is that the ranking of these disease processes will be the same regardless of the movement CCP. Consequently no further time was allocated to this assessment for the lower risk CCPs.

4. Risk Management

Following the identification of the diseases of concern through the hazard identification process and risk analysis above, a risk management plan was developed for each of the major movement pathways. The level of risk management is determined by the relative disease risk and its consequences to devils and other organisms that may be exposed to the identified diseases of concern. A detailed movement pathway was developed for each of the key shipment scenarios involved in moving animals between the various facilities and meta-populations.

Shipment Scenarios within Australia

A. Shipment Scenario I – Wild to Captive

Each movement has a disease transmission risk associated and requires a risk management strategy. Potential sources of disease along the movement pathways are:

- Wild capture: Traps, bait used in the wild and in enclosures (such as lamb or wallaby, occasionally pork or beef), nets, people & protective clothing
- Processing animals: Callipers, microchipping, ear biopsy, PPE, other equipment, blood collection (not routine)
- Shipping containers: Crates, traps, sacks
- Transport: Road vehicles, planes, any vehicle used to move animals
- Quarantine facility(ies) (Currently Taroona holding facility – capacity 77)
- Captive facility

Movement Pathway for Wild to Captive

1. Wild trap → 2. Shipping Crate (or trap) → 3. Vehicle → 4. Pre-shipment quarantine (Taroona) → 5. Crate → 6. Vehicle → 7. Aircraft (for interstate or overseas travel) → 8. Vehicle → 9. Post-shipment quarantine holding → 10. Crate or trap → 11. Vehicle → 12. Captive holding facility

Disease Risk Management Plan for this Movement Pathway

(Numbers refer to stages in the movement pathway)

1. Hygiene of trap: Disinfected since previous use. Currently F10 (1%) or biogram (2%) contact for at least 5 minutes (subject to review) and source of 'clean' bait (e.g. pre-cooked or frozen) to kill DFTD, salmonella and external parasites. In field protocol for personal protective clothing – clean and dry or clean and disinfected for DFTD, removal of organic matter from overalls/apron and footwear. Scrub where necessary. Latex gloves worn in the field; 2 pairs latex gloves in captive pens (see captive protocol in Appendix). Protective glasses as an OH&S recommendation.

2, 5 & 10. Hygiene of crates: Disinfected since previous use (as above); clean (discard substrate), hygienically stored (dry), absorbent substrate; crate appropriate size and design for species.

3, 6, 7, 8, & 11. Transport vehicles: Visually clean and dry (devils are transported in crates or traps), all devils are of the same status in transit with adequate separation from other animals, appropriate ventilation, temperature and humidity. For overseas travel, must comply with IATA requirements.

4 & 9. Quarantine holding: All-in/all-out policy, i.e. single consignment of devils per quarantine period.

- Quarantine period appropriate to diseases of concern (see shipment scenarios below).
- Appropriate facility and husbandry for the species
- Regulated sources of food and water

- Barrier techniques in place for animal carers including hygiene and personal protective gear for handling of devils
- People movement between pens in same site; dedicated equipment per pen, boots rather than footbath, dedicated overalls per pen – freshly warm-laundered and dry overalls (possible addition of trigene disinfectant?)
- Strict enforcement of quarantine security including restricted entry of personnel
- Hygiene of quarantine pen (daily removal of faeces, food)
- Appropriate health screening under GA and monitoring during confinement includes:
  - Physical examination including examination for ectoparasites (ticks, fleas, mites)
  - Blood collection for CBC, MBA (biochemistry) –looking for indicators of muscle, kidney and liver disease and lymphoproliferative disorders
  - Collect extra serum to bank for future testing, e.g. herpesvirus. Opportunistic sampling for research, e.g. karyotyping, can be incorporated into this investigation.
  - Follow-up diagnostic imaging where internal mass suspected from physical exam, e.g. x-ray, ultrasound
  - Faecal exam (ova, coccidia, salmonella)
- While not a biosecurity requirement, screening for chromosomal anomalies advisable for all animals entering captive breeding programs.
- For sites where there are both DFTD infected and non infected devils:
  - Undertake activities in non-infected enclosures before working in infected enclosures
  - After working in infected devil pens, boots are to be cleaned and dried, or cleaned and disinfected, and overalls are to be changed if soiled before entering uninfected pens.
- Feed - field shot game from any area in Tasmania is acceptable. Road kill should not be used (unless you saw it live and hit it in which case it is the same as field shot game). *Note*: While the DFTD risk from roadkill is likely to be very low, it is recommended that research is conducted on holding roadkill in a chiller or freezing as a control of DFTD prior to amending this requirement.

  Decontamination between consignments – Physical cleanup of pen, remove faeces, food, bedding, rake out leaf, time elapsed (not relevant to ectoparasites and salmonella). Where there have been clinical cases of salmonellosis or severe ectoparasite burden – additional decontamination measures as required by the CVO.

12. Captive holding facility: Husbandry, disease preventative and disease monitoring protocols in place and appropriate to maintaining 1) DFTD disease-free status 2) good health and 3) as far as compatible with good health, a broad spectrum of natural parasites and microflora.

Decontamination of infected pens

The most difficult area to decontaminate will be in an inaccessible den area:

- Remove all devils
- General clean up including removing faeces, leftover feed, litter, etc.
- Clean off gross contamination on walls
- Clean floor of den where possible
- Spell pen for 1 month. Subject to review in the light of new information (goes for all of the above).
- Decontamination of pen for ectoparasites if deemed necessary.

B. Shipment Scenario II – Captive to Captive

Potential sources of disease along the movement pathways are:

- Shipping containers: Crates, traps, sacks- use clean dry sacks to contain devils
- Transport: Road vehicles, planes, any vehicle used to move animals
- Holding: Quarantine facility(ies) e.g. if going overseas.
- Captive facility

Movement Pathway for Captive to Captive

1. Captive population → 2. Shipping Crate → 3. Vehicle → 4. Pre-export quarantine (if appropriate) → 5. Crate → 6. Vehicle → 7. Aircraft (for interstate or overseas travel) → 8. Vehicle → 9. Post-shipment quarantine holding → 10. Crate or trap → 11. Vehicle → 12. Captive holding facility

Disease Risk Management Plan for this Movement Pathway

Health examination for movement

- A physical veterinary examination should take place pre- and post-movement before the animal is mixed with other devils. One of these should include examination under general anaesthetic (GA) with:
  - Physical examination including examination for ectoparasites (ticks, fleas, mites)
  - Blood collection for CBC, MBA (biochemistry) – looking for indicators of muscle, kidney and liver disease and lymphoproliferative disorders
  - Follow-up diagnostic imaging where internal mass suspected from physical exam, e.g. x-ray, ultrasound
  - Faecal exam (ova, coccidia, salmonella)
- Any variations to this health screen are at the discretion of the veterinarian of the receiving institution.
- Good communication is required between institutions of origin and destination including provision of past health records.

(Numbers refer to stages in the movement pathway)

1. Hygiene at catching: Clean dry sacks (cleaned disinfected and dried since previous use); other hygiene as per normal management for the facility.

2, 5 & 10. Hygiene of crates: Disinfected since previous use (as for wild to captive); crate clean (absorbent substrate - discard after use), hygienically stored (dry), appropriate size and design for species.

3, 6, 7, 8, & 11. Transport vehicles: Visually clean and dry (devils are transported in crates), all devils are of the same health status in transit with adequate separation from other animals, appropriate ventilation, temperature and humidity. For overseas travel, must comply with IATA requirements.

4 & 9. Quarantine: Period and health screening requirements for overseas export will be determined by export requirements of the importing country.

Feed - Normal meat supply acceptable and field shot game from any area in Tasmania is acceptable. Road kill should not be used (unless you saw it live and hit it in which case it is the same as field shot game).
Note: While the DFTD risk from roadkill is likely to be very low, it is recommended that research is conducted on holding roadkill in a chiller or freezing as a control of DFTD prior to amending this requirement.

Servicing of Pens

People movement between pens in same site:

- Dedicated equipment per pen including boots rather than footbath, freshly warm-laundered and dried overalls (possible addition of trigene disinfectant?)
- For sites where there are both DFTD infected and non infected devils:
    - Undertake activities in non-infected enclosures before working in infected enclosures;
    - Dedicated equipment per infected pen, boots rather than footbath, dedicated overalls per pen – freshly warm-laundered and dry overalls (possible addition of trigene disinfectant?)
- Decontamination between consignments – physical cleanup of pen, remove faeces, food, bedding, rake out leaf, time elapsed between consignments (not relevant to ectoparasites and salmonella).
- Where there has been a clinical case of salmonellosis or severe ectoparasite burden – additional decontamination measures as required by the Chief Veterinary Officers (CVO).

11. Husbandry: Disease preventative and disease monitoring protocols in place and appropriate to maintaining 1) DFTD disease-free status 2) good health and 3) a broad spectrum of natural parasites and microflora, as far as compatible with good health.

Decontamination of infected pens

The most difficult area to decontaminate will be in an inaccessible den area:

- Remove all devils
- General clean up including removing faeces, leftover feed, litter, etc.
- Clean off gross contamination on walls
- Clean floor of den where possible
- Spell pen for 1 month. Subject to review in the light of new information (goes for all of the above).
- Decontamination of pen for ectoparasites if deemed necessary.

C. Shipment Scenario III – Wild to Wild

Wild to wild is taking an animal from a wild environment and releasing into a non-contiguous wild environment. This would entail a period of quarantine for the purpose of health assessment (not just DFTD) prior to release. (NB: Quarantine means devils are managed in isolation from the general devil population and subjected to observation and/or testing or treatment for disease. Observation to include monitoring of body weight.)

Far NW to East

This entails a movement from an area currently believed to be DFTD free to an area where DFTD is known to exist. Consequently DFTD is not a transfer risk so the consideration is on the other diseases listed for concern (above) and appropriate disease screening should apply. Quarantine involves 2 weeks isolation and observation for disease:

- Physical examination – DFTD animals are not to be released to new area in the wild.
- Specific testing – test for heavy worm burden. Treat heavy worm or ectoparasite burden.
- Blood test (as for other movements) – if abnormal profile, hold until normal prior to release.

East to Far NW

From known DFTD infected area to area believed free of DFTD. Wild to wild not permitted.

East to East

DFTD infected to DFTD infected. Consequently DFTD is not a transfer risk so the consideration is on the other diseases listed for concern and appropriate disease screening should apply. Quarantine involves 2 weeks isolation and observation for disease:

- Physical examination – DFTD animals not released to new area in the wild.
- Specific testing – test for heavy worm burden. Treat heavy worm or ectoparasite burden.
- Blood test – if abnormal profile, hold until normal prior to release.

D. Shipment Scenario IV – Wild to Island

(Including virtual islands that are free of DFTD)

Far NW to Island

Least risky from DFTD perspective, but a risk still exists for this and other diseases. A period of quarantine for non-DFTD diseases of concern is required. In this case an enclosure-like facility may be appropriate. Quarantine involves 2 weeks isolation and observation for disease:

- Physical examination – DFTD animals not released to new area in the wild.
- Specific testing – test for heavy worm burden.
- Treat heavy worm or ectoparasite burden. Blood test – if abnormal profile, hold until normal prior to release.

As the island is part of the insurance population, we need to be sure it is DFTD free. Do we need to quarantine for 12 months minimum to ensure DFTD freedom? If several devils are held as a group and DFTD is detected in one animal of the group, the entire group will be considered to be infected until proven otherwise.

East to Island

Risky from DFTD perspective, and a risk still exists for this and other diseases. A period of quarantine is needed for non-DFTD diseases of concern.

If the island is to be part of the insurance population, we need to be sure it is DFTD free. This means that the devils should be held in quarantine for 12 months minimum to ensure DFTD freedom. If several devils are held as a group and DFTD is detected in one animal of the group, the entire group will be considered to be infected until proven otherwise. In this case an enclosure-like facility may be appropriate. In effect the movement becomes Wild to Enclosure (or enclosure) then Enclosure to Wild.

Quarantine involves 2 weeks isolation and observation for disease other than DFTD:

- Physical examination – DFTD animals not released to new area in the wild.
- Specific testing – test for heavy worm burden. Treat heavy worm or ectoparasite burden.
- Blood test – if abnormal profile, hold until normal prior to release.

Island to Tasmania

Depends on the known DFTD infection status and the status of other diseases on the island. Islands with easy public access need to be considered as unknown DFTD status. Islands thought to be DFTD free would be treated the same as **Far NW to Island** (see above).

E. Shipment Scenario V – Enclosure to Wild

DFTD status of enclosure to be verified as DFTD free prior to commencing any movements. DFTD status to be determined/verified by:

- Ensuring protocol for enclosure management has been complied with (see appendix)
- Integrity of enclosure perimeter

- Past animal examination records with no reporting of DFTD
- Examination of a statistical sample (95% confidence of detection @ 1%) of animals under GA for DFTD before movement protocol commences

Pre-movement quarantine requirements needed to deal with non-DFTD diseases, noting that there is a risk of contact with diseases not in Tasmania here with enclosures in mainland Australia (as opposed to enclosures in Tasmania). However, a 2 week quarantine observation should be suitable to address both. *Note:* This situation will be followed by a soft release which allows a further period for observation.

- Animal selection/processing: Pre-movement health check as discussed above.
- Shipping containers: Crates, traps, sacks - use clean dry sacks
- Transport: Road vehicles, planes (apply to all movements)
- Holding: Quarantine facility(ies) e.g,. if going overseas.
- Captive facility

Movement Pathway for Enclosures to Wild

Enclosure population → 1. Trap → 2. Shipping Crate → 3.Vehicle → 4. Quarantine → 5. Crate → 6. Vehicle → 7. Aircraft (for interstate or overseas travel) → 8. Vehicle → 9. Crate → 10. Vehicle → 11. Release

Disease Risk Management Plan for this Movement Pathway

Health examination for movement

A physical veterinary examination should take place at start of pre movement quarantine. This should include general anaesthetic for:

- Detailed physical examination for DFTD and other lesions
- Examination for ectoparasites
- Blood collection for CBC, MBA –looking for indicators of muscle, kidney and liver disease, lymphoproliferative disorders
- Faeces (ova, coccidia, salmonella) collection
- Follow up diagnostic imaging where internal mass suspected e.g. x-ray, ultrasound).
- Any variations are at the discretion of the CVO.

1. Hygiene at catching: Clean dry sacks; hygiene as per normal management for the facility.

2, 5 & 10. Hygiene of crate: Disinfected since previous use (as above); clean (discard substrate), hygienically stored (dry), absorbent substrate appropriate size and design for species.

3, 6, 7, 8, & 11. Transport vehicles: Visually clean and dry (devils are transported in crates), all devils are of the same status in transit and adequate separation from other animals, appropriate ventilation, temperature and humidity. For overseas travel, must comply with IATA requirements.

4 & 9. Quarantine: For overseas export will be determined by export requirements. For sites where there are both DFTD infected and non infected devils:

- Undertake activities in non-infected enclosures before working in infected enclosures;
- Dedicated equipment per infected pen, boots rather than footbath, dedicated overalls per pen – freshly warm-laundered and dry overalls (possible addition of trigene disinfectant?)
- Clinical cases of salmonellosis or severe ectoparasite burden – additional decontamination measures as required (CVO).

- People movement between pens in same site: dedicated equipment per pen, boots rather than footbath, dedicated overalls per pen – freshly warm-laundered and dry overalls (possible addition of trigene disinfectant?)

Feed - Normal meat supply is acceptable and field shot game is also acceptable. Road kill should not be used (unless you saw it live and hit it in which case it is the same as field shot game). *Note*: While the DFTD risk from road kill is likely to be very low, it is recommended that research is conducted on holding road kill in a chiller or freezing as a control of DFTD prior to amending this requirement.

11. Husbandry: Disease preventative and disease monitoring protocols in place and appropriate to maintaining 1) DFTD disease-free status 2) good health and 3) as far as possible a broad spectrum of natural parasites and microflora.

Decontamination of infected pens

The most difficult area to decontaminate will be in an inaccessible den area:

- Remove all devils
- General clean up including removing faeces, leftover feed, litter, etc.
- Clean off gross contamination on walls
- Clean floor of den where possible
- Spell pen for 1 month. Subject to review in the light of new information (goes for all of the above).
- Decontamination of pen for ectoparasites if deemed necessary.

Overseas Options (See Overseas Movement Diagram (Figure 2)

The minister has made it clear that no devils are to be sent overseas; However, in view of the need identified by this PHVA workshop for a large number of holding spaces (up to 1500 devils) to maintain a genetically viable insurance populations, the group examined the disease risks associated with overseas transfers in the event that the current policy may be revised.: Key issues are:

- Lots of unknowns regarding international movement of devils
- Devils are a species of unknown disease susceptibility
- Ethical issues of moving diseased animals overseas

Examples of Possible Diseases of Concern

- Rabies
- Transmissible Spongiform Encephalopathies (TSE)
- Tuberculosis (TB)
- Arboviruses

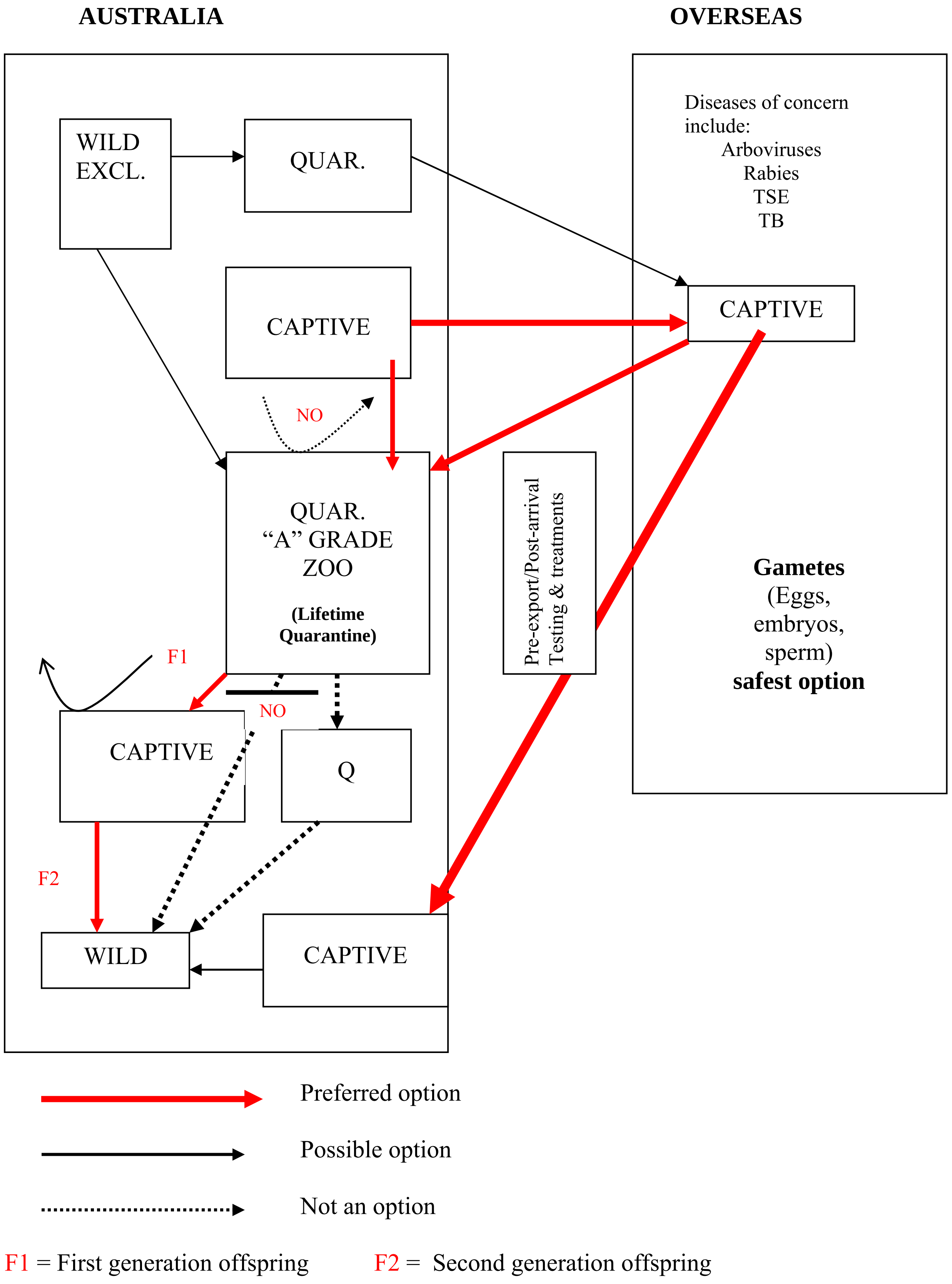
NB - No diagnostic tests validated for this species and the exotic disease susceptibility of deveils is unknown. Would limit overseas containment to zoo enclosures only.

Transport of Devils Overseas

Figure 2 is a movement diagram depicting the potential devil movement pathways between Australia and overseas countries. The diagram incorporates:

- Captive to captive (preferred route)
- Wild to captive
- Enclosure to captive
- *Genetic material (sperm and ova)

Figure 2: Potential overseas export movement pathway for Tasmanian devils.



Movement of Diseased Devils for Research (as opposed to Captive Breeding Programs)

Because the country receiving animals implements its own quarantine requirements, they can request diseased animals and we then lose control of devil movements in that country. This is an issue for the research group and can be brought back to the disease group. Management of diseased animals in another country is out of our control so we need to be very cautious of intentions, etc. before we start making these sorts of agreements.

Transport of Overseas Devils Back to Australia

- Would require lifetime quarantine and surveillance – precautionary principle applied to founder generation (F0)
- To mainland A grade zoos only (Biosecurity Australia)
- Must go to a dedicated Tasmanian devil quarantine facility (e.g., Taronga Zoo) for lifetime quarantine
- Exposure to other devils for breeding, e.g. from wild or elsewhere – permissible but **one way traffic only** – cannot put that devil back into wild/elsewhere
- For progeny – F1s go to other captive facilities/quarantine (not enclosure, island or wild), F2s can go to the wild, etc.

Quarantine

Quarantine is 18 months because the longest time from exposure to visible detection of the disease that has been observed is 10 months. However, the quarantine period and/or requirements will be established by the receiving country. That importing country will also need to make its own health assessment protocols, etc.

Other Options

- From A grade zoo to wild – not acceptable; though possibly acceptable through a quarantine stage
- Genetic material – properly washed ova/sperm/embryos OS captive to captive devils in Australia (cannot introduce rabies, TSE, etc., in semen)
- Testing and treatment – kill internal/external parasites before re-entry into Australia
- New Zealand as an option – no rabies there, fewer arboviruses, no TSEs; (Note - TB, wobbly possum disease are there. Still need importation health standards (Biosecurity Australia)).

Arguments in Favour of Including the Overseas Option

- Provides another degree of flexibility to managing the insurance population
- Reduces risk or genetic bottlenecks
- Overseas can be seen as another basket to put our eggs in (another level of insurance for the captive populations)
- Takes advantage of extra captive spaces overseas
- Could use overseas sites to hold ‘surplus’ post-breeding animals

Notes:

- Enclosures or islands overseas untenable due to low level of disease management capability under these circumstances.
- Need to choose what genetic material goes overseas - international genetics probably just needs to be a backup for genetics in the Australian devil populations – i.e., a duplicate or well representative sample of the Australian genetic makeup. That makes the biosecurity risks better because it minimises movement to and from overseas.

Communications Plan for Devil Movements

Group role	Stakeholder	Information Needs	Communication Method(s)	When	Who
Operational/ implementation (the workers)	Managers of devil facilities e.g. wildlife parks	▪ Biosecurity protocol ▪ Movement requirements ▪ Details of individual movements ▪ Timing of move	Personal- direct (email, phone, fax, etc.)	Need most lead in time	Individual coordinator for each movement
	Vets	▪ As above plus ▪ Specific tests required ▪ Medical histories	Personal- direct (email, phone, fax, etc.)	Couple weeks in advance	As above
	Diagnostic laboratories	▪ As above plus ▪ Specific tests required	Personal- direct (email, phone, fax, etc.)	Couple weeks in advance	As above
	Keepers	As above	Personal- direct (email, phone, fax, etc.)	Need most lead in time	As above
	Field workers	As above	Personal- direct (email, phone, fax, etc.)	Couple weeks in advance	As above
	Registrars/ Record keepers/ curators	▪ As above plus ▪ Medical histories	Personal- direct (email, phone, fax, etc.)	Need most lead in time	As above
Coordination plus information management	Studbook holder ARAZPA	Recommend pairings and movements	Personal- direct (email, phone, fax, etc.)	Minimum 6 months (well in advance)	▪ Curator/ manager of receiving institution ▪ IT management group
	As above	▪ Details of individuals and provenance, parentage (individual studbooks) ▪ Identification	Personal- direct (email, phone, fax, etc.)	After movement completed	Individual coordinator for each movement (possibly registrar, facilities manager or curator)
International affairs/ permitting	DEWHA (Commonwealth Conservation) (Includes CITES)	▪ Information on proposed international movements ▪ Internal protocols (biosecurity, movement requirements) ▪ Responsible for consideration of permits and associated conditions.	▪ Formal-written ▪ Plus some personal- direct (email, phone, fax, etc.)	▪ Couple of years in advance of any proposed offshore movement to establish protocols. ▪ Individual movements minimum of 6 months.	▪ High-level discussion to establish system. ▪ Curator/ manager level for subsequent movements.
	AQIS	As above	As above	As above	As above
	Biosecurity Australia (BA)	As above	As above	As above	As above
Governance	Steering Committee	Overarching information on: protocols, plans, implementation/ update reports, issues.	Formal reporting to committee	Quarterly	Insurance population coordinator
	DPIW	As above	As above	As above	As above

Funders	Funders	Overarching information on project, general goals and details of specific funding opportunities.	As appropriate	Need to know	Marketing and Comms.
External stakeholders and stakeholders	Wildlife biologist working on devils	▪ Biosecurity protocol ▪ Constraints on movements	Standard handout material that research organisation working with devils have a copy and is distributed/ updated	Yearly and when significant changes made to protocols.	▪ Research coordinator ▪ Identify key contact in each receiving organisation
Public	Public	▪ Need to have information available so that they can know how to minimise their impact. (Includes personal protocols.) ▪ General information on strategy: What is being done to prevent spread ▪ Point of contact	▪ Point of contact ▪ Press release ▪ Website (public area) ▪ Newsletter	▪ On-going and; ▪ In advance of significant event/move that may impact them.	DPIW media liaisons officer.
Compliance, auditing and monitoring	CVO, Tasmanian quarantine, AQIS	▪ Protocols ▪ Movements ▪ Issues around biosecurity ▪ Reports of breaches	Personal- direct (email, phone, fax, etc.) (formally provided with protocols)	▪ Don't need much lead time ▪ At time of movement	▪ Planning team (TBA) ▪ Individual coordinator for each movement
	Auditing (compliance with biosecurity)	▪ Protocols ▪ Movements ▪ Reports of breaches	Site visits plus audit check list (REQUIRED)	▪ Routine audits ▪ Post movement	ARAZPA/DPIW
Review of protocols	Manager of protocol	▪ Protocols ▪ Identified issues ▪ New science/ information	Formally seek	Every 12 months or issues/ information based	▪ Steering Committee ▪ Veterinary coordinator (will co-opt necessary group)

Issues from other groups

Note: Scope of this working group is biosecurity so issues outside this scope were not considered by the DRA group. Those items to be actioned as a follow up to this workshop are noted as (REQUIRED)

Enclosures

- Preventative medicine program (REQUIRED)
    - Criteria for intervention and procedure
    - Management of transmission of disease

Captive Group

- Biosecurity for captive release to wild (DONE)
- Contingencies for outbreaks of other disease (REQUIRED)
- Communication plan (DONE)
- Training of veterinarians in devil care and diseases of concern (REQUIRED) and biosecurity issues (DONE)
- Reintroduction of devils and loss of micro-flora (REQUIRED)

Island Population

- Contingencies for outbreaks of other disease (REQUIRED)
- When can release to wild and criteria for determining (REQUIRED)

Non-biosecurity Health Related

- Husbandry (Refer to husbandry manual)
    - Behaviour
    - Diet
    - Common diseases section (REQ\UIRED)
- Research
    - Parasitology
- Reintroduction
    - Management of devils with low prevalence of disease

Action Plan

Aim: Provide disease risk assessment and risk management plan

Critical Questions to be Answered as a Priority

1. Insurance population - If for maintaining genetic diversity, then NOT for DFTD resistance
2. Reintroduction into wild – When can this happen.
3. Salvage and use of genetic material for infected populations.

High

Develop contingency plans for outbreaks of other disease (REQUIRED)

Medium

Low

When can release to wild and criteria for determining (REQUIRED)

5. Action Plan

ISSUE	ACTION	TASKS TO ACHIEVE OBJECTIVE	WHO/ RESPONSIBLE	WHEN/ TIME-LINE	RESOURCE IMPLICATION
Selection for resistance	Propose to Steering Committee the formation of a threat abatement team to discuss a program to actively select for resistance.	Draft a discussion paper to Steering Committee that says insurance population should not be used to select for resistance and proposing that if this is to be done then it needs to happen outside of the insurance population.	Kathy Belov to new Program Manager	21 August 2008	In-kind
Reintroduction into wild.	Present a draft options document to the Steering Committee	Draft document that recommends options. May include options of: ▪ Seed with surplus animals into wild ▪ Vaccinated into disease ▪ Is it necessary for complete depopulation prior to introduction	Rod Andrewartha and Greg Woods.	21 August 2008	In-kind
Salvage and use of genetic material from DFTD infected areas/individuals	Determine from current data age at which juveniles become at risk of natural infection with DFTD. (Both pouch and den.)	Examine available dataset to provide an answer or determine if further research is required.	Senior Scientist	21 August 2008	In-kind

Revision of biosecurity protocols	Review the current protocols in light of the results of the PHVA disease risk assessment. To include protocols for diseased and disease free populations.	Delegate to Kim/ Colette Develop a template movement protocol Draft animal movements database Recommendations (including standards) on the need to have available disease records within the captive facility, which can be accessed to inform movement decisions. And other related documents: ▪ Link to draft PHVA report from Richard. ▪ Conditions for export of Tasmanian devils. NOTE: To include standards.	Rod Andrewartha	End November 2008.	May require back-up clerical support.
	Review risk categorisation	How do we integrate carers and wildlife parks into program? Needs to include a definition of “DFTD free.” Include consideration of site location with regard to biosecurity risk (where can we put animals in Tasmania, mainland and overseas?)	Colette	End November 2008.	In-kind

PHVA report (Disease Risk component)	Completion of the draft report by DRA working group participants	Distribute draft report to working group members by email. Identify specific people to address specific areas. Feedback using track changes.	Richard	First round feedback – end July 2008. Final TBA by Onnie	In-kind
Risk analysis	Assess value of Precision Tree analysis on probability of transfer of DFTD between diseased and non-diseased wild populations of devils	Develop Precision Tree evaluation Circulate for comment by DRA working group	Richard	First round feedback – end July 2008. Final TBA by Onnie	In-kind
Address research needs as identified in DRA PHVA report.	Review DFTD research strategy	Review DFTD research strategy with additions from DRA report. Priority is for research that needs to happen. Includes priority listing and costing and time-line. To Senior Scientist for consideration and reporting to the Steering Committee.	Kathy	End November 2008.	In-kind
	Initiate research into the key research question: “How MHC haplotypes relates to resistance in the wild.”	Develop costed research plan. To Senior Scientist for consideration and then on to Steering Committee.	Greg	21 August 2008	In-kind

Response to breaches	Write guidelines to do with biosecurity incidents.	Guidelines for responding to detection of DFTD in an insurance population and: Known incursion of a wild devil into a captive population. Diagnosis of another significant (non-DFTD) disease in devil population.	Rod	March 2009	In-kind
Information management	Minimum requirements of medical records and central repository.	Define minimum requirements Identify repository and who should manage	Colette	20 December 2008	Possible clerical and IT input.

Parked Issues for Consideration by the Group

- OH&S *Salmonella mississippi* as a cause of human infections (zoonosis) *(INCLUDE IN HUSBANDRY MANUAL)*
- Need to treat all devils before translocation (stress of movement, etc.)
- Documentation and where the samples go? Prioritise when and how and who is contacted in the event of possible DFTD lesions in captivity or other disease *(COMMUNICATIONS PLAN)*
- GAPS in knowledge with regard to DFTD and other diseases *(RESEARCH PLAN)*
- Excess animals – what to do with them. Do we bring those back to Tasmania to do research (senescent animals). Aged animals and euthanasia. Animal welfare issues. Removal of pouch young vs. old animals and euthanasia. Consider the issues with regard to wallaby culls. Need to be transparent about intentions and upfront – everybody needs to know *(NOT BIOSECURITY ISSUE – WELFARE ISSUE)*
- Spotted tailed quolls and other tumours – similar looking to DFTD and not all DFTD lesions *(RESEARCH)*

Tasmanian Devil PHVA
Final Report

Section 7
Modeling Working Group Report

Population Modeling Working Group

Modellers: Kathy Traylor-Holzer, Caroline Lees, Barry Baker, Nick Beeton

Introduction

The task of the Population Modeling Working Group was to provide a simulation modeling tool to assist in the evaluation of various Tasmanian devil insurance population options and strategies. Simulation modeling was used to explore the potential for these options to contribute to the goals of the Save the Tasmanian Devil Steering Committee Insurance Population Strategy.

In preparation for the PHVA workshop, two preliminary baseline models were developed to simulate Tasmanian devil life history in the absence of Devil Facial Tumour Disease (DFTD), one based on demographic rates for wild populations and a second based on demographic rates from studbook data to represent intensively managed captive populations. During the workshop, modellers worked closely with each of the insurance population strategy working groups to build detailed devil models specific to each strategy, drawing upon both preliminary baseline models as appropriate and incorporating relevant mortality factors and anticipated management strategies. CL worked with the Captive Management Working Group, KTH worked with the Free Range Enclosures Working Group, and BB/NB worked with the Islands Working Group to develop and explore these models; subsequent post-workshop model refinement was done by KTH and CL.

Vortex Simulation Model

Computer modeling is a valuable and versatile tool for quantitatively assessing risk of decline and extinction of wildlife populations, both free ranging and managed. Complex and interacting factors that influence population persistence and health can be explored, including natural and anthropogenic causes. Models can also be used to evaluate the effects of alternative management strategies to identify the most effective conservation actions for a population or species and to identify research needs. Such an evaluation of population persistence under current and varying conditions is commonly referred to as a population viability analysis (PVA).

The simulation software program *Vortex* (v9.84) was used to examine the viability of populations managed under each of the three general insurance population strategies. *Vortex* is a Monte Carlo simulation of the effects of deterministic forces as well as demographic, environmental, and genetic stochastic events on wild or captive small populations. *Vortex* models population dynamics as discrete sequential events that occur according to defined probabilities. The program begins by either creating individuals to form the starting population or importing individuals from a studbook database and then stepping through life cycle events (e.g., births, deaths, dispersal, catastrophic events), typically on an annual basis. Events such as breeding success, litter size, sex at birth, and survival are determined based upon designated probabilities that incorporate both demographic stochasticity and annual environmental variation. Consequently, each run (iteration) of the model gives a different result. By running the model hundreds of times, it is possible to examine the probable outcome and range of possibilities. For a more detailed explanation of *Vortex* and its use in population viability analysis, see Lacy (1993, 2000) and Miller and Lacy (2005). PVA using *Vortex* predicts the future fate of populations without bias for well-studied populations (Brook *et al*. 2000).

Baseline Model Parameters for Wild Populations

A baseline *Vortex* model for wild populations of Tasmanian devils was developed prior to the PHVA primarily from data from field studies provided by Jones and Hawkins and colleagues as well as information gleaned from previously published research (Bradshaw and Brook 2005; Guiler 1970a,b; Hawkins *et al*. 2006; Lachish et al. 2007; McCallum and Jones 2006; McCallum *et al.* 2007). These data provided annual estimates of many of the parameters needed in *Vortex*. Environmental variation was calculated by removing average demographic (binomial) variation from the total variation observed over years from the combined datasets. This baseline model was developed to represent a relatively large, stable wild population near carrying capacity (K) in the absence of DFTD or other significant mortality factors and with the potential for positive population growth at densities below K. Its purpose was to estimate baseline demographic rates in healthy, viable wild devil populations for reference in developing specific insurance population models. The model was not intended to model the current wild population to obtain estimates of wild devil population viability; such analyses and projections have been addressed elsewhere (e.g., Bradshaw and Brook 2005; McCallum *et al.* 2007). Table 1 summarises the primary input values used in all baseline models.

General Model Parameters

Number of iterations:	*500*
Number of years:	*100 (about 30 generations)*
Extinction definition:	*Only one sex remains*
Number of populations:	*Single population*
Initial population size (N_i):	*1000 (at stable age distribution)*
Carrying capacity (K):	*1200 (slightly above* N_i*)*

Reproductive Parameters

Mating system: *Polygyny (maximum of 4 female mates per male per year)*

Age of first offspring: *2 years (females); 3 years (males)*
This parameter represents the average age of first reproduction, not the age of sexual maturity or earliest reproductive age observed.

Density-dependent reproduction: *Yes*
Modelled as density-dependence in the percent of females breeding and in mean litter size, as described below.

Percent adult females breeding: *80% (at N=K) to 100% (low density); EV=4%*
Based on limited field data (age-specific rates) and evidence of lower reproduction in high density conditions. Described by the following function (also see Figure 1):

(100-((100-80)*((N/K)^2)))*(N/(0.1+N))

Percent adult males in the breeding pool: *100% of proven males; 60% of males with no prior offspring*

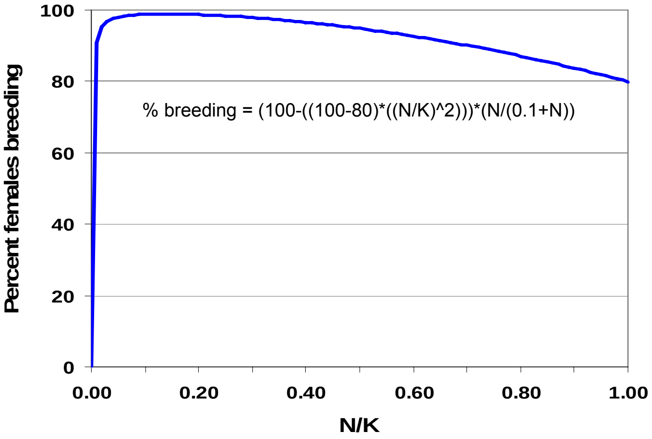


Figure 1. Density-dependent function used in the baseline model for percent of females breeding.

Maximum number of progeny per year: *4*
Mean litter size: 3.32 (at N=K) to 3.65 (at low density); linear decline; EV=0.75%
Based on limited field data in high density and low density (DFTD) conditions.

Percent males at birth: *50%*
There is no evidence that sex ratio at birth differs statistically from 50:50.

Mortality Parameters

Mortality rates: *Age specific (same rates were used for both sexes)*
Juvenile (0-1 yr): *20%* (based on no pouch mortality, and 20% post-weaning to first birthday)
Sub-adult (1-2 yrs): *55%*
Adult (2+ yrs): *45%* (annual)
EV: *2%, 5.5%, 4.5%, respectively (CV = 10%)*
Mortality rates are not well measured in the wild, and estimates involve more uncertainty than estimates for reproductive parameters. Sub-adult and adult mortality rates were suggested by

participants in pre-workshop data collection. Juvenile mortality was derived based on several observations of very low pouch mortality once embryos attach to the nipples for the first 9 months, with post-weaning mortality for the remaining 3 months at a rate similar to that suggested for sub-adults (equivalent to 59% annual mortality). Environmental variation was suggested as being relatively low (coefficient of variation = 10% was used); variation due to demographic stochasticity is automatically built into the modeling process.

Inbreeding depression: *Yes*
In the absence of estimates of inbreeding depression specific to Tasmanian devils, the default value of 3.14 lethal equivalents was used, 50% of which were assigned to lethal alleles and subject to purging. This value is the median LE calculated from studbook data for 38 captive mammal species (Ralls *et al.* 1988). These values were calculated from, and were implemented in the model, as reduced juvenile survival in inbred individuals. As inbreeding depression is known to occur for most aspects of reproductive fitness (e.g., mating ability, juvenile survival, adult survival, fecundity) (Frankham *et al.* 2002), the use of 3.14 lethal equivalents for juvenile survival substantially underestimates its impact. O'Grady *et al.* (2006) concluded that 12 lethal equivalents spread across survival and reproduction is a realistic estimate of inbreeding depression for wild populations. Work on captive populations by Wilcken (2002) indicates that inbreeding depression is at least twice the default value of 3.14 LE, so here it is modelled as double the Ralls *et al.* (1988) level by decreasing the fertility of inbred females using the following multiplier for percent of females breeding:

E ^ (-I*0.0157)

Concordance between environmental variation in reproduction and survival: *Yes*
Default setting used for wild populations in the absence of species- or population-specific data. This means that environmental variation in reproduction and survival are directly linked, such that 'good' years for reproduction are also 'good' years for survival; conversely, 'bad' years for reproduction are linked to 'bad' years for survival (worst case scenario for environmental variation).

Maximum age: *5 years*
Individuals are removed from the model after they pass the maximum age. *Vortex* assumes that animals can reproduce throughout their adult life and does not model reproductive senescence unless functions are used to do so. Devils may live to 6 years of age in the wild, although few reach this age class, and older females have been observed to reach reproductive senescence. Therefore, maximum age (both in terms of reproduction and longevity) was set to 5 years.

Number of catastrophes: *Not included in baseline model*
No catastrophes were included in the baseline wild model, as catastrophic events are likely to differ significantly among the three insurance population strategies and were addressed specifically by each working group. However, a realistic model for wild devil populations would include the risk of catastrophes. Reed *et al.* (2003) examined 88 vertebrate populations and found the risk of severe population decline ($\geq$50%) to be approximately 14% per generation. Therefore, in the absence of specific catastrophe data, a recommended risk of catastrophic events for wild Tasmanian devil populations would be about 5% per year (i.e., once per 7 generations), with a severity factor of 50% reduction in survival in a catastrophic year.

Harvest: *Not included in baseline model*
Supplementation: *Not included in baseline model*

Table 1. Primary parameter input values for the Vortex Tasmanian devil model.

Parameter	**WILD baseline values**	**Islands**	**Free Range Enclosures**	**Captive (zoos)**
Breeding system	Polygyny (up to 4♀♀/♂/yr)	Polygyny (up to 4♀♀/♂/yr)	Polygyny (up to 4♀♀/♂/yr)	Polygyny (up to 4♀♀/♂/yr)
Reproductive lifespan (females)	Ages 2-5 years	Ages 1-5 years	Ages 1-4 or 2-4 years	Ages 2-4 years
Reproductive lifespan (males)	Ages 3-5 years	Ages 3-5 years	Ages 2-5 years	Ages 2-5 years
Density dependent reproduction?	Yes	Yes	No	No
Adult females breeding/yr	100% in low density conditions; (EV=4%); 80% at high densities (at K); (EV=4%)	100% (2-5yr), 20% (1yr) in low density conditions; (EV=5%) 70% (2-5yrs) at high densities (at K); (EV=5%)	% for ages 1 / 2 / 3 / 4 yrs: Low: (10) / 42.5 / 42.5 / 35 Mod: (15) / 70 / 60 / 40 High: (20) / 85 / 85 / 70	% for ages 2 / 3 / 4 yrs: Low: 0 / 34 / 10 Base: 47 / 42 / 22 Mod: 57 / 55 / 35 High: 67 / 67 / 40 HighPlus: 80 / 80 / 80
Males in breeding pool:	60% of unproven males 100% of proven males	60% of unproven males 100% of proven males	60% of unproven males 100% of proven males	Unproven males: 50% (2 yr olds) 80% (3-5 yr olds) 100% of proven males
Maximum litter size	4	4	4	4
Mean litter size	3.65 at low density 3.32 at high densities (at K) (SD=0.75)	3.65 at low density 3.32 at high densities (at K) (SD=0.75)	3.0 (SD=0.5)	2.6 (litter size distribution of 1-4 pups as 19%, 26%, 31%, 24%)
Overall offspring sex ratio	50:50	50:50	50:50	50:50
Inbreeding depression (50% lethal for juvenile mortality)	3.14 LE (as ↑ pup mortality); 3.14 LE (as ↓ females breed.)	3.14 LE (as ↑ pup mortality); 3.14 LE (as ↓ females breed.)	3.14 LE (as ↑ pup mortality); 3.14 LE (as ↓ females breed.)	3.14 LE (as ↑ pup mortality); 3.14 LE (as ↓ females breed.)
% annual mortality (EV):				
0-1 Yr	20% (represents 0% in pouch, 59% post weaning) (2%)	20% (represents 0% in pouch, 59% post weaning) (2%)	10% (1%)	8% (females) (0%) 11% (males) (1.8%)
1-2 Yr	55% (5.5%)	45% (4.5%)	4% (males) (0.4%)	3% (females) (0%) 4% (males) (1.8%)
Adult mortality	45% (4.5%)	45% (4.5%)	4% (2-3 yrs) (0.4%) 10% (4-5) (0.4%)	4% (2-4 yrs) (0-7.5%) 25% (5), 50% (6), 85-95% (7+)
Maximum age	5 years (both sexes)	5 years (both sexes)	5 years (both sexes)	8 yrs (females); 11 yrs (males)
Catastrophe(s)	None (see discussion in text)	Fire: Frequency = 5% 10% reduction in survival	Generic: Frequency = 1% 50% reduction in survival 10% reduction in reproduction	Institution loss: Freq = 10% 7% reduction in survival
Breeding management	Panmictic	Panmictic	Panmictic OR MK static / Max F = 0.3750	Mean kinship (static) Maximum F = 0.3750

Descriptive Results of the Baseline Wild Model

Deterministic Output

The demographic rates (reproduction, mortality and catastrophes) included in the baseline model can be used to calculate deterministic characteristics of the model population. These values reflect the biology of the population in the absence of stochastic fluctuations (both demographic and environmental variation), inbreeding depression, limitation of mates, and immigration/emigration. It is valuable to examine deterministic growth rates (lambda, generation length, and age structure) to assess whether they appear realistic for the species and population being modelled.

Fecundity (both percent of females breeding and mean litter size) varies with density in the baseline model; thus, deterministic rates also vary across population density. Expectations are for substantial population growth potential at low densities, and relatively little growth at carrying capacity. This is based on the observation of Guiler (1970a) of higher breeding success, larger litter size, and greater recruitment in devils in areas of abundance food supply and relative low densities as compared to areas of high food competition. Deterministic rates from the wild baseline model are given in Table 2.

Table 2. Deterministic results for the *Vortex* Tasmanian devil wild baseline model.

Parameter	Value at low densities	Value at N = K
Lambda (λ)	1.107	0.988
Deterministic r (r_{det})	0.102	- 0.013
Generation time (T)	3.19 years	3.23 years

The mortality rates used in the wild baseline model generated a survival curve that appears reasonable for wild devils in DFTD-free conditions (Figure 2). This resulted in a stable age distribution that consisted of about 51% sub-adults and 49% adults, similar to the sub-adult to adult ratio observed by workshop participants in wild populations (Figure 3).

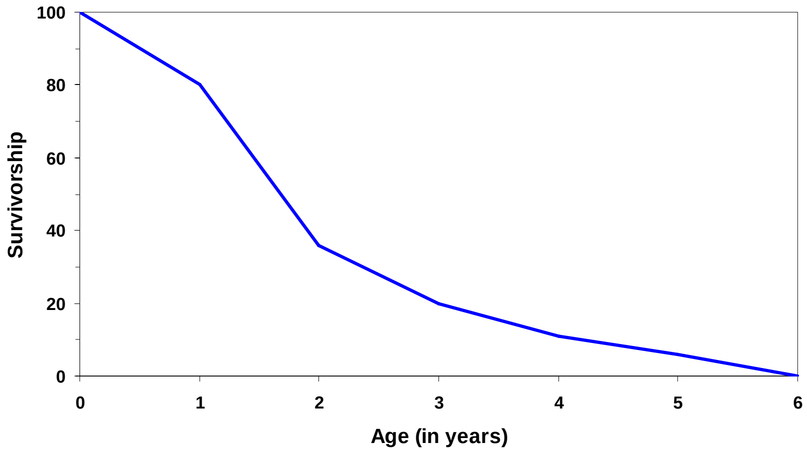


Figure 2. Survivorship curve from input data for wild baseline model.

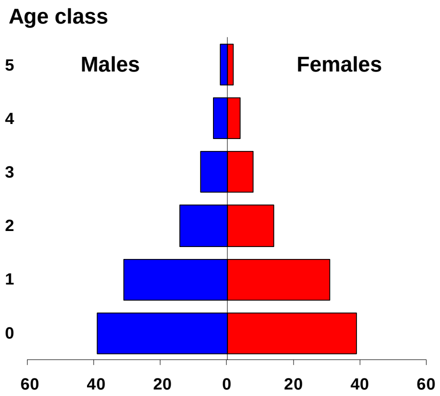


Figure 3. Stable age structure derived from wild baseline demographic rates.

Sensitivity Analysis of Wild Baseline Model

General sensitivity analyses were performed on the primary demographic rates of the wild baseline model to determine which parameters most affected population viability and therefore to what degree data uncertainty may affect this and subsequent devil models. These analyses also suggest those parameters that might be targeted through management to improve population viability.

The following parameters and input values were tested individually (baseline value in **boldface**):

- Juvenile mortality (0-1yr): **20**, 25, 30, 35, 40, 45, 50
- Sub-adult mortality (1-2yr): 50, **55**, 60
- Adult annual mortality (2+yr): 40, **45**, 50
- % unproven males in breeding pool: 100, 80, **60**, 40, 20
- % females breeding (low/high density): **100/80**; 95/80; 95/75; 90/75; 90/70
- Mean litter size (low/density): **3.65/3.32**; 3.5/3.2; 3.3/3.0
- Population size: **1000**, 750, 500, 250, 100

Mortality rates:

The greatest uncertainty surrounding demographic rates of wild DFTD-free Tasmanian devil populations is with respect to age- and sex-specific mortality rates. Near zero mortality of pouch young has been reported in the literature (Guiler 1970b), but there is little to no survival data beyond this age. Mortality rates were relatively sensitive over the ranges explored in terms of their impact on population viability (see Table 3). Workshop participants believed that sub-adult and adult mortality rates are not likely to be higher than those used in the baseline model. Juvenile rates are the most uncertain, and perhaps the most sensitive for model results. This suggests that post-weaning juvenile mortality may be a reasonable focus for both further investigation and also management actions. If juvenile mortality is found to be substantially higher in non-declining populations, then other mortality and/or fecundity values may need refinement to develop a more accurate demographic model for devil populations.

Table 3. Results of wild baseline model sensitivity testing for mortality rates (stochastic r; mean N; gene diversity; probability of extinction; median time to extinction in years). Baseline values given in italics.

Age class	Mortality (%)	Stoch r	N_{100}	GD_{100}	PE_{100}	MedianTE
Juvenile	*20*	*0.001*	*998*	*0.956*	*0*	--
	25	-0.003	773	0.947	0	--
	30	-0.009	469	0.923	0	--
	35	-0.033	158	0.850	0.29	--
	40	-0.068	44	0.706	0.90	82
	50	-0.127	0	0.000	1.00	43
Sub-adult	50	0.009	1197	0.964	0	--
	55	*0.001*	*998*	*0.956*	*0*	--
	60	-0.007	542	0.925	0	--
Adult (annual)	40	0.006	1161	0.962	0	--
	45	*0.001*	*998*	*0.956*	*0*	--
	50	-0.004	720	0.943	0	--

Reproductive parameters:

Population viability was less sensitive to those parameters associated primarily with reproduction (% males in breeding pool, % females breeding, mean litter size). The lowest values resulted in slightly negative growth rates but no risk of extinction in 100 years. A noted exception is rapid population decline and extinction observed with only 20% of unproven males in the breeding; however, this is likely a modeling artefact due to 100% unproven males at the initiation of the model.

Population size:

Populations of 500 individuals or more showed good viability, while populations ≤ 250 declined due to negative stochastic growth rates, lost significant genetic diversity (GD < 0.77), and exhibited some risk of extinction over 100 years. Given the parameter values used in this baseline model, populations of 250 or fewer individuals may be vulnerable to the impacts of stochastic events. The addition of catastrophes or increased impacts of inbreeding depression may increase the vulnerability of these smaller populations.

Application to Insurance Population Models

Input values from the wild and captive baseline models (see Captive Insurance Population Model section for baseline model description) were subsequently revised by the population modellers and working groups with respect to population size, demographic rates, catastrophes, and other parameters as noted to develop management strategy-specific Tasmanian devil models. This enabled the exploration and assessment of these insurance population strategies in terms of long-term viability and their ability to contribute positively toward Save the Tasmanian Devil Steering Committee goals. It is worthwhile to note that these working groups worked independently in the development of their respective insurance population models and may have adopted different philosophies in terms of how optimistic or conservative they chose to be in developing these models, particularly for parameters for which data were scant.

Island Insurance Population Model

Modellers: Barry Baker, Nick Beeton, Kathy Traylor-Holzer

Introduction

The Island Insurance Population option represents the isolation of a free-ranging Tasmanian devil population that essentially operates as a wild population with very little management beyond the initial stocking phase. Such populations may inhabit literal islands or isolated habitat islands/ peninsulas, and are assumed to be maintained in a DFTD-free state.

Island Model Development

The baseline wild population model was used as a basis for developing a Vortex island model. The Islands Working Group reviewed this wild population model and recommended several changes to the demographic input values to better reflect devil island populations (see Table 1). The primary modifications to the wild population model were the following:

1) Inclusion of breeding in 1-year-old females at low densities (20%), going to 0% at K
2) Fewer older females breeding at K (70% instead of 80%)
3) Lower sub-adult mortality (45% instead of 55%)
4) Inclusion of bush fire as a catastrophe (5% annual risk; lower survival during fire year)

These modifications resulted in a baseline model with a strongly positive deterministic growth rate at low densities (r = 0.27) (Table 4) and a stable age structure comprising about 48% sub-adults and 52% adults; these values were considered to be reasonable by the working group members.

Table 4. Deterministic results for the *Vortex* Tasmanian devil island baseline model.

Parameter	Value at low densities	Value at N = K
Lambda (λ)	1.29	1.01
Deterministic r (r_{det})	0.272	0.011
Generation time (T)	2.54 years	2.82 years

Modelling Questions

Discussions between the modellers and the Island Insurance Population Working Group identified the following questions to be addressed by the model:

Impact of Population Size

1) *What is the projected viability of isolated island populations of various sizes, ranging from 25 to 1500 devils (based on the range of potential island sites under consideration)?*

2) *What is the projected viability of multiple isolated mining sites under periodic translocation or supplementation?*

Sensitivity Analysis of Demographic Parameters

3) *What is the impact of increased reproduction in 1-year-old females, particularly at low densities (30-50%)?*

4) *What is the impact of slightly lower reproductive rates for 2+ year old devils (95% maximum for both sexes)?*

5) *What is the impact of increased environmental variation (CV = 20%) in reproductive and mortality rates?*

6) *What is the impact of increased catastrophic and inbreeding effects?*

Scenario 1: Impact of Population Size

What is the projected viability of isolated island populations of various sizes?

Real or virtual island sites that are potential candidates for the development of devil insurance populations vary substantially in size and estimated devil carrying capacity, from 20-30 devils up to as many as 1,500 devils. Small populations are at substantially higher risk of extinction due to the relatively greater impact of stochastic events, particularly if isolated from demographic and/or genetic rescue. The baseline island model was used to project the potential viability of isolated, DFTD-free devil populations over a wide range of population sizes designed to encompass potential island sites. These results are not intended to represent specific locations but are provided as guidance as one factor to consider while assessing potential insurance population sites and strategies.

Vortex Parameters

The baseline island model was run with the following initial population sizes, starting with a stable age distribution: 25, 50, 75, 100, 125, 150, 200, 250, 300, 400, 500, 1000, 1500. K was set slightly higher (1.075 * N) such that density-dependent reproduction maintained a relatively stable population size in the absence of strong stochastic and inbreeding effects. The model began with the population essentially at carrying capacity rather than with the seeding of empty habitat with a small number of founders and therefore assumes that island populations can be successfully established with high levels of genetic diversity. Different strategies for establishing island populations through introduction and subsequent supplementation with founders were not addressed in this modeling exercise.

Results

Model results indicate populations of 100 or fewer devils have poor viability over a 50-year period, with small, declining population size, moderate to high risk of extinction, and substantial loss of gene diversity; extinction is expected (PE = 100%) within 100 years (Table 5). Populations of 150-200 devils fare better over a 50-year period, with no projected risk of extinction and moderate retention of gene diversity; however, they still exhibit a negative stochastic growth rate, leading to substantial loss of gene diversity and increased extinction risk within 100 years (Figure 4). Populations of 250 or more devils exhibit positive stochastic growth rates and essentially no risk of extinction over 100 years; the larger the population, the higher retention of gene diversity and the more stable the population size, with populations $\geq$ 500 having good long-term viability. Periodic supplementation with additional devils could be used to demographically and genetically augment isolated island populations to increase their viability.

Table 5. Results of island model sensitivity testing for population size (stochastic r; mean N for all populations; gene diversity; probability of extinction; median time to extinction in years).

Initial Pop. size	Stoch r	At Year 50			At Year 100			MedianTE
		N_{50}	GD_{50}	PE_{50}	N_{100}	GD_{100}	PE_{100}	
25	-0.090	0	0	1.000	0	0	1.000	18
50	-0.067	9	0.510	0.972	0	0	1.000	34
75	-0.052	18	0.600	0.560	0	0	1.000	48
100	-0.044	38	0.703	0.132	0	0	1.000	63
125	-0.038	66	0.781	0.022	6	0.370	0.976	77
150	-0.029	99	0.835	0	20	0.564	0.742	92
200	-0.006	162	0.885	0	68	0.721	0.074	--
250	0.003	214	0.906	0	144	0.794	0	--
300	0.007	269	0.924	0	215	0.838	0	--
400	0.011	357	0.944	0	327	0.887	0	--
500	0.014	478	0.955	0	438	0.910	0	--
1000	0.023	983	0.977	0	945	0.955	0	--
1500	0.023	1499	0.985	0	1467	0.971	0	--

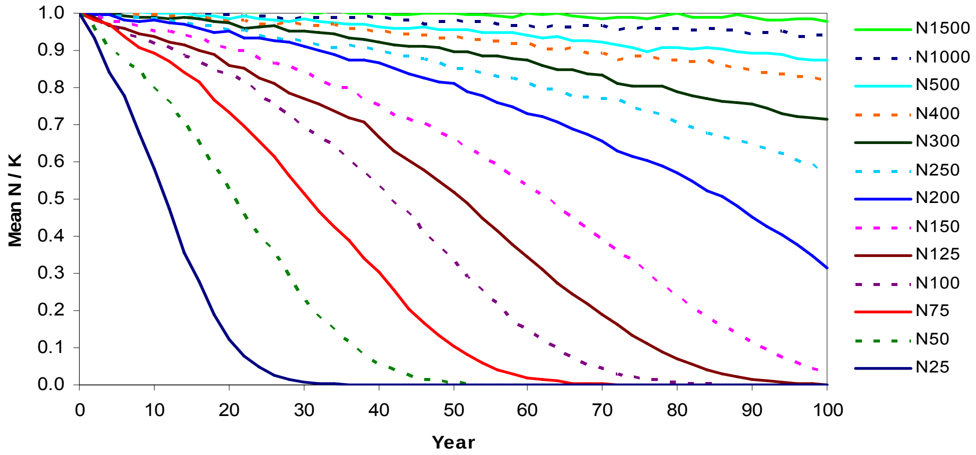


Figure 4. Mean population size as a proportion of carrying capacity over 100 years.

Scenario 2: Viability of Small, Augmented Populations

What is the projected viability of multiple isolated mining sites with periodic translocation or supplementation?

At least seven mining leases in the DFTD-free zone of western Tasmania may be potential candidates for virtual 'islands' for devil insurance populations. Carrying capacity is estimated to be about 20-40 devils per site, with a total maximum of 150 devils; although likely too small to be viable in isolation, it is possible that periodic translocation of devils among sites or supplementation from other devil populations could be used to improve viability.

Vortex Parameters

A metapopulation model was developed using the baseline island model, with seven sub-populations of 20 devils each, aged 1-2 years (equal sex ratio). Four scenarios were modelled:

1) <u>Isolated populations</u>: No migration, translocation or supplementation.
2) <u>Annual translocation</u>: Yearly translocation of approximately one pair of 1-year-olds from each sub-population to the adjacent sub-population such that each sub-population lost one pair (one male, one female) and received one pair. Devils were not transferred into extirpated sites.
3) <u>Supplementation (1 pair)</u>: 1 genetically unrelated pair of 1-year-olds was added to each population once every 5 years (14 new founders added to the metapopulation every 5 years).
4) <u>Supplementation (2 pairs)</u>: 2 genetically unrelated pairs of 1-year-olds were added to each population once every 5 years (28 new founders added to the metapopulation every 5 years).

Results

Small populations of 20 devils are subject to stochastic events and have a high risk of extinction. Annual translocation of one sub-adult pair per sub-population slows population decline but is not sufficient to make such sub-populations viable (Figure 5). Viability of the metapopulation is still far below that of a single panmictic population of about the same size (Tables 5 & 6). Periodic supplementation of sub-populations with new founders provides some demographic and genetic rescue, but is still insufficient to make this metapopulation viable under the conditions modelled.

Table 6. Results of island metapopulation model for small populations under various management options (stochastic r; mean N for all populations; gene diversity; probability of extinction; median time to extinction in yrs).

			At Year 50			At Year 100			
Population	**Scenario**	**Stoch r**	**N_{50}**	**GD_{50}**	**PE_{50}**	**N_{100}**	**GD_{100}**	**PE_{100}**	**MedianTE**
Within Pop Average	Isolated	-0.089	0	0	1.000	0	0	1.000	15
	Transloc	-0.065	0	0	1.000	0	0	1.000	18
	Suppl 1Pr	-0.057	0	0.792	0.980	0	0	1.000	18
	Suppl 2Pr	-0.033	2	0.860	0.871	12	0.850	0.991	23
Metapop	Isolated	-0.141	0	0	1.000	0	0	1.000	22
	Transloc	-0.110	0	0.667	0.998	0	0	1.000	28
	Suppl 1Pr	-0.081	1	0.801	0.872	0	0	1.000	34
	Suppl 2Pr	-0.040	11	0.883	0.368	1	0.848	0.940	52

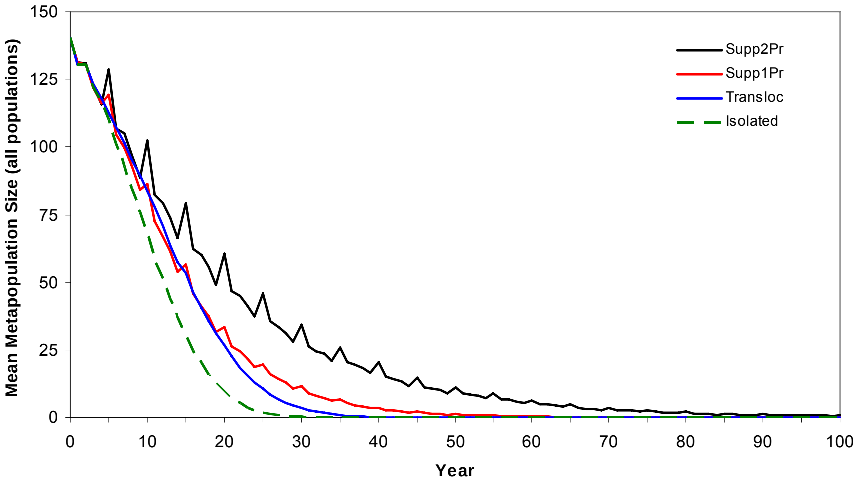


Figure 5. Mean metapopulation size under various management options over 100 years.

Scenario 3: Increased Reproduction of Young Females

What is the impact of increased reproduction in 1-year-old females, particularly at low densities?

There is evidence suggesting that some females reproduce at one year of age, particularly when devil population density is low. The island baseline model incorporates density-dependent reproduction for 1-year-old females with approximately 20% breeding at low density and 0% at K. Sensitivity analysis was conducted with increased levels of breeding for young females in low density conditions.

Vortex Parameters

The probability of breeding for 1-year-old females at low density was increased from 20% in the baseline island model to 30%, 40%, and 50% for populations with N = 50, 100 and 250, the key range over which stochastic growth becomes negative and within which significant transition in population viability occurs (Table 5).

Results

Increased reproduction in 1-year-old females slightly improves population growth, resulting in some cases in larger mean population size and lower risk of extinction (Table 7). These impacts are relatively small and result in no significant change in the viability of these populations over 50-100 years. The largest effect was observed in populations of about N = 100 devils; viability improved over 50 years, but long-term (100 year) viability remained poor.

Table 7. Results of island model sensitivity testing for increased reproduction in 1-year-old females (20%-50% at low density) (stochastic r; mean N; gene diversity; probability of extinction; median time to extinction in years).

Pop. Size/ %Breed	Stoch r	At Year 50			At Year 100			
		N_{50}	GD_{50}	PE_{50}	N_{100}	GD_{100}	PE_{100}	MedianTE
N50/Br20	-0.067	9	0.510	0.972	0	0	1.000	34
N50/Br30	-0.057	1	0.432	0.954	0	0	1.000	38
N50/Br40	-0.050	1	0.405	0.878	0	0	1.000	40
N50/Br50	-0.046	2	0.460	0.834	0	0	1.000	42
N100/Br20	-0.044	38	0.703	0.132	0	0	1.000	63
N100/Br30	-0.036	49	0.716	0.020	1	0.508	0.988	72
N100/Br40	-0.033	57	0.731	0.014	1	0.362	0.980	77
N100/Br50	-0.030	63	0.737	0.006	1	0.421	0.958	81
N250/Br20	0.003	214	0.906	0	144	0.794	0	--
N250/Br30	0.007	223	0.905	0	165	0.801	0	--
N250/Br40	0.010	224	0.906	0	182	0.808	0	--
N250/Br50	0.012	232	0.906	0	196	0.805	0	--

Scenario 4: Lower Reproduction of Adult Females

What is the impact of slightly lower reproductive rates for devils aged 2+ years old devils?

It is unlikely that all adult females produce a litter every year, even under low density conditions. A scenario was constructed to reduce the maximum level of reproduction to 95% for adult devils.

Vortex Parameters
The probability of breeding for adult devils (females ages 2-5 and males ages 3-5) was decreased from a maximum of 100% to a maximum of 95% for a population with N = 250, the size at which stochastic growth turns positive and risk of extinction is essentially zero (Table 5). The percent of proven males (i.e., those that had previously sired offspring) in the breeding pool was also reduced from 100% to 95%.

Results
This reduction in the maximum percent of adults breeding had little effect on the long-term viability of a population of 250 devils. Stochastic growth rate and risk of extinction in 100 years is essentially zero, and genetic diversity retention is similar (Table 8). These effects are not likely to significantly improve the viability of larger populations, nor significantly decrease the poor viability of small populations.

Table 8. Results of island model sensitivity testing for maximum percent of breeding adults (stochastic r; mean N for all populations; gene diversity; probability of extinction; median time to extinction in yrs).

		At Year 50			At Year 100			
%Breed	**Stoch r**	**N_{50}**	**GD_{50}**	**PE_{50}**	**N_{100}**	**GD_{100}**	**PE_{100}**	**MedianTE**
Max100%	0.003	214	0.906	0	144	0.794	0	--
Max95%	0.000	208	0.903	0	118	0.776	0.008	--

Scenario 5: Increased Environmental Variation

What is the impact of increased environmental variation in demographic rates?

Little information is available for the degree of environmental variation in these demographic rates, which require multiple-year measures across a representative sample of annual variation in conditions that affect reproduction and mortality. Workshop participants estimated EV to be low for devils. Analysis of limited field data for the percent of females breeding was conducted to estimate expected demographic stochasticity and partition EV out of the observed variation in yearly rates. This resulted in EV estimates of CV=12% (data from mid-1960s by Guiler) and CV=4% (unpublished data from DFTD-free populations from Jones). No estimates of EV were available for mortality rates.

Vortex Parameters
Environmental variation for the percent of adult females breeding and for all mortality rates was increased from CV ≈ 10% (CV=10% for mortality; 5-7% for % females breeding) to CV ≈ 20% (CV=20% for mortality; 15-21% for % females breeding). In other words, the degree of environmental variation expressed as a standard deviation around the mean was set at 20% of the mean. This is the level of environmental variation (variation between 'good' and 'bad' years) expected for a relatively stable environment. Increases in EV for reproduction and survival were tested separately and in combination for populations of N = 250.

Results
Additional stochasticity provided through increased environmental variation had small but negative effects on population viability (Table 9). This impact is less significant in small populations with poor viability, but does decrease population size and increase risk of extinction over time for populations of 250 (Figure 6). Increased EV in reproduction and mortality had similar impacts; these effects were

larger when both EV measures were increased. Since EV in reproduction and survival were linked in the model, this means that years with poor reproduction were linked with years with low survival.

Table 9. Results of island model sensitivity testing for increased EV in demographic rates (stochastic r; mean N for all populations; gene diversity; probability of extinction; median time to extinction in yrs).

Pop. Size / CV	Stoch r	At Year 50			At Year 100			MedianTE
		N_{50}	GD_{50}	PE_{50}	N_{100}	GD_{100}	PE_{100}	
N100CV10%	-0.044	38	0.703	0.132	0	0	1.000	63
N100CV20%Br	-0.040	28	0.680	0.206	0	0	1.000	60
N100CV20%M	-0.041	29	0.695	0.214	0	0	1.000	61
N100CV20%BrM	-0.041	21	0.648	0.352	0	0	1.000	55
N250CV10%	0.003	214	0.906	0	144	0.794	0	--
N250CV20%Br	0.005	200	0.894	0	108	0.754	0.030	--
N250CV20%M	0.002	199	0.893	0	104	0.747	0.048	--
N250CV20%BrM	-0.002	182	0.881	0.002	64	0.710	0.222	--

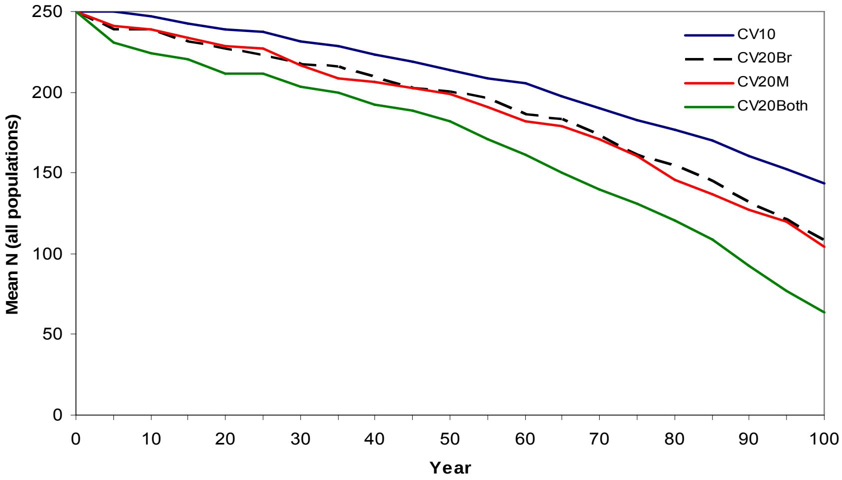


Figure 6. Effect of increased EV on mean population size over 100 years for populations of N = 250.

Scenario 6: Increased Catastrophic Impact and Inbreeding Depression

What is the impact of increased catastrophic and inbreeding impacts?

The impact of catastrophes on survival and the impacts of inbreeding depression on both survival and reproduction may be underestimated in this model based on data derived from wild populations across a wide range of species (Reed *et al*. 2003; O'Grady *et al*. 2006).

Vortex Parameters
The effect of a catastrophe on survival was increased from 10% reduction to 50% reduction in a catastrophic year. The impact of inbreeding on juvenile mortality and on the percent of females breeding were both doubled to simulate an overall effect of approximately 12 lethal equivalents. These effects were modelled for populations of 250, 500 and 1000 individuals.

Results
Increased effects of catastrophes and inbreeding depression to match those observed across other wild populations have a significant effect on population viability. Populations of 250 have essentially 100% probability of extinction in 100 years, and populations ≤ 500 decline significantly and lose substantial amounts of gene diversity (Figure 7). Approximately 1000 individuals are needed under these conditions to show long-term viability (positive growth, little risk of extinction, and high retention of gene diversity) (Table 10).

Table 10. Results of island model sensitivity testing for impact of catastrophes and inbreeding (stochastic r; mean N for all populations; gene diversity; probability of extinction; median time to extinction in years).

Initial		At Year 50			At Year 100			
Pop. size	**Stoch r**	**N_{50}**	**GD_{50}**	**PE_{50}**	**N_{100}**	**GD_{100}**	**PE_{100}**	**MedianTE**
250	0.003	214	0.906	0	144	0.794	0	--
500	0.014	478	0.955	0	438	0.910	0	--
1000	0.023	983	0.977	0	945	0.955	0	--
N250_Incr_Cat_Inbr	-0.055	84	0.845	0.060	0	0.748	0.998	69
N500_Incr_Cat_Inbr	-0.020	355	0.940	0	92	0.822	0.202	--
N1000_Incr_Cat_Inbr	0.005	854	0.972	0	689	0.939	0	--

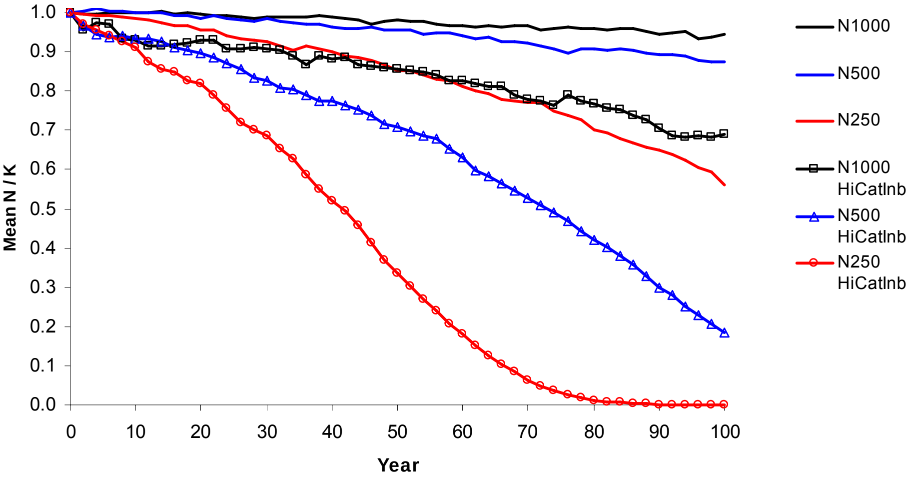


Figure 7. Mean population size as a proportion of carrying capacity, under baseline and increased catastrophe and inbreeding effects.

Summary of Island Model Results

Model results suggest that island populations need to be of substantial size (≥ 250 individuals) to act as viable insurance populations over 50 years. Incorporation of strong catastrophic effects and inbreeding depression (as suggested by work by Reed *et al.* 2003 and O'Grady *et al.* 2006) reduces long-term viability for populations ≤ 500 and increases the minimum population size needed to approximately 1000 individuals. Although variation in the female breeding rates showed little effect on long-term population viability, these models were initiated with populations close to carrying capacity. In reality, island populations likely will be established from a relatively smaller number of founders. Rapid growth to carrying capacity will be essential to reduce extinction risk and retain original founder genetic diversity; factors such as the percent of 1-year-old and adult females breeding will affect the population's growth potential. Additional modeling and planning will be needed to determine the best stocking strategy if this insurance population option is pursued, including the potential need for monitoring and augmentation for demographic or genetic reasons.

Table 11. Simulation results for Island Insurance Population scenarios at 100 years (stochastic r; probability of extinction; mean population size for extant (surviving) only and for all populations; mean gene diversity; median and mean time to extinction in years; standard deviations given as SD).

Scenario	Population	Stoch r	SD(r)	PE	N-extant	SD(Next)	N-all	SD(Nall)	GD	SD(GD)	MedianTE	MeanTE
N25		-0.090	0.348	1.000	0.0	0.0	0.0	0.0	0.000	0.000	18	18
N50		-0.067	0.288	1.000	0.0	0.0	0.0	0.0	0.000	0.000	34	34
N75		-0.052	0.257	1.000	0.0	0.0	0.0	0.0	0.000	0.000	48	48
N100		-0.044	0.235	1.000	0.0	0.0	0.0	0.0	0.000	0.000	63	63
N125		-0.038	0.220	0.976	6.2	2.8	0.2	1.0	0.370	0.265	77	76
N150		-0.029	0.203	0.742	20.5	18.3	5.4	12.9	0.564	0.169	92	86
N200		-0.006	0.163	0.074	68.0	36.3	63.0	39.2	0.721	0.100	--	93
N250		0.003	0.148	0.004	141.0	46.9	140.4	47.7	0.791	0.079	--	94
N300		0.007	0.143	0	214.6	48.8	214.6	48.8	0.838	0.046	--	--
N400		0.011	0.136	0	327.5	55.5	327.5	55.5	0.887	0.029	--	--
N500		0.014	0.133	0	437.7	64.8	437.7	64.8	0.910	0.021	--	--
N1000		0.023	0.142	0	945.2	107.6	945.2	107.6	0.955	0.008	--	--
N1500		0.023	0.120	0	1466.6	145.1	1466.6	145.1	0.971	0.004	--	--
Mines Isolated	Metapop	-0.141	0.272	1.000	0.0	0.0	0.0	0.0	0.000	0.000	22	23
	Within	-0.089	0.401	1.000	0.0	0.0	0.0	0.0	0.000	0.000	15	15
Mines Transl	Metapop	-0.110	0.267	1.000	0.0	0.0	0.0	0.0	0.000	0.000	28	28
	Within	-0.065	0.397	1.000	0.0	0.0	0.0	0.0	0.000	0.000	18	18
Mines Supp1Pr	Metapop	-0.081	0.300	1.000	0.0	0.0	0.0	0.0	0.000	0.000	34	36
	Within	-0.057	0.407	1.000	0.0	0.0	0.0	0.0	0.000	0.000	18	20
Mines Supp2Pr	Metapop	-0.040	0.337	0.940	12.4	5.6	0.7	3.2	0.848	0.051	52	53
	Within	-.0330	0.435	0.991	12.4	5.7	12.4	5.7	0.850	0.047	23	27
N50_Br30		-0.057	0.292	1.000	0.0	0.0	0.0	0.0	0.000	0.000	38	37
N50_Br40		-0.050	0.287	1.000	0.0	0.0	0.0	0.0	0.000	0.000	40	40
N50_Br50		-0.046	0.284	1.000	0.0	0.0	0.0	0.0	0.000	0.000	42	42
N100_Br30		-0.036	0.234	0.988	10.5	7.3	0.1	1.4	0.508	0.251	72	72
N100_Br40		-0.033	0.230	0.980	7.2	4.0	0.2	1.2	0.362	0.257	77	76
N100_Br50		-0.030	0.230	0.958	13.4	13.1	0.6	3.8	0.421	0.223	81	80
N250_Br30		0.007	0.153	0	165.1	42.0	165.1	42.0	0.801	0.058	--	--
N250_Br40		0.010	0.157	0	182.3	38.1	182.3	38.1	0.808	0.061	--	--
N250_Br50		0.012	0.160	0	195.8	35.8	195.8	35.8	0.805	0.060	--	--
Br95Ad		0.000	0.151	0.008	118.7	45.9	117.8	46.9	0.776	0.088	--	99
N100Cv20Br		-0.040	0.293	1.000	0.0	0.0	0.0	0.0	0.000	0.000	60	60
N100CV20Mort		-0.041	0.272	1.000	0.0	0.0	0.0	0.0	0.000	0.000	61	61
N100CV20Both		-0.041	0.330	1.000	0.0	0.0	0.0	0.0	0.000	0.000	55	55
N250CV20Br		0.005	0.234	0.030	111.6	55.9	108.3	58.2	0.754	0.097	--	92
N250CV20Mort		0.002	0.202	0.048	109.6	57.5	104.3	60.8	0.747	0.106	--	92
N250CV20Both		-0.002	0.284	0.222	81.7	59.9	63.6	62.8	0.710	0.124	--	87
N250_Incr_Cat_Inbr		-0.055	0.256	0.998	36.0	0	0.1	1.6	0.748	0.000	69	69
N500_Incr_Cat_Inbr		-0.020	0.220	0.202	115.2	90.9	91.9	93.4	0.822	0.083	--	90
N1000_Incr_Cat_Inbr		0.005	0.203	0	688.7	217.6	688.7	217.6	0.939	0.014	--	--

Free Range Enclosure Insurance Population Model

Modeller: Kathy Traylor-Holzer

Introduction

The Free Range Enclosure (FRE) Insurance Population option represents an array of diverse approaches that involve an intermediate level of management between semi-wild island insurance populations and intensively managed captive (zoo) insurance populations. Population size, density, structure (subdivision) and degree of population management may vary substantially across different applications of this insurance population option. All free range enclosure populations are assumed to be maintained in a DFTD-free state.

FRE Model Development

Aspects of both the baseline wild population model and the baseline captive population model were utilised to develop a Vortex FRE model. The Free Range Enclosure Working Group reviewed and discussed devil demographic rates and other model inputs based on available field data, studbook data, and own personal experience managing devils in FRE-type conditions. The resulting FRE model incorporated the following general framework (specific model inputs can be found in Table 1).

1) Age-specific rather than density-dependent reproduction (similar to captive)
2) Female reproductive rates closer to captive than wild rates
3) Litter size intermediate to wild and captive
4) Mortality rates closer to those observed in captivity than in wild
5) Individuals removed from population at age 6 (post-reproductive)
6) Inclusion of a generic (biological) catastrophe (1% annual risk; 50% reduction in survival, 10% reduction in reproduction during catastrophic year)
7) Models run for 50-year projections (500 iterations per scenario)

Due to the diversity of management conditions as well as the degree of uncertainty in demographic rates falling under the free range population designation, no single baseline model was developed to evaluate this management strategy. Rather, five parameters were varied with probable ranges of management and the results compared to evaluate the relative viability of populations managed under various combined conditions. The parameter values explored in the FRE model were:

Population size (K): 25, 100, 500, 1000 (panmictic breeding within population)
Initial population: 20, 40 (unrelated genetic founders)
Breeding strategy: Panmictic, genetic management (static MK, maximum F = 0.3750)
Females first breed at: 1, 2 (years)
Breeding success: Low, moderate, high (for females ages 1-4), as follows (given as %):

	1Y	2Y	3Y	4Y	
Low:	(10)	42.5	42.5	35	(1/2 of high; similar to zoos)
Moderate:	(15)	70	60	40	(best guess, achievable)
High:	(20)	85	85	70	(optimistic but possible)

The first two parameters (carrying capacity, initial number of founders) are under substantial control of the population managers (i.e., can be managed given sufficient resources). Breeding strategy is also under management control in terms of pairing individuals for breeding, albeit the degree of effectiveness is also influenced by the animals themselves and can be encouraged but not ensured. The final two parameters (age of first reproduction in females, percent of females breeding) can be influenced by management conditions but ultimately are under the control of the devils themselves. Experimental research may be needed to explore and refine those conditions that promote early reproduction and high breeding success rates.

Variation in age of first reproduction and breeding rates both affect potential growth rates and therefore the calculations for deterministic growth rate and generation time. The six different combinations of these rates resulted in the following deterministic results (see Table 12). All demographic scenarios result in positive deterministic growth rates, with strong positive growth with moderate to high breeding success rates.

Table 12. Deterministic results for the *Vortex* Tasmanian devil free range enclosure model.

	Low Br Success		**Moderate Br Success**		**High Br Success**	
Parameter	**AFR 2Y**	**AFR 1Y**	**AFR 2Y**	**AFR 1Y**	**AFR 2Y**	**AFR 1Y**
Lambda (λ)	1.15	1.19	1.31	1.38	1.46	1.54
Deterministic r (r_{det})	0.141	0.183	0.279	0.338	0.393	0.464
Generation time (T)	2.91 yrs	2.75 yrs	2.80 yrs	2.64 yrs	2.91 yrs	2.75 yrs

Modeling Questions

Two primary questions were addressed with respect to modeling the Free Range Enclosure insurance population option: 1) exploration of the five parameters outlined above; and 2) exploration of specific proposed FRE management options. Specifically,

Impact of Key Variables

- *What is the projected viability of FRE populations managed under these various conditions?*
- *Do any of the populations meet the goals of maintaining at least 90% gene diversity for 50 years with sufficient growth potential to provide individuals for reintroduction or other populations?*
- *What is the relative impact of each of the five variables on population viability?*
- *Which variable(s) or combinations of variables have the greatest impact?*

Specific FRE Strategies

- *What is the projected viability of the current two proposed management options for FRE populations (Type 1 and Type 2)?*

Question 1: Impact of Five Key Variables in FRE Management

What is the projected viability of FRE populations managed under these various conditions? Do any of the populations meet the goals of maintaining at least 90% gene diversity for 50 years with sufficient growth potential to provide individuals for reintroduction or other populations?

Population size (carrying capacity), initial number of founders, and breeding strategy are likely to vary across the diversity of options encompassed by the FRE strategy. Age of first reproduction in females and reproductive success observed to date have been variable, are likely dependent upon management conditions, and are to some extent unknown or difficult to estimate reliably. Therefore, models were constructed and analysed to assess the potential for FRE options to serve as viable and valuable insurance populations for Tasmanian devils.

***Vortex* Parameters**

FRE model scenarios were constructed with each unique combination of the five variables outlined above (with the exception of scenarios with K=25 and initial founders = 40), resulting in 84 different FRE management scenarios. Populations were started with either 20 or 40 2-year-old unrelated individuals at equal sex ratio. All scenarios assume that the populations are isolated (no additional animals added) and that no individuals remain in the population past 5 years of age (i.e., individuals are removed from the population at age 6 to simulate the removal of post-reproductive individuals). If situations arise such that only some or none of the post-reproductive animals can be removed from the insurance population, then the population size (carrying capacity) for the breeding population will be smaller than that modelled here (approximately 85% of modelled values, resulting of effective Ks of 21, 85, 425, and 850 individuals, respectively).

Results

Projected population viability is highly variable across the conditions modelled, ranging from populations with poor viability (population declines that lead to 100% risk of extinction, on average in 25-30 years) to highly viable populations with vigorous growth potential (up to r = 0.438) with high levels of genetic retention (97% gene diversity) and no risk of extinction in 50 years (Table 18). Several combined conditions lead to populations that are projected to meet the goals of retaining at least 90% gene diversity for 50 years and have the potential to provide devils for reintroduction or to supplement other insurance populations.

What is the relative impact of each of the five variables on population viability? Which variable(s) or combinations of variables have the greatest impact?

All five variables affect population viability to some degree as might be expected; however, the degree to which they impact population viability over the range of values tested varies, often in combination with other variables. The impacts of each variable are discussed below, in approximate order of relevance to population viability.

Population size (K): *25, 100, 500, 1000*

Large populations (K ≥ 500) are less prone to many stochastic events, such as demographic stochasticity and inbreeding, and are more likely to rebound from environmental variation and catastrophic events. Small populations (K = 25) have a high risk of extinction under all modelled scenarios, likely due to stochastic effects and inbreeding depression. Populations of at least 100 individuals have lower extinction risks and positive growth rates; however, retention of gene diversity is much lower (GD ≤ 86%) with K = 100 than in most large panmictic populations of K ≥ 500. Ultimately, population size may have the greatest effect on population viability, encompassing the entire range of viability extremes from meeting program goals to almost certain extinction.

Breeding success (%♀♀ breeding): *Low, moderate, high*

The percent of adult females producing a litter (referred to breeding success rate in this report) also has a significant impact on FRE population viability. There was much discussion regarding likely and achievable breeding success rates in various captive settings (FRE-style conditions and zoos), resulting in the decision to explore the impacts of relatively high, moderate (most likely), and low success rates. Breeding success was found to have significant impacts on population viability under certain conditions. All populations modelled were initially small (starting with 20 or 40 individuals) and therefore were particularly vulnerable until able to grow large enough to reduce the impact of stochastic events. Rapid growth also promotes greater retention of genetic lines of the initial founders. Moderate to high breeding success allows for populations with large Ks to grow quickly (reaching 100-200 individuals in 3-7 years), while low breeding success prolongs the time period at which populations may remain small (almost 20 years to reach 150 individuals) (Figure 8).

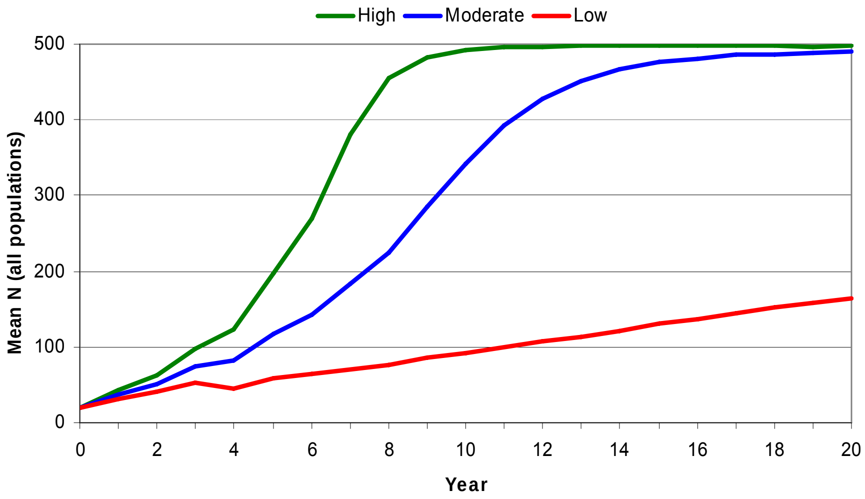


Figure 8. Initial growth of populations with high, moderate and low breeding success rates (K=500, 20 fdrs, AFR=2yrs, panmictic).

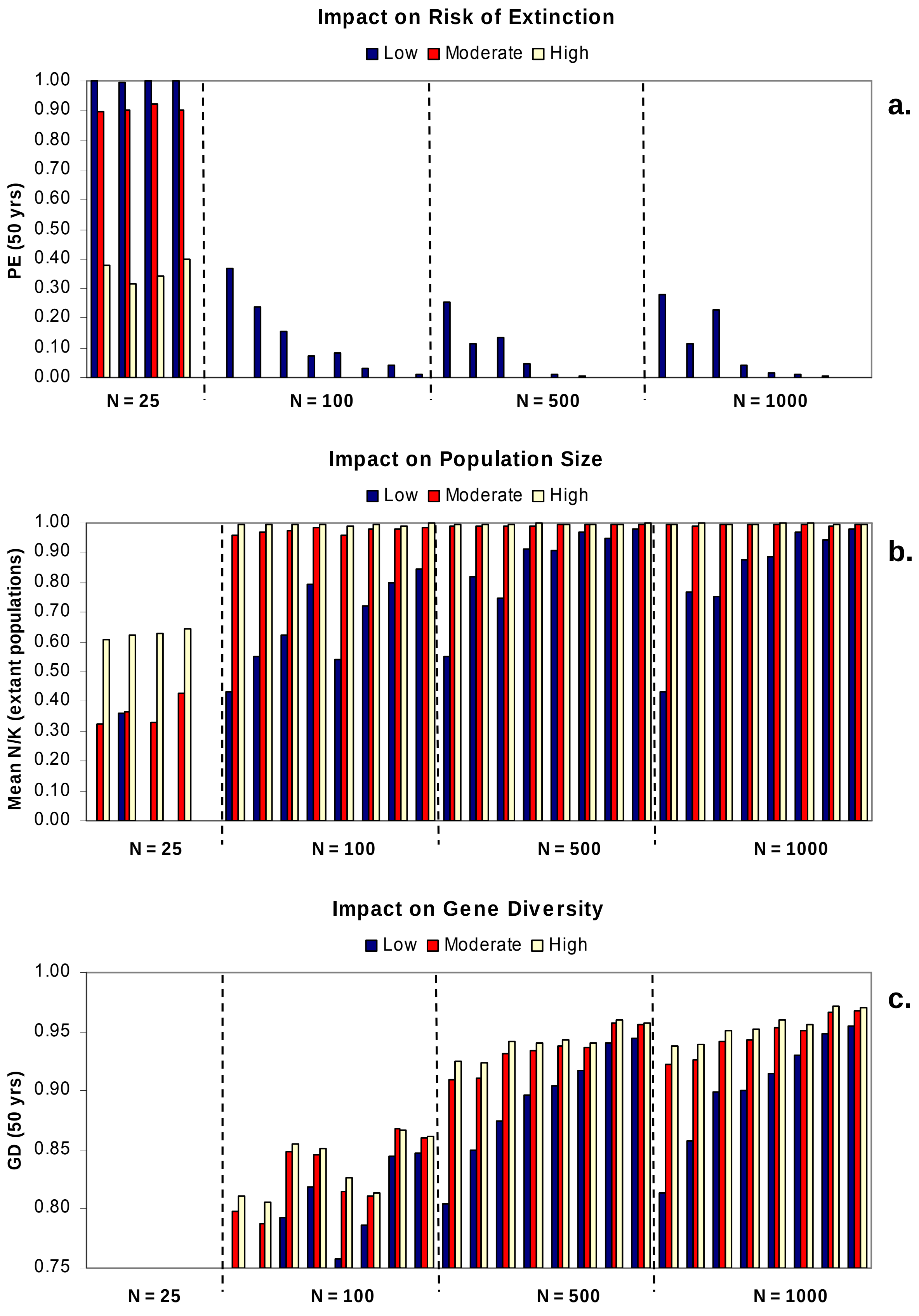


Figure 9. Interaction of carrying capacity and breeding success rate on population viability measures (a: probability of extinction, b: relative population size, and c: gene diversity) at 50 years (all scenarios shown).

Figures 9a-c demonstrate the interaction of population size/carrying capacity and breeding success rate. Small populations (K = 25) often persist with high breeding success, but at reduced size (about 15 individuals) and very low levels of gene diversity. Populations ≥100 show little difference between moderate and high breeding success levels, but in most cases experience reduced viability under low breeding success rates (i.e., conditions with slower initial growth). The long-term impact of low breeding rates varies substantially with the remaining three variables.

Initial population: *20, 40 unrelated founders*
As noted above, populations are at substantial risk of extinction while they remain small. Therefore, populations founded from 20 rather than 40 individuals are at higher risk until they can grow large enough to reduce their vulnerability. This is especially true under conditions of low breeding success, under which populations grow more slowly and remain smaller longer. Risk of extinction and rate of loss of gene diversity are higher for populations initiated with 20 vs. 40 individuals (Table 18), likely due to both demographic and genetic consequences. In practice, additional devils likely would be available either from the wild or other insurance populations to supplement developing FRE populations both demographically and genetically in the initial years of the program. Initial stocking strategies can be explored through further modeling.

Breeding strategy: *Panmictic, genetic management*
Vortex imposes no population or spatial substructuring and therefore treats each population as a panmictic interbreeding population, i.e. each male in the breeding pool has an equal opportunity of mating with each breeding female (in the absence of long-term breeding units or other restrictions built into the model). The working group believed that panmictic breeding is a reasonable approximation of an achievable breeding strategy for free range enclosures, in which individuals are rotated to mix genetic lines and minimise inbreeding. Genetic management in the model describes more intensive management by pairing specific individuals based on mean kinship values (MK). This strategy is effective in slowing the loss of gene diversity and reducing genetic adaptation to captive conditions by equalizing founder representation (see Ballou and Lacy 1995). This breeding strategy has been adopted by most of the world's regional zoo associations for the management of captive populations of endangered species.

Results of the FRE model for devils demonstrate the ability of genetic management to improve population viability in terms of population persistence, size and retention of gene diversity. However, the relative benefit of genetic management varies substantially across conditions. Small populations (K = 25) are at high risk of extinction due to stochastic events, which overshadow the effects of genetic management. Large populations generally exhibit good viability, with genetic management offering relatively small additional benefit over panmictic breeding. Genetic management offers the greatest benefit when populations are of intermediate size and viability (in this model, about 100-200 individuals). Populations of 100 under genetic management accumulate inbreeding and retain gene diversity at levels similar to larger populations under panmictic breeding conditions (Figure 10).

First age of reproduction (females): *1, 2 years*
Early reproduction in females (i.e., some females breeding at age 1 year) has both demographic and genetic consequences. Earlier breeding slightly increases potential growth, allowing populations to grow more quickly, but also shortens generation time (Table 12), which increases the rate at which genetic diversity is lost. Incorporating reproduction in 10-20% of 1-year-old females has little effect on population viability in most scenarios. Exceptions were observed in populations of K≥100 founded with 20 individuals and with low breeding success; in these instances, the increased growth potential provided by the additional reproduction of young females decreased the risk of extinction and increased retention of gene diversity (Figure 11).

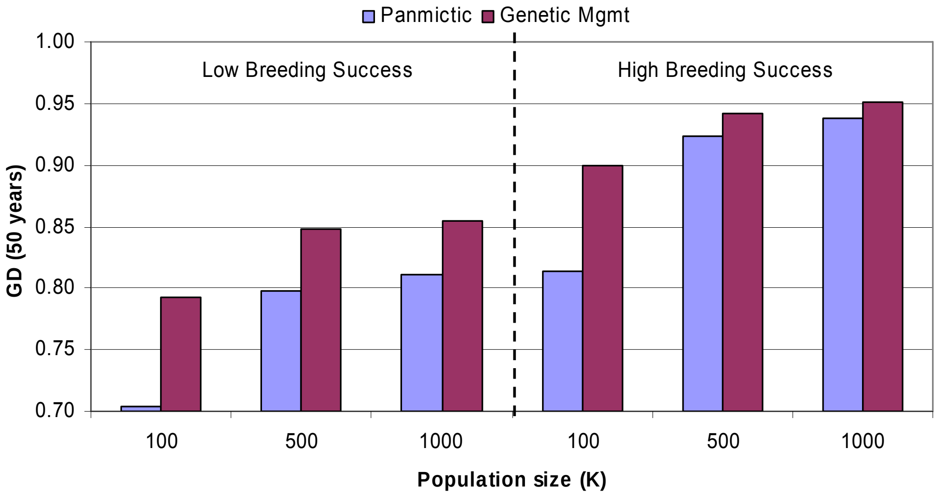


Figure 10. Mean gene diversity retained (at 50 years) for populations of K = 100 to 1000 under various breeding strategies and success rates (20 founders, AFR = 2 yrs).

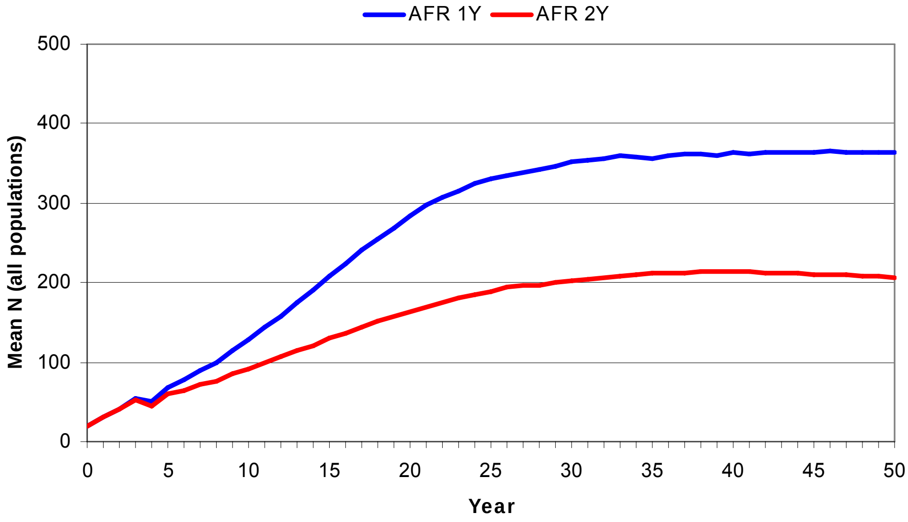


Figure 11. Growth of populations with first age of female reproduction at 1 vs 2 years (K = 500, 20 fdrs, low breeding success, panmictic).

Scenarios Meeting Population Goals

Examination of the various interacting effects of these 5 variables suggests several conditions that are more likely to lead to viable FRE populations capable of retaining high levels of genetic variation and providing devils for reintroduction or supplementation efforts (Tables 13 & 14). These conditions are:

1) Carrying capacity of at least 500 devils (not including post-reproductive individuals), with at least moderate levels of female breeding rates
(PE ≈ 0%; GD > 90%; r > 0.20)

OR

2) Carrying capacity of at least 500 devils (not including post-reproductive individuals), with low female breeding rates **AND** initiated with at least 40 founders
(PE < 2%; GD > 90%; r ≥ 0.10)

OR

3) Carrying capacity of at least 500 devils (not including post-reproductive individuals), with low female breeding rates **AND** initiated with at least 20 founders **AND** managed using mean kinship values **AND** having some breeding of 1-year old females
(PE ≤ 5%; GD ≈ 90%; r ≈ 0.10).

Model results indicate that, under similar conditions, populations of 100 or fewer devils have relatively low risk of extinction and positive growth rates; however, the loss of genetic variation is below the population goal of retention of at least 90% gene diversity over 50 years (Tables 13 & 14). Additional modeling under various conditions can be used to explore populations with carrying capacities between 100 and 500 individuals for retention of at least 90% GD. Alternatively, populations of around 100 individuals may be of value over a short management timeline to supplement other populations.

Table 13. Simulation results for Free Range Enclosure Insurance Population scenarios (boldface indicates scenarios associated with high gene diversity, strong positive growth and no risk of extinction).

	Prob. Extinction (%)			**Gene Diversity (%)**			**Stochastic r**		
N	**Low Br**	**Mod Br**	**High Br**	**Low Br**	**Mod Br**	**High Br**	**Low Br**	**Mod Br**	**High Br**
25	100	90-92	31-40	--	30-57	43-55	- .01-.01	.06-.09	.14-.20
100	1-37	0	0	70-85	79-86	81-86	.01-.11	.17-.26	.30-.38
500	0-25	**0**	**0**	80-94	**91-96**	**92-96**	.03-.15	**.21-.31**	**.34-.43**
1000	0-28	**0**	**0**	81-96	**92-97**	**94-97**	.03-.15	**.22-.33**	**.34-.44**

Table 14. Simulation results for Free Range Enclosure Insurance Population scenarios under low breeding success conditions (boldface indicates scenarios associated with GD≥90%, strong positive growth and low risk of extinction).

	Prob. Extinction (%)			**Gene Diversity (%)**			**Stochastic r**		
	20 Fdr		**40 Fdr**	**20 Fdr**		**40 Fdr**	**20 Fdr**		**40 Fdr**
N	**FR1/GM**	**Other**	**All**	**FR1/GM**	**Other**	**All**	**FR1/GM**	**Other**	**All**
100	7	16-37	1-8	82	70-79	76-85	.08	.01-.04	.06-.11
500	**5**	11-25	**0-1**	**90**	80-87	**91-94**	**.10**	.03-.08	**.10-.15**
1000	**4**	12-28	**0-2**	**90**	81-90	**92-96**	**.10**	.03-.08	**.10-.15**

Question 2: Viability to Two Proposed FRE Scenarios

What is the projected viability of the current two proposed management options for FRE populations (Type 1 and Type 2)?

Members of the Free Range Enclosure Working Group identified two proposed FRE types for further consideration (see Free Range Enclosure Working Group report for further explanation). Table 15 gives the primary parameter values used in these two model scenarios.

1) Type 1 – Devil Island Model: Using the Devil Island facility as a example, this scenario proposes several (6-8) moderately-sized facilities, holding approximately 80-100 devils each, for a total K of about 600 devils; and

2) Type 2 – Enclosure Complex: This scenario proposes a large modular complex comprised of numerous smaller enclosures with managed rotation of individuals among enclosures, holding approximately 900 devils.

Table 15. Primary model parameter input values for the two proposed FRE scenarios (Types 1 and 2).

	Type 1: Devil Island Facilities	**Type 2: Enclosure Complex**
Carrying capacity	600 (0-5 years old)	900 (0-5 years old)
Initial population	50 unrelated founders (2 yr old)	40 unrelated founders (2 yr old) 20 zoo animals (1 yr old)
Supplementation (equal sex ratio)	20 unrelated founders (2 yr old) in Year 2	30 from zoos (1 yr old) in Year 2 30 from zoos (1 yr old) in Year 3
Age of first breeding (♀♀)	2 years	1 year
Breeding success rate	Moderate	Moderate
Breeding strategy	Panmictic Sub-units (K=100 x 6) (isolated) Sub-units (K=100 x 6) (migration)	Panmictic

Results

Both scenarios resulted in viable insurance populations that exhibit strong growth, high retention of gene diversity, and essentially no risk of extinction (Table 16). Inbreeding is higher and genetic diversity lower in the Enclosure Complex scenario due to the large number of related animals from the zoo population used to initiate the population. In the model these animals were selected randomly; however, in practice such individuals would be selected to maximise the genetic benefits and minimise inbreeding in both the FRE and zoo population. In the absence of inbreeding effects, populations that are founded on sufficient founders and managed for moderate levels of breeding success could potentially reach about 600 individuals in 7-8 years and 900 individuals in about 10 years (not including post-reproductive individuals).

Table 16. Simulation results for proposed Type 1 and Type 2 FRE insurance population scenarios (at 50 years).

	Carrying Capacity	Mean Pop. Size	Prob. Extinct (%)	Gene Diversity (%)	Mean Inbreeding	Stochastic r
Devil Island Model	600	596	0	95.7	0.0402	0.256
Enclosure Complex	900	895	0	93.2	0.0654	0.273

Population Subdivision / Connectivity

The Devil Island model is proposed as an interacting population comprised of several separate facilities, similar to the zoo population. Not surprisingly, the Devil Island model performs well, as it constitutes a panmictic population of K = 600 with moderate breeding success and sufficient founders. It is possible, however, that such established FREs may not operate interactively but in isolated or, most probably, with regular exchanges of animals but not as a truly panmictic population.

To investigate the impact of these alternative management options, two additional Devil Island scenarios were modelled. In each, the Devil Island FRE consisted of 6 populations with K = 100, each founded with 8 founders (4 pairs) and supplemented with an additional 4 founders (2 pairs) in Year 2. In the Isolated DI scenario, there is no exchange of individuals among populations and no additional supplementation beyond Year 2. Population founders and supplementation were identical for the Connected DI scenario; however, periodic movement of 1 to 2-year-old males was allowed, such that a male was sent from each facility to each of the other five facilities approximately every 2-3 years.

Modeling results suggest that the viability of isolated populations (K = 100) is substantially lower than that of a single larger population (K = 600); most notable is the high accumulation of inbreeding in these isolated populations (mean F = 0.2205). The risk of extinction is relatively low (PE < 0.02), however, and although inbred, these populations generally persist for 50 years (Table 17). When viewed in combination as a metapopulation, overall viability is good. Since each facility was founded from unrelated founders, their combined retention of gene diversity is high (GD = 95.9%). One challenge to these populations will be the increasing effects of inbreeding depression that could affect demographic rates, eventually leading to high risk of population and therefore metapopulation decline and extinction. Occasional exchange of individuals among facilities can alleviate this risk by substantially reducing inbreeding in the population.

Table 17. Simulation results for alternative Devil Island FRE insurance population scenarios (at 50 years).

		Mean Pop. Size	Prob. Extinct (%)	Gene Diversity (%)	Mean Inbreeding	Stochastic r
Single pop		596	0	95.7	0.0402	0.256
6 pops (Isolated)	Metapop	547	0	95.9	0.2182	0.154
	Within pops	93	0.016	76.3	0.2205	0.147
6 pops (Connected)	Metapop	590	0	95.7	0.0567	0.235
	Within pops	98	0	93.1	0.0568	0.231

Summary of Free Range Enclosure Model Results

The Free Range Enclosure insurance population strategy has the potential to provide viable, genetically diverse populations of Tasmanian devils that potentially could be used in the future for reintroduction efforts or to supplement other insurance populations. There are a wide variety of management options that could be implemented under this strategy, and much is unknown about what can be achieved. Experimental research may be needed to investigate the optimal conditions under which FREs might operate. Results from this FRE model suggest that population viability is dependent upon maintenance of relatively large, interbreeding populations initiated with sufficient founders and moderate reproductive rates to grow the population quickly. Genetic management can slow the loss of gene diversity, particularly when populations are relatively small. Given the complex age-, sex- and density-dependent demographic rates in these models as well as varying initiation and supplementation strategies, it is difficult to calculate reliable Ne/N estimates. Factors that influence early growth and retention of founder genetic lines can significantly affect the loss of gene diversity in the first generations, and this diversity cannot be regained without subsequent supplementation. Given these considerations, model results suggested that Ne/N of about 0.2 may be a reasonable estimate for estimating the effectiveness of free range insurance populations of Tasmanian devils to maintain genetic variation.

Table 18. Simulation results for Free Range Enclosure Insurance Population scenarios at 50 years (stochastic r; probability of extinction; mean population size for extant (surviving) only and for all populations; mean gene diversity; median and mean time to extinction in years; standard deviations given as SD). Scenarios are described by K (carrying capacity); Br (Low, Moderate, High breeding success rate); Fdr (number of founders); PM (Panmictic, Genetic Management); and AFR (♀ age of first reproduction).

Scenario	K	Br	Fdr	PM	AFR	stoc-r	SD(r)	PE	N-ext	SD(Next)	N-all	SD(Nall)	GD	SD(GD)	MdTE	MnTE
K25_W20_BL_F2_R	25	L	20	P	2	-0.005	0.305	1.000	0.0	0.0	0.0	0.0	0.000	0.000	25	25
K25_W20_BL_F1_R	25	L	20	P	1	0.010	0.301	0.996	9.0	9.9	0.0	0.7	0.000	0.000	27	27
K25_W20_BL_F2_GM	25	L	20	GM	2	-0.001	0.295	1.000	0.0	0.0	0.0	0.0	0.000	0.000	27	26
K25_W20_BL_F1_GM	25	L	20	GM	1	0.011	0.295	1.000	0.0	0.0	0.0	0.0	0.000	0.000	27	27
K25_W20_BM_F2_R	25	M	20	P	2	0.062	0.287	0.896	8.1	5.5	0.9	3.0	0.359	0.237	37	35
K25_W20_BM_F1_R	25	M	20	P	1	0.080	0.292	0.902	9.2	5.6	1.0	3.3	0.302	0.228	38	36
K25_W20_BM_F2_GM	25	M	20	GM	2	0.072	0.281	0.920	8.2	6.3	0.7	2.8	0.471	0.201	40	37
K25_W20_BM_F1_GM	25	M	20	GM	1	0.094	0.281	0.900	10.7	7.1	1.1	3.9	0.568	0.142	42	40
K25_W20_BH_F2_R	25	H	20	P	2	0.144	0.263	0.376	15.3	7.4	9.6	9.3	0.455	0.197	--	42
K25_W20_BH_F1_R	25	H	20	P	1	0.171	0.272	0.314	15.6	7.3	10.8	9.3	0.431	0.204	--	42
K25_W20_BH_F2_GM	25	H	20	GM	2	0.170	0.257	0.344	15.7	7.8	10.4	9.7	0.549	0.164	--	45
K25_W20_BH_F1_GM	25	H	20	GM	1	0.195	0.265	0.400	16.1	7.3	9.8	9.6	0.545	0.165	--	45
K100_W20_BL_F2_R	100	L	20	P	2	0.012	0.205	0.366	43.3	29.4	27.5	31.3	0.704	0.130	--	37
K100_W20_BL_F1_R	100	L	20	P	1	0.040	0.198	0.236	54.9	30.1	42.0	35.1	0.720	0.113	--	38
K100_W20_BL_F2_GM	100	L	20	GM	2	0.041	0.185	0.158	62.2	30.0	52.4	35.7	0.792	0.092	--	35
K100_W20_BL_F1_GM	100	L	20	GM	1	0.077	0.170	0.070	79.2	24.7	73.6	31.3	0.818	0.063	--	37
K100_W40_BL_F2_R	100	L	40	P	2	0.056	0.195	0.082	54.3	28.9	49.8	31.4	0.758	0.101	--	40
K100_W40_BL_F1_R	100	L	40	P	1	0.090	0.173	0.030	72.2	27.3	70.1	29.5	0.786	0.077	--	45
K100_W40_BL_F2_GM	100	L	40	GM	2	0.083	0.182	0.042	80.0	23.5	76.6	28.0	0.845	0.050	--	42
K100_W40_BL_F1_GM	100	L	40	GM	1	0.114	0.175	0.010	84.7	22.1	83.8	23.5	0.847	0.054	--	39
K100_W20_BM_F2_R	100	M	20	P	2	0.172	0.152	0.002	96.0	11.2	95.8	11.9	0.797	0.068	--	21
K100_W20_BM_F1_R	100	M	20	P	1	0.216	0.153	0	97.1	9.5	97.1	9.5	0.787	0.070	--	--
K100_W20_BM_F2_GM	100	M	20	GM	2	0.197	0.146	0	97.4	10.2	97.4	10.2	0.848	0.039	--	--
K100_W20_BM_F1_GM	100	M	20	GM	1	0.237	0.145	0	98.7	8.0	98.7	8.0	0.846	0.039	--	--
K100_W40_BM_F2_R	100	M	40	P	2	0.200	0.165	0.002	95.8	11.9	95.6	12.6	0.815	0.060	--	50
K100_W40_BM_F1_R	100	M	40	P	1	0.241	0.161	0	98.1	8.3	98.1	8.3	0.812	0.062	--	-
K100_W40_BM_F2_GM	100	M	40	GM	2	0.221	0.157	0	98.0	9.0	98.0	9.0	0.868	0.032	--	--
K100_W40_BM_F1_GM	100	M	40	GM	1	0.264	0.154	0	98.6	8.5	98.6	8.5	0.860	0.035	--	--
K100_W20_BH_F2_R	100	H	20	P	2	0.297	0.143	0	99.4	6.4	99.4	6.4	0.811	0.056	--	--
K100_W20_BH_F1_R	100	H	20	P	1	0.349	0.143	0	99.6	6.5	99.6	6.5	0.806	0.057	--	--
K100_W20_BH_F2_GM	100	H	20	GM	2	0.315	0.137	0	99.4	7.4	99.4	7.4	0.855	0.036	--	--

Scenario	K	Br	Fdr	PM	AFR	stoc-r	SD(r)	PE	N-ext	SD(Next)	N-all	SD(Nall)	GD	SD(GD)	MdTE	MnTE
K100_W20_BH_F1_GM	100	H	20	GM	1	0.366	0.135	0	99.6	6.2	99.6	6.2	0.851	0.038	--	--
K100_W40_BH_F2_R	100	H	40	P	2	0.319	0.149	0	99.1	7.2	99.1	7.2	0.827	0.049	--	--
K100_W40_BH_F1_R	100	H	40	P	1	0.367	0.148	0	99.6	6.5	99.6	6.5	0.814	0.057	--	--
K100_W40_BH_F2_GM	100	H	40	GM	2	0.336	0.146	0	98.9	6.9	98.9	6.9	0.867	0.033	--	--
K100_W40_BH_F1_GM	100	H	40	GM	1	0.384	0.146	0	99.8	5.7	99.8	5.7	0.861	0.036	--	--
K500_W20_BL_F2_R	500	L	20	P	2	0.031	0.188	0.254	276.8	197.8	206.5	209.0	0.804	0.131	--	34
K500_W20_BL_F1_R	500	L	20	P	1	0.077	0.162	0.112	409.8	153.1	363.9	193.7	0.849	0.089	--	31
K500_W20_BL_F2_GM	500	L	20	GM	2	0.059	0.166	0.134	373.0	168.4	323.0	201.8	0.874	0.080	--	32
K500_W20_BL_F1_GM	500	L	20	GM	1	0.102	0.148	0.046	455.8	107.6	434.8	142.0	0.897	0.053	--	33
K500_W40_BL_F2_R	500	L	40	P	2	0.096	0.156	0.012	453.3	107.0	447.8	117.3	0.905	0.048	--	30
K500_W40_BL_F1_R	500	L	40	P	1	0.135	0.150	0.004	483.9	60.8	481.9	67.9	0.917	0.030	--	37
K500_W40_BL_F2_GM	500	L	40	GM	2	0.112	0.151	0.002	473.3	77.2	472.3	80.0	0.940	0.027	--	32
K500_W40_BL_F1_GM	500	L	40	GM	1	0.151	0.146	0	488.5	51.3	488.5	51.3	0.944	0.029	--	--
K500_W20_BM_F2_R	500	M	20	P	2	0.212	0.124	0	493.7	37.4	493.7	37.4	0.909	0.034	--	--
K500_W20_BM_F1_R	500	M	20	P	1	0.266	0.120	0	495.2	33.3	495.2	33.3	0.910	0.021	--	--
K500_W20_BM_F2_GM	500	M	20	GM	2	0.227	0.120	0	493.6	30.8	493.6	30.8	0.932	0.015	--	--
K500_W20_BM_F1_GM	500	M	20	GM	1	0.278	0.118	0	496.0	25.8	496.0	25.8	0.933	0.012	--	--
K500_W40_BM_F2_R	500	M	40	P	2	0.249	0.130	0	498.2	24.1	498.2	24.1	0.938	0.013	--	--
K500_W40_BM_F1_R	500	M	40	P	1	0.297	0.124	0	497.2	28.1	497.2	28.1	0.936	0.013	--	--
K500_W40_BM_F2_GM	500	M	40	GM	2	0.259	0.129	0	497.0	23.9	497.0	23.9	0.957	0.006	--	--
K500_W40_BM_F1_GM	500	M	40	GM	1	0.309	0.126	0	496.3	23.6	496.3	23.6	0.956	0.007	--	--
K500_W20_BH_F2_R	500	H	20	P	2	0.339	0.114	0	496.4	25.3	496.4	25.3	0.925	0.015	--	--
K500_W20_BH_F1_R	500	H	20	P	1	0.401	0.113	0	497.9	21.8	497.9	21.8	0.924	0.014	--	--
K500_W20_BH_F2_GM	500	H	20	GM	2	0.349	0.110	0	498.0	19.8	498.0	19.8	0.941	0.009	--	--
K500_W20_BH_F1_GM	500	H	20	GM	1	0.409	0.112	0	499.0	14.9	499.0	14.9	0.940	0.009	--	--
K500_W40_BH_F2_R	500	H	40	P	2	0.365	0.118	0	496.6	22.2	496.6	22.2	0.943	0.011	--	--
K500_W40_BH_F1_R	500	H	40	P	1	0.423	0.116	0	498.5	19.6	498.5	19.6	0.941	0.011	--	--
K500_W40_BH_F2_GM	500	H	40	GM	2	0.375	0.117	0	497.3	23.5	497.3	23.5	0.959	0.006	--	--
K500_W40_BH_F1_GM	500	H	40	GM	1	0.433	0.115	0	498.9	16.8	498.9	16.8	0.958	0.006	--	--
K1000_W20_BL_F2_R	1000	L	20	P	2	0.030	0.190	0.282	435.3	375.8	312.6	373.8	0.814	0.116	--	34
K1000_W20_BL_F1_R	1000	L	20	P	1	0.078	0.163	0.116	770.5	345.7	681.1	408.2	0.858	0.085	--	31
K1000_W20_BL_F2_GM	1000	L	20	GM	2	0.060	0.177	0.230	754.7	331.1	581.1	430.6	0.899	0.038	--	33
K1000_W20_BL_F1_GM	1000	L	20	GM	1	0.102	0.149	0.042	873.8	284.5	837.1	329.1	0.901	0.055	--	30

Scenario	K	Br	Fdr	PM	AFR	Stoc-r	SD(r)	PE	N-ext	SD(Next)	N-all	SD(Nall)	GD	SD(GD)	MdTE	MnTE
K1000_W40_BL_F2_R	1000	L	40	P	2	0.098	0.155	0.016	884.8	254.6	870.7	275.9	0.915	0.052	--	39
K1000_W40_BL_F1_R	1000	L	40	P	1	0.138	0.146	0.008	967.5	136.7	959.8	161.2	0.930	0.028	--	35
K1000_W40_BL_F2_GM	1000	L	40	GM	2	0.115	0.148	0.004	943.7	178.6	939.9	187.9	0.948	0.026	--	47
K1000_W40_BL_F1_GM	1000	L	40	GM	1	0.153	0.141	0	981.3	84.9	981.3	84.9	0.955	0.013	--	--
K1000_W20_BM_F2_R	1000	M	20	P	2	0.219	0.117	0.002	996.4	40.6	994.4	60.3	0.923	0.026	--	20
K1000_W20_BM_F1_R	1000	M	20	P	1	0.271	0.119	0	991.6	52.1	991.6	52.1	0.927	0.017	--	--
K1000_W20_BM_F2_GM	1000	M	20	GM	2	0.229	0.119	0.002	995.0	42.3	993.1	61.4	0.942	0.012	--	7
K1000_W20_BM_F1_GM	1000	M	20	GM	1	0.280	0.117	0	993.0	50.1	993.0	50.1	0.943	0.013	--	--
K1000_W40_BM_F2_R	1000	M	40	P	2	0.254	0.126	0	993.9	45.6	993.9	45.6	0.953	0.008	--	--
K1000_W40_BM_F1_R	1000	M	40	P	1	0.303	0.124	0	992.9	47.3	992.9	47.3	0.951	0.009	--	--
K1000_W40_BM_F2_GM	1000	M	40	GM	2	0.261	0.123	0	991.7	55.6	991.7	55.6	0.967	0.005	--	--
K1000_W40_BM_F1_GM	1000	M	40	GM	1	0.315	0.123	0	996.1	41.8	996.1	41.8	0.967	0.004	--	--
K1000_W20_BH_F2_R	1000	H	20	P	2	0.344	0.112	0	995.2	42.3	995.2	42.3	0.938	0.015	--	--
K1000_W20_BH_F1_R	1000	H	20	P	1	0.408	0.110	0	997.5	29.9	997.5	29.9	0.940	0.010	--	--
K1000_W20_BH_F2_GM	1000	H	20	GM	2	0.351	0.112	0	994.0	43.8	994.0	43.8	0.951	0.007	--	--
K1000_W20_BH_F1_GM	1000	H	20	GM	1	0.412	0.109	0	996.8	30.8	996.8	30.8	0.952	0.007	--	--
K1000_W40_BH_F2_R	1000	H	40	P	2	0.370	0.116	0	997.7	29.1	997.7	29.1	0.960	0.006	--	--
K1000_W40_BH_F1_R	1000	H	40	P	1	0.429	0.114	0	997.6	32.6	997.6	32.6	0.957	0.007	--	--
K1000_W40_BH_F2_GM	1000	H	40	GM	2	0.379	0.114	0	996.3	38.9	996.3	38.9	0.971	0.003	--	--
K1000_W40_BH_F1_GM	1000	H	40	GM	1	0.438	0.110	0	997.3	33.1	997.3	33.1	0.970	0.003	--	--
Enclosure complex	900	M	40/80	P	1	0.273	0.138	0	895.3	46.2	895.3	46.2	0.932	0.016	--	--
Devil Island single	600	M	70	P	2	0.256	0.116	0	596.4	25.9	596.4	25.9	0.957	0.007	--	--
Devil Island isolated (meta)	600	M	72		2	0.154	0.135	0	547.0	70.4	547.0	70.4	0.959	0.008	--	--
(within pops average)	100	M	12	P	2	0.147	0.171	0.016	92.6	16.1	92.6	16.1	0.763	0.083	--	26
Devil Island connect (meta)	600	M	72		2	0.235	0.116	0	589.6	42.9	589.6	42.9	0.957	0.007	--	--
(within pops average)	100	M	12	P	2	0.231	0.152	0	98.3	8.6	98.3	8.6	0.931	0.015	--	3

Captive Insurance Population Model

Modellers: Caroline Lees, Kathy Traylor-Holzer

Definition

Captive populations in the insurance population context are those populations in traditional, intensively managed facilities, where population size, structure and pairings for breeding are controlled, primarily to maximise genetic diversity and maintain demographic stability.

Scope

The models presented here are most relevant to the population of Tasmanian devils managed in ARAZPA zoos. However, the broad trends identified would be widely applicable to other populations housed under similar conditions.

Criteria for Success

The working group agreed that indicators of success for this captive component of the insurance meta-population would be:

- A probability of extinction of less than 5% over 50 years;
- Retention of at least 95% wild source gene diversity for 50 years;
- The ability to harvest animals for reintroduction.

The modeling aim for this group was to identify the management actions required to ensure success.

Vortex Baseline Model Parameters

The Tasmanian Devil Studbook, maintained by Carla Srb (Healesville Sanctuary, Victoria) was used extensively in the calculation of model parameters. Data were organised into subsets for analysis using time period, age and location filters.

General Model Parameters

Number of iterations:	*500*
Number of years:	*50 (about 17-18 generations)*
Extinction definition:	*Only one sex remains*
Number of populations:	*Single population*

Initial population size: *86 (population living in ARAZPA zoos on 3 July 2008)*
The starting population is imported as a file generated from the SPARKS (ISIS 2005) studbook containing the current living animals, their ages and genetic relationships.

Carrying capacity (K): *150*
Number of spaces currently committed to the captive program by ARAZPA institutions under the terms of an MOU with the Tasmanian Department of Primary Industries and Water (DPIW).

Reproductive Parameters

Mating system: *Polygyny (maximum of 4 female mates per male per year)*
Both male and female devils may have several mates during the same breeding season, and a single litter may have multiple sires. A polygynous mating system was selected to best represent reality, though it does not take account of females having multiple mates, or of litters having multiple sires.

Age of first offspring: *2 years (females); 2 years (males)*
This parameter represents the average age of first reproduction, not the age of sexual maturity or earliest reproductive age observed. These are the median values calculated from studbook data (sample size N=103 for females; N=83 for males).

Density-dependent reproduction: *No*

Percent adult females breeding: *Age-specific*
Average figures for ARAZPA zoos, calculated from 18 years of studbook data are: 34% for 2 and 3 year-olds and 10% for 4 year-olds. Larger figures were used in the baseline: 47% (2 years-old); 42% (3 years-old) and 22% (4 years-old). These figures reflect percentage females breeding in the recently established insurance population. Though the population is new (established in 2005) and sample sizes are small (N=19 for age 2; N=18 for age 3; N=18 for age 4), the new population is operating under a standardised husbandry regime that is expected to increase female breeding rates over time.

47-((A=3)*5)-((A=4)*25)-((A>4)*47)*[E^(-I*0.0157)]

Using studbook data (1988-2006), environmental variation observed across years was separated into demographic stochasticity (DS) and environmental variation (EV). DS is automatically generated by the model. EV was incorporated using the following function:

6.9-((A>=4)*1.3)

Percent adult males in the breeding pool: *100% proven; age-specific for unproven males*
100% of proven males plus age-specific percentages of unproven males, resulting in, on average, 50% of 2 year-old males and 80% of 3 and 4 year-old males in the breeding pool.

[(A=2)*50]+[(A=3)*(PARITY>0)*100]+[(A=3)*(PARITY=0)*77]+[(A=4)*(PARITY>0)*100]+[(A=4)*(PARITY=0)*63]+[(A=5)*(PARITY>0)*100]+[(A=5)*(PARITY=0)*42]

Number of progeny per year: *Maximum = 4, mean litter size = 2.7*
Females have 4 teats, which sets the upper limit for litter size. They have a maximum of one litter per year. Studbook data for 155 litters gave the following distribution of sizes:

No. offspring	***% litters***
1	19
2	26
3	31
4	24

Percent males at birth: *50%*
There is no evidence that sex ratio at birth differs statistically from 50:50.

Mortality Parameters
Mortality rates: *Age- and sex-specific*
Mortality rates are taken from 18 years of studbook data, modified in the older age classes, where sample sizes were very small, to better reflect likely biology.

Age	**Male Mortality**	**Female Mortality**
0	0.110	0.080
1	0.040	0.030
2	0.040	0.040
3	0.040	0.040
4	0.070	0.070
5	0.025	0.250
6	0.500	0.500
7	0.850	0.950
8	0.850	0.950
9	0.850	0.950
10	0.850	0.950
11	1.000	1.000

The resulting functions for adults were as follows:

Males: 4+((A=4)*3)+((A=5)*21)+((A=6)*46)+((A>=7)*81)
Females: 4+((A=4)*3)+((A=5)*21)+((A=6)*46)+((A>=7)*91)

Using a subset of studbook data (1995-2005), variation observed across years was separated into demographic stochasticity and environmental variation (EV). Sample sizes were small, so some modification was made to better reflect likely biology. In the juvenile and sub-adult age classes (ages 0-1 and 1-2), the EV values used were 2% and 0% respectively. The functions describing the results for the adult age classes are as follows:

Females: 0+((A=3)*1.8)+((A=4)*0)+((A>=6)*19.1)
Males: 1.8+((A=3)*3.1)+((A=4)*5.7)+((A>=5)*16.43)

Inbreeding depression: *Yes*
In the absence of estimates of inbreeding depression specific to Tasmanian devils, the default value of 3.14 lethal equivalents was used, 50% of which were assigned to lethal alleles and subject to purging. This value is the median LE calculated from studbook data for 38 captive mammal species (Ralls *et al.* 1988). These values were calculated from, and were implemented in the model, as reduced juvenile survival in inbred individuals. As inbreeding depression is known to occur for most aspects of reproductive fitness (e.g., mating ability, juvenile survival, adult survival, fecundity) (Frankham *et al.* 2002), the use of 3.14 lethal equivalents for juvenile survival substantially underestimates its impact. Work on captive populations by Wilcken (2002) indicates that inbreeding depression is at least twice this value, so here it is modelled as double the Ralls *et al.* (1988) level by decreasing the fertility of inbred females using the following multiplier for percent of females breeding:

E^(-I*0.0157):

Concordance between environmental variation in reproduction and survival: *No*
It was assumed that in captivity the environment is sufficiently well controlled such that environmental variation in survival and reproduction will be uncoupled.

Maximum age: *11 (males); 8 (females)*
Individuals are removed from the model after they pass the maximum age. *Vortex* assumes that animals can reproduce throughout their adult life and does not model reproductive senescence unless functions are used to do so. Though not the case in the wild, captive devils can have a relatively long period of senescence. Females usually cease breeding before age 5 but can live to age 8, and males generally cease breeding before age 6, but have lived to be age 11 (from studbook data). This was modelled in *Vortex* by applying age- and sex-specific fecundity rates to represent reproductive senescence

Number of catastrophes: 1
A single catastrophe was entered into the model. The DPIW/ARAZPA captive program currently extends across 8 institutions and is likely to expand to include around 15. In the past 10 years, in three separate recovery programs for other species, an entire institution's holdings have been threatened or lost due to fire, cyclone or accidental poisoning. The likelihood of this occurring in the devil program was modelled as a catastrophe, with a 10% probability of occurrence (i.e., about once every 10 years), resulting in the loss of an average institution's worth of animals (i.e., approximately 1/15 or 0.07 of the entire population at carrying capacity – about 10 animals).

Harvest: *Removal of excess young above K*
Vortex offers the option of managing populations to carrying capacity, by reducing the number of females breeding to the number expected to produce the required recruitment rate. If this option is not set, then the model will allow the population to breed freely, and then remove the number of animals surplus to capacity proportionately across age and sex classes. Neither of these options reflects well

the proposed management of the devil captive population. Once at capacity it is proposed that management of surplus be applied to the first age class, whilst the young are in pouch. To mirror this, a harvesting function was applied in the model, whereby at the end of each cycle, the program calculates the number of animals surplus to capacity, then harvests them, 50% from the first female age class and 50% from the first male age class. This is achieved as follows:

A population state variable is set to carrying capacity (PS1 = 150). Optional criteria for harvest are set so that harvest is switched on whenever the total number of animals exceeds carrying capacity (N>PS1). The number of females, and of males, to be harvested is set to one-half of the capacity excess, to be taken from the first age class (# harvested for each sex = 0.5*(N-PS1)).

Supplementation: *Not included in baseline model*

Breeding plan: *Breed where $F \leq 0.375$; use a static mean kinship list*

- Breeding to carrying capacity is not used as population size is controlled using the *Harvest* option (described above).
- The model is set to avoid pairings where the offspring inbreeding coefficient would be greater than or equal to 0.375. In reality a lower threshold of 0.125 would be set initially and then incrementally raised alongside average population inbreeding levels.
- The mean kinship value of an individual is a measure of its average relatedness to the other animals in the population. Gene diversity can be retained more successfully when animals of low mean kinship value are prioritised for breeding, and when they are bred with other animals of similar mean kinship value. A dynamic mean kinship list is expected to perform better that a static one, as it takes into account the results of each proposed pairing before the next is selected (see Ballou and Lacy 1995 for further explanation of genetic management by minimizing mean kinship). In this case the difference was very small, so a static list was used to speed simulations.

Baseline Model Results

Deterministic Output

The demographic rates (reproduction, mortality and catastrophes) included in the baseline model can be used to calculate deterministic characteristics of the model population. These values reflect the biology of the population in the absence of stochastic fluctuations (both demographic and environmental variation), inbreeding depression, limitation of mates, and immigration/emigration. It is valuable to examine deterministic growth rates (growth rate, generation lengths, and age structure) to assess whether they appear realistic for the species and population being modelled.

Table 19. Deterministic results for the *Vortex* Tasmanian devil captive baseline model.

Parameter	Value
Lambda (λ)	1.09
Deterministic r (r_{det})	0.083
Generation time (T)	2.76 years

These rates and values are representative of those seen in the captive population over the past 18 years (Table 19).

The mortality rates used in the captive baseline model generated a survival curve that also reflects the history of the captive population (Figure 12). The resulting stable age distribution consists of about 69% adult animals (Figure 13).

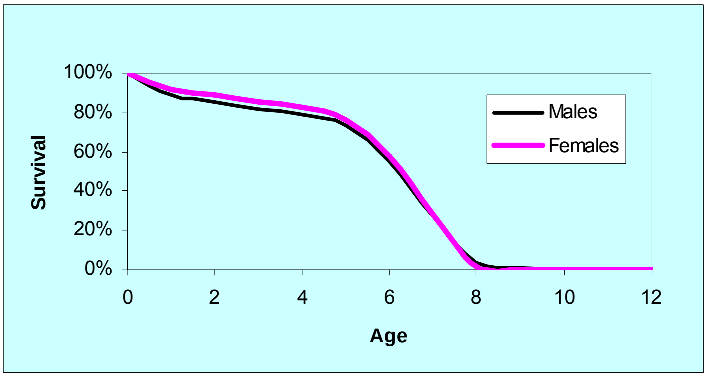


Figure 12. Survivorship curve from input data for baseline captive population.

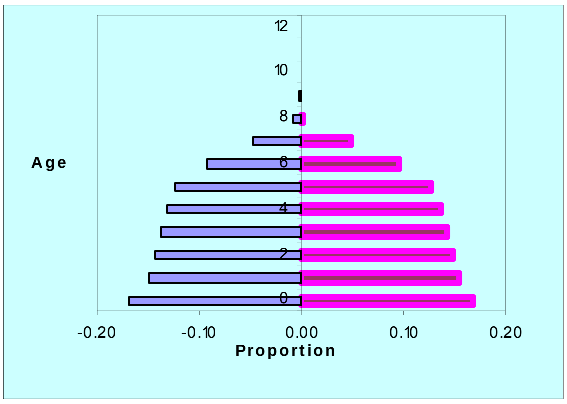


Figure 13. Stable age structure from input data for baseline captive population.

Stochastic Output

When stochastic or chance factors are included in model simulations, the baseline model has a higher probability of extinction than desirable (36.4% risk of extinction over the 50 year time-frame), and the average size of surviving populations is considerably below carrying capacity (mean = 43.90). This is not unexpected; the historical captive population, from which model data were drawn, was supplemented regularly with animals from the wild.

Table 20. Stochastic results for the *Vortex* Tasmanian devil captive baseline model.

Parameter	**Value (at 50 years)**
Stochastic r (r_{st})	-0.039
Probability of extinction (PE)	0.364
Mean time to extinction (Mean TE)	42.1 years
Gene diversity retained (GeneDiv)	0.7656
Average size of surviving populations (N-extant)	43.90 (SD=34.53)
Effective size to actual size ratio	0.23

The effective size to actual size ratio is a measure of how effectively the model population is retaining gene diversity over time. The larger the value, the smaller the population size needed to meet genetic goals. In general, captive populations show effective to actual population size ratios of about 0.3, whereas wild populations show ratios of about 0.1 (see Frankham *et al*., 2002 for further information on effective population size). The baseline population model is therefore not performing as well as expected for a captive population.

Modelling Questions

Questions asked of the model were focused on those parameters that working group members agreed could be influenced through management.

1) What is the impact of increased percentage of females breeding on population viability?

Reported figures for percent females breeding each year in the wild (approximately 80-100% for females aged 2-4 incl.) are higher than those observed in the current or past captive population. In some captive populations this could be the effect of active management to limit numbers, but in the case of Tasmanian devils, where regular supplementation from the wild has been necessary to sustain captive numbers, it is more likely to reflect inconsistent husbandry. Captive management then has not yet realised the species' biological potential and there is room for further manipulation. To investigate the impact of this parameter on population performance, the following ranges of values were explored (see Table 21):

F_Low: reduced percentage of females breeding

Uses average figures calculated from historical captive data (i.e., prior to establishment of the DPIW/ARAZPA insurance population): 34-((A=4)*24)-((A>4)*34)*[E^(-I*0.0157)]

F_Moderate: moderate increase in percentage of females breeding

Uses intermediate values between Baseline and most optimistic projections for 2008 season: [57-((A=3)*2)-((A=4)*22)-((A>4)*57)]*[E^(-I*0.0157)]

F_High: large increase in percentage of females breeding

Uses most optimistic projections for the 2008 breeding season in the DPIW/ARAZPA insurance population: [67-((A=4)*27)-((A>4)*67)]*[E^(-I*0.0157)]

F_HighPlus: "ideal" percentage of females breeding

Uses lower end of range observed for wild females: [80-((A>4)*80)]*[E^(-I*0.0157)]

Table 21. Variations in age-specific values for percentage females breeding.

	Age 2	**Age 3**	**Age 4**
F_Low	0	34	10
F_Baseline	47	42	22
F_Moderate	57	55	35
F_High	67	67	40
F_HighPlus	80	80	80

Results

The percentage of females breeding has a considerable impact on population projections. As the percentage of females breeding increases, the mean population size for surviving populations (N-extant) approaches carrying capacity and becomes more stable – that is, the standard deviation decreases (Figure 14). The moderate, high and wild (high plus) population parameters all provide positive stochastic growth and a sufficiently low extinction probability. None of the scenarios modelled retain sufficient gene diversity to satisfy the agreed success criteria (95% over 50 years) (Table 22).

Table 22. Summary of results for varied annual percentage of females breeding.

	N-extant	**PE**	**GeneDiv**	**Stochastic r (r_{st})**
F_Low	0.00 (SD=0.00)	1.000	0.0000	-0.136
Baseline	43.90 (SD=34.53)	0.364	0.7656	-0.039
F_Moderate	130.77 (SD=23.31)	**0.002**	0.8700	**0.007**
F_High	143.69 (SD=5.10)	**0.000**	0.8833	**0.009**
F_HighPlus	148.42 (SD=4.77)	**0.000**	0.8987	**0.010**

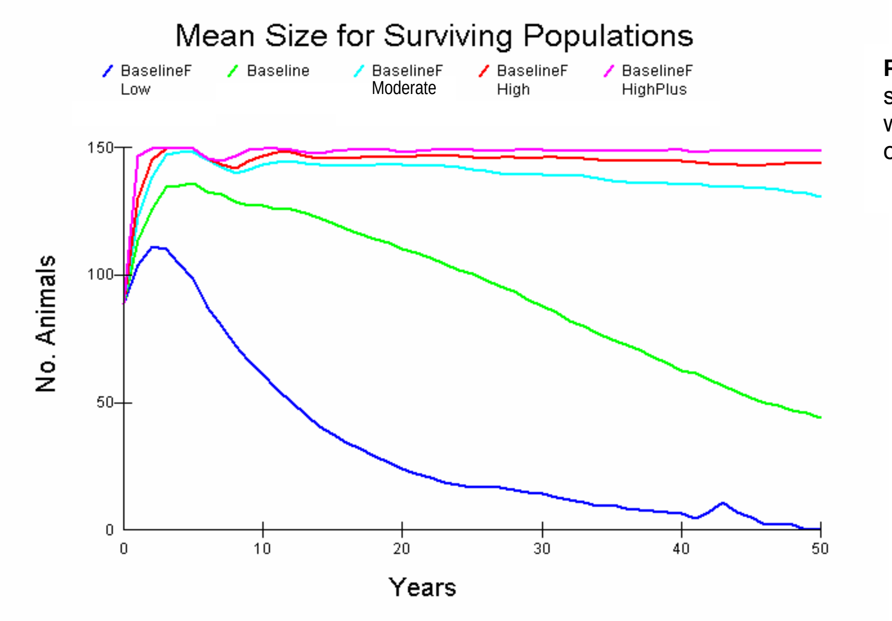


Figure 14. Mean population size for surviving populations with varied annual percentage of females breeding.

2) What is the impact of changes in the percentage of males in the breeding pool?

Historically, not all males have been successful breeders; how much of this is an artefact of management and how much is biological is not known. It is not possible to determine this from studbook data alone, as all males are not necessarily given an opportunity to breed each year. It may be possible, through appropriate management, to increase the pool of potential breeders; this would be expected to have a beneficial effect on demographic rates (if males are limiting), on inbreeding accumulation, and on gene diversity retention. The following changes were made to the model, to explore the impact of changing the percentage of males in the breeding pool. Note that in the first of these scenarios, proven males are not automatically in the breeding pool, as they are in the baseline model.

M_40: lower than Baseline values

40% of males aged 2-5 incl. in the breeding pool: 40-((A>5)*40)

M_100: optimal situation

100% of males aged 2-5 incl. in the breeding pool: 100-((A>5)*100)

Results

As would be expected, the greater the percentage of males in the breeding pool, the higher the population growth rate and gene diversity retention, and the lower the probability of extinction (Table 23). However, even with 100% of males in the breeding pool, growth remains negative and probability of extinction higher than 5%. Mean population sizes for surviving populations (N-extant) are considerably lower than carrying capacity (Figure 15) and highly variable, though this variability reduces as the percentage of males in the breeding pool increases.

Table 23. Summary of results for varied percent of males in the breeding pool.

	N-extant	PE	GeneDiv	Stochastic r (r_{st})
BaselineM_40	13.06 (SD=11.96)	0.896	0.6649	-0.082
Baseline	43.90 (SD=34.53)	0.364	0.7656	-0.039
BaselineM_100	55.14 (SD=37.82)	0.192	0.8035	-0.026

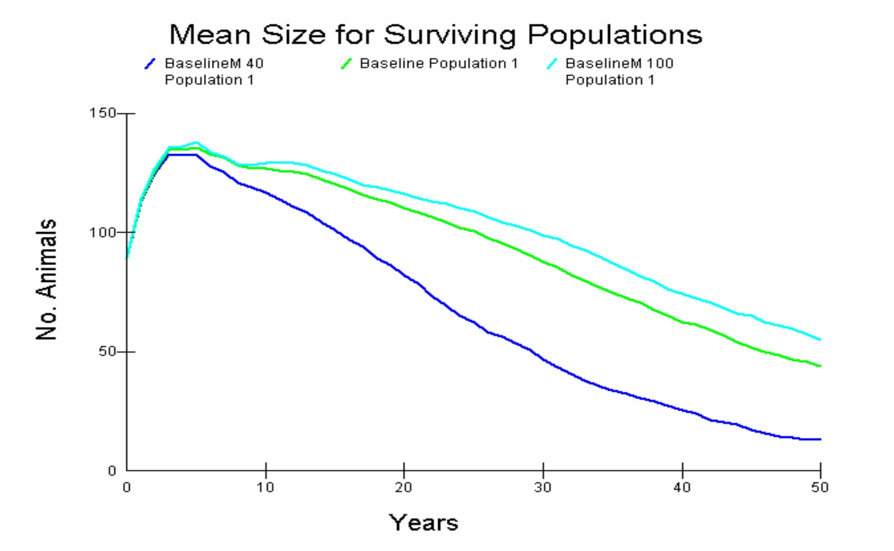


Figure 15. Mean population size for surviving populations with varied percent of males in the breeding pool.

3) What is the impact of increased carrying capacity on population viability?

Provided that the population has the internal ability to grow, increasing carrying capacity will allow the population to expand. All other things being equal, larger populations lose gene diversity and accumulate inbreeding more slowly than small ones, and are less prone to stochastic demographic effects (such as unusually high mortality rates, low birth rate or skewed sex ratio) that could drive them to extinction. A range of carrying capacities (K) were applied to the model. The baseline scenario (K=150) represents the current commitment of spaces to the program by regional zoo association (ARAZPA) members, and the upper limit (450) represents an estimate of the total number of spaces likely to be available in the world's zoos for this species in the immediate future.

Results

Again, the large standard deviation figures shows that population sizes for surviving populations are highly variable. Increasing carrying capacity increases stochastic growth, reduces extinction probability and increases gene diversity retention (Table 24). None of the scenarios modelled satisfy the criteria for success.

Table 24. Summary of results for varied carrying capacity.

	N-extant	**PE**	**GeneDiv**	**Stochastic r (r_{st})**
K150 (Base)	43.90 (SD= 34.53)	0.364	0.7656	-0.039
K200	75.55 (SD= 51.93)	0.190	0.8171	**0.016**
K250	114.22 (SD= 66.34)	0.128	0.8518	**0.020**
K350	170.71 (SD= 101.97)	0.106	0.8709	**0.027**
K450	235.75 (SD= 142.25)	0.118	0.8782	**0.032**

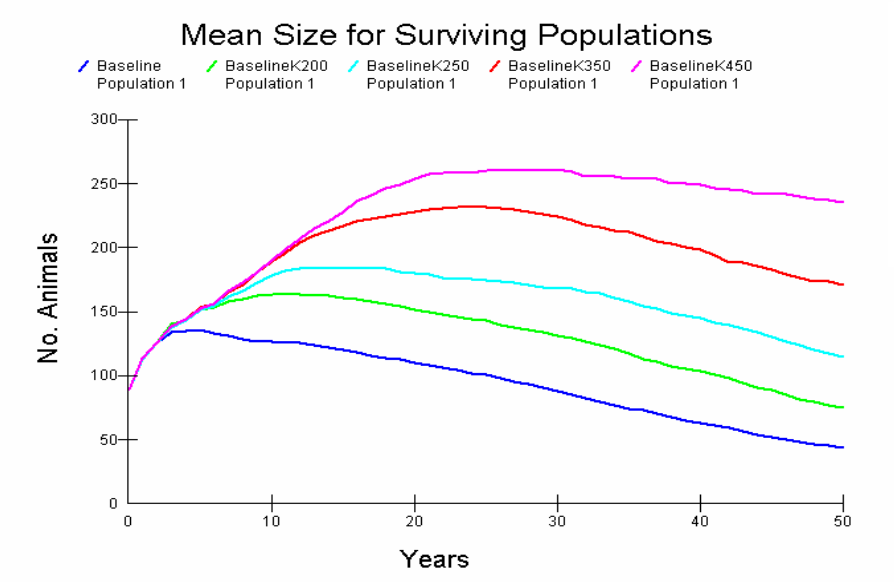


Figure 16. Mean population size for surviving populations with varied carrying capacity.

4) What is the impact of supplementation with unrelated animals on population viability?

Periodic supplementation with unrelated animals can assist long-term genetic health of the population by reducing inbreeding and improving gene diversity. In the model, animals were supplemented every 3 years (approximately one generation) and in numbers expected to be reasonable in the context of the overall insurance meta-population. Supplementation is with 2 year-old animals, as this is the age at which animals usually enter the captive population.

Supp2: 1 male and 1 female adult (1 pair) supplemented every 3 years.
Supp4: 2 male and 2 female adults (2 pairs) supplemented every 3 years.
Supp6: 3 male and 3 female adults (3 pairs) supplemented every 3 years.
Supp8: 4 male and 4 female adults (4 pairs) supplemented every 3 years.

Results

Mean population sizes move closer to capacity and are less variable as supplementation rate increases (Figure 17). As expected, supplementing the population with unrelated animals increases stochastic growth and gene diversity and reduces extinction probability (Table 25). At supplementation rates of 4 or more (animals per generation), the criteria for success are satisfied.

Table 25. Summary of results for varied rates of supplementation.

	N-extant	**PE**	**GeneDiv**	**Stochastic r (r_{st})**
Baseline	43.90 (SD=34.53)	0.364	0.7656	-0.039
Supp2	102.49 (SD=36.95)	**0.000**	0.9270	**0.001**
Supp4	128.76 (SD=24.09)	**0.000**	**0.9565**	**0.007**
Supp6	136.83 (SD= 17.37)	**0.000**	**0.9674**	**0.008**
Supp8	140.29 (SD=15.57)	**0.000**	**0.9730**	**0.009**

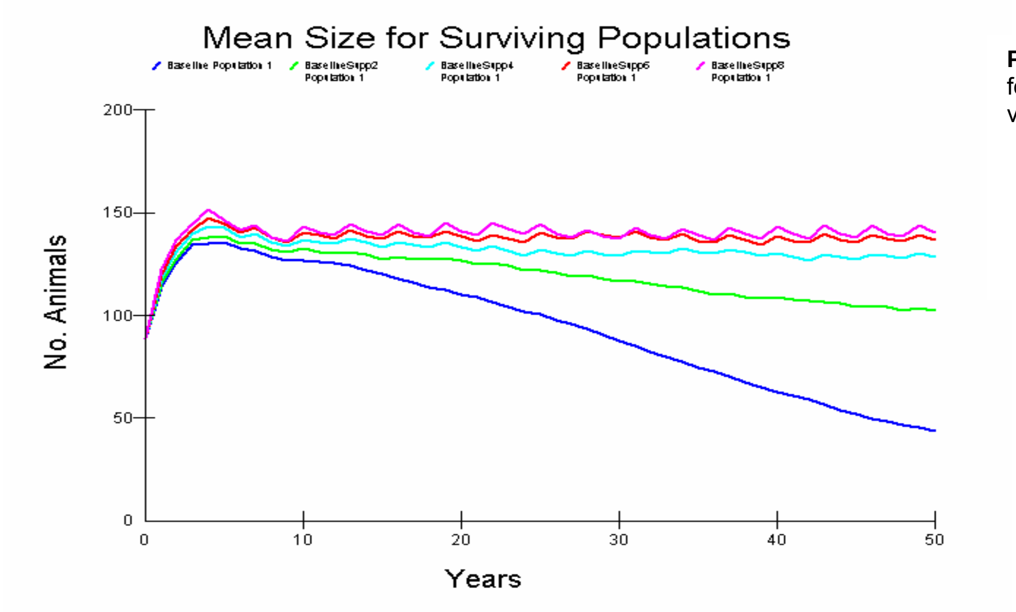


Figure 17. Mean population size for surviving populations with varied rates of supplementation.

5) How does inbreeding affect population viability?

Inbreeding has been shown to reduce reproductive fitness in all well-studied populations of naturally outbreeding species. The effect is associated with increased mortality and decreased productivity (size, yield, fertility, fecundity) in numerous animal species (reviewed in Frankham *et al.*, 2002). We modelled the following three levels of inbreeding depression for the captive population:

NoInb (no inbreeding depression): inbreeding depression turned off in the model – that is, inbred individuals survive and breed as well as non-inbred ones.

NoXtraInb (default inbreeding depression): 3.14 lethal equivalents affecting juvenile survival only, with 50% assigned to lethal alleles and subject to purging.

Baseline (additional inbreeding depression): 3.14 lethal equivalents applied to juvenile mortality and a further 3.14 lethal equivalents applied to female fertility (percent of females producing litters).

Results

Inbreeding depression has a clear impact on population dynamics. In the absence of inbreeding depression the model predicts slightly positive growth, increased gene diversity and low probability of extinction (Table 26; Figure 18).

Table 26. Summary of results for varied inbreeding depression.

	N-extant	**PE**	**GeneDiv**	**Stochastic r (r_{st})**
No inbreeding	129.97 (SD=25.20)	0.004	0.8496	**0.007**
Default (juvenile mortality only)	103.92 (SD=39.46)	0.050	0.8292	-0.003
Baseline (juv mort + fecundity)	43.90 (SD= 34.53)	0.364	0.7656	-0.039

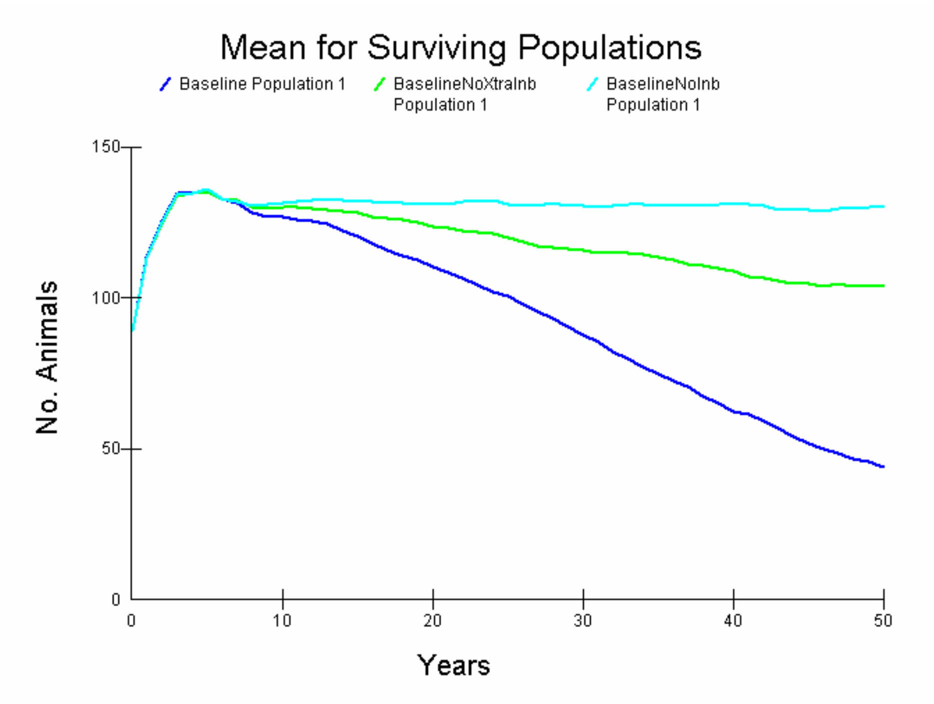


Figure 18. Mean population size for surviving populations with varied levels of inbreeding.

Discussion

The baseline model does not satisfy the criteria for success. Probability of extinction is too high, gene diversity retained too low, growth rate negative, and mean population size is well below carrying capacity and highly variable. Increasing the percent of females breeding, increasing carrying capacity, supplementing the population with unrelated animals, and increasing the percent of males in the breeding pool all have a positive effect on population growth, probability of extinction, and gene diversity retention. Of these, increasing the male breeding pool has the least effect, with negative stochastic growth persisting even with 100% of males in the pool. At the values modelled, increasing the percent of females breeding had the greatest stabilising effect on the population, considerably reducing the variability in mean population size (for surviving populations). At the values modelled, only increasing the percent of females breeding and supplementing with unrelated animals succeeded in reducing extinction probability below 5% and only supplementation (of at least 4 animals per generation) retained the required amount of gene diversity (95%) over the 50 year period. Inbreeding depression has a negative effect on population viability, such that managing inbreeding rates within the population is likely to be a valuable management action.

Management Scenarios

Management scenarios focused on determining which combination of management steps could be applied to increase the likelihood that the captive population will meet the agreed criteria for success.

Scenario 1: Optimistic 2008 female breeding rates are sustained and the population is supplemented to reduce accumulation of inbreeding and improve genetic diversity.

Increasing female breeding rate alone did not achieve the required level of gene diversity retention. Here it is combined with supplementation to assess the impact on required supplementation rates.

Modifications to Baseline

Female breeding rate is increased to a more optimistic level: [67-((A=4)*27)-((A>4)*67)] and sub-adult animals are supplemented every generation (3 years), 50% females and 50% males.

Results

Supplementation of at least 4 animals per generation increases gene diversity retention to the level required (Figure 19). Combining this with the higher rate of female breeding increases stochastic growth and stabilises population size (SD for N-extant is lower) (Table 27). At the growth rates observed it should be possible to harvest between 21.5% (approx. 32 animals) per year (for a supplementation rate of 4 animals per generation) and 23.6% (approx. 35 animals) per year (for a supplementation rate of 8 animals per generation). This scenario meets the criteria for success for supplementation rates of 4 or more animals per generation.

Table 27. Summary of results for optimistic female breeding rates with supplementation.

	N-extant	**PE**	**GeneDiv**	**Stochastic r (r_{st})**
F_HighSupp2	149.67 (SD=5.59)	**0.00**	0.9422	**0.200**
F_HighSupp4	150.13 (SD=5.17)	**0.00**	**0.9578**	**0.215**
F_HighSupp6	149.93 (SD=5.53)	**0.00**	**0.9658**	**0.226**
F_HighSupp8	149.77 (SD=5.68)	**0.00**	**0.9707**	**0.236**

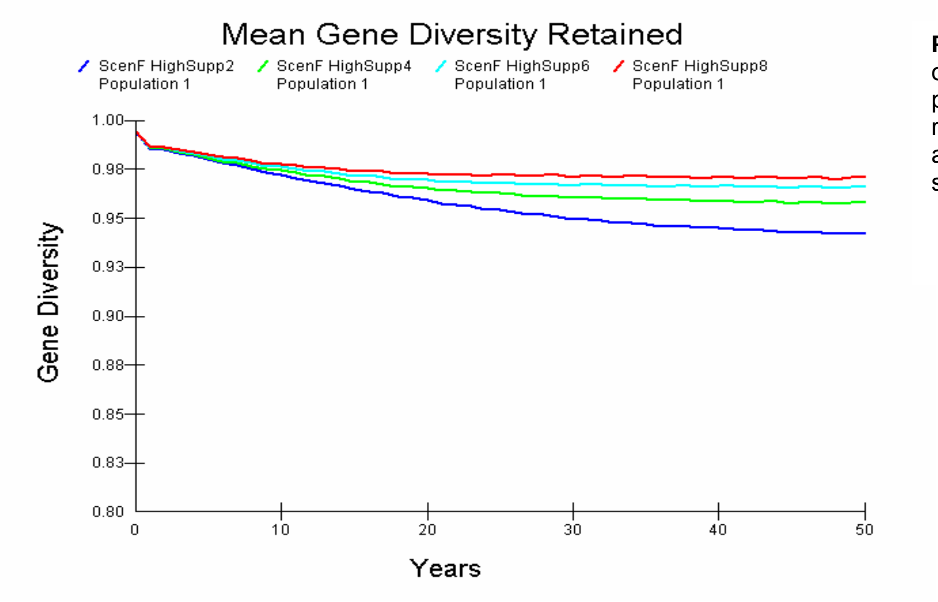


Figure 19. Gene diversity over time for surviving populations with optimistic rates of females breeding and varied rates of supplementation.

Scenario 2: Optimistic 2008 female breeding rates are sustained and carrying capacity is increased to reduce accumulation of inbreeding and improve genetic diversity.

Increasing carrying capacity resulted in increased stochastic growth rate (see above) but was not sufficient to reduce the probability of extinction below 5% or to adequately improve gene diversity retention. Increasing the percent of females breeding reduced extinction probability to the required level but also did not retain sufficient gene diversity. This scenario combines the two effects.

Modifications to Baseline

Female breeding rate is increased to a more optimistic level: [67-((A=4)*27)-((A>4)*67)] and carrying capacity is varied from 150-450.

Results

Combining the increase in females breeding with carrying capacity allows all success criteria to be met, but only the highest capacity modelled (K = 450) (Table 28). According to the stochastic growth rate, at this capacity it should be possible to take an annual harvest of approximately 20% or 90 animals.

Table 28. Summary of results for optimistic female breeding rates and varied capacity.

	N-extant	**PE**	**GeneDiv**	**Stochastic r (r_{st})**
F_High K=150	149.39 (SD=5.10)	**0.00**	0.8960	**0.180**
F_High K=200	199.31 (SD=6.09)	**0.00**	0.9182	**0.190**
F_High K=250	250.09 (SD=6.17)	**0.00**	0.9308	**0.196**
F_High K=350	250.11 (SD=7.27)	**0.00**	0.9454	**0.200**
F_High K=450	450.15 (SD=9.12)	**0.00**	**0.9537**	**0.204**

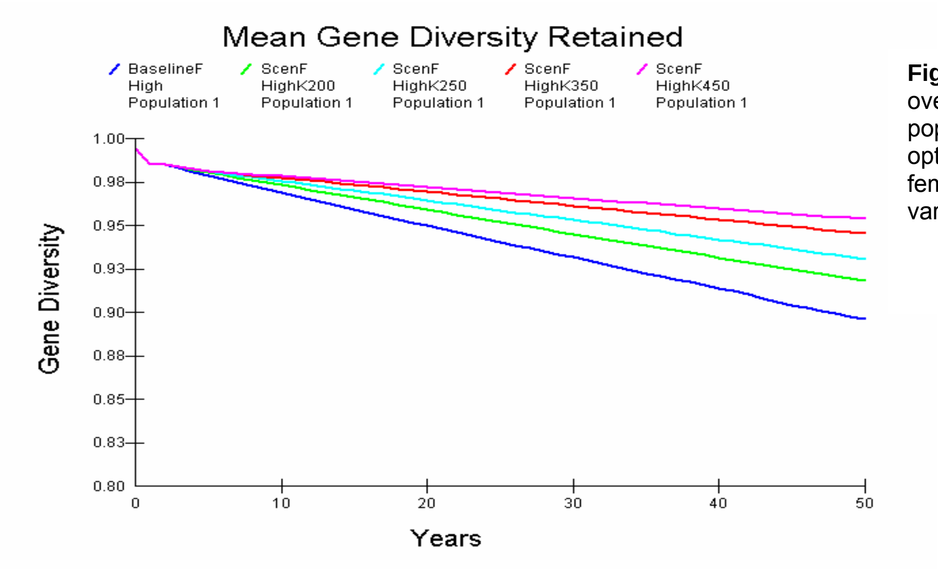


Figure 20. Gene diversity over time for surviving populations with optimistic rates of females breeding and varied carrying capacity.

Summary of Captive Population Model Results

Increasing female breeding rate in combination with modest rates of supplementation (around 4 animals every 3 years) confers an extinction probability of zero, meets gene diversity targets and increases stochastic growth to a greater extent than either effect in isolation, allowing greater harvest (approximately 32-35 animals at K = 150). However, it relies on a regular supply of unrelated animals. Where regular supplementation is not possible, the criteria for success can be met by increasing carrying capacity to around 450 animals.

To meet the criteria for success, future management of the captive population should focus, in descending order of priority, on:

- Increasing the percentage of females breeding.
- Organising supplementation with a small number of unrelated animals each generation (e.g., approximately 4) or, if this is not possible, growing the population rapidly to 450 individuals.
- Increasing the number of males in the breeding pool.

Importantly, with annual percentage females breeding increased to the optimistic values predicted for the 2008 season (F_High), effective size to actual size ratio in the model is increased to about 0.50 (from the baseline value of 0.23). This is better than expected for a captive population and achieving this ratio consistently would substantially reduce the number of intensively managed captive animals required to meet the overall insurance strategy goal of achieving an effective population size (Ne) of 500.

Table 29. Simulation results for Captive Insurance Population scenarios at 50 years (stochastic r; probability of extinction; mean population size for extant (surviving) only and for all populations; mean gene diversity; median and mean time to extinction in years; standard deviations given as SD).

Scenario	stoc-r	SD(r)	PE	N-extant	SD(Next)	N-all	SD(Nall)	GD	SD(GD)	MedianTE	MeanTE
Baseline	-0.039	0.155	0.364	43.9	34.53	28.04	34.61	0.7656	0.1236	--	42.1
% Females Breeding											
F_Low	-0.136	0.223	1.000	0	0	0	0	0	0	24	24.1
F_Plus	0.007	0.093	0.002	130.77	23.31	130.51	24.01	0.8700	0.0398	--	38
F_High	0.180	0.094	0	149.39	5.10	149.39	5.10	0.8960	0.0212	--	--
F_HighPlus	0.010	0.079	0	148.42	4.77	148.42	4.77	0.8987	0.0241	--	--
% Males in Breeding Pool											
M_40	-0.082	0.199	0.896	13.06	11.96	1.41	5.53	0.6649	0.1309	38	36.7
M_100	-0.026	0.141	0.192	55.14	37.82	44.61	40.29	0.8035	0.1072	--	43.4
Increasing carrying capacity											
K=200	-0.021	0.137	0.190	75.55	51.93	61.26	55.28	0.8171	0.1014	--	41.9
K=250	-0.009	0.128	0.128	114.22	66.34	99.63	72.73	0.8518	0.0868	--	39.6
K=350	-0.001	0.124	0.106	170.71	101.97	152.65	109.78	0.8709	0.0873	--	40.9
K=450	0.003	0.125	0.118	235.75	142.25	207.96	153.7	0.8782	0.1037	--	41.3
Supplementation every 3 years											
Supp2	0.001	0.112	0	102.49	36.95	102.49	36.95	0.9270	0.0217	--	--
Supp4	0.007	0.103	0	128.76	24.09	128.76	24.09	0.9565	0.0088	--	--
Supp6	0.008	0.100	0	136.83	17.37	136.83	17.37	0.9674	0.0052	--	--
Supp8	0.009	0.101	0	140.29	15.57	140.29	15.57	0.9730	0.0038	--	--
Inbreeding Depression											
Juvenile mortality only (3.14 LE)	-0.003	0.115	0.050	103.92	39.46	98.74	44.61	0.8292	0.0669	--	42.0
No inbreeding	0.007	0.101	0.004	129.97	25.20	129.45	26.45	0.8496	0.0441	--	35.5
Scenario 1											
F_High	0.180	0.094	0	149.39	5.10	149.39	5.10	0.8960	0.0212	--	--
F_HighSupp2	0.200	0.091	0	149.67	5.59	149.67	5.59	0.9422	0.0116	--	--
F_HighSupp4	0.215	0.089	0	150.13	5.17	150.13	5.17	0.9578	0.0072	--	--
F_HighSupp6	0.226	0.089	0	149.93	5.53	149.93	5.53	0.9658	0.0055	--	--
F_HighSupp8	0.236	0.090	0	149.77	5.68	149.77	5.68	0.9707	0.0042	--	--
Scenario 2											
BaselineF_High	0.180	0.094	0	149.39	5.10	149.39	5.10	0.8960	0.0212	--	--
ScenF_HighK200	0.190	0.087	0	199.31	6.09	199.31	6.09	0.9182	0.0156	--	--
ScenF_HighK250	0.196	0.081	0	250.09	6.17	250.09	6.17	0.9308	0.0118	--	--
ScenF_HighK350	0.200	0.077	0	350.11	7.27	350.11	7.27	0.9454	0.0084	--	--
ScenF_HighK450	0.204	0.074	0	450.15	9.12	450.15	9.12	0.9537	0.0068	--	--

Conclusion of Insurance Population Modeling Results

The results from the three insurance population models for Tasmanian devils suggest the conditions under which each management option is likely to make a valuable contribution toward achieving the goals of the Save the Tasmanian Devil Steering Committee Insurance Population Strategy. General conclusions that can be drawn from these modeling exercises include the need for relatively large, interbreeding devil populations in order to ensure population persistence and long-term maintenance of high levels of genetic variation. Populations of 500-1000 or more individuals show relatively high performance in terms of viability measures, whereas populations around 250 individuals likely will require higher levels of management to attain similar levels. Smaller populations of 100-150 may have more limited, short-term value but will likely require occasional genetic and/or demographic supplementation to counteract inbreeding depression and other stochastic threats to viability.

Most if not all of any future insurance populations may be established with a relatively small number of founders. Such circumstances emphasise the importance of strong demographic growth to quickly grow the population to a size at which it is less vulnerable to stochastic events and can capture a greater proportion of the genetic diversity of the founding population. Breeding success rates among adult females may be the most likely parameter than can be promoted to effect stronger population growth. High growth rates and large population size both serve to increase the potential for an insurance population to produce individuals for reintroduction or to supplement smaller, more vulnerable insurance populations.

A large and genetically representative founder base not only will help to reduce demographic risks and early inbreeding, but is important for establishing an insurance population that captures the genetic adaptive potential of the wild devil population. Large population size can help to counteract the loss of genetic variation through genetic drift. Although not modelled here, genetic management and maintenance in natural conditions can help to minimise adaptation to captivity. Genetic change over time is an important consideration if insurance populations are to serve effectively for future reintroduction efforts.

Each insurance population strategy has its advantages as well as its own set of challenges – biological, logistical, financial and/or political. Many of these advantages and challenges were outlined by the respective working groups. Each option has the potential under the right conditions to contribute as one component of a diverse metapopulation strategy to guard against species extinction.

References

Ballou, J.D. and R.C. Lacy. 1995. Identifying genetically important individuals for management of genetic variation in pedigreed populations. Pages 76-111 in J. D. Ballou, M. Gilpin, and T. J. Foose, eds. *Population Management for Survival and Recovery: Analytical Methods and Strategies in Small Population Conservation*. Columbia University Press: New York.

Bradshaw, C.J.A. and B.W. Brook. 2005. Disease and the devil: density-dependent epidemiological processes explain historical population fluctuations in the Tasmanian devil. *Ecography* 28: 181-190.

Brooks, B.W., J. J. O'Grady, A.P. Chapman, M.A. Burgman, H.R. Akcakaya, and R. Frankham. 2000. Predictive accuracy of population viability analysis in conservation biology. *Nature* 404:385-387.

Frankham, R., J.D. Ballou, and D.A. Briscoe. 2002. *Introduction to Conservation Genetics*. Cambridge University Press: Cambridge, UK.

Guiler, E.R. 1970a. Observations on the Tasmanian devil, *Sarcophilus harrisii* (Marsupialia: Dasyuridae) I. Numbers, home range, movements, and food in two populations. *Aust. J. Zool.* 18:49-62.

Guiler, E.R. 1970b. Observations on the Tasmanian devil, *Sarcophilus harrisii* (Marsupialia: Dasyuridae) II. Reproduction, breeding, and growth of pouch young. *Aust. J. Zool.* 18:63-70.

Hawkins, C.E., C. Baars, H. Hesterman, G.J. Hocking, M.E. Jones, B. Lazenby, D. Mann, N. Mooney, D. Pemberton, S. Pyecroft, M. Restani, and J. Wiersma. 2006. Emerging disease and population decline of an island endemic, the Tasmanian devil *Sarcophilus harrisii. Biological Conservation* 131:307-324.

ISIS. 2005. Single Population Analysis and Record Keeping System, version 1.54. International Species Information System, Eagan, MN.

Lachish, S., M. Jones, and H. McCallum. 2007. The impact of disease on the survival and population growth rate of the Tasmanian devil. *Journal of Animal Ecology* 76:926-936.

Lacy, R.C. 1993. Vortex: A computer simulation model for population viability analysis. *Wildlife Research* 20:45-65.

Lacy, R.C. 2000. Structure of the Vortex simulation model for population viability analysis. *Ecological Bulletins* 48:191-203.

McCallum, H. and M. Jones. 2006. To lose both would look like carelessness: Tasmanian devil facial tumour disease. Unsolved Mystery; Public Library of Science, *Biology* 4 (10): 1671-1674.

McCallum, H., D.M. Tompkins, M. Jones, S. Lachish, S. Marvanek, B. Lazenby, G. Hocking, J. Wiersma, and C.E. Hawkins. 2007. Distribution and impacts of Tasmanian Devil Facial Tumor Disease. *EcoHealth* 4(3):318-325.

Miller, P.S. and R.C. Lacy. 2005. *Vortex: A Stochastic Simulation of the Extinction Process. Version 9.50 User's Manual*. Apple Valley, MN: Conservation Breeding Specialist Group (SSC/IUCN).

O'Grady, J.J., B.W. Brook, D.H. Reed, J.D. Ballou, D.W. Tonkyn, and R. Frankham. 2006. Realistic levels of inbreeding depression strongly affect extinction risk in wild populations. *Biological Conservation* 133:42-51.

Ralls, K.R., J.D. Ballou and A. Templeton. 1988. Estimates of lethal equivalents and the cost of inbreeding in mammals. *Conservation Biology* 2(2):185.193.

Reed, D.H., J.J. O'Grady, J.D. Ballou and R. Frankham. 2003. Frequency and severity of catastrophic die-offs in vertebrates. *Animal Conservation* 6:109-114.

Wilcken, J. 2002. The cost of inbreeding revisited. M.Sc. thesis, Macquarie Univ., Sydney, Australia.

Tasmanian Devil PHVA
Final Report

Section 8
Resistance Issues Working Group Report

Resistance Issues for the Insurance Population

Working Group Participants: *Kathy Belov, Greg Woods, Anne-Maree Pearse, Hamish McCallum, Caroline Lees and Dick Frankham*

Background

The Major Histocompatibility Complex (MHC) is the key region of the genome involved in immune response and graft rejection. DFTD, a cancerous devil cell, has spread due to lack of MHC diversity in Tasmanian devils. Essentially the tumour MHC type is so similar to that of the host, that the host immune system does not recognise the foreign cell as foreign (non-self) and does not mount an immune response.

Populations in the far northwest have some MHC types not found in the east. It is feasible that these differences are sufficient that the host's immune system will recognise them as foreign and mount an immune response. There is already some evidence of resistance in the wild. Three devils in West Pencil Pine have generated antibody responses to DFTD, suggesting they have been exposed to the disease and seroconverted. The progress of disease spread has slowed down in WPP. Cedric (who is MHC different to DFTD) has mounted an Ab response to killed DFTD cells and has since resisted challenge with live cells. Clinky (who has a very similar MHC type to DFTD) did not mount an immune response, and has developed DFTD following challenge.

There are currently up to 12 different DFTD strains based on karyotype demonstrating that DFTD has become hypermutable and is evolving. This could result in several scenarios: 1) The tumour could become more aggressive and unstable and drive itself to extinction; 2) The tumour could evolve to be less aggressive and grow more slowly. This could lead to a tumour that takes longer to lead to death, is more difficult to diagnose, could lead to a longer timeline for spread (more opportunity for spread) and higher risk of moving an undiagnosed infected animal; 3) The tumour could evolve immune evasion strategies (such as downregulating MHC expression). This is what happened with canine transmissible venereal tumour (CTVT), allowing the tumour to cross the MHC-barrier from wolves into dogs, jackals and coyotes.

It is predicted that DFTD will experience strong selection pressure as it has recently come in contact with new MHC types. Strong selection for immune evasion may lead to tumour variants which could affect MHC-disparate devils and perhaps cross the species barrier.

Recommendations

Selection for resistance

Given our current knowledge on the mechanism of resistance, it is unwise to select for MHC types while ignoring other markers. If you target one region of the genome, you lose diversity elsewhere in the genome. It is possible that genes outside the MHC are also involved in resistance to disease. There is a risk that if we select for specific genotypes that provide resistance to DFTD that we can select for alleles that lead to susceptibility for another disease.

Selective breeding for resistance is not part of the insurance population strategy. The strategy is focused on maintaining maximum overall genetic diversity across the genome. Because of the importance of the MHC in the disease response, MHC diversity in the founders should be maximised by appropriate sampling from the wild. MHC allele frequencies in the insurance population pedigree should be tracked and those vulnerable to loss identified. Probability of persistence of those vulnerable MHC types can be increased through careful management within a strategy for maintaining overall genetic diversity. This can be achieved through preferential breeding of littermates holding the rarer MHC alleles, following initial selection of those litters according to whole genome diversity indicators.
We should also attempt to maintain the AC5 chromosome within the population as this chromosomal polymorphism provides a further mechanisms of genetic variation.

We propose to change the wording of “selective breeding” to “management of emerging resistance alleles” in all Save the Devil releases.

Evolution of DFTD

Some animals are likely to be refractory to the current strain. This could lead to suggestions that the insurance strategy is no longer necessary.

DFTD has already begun to evolve. As the disease front reaches MHC-disparate populations it will come under strong selection pressure to evolve immune evasion strategies. Basing insurance strategies around evolution of resistance to one strain is most unwise.

The insurance population should focus on maintaining overall genetic diversity. Evolution of DFTD strains could minimise the impact of genetic resistance on the wild population. It is vitally important to track DFTD evolution at the disease front.

Vaccine development

Vaccine development is uncertain, long term and may not work effectively as:

- The tumour is evolving.
- Vaccines against tumours in humans don’t work. However, vaccine development against cancers in inbred mice has been successful.
- Autoimmunity could be induced by injecting a killed cell which is very similar to the host.

Vaccine development should remain a research objective as we do not have the technology to implement it currently. In the future it may be useful for reintroduction of insurance animals into the wild. Research should focus on discovery of tumour antigens.

Tasmanian Devil PHVA
Final Report

Appendix 1
Participant List & Introductions

Participant List

Name	Affiliation	Email Address
Paul Andrew	Taronga Conservation Society Australia (TCSA)	pandrew@zoo.nsw.gov.au
Rod Andrewartha	Department of Primary Industries and Water (DPIW)	rod.andrewartha@dpiw.tas.gov.au
Barry Baker	Latitude 42 Environmental Consultants Pty Ltd	barry.baker@latitude42.com.au
Nick Beeton	School of Zoology (UTAS)	beetonn@utas.edu.au
Kathy Belov	Australasian Wildlife Genomics Group (USYD)	kbelov@vetsci.usyd.edu.au
Simon Boughey	Senior Advisor, David Llewellyn MHA, Minister Primary Industries and Water	simon.boughey@dpiw.tas.gov.au
Onnie Byers	Conservation Breeding Specialist Group (CBSG)	onnie@cbsg.org
Brooke Craven	Department of Primary Industries and Water (DPIW)	brooke.craven@dpiw.tas.gov.au
Bruce Englefield	East Coast Natureworld	benglefi@tassie.net.au
Mark Flanigan	Department of the Environment, Water, Heritage and the Arts (DEWHA)	Mark.Flanigan@environment.gov.au
Dick Frankham	Macquarie University	rfrankha@ELS.mq.edu.au
Auntie Pat Green	Tasmanian Aboriginal Land and Sea Council (TALSC)	
Collette Harmson	Department of Primary Industries and Water (DPIW)	colette.harmsen@dpiw.tas.gov.au
Clare Hawkins	Department of Primary Industries and Water (DPIW)	clare.hawkins@dpiw.tas.gov.au
Cheryl Hill	Foundation for Australia's Most Endangered Species Inc	geoffrey.hill@fame.org.au
Mark Holdsworth	Department of Primary Industries and Water (DPIW)	Mark.Holdsworth@dpiw.tas.gov.au
Hank Horton	Tasmanian Aboriginal Land and Sea Council (TALSC)	manager@talsc.net.au
Stewart Huxtable	Department of Primary Industries and Water (DPIW)	Stewart.Huxtable@dpiw.tas.gov.au
Richard Jakob-Hoff	New Zealand Centre for Conservation Medicine	Richard.Jakob-Hoff@aucklandcity.govt.nz
Menna Jones	School of Zoology (UTAS) and DPIW	menna.jones@dpiw.tas.gov.au
Lisa Keen	Taronga Conservation Society Australia (TCSA)	lkeen@zoo.nsw.gov.au
Androo Kelly	Trowunna Wildlife Park	androo@trowunna.com.au
Caroline Lees	Australasian Regional Association of Zoological Parks and Aquaria (ARAZPA)	lees.caroline@gmail.com
Dan Lunney	Reserve and Wildlife Conservation Branch (DECC)	dan.lunney@environment.nsw.gov.au
Hamish McCallum	School of Zoology (UTAS)	hamish.mccallum@utas.edu.au
Nick Mooney	Department of Primary Industries and Water (DPIW)	nick.mooney@dpiw.tas.gov.au
David Obendorf	Wildlife Veterinarian	davidobendorf@tassie.net.au
Anne-Maree Pearse	Animal Health Laboratory (DPIW)	anne-maree.pearse@dpiw.tas.gov.au
David Pemberton	Wildlife and Marine Conservation Section, DPIW	David.Pemberton@dpiw.tas.gov.au
Martin Phillips	Australasian Regional Association of Zoological Parks and Aquaria (ARAZPA)	martin@arazpa.org.au
David Sinn	University of Tasmania	david.sinn@utas.edu.au
Kim Skogvold	Department of Primary Industries and Water (DPIW)	Kim.Skogvold@dpiw.tas.gov.au
Rebecca Spindler	Taronga Conservation Society Australia (TCSA)	rspindler@zoo.nsw.gov.au
Carla Srb	Healesville Sanctuary	csrb@zoo.org.au
Kathy Traylor-Holzer	Conservation Breeding Specialist Group (CBSG)	kathy@cbsg.org
John Weigel	Australian Reptile Park	jweigel@reptilepark.com.au
Penny Wells	Department of Primary Industries and Water (DPIW)	penny.wells@dpiw.tas.gov.au
John Whittington	Department of Primary Industries and Water (DPIW)	John.Whittington@dpiw.tas.gov.au
Greg Woods	Menzies Research Institute (UTAS)	g.m.woods@utas.edu.au
Rupert Woods	Taronga Conservation Society Australia (TCSA)	rwoods@zoo.nsw.gov.au

Participant Introductions

1. What do you hope will be accomplished during this workshop?

I hope that everybody here will agree to work together as a team within and outside of this room to achieve our common goal – to save Tassie devils from extinction on the wild.

Ensure genetic diversity maintained/ “resistant” devils; collaboration/cooperation between different groups; strategy to ensure survival.

Bring expertise together and exchange ideas to come up with the best strategy to save the devil and preserve devils in captivity and eventually be able to return them to the wild.

A clear direction forward for an insurance strategy that integrates wild and captive populations, allows for future reestablishment of wild populations and is adaptive to emerging and changing knowledge of disease.

Clear practical guidance of the management and ultimate reintroduction of the insurance population.

Development of integrated insurance strategy robust to uncertainly – can’t have all eggs in one basket so need to know what the baskets are, and how to distribute eggs between baskets.

Participation and connections that foster collaboration, central focus being the Tasmanian devil and its conservation in the wild; healthy dialogue over the range of interconnected disciplines.

A clear and co-operative working thru the issues to assist the Tasmanian devils’ long term survival in wild; having a practical process and approach to “insuring” we make the right decisions in relation to “insurance” strategy (to focus on the devils and not the people).

A clear plan to allow us to move forward in establishing in insurance populations including selection of locations/identification of areas for insurance populations. Rather than just talking I want decisions, clear and concise guidelines/outcomes.

To design a long-term and effective strategy to reduce the possibility of extinction of the Tasmanian devil utilising all the knowledge we have accumulated in recent times; sustainable populations.

Clear and focused objectives and strategies for the captive management of both behavioral and genetic components of the insurance populations.

Ensure that captive management of devils is integrated at all levels (state, national and international), and all those with genuine capacity and desire have the opportunity to contribute.

Genuine plan with practical and achievable steps to meet the 4 goals of the insurance population strategy, to implement straight away; I hope to learn more around the issues, ecological/reintroduction that I can apply to these issues over time.

The means to guarantee the survival of the devil should other avenues fail within the timescale available.

A clear pathway forward for the management of the insurance population to achieve the goals of the strategy.

The best available scientific advice and information will be collated, analysed and developed into a practical and realistic plan that clearly informs where we go from here with the insurance strategy for the Tasmanian devil.

Saving the devil

Plan that ARAZPA zoos can cost and implement

High quality genetic plan for Tasmanian devil

A common vision and agreed strategy that will focus available resources in the most effective way possible to ensure the long-term survival of the Tasmanian devil.

A practical, implemental insurance population plan that provides the basis for the establishment of a sustainable Tassie devil population.

I hope to see the formation of a strategy to expand the project Ark metapopulation to desired proportions

Save the devil

A real plan that has substance that is owned by all parties, regardless of their starting positions – this is about the Tasmanian devil, not 'us'.

I want to walk out the door knowing what I have to do to make the insurance population work, with having devils in the wild being the end point.

Clear directions that include all the threats facing the devil from land clearing to disease; I don't believe the devil numbers have changed dramatically over the last 200 years because of disease – it is all the other threats; I do believe we have effective "devil reserves" already waiting to be managed.

A clear exposition of the problem, the options for resolving it and the role of NSW spelt out so that it can achieve departmental (DECC) and Minister support.

Long term strategy for the survival of the Tasmanian devil trough all practical options for the species and its population that can be fully agreed to at a political level and across all Tasmanian government agencies/ministers.

A realistic view of what can be done in terms of actually helping devils.

Consensus and an effective plan

A better understanding of the best way forward in saving the Tasmanian devil.

Development of a working model for Tasmanian devils that has the support of all stakeholders.

A clearer plan and set of firm decisions on the establishment and organisations of insurance populations – how many, where, for how long, who organises, what…; improved understanding between collaborating organisations.

Clearly articulated plan with goals, objectives, milestones and timelines where roles and responsibilities are clearly defined; a better understanding in my mind of the resources required: what it is going to cost in time, money, other resources?

2. What do you hope to contribute?

I'd like to contribute passion, enthusiasm and the sharing of information to gain a better understanding of Tasmanian devils.

Knowledge regarding immune response of devil (also tumour immunity)

Information about devil immunogenetics (MHC genes – genes that determine immune response).

Knowledge of devil/ecology, evolution and population genetics.

Here to learn but contribute public policy perspective and particularly practicalities to get it done.

Ideas through collaborations; experience with Tasmanian wildlife from the perspective of health status and disease expressions; understanding gaps in knowledge; defining retrospective and prospective timelines to the natural history of Tasmanian devil within the bioecology of this approx. 68,000 km^2 island.

Perspective pf disease ecology, population modeling and parameter estimation.

My knowledge and optimism/pragmatism and experience over 20 years of breeding and managing captive devils and living with the animals.

Whatever little I can do to assist in this process.

My knowledge of the captive component of the species thorough my role as studbook keeper.

Knowledge and info on fecundity in wild populations; ideas on practical approaches and risks to implementing the insurance population strategies/objectives in Tasmania; how we can incorporate devils in Tasmanian wildlife parks.

Whatever the workshop requires (providing I remain clothed!); contribute my knowledge of captive management and reintroductions for experience with OBPs and devils.

Knowledge around legislation, policy context and environ mental considerations. Structured thinking to assist round setting goals and strategies.

A suggestion and demonstration of part of the means to guarantee the survival of the devil.

Some understanding of the opportunities and constraints under which the program operates.

My area of expertise is the policy and legislative framework around biodiversity and threatened species management in Tasmania.

Welcome to country.

Articulate the result to ARAZPA members

Genetic expertise and broader inputs

I hope to inject a positive note to the proceedings to the extent that participants believe the Australian community will get behind such an effort; any expertise that I have as a lay person to facilitate the process.

Help the group as a facilitator to develop a viable practical disease risk management plan in support of the insurance population.

I hope to introduce a worthwhile alternative to achieving the intended goal described above that will be broadly discussed and shaped during the course of the workshop.

Anything to save the devil; welcome to country

Objectively, pragmatism, help make decisions how to work cooperatively; project management skills.

Facilitation, organisations and general opportunities to taste Tasmanian food and wine.

What I know about the present and past biology particularly distribution; I hope to have an opportunity to provide the evidence of what I believe is proof that devils lived on Bruny Island in the late 1800s.

An ecological outlook on the issue and a grasp of the problem as a member of the IUCN Marsupial Specialist Group as well as a NSW research scientist.

Political nuances of Tasmania.

A focus on what can be achieved to lessen the ecological impact of loss of devils, however extensive that loss may be.

Communications

Knowledge of how population modeling can help inform our decision-making.

Advice on parameter estimation and model development that will lead to a good working model that in turn will lead to good conservation outcomes for the Tasmanian devil.

Info on the status and demography of the wild population, including knowns and unknown and the degree of certainty around these.

Reality check; management paradigm: understanding of the need for structure and discipline and need to make hard decisions; understanding that in a collaborative approach you can’t always get what you want.

Tasmanian Devil PHVA
Final Report

Appendix 2
Invitation & Invitation List

Tasmania
Explore the possibilities

CONSERVATION
BREEDING
SPECIALIST GROUP

SAVE THE TASMANIAN DEVIL PROGRAM

POPULATION AND HABITAT VIABILITY ASSESSMENT (PHVA)

SALAMANCA INN CONFERENCE CENTRE, HOBART - 3-6 July 2008

Dear Colleague,

You are invited to attend the Tasmanian Devil Population and Habitat Viability Assessment (PHVA) to be held 3-6 July 2008 at the Salamanca Inn Conference Centre, Hobart, Australia.

As you would be aware the Tasmanian Devil, has suffered significant population decline in recent years due to Devil Facial Tumour Disease (DFTD), an infectious cancer which is transmitted between individuals through biting. The low genetic diversity in Tasmanian Devils has increased their susceptibility to this disease and animals usually die within months of clinical expression. Average sightings have declined by 53% over the past 10 years and the current prognosis is extinction of the species within 25-30 years.

Significant Federal, State and non-government resources are being directed towards a number of conservation and research efforts. *The Save the Tasmanian Devil Steering Committee* (STDSC) consisting of National and State representatives, the University of Tasmania, non-government stakeholders and conservation experts has been established to oversee implementation of recovery actions designed to help save the species from extinction.

One of the priorities agreed by the STDSC is the establishment of an insurance population to guard against complete extinction of the species and to provide a source of animals for reintroduction should this be needed. An overarching framework and strategy for the proposed insurance population has been developed and approved by the Committee, and establishment of the insurance population through collection of founders is underway. The strategy describes an insurance population comprising a number of interacting components - some intensively managed in captivity and some less intensively managed in extensive exclusion areas. To date though, only some of the necessary work has been done to mobilize this potential conservation resource.

The aim of this workshop is to review the strategy in light of current knowledge, assessing the feasibility of its component parts and, from the result, build a plan of action - what needs to be considered before action is taken, what needs to be done, when, by whom and with what resources. To this end, The Hon. David Llewellyn MHA, Minister for Primary Industries and Water, Tasmania, has invited CBSG – a specialist group of the IUCN's Species Survival Commission – to facilitate the workshop. Using CBSG tools and processes designed specifically for this type of problem, the workshop will bring together key stakeholders and conservation practitioners and subject experts to resolve issues inhibiting insurance population deployment and to carve a way forward for implementation of the insurance strategy.

You have been identified as a valuable contributor to this workshop and we hope you will be able to join us in Hobart in what promises to be an important step forward in this important recovery effort.

Workshop Registration
As space is limited, we ask that you let us know immediately if you plan to attend the workshop. **Please register by contacting Rebecca Spindler at rspindler@zoo.nsw.gov.au.** We have a

limited budget for this workshop, provided by Taronga Conservation Society Australia, and we hope that your institution will support your attendance.

Please include the following information in your registration:
- Name and Contact Information
- Dietary Needs
- Accessibility Needs
- Dates of Stay

Information on hotel accommodation and airport transportation will be sent at a later date.

Meeting Hosts

Mr. Mark Holdsworth
Captive Management and Reintroduction Manager
Conservation,
Tasmanian Department of Primary Industries and Water
Australia
Mark.Holdsworth@dpiw.tas.gov.au

Dr. Rebecca Spindler
Manager, Research and

Taronga Conservation Society
rspindler@zoo.nsw.gov.au

IUCN/SSC Conservation Breeding Specialist Group

Dr. Onnie Byers
Executive Director
onnie@cbsg.org
http://www.cbsg.org/

Invitation List

Name	Organization
Steering Committee	
Kim Evans	Department of Primary Industries and Water (DPIW)
Mark Flanigan	Department of the Environment, Water, Heritage and the Arts (DEWHA)
Peter Mooney	Parks and Wildlife Service (Tasmania)
Susan Jones	School of Zoology (UTAS)
Alex Schaap	Department of Primary Industries and Water (DPIW)
Rupert Woods	Taronga Conservation Society Australia (TCSA)
Paul Andrew	Taronga Conservation Society Australia (TCSA)
Penny Wells	Department of Primary Industries and Water (DPIW)
John Whittington	Department of Primary Industries and Water (DPIW)
Wildlife Biologists esp Tassie Devils	
Menna Jones	School of Zoology (UTAS) and DPIW
Clare Hawkins	Department of Primary Industries and Water (DPIW)
Stewart Huxtable	Department of Primary Industries and Water (DPIW)
Nick Beeton	School of Zoology (UTAS)
Nick Mooney	Department of Primary Industries and Water (DPIW)
David Pemberton	Wildife and Marine Conservation Section, DPIW
Anne-Maree Pearse	Animal Health Laboratory (DPIW)
Heather Hesterman	School of Zoology (UTAS)
Daniel Tompkins	Landcare Research, New Zealand
Experts in Relevant Research	
David Obendorf	
Barry Baker	Latitude 42 Environmental Consultants Pty Ltd
Hamish Mccallum	School of Zoology (UTAS)
Chris Dickman	The Institute of Wildlife Research (USYD)
Kathy Belov	Australasian Wildlife Genomics Group (USYD)
Stephen Pyecroft	Animal Health Laboratory (DPIW)
Greg Woods	Menzies Research Institute (UTAS)
Michael Driessen	Department of Primary Industries and Water (DPIW)
Chris Bunn	Product Integrity, Animal and Plant Health, Office of the Chief Veterinary Officer
Dick Frankham	Macquarie University
Dan Lunney	Department of Environment and Climate Change
Captive Management and Recovery Plan	
Mark Holdsworth	Department of Primary Industries and Water (DPIW)
Androo Kelly	Trowunna Wildlife Park
Rod Andrewartha	Department of Primary Industries and Water (DPIW)
Collette Harmson	Department of Primary Industries and Water (DPIW)
Carla Srb	Healesville Sanctuary
Martin Phillips	Australasian Regional Association of Zoological Parks and Aquaria (ARAZPA)
Exclosures/Islands	
John Weigel	Australian Reptile Park
Bruce Englefield	East Coast Natureworld
Cheryl Hill	Foundation for Australia's Most Endangered Species Inc (FAME)
Sarah Munks	Forest Practices Authority, Tasmania
Sarah Legge	Australian Wildlife Conservancy
Legislative/Permitting	
Steven Jackson	NSW Department of Primary Industries (NSW DPI)
Brooke Craven	Department of Primary Industries and Water (DPIW)
Ron Hearing	Reserve and WIldlife Conservation Branch (DECC)
Graeme Barden	Department of the Environment, Water, Heritage and the Arts (DEWHA)
Native Title Holders	
Auntie Pat Green	Tasmanian Aboriginal Land and Sea Council (TALSC)
Fiona Newsom	Tasmanian Aboriginal Land and Sea Council (TALSC)
Hank Horton	Tasmanian Aboriginal Land and Sea Council (TALSC)
Andry Sculthorpe	Tasmanian Aboriginal Land and Sea Council (TALSC)
Karlie Goodwin	Tasmanian Aboriginal Land and Sea Council (TALSC)

Government Liason	
Simon Nally	Department of the Environment, Water, Heritage and the Arts (DEWHA)
Veronica Ritchie	Department of the Environment, Water, Heritage and the Arts (DEWHA)
Simon Boughey	Senior Advsior, David Llewellyn MHA, Minister Primary Industries and Water
Lisa Keen	Taronga Conservation Society Australia (TCSA)
Facilitation	
Onnie Byers	Conservation Breeding Specialist Group (CBSG)
Rebecca Spindler	Taronga Conservation Society Australia (TCSA)
Population Modelling	
Kathy Traylor-Holzer	Conservation Breeding Specialist Group (CBSG)
Caroline Lees	Australasian Regional Association of Zoological Parks and Aquaria (ARAZPA)
Conservation Medicine	
Richard Jakob-Hoff	New Zealand Centre for Conservation Medicine